Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 1

An overview of labour-based technologies and methods in employment-intensive works

cidb
development through partnership

Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment-intensive construction works

In this set: (colour coded)

Part 1

An overview of labour-based technologies and methods in employment-intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

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Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

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4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Waterbound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

EXPANDED PUBLIC WORKS PROGRAMME
Creating opportunities towards human fulfilment

ENGINEERS AGAINST POVERTY

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for employment-intensive construction works

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1ST Edition of CIDB document 1022
March 2005

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

cidb
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Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1 Background

Engineers have traditionally used their skills and expertise to ensure that structures or structural components are serviceable and durable in addition to possessing adequate strength and stability. A well designed structure is, normally, considered to be one which meets these requirements in the most economically efficient manner, least cost being the measure of value for money. Engineers similarly design services using the same approach. In recent years, however, the term 'value for money' has in South Africa been broadened to take cognisance of socio-economic and political benefits. Government has realised that there is a cost to unemployment and poverty and that there is a price to be paid for the economic empowerment of marginalised communities. Accordingly, value for money is now assessed in a revised context.

There are definite relationships between employment opportunities, available skills, entrepreneurship and the use of small scale enterprises in the creation and maintenance of assets. The construction strategies that are adopted can be used to address social and economic needs and concerns and, depending upon how they are structured, to facilitate the economic empowerment of marginalised sectors in a focussed manner. Thus, the process of constructing assets can be just as important as the provision of the assets themselves.

Projects involving the creation of assets can also promote sustainable community development should they be structured so as to:

- create employment opportunities;
- promote community involvement;
- impart technical skills to the unskilled and semi-skilled members of the community;
- transfer administrative, commercial and managerial skills to the community;
- retain, as far as is possible, the funds expended on the project within the community; and
- develop contractors from within the community in which they are to be constructed.

Projects that address these objectives allow the resources of the community to be built up in an endogenous manner, i.e., to be grown from within.

The Green Paper on Public Sector Procurement Reform in South Africa (1997) suggests that Procurement should facilitate the generation of jobs in South Africa by:

- ensuring that the foreign content in contracts involving goods, services and works is minimised.
- encouraging the substitution of labour for capital.
- supporting the use of 'labour friendly' technologies which utilise a higher degree of labour input than is the case for conventional technologies, or are well suited to implementation by small scale enterprises.
- encouraging and developing small scale enterprises to implement employment-intensive practices and 'labour-friendly' technologies.

All of the above presupposes that appropriate labour-based methods and technologies are readily available to those engaged in construction works as designers and constructors.

2. The employment potential of construction projects

2.1 An overview

Expenditure in any sector of the economy will create employment opportunities. Some sectors of industry are, however, more efficient than others at generating employment opportunities for a given capital inflow. Industries where the potential for the effective substitutions of labour for capital and local resources for imports exist, can expect to achieve enhanced performance in the provision of employment opportunities. The construction industry is an industry that may be regarded as being amongst the most efficient in generating employment for a given capital inflow.

The Green Paper on an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry (1997) suggests that the construction industry in 1997 could generate between 11 and 23 direct, indirect and derived jobs per million Rand invested in the different sectors of the industry. (Average of approximately 17 jobs per million Rand invested). It points out, however, that although these figures are slightly higher than other industrial sectors they do not justify infrastructure investment beyond the immediate requirements in order to create jobs. If, however, the number of jobs created can be increased for example by substituting people for machines, investment in infrastructure projects will become more attractive.

Employment-intensive works have been highly visible in the civil engineering sector. The civil engineering sector is plant-intensive when compared to the building sector. The building sector, in general, generates more employment opportunities per unit of expenditure than does the civil engineering sector. If, however, labour is substituted for machines, this position can be reversed. Alternatively, if a blend of labour and light equipment is used on civil engineering projects, the difference in labour-intensiveness between the two sectors reduces.

Several employment-intensive works programmes have been implemented in Africa and Asia over the last two decades. These labour-and resource-based programmes have aimed to serve several purposes simultaneously. Above all they have aimed to influence infrastructure investment policies so as to maximise employment and income generation, the creation of productive assets and poverty alleviation.

Employment-intensive methods have been employed in South Africa on construction projects which include rural gravel roads; low level bridges; small dams; residential township roads (surfaced and gravel); water and sewerage reticulation for townships; bituminous surfacing of roads; low voltage electrical reticulations; stormwater drainage systems; and on-site sanitation. Road maintenance projects have included regravelling, and routine road maintenance.

Other employment-intensive construction-related projects have included materials manufacture (precast concrete products, timber roof trusses, metal window frames); agricultural structures (dams, erosion control measures, irrigation projects); building works (community centres, clinics, schools, classrooms, housing); and electrification.

2.2 Quantitative information on the potential of labour-based technologies and methods

The authors of a report commissioned in 1994 by the National Housing Forum in South Africa, suggested that there are a number of ways in which employment opportunities in the provision of housing and related infrastructure can be

maximised. These relate to forms of construction, construction methods, and manufacturing methods.

They recognised that in order to achieve the goal of maximising employment opportunities, quantitive information needed to be made available to developers, architects, engineers and the like as to which technologies, construction methods, materials etc. would be likely to promote high employment. Employment opportunities in the construction of the built environment, i.e., houses, amenities and infrastructure, were examined in some detail in this National Housing Forum study. Manufacturers and producers of a wide range of construction materials were approached to provide information regarding the number of person hours required to produce their products. It appeared logical that this figure should include all the time spent on obtaining raw materials, manufacturing of the item and stockpiling the item prior to distribution and could be based on the total number of person-hours worked in the industry (management, administrative staff, workers etc.) and the quantity of the item produced. Some of the results of this survey are summarised in Table 1. The researchers, using the CSIR Division of Building Technology's Housing Delivery Systems Analysis (HDSA) database, were able to estimate the number of person-hours required to construct a masonry house for any given floor plan. In this manner, they were able to compare the total number of person hours required to construct houses using different forms of construction (see Table 2). They suggested that employment opportunities should be linked to cost to ensure that sector effectiveness and efficiency were not impaired. Table 3 compares the cost per person-hour generated for the different forms of house construction presented in Table 2.

Table 1 : Approximate number of person-hours required to manufacture some building and construction materials

ITEM	DESCRIPTION	UNIT	PERSON-HOURS PER UNIT
Aggregate	- sands for mortar, plaster and subbase material	ton	0,12
	- stone for concrete, waterbound macadam; and road bases	ton	0,27
	- transport (20 km haul)	ton	0,13
Bitumen	- road grade	ton	0,7
Cement	- OPC	ton	1,1
Clay sewer pipes	- 150 m diam	100 m	68,2
	- 150 x 150 junction	1	0,9
Clay masonry units	- 106 x 212 x 73 (high-tech plant)	1 000	3
	- 106 x 212 x 73 (normal plant)	1 000	9-9,5
Concrete masonry units	- 140 mm hollow (plant manufacture)	10 m^2	5,6-8,2
	- 140 mm hollow (hand manufacture)	10 m^2	22,4
Concrete paving units	- 65 mm thick (plant manufacture)	10 m^2	3,6-4,1
Concrete pipes	- 450 mm dia	100 m	100
	- 600 mm dia	100 m	125
Concrete roof tile		10 m^2	0,9
Door frames	- standard pressed metal	1	0,5
FC roof sheeting		10 m^2	4,1
FC ceiling board		10 m^2	1,9
FC sewer pipe	- 150 mm dia	100 m	23
Gate valve	- 80/90 mm dia RSV	1	2,0
Glass	- 3 mm float	100 m^2	4,2
Gypsum ceilings		10 m^2	3,3
HDPE pipe	- 32 mm dia (water)	100 m	3
Paint	- PVA	100 litre	5
Polyethylene	- pipe grade	ton	3,3
Polypropylene	- pipe grade	ton	5,2
Precast concrete products	- average	ton	7,8
Steel roof sheeting	- 0,6 mm galvanised	ton	21,1
Steel sections	- commercial grade angles, channels and IPEs	ton	10,1
Timber	- structural grade	m^3	19,6
uPVC pipes	- 160 mm dia (sewer, HD)	100 m	30
Window frames	- ND54	1	1,3
	- NC1	1	0,8

Table 2 : Comparison of the number of person-hours required to construct non-masonry and masonry houses

CONSTRUCTION	NUMBER OF PERSON-HOURS (hours) (NON-MASONRY)			NUMBER OF PERSON-HOURS (hours) EQUIVALENT MASONRY HOUSES (hours)		
	MATERIALS	SITE LABOUR	TOTAL	MATERIALS	SITE LABOUR	TOTAL
Timber (SALMA)	300	1 180	1 480	200	1 700	1 900
Precast concrete panels and posts (Blitz)	150	210	360	120	1 120	1 240
Steel frame with 110 mm brick infill panels (Belaton)	330	880	1 210	160	1 400	1 560

The researchers demonstrated how similar statistics could be generated for the provision of township services. Table 4 presents such statistics for the servicing of stands in a specific low-cost housing development in South Africa (typical electrification costs are included for comparative purposes). Table 5 presents statistics relating to the potential in roadwork activities. Person hours associated with the excavation of trenches using labour-based construction methods, based on statistics derived from Soweto's Contractor Development Programme, were then substituted for those associated with plant-based construction. The implications of using these construction methods are reflected in Table 6.

Table 3 : Evaluation of non-masonry house types

CONSTRUCTION TYPE	ESTIMATED COSTS (1994) (Rand)		COST/PERSON-HOUR (Rand/person-hour)	
	NON-MASONRY	MASONRY EQUIVALENT	NON-MASONRY	MASONRY EQUIVALENT
Timber (SALMA)	47 200	46 100	32	24
Precast concrete panels and posts (Blitz)	16 000	20 300	44	16
Steel frame with 110 mm brick infill panels (Belaton)	28 400	30 800	23	20

Table 4 : Person-hours required in the provision of infrastructure for a low cost township using conventional construction methods

SERVICE	ESTIMATED PERSON-HOURS (%)		ESTIMATED TOTAL NUMBER OF PERSON-HOURS/ERF	COST/PERSON-HOUR (Rand/person hour) (March 1992)
	MATERIALS MANUFACTURE	SITE LABOUR		
	NON-MASONRY	MASONRY EQUIVALENT	NON-MASONRY	MASONRY EQUIVALENT
Water	13	87	39	20
Sewerage	16	84	43	14
Roads (low standard)	14	86	21	36
Stormwater	8	92	26	16
Electricity	70	30	117	20

Table 5: The employment potential of various roadwork activities

ACTIVITY	THICKNESS (mm)	PERSON-HOURS TO PRODUCE AND CONSTRUCT (person-hours/m^2)	
		PLANT-BASED	LABOUR-BASED
Road bed preparation (R&R)	–	0,033	0,350
Gravel wearing course (G5)	125	0,160	1,000
Gravel wearing course (G4)	150	0,192	1,200
Base course (G4)	150	0,192	1,200
Base course (G3)	125	0,165	NA
Subbase (G6)	150	0,192	1,200
Waterbound macadam base course	100	1,040	1,370
Slurry	15	0,110	2,011
Asphalt	25	0,140	1,170
Concrete blocks	60	0,930+	2,120#
Cast *in situ* (plastic cell) blocks	–	0,38	1,80

Table 6: Provision of water and sewer reticulation in a housing development using labour-based methods of construction

SERVICE	LABOUR PERSON-HOURS/ERF		COST/PERSON-HOUR (Rand/person hour) (March 1992)	
	Plant-based	Labour-based	Plant-based	Labour-based
Water	39	58	20	14
Sewerage	43	72	14	9

An analysis of Soweto's Contractor Development Programme, a programme which embraced labour-intensive methods and labour-based technologies and trained and encouraged the community to participate in the managerial, commercial and administrative aspects of construction, revealed some interesting statistics some of which are set out in Tables 7 to 9. The programme generated employment at a cost of approximately R18 /person-hour, whereas the average cost for the civil engineering industry in South Africa during the study period amounted to approximately R37-50 /person-hour.

Table 7: Estimated number of person-hours generated in Soweto's Contractor Development Programme

TYPE OF CONSTRUCTION	UNIT	ESTIMATED NUMBER OF PERSON-HOURS/UNIT (hours/unit)			
		Plant-based	Labour-based	Plant-based	Labour-based
Road construction (waterbound macadam + stormwater)	m^2	0,5	6,8	1,8	9,1
Road construction (concrete block paving + stormwater)	m^2	0,7	8,0	1,8	10,5
Secondary Water Mains	m	0,4	5,9	0,9	8,2
House Connection	erf	0,6	31,4	6,0	38,0

Table 8: Expenditure per unit of employment generated in Soweto's Contractor Development Programme

TYPE OF CONSTRUCTION	UNIT	ESTIMATED EXPENDITURE/PERSON-HOUR (RAND)
Road construction (waterbound macadam)	m^2	17,9
Road construction (concrete block paving)	m^2	18,4
Secondary Water Mains	m	17,4
House connections	erf	17,1

Table 9: Percentage of construction cost retained by the community in Soweto's Contractor Development Programme

DESCRIPTION	ROAD CONSTRUCTION	SECONDARY WATER MAINS	HOUSE CONNECTIONS (PLUMBING)
Labour contract	26	22	33
Transport	2	8	9
Materials Management	2	3	2
Construction Management	7	6	6
TOTAL	37	39	50

2.3 The impact of choice of technology and construction methods on employment

An examination of Tables 3 to 8 indicates that the choice of technology has a marked influence on the number and location of employment. For example, a masonry house may generate 3,5 times more person-hours of employment than an equivalent precast concrete house. The same precast concrete house may, however, generate 1,25 times more person-hours of employment in the manufacture of materials than the masonry equivalent.

The choice of construction method can, particularly in the case of civil engineering projects, significantly influence the total number of person hours of employment generated. The construction of conventional masonry housing units, depending upon the standards adopted, realises approximately 50% more employment opportunities per unit of expenditure than plant-based servicing of sites. If, however, sites are serviced using labour-based construction practices, without increasing the total construction cost, this is 50% more effective than the construction of masonry housing units in creating employment opportunities.

The choice of manufacturing method of construction components can also significantly affect the number of employment opportunities generated. For example, the ratio of person hours employment generated in conventional construction on-site to that generated in the conventional off-site manufacture of the associated materials is 9 : 1 for house construction and 6,5 : 1 for township services (roads, stormwater drainage, water supply and sewerage). There is, clearly, considerable scope for increasing employment opportunities through the use of employment-intensive methods of manufacture of materials.

Changes in methods and technologies, which increase the labour content of construction and the manufacture of materials, can yield increases in the number of employment opportunities generated per unit of expenditure. This however, requires large, well established companies to change their work methods and reduce their reliance on capital intensive technologies; a difficult task. In contrast, small scale enterprises, who, being small, have limited access to capital and invariably operate and conduct their businesses in a more employment-intensive fashion and favour light equipment-based forms of construction, would have little difficulty in adopting new methods and technologies.

Recent research in South Africa has indicated that, provided there is little or no cost premium associated with employment-intensive practices, the overall increase in employment opportunities for a given project over conventional plant-based practices may reach a factor of 2 in urban infrastructure and 3 in rural road construction; increases which are extremely valuable.

3. The impact of the choice of technology

The choice of technology not only influences employment parameters, as previously described, but determines who is able to participate in a project. The following two examples on the impact of technology choices illustrate this.

In the first example, a church community wished to construct a 600 m^2 church hall on a site where moderately expansive clays were present. A member of the congregation, who had recently been made redundant, volunteered to construct the building on a labour only basis. He had some building experience and had access to some bricklayers and a small truck and trailer. In addition, he had the necessary commercial credibility to hire any minor equipment which he required.

The builder did not, however, have access to carpenters capable of constructing forms for reinforced concrete work. Nor did he own any formwork or have the experience to supervise reinforced concrete works. So, if the hall had been designed as a reinforced concrete framed building, he could not have constructed it and the church would have had to look outside their congregation for someone to construct the hall.

To accommodate the builder, the hall was designed as a reinforced masonry structure. Reinforcement was placed in masonry columns and bedjoints, and fabric reinforcement in cavity walls. Using this form of construction, no formwork was required and the builder was able to use his bricklayers to construct the entire structure. The form of construction proved to be very cost effective, particularly in view of the founding conditions.

In the second example, a rural community was allocated funds for the construction of school classrooms and toilet blocks, the intention being that the community, with appropriate management and technical support, would itself undertake the construction. Most of the structures were located on expansive clay and total surface movements of approximately 50 mm were predicted. Typically, structures built on sites of this nature in South Africa are founded on stiffened reinforced concrete rafts, or on piles. The community simply did not have the skills necessary for these forms of construction.

Alternative solutions were sought. A cellular raft (Boucell, i.e., a foundation system which comprises two horizontal fabric reinforced slabs interconnected by a series of web beams) was finally decided upon. This system did present a few construction challenges that required some innovation to overcome. Old tyres that were obtained at no cost, filled with soil were used as void formers. Masonry was used to create a perimeter beam. (As the width of an average tyre is 170 mm, this solution enabled a course height of 85 mm to be maintained in the structure). The space at the centre of four adjoining tyres proved ample for the placing of shear links. The rafts were readily and economically constructed by the community.

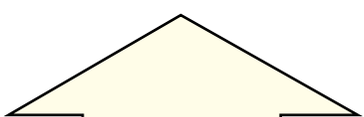
Sometimes it is more appropriate to look to old technologies rather than to attempt to optimise current technology. In Zimbabwe and South Africa, rubble masonry, an old technology that was investigated by 19th century engineers has been resurrected. Rubble masonry is a building material comprising uncut stones bound together with cementitious mortar. Several small dams and bridges have recently been constructed at considerably lower costs than conventional alternative designs. The advantages of using this employment-intensive technology instead of conventional alternatives, include the following:

- The only material purchased is cement.
- The acquisition costs of sand and stone, sourced in close proximity to the site, are limited to wages for the gatherers and any blasting of rock which may be necessary.

- Transportation costs are minimised, as cement which accounts for approximately 7% of the mass of the rubble masonry structure is the only material which is hauled any significant distance.
- Rubble masonry requires no vertical formwork to contain it during placement.

This technology has not only increased employment opportunities per unit of expenditure, but has also afforded unskilled people, who live in close proximity to the projects, access to employment opportunities in Contractor development in the roads sector can be viewed as a function of the mechanisation level of the contractors as illustrated in Figure 1. As contractors master technologies that make use of light plant, they can purchase and acquire increasingly more costly plant and transform their businesses into fully mechanized ones.

Figure 1: Mechanisation level of some labour-intensive construction techniques



Construction technique	Level of Mechanisation	Discussion
Crushed Stone / Cemented	High	• Machine intensive
100 – 150 mm water-/dry bound Macadam	High	• Heavy (12 tonne) roller required. • Density specification to be met. • Light surfacing types (seals) not recommended.
Foam gravel bases	High	• Graded material to be compacted to specification. • Mechanical mixing often introduced.
100 – 150 mm composite Macadam	Medium	Heavy (12 tonne plus) roller required. Density specification to be met.
Emulsion treated bases	Medium	• Graded material to be compacted to specification. • Mechanical mixing often introduced.
Concrete Interlocking blocks	Medium	Manufacturing considered mechanised.
75 mm composite Macadam	Low	Only light pedestrian rollers required. "Orientation of aggregate sufficient.
Slurry-bound Macadam	Low	Only light pedestrian rollers required. "Orientation" of aggregate sufficient.
Direct labour	Entry point	Entry point

4. Implementation mechanisms

4.1 Overview

In several countries in Africa and Asia long term national programmes of labour-intensive road construction and maintenance have been established. These national programmes have resulted in the creation of employment and the efficient production of as good a quality of construction and maintenance as is allowed by the funding available. This has usually, however, been executed on a pilot project basis. These programmes have resulted in the development and establishment of the skilled personnel required to supervise the site works, to liase with the beneficiary communities and to plan and administer these programmes.

The World Bank in a paper on expanding labour-based methods in road works (1996) has identified six basic delivery/implementing mechanisms, viz.:

I The force account model ('in house' workforce) whereby a government body hires labour directly (either as individual workers or as worker teams) and provides the necessary supervision, administration and management required to execute the works.

II The conventional model whereby a conventional contractor hires labour directly and provides the supervision, administration and management required to execute the works.

III The sub-contracting model whereby a large contractor or firm sub-contracts the portions of the projects that are labour-based to small contractors and assumes overall responsibility for the supervision, administration and management required to execute the works.

IV The government-run model whereby the responsibility for all aspects of contractor development, including small contractor administration and payment, and the overall responsibility for the supervision, administration and management required to execute the works, lies with a government agency.

V The agency model whereby the responsibility for all aspects of contractor development including small contractor administration and payment and the overall responsibility for the supervision, administration and management required to execute the works, lies with an independent non-profit management agency or with a for-profit consulting firm.

VI The development team model whereby the responsibility for all aspects of contractor development and the management of the works is divided amongst the Client Body (Employer), a Construction Manager and a Materials Manager.

Models II and III promote the use of labour-based construction practices amongst established contractors; models IV to VI promote the expansion of such methods among small-scale contractors.

In force account operations (Model I), government has direct control over the outcomes of employment-intensive projects and is at risk for any failure to achieve programme objectives. The Government's control over the works in all the other models is, however, diminished. Its risk of failure in these models is reduced, the extent of which is dependent upon the model which is selected. The total project costs of each of the models which involve the private sector is in turn directly related to how risk is managed and assigned to the contracting parties and the nature and complexity of the work involved.

Model VI – a South African innovation

Model V is commonly encountered in French speaking nations in West Africa where it is referred to as the Agetip model (non-profit contract management agency). Generally, model IV involves fixed rate contracts. Model VI was developed in South Africa and pioneered through Soweto's Contractor Development Programme. It is sufficiently flexible to be used either to develop and support small scale contractors, particularly in the early stages of their development, or to implement 'labour pool worker programmes' in the same manner as is done in the force account model, but with private sector firms (construction or consulting) assuming responsibility for the supervision, administration and the management of the labour, and the risk of cost overruns or failure to achieve the required quality or programme objectives being shared between the parties.

4.2 The engagement of small scale contractors in construction contracts

Construction can be regarded as the synthesis of the following:

- Construction management
- Materials management
- Materials supply
- Plant and equipment
- Labour

Employment-intensive construction is by nature management-intensive and requires that all the aforementioned functional activities be addressed in a project. This is true irrespective of whether or not the construction work is executed by means of force account or large or small scale contractors. Contractors, as is the case with labour units established within governmental agencies, need to have administrative, managerial and technical skills. In addition contractors, if their businesses are to be sustained, need to have commercial skills. Small contractors, particularly newly established businesses, frequently have limited skills and are unable to control cost, time and quality on their projects. Models IV to VI are structured to address these problems.

Numerous pilot projects in a number of countries, using the abovementioned implementation methods, have demonstrated that providing adequate controls and management are put in place, direct labour and small scale contractors can successfully execute labour-based/employment-intensive projects. The challenge, however, lies in expanding these pilot projects into major programmes which can make a significant impact on the employment problem or programme objectives.

Many of the aforementioned models attempt to develop small scale contracting capacity to effect employment-intensive works that may previously have been executed using the force account model. Frequently the development of small scale enterprises is seen as a means of expanding programmes in a manner which reduces the management, supervisory and administrative burden placed on government's in-house resources and the risk exposure of cost overruns on programmes.

The quantum of work which can be executed by small contractors in terms of models IV to VI on works of a relatively complex nature, or which have significant specialist or high equipment components, is limited as the breaking down of projects into small contracts is not always justifiable from either a cost or management point of view owing to:

- the division of responsibilities, interdependence of activities, programming, duplication of establishment charges and utilisation of resources
- the lack of skilled management resources;
- the general lack of commercial skills in small scale enterprises; and
- the increased administration of such contracts by public bodies and their agents.

As a result, the use of large scale contractors to engage more labour or to subcontract to small scale contractors has been reconsidered. Unfortunately, onerous conditions have frequently been imposed on contractors which in many instances has impaired their performance and ability to efficiently and effectively deliver infrastructure. This has often translated into increased construction costs and a concomitant erosion of the total volume of potential employment which can be realised through construction projects. In extreme cases, conventional equipment-based construction may have yielded more employment opportunities for the same amount of expenditure.

Targeted Procurement Procedures

An innovative new approach to procurement which addresses the current short comings of Models II and III has been developed in South Africa, viz Targeted Procurement. Targeted Procurement enables Models II and III to be efficiently and effectively implemented with minimal interference on a contractor's ability to perform. (See Appendix 2)

4.3 Increasing employment opportunities generated per unit of expenditure

Two alternative procurement approaches to implementing employment-intensive works methods can be adopted:

Method 1: Lay down the use of specific employment-intensive technologies and methods of construction/manufacture in the tender document (a variation to this approach is to specify the minimum amount of wages which are required to be paid in respect of a particular contract);[1]

Method 2: Afford tenderers the opportunity to choose the technology/construction method/method of materials manufacture which they wish to use in order to maximise the participation of labour in construction works and in so doing win bids .

Suitable resource specifications can be used in both methods to ensure that the deliverables are attained. Either method may be used to increase the quantity of employment generated per unit of expenditure. Method 1 achieves this objective by restricting the use of certain types of plant/manufacturing methods and by specifying particular technologies. Method 2 (i.e. the Targeted Procurement approach), on the other hand, by means of development objective/price mechanisms and resource specification, enables tenderers to tender the amount of targeted labour, which they undertake to engage in the performance to the contract. Method 2, accordingly, permits tenderers to use their knowledge, skill and creativity in arriving at an optimum economic mix of equipment, technology and labour in order to meet objectives and win bids.

The economic viability of Method 1 is, however, dependent on the ability of the designer/specifier to forecast cost. Any potential price premium in Method 2 can be readily assessed during the adjudication of bids. Method 2 therefore has the distinct advantage that bid prices will usually fall within acceptable limits and economic justification of decisions relating to employment-generation will not be necessary.

The Green Paper on Public Sector Procurement Reform in South Africa in this regard proposes the following:

- *A distinction should be made in the targeting of local labour in order to stimulate local economies and the increase in employment opportunities generated per unit of expenditure. Increased credits in development objective/price mechanisms should be granted to encourage the increase in employment opportunities generated per unit of expenditure where tenderers are permitted to choose technologies and work methods.*
- *Any premiums to be paid in respect of employment-intensive practices should be determined and accepted prior to the award contracts. employment-intensive practices should result in the generation of jobs as opposed to the displacement of jobs.*

The Interministerial Task Team for Construction Industry Development in their Recommendations on Refinements in Public Sector Procurement Policy, Practices and Procedures in the Construction Sector reinforce the green paper proposals, viz:

- *Procurement in engineering and construction works should facilitate the generation of jobs in South Africa by:*
  - ❍ *encouraging the substitution of labour for capital;*
  - ❍ *supporting the use of 'labour friendly' technologies which utilise a higher degree of labour input than is the case for conventional technologies, or are well suited to implementation by small scale enterprises; and*

[1] The Guidelines for the implementation of labour-intensive infrastructure projects under the Expanded Public Works Programme (EPWP) require that method 1 be used in the construction of low volume roads, sidewalks, stormwater drainage and shallow trenches.

- *encouraging and developing small scale enterprises to implement employment-intensive practices and 'labour-friendly' technologies.*

- *Targeted Procurement should be used to encourage cost-effective employment-intensive practices.*
- *Any premiums to be paid in respect of employment-intensive practices should be determined and accepted prior to the award of contracts. employment-intensive practices should result in the generation of jobs as opposed to the displacement of jobs.*

Appendix 2 provides guidance on the use of Targeted Procurement Procedures on infrastructure projects to increase employment per unit of expenditure. It should be noted in this regard that SANS 1914-5 (Participation of Targeted Labour) can be used to measure the nature and quantum of employment used in both of the aforementioned procurement approaches to implementing employment-intensive works. SANS 1921-5 (Earthworks activities which are to be performed by hand) identifies earthworks activities and sub-activities which the contractor must execute by hand, can be used to readily describe the scope of work in a contract which is be executed using Method 1.

5. Selected specialist and related literature

1. Standards South Africa: SANS 1914: *Targeted construction procurement*
   Part 1: Participation of targeted enterprises
   Part 2: Participation of targeted partners in joint ventures
   Part 3: Participation of targeted enterprises and targeted partners in joint ventures
   Part 4: Participation of targeted enterprises and targeted labour (local resources)
   Part 5: Participation of targeted labour

2. Standards South Africa: SANS 10396: *Implementing Preferential Construction Procurement Policies using Targeted Procurement Procedures*

3. Watermeyer RB. (Ed) Contractor Development in Labour-based Construction. The Contractor Development Team, Johannesburg 1992.

4. McCutcheon RT, van Zyl CWL, Croswell J, Meyer D and Watermeyer RB. Interim Guidelines for Labour-based Construction Projects. Development Bank of Southern Africa 1992.

5. Watermeyer RB. Community-based construction : a route to sustainable development. JSA Inst Civ Eng Vol 36, No. 1, First quarter, 1995.

6. Watermeyer RB. Evaluating employment and community opportunities presented by building and construction projects. employment-intensive Construction Fifteenth Annual Transportation Convention, University of Pretoria, June 1995./Volume 5, ATC Research Forum, ISSN 1019-1909, 1995.

7. Watermeyer RB. Soweto's Contractor Development Programme: 1988-1998. City Development Strategies. Issue no 1 October 1999

8. Watermeyer R.B. Job creation in public sector engineering and construction works projects : why, what and how ? Commonwealth Engineer's Council 50th Anniversary Conference : Engineering to survive - human shelter and the relief of poverty : sustainable solutions. Fourways, August 1997.

9. Watermeyer R.B. Mobilising the Private Sector to Engage in Labour-Based Infrastructure works : A South African Perspective. Sixth Regional Seminar for Labour-based Practitioners. Ministry of Works, Transport and Communications in collaboration with ILO/ASIST, Jinja, Uganda, October 1997.

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11. Watermeyer RB. The use of Procurement as an Instrument of Local Economic Development. Institute of Municipal Engineers of South Africa's Biennial conference, Kempton Park, October,1999.

12. Watermeyer R.B. The use of Targeted Procurement as an instrument of Poverty Alleviation and Job Creation in Infrastructure Projects. Public Sector Procurement Law Review, Number 5 pages 201-266. 2000

13. Watermeyer RB and Band NG. The Development of Small Scale Enterprises, Skills, Entrepreneurship and Employment Opportunities through the Provision of Housing. Working Group 3, National Housing Forum, November 1994.

14. Watermeyer RB, Nevin G, Amod S and Hallett RA. An evaluation of projects within Soweto's Contractor Development Programme. JSA Inst Civ Eng, Vol 36, No.2, Second quarter, 1995.

15. Watermeyer R, Gounden S, Letchmiah D and Shezi S. Targeted procurement: a means by which socio-economic objectives can be realised through engineering and construction works contracts. SA Inst CivEng, March 1998.

16. National Department of Public Works. Guidelines for enhancing employment opportunities in the delivery of infrastructure projects. A National Public Works Programme Initiative, May 1999.

17. Technical Committee on a Public Works Programme. National Employment Creation Programme for the Provision of Public Infrastructure Using Labour Intensive Methods. National Economic Forum, April 1994.

18. Department of Transport. Synthesis document on Labour-based work for road and street construction and the development of small business opportunities in South Africa. South African Roads Board.

19. Steidl D. Productivity Norms for Labour-Based Construction. ASIST Information Service Technical Brief No. 2. International Labour Organisation 1998.

20 Standards South Africa. SANS 1921-5, Construction and management requirements for works contracts, Part 5: Earthworks activities which are to be performed by hand.

22 McCutcheon, RT and Taylor Parkins, FLM (Editors). Employment and High-Standard Infrastructure. Work Research Centre for Employment Creation in Construction. School of Civil and Environmental Engineering, University of the Witwatersrand, 2003.

Note

The International Labour Organisation has a publication which catalogues a number of key publications which may be obtained from their ASIST Information Service entitled "The Labour-Based Technology Source Book" (see www.ilo.org/asist for further particulars).

Appendix 1: Quantitative Employment Data on selected construction activities

Sources of data

A: HOUSING AND RELATED INFRASTRUCTURE

Source: Watermeyer and Band's National Housing Forum Report (1994) on the Development of Small Scale Enterprise, Skills, Entrepreneurship and Employment Opportunities through the Provision of Housing (see www.targetedprocurement.com)

Table A1: Approximate number of manhours required to manufacture various building and construction material
Table A2: Comparison of engineering materials
Table A3: Manufacture of precast concrete components
Table A4: The use of bitumen in plant-based and labour-based surfacing options
Table A5: Manhours associated with the manufacture of 150 mm diameter sewer pipes
Table A6: Typical manhours required in the manufacture of building components
Table A7: Number of manhours required in the construction of various masonry houses
Table A8: Kwa Thema Extension 7: civil services for 805 erven constructed using conventional plant-based methods
Table A9: Manhours required in the provision of infrastructure for a low cost township using conventional construction methods
Table A10: Comparison of the number of manhours required to construction non-masonry and masonry houses
Table A11: Kwa Thema Extension 7: water and sewer reticulation for 805 erven using labour-based methods of construction
Table A12: Manhours required to provide and construct various township roads
Table A13: Manhours associated with roadwork layers
Table A14: Manhours required to surface roads
Table A15: Manhours required to provide and construct an *in situ* paved blocked pavement
Table A16: Productivities for piece and task work in KwaZulu-Natal
Table A17: Trends in excavation rates for pickable material in various projects
Table A18: Trench excavation rates for a 6-hour task
Table A19: Productivities for labour performing various construction activities
Table A20: Manhours associated with layerworks and kerbing on various township roads

B: MINIMUM PRODUCTIVITY LEVELS

Source: Notice in terms of Section 70(2) of the Labour Act, 1992. Agreement on conditions of employment entered into between the Metal and Allied Namibian Works Union and the Construction Industries Federation of Namibia 6 April 2000, Government Gazette 31 May 2000 (No. 2340).

No Tables

C: ESTIMATED PRODUCTION RATES FOR CONCRETE BLOCK PAVING

Source: A Nkambule: A review of Labour-intensive Concrete Block Paving van Wyk and Louw Inc.

Table C1: Labour-intensive production rates

Appendix 1: Quantitative employment data on selected construction activities

Comprehensive quantitative data on employment generated by various construction activities is generally lacking in the literature. The data which follows, however, appears in the literature. Users of this data should consult the publications referenced to obtain the assumptions behind the reported data.

D: CONCRETE MASONRY GRAVITY DAMS CONSTRUCTION

Source: King CD. Employment creation through the design and construction of medium sized concrete masonry gravity dams in South Africa using labour-based construction methods: A comparison of alternative technologies. A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg in partial fulfillment of the requirements for the degree of Master of Science in Engineering Johannesburg, 1994.

Table D1: Balfour dam: Productivity figures for required construction activities

E: EXCAVATION

Source: A critical analysis of the community-based Public Works Programme in South Africa. A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in fulfillment of the requirements for the degree of Master of Science in Engineering, Johannesburg, July 1996

Table E1: Productivity data for excavation by hand

F: LABOUR-BASED STONE PAVED ROADS

Source: S AL-Fayadh. Labour-based Stone Paved Roads. Kampang Cham Province International Labour Organisation. Technical Assistance to the Labour-based Rural Infrastructure Works Programme CMB/97/M02/S10

Table F1: Work norms: Labour-based stone paved roads

G: EARTHWORKS

Source: McCutcheon, RT, van Zyl CWL, Croswell J, Meyer D and Watermeyer RB. Interim guidelines for labour-based construction projects. Construction and Development series. Number 2 Development Bank of Southern Africa, February 1993.

Table G1: Average task output values
Table G2: Detailed task rates for excavation

H: STORMWATER DRAINAGE

Source: Balmaceda P, John R and Horak E. Planning and construction of a stormwater system by labour-intensive methods in an urban environment. Fifteenth Annual Transportation Convention, 1995.

Table H1: Output data assumed for feasibility analysis
Table H2: Laying concrete pipes – summary of information from work study

J: BITUMEN SURFACING

Source: SABITA Labour-enhanced construction for bituminous surfacings Manual II March 1993

Table J1: Preliminary South African bitumen surfacing production rates under average conditions

K: ROAD PROJECTS

Source: Greyling MR, Critical analysis of labour-intensive road projects in South Africa funded form the sale of strategic oil. A dissertation submitted to the faculty reservers of Engineering, University of the Witwatersrand, Johannesburg, in fulfillment of the requirements for the degree of Master of Science of Engineering, 1994.

Table K1: Productivity achieved per activity (Pa) for each road authority
Table K2: Productivity data for standard conditions
Table K3: Adjustment factors applied to standard productivity data (According to Coukis et al, 1983: Table 7.7)
Table K4: Range of adjustment factors applied to standard productivity data (Coukis et al, Table 7.7 1983)
Table K5: Productivity ratings (Pr-1) per activity (Assessment 1)
Table K6: Productivity achieved in Kenya (de Veen, 1983) and Malawi (Relf, Hagen and Akute, 1987)
Table K7: Productivity rating (Pr-2) Assessment 2

L: ROADWORKS

Source: Watermeyer R(ed) Contractor Development in Labour-based Construction

M: EARTHWORKS

Source: Steidl D. Productivity Norms for Labour-Based Construction ASSIST Information Service Technical Brief No. 2 International Labour Organisation 1998.

Table M1: Soil excavation characteristics
Table M2: Site clearing norms – country data
Table M3: Site clearing norms – recommended values
Table M4: Excavation norms – country data
Table M5: Excavation norms – recommended values
Table M6: Wheelbarrow haulage norms – country data
Table M7: Wheelbarrow haulage norms – recommended values
Table M8: Typical haulage rates for manually loaded equipment
Table M9: Loading, unloading and spreading norms – country data
Table M10: Loading, unloading and spreading norms – recommended values
Table M11: Compaction norms – country data and recommended values
Table M12: Culvert laying norms – country data
Table M13: Culvert laying norms – recommended values
Table M14: Typical equipment/labour combinations for gravelling
Table M15: Summary of recommended values
Table M16: Average worker input for completed operations
Table M17: Country data for site clearing activities
Table M18: Country data for excavation activities
Table M19: Country data for haulage activities
Table M20: Country data for loading, unloading and spreading activities
Table M21: Country data for compaction activities
Table M22: Country data for culvert laying activities

N: TASK OUTPUT RATES

Source: Department of Public Works: Guidelines for enhancing employment opportunities in the delivery of infrastructure projects – a national Public Works Programme Initiative

Table N1: Task output rates

O: TYPICAL TASK RATES

Source: McCutcheon and Marshall. Labour-intensive construction and maintenance of rival roads: Guidelines for the training of road builders. Construction and Development Series, November 14, Development Bank of Southern Africa. Development Paper 60, November 1996.

Table O1: Average task output values
Table O2: Detailed task rates for excavation

A: HOUSING AND RELATED INFRASTRUCTURE

Source: Watermeyer and Band's National Housing Forum Report (1994) on the Development of Small Scale Enterprises, Skills, Entrepreneurship and Employment Opportunities through the Provision of Housing (see www.targetedprocurement.com)

Chapter 2: Employment opportunities through the provision of housing

Table A1 : Approximate number of manhours required to manufacture various building and construction materials

PRIVATE ITEM	DESCRIPTION	UNIT	MANHOURS PER UNIT	SOURCE OF INFORMATION	REMARKS
Aggregates	– sands for mortar, plaster and subbase material	ton	0,12	Hippo Quarries (M Doyle)	
	– sands for concrete	ton	0,15		
	– stone for concrete; aggregate for waterbound macadam; crushed stone for road base courses	ton	0,27		
	– transport	ton	0,13		20 km haul distance, 12 ton truck; one mechanic to 10 trucks
Asbestos		ton	41,5	Central Asbestos (Pty) Ltd (J Maree)	
Bitumen	road grade	ton	0,7	SABITA (R Vos)	Distribution to within 200 km. Excludes imported crude oil
Cement	OPC	ton	1,1	Anglo Alpha (C Ehrke)	Transport and distribution excluded
Clay sewer pipe	150 mm diam	100 m		Vitro Building Products (H Grobler)	Including constituent materials, but no distribution
	– raw material		1,90		
	– manufacture		66,30		
	TOTAL		**68,20**		
	100 mm diam pipe	100 m			
	– raw material		1,03		
	– manufacture		45,04		
	TOTAL		**46,07**		
	150 x 150 mm junction	No			
	– raw material		0,01		
	– manufacture		0,86		
	TOTAL		**0,87**		
	100 mm 90^2 Bend	No			
	– raw material		0,01		
	– manufacture		0,30		
	TOTAL		**0,31**		
Clay masonry units	106 x 212 x 73	No		Clay Brick Association (N Louw)	Production manhours vary depending on plant used
	– hightech plant	1 000	3		
	– normal plant	9 – 9,5			
Concrete masonry units	140 mm (hollow)	10 m^2		Concrete Masonry Association (P Kelly)	Excludes transport to site. Production manhours vary depending on plant used
	– materials		0,6		
	– production		5,1 – 7,6		
	TOTAL		**5,6 – 8,2**		
	140 mm (solid)	10 m^2			
	– materials		1,1		
	– production		5,1 – 7,6		
	TOTAL		**6,2 – 8,8**		
	140 mm (hollow)	10 m^2			
	– materials		2,4	Portland Cement Institute (B Raath)	Manual equipment Own quarry Hand mixing
	– production		20,0		
	TOTAL		**22,4**		

Table A1 : Approximate number of manhours required to manufacture various building and construction materials – (continued)

PRIVATE ITEM	DESCRIPTION	UNIT	MANHOURS PER UNIT	SOURCE OF INFORMATION	REMARKS
Concrete paving units	65 mm thick – materials – production **TOTAL**	10 m²	 0,5 3,1 – 3,6 **3,6 – 4,1**	Concrete Masonry Association (P Kelly)	Excluding transport to site
Concrete pipes	***Stormwater pipe*** 450 mm diam 600 mm diam – material – production **TOTAL** 900 mm diam – material – prodction **TOTAL** 1 350 mm diam – material – production **TOTAL** ***Sewer pipe*** 450 mm 600 mm 900 mm 1 350 mm	 100 m 100 m 100 m 100 m 100 m 100 m 100 m 100 m	 100 45 80 **125** 100 100 **200** 215 120 **335** 104 132 210 350	Fraser Fyfe (Pty) Ltd (A Dotton)	Including raw materials Including raw materials and sacrificial lining
Concrete roof tile	– production – materials **TOTAL**	10 m²	0,66 0,22 **0,88**	Watson Tile Corporation (K Watson)	
Door frames	standard	No	0,5	Wispeco (N Crosby)	Excludes steel in frame
FC Roof sheeting	 – production – materials **TOTAL**	10 m²	 3,9 0,2 **4,1**	Everite (P North)	
FC Ceiling board	4 mm – production – materials **TOTAL**	10 m²	 1,8 0,1 **1,9**	Everite (P North)	
PC sewer pipe	150 mm diam	100 m	23	AC Pipes Klipriver (A Kapp)	Includes all constituent materials
Gate valve	80/90 mm diam RSV	No	2,0	Czechtech cc (R Garrett)	Includes casting, machining, assembly and overheads
Glass	3 mm float – production – materials **TOTAL**	100m²	 3,6 0,6 **4,2**	PFG Flat Glass (J Henning)	
Gypsum ceilings		10 m²	3,25	Gypsum Industries (Snowden)	12,5 mm
HDPE pipe	600 mm spiral wound – material – production **TOTAL** 32 mm diam (water) – materials – manufacture **TOTAL**	100 m 100 m 	 7 178 **185** 1 2 **3**	Spiropipe (A Rex) Main Industries (D Chesney-Jones)	 Class 12
Hyson-cells		100 m²	0,03	Hyson-cells (J Brokenshire)	
Paint	PVA	100 litre		Plascon Group Services (R Johannsen)	Excludes raw materials

Table A1 : Approximate number of manhours required to manufacture various building and construction materials – (continued)

PRIVATE ITEM	DESCRIPTION	UNIT	MANHOURS PER UNIT	SOURCE OF INFORMATION	REMARKS
Polythylene (Pipe grade)	– raw material – production – quality control – stockpiling **TOTAL**	ton	0,08 4,59 0,56 0,06 **5,23**	Safripol (J Kellerman)	
Precast Concrete Products	– raw materials – mixing process – casting of concrete – transport – administration – maintenance **TOTAL**	ton	0,54 0,14 4,02 1,77 0,66 0,75 **7,82**	Blitz Betonwerke (N Erasmus)	Average for product range
Steel roof sheeting	0,6 mm galvanised – mining of iron ore, dolomite, coal, etc – Steel making to profiled section **TOTAL**	ton	1,1 20 **21,1**	Iscor (S Evans)	Includes mining, etc but excludes production of zinc for galvanising
Steel sections	Commercial grade angles, channels and IPEs – mining of iron ore, dolomite and coal, etc – steel making to rolling into sections **TOTAL**	ton	 1,1 9,0 **10,1**	Iscor (S Evans)	Includes mining, etc.
Timber	Structural grade – planting/thinning pruning – harvesting – transport of logs to sawmill subtotal – processing – presevative treatment – transport to merchants – handling by merchants subtotal **TOTAL**	1 m^3	 2,5 2,5 0,3 5,3 10,0 2,0 0,3 2,0 14,3 **19,6**	SALMA (P Bryant)	Planting to saw mill represents a 28-year period Processing to handling by merchants represents a 6-week period
uPVC sewer pipe	160 mm diam (sewer) – materials – manufacture – distribution **TOTAL** 90 mm diam (water) – materials – manufacture – distribution **TOTAL**	100 m 100 m 	 1 22 7 **30** 1 24 7 **32**	Main Industries (Pty) Ltd (D Chesney-Jones)	Heavy duty pipe Class 12
Window frames	– ND 54 – NC1 – NC2	No No No	1,25 0,8 0,9	Wispeco (N Crosby)	Excludes steel in frame
Zinc		ton	25,4	Zinc Corporation of South Africa (Ltd) (M Buncombe)	

Table A2 : Comparison of engineering materials

MATERIAL	MANHOURS TO PRODUCE A CUBIC METRE	MANHOURS TO PRODUCE A TON	REMARKS
Concrete+	1,6	0,7	
High density polyethylene	3,1	3,3	Pipe grade quality
Masonry (class II mortor)	5,0	2,3	
Polypropylene	4,9	5,2	Pipe grade quality
Steel	78,8	10,1	Angles, channels
Timber	19,6	39,2	and IPEs Structural grade

\+ Mechanical batching and mixing included
* Pipe extrusion excluded
' Laying of units and mixing of mortar excluded

Table A3 : Manufacture of precast concrete components

OPERATION	ACTIVITIES		MANHOURS/TON
Raw materials	Cement: Aggregates:	production, transport to yard, pump into silo quarry operations, loading, transport	0,54
Mixing process	Boomscraper; weigh process, wash supply		0,14
Casting of Concrete	Cleaning of moulds: Mesh reinforcements: Casting and finishing: Curing: Remoulding:	brushing, cleaning, carrying to cleaning area, mixing of oil, applying of oil to moulds, move to casting yard cutting, carrying, placing transport moulds, casting, vibrating, smoothing off cover moulds with canvas, placing of wet steamer, firing of boilers, steaming, filling of water tank, stacking loosen sides, strip mould, transport to stacking area, stacking, carry moulds to steaming area	4,02
Transport	Load on fork truck, drive to truck, load truck with laour, cover load with netting transport to erection are/township, offload		1,77
Administration			0,66
Maintenance of moulds	Welding, repairing, straightening, inspecting		0,75
TOTAL			7,82

Table A4 : The use of bitumen in *plant-based* and *labour-based* surfacing options

TYPE OF CONSTRUCTION	DESCRIPTION	MANHOURS/ TON OF BITUMEN
Plant-based	Hot-mix asphalt Chip and spray Slurry	0,8 2,4 – 4,3 2,4
Labour-based	Cape seal and chip and spray Coarse slurry Hot-mix asphalt	30 60 15 – 20

* Sum of manhours involved in manufacture of materials, transport of materials and placing of surfacing

Table A5 : Manhours associated with the manufacture of 150 mm diameter sewer pipes

PIPE MATERIAL	MANHOURS REQUIRED TO PRODUCE A METRE OF PIPE	UNIT COST/MANHOUR (Rand/manhour)
Clay	0,68	R 27–94
UPVC	0,23	R 65–22
Fibre cement	0,23	R 86–96

* No allowance for transport and distribution included.

Table A6 : Typical manhours required in the manufacture of building components

COMPONENT		UNIT	APPROXIMATE NUMBER OF MANHOURS REQUIRED TO MANUFACTURE A UNIT	REMARKS
Ceilings	– 4 mm fibre cement	m^2	0,3	Including timber supports
	– 6,4 mm gypsum	m^2	0,3	
Concrete	–	m^2	1,2	Grade 15 or 20
Cladding	– 12,7 mm gypsum	m^2	0,35	Excludes timber supports
Doors	– external	No	2,2	Standard door (timber) + frame
	– internal	No	1,4	
Masonry	– 90 mm walls	m^2	0,45	
	– 110 mm wall	m^2	0,55	
	– 140 mm walls	m^2	0,7	
	– 220 mm walls	m^2	1,1	Negligible
Paint			–	
Plaster	– one coat (external)	m^2	0,95	
	– one coat (internal)	m^2	0,9	
Roofing	– concrete tiles	m^2	0,2	Includes purlins/battens
	– galvanised iron	m^2	0,2	
	– fibre cement	m^2	0,5	
Roof trusses[55]				6 m span assumed;
	– concrete tiles	m^2	0,3	Fabrication excluded
	– fibre cement	m^2	0,25	
	– galvanised iron	m^2	0,25	
Screeds		m^2	1,2	Includes glass and frames
Windows		m^2	1,0	

* Imported asbestos excluded.

Table A7 : Number of manhours required in the construction of various masonry houses

FLOOR AREA (m^2)	PHYSICAL FACTOR	STRUCTURE AND FINISHES	NUMBER OF MANHOURS (hours)		
			MATERIALS	SITE LABOUR	TOTAL
45	38,6	• No water and sanitary fittings • No electricity • Double pitched, sheeted roof • Ceilings • Bagged and painted internally and externally	120	1 120	1 240
51	56,5	• Internal water and sanitary fittings • Internal electrical reticulation • Double pitched sheeted roof • Ceilings • Plastered and painted internally and externally	160	1 400	1 560
80	82,3	• Internal water and sanitary fittings • Internal electrical reticulation • Double pitched sheeted roof • Ceilings • Plastered and painted internally and externally	200	1 700	1 900

Table A8 : Kwa Thema Extention 7: civil services for 805 erven constructed using conventional *plant-based* methods

SERVICE	LEVEL OF SERVICE	UNITS/ ERF	COST/ ERF	ESTIMATED NUMBER OF MANHOURS (manhours/erf)		
				MATERIALS	CONSTRUCTION+	TOTAL
Water	• Class 9 uPVC pipes (63 mm to 200 mm diam.) • Resilient seal gate valves and fire hydrants • Erf connections and water meters in boxes	10,0 m	789	5	34	39
Sewer	• 100 mm diam clay sewer pipes • Manholes and erf connection	8,4 m	618	7	36	43
Stormwater	• 450 - 750 mm diam concrete pipes • Junction boxes, manholes and catchpits • Headwalls and stone pitching • Concrete stormwater channels across roads • Earth drains	0.9 m	403	2	24	26
Roads	• Cast *in situ* kerbing • Cable ducts • 25% asphalt, surfaced roads on crushed stone bases; remainder provided with a gravel wearing course	47 m^2	755	3	18	21
TOTAL	All services		**2 565**	**17**	**112**	**129**

* Including P & G but excluding VAT and professional fees (March 1992)
\+ Construction labour including non-productive P & G time (Average between two construction companies)

Table A9 : Manhours required in the provision of *infrastructure* for a low cost township using conventional construction methods

SERVICE	ESTIMATED MANHOURS (hours)		ESTIMATED TOTAL NUMBER OF MANHOURS/ERF	COST/MANHOUR (rand/manhour)
	MATERIALS	SITE LABOUR		
Water	13	87	39	20
Sewerage	16	84	43	14
Roads	14	86	21	36
Stormwater	8	92	26	16
Electricity	70	30	117	20

Table A10 : Comparison of the number of manhours required to construct non-masonry and masonry houses

CONSTRUCTION TYPE	NUMBER OF MANHOURS (hours)			NUMBER OF MANHOURS FOR EQUIVALENT MASONRY HOUSES (hours)		
	MATERIALS+	SITE LABOUR	TOTAL	MATERIALS+	CONSTRUCTION	TOTAL
Timber (SALMA)[12]	300	1 180	1 480	200	1 700	1 900
Precast concrete panels and posts (Blitz)[11]	150	210	360	120	1 120	1 240
Steel frame with 110 mm brick infill panels (Belaton)[56]	330	880	1 210	160	1 400	1 560

\+ Based on information received by manufacturers and estimates from Table 2.12; manhours involved in sanitary services, electrical services and sundry items not included.
' Plant-based masonry manufacture.

Table A11 : Kwa Thema Extention 7: water and sewer reticulation for 805 erven using *labour-based* methods of construction

SERVICE	LABOUR MANHOURS/ERF*		COST/MANHOUR+ (Rand/manhour)	
	Plant-based	*Labour-based*	*Plant-based*	*Labour-based*
Water	39	58	20	14
Sewerage	43	72	14	9

* Includes manhours in respect of P & G and manufacture of materials.
\+ Based on assumption that plant-based and labour-based technologies have no effect on cost.

Table A12 : Manhours required to provide and construct various township roads

ROAD	CONSTRUCTION TECHNOLOGY	WIDTH (m)	MAN-HOURS/m^2	MAN-HOURS/km	LABOUR-BASED TO PLANT-BASED RATIO
Class D: light gravel	*Plant-based* *Labour-based*	5 5	0,24 1,86	1 215 9 300	7,7
Class D: heavier gravel	*Plant-based* *Labour-based*	5 5	0,50 3,67	2 475 18 350	7,4
Manhours for 3 m wide surfaced Class D roads					
Slurry with gravel base	*Plant-based* *Labour-based*	3 3	1,4 8,06	4 431 24 183	5,5
Slurry with WBM base	*Plant-based* *Labour-based*	3 3	2,27 7,75	6 819 23 253	3,4
Asphalt with G3 base	*Plant-based* *Labour-based*	3 3	1,5 6,39	4 500 19 155	4,3
Asphalt with WBM base	*Plant-based* *Labour-based*	3 3	2,30 6,96	6 909 20 880	4,6
Concrete block	*Plant-based* *Labour-based*	3 3	2,19 6,82	6 555 20 460	3,1
Manhours for 5 m wide surface Class D roads					
Slurry with gravel base	*Plant-based* *Labour-based*	5 5	1,18 7,54	5 885 37 705	6,4
Slurry with WBM base	*Plant-based* *Labour-based*	5 5	1,95 7,13	9 765 35 655	3,7
Asphalt with G3 base	*Plant-based* *Labour-based*	5 5	1,19 5,72	5 950 28 575	4,8
Asphalt with WBM base	*Plant-based* *Labour-based*	5 5	1,99 6,33	9 965 31 650	3,2
Concrete block	*Plant-based* *Labour-based*	5 5	1,77 6,02	8 825 30 100	3,4
Manhours for 6 m wide surfaced Class B roads					
Slurry with WBM base	*Plant-based* *Labour-based*	6 6	1,13 6,61	6 750 39 636	5,8
Slurry with WBM base	*Plant-based* *Labour-based*	6 6	2,05 7,62	12 270 45 726	3,7
Slurry with WBM base	*Plant-based* *Labour-based*	6 6	1,20 6,08	7 170 36 450	5,1
Slurry with WBM base	*Plant-based* *Labour-based*	6 6	2,12 7,09	12 690 45 540	3,3
Concrete block	*Plant-based* *Labour-based*	6 6	2.01 8,19	12 072 49 140	4,1

Figure 2.2: Number of manhours required to construct a kilometre of road

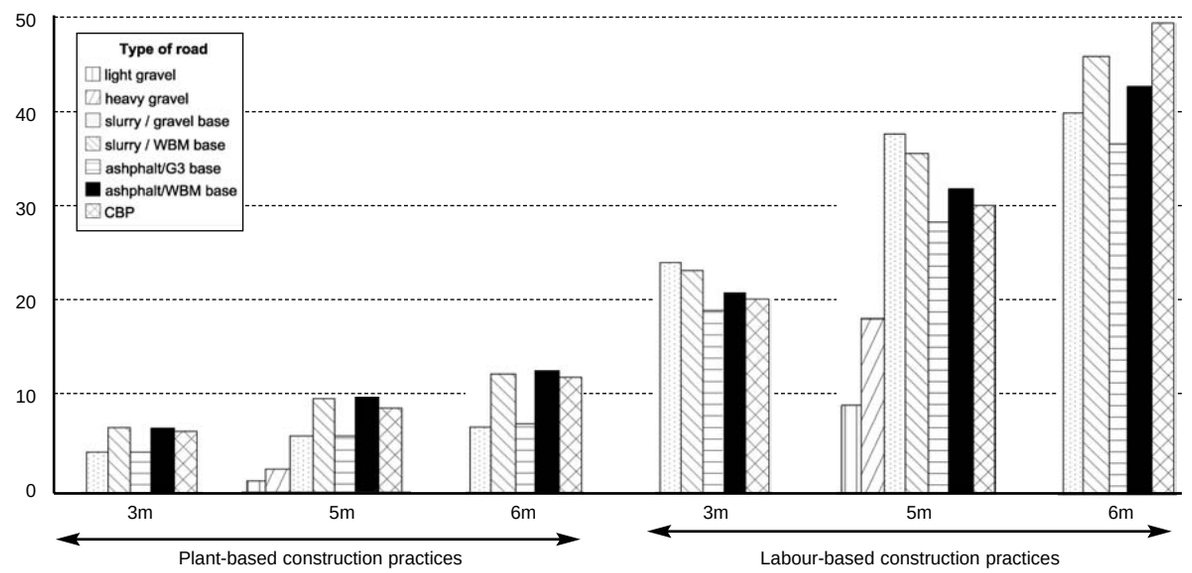

Table A13 : Manhours associated with roadwork layers

LAYER	THICKNESS	MANHOURS TO PRODUCE AND CONSTRUCT (manhours/m²)	
		PLANT-BASED	*LABOUR-BASED*
Road bed preperation (R&R)		0,033	0,350
Gravel wearing course (G5)	125	0,160	1,000
Gravel wearing course (G4)	150	0,192	1,200
Base course (G4)	150	0,192	1,200
Base course (G3)	125	0,165	-
Subbase (G6)	150	0,192	1,200
Waterbound Macadam base course	100	0,040	1,370

Table A14 : Manhours required to surface roads

SURFACING		MANHOURS IN RESPECT OF MATERIALS AND CONSTRUCTION (manhours/m²)	
TYPE	THICKNESS	*PLANT-BASED*	*LABOUR-BASED*
Slurry	15 mm	0,110	2,011
Asphalt	25 mm	0,140	1,170
Concrete blocks	60 mm	0,930+	2,120

+ Factory produced block paving
' Blocks manufactured on site using labour-intensive equipment

Table A15 : Manhours required to provide and construct an *in situ* paved block pavement

OPERATION	MANHOURS/m2			
	OPTION NUMBER			
	1	2	3	4
	Concrete pump mixer and front end loader	*Concrete pump mixer and wheel barrows to place grout*	*Hippo drums and wheel barrows*	*with crushing own stone and sieving sand*
Laying of cells	0,06	0,06	0,06	0,06
Place stones and compact	0,10	0,37	0,37	0,99
Mix and place grout	0,10	0,19	0,37	0,72
Finishing	0,03	0,03	0,03	0,03
TOTAL	0,38	0,65	0,83	1,80

* Sum of manhours involved in manufacture of materials, transport of materials and construction of surfacing. Preparation of *in situ* soil not included.

Chapter 4: RECENT DEVELOPMENTS IN EMPLOYMENT OPPORTUNITIES IN THE PROVISION OF INFRASTRUCTURE

Typical production 'rates, based on the authors' experience, for a six hour task, in soft materials where the depth of excavation does not exceed 2,5 m, are presented in Table A18 It can be seen from Table A18 that productivity drops sharply as the material becomes more difficult to excavate by hand – the approximate ratios between soft class 1 : soft class 2 : soft class 3 being approximately 2,1:1,6:1,0 and for depths of 0-1,0:1,0-1,5:1,5-2,0:2,0-2,5 being approximately 2,2:1,9:1,5:1,0.

Alternative excavation rates for different types of material, including hard rock, are presented in Table A19. It should be noted that productivities can vary between communities, for the same ground conditions. This may be attributed to different work ethics being prevalent. Thus although the figures contained in Table A18 may be regarded as being typical, they do not necessarily apply in all communities.

Table A16 : Productivities for piece and task work in KwaZulu-Natal

ACTIVITY	RATE	
	LAST 500 M SECTION B (PIECEWORK)	REMAINDER OF PROJECT (TASK WORK)
Clearing (medium to thick bush)	34 m /person/day	20 to 45m /person/day
Setting out (bulk earthworks & surfacing) – team size (4+1)	125/day	100 m/day
Bulk earthworks (incl spreading and levelling)	3,3 m /person/day	0,8 to 1,8 m/person/day
Excavation of storm-water drains (average depth 1 m, 350 mm width)	1,5 m /person/day	0,9 to 2 m /person/day
Drifts (unlined) – team size (5+1)	1 drift/day for 5 man team	drift/day for 5 man team
Surfacing	5,5 m/person/day	5 m/person/day

Table A17 : Trends in excavation rates for pickable material in various projects

PROJECT/PROGRAMME	PRODUCTION RATES FOR EXCAVATION IN PICKABLE MATERIALS
Soweto's Contractor Development Programme	2,8 to 3,2 m³/6 hour task
Kenyan Rural Roads Programme	3,0 m³/man/day
KwaZulu road construction	0,7 to 1,0 m³/man/day
KwaZulu road construction	0,3 to 1,1 m³/man/day
Gazankulu and Venda	1,0 m³/person/day
Ciskei	0,6 to 0,8 m3/man day
Ilinge	2,3 m³/man day
Ibhayi	6,0 m³/man/day
Siviele Konstruksie	5 – 12 m³/man/day
SAFCEC	
– up to 1,0 m deep	2,5 – 5,0 m³/man/day
– up to 1,5 m deep	1,1 – 4,0 m³/man/day
World Bank standard	3,0 to 4,0 m³/man/day

Table A18 : Trench excavation rates for a 6-hour task

EXCAVATION	TYPICAL PRODUCTION PER 6-HOUR TASK FOR DEPTH RANGE (m^3)			
	0 – 1,0	1,0 – 1,5	1,5 – 2,0	2,0 – 2,5
Soft class 1	3,5	3,0	2,4	1,6
Soft calss 2	2,8	2,4	1,8	1,3
Soft class 3	1,7	1,5	1,2	0,8

* Refer to Appendix B for classification of material types.

Productivity is also affected by the level of skill. This is clearly evident in certain of the production rates presented in Table A19. A document prepared for the South African Roads Board makes the observation that improved productivity can be expected once skills have been extensively developed. The people involved will realise that they can improve their income by producing more of the finished or required product. This will develop a healthy competition for the available work.

APPENDIX A: STUDY ON LABOUR COMPONENT OF ROADS

Basis for calculation

Estimates of the number of manhours/m^2 of road constructed are based on the sum of the following, as appropriate:

- labour required to produce raw materials such as cement in a cement plant;
- labour required to manufacture precast concrete products either in a factory or on site;
- labour required to obtain materials in quarrying operations;
- labour to transport materials or precast concrete products to the site; and
- labour to construct layers and items.

Table A19 : Productivities for labour performing various construction activities

Construction Activity	Rate
Road construction (man-days per km):	
Low specification rural access roads	1500 - 2600
Road maintenance (km per man):	
Unsurfaced roads, using the lengthman system	1,5 - 2,5
Excavation (man-days per m^3):	
Ordinary soil } these rates can be doubled	0,43 - 0,67
Gravelly soil } for trench excavation	0,77
Boulder mix } below 2 metres	1,10
Medium rock cutting	1,60
Hard rock cutting	2,50
Aggregate Production (man-days/m^3):	5 - 14
Concrete (man-days per m^3 placed):	1,1
Mason labour	4,0
Unskilled labour	
Brick masonry (man-days per m^3 placed):	1,1 - 1,4
Mason labour	2,8
Unskilled labour	
Rubble stone masonry (man-days per m^3 placed):	
Mason labour	1,4
Unskilled labour	3,2
Dressed stone masonry (man-days per m^3 placed):	
Mason labour	2,8
Unskilled labour	5,0
Plastering (man-days per m^2 placed):	
Mason labour	0,14
Unskilled labour	0,22

Assumptions

The following assumptions were made:

- Plant productivity is equal to SAFCEC norms.
- *Labour-based* tasks are based on an 8-hour day and plant-based tasks on a 9,5 hour day.
- All gravel materials are available at a 20 km haul distance.
- Crushed stone is available at a 20 km haul distance.
- All plant and equipment are freely available on the site in question.
- Roadway has single camber.
- Ground surface has a fall parallel to the camber.
- Depth of final road surface is 120 mm below original ground level.
- Box cut extends 300 mm beyond kerb.
- All material from box cut is spoilt.
- Double handling is required with respect to excavated material as spoil is stockpiled prior to spoiling in labour-based approach.
- Hand quarrying and hand loading assumed in labour-based approach.
- All excavated material is classified as soft class 2.

Table A20 : Manhours associated with layerworks and kerbing on various township roads

LAYER	TYPE	MANHOURS REQUIRED TO CONSTRUCT A SQUARE METRE OF ROAD	
		PLANT-BASED	*LABOUR-BASED*
	Light gravel road, 5 m wide		
Wearing course	125 G5	0,160	1,000
Box cut to spoil		0,050	0,510
R&R subgrade		0,033	0,350
Kerbing	nil	–	–
TOTAL		0,243	1,860
	Heavier gravel road, 5 m wide		
Wearing course	150 G4	0,192	1,200
Subbase	125 G5	0,160	1,000
Box cut to spoil		0,110	1,120
R&R subgrade		0,033	0,350
Kerbing	nil	–	–
TOTAL		0,495	3,670
	Class D road, 3 metre wide, with bituminous slurry surfacing		
Surfacing	Slurry 15 mm	0,110	2,011
Basecourse	150 G4	0,192	1,200
Subbase	150 G6	0,192	1,200
Box cut to spoil		0,220	1,320
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,730	0,980
TOTAL		1,477	8,061
	Class D road, 3 metre wide, slurry surfacing, WBM		
Surfacing	Slurry 15 mm	1,110	2,011
Basecourse	100 WBM	1,040	1,370
Subbase	125 G6	0,160	1,000
Box cut to spoil		0,200	2,040
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,730	0,980
TOTAL		2,273	7,751
	Class D road, 3 metre wide, with asphalt surfacing		
Surfacing	Asphalt 25 mm	0,140	1,170
Basecourse	125 G3	0,165	0,165
Subbase	150 G6	0,192	1,200
Box cut to spoil		0,240	2,520
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,730	0,980
TOTAL		1,500	6,385
	Class D road, 3 metre wide, asphalt, WBM		
Surfacing	Asphalt 25 mm	0,140	1,170
Basecourse	100 WBM	1,040	1,370
Subbase	125 G6	0,160	1,000
Box cut to spoil		0,200	2,090
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,730	0,980
TOTAL		2,303	6,960
	Light gravel road, 5 m wide		
Surfacing	Concrete block	1,040	2,310
Basecourse	150 G4	0,192	1,200
Box cut to spoil		0,190	1,980
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,730	0,980
TOTAL		2,185	6,820

Table A20 – continued

LAYER	TYPE	MANHOURS REQUIRED TO CONSTRUCT A SQUARE METRE OF ROAD	
		PLANT-BASED	*LABOUR-BASED*
Class D road, 5 metre wide, with bituminous slurry surfacing			
Surfacing	Slurry 15 mm	1,110	2,011
Basecourse	150 G4	0,192	1,200
Subbase	150 G6	0,192	1,200
Box cut to spoil		0,210	2,190
R&R subgrade		0,033	0,360
Kerbing	Mountable	0,440	0,590
TOTAL		1,177	7,541
Class D road, 5 metre wide, slurry surfacing, WBM			
Surfacing	Slurry 15 mm	1,110	2,011
Basecourse	100 WBM	1,040	1,370
Subbase	125 G6	0,160	1,000
Box cut to spoil		0,170	1,810
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,440	0590
TOTAL		1,953	7,131
Class D road, 5 metre wide, with asphalt surfacing			
Surfacing	Asphalt 25 mm	0,140	1,170
Basecourse	125 G3	0,165	0,165
Subbase	150 G6	0,192	1,200
Box cut to spoil		0,220	2,240
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,044	0,590
TOTAL		1,190	5,715
Class D road, 5 metre wide, asphalt, WBM			
Surfacing	Asphalt 25 mm	0,140	1,170
Basecourse	100 WBM	1,040	1,370
Subbase	125 G6	0,160	1,000
Box cut to spoil		0,180	1,850
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,044	0,590
TOTAL		1,993	6,330
Class D road, 5 metre wide, concrete block surfacing			
Surfacing	Concrete block	0,930	2,120
Basecourse	150 G4	0,192	1,200
Box cut to spoil		0,170	1,760
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,044	0,590
TOTAL		1,765	6,020
Class B road, 6 metre wide, with bituminous slurry surfacing			
Surfacing	Slurry 15 mm	0,110	2,011
Basecourse	125 G3	0,165	0,165
Subbase	150 G4	0,267	1,800
Box cut to spoil		0,190	1,990
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,360	0,490
TOTAL		1,125	6,606

of the production rates presented in Table A19. A document prepared for the South African Roads Board makes the observation that improved productivity can be expected once skills have been extensively developed. The people involved will

Table A20 – continued

LAYER	TYPE	MANHOURS REQUIRED TO CONSTRUCT A SQUARE METRE OF ROAD	
		PLANT-BASED	*LABOUR-BASED*
Class B road, 6 metre wide, slurry surfacing, WBM			
Surfacing	Slurry 15 mm	0,110	2,011
Basecourse	125 WBM	1,160	1,580
Subbase	150 G5	0,192	1,200
Box cut to spoil		0,190	1,990
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,360	0,490
TOTAL		2,045	7,621
Class B road, 6 metre wide, with asphalt surfacing			
Surfacing	Asphalt 30 mm	0,170	1,400
Basecourse	125 G3	0,165	0,165
Subbase	150 G4	0,267	1,600
Box cut to spoil		0,200	2,070
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,360	0,490
TOTAL		1,195	6,075
Class B road, 6 metre wide, asphalt, WBM			
Surfacing	Asphalt 30 mm	0,170	1,400
Basecourse	125 G3	0,160	0,580
Subbase	150 G4	0,192	1,200
Box cut to spoil		0,200	2,070
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,360	0,490
TOTAL		2,115	7,090
Class B road, 6 metre wide, concrete block surfacing			
Surfacing	Concrete block	0,930	2,120
Basecourse	150 G5	0,267	1,600
Subbase	150 G5	0,192	1,200
Box cut to spoil		0,230	2,430
R&R subgrade		0,033	0,350
Kerbing	Mountable	0,360	0,490
TOTAL		2,012	8,190

B: MINIMUM PRODUCTIVITY LEVELS

Source: Notice in terms of Section 70(2) of the Labour Act, 1992. Agreement on conditions of employment entered into between the Metal and Allied Namibian Works Union and the Construction Industries Federation of Namibia 6 April 2000, Government Gazette 31 May 2000 (No. 2340).

The minimum wage rate as determined and agreed under item three above are subject to minimum productivity levels as below. Failure to maintain productivity levels will be addressed by additional training or disciplinary and incapacity procedures as the case may be.

1. Labourer

Excavations in pickable material (not exceeding 2 m deep)	2 to 7 m^3/day
Filling under surface beds	5 to 7 m^3/day
Concrete (mix and place in terms of 1 artisan / 10 labourers)	3 to 6 m^3/day

2. Bricklayer/Plasterer

Stock bricks	685 no. / day
Face bricks	450 no. / day
Plaster to horizontal surfaces	22,5 m^2/day
Plaster to vertical surfaces	31,5 m^2/day

3. Carpenter

Rough formwork to all structures	22,5 m^2/day
Smooth formwork to all structures	16,2 m^2/day
Hanging doors with furniture	8 no. / day
Ceilings including brandering	27 m^2/day
Roof covering including purlins	67,5 m^2/day

4. Tiler

Glazed tiles to walls	19,8 m^2/day
Ceramic tiles to floors	21,6 m^2/day

5. Painter/Glazier

Undercoat and two coats paint to walls	37,8 m^2/day
Undercoat and two coats paint to ceilings	30,6 m^2/day
Two coats varnish to wood	32,4 m^2/day
Prime, first coat and two coats enamel to surfaces	32,4 m^2/day
Glazing generally	31,5 m^2/day

6. VA Tile/Carpet Layer

VA tiles to floor	72 m^2/day
Carpet plus underfelt to floors	67,5 m^2/day

Source: A Nkambule: A review of Labour-intensive Concrete Block Paving van Wyk and Louw Inc.

Table C1 : Labour-intensive production rates

OPERATION	ACTIVITY	MINIMUM TASK (R McCutcheon)
Site clearance	Bush clearing Stripping and grubbing Tree and stump removal	150 - 750 m²/day 100 - 200 m²/day Experience
Earthworks	Slotting Excavation to level: Cut < 250 mm > 250 mm Borrow to fill: Excavate & load (throwing 0-4m) in:- loose soil firm soil hard soil Haulage (wheelbarrow): 0 - 20 m 40 - 60 m 80 - 100 m Spreading	4 m³/day (R McCutcheon) 5 m³/day 4 m³/day 3,5 m³/day (K25-Work study) 2,5 m³/day 1,5 m³/day 13,5 m³/day (R McCutcheon) 8,0 m³/day 5,5 m³/day 12 m³/day
Edge restraint	Lay precast kerb units Backfill to side wall and hand tamping Concrete edge beam	10 m/day (C. Dyer) 3 m³/day 10 m/day (Montshioa Report)
Block paving	Placing the bedding sand, laying the units, compacting the units, filling the joints and removing excess sand	6 m²/day (SA Const World Oct 1994) 100 m²/5 persons/day (Montshioa Report)

D: CONCRETE MASONRY GRAVITY DAMS CONSTRUCTION

Source: King CD. Employment-creation through the design and construction of medium sized concrete masonry gravity dams in South Africa using labour-based construction methods: A comparison of alternative technologies. A project report submitted to the faculty of engineering, University of the Witwatersrand, Johannesburg in partial fulfilment of the requirements for the degree of Master of Science in Engineering, Johannesburg, 1994.

Table D1 : Balfour Dam: Productivity figures for required construction activities

ACTIVITY	DATE	OUTPUT
Stone collecting	1991 September 1994	0,09 m³/man/day 0,57 m³/man/day
Concrete building	September/October 1993 October/November 1993 November/January 1994 January/February 1994 September 1994	0,71 m³/man/day 0,61 m³/man/day 0,43 m³/man/day 0,74 m³/man/day 2,29 m³/man/day
Block making	September/October 1993 October/November 1993 November/January 1994 January/February 1994 September 1994	3,14 blocks/man/day 2,2 blocks/man/day 2.14 blocks/man/day 2,83 blocks/man/day 4,56 block/man/day

NOTE:
(i) Items like stone collecting is not on-going everyday. The team is used for excavating and cleaning as well, so accurate figures are not obtainable.
(ii) Stones are added to the concrete when it is cast in the wall. These two operations can only match the volumes of concrete batched and the teams cannot thus control their own productivity.

Table E1 : Productivity data for excavation by hand

MATERIAL TYPE	EXCAVATION ONLY m³/MANDAY		
	DAILY PAID	TASK WORK	PIECE WORK
Soft/very loose soil	1.67 – 5.00	3.34 – 10.00	6.67 – 20.00
Firm/loose soil	1.04 – 3.13	2.09 – 6.26	4.17 – 12.50
Stiff/compact soil	0.75 – 2.25	1.50 – 4.50	3.00 – 9.00
Very stiff/dense soil	0.60 – 1.79	1.19 – 3.57	2.38 – 7.14
Hard/very dense soil	0.49 – 1.47	0.98 – 2.94	1.96 – 5.88
Soft rock	0.42 – 1.25	0.84 – 2.51	1.67 – 5.01
Source: Derived Table from World Bank (in Coukis, 1983:180 & 284)			

E: EXCAVATION

Source: A critical analysis of the community-based Public Works Programme in South Africa. A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science in Engineering, Johannesburg, July 1996

F: LABOUR-BASED STONE PAVED ROADS

Source: S AL-Fayadh. Labour-based Stone Paved Roads. Kampang Cham Province International Labour Organisation. Technical Assistance to the labour-based Rural Infrastructure Works Programme CMB/97/M02/S10

Table F1 : Work Norms: Labour-based stone paved roads

TASK	METHOD	UNIT	WORK NORM UNIT/DAY	REMARKS
Breaking stone boulders	Crowbar and sledgehammer	Blocks	17 20	200 mm thick blocks 150 mm thick blocks
Loading and unloading blocks from trucks or oxcarts	Wheelbarrow and/or by hand	Blocks	180	Unskilled labour
Shaping the blocks	Club hammer and cutting tools	Blocks	100	Unskilled labour
Dressing the blocks	Club hammer and cutting tools			
Box cutting, sand cushioning and construction filter drains	How, shovel, spade, rake/spreader pickaxe, mattock, bungee or basket, wheelbarrow, hand rammer and watering can	m^3	1,75	Unskilled labour
Packing stones	Club hammer and by hand	m^2	6,5	Skilled labour
Filling voids	Shovel, spade, rake/spreader, bungee or basket and wheelbarrow	m^2	30	Unskilled labour
Compaction	Plate compactor and pedestrian roller	m^2	20	Unskilled labour
Construction of shoulder	How, shovel, spade, rake/spreader pickaxe, mattock, bungee or basket, wheelbarrow, hand rammer and watering can	m^3	1,75	Unskilled labour
Clearing the site		m	20	Unskilled labour

G: EARTHWORKS

Source: McCutcheon, RT, van Zyl CWL, Croswell J, Meyer D and Watermeyer RB. Interim guidelines for labour-based construction projects. Construction and Development series. Number 2 Development Bank of Southern Africa, February 1993.

Table G1 : Average Task Output Values

OPERATION	ACTIVITY	MINIMUM TASK
Site clearance	Bush clearing – dense – light to medium Stripping and grubbing Tree and stump removal Boulder removal	Determine on site 150 – 750 m^2/day 100 – 200 m^2/day Experience 200 day/km
Earth works	Slotting Excavation to level: Cut < 250 mm > 250 mm Borrow to fill: Haulage (wheelbarrow): 0 – 20m 40 – 60m 80 – 100m Spreading	4 m^3/day 5 m^3/day 4 m^3/day 4 m^3/day 13,5 m^3/day (R McCutcheon) 8,0 m^3/day 5,5 m^3/day 12 m^3/day
Drainage	Ditching Sloping Camber formation Mitre drains Catchwater drains Scour checks Culvert installation	3,75 m^3/day 3,75 m^3/day 100 m^2/day 3,75 m^3/day 3,75 m^3/day 25/day max. 20 days/line
Gravelling	Excavation Load Spreading	3 m^3/day 6 m^3 (loose)/day 12 m^3/day
Source: McCutcheon (1983) an Simpson (1980)		

Table G2 : Detailed task rates for excavation

SOIL TYPE	TOOLS	TASK RATES (m^2/man-day) THROWING DISTANCE (m)		
		0 – 4	4 – 6	6 – 8
Loose, not sticky soil Firm soil Very hard soil, hard soil mixed with stones	Shovel, jembe Shovel, fork jembe Pickaxe. frk jembe, shovel	5,0 – 6,0 3,5 – 4,5 2,0 – 3,0	4,5 – 5,5 3.0 – 4,0 1,8 – 2,5	3,5 – 4,5 2,5 – 3,5 1,7 – 2,5
Source: de Veen (1980)				

H: STORMWATER DRAINAGE

Source: Balmaceda P, John R and Horak E. Planning and construction of a stormwater system by labour-intensive methods in an urban environment. Fifteenth Annual Transportation Convention, 1995.

Table H1 : Output data assumed for feasibility analysis

MAIN ACTIVITY	SUBACTIVITY	GANG SIZE	PRODUCTION RATE
Machine Excavation	Excavation of soft soil Excavation of soft rock Excavation of hard rock	Only supervisor Only supervisor Only supervisor	100 m^3 30 m^3 6 m^3
Hand Excavation	Excavation of soft soil,10-man gang Excavation of soft rock, 10-man gang	10-man gang 10-man gang	20 m^3 10 m^3
Pipe laying by machine	Concrete pipes (ø 450 mm): trimming, bedding, laying, backfilling & compaction Concrete pipes (ø 600 mm): trimming, bedding, laying, backfilling & compaction	5-man gang 5-man gang	14,4 m 14,4 m
Pipe laying by hand	Concrete pipes (ø 450 mm): trimming, bedding, laying, backfilling & compaction Concrete pipes (ø 600 mm): trimming, bedding, laying, backfilling & compaction Plastic pipes (ø 450 mm): trimming, bedding, laying, backfilling & compaction	10-man gang 10-man gang 5-man gang	12 m 9,6 m 18 m
Masonry	Batching, mixing and pouring concrete for channel floor Construction of brick-wall for culvert (transport, batching and mixing concrete) Construction of kerb-inlets, manholes and grids (max length of chamber: 2,4 m) (Transport, batching and mixing of mortar, machine backfilling & compaction) Construction of kerb-inlets, manholes and grids (max length of chamber: 2,4 m) (Transport, batching and mixing of mortar, hand backfilling & compaction)	5-man gang 10-man gang 5-man gang 5-man gang	3 m^3 60 m^2 0,33 number 0,25 number

Table H2 : Laying concrete pipes - summary of information from work sudy

PIPE DIAMETER	COSTING INFO	GANG UTILISATION		INPUT/OUTPUT COEFF GANG SIZE		OPTIMUM
(mm)	(Man-hours/m)	Idle time %	Utilisation %	(min/pipe)	(m/hour)	(number)
450	1,16	49,4	50,6	27,782	5,2	6
525	1,16	49,4	50,6	27,782	5,2	6
600	1,16	49,4	50,6	27,782	5,2	6
675	1,54	55,2	44,8	27,782	5,2	8
750	1,54	55,2	44,8	27,782	5,2	8

J: BITUMEN SURFACING

Source: SABITA Labour-enhanced construction for bituminous surfacings Manual II March 1993

Table J1 : Preliminary South Afican bituman surfacing production rates under average conditions

ITEM	METHOD	PRODUCTION RATE
Sweep basecourse	Hand broom	1 000 m^2/man-day
Load and spray water and prime	Tractor, trailer, 2 000 litre tank, pump, spraybar	6 100 m^2/5 man-days
	Bakkie, 750 litre tank, handlances	3 800 m^2/5 man-days
	200 litre drum on trolley	3 300 m^2/5 man-days
Load, heat, spray dust palliative or bitumen onto geotextile	Tractor, trailer, 2 000 litre tank, pump, spraybar	2 800^2/5 man-days
	Bakkie, 750 litre tank, handlances	1 800 m^2/5 man-days
	200 litre drum on trolley	1 500 m^2/5 man-days
Spread chip and backchip as required	Stone or sand	200-400 m^2/man-day
Slurry mix on site and spread	Small concrete mixer, hand tools	10 m^3/15 man-days

K: ROAD PROJECTS

Source: Greyling MR, Critical analysis of labour-intensive road projects in South Africa funded form the sale of strategic oil. A dissertation submitted to the Faculty reservers of Engineering, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science of Engineering, 1994.

Table K1 : Productivity achieved per activity (Pa) for each road authority

ACTIVITY	UNIT	KWZ	QWA	LEB	KWD	GAZ & VEN	BOP	CIS	TRN-QMC	TRN-DWE	TRN-DAF
Site clearance (grubbing)	m²/md	20–45	15–30	–	–	9	15–95	64–210	–	–	25
Excavation											
– loose	m³/md	3	1,5–2,5	0,8	–	1	1,2–1,9	0,4–0,8	1,3	2,0	1,3
– stiff	m³/md	–	1–2	0,6	0,3–0,5	–	0,5–0,8	–	0,8	–	0,8
Loading (1m rise)	m³/md	6	6	–	–	–	1,4–1,9	15	–	2,0	2,0
Unloading (300mm)	m³/md	6	7	–	–	–	1,4–2,2	3	–	–	–
Spreading/shaping	m²/mcd	12	2,5	–	93	2,5	6	1,7	1–2	2	2,5–3
Watering: cart	m²/md		25	–	–	–	12–64	–	–	–	–
: cans	m³/mcd		–	–	35			14,7			
Compaction vibratory	m³/md										
– roller			12	–	–	–	17–53	–	–	52	20
– tamper			–	–		–	–	1,5	–	–	–
Grouted stone	m³/md		0,6	–	2,5	–	–	–	–	0,2	–
pitching	m³/md	1	–	0,4	–	1	0	3,6	–	0,6	
Loose stone	m/md	0,5	0,8	0,4	0,4	1,5	–	–	–	1	–
packing	m/md		–	–	–	–	50	3,5	–	–	–
Pipe laying	m³/md	0,5	1	0,4	–	–	–	0,5	–	–	–
Fencing	m³/md		0,6–1,5	1,5–	–	–	–	0,75	1	0,3	–
Rock Collection	no/md (1km)	0,2	0,6	2	0,02	0,2	0,03	–	0,8–	0,6	–
Masonry walls	m³/md		1,5	–	2	0,4	–	–	1,5	0,6	–
Drifts (dry masonry)	m/md	125	–	1,5	–	–	48	–	–	–	–
Concrete mix & pour	m³/mcd		0,45	–	–	–	–	1–2	–	–	–
Setting out	m³/mcd		–	0,4–0,6	–	–	10–19	2	–	–	–
Gabion construction					57	–	–	15	–	–	–
Haul – tractor/trailer	m³/md								37	–	–
– truck 3km			–	–	–	–	–				
– w/barrow (100m)			2	–				1	–		

NOTE:
1) md = man-days; mcd – machine-days
2) measurement and control of productivity only carried out on a limited basis
3) TPA, PAO,NPA CPA and KaNgwane have been excluded due to either the plant – intensive nature of their projects or lack of sufficient representative data

Table K2 : Productivity data for standard conditions

ACTIVITY	UNIT	PRODUCTIVITY NORM(Pn)	SOURCE
Site clearance (grubbing)	m^2/md	100	ILO (CTP 40)
Excavation – loose	m^3/md	5,1 (ave)	WB, Tab F-3
– stiff	m^3/md	2,7 (ave)	WB, Tab F-3
Loading (1m rise)	m^3/md	3,8	WB, Tab F-4
Unloading (300mm)	m^3/md	6	WB, Tab F-4
Spreading / shaping	m^3/md	11	WB, Tab F-7
Watering: cart (4000L)	m^3/mcd	886	Appendix N
: cans (20L)	m^3/md	37	Appendix N
Compaction – s roller (200kg)	m^3/mcd	8 (150–200 mm layer)	WB, Tab F-8
– tamper (75mm)	m^3/md	3,8 (75 mm, 3 passes)	WB, Tab F-9
Grouted stone pitching	m^3/md	0,5	ILO (CTP 40)
Loose stone packing	m^3/md	1,5	ILO (CTP 40)
Pipe laying	m/md	0,5	ILO (CTP 40)
Rock Collection (1km)	m^3/md	2,5	ILO (CTP 40)
Masonry walls	m^3/md	0,5	ILO (CTP 40)
Drifts (dry masonry)	No./md	1,5	ILO (CTP 40)
Concrete mix & pour	m^3/md	0,5	ILO (CTP 40)
Setting out	m/md	100	ILO (CTP 40)
Haul – w/barrow (100m)	m^3/md	2,2	WB, Tab F-9
– tractor/trailer (3km)	m^3/mcd	18	Appendix N
– truck 3km	m^3/mcd	24	WB, Tab F-10

WB: World Bank (Coukis et al, 1983)
ILO (CTP 40): World Employment Programme (Ghana), (de Veen, 1985)
– Average management and incentives
md = man-day
mcd = machine-day

Table K3 : Adjustment factors applied to standard productivity data (according to Coukis et al, 193: Table 7.7)

AUTHORITY	MANAGEMENT QUALITY (REFER TOTABLE 6.8) (1)	ENVIRONMENTAL CONDITIONS (2)	PAYMENT SYSTEM	FACTORS (f) (See below)
KWZ	Good	Good	Daily	0,75
QWA	Good	Fair	Piecework	1,5
GAZ	Poor	Fair	Daily	0,33
KWD	Good	Good	Taskwork	1,5
LEB	Good	Good	Daily	0,75
BOP	Fair	Good	Daily; Taskwork	0,75
VEN	Poor	Fair	Daily	0,33
CIS	Fair	Good	Taskwork	1,25
TRN - OMC	Poor	Fair	Taskwork	0,75
- DWE	Fair	Fair	Daily	0,5
- DAF	Poor	Good	Daily	0,5

(1) Supervision and quality control
(2) See note below Table K4

Table K4 : Range of adjustment factors applied to standard productivity data (Coukis et al, Table 7.7 1983)

PAYMENT SYSTEM	AREAS WITH LITTLE OR NO EXPERIENCE IN LI CONSTRUCTION
Daily paid	0.25 – 0.75
Taskwork	0.5 – 1.5
Piecework	1 – 3 (Upper limit will be taken as 2 due to insufficient planning time)

NOTE: The top end of the range in Table K4 has been used in Table K3 where management and/or environmental conditions have been more than satisfactory. Consequently the reverse applies to poor conditions. The conditions recorded on site visits by the author include: site/human environment as well as climate, i.e. temperature, rainfall, drought, type of work, terrain, traffic interference, nutrition, local violence and so forth.

Table K5 : Productivity ratings (Pr-1) per authority per activity (Assessment 1)

ACTIVITY	UNIT	KWZ	QWA	LEB	KWD	GAZ-VEN	BOP	CIS	TRN-OMC	TRN-DWE	TRN-DAF	%
Site clearance (grubbing)	m²/md	2	1			1	3	5			3	50
Excavation												
– loose	m³/md	4	2	1		3	2	1	2	5	3	51
– stiff	m/md		2	2	1		2		2		3	40
Loading (1m rise)	m³/md	5	5				3	2		5	5	83
Unloading (300mm)	m³/md	5	4				2	2				65
Spreading/shaping	m³/mcd	5	1			3	3	1	1	2	3	48
Watering:												
– cart (4000L)	m²/md		1		1		1					20
– cans (20L)	m²/mcd							2				
Compaction												
– v roller (200 kg)	m²/mcd		5		5		5			5	5	100
– tamper 75 mm	m³/md							2				40
Grouted stone pitching	m³/md		4		5					4		87
Loose stone packing	m²/md	5		2		5		5		4		84
Pipe laying	m/md	5	5	5	3	5				5		93
Rock Collection (91km)	m³/md	2	2	1				1				30
Masonry walls	m³/md		5	5				5	5	5		100
Drifts (dry masonry)	No./md	1	2		1	2	1		5	4		46
Concrete mix & pour	m³/md		5	5	5	5				5		100
Setting out	m/mcd	5					3					80
Haul –												
wheelbarrow 100 m	m³/md	3						2				50
– tractor/trailor (3km)	m³/mcd						5	1				60
– truck (3 km)	m³/mcd				5			3	5			87
Rating (%)		75	63	60	65	69	55	49	67	86	73	66

Where:

Pr	RANGE
5	Pa ≥ fPn
4	0.75fPn ≤ Pa < fPn
3	0.5fPn ≤ Pa < 0.75fPn
2	0.25fPn ≤ Pa < 0.5fPn
1	0 ≤ Pa < 0.25fPn

Pa = productivity achieved (Table K1)
Pn = productivity norm (Table K2)
f = factor (Table K3)
Pr-1 = productivity rating (/activity)

Table K6 : Productivity achieved in Kenya (de Veen), 1983) and Malawi (Relf, Hagen and Akute, 1987)

ACTIVITY	UNIT	PRODUCTIVITY RANGE	AVERAGE	SOURCE
Site clearance (grubbing)	m²/man-day	100-250	175	K.R.A.R.P
Excavation – loose	m³/man-day	5-6	5,5	K.R.A.R.P
– stiff	m³/man-day	3,5-4,5	4	K.R.A.R.P
Loading – 1m rise (loose)	m³/man-day	12-15	13,5	K.R.A.R.P
Haulage – w/barrow (100m)	m³/man-day	5,5-7	6,3	K.R.A.R.P
Spreading/shaping	m³/man-day	12	12	K.R.A.R.P
Compaction – tamper	m³/man-day	12-15	13,5	K.R.A.R.P
Pipe laying	m/man-day	1,7	1,7	D.R.I.M.P
Masonry walls	m³/man-day	1,3	1,3	D.R.I.M.P
Concrete mix & pour	m³/man-day	1,6	1,6	D.R.I.M.P
Grouted stone pitching	m³/man-day	1,75	1,7	D.R.I.M.P
Loose stone packing	m³/man-day	3	3	D.R.I.M.P

Table K7 : Productivity rating (Pr-2) Assessment 2

ACTIVITY	UNIT	KWZ	QWA	LEB	KWD	GAZ & VEN	BOP	CIS	TRN-OMC	TRN-DWE	TRN-DAF	%
Site clearance (grubbing)	m³/md	1	1	–	–	1	2	4	–	–	1	33
Excavation – loose	m³/md	3	2	1	–	1	2	1	1	2	1	31
– stiff	m³/md	–	2	1	1	–	1	–	1	–	1	23
Loading (1m rise) (loose)	m³/md	2	2	–	–	–	1	1	–	1	1	27
Haulage – w/barrow (100 m)	m³/md	–	2	–	–	–	–	1	–	–	–	30
Spreading/shaping	m³/md	5	1	–	–	1	3	1	1	1	–	37
Compaction – tamper	m³/md	–	–	–	–	–	–	1	–	–	–	–
Pipe laying	m/md	2	2	1	1	4	–	–	–	3	–	43
Masonry walls	m³/md	–	4	5	–	–	–	3	4	1	–	68
Concrete mix & pour	m³/md	–	4	4	5	2	–	–	–	2	–	68
Grouted stone pitching	m³/md	–	2	–	5	–	–	–	–	1	–	53
Loose stone packing e.g. drifts	m³/md	2	1	1	1	2	1	5	2	1	–	36
Rating (%)		50	42	43	52	37	33	43	36	30	20*	41

NOTE:
md = man-day
* Transkei (D.A.F): Too few activities were monitored for an accurate assessment to be made.

L: Roadworks

ACTIVITY	DAILY PRODUCTION (production/ contractor/day)	TASK (production/ labourer/day
Soft excavation	80,0 m^3	3,2 m^3
Intermediate excavation	40,0 m^3	1,6 m^3
Loading and carting away of spoil	137,5 m^3	5,5 m^3
Leveling of road bed	1 500,0 m^2	60,0 m^2
Picking of road bed	1 000,0 m^2	40,0 m^2
Compaction of road bed	500,0 m^2	–
Construction of kerbing:		
straight	162,5 m	6,5 m
curved	50,0 m	2,0 m
Spreading of waterbound macadam	1 250,0 m^2	50,0 m^2
Leveling of waterbound macadam	625,0 m^2	25,0 m^2
Spreading of fines (dry processing)	1 250,0 m^2	50,0 m^2
Compacting of waterbound macadam	500,0 m^2	20,0 m^2

L: ROADWORKS

Source: Watermeyer R(ed) Contractor Development in Labour-based Construction

Since task work forms the basis of measurement and payment in labour-based construction work, construction rates need to be assessed at an early stage of a project. Pilot schemes (small scale, trial or demonstration projects) can be run before the main project to determine these rates. A recent road building pilot project undertaken in Soweto yielded the following production rates for a contractor employing 25 labourers:

Table M1 : Soil excavation characteristics

ACTIVITY DEFINITION	SOIL DESCRIPTION		SUITABLE TOOLS (Rand/manhour)
	Cohesive	*Non-cohesive*	
Soft	Soft	Very loose	Easily excavated with a shovel or hoe
Medium	Firm	Loose	Can be dug with a shovel
Hard	Stiff	Compact	Mattock, pick or other swung tool required
Very hard	Very stiff or hard	Dense or very dense	Crowbar required in addition to pick
Rock		Rock	Sledge hammer and chisels required

M: EARTHWORKS

Source: Steidl D. Productivity Norms for Labour-Based Construction ASSIST Information Service Technical Brief No. 2 International Labour Organisation 1998.

Table M2 : Site clearing norms - country data

COUNTRY	AVERAGE PRODUCTIVITY BY TYPE OF COVER m^2 per worker day				
	Dense bush	*Medium bush*	*Light bush*	*Grubbing*	*De-stumping*
Botswana	–	750	750	150	–
Cambodia	30	60	100	15	0,75
Ghana	–	–	375	375	–
Indonesia	130	175	–	37,5	1
Kenya	50	150	300	100	–
Lesotho	50	100	250	65	–
Tanzania	50	100	250	150	3,5
Zimbabwe	200	–	300	250	–
WB Study	–	–	150	15	–
Median	**50**	**125**	**275**	**100**	**1**

Table M3 : Site clearing norms - recommended values

	AVERAGE PRODUCTIVITY BY TYPE OF COVER m² per worker day				
	Dense bush	*Medium bush*	*Light bush*	*Grubbing*	*De-stumping*
Country median	50	125	275	100	1
Site trials	105	209	311	209	–
RARP	320	480	640	I75	–
Recommended value	**100**	**200**	**350**	**175**	By experience

Table M4 : Excavation norms - country data

COUNTRY	AVERAGE PRODUCTIVITY BY SOIL CLASSIFICATION m³ per worker day				
	Soft	*Medium*	*Hard*	*Very hard*	*Rock*
Botswana	4,15	3,8	2,5	1,9	–
Cambodia	2,75	2	1,25	0,75	–
China	9	7,0	3	2	–
Ghana	3,75	3,75	3,75	3,75	–
Indonesia	–	–	2,75	–	–
Kenya	5	3,5	2,25	1,75	0,75
Lesotho	4,5	3,5	2,75	1	0,05
Nepal	–	3,3	2,5	–	0,61
Tanzania	5,5	4,5	4	2,5	–
Zimbabwe	5,5	5,5	4	3,5	2
WB Study	6,7	2,1	3	2	1,7
Median	**5,00**	**3,50**	**2,75**	**2,0**	**0,75**

Table M5 : Excavation norms - recommended values

	AVERAGE PRODUCTIVITY BY SOIL CLASSIFICATION m³ per worker day				
	Soft	*Medium*	*Hard*	*Very hard*	*Rock*
Country median	5,00	3,50	2,75	2,00	0,75
Site trials	3,6	3,2	3,45	2,2	0,8
RARP	5,5	4	3	2	–
Recommended value	**5,0**	**3,5**	**3,0**	**2,0**	**0,8**

Table M6 : Wheelbarrow haulage norms - country data

COUNTRY	WHEELBARROW HAULAGE NORMS BY HAUL DISTANCE m³ per worker day					
	0-20 m	*20-40 m*	*40-60 m*	*60-80 m*	*80-100 m*	*100-150 m*
Botswana	8,4	7	6,7	5,6	5,2	4,7
Kenya	10,5	10,5	8	6,5	5,5	4,5
Lesotho	8	6	5	4,5	4	–
Tanzania	11	11	8,25	6,25	5,25	5
Zimbabwe	5	5	5	5	5	4
Median	**8,4**	**7**	**6,7**	**5,6**	**5,2**	**4,6**

Table M7 : Wheelbarrow haulage norms – recommended values

	WHEELBARROW HAULAGE NORMS BY HAUL DISTANCE m³ per worker day					
	0-20 m	*20-40 m*	*40-60 m*	*60-80 m*	*80-100 m*	*100-150 m*
Country median	8,4	7,0	6,7	5,6	5,2	4,6
Site trials	5,3	4,8	4,6	4,3	4,2	4,1
RARP	13,5	10,5	8,5	6,5	5,5	–
Recommended value	**8,5**	**7,0**	**6,5**	**5,5**	**5,0**	**4,5**

Table M8 : Typical haulage rates for manually loaded equipment

Haul route condition	*Good*					*Average*					*Poor*				
Haul distance (km)	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10
Trips per day per truck	22	19	16	11	8	18	15	12	8	6	16	12	10	7	5
Trips per day per tractor/ trailer combination	20	12	8	6	4	18	11	6	5	4	16	9	4	4	3

Table M9 : Loading, unloading and spreading norms – country data

COUNTRY	AVERAGE PRODUCTIVITY RATES m³		
	Loading	*Unloading*	*Spreading*
Botswana	12	–	14
Cambodia	8	15,5	5,25
Ghana	6,7	10	–
Kenya	10	9	13,5
Lesotho	5	–	14,25
Tanzania	11	–	15
Zimbabwe	8,5	–	9
World Bank	–	–	11
Median	**8,5**	**10**	**13,5**

Table M10 : Loading, unloading and spreading norms – recommended values

COUNTRY	AVERAGE PRODUCTIVITY RATES m³ per worker day		
	Loading	*Unloading*	*Spreading*
Country median	8,5	10	13,5
Site Trials	6,5	11	12
RARP	8,5	–	13,5
Recommended value	**8,5**	**10**	**13.5**

Table M11 : Compaction norms – country data and recommended values

COUNTRY	MANUAL COMPACTION	EQUIPMENT COMPACTION
	m^3 per worker-day	*m^2 per roller-day*
Cambodia	10	–
China	3,2	–
Kenya	7,5	700
Lesotho	15	700
Tanzania	9	700
Median	***9,0***	***700***
Recommended value	**9,0**	**700**

Table M12 : Culvert laying norms - country data

COUNTRY	ACTIVITY		
	Culvert installation m per worker-day	*Concrete m^3 per worker-day*	*Masonry m^3 per worker-day*
Cambodia	–	1,25	1,25
China	1,2	–	–
Kenya	0,3	1	1,5
Lesotho	1,1	1,75	1,35
Zimbabwe	0,8	0.8	0,75
Median	**0,9**	**1,13**	**1,3**

Table M13 : Culvert laying norms – recommended values

COUNTRY	ACTIVITY		
	Culvert installation m per worker-day	*Concrete m^3 per worker-day*	*Masonry m^3 per worker-day*
Country media	0,9	1,13	1,3
Site trials	0,95	0,6	0,6
Recommended values	**0,9**	**1,0**	**1,0**

Table M14 : Typical equipment/labour combinations for gravelling

HAUL DISTANCE	LOAD PER DAY	TOTAL VOLUME	EXCAVATION	LOADING	UN-LOADING	SPREADING
Km	*Unit*	*Loose m^3*	*Workers per tractor*	*Workers per tractor*	*Workers per tractor*	*Workers per tractor*
0 to 2	18	54	18	7	6	4
2 to 4	11	33	11	4	4	2
4 to 6	7	21	7	3	2	2
6 to 8	5	15	5	2	2	1
8 to 10	4	12	4	2	1	1

Table M15 : Summary of recommended values
SITE CLEARING

	AVERAGE PRODUCTIVITY BY TYPE OF COVER m² per worker day				
	Dense bush	*Medium bush*	*Light bush*	*Grubbing*	*De-stumping*
Recommended value	100	200	350	175	By experience

Table M15 : Summary of recommended values
EXCAVATION

	AVERAGE PRODUCTIVITY BY SOIL CLASSIFICATION m³ per worker day				
	Soft	*Medium*	*Hard*	*Very hard*	*Rock*
Recommended value	5,0	3,5	3,0	2,0	0,8

Table M15 : Summary of recommended values
WHEELBARROW HAULAGE

	WHEELBARROW HAULAGE NORMS BY HAUL DISTANCE m³ per worker day					
	0-20 m	*20-40 m*	*40-60 m*	*60-80 m*	*80-100 m*	*100-150 m*
Recommended value	8,5	7,0	6,5	5,5	5,0	4,5

Table M15 : Summary of recommended values
LOADING, UNLOADING AND SPREADING

	AVERAGE PRODUCTIVITY RATES m³ per worker day		
	Loading	*Unloading*	*Spreading*
Recommended value	8,5	10	13,5

Table M15 : Summary of recommended values
COMPACTION

	MANUAL COMPACTION	EQUIPMENT COMPACTION
	m³ per worker-day	*m² per roller-day*
Recommended value	9,0	700

Table M15 : Summary of recommended values
CULVERT LAYING

	CULVERT INSTALLATION	CONCRETE	MASONRY
	m per worker-day	*m³ per worker-day*	*m³ per worker-day*
Recommended value	0,9	1,0	1,0

Table M15 : Summary of recommended values
TYPICAL HAULAGE RATES FOR MANUALLY LOADED EQUIPMENT

Haul route condition	*Good*					*Average*					*Poor*				
Haul distance (km)	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10
Trips per day per truck	22	19	16	11	8	18	15	12	8	6	16	12	10	7	5
Trips per day per tractor/ trailer combination	20	12	8	6	4	18	11	6	5	4	16	9	4	4	3

Table M15 : Summary of recommended values
TYPICAL EQUIPMENT/LABOUR COMBINATIONS FOR GRAVELLING

HAUL DISTANCE	LOAD PER DAY	TOTAL VOLUME	EXCAVATION	LOADING	UN-LOADING	SPREADING
Km	*Unit*	*Loose m^3*	*Workers per tractor*	*Workers per tractor*	*Workers per tractor*	*Workers per tractor*
0 to 2	18	54	18	7	6	4
2 to 4	11	33	11	4	4	2
4 to 6	7	21	7	3	2	2
6 to 8	5	15	5	2	2	1
8 to 10	4	12	4	2	1	1

Table M16 : Average worker input for completed operations

PROJECT	OPERATION	INPUT
	Construction of	*worker days/km*
Botswana	Earth road	1981
Botswana	Gravel topping only	2157
Ghana DFR	Gravel lowland road	1580
Kenya MRP	Earth lowland road	1442
Kenya MRP	Gravel topping only	1819
Kenya MRP	Regravelling	1209
Laos LAO/90/MO1/FRG	Gravel lowland road	2203
Lesotho LCU	Gravel lowland road	2645
Lesotho LCU	Gravel mountain road	4400
Zimbabwe LBDU	Gravel lowland road	3260

ANNEX 2: Country productivity data

Note: There are many gaps in the tables below. However, it is hoped that the publication and dissemination of this brief will stimulate readers to contribute to filling in the gaps. If you have relevant data, please send it to one of the ASIST offices (see the back cover for addresses).

Table M17 : Country data for site clearing activities

PRODUCTION TARGETS	BUSH CLEARING						OTHER CLEARING					
	Dense		Medium		Light		Grubbing		De-stumping		Boulder removal	
Country	*m²*	*m²*	*m²*	*m²*	*m²*	*m²*	*m²*	*m²*	*No*	*No*	*No*	*No*
	Min	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Botswana				750		750		150				
Cambodia	20	40	40	80	80	120	10	20	1	1		
China												
Ghana					350	400	350	400			5	15
India		130	150	200			30	45		1		
Kenya		50		150		300	0	200		Exp		Exp
Lesotho		50		100		250	30	100		1		Ds
Mozambique												
Tanzania		50		100		250		150	2	5	Ds	Ds
Thailand												
Zimbabwe		200				300	200	300			1	10
World Bank						150		15				
Minimum	20	40	40	80	80	120	0	15	1	1	1	10
Maximum	20	200	150	750	350	750	350	400	2	5	5	15
Average	20	87	95	230	215	315	103	153	1	2	3	13
Median	20	50	95	125	215	275	30	150	1	1	3	13
Number of records	1	6	2	6	2	8	6	9	2	4	2	2

Table M17 : Country data for site clearing activities

ACTUAL OUTPUT	UNIT	BOTSWANA		GHANA		KENYA		LESOTHO		MOZAMBIQUE		ZIMBABWE	
Clearing		*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*
Dense Bush	m2		17,4		33,9		11,3						
Medium Bush	m2		29,2		53,8		27,5						45
Light Bush	m2		35		64,9		52,5						65
Grubbing <20 cm	m2				27,5		31,3						75
De-stumping > 20 cm	No												
Boulder removal	No												

Ds = Depends upon the size; Exp = By experience

Table M18 : Country data for exacavation activities

PRODUCTION TARGETS FOR EXCAVATION IN CUBIC METRES PER TASK

	SOFT		*MEDIUM*		*HARD*		*VERY HARD*		*ROCK*	
Country	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Botswana	3,8	4,5	3,1	4,5	2,5	2,5	1,9	1,9		
Cambodia	2,5	3,0	1,5	2,5	1,0	1,5	0,5	1,0		
China		9,0		7,0		3,0		2,0		
Ghana	3,0	4,5	3,0	4,5	3,0	4,5	3,0	4,5		
Indonesia			1,7	3,5		2,5				
Kenya	4,0	6,0	2,0	5,0	1,5	3,0	1,5	2,0	0,5	1,0
Lesotho	4,0	5,0	3,0	4,0	2,5	3,0	0,5	1,5	0,5	1,5
Mozambique										
Tanzania	5,0	6,0	4,0	5,0	3,5	4,5	2,0	3,0		
Thailand										
Zimbabwe	5,0	6,0	5,0	6,0	3,0	5,0	3,0	4,0	1,0	3,0
World Bank		6,7		4,2		3,0		2,0		1,7
Minimum	2,5	3,0	1,5	2,5	1,0	1,5	0,5	1,0	0,5	1,0
Maximum	5,0	9,0	5,0	7,0	3,5	5,0	3,0	4,5	1,0	3,0
Average	3,9	5,6	2,9	4,6	2,4	3,3	1,8	2,4	0,7	1,8
Median	4,0	6,0	3,0	4,5	2,5	3,0	1,9	2,0	0,5	1,6
Number of records	7	9	8	10	7	10	7	9	3	4

Table M18 : Country data for exacavation activities

ACTUAL OUTPUT OF EXCAVATION IN CUBIC METRES PER TASK

	SOFT		*MEDIUM*		*HARD*		*VERY HARD*		*ROCK*	
Country	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*
Botswana	5,2	3,6	5,2	3,2	5,2	2,9				
Cambodia	6,0		6,0		6,0		6,0		6,0	
China	10,0		10,0		10,0		10,0			
Ghana	5,0	4,1	5,0	4,1	5,0	4,1	5,1	4,2		
Indonesia										
Kenya	4,0	3,0	5,0	2,5	5,0	2,0	1,5	1,3	5,0	0,9
Lesotho		3,3		2,9				1,4		0,7
Mozambique										
Tanzania										
Thailand										
Zimbabwe	5,0	5,0	5,0	4,5	5,0	4,0	5,0	3,0		
World Bank		6								
Minimum	4,0	3,0	5,0	2,5	5,0	2,0	1,5	1,3	5,0	0,7
Maximum	10,0	5,0	10,0	4,5	10,0	4,1	10,0	4,2	6,0	0,9
Average	5,9	3,8	6,0	3,4	6,0	3,3	5,5	2,5	5,5	0,8
Median	5,1	3,6	5,1	3,2	5,1	3,5	5,1	2,2	5,5	0,8
Number of records	6	5	6	5	6	4	5	4	2	2

Table M19 : Country data for haulage activities

PRODUCTION TARGETS FOR HAULING IN CUBIC METRES PER TASK

	0-20 m		*20-40 m*		*40-60 m*		*60-80 m*		*80-100*		*100-150 m*	
Country	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Botswana		8,4		7,0		6,7		5,6		5,2		4,7
Cambodia												
China												
Ghana												
Indonesia												
Kenya		10,5		10,5		8,0		6,5		5,5		4,5
Lesotho		8,0		6,0		5,0		4,5		4,0		-
Mozambique												
Tanzania	10,0	12,0	10,0	12,0	7,5	9,0	6,0	6,5	5,0	5,5		5,0
Thailand												
Zimbabwe		5,0		5,0		5,0		5,0		5,0		4,0
World Bank												
Minimum	10,0	5,0	10,0	5,0	7,5	5,0	6,0	4,5	5,0	4,0	0,0	4,0
Maximum	10,0	12,0	10,0	12,0	7,5	9,0	6,0	6,5	5,0	5,5	0,0	5,0
Average	10,0	8,8	10,0	8,1	7,5	6,7	6,0	5,6	5,0	5,0	0,0	4,6
Median	10,0	8,4	10,0	7,0	7,5	6,7	6,0	5,6	5,0	5,2	0,0	4,6
Number of records	1	5	1	5	1	5	1	5	1	5	0	4

Table M19 : Country data for haulage activities

ACTUAL OUTPUT OF EXCAVATION IN CUBIC METRES PER TASK

	0-20 m		*20-40 m*		*40-60 m*		*60-80 m*		*80-100*		*100-150 m*	
Country	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*
Botswana	5,0	6,0	5,0	5,0	5,0	4,5	5,0	4,0	5,0	3,8	5,0	3,3
Cambodia												
China												
Ghana	5,9	4,6	5,9	4,6	5,9	4,6	5,9	4,6	5,9	4,6	5,9	4,6
Indonesia												
Kenya												
Lesotho		3,5		3,5		3,5		3,5		3,5		3,5
Mozambique												
Tanzania												
Thailand												
Zimbabwe	5,0	9,0	5,0	9,0	5,0	8,0	5,0	7,0	6,0	6,0	6,0	5,0
World Bank												
Minimum	5,0	3,5	5,0	3,5	5,0	3,5	5,0	3,5	5,0	3,5	5,0	3,3
Maximum	5,9	9,0	5,9	9,0	5,9	8,0	5,9	7,0	6,0	6,0	6,0	5,0
Average	5,3	5,8	5,3	5,5	5,3	5,2	5,3	4,8	5,6	4,5	5,6	4,1
Median	5,0	5,3	5,0	4,8	5,0	4,6	5,0	4,3	5,9	4,2	5,9	4,1
Number of records	3	4	3	4	3	4	3	4	3	4	3	4

Table M20 : Country data for loading, unloading and spreading activities

PRODUCTION TARGETS		BOTSWANA		CAMBODIA		CHINA		GHANA		INDONESIA		KENYA	
Load, unload spread	*Unit*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Loading soil	m3		12	8	12							8	10
Loading gravel	m3			5	7				6.7			8	10
Unloading soil	m3			15	20							8	10
Unloading gravel	m3			12	15				10			8	10
Spreading soil	m3		10	5	7.5							12	15
Spreading soil	m2								50		60		
Spreading gravel	m3		18	3.5	5							12	15
Spreading gravel	m2							50	75	35	50		

Table M20 : Country data for loading, unloading and spreading activities

PRODUCTION TARGETS		LESOTHO		MOZAMBIQUE		TANZANIA		THAILAND		ZIMBABWE		WORLD BANK	
Load, unload spread	*Unit*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Loading soil	m3					12	15						
Loading gravel	m3		5			7	10			8	9		
Unloading soil	m3												
Unloading gravel	m3												
Spreading soil	m3	14	16			15	18			7	10		11
Spreading soil	m2		90			60	90						
Spreading gravel	m3	12	15				12				10		
Spreading gravel	m2		60				60						

Table M20 : Country data for loading, unloading and spreading activities

ACTUAL OUTPUT		BOTSWANA		CAMBODIA		CHINA		GHANA		INDONESIA		KENYA	
Load, unload spread	*Unit*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*
Loading soil	m3			6								6	9
Loading gravel	m3			6				6,25	6,25			6	9
Unloading soil	m3			6									9
Unloading gravel	m3			6					12,7			6	9
Spreading soil	m3			6									
Spreading soil	m2							5,4	91			6	13
Spreading gravel	m3			6								6	13
Spreading gravel	m2							5,8	86				

Table M20 : Country data for loading, unloading and spreading activities

ACTUAL OUTPUT		LESOTHO		MOZAMBIQUE		TANZANIA		THAILAND		ZIMBABWE		WORLD BANK	
Load, unload spread	*Unit*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*
Loading soil	m3									5	6		
Loading gravel	m3									5	6		
Unloading soil	m3									5	11		
Unloading gravel	m3									5	11		
Spreading soil	m3									5	11		
Spreading soil	m2												
Spreading gravel	m3									5	11		
Spreading gravel	m2												

Table M21 : Country data for compaction activities

PRODUCTION TARGETS	HANDRAMMER					
	Formation		Structure		Slopes	
	m³		m³		m³	
Country	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Botswana						
Cambodia	10,0	12,5			7,5	10,0
China		5,7		2,5		1,5
Ghana						
Indonesia						
Kenya			6,0	9,0	6,0	9,0
Lesotho						
Mozambique						
Tanzania	8,0	10,0				
Thailand						
Zimbabwe						
World Bank						
Minimum	8,0	5,7	6,0	2,5	6,0	1,5
Maximum	10,0	12,5	6,0	9,0	7,5	10,0
Average	9,0	9,4	6,0	5,8	6,8	6,8
Median	9,0	10,0	6,0	5,8	6,8	9,0
Number of records	2	3	1	2	2	3

Table M21 : Country data for compaction activities

PRODUCTION TARGETS	MECHANICAL											
	Formation		*Structures*		*Slopes*		*Structures*		*Slopes*		*Structures*	
	m³		*m³*		*m³*		*m³*		*m³*		*m³*	
Country	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Botswana												
Cambodia	75,0	100,0			10,0	13,5						
China		16,7										
Ghana												
Indonesia												
Kenya												
Lesotho	100,0	150,0						700,0				
Mozambique												
Tanzania		140,0						700,0				
Thailand												
Zimbabwe		250,0										
World Bank	170,0	280,0										
Minimum	75,0	16,7			10,0	13,5	0,0	700,0				
Maximum	170,0	280,0			10,0	13,5	0,0	700,0				
Average	115,0	156,1			10,0	13,5	0,0	700,0				
Median	100,0	145,0			10,0	13,5	0,0	700,0				
Number of records	3	6			1	1	0	2				

Table M22 : Country data for culvert laying activities

PRODUCTION TARGETS		BOTSWANA		CAMBODIA		CHINA		GHANA		INDONESIA		KENYA	
Compaction	*Unit*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Culvert laying													
600 mm	m			6	12		1,4						0,33
900 mm	m						0,9						0,33
Concrete work	m^3			1	1,5	0,1	0,2						1
Stone masonry	m^3			1	1,5								1,5

Table M22 : Country data for culvert laying activities

PRODUCTION TARGETS		LESOTHO		MOZAMBIQUE		TANZANIA		THAILAND		ZIMBABWE		WORLD BANK	
Compaction	*Unit*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Culvert laying													
600 mm	m	1	1,1				0,36			0,5	0,9		
900 mm	m												
Concrete work	m^3	1,5	2							0,6	1		
Stone masonry	m^3	1,2	1,5							0,5	1		

Table M22 : Country data for culvert laying activities

ACTUAL OUTPUT		BOTSWANA		CAMBODIA		CHINA		GHANA		INDONESIA		KENYA	
Compaction	*Unit*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*
Culvert laying													
600 mm	m			7								5	
900 mm	m												
Concrete work	m^3			7								6	0,28
Stone masonry	m^3			7								6	0,3

Table M22 : Country data for culvert laying activities

ACTUAL OUTPUT		LESOTHO		MOZAMBIQUE		TANZANIA		THAILAND		ZIMBABWE		WORLD BANK	
Compaction	*Unit*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*	*Hr/task*	*Max*
Culvert laying													
600 mm	m		7	1							0,9		
900 mm	m		7	0,8									
Concrete work	m^3		7	0,5							1		
Stone masonry	m^3		7	0,5							1		

N: TASK OUTPUT RATES

Source: Department of Public Works: Guidelines for enhancing employment opportunities in the delivery of infrastructure projects – a national Public Works Programme Initiative

1. Indicative production rates for selected activities

The following production rates are presented as a guide only. Actual production rates may vary, depending on local conditions.

Table N1 : Task output rates

ACTIVITY	DESCRIPTION	UNIT	PRODUCTION RATES (Various sources)	RECOMMENDED PRODUCTION RATE
Clear and grub	Clearing	m^2	150 250 150 300–800	150–300
	Clearing and grubbing	m^2	150 60 80 100 180	– 80–150
Excavation	Trenches (± 0,5 m wide) (0,0 m to 1,0 m deep)	m	9,5 7,5 10	7–10
	Trenches (± 0,5 m wide) (1,0 m to 1,25 m deep)	m	7,0 5,5 6,0	5–7
	Trenches (normal trench width and depth)	m^3	6,0 5,6 4,5 2,5 2,0 3,5	3–6
Excavation	Earthworks – Soft class 1 soil) (In wider excavations double handling might have to be allowed for)	m^3	4,0–5,5 4,8 2–5,5 4,0 2,8–3,2 3,0 2,3 6,0 5–12 2,5–5,0 3,0–4,0 4,8–5,5 3,0 2,5 3,5 3,3 2,0–4,0 1,6–2,4 2,0–3,0	2,5–5,0
	– Intermediate (soil) (In wider excavations double handling might have to be allowed for)	m^3	2,5–3,5 3,3 4,0 2,5 2,0	2,0–3,0
	– Hard (soil) (In wider excavations double handling might have to be allowed for)	m^3	2,1–2,2 2,0 1,6 0,5–2,0	1,0–2,0

Table N1 : Task output rates

ACTIVITY	DESCRIPTION	UNIT	PRODUCTION RATES (Various sources)	RECOMMENDED PRODUCTION RATE
Borrowpits	Select and load rock	m^3	2	2
	Feed crusher	m^3	3,5	3,5
	Load gravel	m^3	6	6
Spreading	Earthworks	m^3	12,0	
			7,0	7,0–12,0
			12,0–16,0	
	Remove oversize material	m^3	2,5	2–3
	Verge (incl. Compaction)	m^3	4,7	4–5
Hauling	Wheelbarrow	m^3	13,5	10–13
	0m–20m		10,5	
	40m–60m	m^3	10,5	8–10
	60m–80m	m^3	8,0	6–8
			6,5	
	80m–100m	m^3	7,0	5–6
			5,0	
Backfilling	Trenches	m^3	4,0	4–8
			10,5	
	Excavations	m^3	2,0–5,0	2–5
Waterbound Macadam (WBM)	Construct	m^3	0,8	
			0,6	0,5–0,8
			0,16	
	Spread coarse material	m^3	4,7	4,7
	Spread and broom fines	m^3	4,7	4,7
Surfacing	Sweep basecourse	m^3	490	1 000
			1 000	
	Spread chips and backchip	m^2	300	200–400
			200–400	
	Slurry mix and spread	m^3	1,5	0,8–1,2
			0,67	
	Spread asphalt	m^3	0,4	0,4
Concrete blocks	Laying of blocks	m^3	20	15–20
			17	
Kerbs	Laying of pre-cast	m	10	10–20
			26	
Manhole construction	Place precast manhole rings (300 mm high)	no	4,5	4,5
	Mix and place benching	no	2	2
	Place precast manhole cover-slabs	no	2,5	2,5
Concrete	Mixing	m^3	0,7–3,0	0,7–1,5
	Placing	m^3	1,1–4,0	1,0–4,0
Roadmarking	Painting (100 mm line)	m	150	150
Pipe laying	100–150 mm diameter sewer	m	19–24	19–24
	100–150 mm diameter water	m	14–19	14–19
	HDPE water pipe	m	125	125

O: TYPICAL TASK RATES

Source: McCutcheon and Marshall. Labour-intensive construction and maintenance of rival roads: Guidelines for the training of road builders. Construction and Development Series, November 14, Development Bank of Southern Africa. Development Paper 60, November 1996.

Table O1 : Average task output values

OPERATION	ACTIVITY	MINIMUM TASK
Site clearance	Bush clearing – dense light to medium Stripping and grubbing Tree and stump removal Boulder removal	Determine on site 150 m^2 - 750 m^2/day 100 m^2 - 200 m^2/day Experience 200 day/km
Earthworks	Slotting Excavation to level Cute < 0,25 m > 0,25 m Borrow to fill Haulage (wheelbarrow) 0-20 m 40-60 m 80-100 m Spreading	4 m^3/day 5 m^3/day 4 m^3/day 4 m^3/day 13,5 m^3/day 8,0 m^3/day 5,5 m^3/day 12 m^3/day
Drainage	Ditching Sloping Camber formation Mitre drains Catchwater drains Scour checks Culvert installation	3,75 m^3/day 3,75 m^3/day 100 m^2 /day 3,75 m^3/day 3,75 m^3/day 25/day max. 20 days/line
Gravelling	Excavation Load Spreading	3 m^3/day 6 m^3 (loose)/day 12 m^3/day

Source: McCutcheon (1983) and Simpson (1980)

Table O2 : Detailed task rates for excavation

SOIL TYPE	TOOLS	TASK RATES (m^3/man-day) THROWING DISTANCE (m)		
		0 - 4	4 - 6	6 - 8
loose, not sticky soil Firm soil Very hard soil, hard soil mixed with stones	Shovel, jembe Shovel, fork jembe Pickaxe. fork jembe, shovel	5,0 - 6,0 3,5 - 4,5 2,0 - 3,0	4,5 - 5,5 3,0 - 4,0 1,8 - 2,5	3,5 - 4,5 2,5 - 3,5 1,7 - 2,5

Source: De Veen (1980, 1983)

Table O3 : Resource inputs, example from Lesotho

REF	WORK ITEM	UNIT	LABOUR m.d	PLANT						MATERIALS			
				tpd	rd	ftd	Spray day	cd	Mixer day	Cement pkt	Stone cu.m	Bitume drum	Weldi-mesh m2
1	Formation work												
	Excavation 1500 cu m/km	km	1280										
	2000 cu m/km	km	1480										
	2500 cu m/km	km	1730										
	3000 cu m/km	km	1980										
2	Gravelling - haul = 0-2 km	km	823	14	10								
	5 m wide	km	1025	20	10								
	- haul = 2-7 km	km	1175	41	10								
3	5 m wide												
	- haul = 7-20 km												
	5 m wide												
	Road maintenance												
	(lengthmen system)												
4	Dry stone masonry	cu.m	2,5										
	= w.bhaul of stone	cu.m	2	0,065									
5	= tphaul												
	of stone & sand	cu.m	3,7	0,022						1,7			
	Cement bound	cu.m	3,1	0,098						1,7			
6	Stone masonry	cu.m	3,5	0,091						7			
	= w.bhaul of stone & sand	cu.m	3	0,161						7			
7	= tphaul	cu.m	3,7	0,065						5			
	of stone & sand	cu.m	3,1	0,141				9	5				
8	1:2:4 concrete	km	336						5,6				
9	= w.bhaul of stone & sand	km	224										
10	= tphaul	lin.m	1										
	of stone & sand	lin.m	0,84	0,007				0,5					
	1:3:6 concrete			0,029				0,5					
	= w.bhaul of stone & sand												
	= tphaul												
	of stone & sand												
	Track excavation												
	Ditch excavation												
	Ditch lining												
	= w.bhaul of stone & sand												
	= tphaul												
	of stone & sand												
11	Grassing	sq.m	0,1			0,006	0,003						
12	Gabions	cu.m	3,2		0,05								
	= w.bhaul of stone	cu.m	2,7		0,12								
	= tphaul												
	of stone & sand												
13	600 pipe culvert	per culv	11		0,3								
	900 pipe culvert	per culv	12		0,5								
14	Stone slab culvert	per culv	42		0,212					8			
	= w.bhaul of stone & s and	per culv	41		0,374					8			
15	= tphaul	per culv	6		0,039					3			
	of stone & sand	per culv	5		0,185					3			
	Culvert headwalls												
	= w.bhaul of stone & sand												
	= tphaul												
	of stone & sand												

Table O3 : Resource inputs, example from Lesotho (continued)

REF	WORK ITEM	UNIT	LABOUR m.d	PLANT						MATERIALS			
				tpd	rd	ftd	Spray day	cd	Mixer day	Cement pkt	Stone cu.m	Bitume drum	Weldi-mesh m^2
16	Vented ford = w.bhaul	lin.m	29		0,53					44			2 shts
	of concrete	lin.m	25		1,05					44			2 shts
17	= tphaul	lin.m	18		0,3				0,25	25			2 shts
	of stone & sand	lin.m	15		0,63				0,25	25			2 shts
18	Vented ford (rock)												
	= w.bhaul	per arch	63,3		1,1					76			16,2
	of stone & sand	per arch	54,7		2,26					76			16,2
19	= tphaul	m/bridge	51		0,26					20			
	of stone & sand	m/bridge	44		1,18					20			
20	Minibridge = w.bhaul	per arch	731		12					800			
	of stone & sand	per arch	635		25					800			
21	= tphaul	per struc	375		2					150			
	of stone & sand	per struc	323		9					150			
	(wingwalls) = w.bhaul												
	of stone & sand												
	= tphaul												
	of stone & sand												
	Pipe arch = w.bhaul												
	of stone & sand												
	= tphaul												
	of stone & sand												
	(wingwalls) = w.bhaul												
	of stone & sand												
	= tphaul												
	of stone & sand												
22	Lime stab base												
	= gravel	km	1589		14	20				2500li			
	hl=0-2km 5m wide	km	1800		20	20				2500li			
	= gravel	km	1950		41	20				2500li			
23	hl=2-7km 5m wide	km	56				2				20	48	
24	= gravel	km	630			20	25	35			107	123	
25	hl=7-20 5m wide	km	830			10	15	25		10	99	87	
	Thickened edge												
	(bitumen surfacing)												
	Double seal surfacing												
	Cape seal surfacing												
26	Concrete blocks (production)	100 blocks	4,1		0,065					5,1			
27	Concrete blockwork	100 sq.m	7+4,5*		2,05					71			
28	(building)	cu.m	3+2,5*		0,105					1,7			
29	Random rubble masonry	100 sq.m	3,3+8*		0,062					3,4			
30	(building)	100 lin.m	30							14			
	Pointing (masonry)												
	Security fencing					0,5							

ABBREVIATIONS

sq.m	square meters	m^2 st	m^2 stone	lu	load & unload	rd	roller day
cu.m	cubic metres	db	drum bitumen	cd	day	sc	spread and compact
	quantity	ftd	flat truck day	lpkt	lime packet	bit.	bitumen emulsion
m.d.	man-day	bp	budge productivity	sqmwm	sq.m weldmesh	cpkt	cement packet
tpd	tipper day	cl	collect and load	mp	mix and place	swm	sweet weldmesh
std	spray truck day	h	haul	lh	load and haul		

* Skilled labour

Source: Extracted from Taylor, 1987. Labour-Construction Unit; Scott Wilson Kirkpatrick

Appendix 2: Implementing employment-intensive infrastructure projects which target the increase of employment opportunities generated per unit of expenditure

(Annex G of SANS 10396: Implementing Preferential Construction Procurement Policies using Targeted Procurement Procedures)

G1 Introduction

Changes in methods and technologies, which increase the labour component in construction and the manufacture of materials, yield the greatest increase in the number of employment opportunities generated per unit of expenditure. This requires established companies to reduce their reliance on capital intensive technologies. Suitable methods and technologies are usually readily implemented by small scale enterprises, who by being small, have limited access to capital and invariably operate and conduct their businesses in a more employment-intensive fashion and favour light, non-equipment-based forms of construction.

Various statistics have been put forward to quantify the impact of introducing employment-intensive construction practices. Many of them relate to the methods of measurement which are adopted. The following parameters are commonly used to evaluate employment-intensive construction practices:

The multiplier in employment opportunities (i.e. the ratio of the total number of personhours generated in the construction of a specified structure, service or activity using labour-based technologies, to that using plant-based technologies).

Expenditure per unit of employment generated (i.e. the ratio of total construction costs excluding VAT but including any management fees directly related to construction activities to total volume of employment-generated (manhours) in the construction of a structure or service.

Construction expenditure retained within the community.

This informative annex focuses on the use of the SANS 1914-5 targeted construction procurement (Participation of Targeted Enterprises) standard to encourage cost-effective employment-intensive practices.

NOTE : The fundamental difference between the SANS 1914-4 targeted construction procurement standard (Participation of Targeted Enterprises and Targeted Labour (Local Resources)) and the SANS 1914-5 standard (Participation of Targeted Labour) is that the former targets enterprises and labour whereas the latter targets only labour. Many of the techniques presented in this Annex can also be applied to the targeting of labour in terms of the SANS 1914-4 standard.

G2 Defining targeted labour

Increases in employment opportunities generated per unit of expenditure on infrastructure projects can best be achieved by targeting unskilled/semi-skilled labour. Targeted labour may accordingly be defined in terms of statutory wage rates, e.g., persons who earn not more than one and a half times the minimum statutory wage rate. In some instances, there may be merit, in the interests of local economic development, to include residency within a broad geographical area in the definition.

SAMPLE DEFINITIONS

South African citizens who permanently reside within the boundaries of ..... and earn wages and allowances amounting to less than R..... per hour. It is incumbent on individuals to demonstrate their claims to such residency on the basis of identification and association with and recognition by members of the community residing within the aforementioned areas.

G3 Encouraging contractors to make more use of targeted labour in excavation activities

In order to meet goals for the engagement of targeted labour, or to tender increased contract participation goals, contractors may have to undertake some, or all, soft excavations by the use of hand labour. In order to minimise their risk exposure in performing such activities, there needs to be :

- A labour policy in place which sets out the conditions of employment for temporary workers (i.e. project specific workers),
- A mechanism in terms of which contractors can define the portion of the excavation works which will be excavated by hand methods.

If this is not done, contractors will not be able to increase job opportunities in earthworks activities as they would be exposed to unacceptable risks. The abovementioned employment policy and mechanism should accordingly be clearly set out in the tender documents and form an integral part of the contract.

The conditions of employment pertaining to the employment of temporary workers (i.e. project specific workers) can be described in the Works Information. (These conditions will not be necessary should project specific workers be engaged in terms of statutory labour provisions. It may, however, in certain circumstances be desirable to vary such provisions in order to increase the participation of targeted labour, in which case such conditions should be fully described.). SANS 1914-5 requires contractors to enter into formal contracts with targeted labour. Credit towards the attainment of contract participation goals can be denied should contractors fail to engage targeted labour in accordance with the conditions of employment as laid down in the Works Information.

A suitable mechanism to enable contractors to define portions of excavation work which may be carried out by hand methods is to permit contractors during the tender stage to nominate the quantity of materials which they wish to excavate using hand methods. The approach outlined below is suggested.

The initial classification of material to be excavated should be in accordance with the relevant provisions of a standard system of measurement. However, soft excavation to be undertaken by hand labour, using hand tools, can be further broken down by the introduction of an additional class of material, viz., soft excavation Class A, in accordance with the provisions of the Contract Prices as follows:

ABBREVIATIONS

Criteria for classifying material as soft excavation Class A *		
Dynamic cone penetrometer - minimum number of blows required to penetrate 100 mm	Granular materials 7-15 +	Cohesive materials 6 to 8 +
Consistency	Dense - high resistance to penetration by the point of a geological pick; several blows required for removal of material.	Stiff / Very stiff Stiff - can be indented by thumb-nail; slight indentation produced by pushing geological pick point into soil; cannot be moulded by fingers. Very stiff - indented by thumb-nail with difficulty; slight penetration of point produced by blow of geological pick.

* Soft excavation Class A is material which, using a pick or equivalent hand swing tool, can only be excavated with difficulty.

The total estimated quantity of excavation, as classified in terms of a standard system of measurement, should be indicated in the Contract Prices. The contractor should be permitted to sub-divide this quantity into two components, viz., the quantity of material to be excavated by the use of powered, mechanical equipment and the quantity to be excavated by hand labour using hand tools. One third (1/3) of every quantity of excavation to be undertaken by hand labour should be entered against the appropriate extra-over items provided in the Contract Prices, but left blank, for soft excavation Class A. This will ensure that material which can be picked with difficulty is catered for and the transition from hand excavation to machine excavation is graded.

Should the contractor fail to indicate a quantity of excavation to be undertaken by hand labour, notwithstanding that he would find it necessary to utilize hand labour, it will be assumed that all excavation, whether undertaken by machine, or by hand labour, is to be paid for at the rates tendered for machine excavation.

The contractor should be required to undertake at least the quantities of excavation by hand labour which he tendered, unless the total quantity of excavation proves to be less than scheduled, in which case the minimum quantity to be undertaken by hand labour will be reduced pro-rata by the Employer's Representative. This procedure will also provide a basis for reducing contract participation goals should such adjustments be necessary.

Should the total quantity of excavation prove to be greater than that scheduled, the contractor may choose the method of excavation for the excess quantity, unless the rates for excavation by machine would result in lower costs than for hand excavation, in which case the Employer's Representative will have the right to instruct the contractor to undertake the excavation by machine.

Insert the following into the conditions of tender:
SOFT EXCAVATIONS

In order to meet goals for the engagement of Targeted Labour, the Tenderer may intend to undertake some, or all, soft excavations by the use of hand labour.
The initial classification of material to be excavated shall be in accordance with the relevant provisions of …….. However, soft excavation to be undertaken by hand labour, using hand tools, shall be further broken down by the introduction of an additional class of material, viz., soft excavation Class A, in accordance with the provisions of the project specification.
The total estimated quantity of excavation, as classified in terms of …… is indicated in the Contract Prices. The tenderer may sub-divide this quantity into two components, viz., the quantity of material to be excavated by the use of powered, mechanical equipment and the quantity to be excavated by hand labour using hand tools.
One third (1/3) of every quantity of excavation to be undertaken by hand labour must be entered against the appropriate extra-over items provided in the Schedules for soft excavation Class A.
Should the tenderer fail to indicate a quantity of excavation to be undertaken by hand labour, notwithstanding that he would find it necessary to utilise hand labour, it will be assumed that all excavation, whether undertaken by machine, or by hand labour, is to be paid for at the rates tendered for machine excavation.

The Contract Prices can reflect this mechanism as follows :

The Contract Prices can reflect this mechanism as follows:

ITEM NO.	DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT R C
3.1	Earthworks Excavate trenches in all materials, backfill and dispose of surplus material for stormwater pipes not exceeding 1,5 m deep (Total quantity 1 500 m3) to be allocated in items 3.1.1 and 3.1.2 below in accordance with Part 3 of the Conditions of Tender.				
3.1.1	Machine excavation	m^3	..... *		
3.1.2	Hand excavation	m^3	..... *		
3.1.3	Extra over 3.1.2 for hand excavation in soft class A. (Quantity to be one third of quantity entered under 3.1.2)	m^3	..... *		
3.2	Extra over items 3.1.1 and 3.1.2 for :- : Intermediate excavation : Hard rock excavation	m^3 m^3	250 150		
* To be completed by the contractor.					

G4 Encouraging contractors to implement employment-intensive road technologies

The labour-intensiveness of roadworks is highly dependent upon the choice of technology and the cost of roadworks is, accordingly, sensitive to the choice of technology. If, however, the contractor is permitted to select the technology and contracts are awarded in terms of a development objective price mechanism, a balance between price and the attainment of socio-economic deliverables can be achieved.

A simple way to do this is to present contractors with a range of options which are acceptable to the employer and to permit contractors to tender and price what they see to be the most competitive options.

Contract Prices can reflect this mechanism as follows :

The Contract Prices can reflect this mechanism as follows:

ITEM NO.	DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
					R C
1.1	BASE Option A: Construct base course with graded crushed stone from commercial sources Option B: Construct dry/-waterbound Macadam base course with stone imported from designated sources. Construct base course using Option ..... (to be completed by contractor)	m^2	2010		
ITEM NO.	DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
					R C
1.2	PAVEMENT STRUCTURE Option A : 150 mm C4 subbase, 100mm G1 base, 20 mm AC wearing course, complete Option B : 100 mm C4 subbase, 100mm WM2 base, 20 mm AC wearing course complete Option C : 100 mm G7 subbase, 20mm bedding sand, 60 mm type SA interlocking blocks complete Construct pavement using option ..... (to be completed by contractor)	m^2	2000		

The following clause should be inserted into the Conditions of Tender in order to cater for the different quantities which result from the different thicknesses of layerworks. This is important in the adjudication of tenders.

PAVEMENT STRUCTURES

In order to meet the contract participation goal, the Contractor may select a pavement structure from the alternatives presented on the drawing. Each option or component thereof is scheduled separately in the Contract Prices. The Contractor must state in his tender under the relevant scheduled item which alternative his tender is based on. Contractors will be bound to the pavement structure so selected.
The quantities scheduled in respect of earthworks are based on the pavement design with the greatest depth. Adjustments will be made by the engineer in the tendered price to reflect changes in earthworks costs arising from pavement selections prior to the awarding of points for price.

Notes

Notes

Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour-based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major contributing organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
National Housing Forum
Congress of South African Trade Unions

Plus many individuals from construction companies

"Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings."

Nelson Mandela, 2005 – Global Campaign for Action against Poverty

Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 2-1

Labour-based construction methods for earthworks

cidb
development through partnership

Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment-intensive construction works

In this set: (colour coded)

Part 1

An overview of labour-based technologies and methods in employment-intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

3.2 The BESA building system

Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

4.2 Rubble masonry dam construction technology

4.3 Rubble masonry concrete arch bridge construction technology

4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Waterbound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

EXPANDED PUBLIC WORKS PROGRAMME
Creating opportunities towards human fulfilment

ENGINEERS AGAINST POVERTY

Labour-based methods and technologies
for employment-intensive construction works

A cidb guide to best practice

1ST Edition of CIDB document 1023 March 2005

Best Practice Guideline – Part 2-1

Labour-based construction methods for earthworks

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

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Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1. Introduction

1.1 History, current practice, brief description of the activities (ELHUS)

An extensive study on the feasibility of labour-based construction conducted by the World Bank concluded that "Labour-intensive methods are technically feasible for a wide range of construction activities and can generally produce the same quality of product as equipment-intensive methods". The term 'employment-intensive' does not mean that only labour should be used in the construction process, but implies the use of a range of machine/labour combinations, based on considerations of quality, cost and time constraints. This World Bank study specifically singled out the earthworks operations of Excavate, Load, Haul, Unload and Spread (ELHUS), as being activities that could potentially be undertaken economically by labour. More recent experience in South Africa and elsewhere has expanded this list of activities.

Several specifications have been written for employment-intensive earthworks; the more successful ones being modelled on SANS 1200 series (Standardized specification for civil engineering construction). Standards South Africa has recently published SANS 1921-5 (Construction and management requirements for works contracts, Part 5: Earthworks activities which are to be performed by hand). This standard identifies earthworks activities and sub-activities which a contractor must execute by hand.

Note: Earthworks – traditionally a labour-based activity

Earthworks are at the core of most civil engineering construction, especially road construction. For centuries earthworks have been executed using employment-intensive methods and there is no doubt that a wide range of earthworks can be executed in this manner. In recent decades, however, most earthworks have been executed using equipment-based methods. Accordingly, most of the knowledge and skills that are needed for effective employment-intensive earthworks have been lost. Furthermore there are labour-related activities that are very difficult and therefore time consuming and uneconomic. With these activities it is often recommended to use some equipment to complement the labour-based activities. These guidelines try and address these issues by providing best-practice guidelines for earthworks.

1.2 Common general difficulties

Before continuing, it is important to note that labour-based earthworks activities are often perceived as the simplest and most 'backward' of all construction activities in many projects. Because of this attitude, the works are often not planned properly. The perception that labour-based earthworks are just 'pick and shovel' activities that do not require a serious approach is probably the most important reason that productivities on the projects where this attitude prevails are below expectations (and the costs above expectations).

It cannot be stressed enough that in order to have cost-effective employment-intensive earthworks, one needs to approach, plan, execute and monitor the works with the same level of commitment and seriousness as is done when expensive equipment is hired. The work must be planned, ensuring sufficient manpower so that the required deadlines can be met, different activities should often have different team sizes so that the productivities are balanced, proper tools should be provided and adequate supervision should be in place. All of these and other important activities are often neglected and as a result the obtained productivities are too low. The fact that employment-intensive methods were used is then often blamed. If any work is not taken seriously and not planned properly, productivities will be low, regardless of whether employment-intensive or equipment-intensive methods are used.

2. Clearing and grubbing

Note

SANS 1921-5 requirement for clearing and grubbing is:
Grass and small bushes shall be cleared by hand.

Tools

The tools used for clearing and grubbing depend on the materials to be cleared. The list below gives tools typically required. However, if there are no trees to be cleared, then tree-cutting tools are not needed.

- Axe
- Saw
- Rope
- Slasher or sickle
- Rake
- Pick
- Shovel or spade
- Fork
- Watering can and water
- Hand stamper
- Drinking water

2.1 Introduction

Clearing and grubbing involves the cutting down of trees, bush and other vegetation and the subsequent grubbing and removal of the root systems. Topsoil removal is sometimes included or is scheduled under earthworks. The ground is left clear for further construction activities.

2.2 Standards

In conventional specifications, clearing and grubbing is specified as follows:

COLTO, 1998, Section 1700: Clearing and grubbing
Clearing and grubbing is measured in hectare, to the nearest one-tenth ha, and encompasses all work necessary for the clearing of the surface, the removal of boulders, the removal and grubbing of trees and stumps (except large trees as defined below), cutting branches, backfilling cavities, demolishing and disposal of structures, and the removal, transporting and disposal of all materials arising. Large trees are defined as having a girth exceeding one metre. Removal and grubbing of large trees is paid by individual number of trees, categorised into girth steps of one metre.

SANS 1200 C, 1982: Site clearance
Clearing and grubbing is measured in hectares, to the nearest one-tenth ha, and encompasses all work necessary for the clearing of the surface, the removal of boulders, the removal and grubbing of trees and stumps (except large trees as defined below), cutting branches, backfilling cavities, demolishing and disposal of structures, and the removal, transporting and disposal of all materials arising. Large trees are defined as having a girth exceeding one metre. Removal and grubbing of large trees is paid by individual number of trees, categorised into girth steps of one metre. Several options are given for specific items unsuitable for inclusion in the general clearing pay item, like fences, hedges, pipelines, transmission lines, cables, structures and buildings. Topsoil is separately scheduled in m^3.

2.3 Practical guidelines for labour-intensive clearing and grubbing

Many of the activities are conventionally carried out by labour teams.
With modest training and good organisation, clearing and grubbing can be efficiently carried out by labour. The sequence of operations is important [Ntja, 2000]. Team sizes should generally comprise about five people. Once one activity has progressed to the point where sufficient space has been cleared, the next activity can be initiated. The numbers of teams engaged should be related to their productivity and speed. The teams should be in some reasonable balance, so that no portion of the work delays other activities or progresses too far ahead.

1. Trees within the area to be cleared should be cut first. The tree tops should be cut, leaving a trunk about five metres high. All side branches should be cut off using axes and saws. The timber resulting from the trees should be sawn up into convenient lengths and stacked to one side. Separate piles should be made for leaves and thin branches.
2. Bush and other tough vegetation should be cut down, to ground level if possible, cut to convenient lengths and stacked.
3. Grass and remaining vegetation should then be removed at ground level by means of spades or hoes. The resulting debris should be raked to one side and added to the piles of thin branches and leaves.
4. Once a large enough portion of ground is clear, a trench should be dug around the nearest tree and roots chopped through. The trench should be

about one metre deep (less if the tree is small) and should attempt to undermine the tree stump. As soon as one tree has been trenched and all accessible roots cut through, a rope should be fixed to the top of the trunk and a team of labourers tasked to pull the tree down. As the tree moves, further roots may become visible and accessible: these roots should be cut free at the level of the base of the hole while the pulling team rests. Progressively the tree trunk is thus brought down, using the leverage of the length of the trunk to tear out as many roots as possible. Once the tree and stump have been brought down, they should be rolled away from the hole and cut into convenient lengths. Depending upon the specification, major roots may need to be dug out and removed to a specified depth.

5. Large bushes should be trenched and their root systems removed. The roots of smaller bushes can be dug out together with the grass roots (see 7 below).
6. The soil dug out of the trenches around trees and large bushes can then be returned to the trenches. Roots should be carefully separated from the soil and only clean soil used for backfill. Some specifications will require the tree hole backfill to be compacted in thin layers [CSRA, 1987].
7. Specifications generally require all roots to be removed to a particular depth, dependant on subsequent operations. To achieve this, the soil should be dug over to the specified depth and all root material removed. Garden forks are efficient tools for this activity. If the topsoil has to be removed, this is best combined with the digging for root removal. It is often advantageous that topsoil contains a relatively high proportion of vegetable matter.
8. The debris resulting from the clearing and grubbing should be disposed of as instructed. Timber will usually be snapped up by the local people for firewood. If regulations permit, the thin sticks, roots and leaves can be burnt and the ashes dispersed into the bush adjacent to the works (where it will act as fertiliser). Otherwise the rubbish may need to be transported to worked-out borrow pits and spread.

2.4 Productivities

Typical productivities and task rates for clearing and grubbing are tabulated in Tables 1 and 2.

Table 1: Productivities for clearing and grubbing (Ntja, 2000)

ACTIVITY	DESCRIPTION	OPTIMUM PRODUCTION IN SQUARE METRES PER PERSON-DAY
Bush clearing	Medium dense bush (4 - 7 bushes per 100 m^2)	500
Grass clearing	Removal of vegetation to ground surface	124
Destumping	Removal of stumps and major roots	85
Grubbing	Root removal to 250 mm depth in soft loamy soil	60

Note: The figures given above are standard productivity rates and should be factored downwards to take account of environmental, social and other local conditions.

Table 2: Typical Task Rates for clearing and grubbing (MRP Technical Manual, 1992)

ACTIVITY	TASK RATE IN SQUARE METRES PER PERSON-DAY
Bush clearing	300 to 1000
Stripping and grubbing	200
Tree and stump removal	From experience

3. ELHUS and compaction

Note: SANS 1921-5 requirement for ELHUS activities

Trench excavation
All materials excavatable by hand in trenches that have a depth of less than that indicated in the specification data (see annex A) shall be excavated by hand.
The excavation of any material in trenches shall not be performed by hand if it presents the possibility of danger or injury to workers.

Compaction of backfilling to trenches in areas not subject to traffic
Backfilling to trenches in areas not subjected to traffic shall be placed in layers of thickness (before compaction) not exceeding 100 mm. Each layer shall be compacted using hand stampers such that:
a) a Proctor density of 90 % is achieved,
b) more than five blows of a dcp are required to penetrate 100 mm of the backfill, provided that the backfill does not comprise more than 10 % gravel of size less than 10 mm and contains no isolated boulder,
c) The density of the compacted trench backfill is not less than that of the surrounding undisturbed soil when tested comparatively with a dcp.

Excavations other than in trenches
All material excavatable by hand in excavations other than trenches including topsoil shall be performed by hand. Harder material may be loosened by mechanical means before excavation by hand.
The excavation of any material in excavations other than trenches shall not be performed by hand if it presents the possibility of danger or injury to workers.

Shaping
All shaping in material excavatable by hand shall be undertaken by hand.

Loading
All loading shall be done by hand, regardless of the method of haulage.
Haul
Where the haul distance is not greater than 150 m, excavated material shall be hauled to its point of placement by means of wheelbarrows.

Offloading
All material, however transported, shall be off-loaded by hand, unless tipper-trucks are utilized for haulage.

Spreading
All material shall be spread by hand.

Compaction
Small areas may be compacted by hand provided that the specified compaction is achieved.

Table 3: Team balancing exercise

	ACTIVITY	Productivity (worker/day)	Quantity	Man days required
1	Excavation of soft material	3m^3	150	50
2	Loading of soft material	5m^3	150	30
3&4	Hauling & Unloading (100 m)	6 m^3	150	25
5	Spreading	15m^3	150	10

3.1 Introduction

Excavating, Loading, Hauling, Unloading and Spreading can together be referred to as ELHUS. These activities are often grouped together because they usually follow each other during earthworks construction and involve the same material, i.e. the material that is excavated is usually also loaded, hauled, etc. Furthermore, material that is spread, is usually also compacted again, and the spreading and compaction activities are also linked as will be described. The links between these activities, and how these links affect the planning and execution of these activities and so create the need for team balancing, will be described first. After this, these activities will be dealt with individually focusing on the specifics of each.

3.2 Team balancing

3.2.1 Description and importance

While the individual activities of ELHUS are different, they are so interdependent that it is important that they are considered together, especially in the planning stages. These activities seldom occur in isolation on a roads project. Generally, the material that is excavated needs to be loaded, hauled, unloaded and spread in an area where there is a need for fill. As such these activities should be planned together and the teams of labourers executing the different activities should be selected in such a way that the teams' productivities are equal so that no team is delayed by the subsequent one. This is referred to as team balancing and is crucial in achieving a productive labour-intensive construction site. While team balancing may seem obvious, it is often overlooked in the planning phase. This is probably due to the fact that many contractors are unfamiliar with the different productivity rates for different activities and often assume that one labourer has the same productivity for each activity. An example of team balancing is provided below.

3.2.2 Example – Team balancing exercise

In this example, 150 m^3 of soft soil needs to be cut (excavated) and used for fill on a section which is on average 100 m further. The overall planning demands that this activity is completed within one week.

Since this activity needs to be completed in one week, which has five working days, the teams would have to be as follows in order for each worker to work optimally:

Excavation team:	50 person-days /5 days = 10 labourers
Loading team:	30 person-days / 5 days = 6 labourers
Hauling and unloading team	25 person-days / 5 days = 5 labourers
Spreading team	10 person-days / 5 days = 2 labourers

Every team is now balanced and no workers should be idle, waiting for other workers to finish their tasks. In general productivities can vary and often one needs to do a trial in which the assumed productivities are tested and the team adjusted if the productivities assumed are not accurate. This must be done at the beginning of the project so that the measured productivities can be used.

While this may seem a very simple planning exercise, unfortunately it is often not done and it is not common to find construction sites where the teams for each ELHUS activity are of the same size. The principle of team balancing does only apply to ELHUS activities of course but applies to most roadwork activities to be executed using labour-intensive methods.

Together the ELHUS activities form the bulk of the earthworks in most road construction. If they are not planned properly and the productivities are low, costs will escalate and it is likely that the client will be pressured into bringing in equipment for speeding up productivity. This does not mean that labour-intensive earthworks are not economically feasible, it just means that it was poorly planned.

The ELHUS activities will now be described individually, as their specifications are different and they are usually separate items in a Bill of Quantities. Nonetheless, the team-balancing requirements described above must be kept in mind.

3.3 Classification of material and effect on productivity for each activity

One very important aspect influencing productivity is the type of material in which ELHUS activities take place. Harder materials are more difficult to excavate by hand and so the productivities will be lower. It is therefore important to distinguish between the different materials with which one works and to adjust the productivities and team sizes accordingly.

It is not simple, however, to distinguish between different kinds of materials and it is often difficult to accurately classify a material and thus predict the productivity. It is therefore necessary to have a trial and /or work study done to be able to accurate measure the productivity. In many cases though, existing standards and guidelines can provide a classification that will enable sufficiently accurate predictions for the purposes of initial team planning.

The classification of materials can be profoundly affected by the season during which excavation is carried out. Relatively hard material can be significantly softened during the wet season and conversely, very soft materials (particularly heavy clays) can be extremely hard during the dry season. Slow but sustained application of water can thus change the consistency/excavatability of a material significantly. It should be remembered that the material classification at the time of planning a project may thus differ significantly from that at the time of construction, and the capacity to modify team balance/compositions and tasks or expected rates of production on site must thus be available.

Materials for layer works should not contain large particles; a maximum size of less than two-thirds of the compacted layer thickness is usually specified for support layers and a maximum size of wearing course materials for unsealed roads should be restricted to 40 mm. In order to minimise unnecessary haulage costs and material spoiled during construction, oversize material should be removed during the excavation/loading process. This can be effectively done using screens or small grizzlies. The material removed during this process should be stockpiled separately in the borrow area as it is often a potentially useful source of concrete stone, rip-rap, erosion protection material, material for gabion baskets or even stone packing or grouted stone pitching.

3.4 Tools and plant

3.4.1 Quality of tools

Under no circumstances should tools ever be bought only on the basis of lowest price. The quality of tools is of prime importance. Tools can influence productivity positively or negatively. As the cost of tools rarely exceeds 1% to 2% of project costs, it is not worth saving on part of one percent and as a consequence reduce productivity by perhaps 40%, which has a much larger influence on project costs.

In South Africa with unrestricted imports, it is easy to buy poor tools when buying only on price. Tools must be made from appropriate steels, properly tempered. Handles must be of good quality: steel, timber or reinforced rubber can all be acceptable if made to high standards. Tool to handle fastening must also have had sufficient attention: e.g. round-eyed hoes will spin around the handle, where oval eyes provide fixity. Guidance in this regard can be obtained from publications such as the ILO's "Guide to tools and equipment for labour-based road construction" [Howe, 1981] and the many South African National Standards with regard to specific tools. If in doubt about quality, it is good practice to obtain a sample of each tool needed and to test the tool against the relevant South African National Standards.

Appropriate tools must be chosen. The productivity of labour and the quality of the job depends strongly on the provision of the correct tools. For example, as a roads engineer you would not choose a bulldozer to cut basecourse levels, you would insist on a grader in good condition.

Training in the use of hand tools is also important. Unskilled labour, with a passing knowledge of agriculture, need to be taught the correct way to handle unfamiliar tools. For example, people who know only the use of a hoe will not know how to swing a pick. The increase in productivity after being shown the proper use of a pick will be considerable.

Tools also require regular sharpening, failing which productivity will drop.

Different kinds of tools (i.e. many kinds of shovels, wheelbarrows, etc.)

Typical types of tool that are needed are:

Excavation:	Soft: Shovel Medium: Pick and shovel Hard: Pick, crowbar and shovel
Material processing:	Screen Grizzly
Loading:	Shovel
Haul:	Wheelbarrow: Typically 50 to 70 litres Donkey Cart
Unload:	Wheelbarrow Shovel/ rake
Spread:	Shovel Rake Leveling beam

Mechanical compaction equipment and pneumatic and rock-breaking equipment may also be required to complement manual activities. Apparatus for carrying out a Dynamic Cone Penetrometer (DCP) test should also be available.

3.4.2 Tools and equipment for measuring and quality control

It is important that equipment for measuring and quality control is not neglected on employment-intensive projects. They are as essential for achieving the required quality as is the case with equipment-based construction. As always, as the

size of the project decreases, less spending in real terms (not in relation to the size of the project) is available for quality control. However, it is important that the same proportion if not more is spent on quality control and measurements than in the case of equipment-based projects.

3.5 Practical guidelines for excavation

3.5.1 Methods of classifying earthworks

Excavation is normally classified for purposes of payment. SANS 1200 D, for example, classifies plant-based earthworks as being soft, intermediate, hard rock, boulder class A and boulder class B. Boulder class excavation is classified in terms of the size and volume of boulders contained in the soil matrix whereas the classifications for soft, intermediate and hard rock are in terms of the capabilities

SANS 1921-5 classifies material excavated by hand as follows:

Material excavatable by hand: cohesive and granular material the properties of which are such that it can be efficiently removed by hand.
Unless otherwise stated in the scope of work or in the specification data, all materials that have the following characteristics shall be deemed to be materials excavatable by hand:

a) **Granular materials:**
   1) where the consistency of the material, when profiled in terms of table 1, is classified as very loose, loose, medium dense, or dense,
   2) where the material is a gravel that has a maximum particle size of 10 mm and contains no cobbles or isolated boulders, no more than 15 blows of a dcp are required to penetrate 100 mm.

b) **Cohesive materials:**
   1) where the consistency of the material, when profiled in terms of table A, is classified as very soft, soft, firm, stiff or stiff to very stiff,
   2) where the material is a gravel that has a maximum particle size of 10 mm and contains no cobbles or isolated boulders, no more than 8 blows of a dcp are required to penetrate 100 mm.

Note:

In some instances it may be appropriate to modify the definition for materials excavatable by hand (see annex B).

Table A — Consistency of materials

GRANULAR MATERIALS		COHESIVE MATERIALS	
CONSISTENCY	DESCRIPTION	CONSISTENCY	DESCRIPTION
Very loose	Crumbles very easily when scraped with a geological pick	Very soft	Geological pick head can easily be pushed in as far as the shaft of the handle
Loose	Small resistance to penetration by sharp end of a geological pick.	Soft	Easily indented by thumb; sharp end of a geological pick can be pushed in 30 mm to 40 mm; can be moulded by fingers with some pressure
Medium dense	Considerable resistance to penetration by sharp end of a geological pick	Firm	Indented by thumb with effort; sharp end of geological pick can be pushed in up to 10mm; very difficult to mould with fingers; can just be penetrated with an ordinary hand spade
Dense	Very high resistance to penetration by the sharp end of geological pick; requires many blows for excavation	Stiff	Can be indented by thumb-nail; slight indentation produced by pushing geological pick point into soil; cannot be moulded by fingers
Very dense	High resistance to repeated blows of a geological pick	Very stiff	Indented by thumb-nail with difficulty; slight indentation produced by blow of a geological pick point

of specific items of plant. The classification system for labour-based methods is, however, frequently coupled to the equipment or tools needed in the excavation operations. Early earthworks classifications (Croukis, 1983) required materials to be classified initially as being cohesive or non-cohesive and thereafter to be codified in terms of a field recognition test (i.e. in terms of moulding in fingers or excavation with a specified tool), unconfined compressive strength, relative density and liquidity index. (The liquidity index equals the quotient of the natural water content minus the plastic limit and the liquid limit minus the plastic limit). Expected rates of production were then coupled to earthworks classifications.

Several labour-based excavation classifications evolved in South Africa to enable not only expected productivities to be estimated, but also to facilitate payment to contractors in a number of contracting strategies.

Standardised specifications for community-based construction, S100 D: Earthworks *[Soderlund and Schutte, 1993]*

"The Engineer will classify excavated materials as soft Class 1, soft Class 2, soft Class 3, firm, intermediate or rock".

"In the first instance, the classification shall be based on the descriptions given in Table 4. In the event of disagreement between the Contractor and the Engineer, the Engineer shall classify the material in accordance with Tables 5 and 6. The decision of the Engineer on the classification shall then, subject to the provisions of the Contract, be final and binding.

The Contractor shall notify the Engineer of the presence of what he considers to be rock or intermediate material immediately upon discovery thereof. The Engineer will inspect the material and decide whether it warrants the use of pneumatic tools or rock breaking equipment. In the case of isolated boulders set in a soil matrix, the Engineer may order the Contractor to either widen the excavation and roll the boulders sideways or lift the boulders out from the trenches.

In the event that the Engineer decides that the use of pneumatic tools, rock breaking equipment, or blasting is necessary, he will classify the material accordingly and arrange for the quantity thereof to be measured. The Construction Manager will supply all necessary pneumatic equipment and arrange for others to break up rock into manageable pieces".

Table 4: Classification of excavated materials

CLASSIFICATION	DESCRIPTION
SOFT Class 1	Material which can be excavated by means of a suitable shovel without the use of a pick or other hand swung tool
SOFT Class 2	Material which can be readily excavated with the aid of a pick or other hand swung tool
SOFT Class 3	Material which can be excavated with difficulty with the aid of a hand swung tool
INTERMEDIATE	Material which is difficult to excavate by hand even with the aid of a crow bar and requires the assistance of pneumatic tools for economic removal
ROCK	Material which cannot be economically fragmented and loosened by hand implements and pneumatic tools except by drilling and blasting or the use of rock breaking equipment

Table 5: Classification of materials in terms of consistency and shear strength

MATERIALS CLASSIFICATION	CONSISTENCY (as defined in Table 6)		NUMBER OF DCP BLOWS TO PENETRATE 100 mm+	
	GRANULAR SOIL	COHESIVE SOIL	GRANULAR SOIL	COHESIVE SOIL++
SOFT Class 1	Very loose to loose	Very soft to soft	≤ 2	≤ 1
SOFT Class 2	Loose to medium dense	Soft to stiff	2 – 6	1 – 5
SOFT Class 3	Dense	Stiff to very stiff	7 – 15	6 – 8
INTERMEDIATE	Very dense	Very stiff	16 – 50	> 8
ROCK	–	–	–	–

\+ *Only applicable to materials comprising not more than 10% gravel (particles having dimensions > 2 mm) of size less than 10 mm and materials containing no isolated small boulders.*

++ *This could be subjective depending on the moisture content of the cohesive material*

Table 6: Consistency of materials

GRANULAR MATERIALS		COHESIVE MATERIALS	
CONSISTENCY	DESCRIPTION	CONSISTENCY	DESCRIPTION
Very loose	Crumbles very easily when scraped with a geological pick	Very soft	Geological pick head can easily be pushed in as far as the shaft of the handle
Loose	Small resistance to penetration by sharp end of a geological pick	Soft	Easily indented by thumb; sharp end of a geological pick can be pushed in 30-40 mm; can be moulded by fingers with some pressure
Medium dense	Considerable resistance to penetration by sharp end of a geological pick	Firm	Indented by thumb with effort; sharp end of geological pick can be pushed in up to 10mm; very difficult to mould with fingers; can just be penetrated with an ordinary hand spade
Dense	Very high resistance to penetration by the sharp end of geological pick; requires many blows for excavation	Stiff	Can be indented by thumb-nail; slight indentation produced by pushing geological pick point into blows for excavation soil; cannot be molded by fingers
Very dense	High resistance to repeated blows of a geological pick	Very stiff	Indented by thumb-nail with difficulty; slight indentation produced by blow of a geological pick point

The Soderlund and Schutte classification contains three classes of excavation relating to excavation by means of hand tools. As is the current practice when using SANS 1200 D, the Engineer will classify the material on the basis of a visual inspection and his knowledge of expected productivity rates in terms of Table 4. In practice, however, the establishment of the boundaries between soft Class 2 and soft Class 3, and soft Class 3 and intermediate can be highly subjective and the Engineer requires a less subjective means of determining the classification of a particular material in the event of a dispute arising. In the event of a disagreement on the classification between the Contractor and the Engineer, the Engineer can be called upon to classify the material in accordance with Tables 5 and 6. The methodology also permits labour-based contractors to classify material themselves should they be in possession of a dynamic cone penetrometer (DCP) and the profile does not have more than 10% gravel particles (Watermeyer, 1997).

VARIATIONS AND ADDITIONS TO SANS 1200 DM – EARTHWORKS (ROADS, SUBGRADE) FOR LABOUR-INTENSIVE CONSTRUCTION OF LIGHTLY TRAFFICKED ROADS

[WPC van Steenderen MSc project report: 1995]

VA-DM 3 MATERIALS

VA-DM 3.1 CLASSIFICATION FOR EXCAVATION PURPOSES

Delete this clause entirely and replace with:
Excavation will be classified for payment as follows:

VA-DM 3.1.1 Soft

Soft material shall be loose soil which can be efficiently excavated with a flat spade not exceeding 250 mm in width.

VA-DM 3.1.2 Firm

Firm material shall be soil which can be efficiently loosened with a fork or a forked hoe.

VA-DM 3.1.3 Hard

Hard material shall be soil which can only be loosened with many blows of a sharp pickaxe or mattock.

VA-DM 3.1.4 Soft Rock

Soft rock shall be material which is too hard to pick loose by hand and requires pneumatic tools to loosen it sufficiently for subsequent excavation with hand tools.

VA-DM 3.1.5 Hard Rock

Hard rock shall be rock which cannot be efficiently loosened with pneumatic tools and normally requires blasting.

VA-DM 3.1.6 Boulders

Boulders shall be hard rocks over 0.01 cubic metre and up to 0.20 cubic metre in volume. Larger boulders shall be classified as hard rock.

ANNEX G OF SANS 10396: IMPLEMENTING PREFERENTIAL PROCUREMENT POLICIES USING TARGETED PROCUREMENT PROCEDURES

A suitable mechanism to enable contractors to define portions of excavation work which may be carried out by hand methods is to permit contractors during the tender stage to nominate the quantity of materials which they wish to excavate using hand methods. The approach outlined below is suggested.

The initial classification of material to be excavated should be in accordance with the relevant provisions of a standard system of measurement. However, soft excavation to be undertaken by hand labour, using hand tools, can be further broken down by the introduction of an additional class of material, viz., soft excavation Class A, in accordance with the provisions of the Contract Prices as set out in Table 7.

The total estimated quantity of excavation, as classified in terms of a standard system of measurement, should be indicated in the Contract Prices. The contractor should be permitted to sub-divide this quantity into two components, viz., the quantity of material to be excavated by the use of powered, mechanical equipment and the quantity to be excavated by hand labour using hand tools.

One-third (1/3) of every quantity of excavation to be undertaken by hand labour should be entered against the appropriate extra-over items provided in the

Contract Prices, but left blank, for soft excavation Class A. This will ensure that material which can be picked with difficulty is catered for and the transition from hand excavation to machine excavation is graded.

Should the contractor fail to indicate a quantity of excavation to be undertaken by hand labour, notwithstanding that he would find it necessary to utilize hand labour, it will be assumed that all excavation, whether undertaken by machine, or by hand labour, is to be paid for at the rates tendered for machine excavation.

The contractor, should be required to undertake at least the quantities of excavation by hand labour which he tendered, unless the total quantity of excavation proves to be less than scheduled, in which case the minimum quantity to be undertaken by hand labour will be reduced pro-rata by the Employer's Representative. This procedure will also provide a basis for reducing contract participation goals should such adjustments be necessary.

Should the total quantity of excavation prove to be greater than that scheduled, the contractor may choose the method of excavation for the excess quantity, unless the rates for excavation by machine would result in lower costs than for hand excavation, in which case the Employer's Representative will have the right to instruct the contractor to undertake the excavation by machine.

Table 7: Criteria for classifying material as soft excavation Class A *

Dynamic cone penetrometer – minimum number of blows required to penetrate 100 mm	Material
7-15 +	Granular materials Dense consistency – high resistance to penetration by the point of a geological pick; several blows required for removal of material
6 to 8 +, ++	Cohesive materials Stiff / Very stiff consistency Stiff – can be indented by thumb-nail; slight indentation produced by pushing geological pick point into soil; cannot be moulded by fingers. Very stiff – indented by thumb-nail with difficulty; slight penetration of point produced by blow of geological pick

* *Soft excavation Class A is material which, using a pick or equivalent hand swing tool, can only be excavated with difficulty.*

\+ *Only applicable to materials comprising not more than 10% gravel (particles having dimensions > 2, mm) of size less than 10 mm and materials containing no isolated small boulders.*

++ *Cohesive materials with a DCP penetration rate of 6 to 8 blows/100 mm when wetter than Optimum Moisture Content would still be diggable with a spade and pick.*

3.5.2 Excavating to level

When excavating to level, approach the final level with care: do not over-excavate. Instruct the workers how to measure the depth of the excavation. It may be necessary to dig a small hole to the correct depth to show the worker where the final level is. These 'demonstration holes' should be set out with boning rods or string-lines.

Each worker should be instructed in the importance of obtaining the right level. Properly instructed workers take a pride in their work. The team leader must also carry out quality control regularly. It is not good enough to check the depth and level when the work is finished, as this is always too late. Regular checking is important, as it shows the worker the importance of achieving the correct level.

The excavatability of a material is seldom consistent over wide areas, with isolated areas or thin layers of harder (or drier material). The use of controlled applications of water in these areas to make the material easier to excavate should not be ignored. This is particularly relevant to clayey materials, which can become very hard when dry. In these cases, however, they should not be over watered as it is almost equally difficult working with excessively sticky materials.

Excavating bedrock and boulders

Bedrock or large residual boulders are frequently encountered in the sub grade. If these are localised or sporadic, it is not always necessary to use explosives for their removal during excavation to level. Considerable success has been achieved using fires and water. In this process, scrub and dry wood removed during the clearing and grubbing is placed directly on the exposed rock and burnt. Once the rock is at a high temperature, relatively large amounts of cold water are thrown onto the rock. The rapid cooling effect results in effective fracturing and comminution of the material for relatively easy removal and disposal. The fractured rock is usually relatively fresh and can often be used as a construction material for other activities.

3.5.3 Excavating to shape

Most excavations must be made to a specific shape. The hole for a foundation must be wide enough and long enough to fit the foundation. If the hole is too large, then more concrete may have to be used to fill it, which is a waste of concrete and money and time.

For foundation excavations, set up profiles to show exactly where the sides of the excavations need to be. String-lines and spirit levels or plumb bobs may be needed to transfer the lines of the excavation to the floor of the hole.

Ditches need the outer edges to be set out by means of pegs, joined by string. Alternatively, powdered lime or coloured sand can be used to mark edges of the ditches. Ditch templates are then useful to control the width and side slopes. Templates are made up of a few wooden planks to the shape or slope desired. Templates must be used with a spirit level. Workers should be instructed in the correct use of ditch templates and the team leader must regularly check on the quality and accuracy of the work and the condition of any templates being used.

3.5.4 Excavating to stockpile

Material being excavated in borrow pits for use as unsealed road wearing course or structural layers in sealed roads must be stockpiled to ensure homogeneity and consistency of quality during placing. This requires a careful design of the borrow area such that a continuity of material movement is possible and the need for double handling is minimised. In borrow pits where the material quality is variable, a dedicated stockpile area away from the excavation area is preferable. Material should be excavated into wheelbarrows and dumped nearby. This should be spread in layers about 200 mm thick over an area of about 2 000 m^2 (45 by 45 m). A second and third layer of excavated material should be placed above this resulting in a layer some 600 mm thick. This would generally provide adequate material for construction of one kilometre of wearing course with a width of 6 metres and a compacted thickness of 150 mm. Depending on the materials involved, difficulties may be encountered during the movement of wheelbarrows on the uncompacted stockpile surface, in which case wooden boards or planks should be placed to facilitate this movement. Plank ramps are also necessary for the wheelbarrows to access the top of the stockpile for the second and third layers.

Testing stockpiled materials

Stockpiled materials should be tested to ensure the correct quality for their intended purpose. Generally four samples per 1 000 m^3 are adequate: these samples should be randomly collected and be representative of the full thickness of the stockpile.

Where material removed from cut or adjacent to the road is to be used for pavement or wearing course layers, this needs to be relatively homogeneous. Variable materials will need to be stockpiled along the road and tested prior to use. Homogeneous materials can be placed directly on the road but will require more testing than is generally specified.

3.5.5 Productivities

Productivities can be linked to earthworks classifications and specific activities as illustrated in Tables 8 and 9.

Table 8: Trench excavation rates (Watermeyer and Band, 1994)

Excavation type*	Typical production per 6 hour task for depth range (m^3)			
	0 – 1,0 m	1,0 – 1,5 m	1,5 – 2,0 m	2,0 – 2,5 m
Soft class 1	3,5	3,0	2,4	1,6
Soft class 2	2,8	2,4	1,9	1,3
Soft class 3	1,7	1,5	1,2	0,8

* *Excavation classified in accordance with Soderlund and Schutte's classification*

Table 9: Excavation, measured in place

EXCAVATION	TOOLS	TASKS IN M^3/M-D THROWING DISTANCE	
		UP TO 4 M	4 TO 6 M
Loose soil	Shovel	5 to 6	4,5 to 5
Sticky soil	Spade, fork, forked hoe	2 to 3	1,5 to 2
Firm soil	Pick, shovel, spade, hoe	3 to 4,5	2,5 to 4
Hard stony gravel	Pick, shovel, crowbar	1,5 to 2	1 to 1,5

3.5.6 Quality control

Excavation quality control comprises essentially correct setting out and subsequent checking that the excavation complies with the geometric requirements. In the case of borrow pit excavation, the geometry is irrelevant and the material quality is crucial. This requires materials quality control, usually exercised by a qualified technician, as described above.

Comprehensive guidance on the selection of materials and quality assurance can be found in the ILO publication Material selection and quality assurance for labour-based unsealed road projects (1998). A comprehensive field test kit containing all of the equipment necessary to carry out the specified tests has been developed to complement the ILO document.

3.6 Practical guidelines for loading

3.6.1 Practical tips

Several possibilities exist for loading. Wheelbarrows may be loaded directly from an excavation and wheeled away when full. Other, more costly forms of transport require rapid loading in order to contain costs. Therefore, loading from a stockpile becomes important. This is also recommended for materials where the quality is closely specified, e.g. unsealed road wearing coarse and structural pavement layers.

Tipper trucks, flatbed trucks and tractors and trailers can all be used for transportation. As they are expensive machines, the economics of loading and offloading can strongly influence the choice of machine for a project. Each machine must earn its cost. A prime mover that stands for most of the day is not earning: these machines must travel.

Tipper trucks have the advantage that they are able to discharge their load quickly and without assistance, but have the disadvantage that they are high and difficult to load by hand. Flatbed trucks are lower than tippers and can therefore be more easily loaded, but have to be offloaded by hand. Tractors must be used with more than one trailer, so that one trailer can be loaded while the other trailer is being towed away with gravel for the works. When the tractor returns with an empty trailer, the next must already be loaded and ready to be hitched up to the tractor in the place of the empty trailer. One tractor with two or three trailers can be quite efficient. However, if only one trailer is available, then the efficiency drops and the transport will be more costly.

The loading area must be carefully planned so that the transport can enter, be loaded quickly and leave again. Loading by throwing materials upwards takes much effort and is slow. Loading at the same level is quicker and does not need as much effort. Loading downwards is easy and therefore quick. It is accordingly

Table 10: Loading productivities

LOADING	TOOLS	TASKS m^3/m-d Volume measured loose
Wheelbarrow	Shovels	12 to 15
Trailer		7 to 10
Truck		4 to 6

Table 11: Influence of loading height (Coukis, 1983)

Loading height m	Loading productivity per man-day, m^3
Below	5.88
Level	5.26
0.5 m above ground level	4.55
1.0 m above	3.85
1.5 m above	3.23
2.0 m above	2.70

preferable to arrange the loading area so that the vehicles are below and the loaders work from above. If a U-shaped recess can be used as loading bay, then more workers can cluster around each vehicle and load it rapidly from pre-arranged stockpiles.

3.6.2 Productivities

Tables 10 and 11 provide typical productivities. As can be seen the productivity rates in each vary considerably. This is not untypical though, because of the many factors affecting the productivity in labour.

3.7 Practical guidelines for hauling

Transportation is an essential part of roadworks. Soils and gravels need to be excavated and moved, placed and compacted. Transportation ranges from throwing soil with a shovel a few metres to carrying it in a truck for several kilometres. Each kind of transportation has different characteristics and gives different problems. Different countries use different methods. For example, in India, head-baskets are widely used for transporting soils, gravels and other materials like concrete.

The volume of the vehicle transporting the material is frequently used for payment. Therefore, it is important to make sure that all vehicles are fully loaded: wheelbarrows, trailers, trucks, etc.

Shovels: Shovels can be used to throw soil up to about 4 m. If a longer distance is needed, only a very strong worker will be able to throw soil further than 4 m, perhaps up to 6 m or 7 m. Less strong workers will have to carry the shovel with soil until near enough to throw it. Excavation productivity is lower if the soil has to be thrown or carried over a distance. A point is quickly reached where productivity will increase when wheelbarrows are used instead of carrying and throwing from a shovel. This distance is between 6 m and 10 m.

Table 12: Wheelbarrow productivity

Haul distance m	Trips per day: wheelbarrow loaded by pusher
Up to 20	270 trips @ 50 litre =13,5 m^3
20 – 40	220 trips = 11,0 m^3
40 – 60	160 trips = 8,0 m^3
60 – 80	130 trips = 6,5 m^3
80 - 100	110 trips = 5,5 m^3

* *Excavation classified in accordance with Soderlund and Schutte's classification*

Wheelbarrows: Wheelbarrows are used for haulage up to 100 m, and in certain circumstances, up to 200 m. Good quality wheelbarrows with rubber tyres on steel wheels with roller bearings are best. Solid rubber tyres are preferred to pneumatic tyres, to avoid problems with punctures. Most wheelbarrows made for concrete work have a capacity of 50 litres to 65 litres. Larger wheelbarrows are also available.

Wheelbarrows function best when a smooth path or runway is available for travel. It improves productivity to spend some effort in providing a better pathway. One way traffic or a 'circular' route should be chosen whereever possible to speed up the transportation of soils, as waiting is reduced or eliminated and as it reduces time lost in turning the wheelbarrow around after tipping or loading. The productivity and time taken for a wheelbarrow trip depends not only on the length of the haul, but also on the rise. Pushing a loaded barrow uphill takes more effort and time than if the path were level. If steep slopes have to be negotiated, a helper with a hook can greatly speed the passage of the wheelbarrow up the slope, by hooking onto the front and pulling the load up the slope.

If wheelbarrows are to be used to transport loads up scaffolding, care must be given to making the scaffolding runways wide enough and to providing substantial handrails to the runways. If a worker pushing a heavily loaded wheelbarrow looses his balance, he must be supported by the handrailing and must not be able to fall through and off the scaffold.

Donkey carts: Donkey carts are efficient transportation for distances of up to about 2 or 3 kilometres. Carts have a capacity of between 0.50 m^3 and 2.0 m^3. This is a large variation, so every cart should be measured to ascertain its volume.

The care of the donkeys must be good, as they can easily be overworked. Donkeys need regular water and fodder. Fresh clean water must be provided at the loading and the offloading points. In order to perform their function correctly, donkey carts must be kept in good condition. Well lubricated wheels lighten the load. If steep gradients are to be negotiated by donkey carts, it is essential that they be fitted with brakes. Punctures must be mended immediately.

Tractor-trailer combinations: Trailer volumes vary from about 1,0 m^3 up to 5 m^3 and sometimes larger. This is a large variation so every trailer should be measured up and its volume calculated.

Tractors must be used with more than one trailer, so that one trailer can be loaded while the other trailer is being towed away with gravel for the works. When the tractor returns with an empty trailer, the next must already be loaded and ready to be hitched up to the tractor in the place of the empty trailer. One tractor with two or three trailers can be quite efficient. However, if only one trailer is available, then the efficiency drops to low levels and the transport will be costly.

Minimising load vibration and segregation of particle sizes

Whatever the mode of hauling, the haul road should be as smooth as possible to minimise vibration of the load and segregation of the particle sizes. Where particularly rough sections of the haul 'road' exist, travel speeds should be reduced. This problem applies more to larger loads than smaller ones such as wheelbarrows. The application of moisture to the material in the stockpile reduces its propensity to segregate during transport. This water has the added benefit of providing a more uniform distribution of moisture than can usually be obtained by applying water on the road.

Trucks: Tipper trucks have several advantages over tractors. They travel faster and are able to discharge their load quickly, and so are more economical on longer haul routes. However, tippers have high sides and can be slow to hand-load. Loading from ground level requires every shovel-full to be heaved upwards to a height of at least two metres. Accordingly, the loading area should be so arranged that the truck is below the loaders so that they can work from above. Flatbed trucks are lower than tippers and can therefore be more easily loaded.

3.8 Practical guidelines for unloading

Unloading of construction materials requires planning to eliminate excessive double handling. Road gravels should be offloaded down the middle of the roadway, unless the layer work is being constructed under traffic, in which case, the material should be offloaded down the middle of a lane.

Wheelbarrows can be tipped across the width of the layer, at the spacing required by the quantity requirement of the layer. This will reduce later handling.

Offloading a trailer from a tractor-trailer combination, should be done quickly, in order to keep the tractor from idling. Some trailers are fitted with a tipping mechanism, which, when released, allows the load to tip backwards onto the road. Other trailers have hinged sides that can be flapped down to facilitate offloading with shovels. Others still have a fixed body and simply have to be

Table 13: Donkey cart haulage productivity (based on 0,5 m³ carts) (McCutcheon and Marshall, 1996)

Haul distance m	Trips per donkey cart per day
UP TO 200	19
200 – 300	16
300 – 400	14
400 – 500	13
500 –650	11
650 – 800	10
800 – 900	9
900 – 1050	8
1050 – 1150	7
1150 – 1500	6
1500 – 2000	5

Note: The figures include loading and offloading by team members (not the donkey cart driver).

emptied with shovels. Sufficient workers must be allocated to offloading, but no more. Too many workers will either get in each other's way and slow down the offloading, or will distract the offloaders with chatting and joking. When the trailer is empty and the tractor tows it back to the borrow pit, the workers should spread the loads while waiting for the next tractor to arrive.

If large four-wheeled trailers are used, thought should be given to possible increases in productivity if a fully loaded trailer could be unhitched at the offloading point, to be cleared at leisure, while an empty trailer is hitched up to the tractor to be taken back to the borrow pit for reloading. This system therefore has full and empty trailers at both the borrow pit and at the road, while the tractor travels between, towing trailers each way. Obviously several trailers are needed.

Offloading a truck must, likewise, be done quickly, in order to keep the truck from idling. Tipper trucks can offload the material quickly onto the road and do not need workers to help. Flatbed trucks have hinged sides that can be flapped down to facilitate offloading with shovels.

Productivities

For use of wheelbarrows, the unloading is usually included in the haulage productivity rate. Furthermore other haulage equipment has a means for unloading that requires negligible labour input. The notable exception is the offloading of a flatbed truck where a productivity of 15 m³/m-d can be assumed.

Care must be taken during loading and offloading of material that segregation of the particles does not occur. This is usually minimised during tipping but can be a problem if material is unloaded using shovels, particularly if the material is thrown some distance: the larger heavier particles travel further resulting in most of the fines being near the truck/trailer and the coarser materials lying separately some distance away. This is particularly common when the labour attempts to use the unloading phase of the operation to spread the material. Unloaded material should be dumped over as small an area as practically possible to avoid segregation.

3.9 Practical guidelines and productivities for spreading

A common problem in the construction of earthworks is the control of moisture content. In conventional road construction, the material is spread and watered and then windrowed by a grader from one side of the road to the other. During this process all the material in the layer is gathered together and mixed. The process ensures uniformity of material and of moisture. Once mixed, the material is placed and compacted.

Using labour the above process cannot easily be duplicated. Particularly when *in situ* soils are being used, the material characteristics can change within the space of a few metres. Usually the material is spread to level, watered and mixed by being turned over a few times by a team of labourers with shovels. The material is not mixed from side to side or longitudinally, as would be the case with a grader. The resulting material and its moisture content are non-uniform across the width and length of the section.

Most water bowsers throw water unevenly: more in the centre and less at the sides. If water is applied by hand using a hose, the application is probably even more non-uniform.
To solve the problems enumerated above, the following method is proposed:
- The material to be compacted in the layer should be placed along the middle

of the road, in the correct quantity to produce a compacted layer at the correct level.

- The material should be opened out to form a flattened heap about 2 to 2.5 m wide, roughly levelled across the top.
- This 'windrow' should then be watered, preferably with a water bowser. If a hose is used, particular care must be taken to obtain an even application of water.
- The material should then be mixed by a labour team, using shovels or forks which best suit the soil. The material will probably need additional applications of water, which should be done as above. The extra water should be mixed into the soil to produce uniform moisture throughout the flattened heap.
- Once uniform and at a moisture content somewhat higher than optimum, the heap should be spread across the road width and levelled using string-lines from profiles for level control, making allowance for bulking (33% to 50%). The soil should be above OMC to allow for evaporation during placing and levelling. It should be noted that the Modified AASHTO OMC (Method A7 in TMH1) is generally applicable to plant used on conventional road projects. OMC determined at Proctor compaction effort (Test ASTM D698) is probably more appropriate for labour-based projects, where pedestrian rollers are employed. This is usually two or three per cent higher than the Mod AASHTO OMC, with a concomitantly lower maximum dry density.
- Rolling should commence, working from the sides towards the middle to preserve the camber, or from the low side to the high side to preserve the cross fall. The first pass of the roller should be without vibration, to press the soil into shape without much compaction. The shape and level must immediately be carefully checked and corrected, with all hollows being filled and all bumps being skimmed, by a small skilled labour team. Compaction then continues, using vibration. The shape and level must be continually checked and corrected during the first few compaction passes, as, unlike with conventional plant construction, it is practically impossible to use labour to provide a smooth final cut.

Productivities

Typical productivities for spreading and related activities are:

- Spreading only
  12 m^3 per worker per day
- Water, mix, spread and level
  3 m^3 per worker per day

3.10 Practical guidelines for compaction

3.10.1 General considerations

Compaction by hand in earthworks activities can at best only reduce settlements to within acceptable limits as the compactive effort is insufficient to provide satisfactory engineering properties required in most applications. Accordingly, in practice, hand compaction can only be contemplated in trench excavations in untrafficked areas where a level of compaction in excess of 87 to 88% of modified AASHTO density is likely to contain trench settlements to within acceptable limits. Higher compaction levels can only be achieved by using mechanical compaction equipment and not by means of hand methods with any degree of consistency.

Note: SANS 1921-5 requirements for compaction of backfilling to trenches in areas not subject to traffic

Backfilling to trenches in areas not subjected to traffic shall be placed in layers of thickness (before compaction) not exceeding 100 mm. Each layer shall be compacted using hand stampers such that:

a) a Proctor density of 90% is achieved,
b) more than five blows of a dcp are required to penetrate 100 mm of the backfill, provided that the backfill does not comprise more than 10% gravel of size less than 10 mm and contains no isolated boulder,
c) The density of the compacted trench backfill is not less than that of the surrounding undisturbed soil when tested comparatively with a dcp.

Tests to provide compaction characteristics of soil were first introduced by Proctor in the USA as a means of controlling the degree of compaction during construction. Proctor's test represented in the laboratory the state of compaction that could be reasonably achieved in the field using plant available at the time. However, with the subsequent introduction of heavier earth moving and

compaction equipment higher densities became obtainable in practice. As laboratory test using increased energy of compaction was then introduced to reproduce higher compacted densities viz modified AASHTO test. Accordingly, density requirements where light equipment or hand stamping is used should rather be measured in terms of Proctor densities and a value of 90% Proctor density should suffice for untrafficked areas. This is achievable by means of hand stamping.

DCPs can be readily used to control compaction in trenches in untrafficked trenches. Material with a medium dense / stiff consistency (refer to Table 6) are unlikely to settle under conventional loads. A value of not less than five blows / 100 mm of material at compaction moisture content can be used to specify the compaction requirements.

3.10.2 Existing standards for compaction

Compaction is normally classified for purposes of payment. The classification system is usually coupled to the equipment or tools used for compaction operations.

Conventionally, compaction operations are classified as follows:

COLTO, 1998, Section 3300, Mass earthworks
Three classes of compaction are specified. These are given below. The engineer is given considerable authority in terms of the specification to order the contractor to use specific items of plant in various combinations.

- Compaction to a minimum percentage of modified AASHTO density, where "the contractor shall be at liberty to employ any type of compaction equipment he may choose so as to achieve such density over the full specified depth of the layer",
- Eight-pass roller compaction comprises eight passes of any combination "of the following items of plant: heavy grid rollers, sheep's-foot rollers, tamping rollers, flat wheel rollers and vibratory rollers or any other item of plant deemed by the engineer to be suitable". The rollers are described in terms of size, mass, speed and frequency of vibration,
- Three-pass roller compaction comprises three passes of a heavy roller, as described under the 8-pass roller compaction clause, or with an impact roller (which is described in some detail).

SANS 1200 D, 1988, Earthworks
Compaction requirements are given in terms of percentage of modified AASHTO maximum density.

SANS 1200 DM, 1981, Earthworks (roads, subgrade)
Compaction requirements are given in terms of percentage of modified AASHTO maximum density.

Labour-based specifications: Soderlund and Schutte, 1993: Standardised specifications for community-based construction, S100 DB: Earthworks (service trenches).

Clause 5.7.2 Compaction (areas not subject to traffic).
"Each trench shall be backfilled in layers of thickness (before compaction) not exceeding 100mm and the material shall be compacted, using hand stampers, to 95% Proctor density. Where in terms of the Project Specifications, hand stamping is not permitted, trenches shall be backfilled in layers of thickness (before

compaction) not exceeding 150 mm and the material shall be compacted by means of mechanical equipment to 90% of mod AASHTO density."

3.10.3 Compaction equipment

For roadworks, mechanical compaction is needed to ensure that compaction is achieved throughout the depth and over the area of the layerworks. The problem is actually one of plant selection. The compactor must be massive enough to achieve the specified performance, but should be small enough to keep up with the production of teams of labourers. Within limits, more labour teams can be allocated to earthworks in order to balance the compactor output.

Many projects have been successfully carried out using small pedestrian or sit-on rollers. It is, however essential that compaction is carried out at the correct moisture content for the effort.

The problem in perspective

The problem is put into perspective when one realizes that a large self-propelled vibrating roller can compact up to 300 m^3 per hour, which is approximately the weekly output of one labour team. Small walk-behind pedestrian rollers are often too light and therefore too slow, as multiple passes of the roller are required to achieve the soil densities. These small rollers quickly become costly, particularly when the layer thickness is reduced and multiple layers are required to make up the total thickness. This practice, is however, not recommended as layers less than about 50 mm often delaminate under traffic.

It is not good practice to restrict the use of mechanical compaction plant on a labour-based project. The contractor should be allowed unfettered use of his hard-won expertise in the selection and use of compaction plant.

3.10.4 Practical tips

Labour-based compaction of large areas is generally a slow and tedious process, difficult to control with any accuracy. Hand stampers should not be used for compaction of large areas, but can be quite successful in narrow or restricted areas like trenches in untrafficked areas.

For compaction around pipes and cables, hand stampers are probably the safest and most reliable method of ensuring adequate soil support. Before enough soil cover has been achieved, machine compaction to pipes and cables will almost guarantee damage or overstressing of the pipe or cable materials. Adequate soil cover is generally accepted to be about 300 mm for small mechanical compactors (SANS 1200 LB, 1983). Greater precautions (and therefore greater soil cover) should be taken for larger mechanical compactors.

Service trenches can be adequately compacted over their full depth by hand, using stampers. Because the energy input is relatively low, the layer thickness needs to be restricted. 100 mm (compacted) is generally the maximum thickness that can be compacted by hand. Attention must be given to achieving soil moisture conditions close to optimum moisture content. The preferred standard is the Proctor test, with its optimum moisture requirement. The Proctor optimum, which is wetter than the modified AASHTO optimum, lends itself to hand compaction.

It is recommended that all structural pavement layers and unsealed wearing courses are compacted to refusal for the plant available. This requires proof rolling where after each roller pass, a DCP test is carried out through the layer. It will be found that at a certain number of passes the DCP penetration rate will become

The control of moisture content

A common problem in the compaction of earthworks is the control of moisture content. (see 3.9). In labour-based roadworks, much effort must go into achieving some uniformity of both material and moisture content across a layer. This will ensure better compaction.

The following is recommended:

- After the moist material has been spread and levelled, rolling should commence, working from the sides towards the middle to preserve the camber, or from the low side to the high side to preserve the cross fall. The first pass of the roller must be without vibration, to press the soil into shape without much compaction. The shape and level must immediately be carefully checked and corrected, with all hollows being filled and all bumps being skimmed, by a small skilled labour team. Compaction then continues, using vibration, until the planned number of passes is reached. The shape and level must be continually checked and corrected during compaction.
- After compaction the density should be checked, before the layer dries out. A nuclear density probe with parallel gravimetric moisture determination is preferred, but is rarely justified in terms of cost. A DCP can be used, but calibration will be needed. If the density is not as specified, the roller must continue with a few more passes. Additional water may be required.

Productivities

As in general, on labour-based projects, compaction equipment is used, the productivities can be obtained from the relevant manuals for the type of equipment used. As mentioned earlier, crucial to achieving cost-effectiveness is to select the type of equipment that has comparable productivities with that of the labour team that uses it (i.e. the compactor needs to be incorporated in the team planning exercise). Important when doing this is to ensure the availability of the compactor, as improper planning when sharing a compactor can lead to unavailability when required.

Quality assurance guidance

Comprehensive guidance on the selection of materials and quality assurance can be found in the ILO publication 'Material selection and quality assurance for labour-based unsealed road projects' (1998) and the Roads Directorate of the Johannesburg City Council's Technical note on the backfilling and reinstatement of trenches (Horak, 1993).

constant and additional passes may even result in decreased density. This allows a method specification to be employed for that material as well as providing a target penetration rate for quality control purposes.

3.10.6 Quality control

Quality control is required at different stages of the work. Material quality is the first essential one. Geometrical compliance of the finished layerwork is the second requirement and only then compliance with the density specification. Geometrical requirements should be checked carefully and adjusted, during the rolling.

Quality control of the finished layer requires that the material thickness is correct and the density has been achieved. Using the proof rolling method described above, the refusal density (in terms of the DCP penetration rate) for the prevailing conditions and a "method specification is identified. These are generally sufficient to control compaction of labour-based projects. Their simplicity and ease of testing allow significantly more testing than would normally be carried out for quality assurance, even on large projects using conventional construction methods.

In trenches across trafficked areas, the DCPs and Rapid Compaction Control Devices (a spring loaded steel rod with a 32 degree cone shaped point complete with trigger mechanism) should be used to confirm the adequacy of the compaction.

4. Safety

4.1 Introduction

The provisions of the Occupational Health and Safety Act (Act 85 of 1993) have to be met. Employment-intensive sites are sometimes more informal than conventional construction sites, and either ignore the OHS Act or make the application of strict safety regulations more difficult. Safety is not a matter that can be neglected, so whatever shape or form the management of employment-intensive sites may take, it must be aware of safety and all its implications.

Employment-intensive construction, as an industry, is more likely than the conventional construction industry to employ people that have no previous employment experience at all. These people are most vulnerable to becoming involved in accidents, because they have not learned the potential dangers. Induction into safety on site is essential for all newly recruited workers, but even more important for the first-time employees.

Few employers in the construction industry have a vision of an injury-free and damage-free workplace (Strydom, 1999). However, this vision may be workable on employment-intensive construction sites, largely due to the absence of large machines. Because of this, employment-intensive construction sites should be inherently safer than conventional construction sites. Even so, a proactive approach to safety is the only possible way to achieve an injury-free workplace (Strydom, 1999 and Smallwood, 1999a). If employers realise that one of their most important resources are people, then the goals of health and safety in the workplace are logical and cost effective. The vision of an injury-free workplace then leads to sharp focus of management (Smallwood, 1999a). Injury free means zero injuries. Any lesser goal would imply that injuries are acceptable.

4.2 Management of safety

Start with a financial budget. Implementing a safety programme costs money and takes time. Once a safety culture has been established, the ongoing costs of safety are very much less than the costs of accidents. The budget must make provision for: planning, training, implementation, measuring, feedback to top management and to the work force, and retraining.

The management plan demonstrates how the company will fulfil OHS policy by setting objectives and targets. It will note the resources, particularly the people, needed to implement safety systems. Site specific safety plans include safety of the chosen method of construction, by risk identification followed by risk minimisation and management of the remaining hazards. Contingency planning is essential. Emergency procedures must be established. Communication systems may have to be set up, as the construction site may impose its own limitations on conventional communication.

Keep safety planning as simple as possible within the complexity imposed by the work being undertaken. Address the culture, allocate enough resources and set up a user-friendly system.

4.3 Safety in any operation

Below are some of the steps necessary to achieve an injury-free workplace:

- Implement the Occupational Health and Safety Act provisions, rules and regulations,
- Talk about safety,
- Implement 'Behaviour-Based Safety' or 'pro-active control of safety' [Strydom, 1999],
- Hold 'toolbox talks' [Smallwood, 1999, b].

Implement the Occupational Health and Safety Act

This Act defines the legal framework within which every employer and employee has to conduct business. Implementing the Act includes the identification of all hazardous and unsafe conditions and then taking all possible measures to improve these conditions. Training of the management, supervisors and workers must be included in the measures used to mitigate unsafe conditions. Implementing the rules, regulations and the spirit of the Act must be the starting point and the basis upon which a culture of safety at work can be built.

Talk about safety

Talk about safety at every meeting (on site and off site). Safety MUST be on the agenda of every planning and construction meeting. People have to be made aware of safety and the part they can play to enhance safety.

Implement 'Behaviour-Based Safety'

'Behaviour-Based Safety' or 'pro-active control of safety' [Strydom, 1999] can be introduced by saying that accident statistics show only the tip of the unsafe iceberg. For every reported accident there are many near misses and probably also many small-damage incidents (which are not reported). Each near miss was almost a severe 'accident'. Luck played a major role in keeping the statistics of 'accidents' down. All these near misses and low-damage incidents need to be recorded so that the accident profile of the construction site can be assessed and the true magnitude of the risks evaluated. Once the frequency of the 'accidents waiting to happen' has been assessed, then management is in a position to take remedial action. This is a relatively new approach but is probably the only pro-active approach to safety that can be implemented [Strydom, 1999].

Toolbox talks

Toolbox talks should be given by first line supervisors. Toolbox talks should take no more than 10 to 15 minutes and can be used to introduce a new activity or to discuss generic health and safety issues. If held at the start of a workday, they have less impact on work time than when presented during the day. Toolbox talks should encourage worker participation and engender teamwork. They provide the opportunity to discuss quality, productivity and safety issues [Smallwood, 1999b] or any other matters. Toolbox talks are the ideal way in which behaviour-based safety principles can be communicated to the work teams. Site Managers should attend these talks as frequently as they can, to indicate that safety is part of the job and has their full support.

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Notes

Notes

Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour-based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major contributing organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
National Housing Forum
Congress of South African Trade Unions

Plus many individuals from construction companies

"Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings."

Nelson Mandela, 2005 – Global Campaign for Action against Poverty

Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 3-1

Precast concrete products, bricks and block making

cidb
development through partnership

Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment-intensive construction works

In this set: (colour coded)

Part 1

An overview of labour-based technologies and methods in employment-intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

3.2 The BESA building system

Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

4.2 Rubble masonry dam construction technology

4.3 Rubble masonry concrete arch bridge construction technology

4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Waterbound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

EXPANDED PUBLIC WORKS PROGRAMME
Creating opportunities towards human fulfilment

ENGINEERS AGAINST POVERTY

Labour-based methods and technologies
for employment-intensive construction works

A cidb guide to best practice

1ST Edition of CIDB document 1024 March 2005

Best Practice Guideline – Part 3-1

Precast concrete products, bricks and block making

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

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Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1. Introduction

Precasting is an economical means of producing high-quality concrete items. It is an accepted, proven and traditional method for making items required in buildings and civil engineering such as bricks, blocks, sills, lintels, paving blocks and slabs, kerbs, pipes of small diameter, and retaining blocks. Precast concrete units for the garden, such as flower pots, trellis supports, security fences, fencing posts, decorative slabs, poles for clothing lines, washbasins, gravestones, flower bed edging, sculptures, bird baths and drainage elements are popular. The range of precast concrete products to be made is only limited by the imagination and market requirements.

Note

The small-scale manufacture of precast concrete products, bricks and blocks is a labour-based form of producing units that can be used in construction and other uses. Production can be carried out in the open, the processes are simple and equipment does not require high capital investment. Products can be competitive compared with *in situ* cast concrete elements.
This chapter covers small-scale operation, from completely labour-intensive manufacture to the use of some machinery either fuel or electricity driven.
Concrete is made by mixing stone, sand, cement and enough water to make the mixture workable (suitable for compaction). The basic concrete mixture and the ingredients are discussed together with plant and equipment requirements.

Concrete is probably the most widely used construction material worldwide in both volume and diversity of application. Concrete is a material that literally forms the basis of our modern society. It has a proven record of use by both small- and large-scale operators.

Precast concrete is a design material with its own criteria of optimum size, shape and profile and its own peculiar dimensional, production and erection problems. Repetition is inherent in the precasting operations for simple economic reasons. An understanding of precast concrete begins with the realisation that it is more a process – a production process than a material, i.e. precast concrete products.

A typical element must be designed within certain size limitations because of transportation from plant to site. The thickness of an element directly affects its rigidity and is important not only for handling but also for deformation while curing or storing to minimise warping and damage.

Precast concrete is produced either by placing and compacting wet concrete into moulds, stripping the moulds when adequate strength has been reached, curing and storing until used or using a semi-dry concrete mix which is placed in the mould, compacted and extruded (pushed out) from the mould immediately compaction is completed, the units being cured and stored until use.

This latter process is used in the manufacture of concrete masonry and paving units as the most economic system of producing large volumes of bricks, blocks and pavers. (It should be noted that bricks and blocks are referred to in the South African National Standards as masonry units.)

2. Overall considerations and planning

See Annex A

In Annex A, details are given of various precast concrete products and concrete masonry units that can be made by a small-scale manufacturer.

Before embarking on the manufacture of precast concrete products (in this section includes bricks and blocks), many decisions have to be made and consideration should be given to a number of issues, as detailed below:

What products should be made and how many?
This will involve a market survey of the following:

- What is the target market? Precast products to be used in building residential, (single, double or multi-storey), commercial, industrial, educational, health, community or other types of building, for domestic use around the house or for road construction, etc. If concrete masonry units (CMUs) are to be made, should they be bricks or blocks, should they be solid or hollow, what size and especially the thickness of the unit? Should they be strong enough only for single storey houses or for use in walls that are more highly stressed? Determining the demand for the various products is an essential step in planning for production,
- What other competing manufacturers of precast concrete products are in the area and what are their prices?
- What should the target volume be for production – immediately and say in two, five and ten year's time? (A thumb-suck exercise).

Where should the plant be located?
Where is the main market situated now, and where will it be in the future? What area of land is required? This will take account of size and type of plant, its capacity and associated storage areas, ancillary buildings such as office, storerooms, workshop, laboratory, change rooms, display area, etc. Costs of transporting the products to various markets (is the site accessible to an existing road structure?) and the maximum viable distances should be considered. Is labour readily available on site? Is the area secure or do special provisions have to be made to prevent theft, etc? Is the site level or nearly so?

What materials should be used?
What types of cement are available? What aggregates are available, at what cost and how should they be combined to meet the requirements of the products to be made? Have the aggregates, especially pit and river sands been used before to make sound concrete or do the materials have to be tested?

What equipment should be purchased?
This will obviously relate to the size of the market and whether production should be completely labour-intensive or fully automated or somewhere in between, i.e. semi-automated.

With precast products determien what moulds are required – size, type of mould material – steel, fibreglass, wood, etc? Is the concrete to be compacted into the moulds by hand-compaction, immersion or mould vibrators or on a vibrating or a jolting table?

With the manufacture of concrete masonry units should the brick or block making machine be fixed or should it be mobile, easily moved to meet the needs of new markets in a different location? Should the machine be stationary and use pallets or should it be an egg-laying machine depositing units on a concrete slab?

How should the materials be stored (cement, aggregates, etc.), in star compartments, hoppers or in piles and how should materials be handled and transported (wheelbarrows or conveyors for subsequent batching)?

Should the cement and aggregates be volume or weight batched? How should

they be mixed, by hand or mechanical mixer, and if so, how large and what type of a mixer?

How will newly de-moulded or extruded products be handled, stacked, transported and packaged for delivery, by hand or specialised equipment?

Does the equipment or part of it need to be under cover? What is the likely interruption of production from inclement weather – rain, lightning, hot or cold weather? How does working under cover or in the open affect the productivity of the operators?

How will the products be cured – under plastic cover, watered at regular intervals or not cured at all? How does this affect strength gain and after what period will the products have sufficient strength to be sold and delivered?

Will there be a laboratory on site or are there outside facilities available for control and acceptance testing?

Will the plant be profitable?
This involves an estimate of all costs: land buildings, equipment; cost of labour and materials; allowance for wastage, maintenance, replacement, etc, and all other economic factors affecting money, interest, profit, taxation, etc.

Planning production
Once the type and quality of concrete products to be made have been decided upon, planning of production is required.

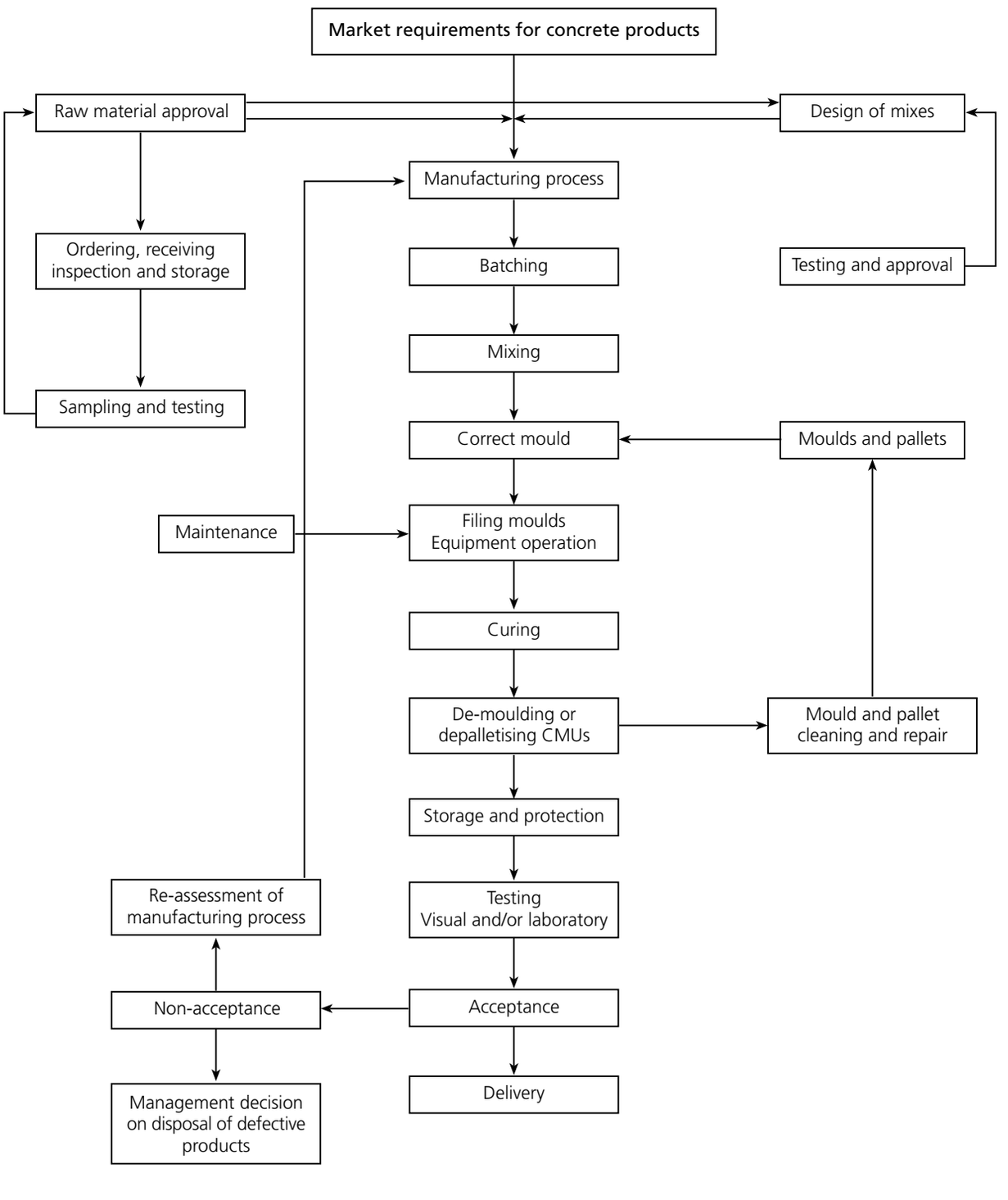
This involves deciding on materials to be used, mix proportions, raw material handling and storage, batching, mixing, manufacture, transporting, curing, de-moulding or de-palletising or removal of products from concrete slab and stacking ready for delivery.

The capacity of each piece of equipment to perform its task in the allotted time is important.

Thus all equipment should be in phase, i.e. the mixer capacity should be adequate to keep the block machine in full production. Consideration should also be given to alternate forms of production, if one piece of equipment is not performing satisfactorily.

A typical flow chart of the various manufacturing operations is shown in Figure 1.

Figure 1: Flow diagram of main activities in precast concrete production



3. Material requirements

3.1 Cement

Cement is the standard binder used with aggregates for the manufacture of precast concrete.

The quality of cement, particularly with regard to the rate of strength gain and sensitivity to curing, or lack of curing in many cases, should be considered in choosing a cement. In cold weather the rate of gain of strength is reduced and 'ultimate' (say 7 or 28 day required strength) strength may take longer. Concrete may have to be left in the moulds for a longer period before de-moulding or masonry units made on an egg-laying machine may have to be left on the concrete slab for an extra day.

Only cements or cement blends bearing the SABS mark should be used. This means that all aspects of manufacture have been controlled and meet acceptable standards.

All cement should comply with SANS 50197-1, Cement types CEM II and CEM III will develop strength more slowly than CEM I. This may affect production rates. For precast concrete it is recommended the strength class be at least 32,5N preferably 42,5N or 42,5R.

3.2 Aggregates

Aggregates form the bulk of concrete. They significantly affect the cost and quality of the final product and the ease with which the products are manufactured and finished. Aggregates used are mostly derived from solid rock, which is crushed or has been broken down by weathering. Alternative aggregates or waste products such as furnace clinker and furnace bottom ash, fly ash, crushed burnt clay brick and slag are also used extensively in the manufacture of concrete masonry units, where available. All sources of these aggregates should be checked to see they are of adequate quality. This might be done by testing the aggregates in a laboratory or by reference to the successful service performance of the aggregates in concrete, say over a five-year period.

Aggregates are divided into two types according to size:- sand (or fine aggregate – most material passing though a 4,75 mm square opening) and stone (or coarse aggregate consisting of particles too big to pass through a 4,75 mm sieve).

The physical properties of shape, surface texture and grading of the aggregates are significant factors in the manufacture of concrete.

However, in the manufacturing and quality control process the most important factor is the consistency of the quality of aggregate, thus avoiding frequent adjustments of mix proportions or in concrete masonry unit manufacture adjustments to the operation of the 'block' machine.

Generally, the choice of an aggregate depends on its availability, cost, the ease with which it can be made into the required product (especially hollow masonry units with thin shells) and the properties (strength, durability, appearance) the aggregate imparts to the product.

In general, aggregates should consists of clean, hard, strong, dimensionally stable

No ideal grading

There is no such thing as an ideal grading as there are conflicting requirements for an aggregate in the manufacturing process.
For instance for the filling of moulds, aggregates of rounded chunky shape and smooth texture (like glass marbles) produce concrete that flows easily. But on de-moulding or on extrusion of the masonry unit from the mould green strength (early strength) is required. This is best achieved by using aggregates of elongated shape and rough surface texture.

Checking for aggregate suitability

The choice of aggregates is a compromise or optimisation of factors. Blending of up to three aggregates is generally the practical solution to obtaining suitable aggregates. To evaluate the suitability of an aggregate, check:

Before use
- general soundness and chemical stability (especially waste products),
- physical characteristics (particle shape, surface texture, grading and water absorption).

In use
- performance in the manufacturing process noting any production problems,
- influence on the properties and characteristics of the final product, noting surface textures, arrises, uniformity, density and strength.

and durable particles free from clay coatings or foreign materials (especially organic matter) that may interfere with the normal strength development of the cement. Aggregates that do not have a reliable service performance record should be tested in a laboratory.

3.3 Pigments

Pigments may be used to colour concrete. The production of colour-stable concrete requires care both in choice of colours and in the composition of the concrete mix. Specialist advice should be sought on best pigments to use to obtain the required colour and their dosage.

The final choice of pigment and appropriate dosage will be made on the visual examination of dry concrete in which the pigment has been used. Usually in the preliminary stages, concrete is made with a range of dosages of cement pigment to determine the optimum dosage to give the required colour. Dosages should not exceed 7% of the mass of cement.

Concrete properties modified

Properties of concrete that may be modified by the use of an admixture are one or more of the following:

Fresh concrete

- workability and cohesiveness in the wet concrete, viz. concrete flow may be improved and the likelihood of segregation reduced,
- reduction of water content without changing workability means a reduction in drying shrinkage and cement content,
- setting time, either retarded or accelerated to suit special requirements of precasting, finishing and de-moulding.

Hardened concrete

- increased rate of gain of strength,
- increased durability,
- decreased permeability.

3.4 Admixtures

Chemical admixtures are materials (usually in liquid form) that are added in small amounts to the concrete at the mixing stage to modify the properties of concrete in either the fresh and/or the solid state.

The type of admixture to be used should, in the first instance, be based on the manufacturer's advice. The final decision should be based on cost comparisons and experiments. Observations of the effect of admixtures on the concrete would cover:

- flow and compaction of concretes in the mould
- ease of de-moulding or extrusion from the moulds (CMUs),
- visual examination noting uniformity and segregation, if any
- strength and drying shrinkage of the hardened unit.

Admixtures should not be regarded as a substitute for good materials, good mix design and good workmanship.

3.5 Water

Water in concrete makes the fresh concrete workable and reacts with the cement to give strength to the concrete; its quality is important. Water fit to drink is normally suitable. Evaluation of suspect water such as industrial wastewater, water from underground mining activities and raw effluent may be carried out by observing if the setting and strength gain of the concrete is affected.

Turbid (murky) water should be allowed to settle before use to remove suspended solids which could have unexpected effects. Algae in mixing water can give a greenish tinge to the concrete, while entrained air might reduce strength.

Seawater may be used in concrete where efflorescence and mottling does not matter and in un-reinforced concrete. Seawater causes rusting of steel-reinforcement, lifting hooks, ties, etc. and should not be used in reinforced concrete.

4. Major equipment required with comments on their use

4.1 Mixers

Free-fall mixers, e.g. tilting drum and reversing drum have blades that lift the concrete to the top of the drum and allow it to fall and so mix. These mixers are suitable for most normal concretes but cannot handle concretes of low workability, of lean mix proportions and concrete that is over-cohesive (very sticky). Mixing time is between 90 and 150 seconds.

Forced-action mixers, e.g. pan mixers have blades that shear the concrete. Pan mixers consist of either a stationary pan with rotating blades or a rotating pan and blades. This type of mixer can handle concrete of any workability especially the semi-dry concrete mixes required for making bricks and blocks. Mixing time is between 60 and 120 seconds.

It should be noted that concrete can be mixed by hand if so required in the planned manufacturing process.

4.2 Block making machines

Machines are of two types:

A stationary machine deposits its extruded units on a pallet, which is removed for subsequent maturing and curing of units.

An egg-laying machine deposits its extruded units on a concrete slab, then moves forward to 'lay' the next set of units. Units are removed from the slab the next day, or, in cold weather, two days after manufacture unless richer mixes are used.

The essential features of a machine are a hopper to store the concrete for feeding into the mould, apparatus for compacting the concrete in the mould and subsequent pushing out of the units from the mould.

Depending on the type of machine and the abovementioned factors, machines cycles vary from 1,5 to 4,0 per minute.

With egg-laying machines, allowance has to be made for the time it takes to move to the new dropping position and the time it takes at the end of a run to turn the machine around.

The planeness, trueness and surface texture of the concrete slab surface significantly affects the height of the units and the ease with which they can be removed from the concrete surface. The minimum area of slab should be such that it can accommodate one day's production. Details of the casting of the slab are given in Appendix D.

Factors affecting machine productivity

The productive capacity of a machine depends on:

- The type of unit being made. With solid units moulds are quickly filled with slight primary vibration and say one pass of the feeder drawer. With hollow units with 25 to 27 mm thick shells, longer vibration times are required with up to seven or eight passes of the feeder drawer over the mould to fill the mould,
- The number of units that can be fitted into the available mould area for extrusion onto a pallet or dropped on the concrete slab in the case of egg-laying machines,
- The concrete mix and its flow characteristics in the filling of the mould, its sensitivity to primary and secondary vibration, viz. duration required for compaction, and subsequent extrusion.

In the market place, there are a range of machines available and machine manufacturers should be consulted on type of machine and ancillary equipment available, their costs of operation and potential production capacity.

5. Manufacture

5.1 Operations

The manufacturing process involves a wet side, viz. batching, mixing and casting or extruding of the CMUs, with appropriate concrete mixes, and a dry side, viz. curing, handling and assessment of the finished product.

Basic principles for batching

Basic principles are that:

- materials should be protected from deterioration or contamination until used;
- methods of storing, handling and batching should ensure minimum segregation of the aggregates, i.e. separation of the different sizes in the aggregate; and
- all materials, cement, aggregates, water, pigments and admixtures must be batched to acceptable degrees of accuracy.

Containers used for batching should be robust. Builder's wheelbarrows (which have a capacity of 65 ℓ) and steel buckets and drums are suitable. Batching should be done by pouring material loosely into the container to overfill it, and striking off level with the brim. Partial filling of containers leads to non-uniform batching. Containers should therefore be sized accordingly.

To avoid errors, there should be sufficient containers to measure out a complete batch without having to use any container more than once.

The concrete must be thoroughly mixed.

5.2 Batching (including storage and handling)

5.2.1 Cement

Cement may be stored in paper bags but protected from any deterioration, or in silos. Cement should preferably be batched by mass, either using a full 50 kg bag or weighing each batch of cement either from a silo or opened bags. Volume batching must allow for the bulking of the cement, normally around 20%.

5.2.2 Aggregates

Aggregates should be stored and handled so as to reduce segregation and contamination. Storage areas should be adequate for frequency of delivery and subsequent demand. There should be no intermingling of different aggregates.

If wet aggregates are delivered they should be allowed to drain; normally on a concrete surface. When some sands drain silt and/or clay are deposited at the base of the stored sand. These materials should be removed and discarded when ground storage areas are emptied. When frequent rain occurs aggregates should be stored under cover.

Batching may be carried out by volume or mass. With volume batching, an allowance for moisture in the sand should be made and for its bulking.

Some clinker or ash aggregates absorb up to 20% of their mass in water. Pre-wetting the aggregate reduces the likelihood of a rapid loss in workability of the concrete during and after mixing.

5.2.3 Water

Water is batched by volume. An experienced operator can judge the amount of water required in the particular concrete. If stored in tanks, the water should be protected from low temperatures, as this affects the setting time of the concrete and its rate of gain of strength.

In hot weather, water flowing in black pipes subject to direct sunlight can become excessively hot and cause rapid loss of workability of the concrete. Pipes should either be protected or insulated, or water should be stored when cool for subsequent use.

5.2.4 Pigments

Pigments are best batched by pre-weighing, and storing in plastic or other suitable containers. The pigments should be introduced gradually into the dry ingredients (cement and aggregate) during the mixing process.

5.2.5 Admixtures

Admixtures are usually liquid and measured by volume. Admixtures should be checked for settlement. Stirring at regular intervals may be required.

Admixtures should preferably be added to the mixing water during the mixing process.

5.3 Mixers and mixing

The concrete must be thoroughly mixed. Small quantities may be mixed by hand on a concrete floor or steel sheet. Machine mixing is preferable. For semi-dry mixes the best type of mixer is a pan mixer. Free-fall drum mixes are suitable for the more workable concrete.

The order of charging the mixer and the duration of the mixing are important factors affecting the quality of unit being made and its variability.

Natural aggregates of low water absorption are best charged with all aggregates, then all cementitious materials.

Dry mix combined materials and then add required water. Mix for at least 60 seconds with pan mixers and 120 seconds with drum mixers. If subsequently mixes have to be re-tempered, mix concrete for at least one minute after addition of water.

For clinker (ash) type aggregates of high water absorption charge mixer with aggregates. Add half to two-thirds of total mixing water and mix for 30 seconds. Then add cementitious materials and balance of mixing water and mix for at least 90 seconds.

Mixing duration should ensure thorough and intimate mixing of the mix ingredients. Excessively long mixing times, more than 15 minutes, affect the workability of the concrete adversely. The amount of water added to the mix depends on the workability required. This depends on how the concrete is to be compacted in the moulds.

5.4 Transporting

Transport the concrete from the mixer to the mould in such a way that it does not segregate. If segregation (separation of stone and cement paste) is unavoidable, remix the concrete before placing it in the mould. Protect the concrete from contamination and from drying out.

Distribute the concrete evenly in the mould. Do not place the concrete in one position and rely on the vibration to distribute it because this causes segregation.

5.5 Compaction and finishing

The concrete is to be compacted into the mould by any method that will ensure dense concrete.
Precast concrete is usually compacted by means of mechanical vibrators attached to the mould or by placing the mould on a vibrating table. Continue to vibrate the concrete until a water sheen appears on the surface and air bubbles no longer break through the surface.

Hand compacting, which should be used only for limited numbers of small items, may be done by: tamping the concrete with the end of a conveniently sized piece of timber or steel; jigging or jolting the mould; or a combination of tamping and jigging.

Use the edge of a screedboard (a planed wooden plank used on edge) which rests

on the top edges of the mould to strike off the concrete flush with the top of the mould. The concrete may be wood-floated if necessary.

Newly cast concrete must be protected from rain which could damage and soften the surface. It is also most important to protect the concrete against loss of moisture from the exposed surface. If moisture is lost the fresh concrete shrinks and this shrinkage can cause serious cracking. Possible ways of preventing moisture loss are:

- Work indoors or at least in shade,
- Place screens around the working area to keep out drying winds,
- Once the concrete has been compacted, struck off and floated, maintain a water sheen on the surface by fog spraying with water or cover with plastic sheeting.

Concrete must be protected until it sets and curing can start.

Precast items must be de-moulded carefully so as to avoid damage to the concrete. Once they are de-moulded, they should be stacked or supported in such a way that they do not warp or twist.

Finishes and decorative effects are basically achieved by either casting the concrete against a formed or sculptured mould surface or by the early-age working of the surface.

Working the surface while the concrete is in a green state might involve wood or steel trowelling, brooming, tooling, rubbing and carving, sprinkling special colour aggregates and compacting into the surface, or exposing the coarse aggregate by gently washing out the fines.

The concrete should be easily de-moulded. Either the moulds can be pulled apart and the product left in position or the moulds turned upside down to remove the product from the mould. The ease of de-moulding will depend on the mould oil used and the taper of the mould, usually 1 to 50 to 200 for steel moulds and less for plastic moulds.

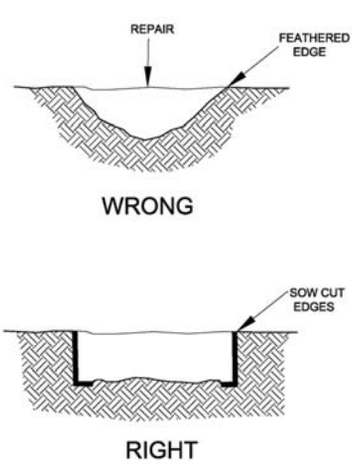
Any minor blemishes on the finished products such as small chipped edges and corners and blowholes (small voids of roughly spherical shape) should be repaired as soon as possible if the quality and value of the product warrants repair.

With the repair of blowholes no surface preparation is necessary. Use a mixture of one cement to two plaster sand, by volume, plus enough water to give a slurry consistency. Do not pre-wet the concrete and work the repair mix over the whole area with a sponge until holes are filled. Remove excess material with a wet sponge, spray surface lightly with a mist sprayer and cover immediately, with plastic sheeting. Keep covered for seven days and then allow to dry slowly.

With other repairs, ensure that feather edges are avoided. Where necessary, the outline of a repair should be cut with a masonry cutting disc or saw to ensure a square edge. (See Figure 2.)

Removes loose material and clean. Prime the surface with a slurry of equal volumes of cement and dry plaster sand with sufficient water to achieve a paint consistancy. Apply the mix one volume cement to two volumes sand, with sufficient water to be able to fully compact with a trowel. Finish surface with wood or steel trowels, sponges or brushes. Moist cure the repair for at least seven days.

Figure 2: Edges to repairs



5.6 Concrete mix proportions

5.6.1 General

The ingredients of concrete should be combined to give the required properties to the product at lowest cost, i.e. with the hardened concrete the product should have strength, durability and suitable appearance and in the fresh state workability and cohesiveness so the concrete can be 'cast' into moulds easily without segregation of the ingredients, and can easily be compacted.

Precast concrete requires a wet flowable mix, the concrete is compacted finished and left in the moulds for some time, hours or days before de-moulding. Precast products are prone to damage and breakages when they are de-moulded and when they are handled. Concrete should therefore have a relatively high strength, which should develop as rapidly as possible after casting.

Concrete for making masonry units, while having the same ingredients, has different mix proportions and workability because of different equipment being used and manufacturing techniques. As the units are extruded (pushed out) from the moulds after only 5 to 30 seconds in the moulds the concrete has to have sufficient 'green' strength so that the bricks or blocks will not, after extrusion, collapse or lose shape. This is achieved by using semi-dry concrete of low workability and aggregates and mix proportions that mechanically interlock. Strength is required for the units to be removed from the slab or pallet so they are not damaged in handling.

To determine the best mix proportions trial mixes are necessary. In the first instance, nominal mix proportions are used and then by a process of trial and error the mixes are adjusted to suit the particular product being made, the manufacturing equipment and the competence of the operator using the equipment. In assessing the best concrete mix the quality of the final product is the main criteria, while ease of manufacture at lowest cost must be considered.

Strength may be determined by testing the whole product or by making concrete cubes from the mix used and testing in a laboratory.

Durability suggests long-life maintenance-free concrete and is based on a service record of satisfactory performance. This is not necessarily known at the time of manufacture and therefore good sound and acceptable practices must be followed, e.g. clayey sands in the concrete should be avoided as drying shrinkage and the possibility of cracks and crazing occurring are likely. Also sands that require an excess of water when used in concrete should be avoided. Products should not crack easily when lifted or handled.

5.6.2 Trial mixes and manufacture: Precast concrete products

Trial mix proportions of cement, sand and stone are given in Table 1.

Table 1: Trial mix proportions by volume for concrete for precasting

	6,7 mm stone		9,5 mm stone		13,2 mm stone		19 mm stone	
	Large batch	Small batch	Large batch	Small batch	Large batch	Small batch	Large batch	Small batch
Cement	1 bag	1	1 bag	1	1 bag	1	1 bag	1
Sand	75 ℓ	2	75 ℓ	2	75 ℓ	2	75 ℓ	2
Stone	40 ℓ	1	50 ℓ	1 1/4	55 ℓ	1 1/2	75 ℓ	2

Table 2: Minimum concrete thickness for various stone sizes

Stone size, mm	6.7	9.5	13.2	19.0
Minimum concrete thickness, mm	30	40	50	60

Note: The largest size stone should be used for highest strength, or lowest cement content. The size of stone should not exceed about one quarter of the thickness of the concrete item being precast.

The following should be observed when adjusting the mix proportions:

- Use sufficient water in the mix to give a plastic mix that can be compacted with the means available,
- For small batches use the same size container for each material. For example, if the container volume is 6 ℓ the mix for 9,5 mm stone is:
  Cement: 6 ℓ
  Sand: 2 x 6 = 12 ℓ
  Stone: $1\frac{1}{4}$ x 6 = 7,5 ℓ
- Measure all materials by pouring loosely into the container and striking off flush with the brim,
- Measure sand in the damp state,
- Sand and stone content should be assessed as follows:
  - Make up a batch of concrete according to the proportions given in Table 1. Compact the concrete in the mould using the means available (i.e. mechanical vibration or hand stamping). Examine the top surface of the concrete. If stones protrude, the stone content of the mix is too high. If not, scrape the concrete with the point of a nail. If the stone content of the concrete is right, stone particles should be found about 2 mm below the surface. If the shallowest particles are deeper than this, the stone content is too low.
  - If stone content is too high, reduce it by say 10% and increase the sand content by the same amount (same overall volume), then reassess.
  - If stone content is too low, increase it by 10% and reduce the sand content by the same amount, then reassess.

5.6.3 Preparing the mould: Surfaces

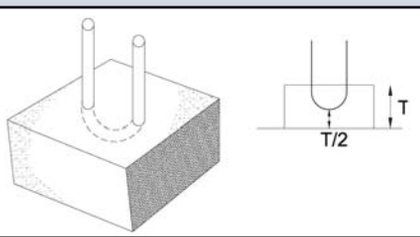
In the manufacturing process, attention should be given to:

- Surfaces of the mould that will come into contact with the concrete should be cleaned and then given a very thin coating of mould-release oil. (Rubber moulds do not normally require a release agent),
- mould-release oils are formulated specifically for concrete casting and are obtainable from oil companies and reputable manufacturers of concrete admixtures. The use of straight lubricating oil is not recommended.

5.6.4 Reinforcement and its fixing

If precast units are reinforced, the reinforcement should be kept in the correct position in the mould while the concrete is placed and compacted. Spacers of plastic or high-strength mortar may be used to support the steel and ensure that the minimum concrete cover is provided.

Figure 3: Details of mortar spacer block



Plastic spacers are commercially available from specialist suppliers.

Mortar spacer blocks may be made with a 1:1 ratio of cement and concrete sand and sufficient water to make a workable consistence. Details of a spacer block are shown in Figure 3. Cover the blocks to prevent drying out after casting and place them in

water the next day. Keep the blocks in water for at least a week before using them.

5.6.5 Trial mixes and manufacture concrete masonry units

The trial and error process for determining best mix proportions for concrete masonry unit manufacture requires a rigorous and thorough approach, otherwise false conclusions will result and mix proportions will be accepted and used that are not the best. Final decisions on aggregate blends and concrete mix proportions are based on observations, analysis of actual manufacture and the results of tests on the units made.

This involves the following steps and is influenced by the type of machine used, how it is operated and the units being made, bricks of blocks, hollow or solid:

- determining the best blend of aggregates,
- determining the aggregate to cement ratio,
- determining the optimum water content,
- a cost analysis.

The starting point is using a mix of 1:8 of 50 kg cement to four wheelbarrows aggregate.

If three materials are available: stone, river sand and pit sand, try the following blends tabulated in Table 3. If crusher sand is available and does not have an excess of very fine material (say dust) it may replace the river and pit sand blend.

Table 3: Trial mix proportions by volume for manufacturing bricks and blocks

Cement (50 kg bag)	Stone	River sand	Pit sand
	Wheelbarrows		
1		4	
1		3	1
1		2	2
1	1	2	1
1	2	1	1
1	1	1	2

If an existing mix has been used vary the aggregate blends; firstly to be coarser and then secondly to be finer than the existing mix by small changes in the various materials.

In all cases use as much water as possible in the mix so that the units don't lose shape on being extruded from the mould, or become too sticky (cohesive) because of clayey material in the sand.
Highest strengths of units occur when maximum water content is used. Often the surface texture of the unit will change from smooth and uniform with little water to a coarser texture with more water. The coarse texture units are normally stronger using the same aggregate blends.

If the surface texture is too coarse, increase the fines and reduce the coarse materials.

Besides noting the surface texture of the units observe how easily the concrete flows into the mould, particularly with hollow units where the shell width is normally between 25 and 35 mm.

With hollow units the maximum size stone is 6,7 mm but with solid units the stone size can be up to 19 mm. Generally mixes with large size stone are more economical in cement than mixes with small size stone for the same compressive strength. Also more stone and less sand are required in the mix with large size stone.

To determine the best cement to aggregate ratio for the masonry unit being made is to test the unit to destruction in a compressive strength test. If this is not possible, then observations have to be on all aspects in the manufacture and service performance of the unit on site to decide on cement to aggregate proportions noting any defects that occur such as chipped corners, edges and cracks.

If the best blend of available aggregates is unsatisfactory in making the required masonry unit, consider using admixtures. Further trial mixes are then necessary.

Once the aggregate blends and cement to aggregates ratios have been decided upon, then the optimum (best) moisture content should be determined. The water content depends on the materials, mix proportions, characteristics of the machine and how operated or how well concrete compacted into moulds by hand, the dimensions and configurations of the units being made. The mixer operator or machine operator should be trained to achieve the best water content consistently. A water sheen (glistens) on the external face of the unit immediately after extrusion is an indication that the water content is near optimum.

With 'wet' mixes using an egg-laying machine, difficulty is sometimes experienced in removing units the next day from the concrete slab. Usually a rough-textured concrete slab surface, say wood floated as distinct from steel trowelled will have less adhesion bond between unit and slab than a smooth textured surface.

A cost analysis based on the concrete mix proportions to be used in full-scale production, costed out in terms of material and production costs should be made.

In determining the yield of the mix, the mass of all ingredients divided by the average mass of the unit will determine the yield.

Often aggregate is delivered and priced by volume and aggregate is batched by mass. It is necessary to convert the unit cost into an appropriate unit cost, say cost per kg.

5.7 Curing

Concrete is cured by ensuring that there is sufficient moisture available and that the temperature is suitable for the chemical reaction (called hydration) between cement and water to occur. Concrete does not gain strength by drying out. If allowed to dry out soon after manufacture it will not gain its full strength. At low temperatures the chemical reaction takes place more slowly and products have to be left in their moulds for longer periods. At higher temperatures, the chemical reaction is more rapid but the quality of the mature product may be inferior.

Concrete products may be cured by immersing in water, or spraying continuously with water, or wetting the concrete and wrapping or covering with a plastic sheet. Curing should be continued for at least seven days in normal weather (20 °C to 25 °C) and longer at lower temperatures.

6. Material quantities for concrete

The quantities given in Tables 4 and 5 are approximate; they form a basis for a first estimate of quantities to be used in manufacture. Checks on quantities of materials used should be made as production progresses. The mix proportions in the tables are based on materials (sand and stone) being batched in a loose state, i.e. poured loosely into the batching container without being compacted. The volume of a 50 kg bag of cement when poured loosely into a container is approximately 38 to 40 ℓ. No allowance has been made for wastage.

Table 4: Material quantities for precast concrete (± 25 MPa at 28 days)

Material	6,7 mm stone		9,5 mm stone		13,2 mm stone		19,0 mm stone	
	Large batch	Small batch	Large batch	Small batch	Large batch	Small batch	Large batch	Small batch
	Quantities for 1 bag of cement in volume of damp bulked aggregates							
Cement	1 bag	1	1 bag	1	1 bag	1	1 bag	1
Sand	75 ℓ	2	75 ℓ	2	75 ℓ	2	75 ℓ	2
Stone	40 ℓ	1	50 ℓ	1.25	55 ℓ	1.5	75 ℓ	2
	Quantities for 1 cubic metre of concrete in volumes of damp bulked aggregates							
Cement, bag	10.0		9.5		9.2		8.4	
Sand, litre	750		710		695		625	
Stone, litre	400		475		510		625	
	Quantities for 1 cubic metre of concrete in mass (kg) of damp material							
Cement, kg	500		475		460		420	
Sand, kg	870		825		805		725	
Stone, kg	600		715		765		940	

Table 5: Material quantities for concrete masonry units

Mix proportions cement to aggregate approximate	Whole bag mixes (50 kg)							
	Cement-sand mixes			Concrete mixes (10 mm stone) per cubic metre of concrete				
	per batch	per cubic metre of mortar		per batch		per cubic metre of mortar		
	sand, ℓ/bag	cement, bags	sand, m^3	sand, ℓ/bag	stone, ℓ/bag 5h	cement, bags	sand, m^3	stone, m^3
1:4	150	8.8	1.35	120	50	8.1	1.0	0.4
1:5:25	200	7.3	1.35	150	60	6.5	1.0	0.4
1:6:50	250	5.8	1.35	200	80	5.0	1.0	0.4
1:8	300	4.8	1.35	240	90	4.2	1.0	0.4
1:10:50	400	3.5	1.35	310	130	3.2	1.0	0.4
1:11:75	450	3.1	1.35	360	140	2.8	1.0	0.4

Table 6 provides materials quantities and mass of single masonry units based on:

- Loose bulk densities, kg/m^3 – Sand 1400: Stone 1500
- Relative densities – Sand 2.65: Stone 2,65
- Bulking of sand – 20%

Table 6: Volume and masses for concrete masonry units

Work size of unit l x b x h	Solid units		Hollow units			
	Volume ℓ	Mass kg	No. of cores	Minimum shell thickness mm	Volume ℓ	Mass kg
Modular dimensions						
190 x 90 x 90	1.6	3.4	–	–	–	–
290 x 90 x 90	2.4	5.2	2	25	1.7	3.5
290 x 140 x 90	3.7	8.1	2	25	1.9	4.2
290 x 140 x 140	5.7	12.6	2	25	2.9	6.5
390 x 90 x 90	3.2	7.0	2	25	2.1	4.6
390 x 190 x 90	6.7	14.8	2	32	3.5	7.7
390 x 90 x 190	6.7	14.8	2	25	4.5	9.9
390 x 140 x 190	10.4	22.9	2	25	5.4	11.9
390 x 190 x 190	14.1	31.0	2	32	7.6	16.7
Imperial dimensions						
222 x 106 x 73	1.7	3.8	–	–	–	–
440 x 110 x 220	10.7	23.5	2	25	7.5	16.5
440 x 140 x 190	11.8	25.8	2	25	6.0	13.2
440 x 220 x 220	21.3	46.9	2	37	10.9	24.0

NOTE: Hollow unit (block) quantities are based on maximum core size and minimum shell thickness. Cores taper 3 mm in 190 mm and 1,5 mm in 90 mm. Webs taper in both directions. Solid units have no cores. The mass is based on using natural aggregates with a concrete density of 2 200 kg/m^3

7. Quality control checks on manufacturing process (schedule of checks)

Table 7 provides guidance on quality control checks which should be conducted in the manufacturing process. Figure 4 outlines some practical checks which can be conducted in the manufacture of concrete masonry units in the absence of laboratory equipment.

Table 7: Recommended quality control checks

Item	Property to be checked	Test	Frequency	Notes
1. Materials				
Cement	General quality	See notes	See notes	Check cement of right type and cement has an SABS mark on bag
	Contamination by moisture	Visual examination for lumps in cement	When contamination is suspected	Cement contamination occurs during transportation or storage. If lumps not broken by had, sieve out lumps and use a richer mix
	Age of cement at time of use	Compare delivery dates and date of proposed use	Test when cement is older than 3 months and cement is stored in bags	Ask cement manufacturer to test and advise. Loss of strength occurs with time
Aggregates	Quality as ordered and delivered	Appropriate tests (Maybe visual such as right size stone, clay or organic matter in sand, etc.)	When quality suspect	Initial acceptance criteria for aggregates vary and are unique for each manufacturer. More important is consistency of quality of aggregates in manufacture
Pigments	General quality	Manufacturer / Supplier to provide test certificate	At beginning of production and when changes noted	
Admixtures	General quality (check storage and shelf life not exceeded)	Obtain test certificates or quality statement on admixture by manufacturer/supplier	At beginning of production and when changes noted	BS 5075 Parts 1 and 3 details specification requirements
Water	Purity as it affects setting and strength of cement	Refer SANS 10100-2	When quality of water suspect	Municipal water needs to be checked
Reinforcement steel	General quality Contamination (free from loose mill scale and other coatings that will adversely affect bond)	Obtain manufacturers test certificate Visual check	At commencement of contract. Daily or at frequent intervals when rebar is being used	Refer SANS 190, 920 and 1024
2. Production				
Material acceptance				
Cement	Type of cement	Visual check of type, bags or delivery note. Bags not broken	When delivered	
Aggregates	Appearance	Visual check on type, cleanliness, contamination and segregation	When delivered	
	Sampling and preparation of test sample	SANS 195 SANS 197	When any testing done	Testing representative samples important for meaningful test results
	Grading (Sieve analysis) Relative density	SANS 201 SANS 5844	When changes noted that affect quality of product At beginning of contractor if geological type of aggregate changed	Compare grading with previously established grading limits. Information used in the design of mixes or calculations of yield of mixes based on voids in aggregates

Table 7: Recommended quality control checks – (continued)

Item	Property to be checked	Test	Frequency	Notes
2. Materials				
Material acceptance				
	Bulk density and voids content	SANS 5845	When changes noted or every 50 to 150 m^3	Information used in design of mixes or calculations of yield of mixes. Voids content used as a control check on quality of blended aggregates
	Bulking of sand	SANS 5856	When moisture content of sand changes significantly	Required for adjusting volumes of sand in batching
Pigments	Type	Visual check on containers and/or delivery note	When delivered	
Batching				
General	That correct materials and correct mix proportions used	Visual check materials. Check mix proportions	Daily and when new mix proportions specified	
Cement	By mass	With 50 kg bags no test required. Check load scale accuracy	Daily	A split bag of 25 kg parts can be measured by equal volumes
	By volume	Check container volume that allowance made for bulking	When container first used or when type of cement changed	Note: Different types of cement bulk differently. Volume batching of cement is poor practice
Aggregates	By mass	Check moisture content of sand and adjust mass	Daily	
	By volume	Check container size. Check allowance for bulking	When first used. When significant moisture changes occur	Establish by experiment a sand bulking versus moisture content curve for each sand.
Admixture	By volume	Check dispensing apparatus set correctly	When first used. Daily	
Pigments	By mass	Check correct mass	Daily	Normally pigments pre-weighed and placed in container for subsequent introduction into the mix
	By volume	Check container size	When first used	
Low density aggregates such as clinker	Soundness (pop-outs)	Refer to SANS 794 and SAN 1215	When pop-outs noted and then twice per month	Test required when clinker, ash and similar waste products used
	Sulphur trioxide	Refer to SANS 794	Once per month or when problems noted	
	Loss on ignition	Refer to SANS 794	Once per month or when problems noted	
Water addition	Water content	Visual assessment by operator of concrete workability and amount of water required	Each mix made	Various aids can be used by operator in visually judging water required, i.e. hand and bar tests
Reinforcement	Type, size and not contaminated	Measurement and visual examination	When used	Check dimensions if reinforcement bent, i.e. as in stirrups

Table 7: Recommended quality control checks – (continued)

Item	Property to be checked	Test	Frequency	Notes
2. Materials				
Mixing				
	Materials to be used	Visual check that all ingredients of correct type and mixer not overloaded	Daily	
	Uniformity of mix	Visual	Frequently	Particularly important with hand mixing
	Cleanliness of mixer	Visual	Daily or when break in mixing	With hand mixing ensure surface on which ingredients mixed is clean
	Adjustment of scrapers, etc. in mixer (if present) for wear and correct adjustment	By measurement	Daily	Important in pan mixers to prevent segregation of ingredients
	Order of introduction of mix ingredients	Visual	Daily	Order of batching to be determined by experience. Pre-mixing absorbent aggregates such as clinker with water to be considered
	Mix consistence	Visual	Each mix	If consistence viz workability, plasticity, etc. not correct immediately investigate reason
	Duration of mixing	Check time of mixing from time all water and cement are in contact, to discharge	Frequently	Minimum and maximum mixing times to be given to mixer operator
	Re-tempering	Visual	When mixing time extended, loss of workability and extra water added.	Operator to be advised on maximum amount of water that can be added
	Discharge	Visual to ensure complete discharge	After each mix	Ensure no build-up of mortar or concrete in the mixer
Precast concrete products (refer also to general comments)				
Mould	Correct type, dimensions, accuracy and undamaged	Visual and by measurement	At beginning of casting and afterwards at frequent intervals	Check moulds for wear and damage
	Preparation for casting	Visual	Frequently	Check use of mould release oil. Rubber moulds do not require a release agent
Reinforcement	Correct type, diameter and bending dimensions	Measurement	Frequently	Check against drawings
	Position in mould with correct cover	Measurement and check spacer blocks	Frequently	Refer drawings and specification
Concrete	Mix ingredients and proportions	Visual	At beginning of casting and frequently	Refer to section on materials and batching
	Batching, mixing, placing, compaction and finishing	Measurement and visual	At beginning of casting and frequently	Ensure concrete does not segregate in transporting and placing. Check best compaction techniques by hand, vibration immersion or mould, or jolting. Check finishing-trowelling hessian drag, sand or stone topping, etc.

Table 7: Recommended quality control checks – (continued)

Item	Property to be checked	Test	Frequency	Notes
2. Materials				
Concrete masonry units (refer also to general comments)				
Mould	Correct type, dimensions, accuracy and undamaged	Visual and by measurement	Regular checks on growth of unit sizes	Dimensional tolerances to SANS 1215
	Relationship between plan dimensions of moulds and tamper head	Visual and by measurement	When excessive amount of concrete extruded between tamper head and mould	Also applies to small machines hand operated
Machine operation	Functioning of machine	By observation of how equipment operates	When problems noted	With single block moulds ensure proper compaction of concrete in mould
	Distribution of concrete into mould box	Measure heights and mass of fresh units over total mould area	On introduction of new moulds, and/or concrete mix, at frequent intervals	Non-uniform distribution of concrete in moulds requires special attention
	Primary and secondary vibration	Check duration of vibration times	Frequent intervals	The degree of compaction of units by vibration significantly affects strength of units and productivity. With hand compaction ensure unit well tamped to required height
	Surface appearance on extrusion from mould that units not damaged or distorted	Visual	Frequently	Check presence of water sheen on face of unit, concrete sticking to tamper head on extrusion, uniformity of texture, colour and compaction
	Height of unit	By measurement	Frequently	Weighing unit at same time as height measured gives an assessment of the distribution of concrete in moulds and uniformity of compaction
Splitting of units to give a 'rock face'	Visual appearance	Visual together with compressive strength tests	When significant variations in surface texture noted	For consistent surface texture compressive strength of units should be in an agreed range
General comments: precast concrete and concrete masonry units				
Moulds, pallets and working area	Condition of moulds, pallets and concrete surface on which operations take place	Visual	Frequently	Maintain moulds and pallets. Keep working surfaces free from debris, etc.
Handling	Damage, if any, in de-moulding, or depalletising, transporting and stacking	Visual	Frequently	Products should be stored and stacked on hard, plane and unyielding surfaces which drain.
Curing	Protection of fresh products/ units and curing (duration and temperature)	Visual	Ongoing	Extent and types of curing to suit local requirements and products / units being made
Storage	Marking of stacks for subsequent identification, testing and clearance for delivery	Acceptance and control testing	Ongoing	Allow for products / units not complying with required standards to be stacked separately for subsequent management decision on their disposal
3. Testing				
Ideally all products made should be tested regularly for compliance with requirements such as strength, etc. and the production process monitored to ensure that products are not over or under strength, i.e. that the manufacturing process is not wasteful, viz. too much cement being used mainly or products condemned for say inadequate strength. There should be a continuous process of assessing the quality of products made and modifying the process to give best and most economical production. If testing is impractical or unaffordable, products should be continually assessed for dimensional accuracy, surface finishes and whether corners and edges damaged on de-moulding or when transported, stacked and delivered to site. Reports back from site on satisfactory or unsatisfactory performance of products in service can assist in assessing the quality of products.				

8. Employment potential of precast concrete operations

Table 8 provides some insights into the employment potential of precasting operations of a typical medium-sized manufacturer.

Figure 4: Simple site guides to quality in the manufacture of concrete masonry units

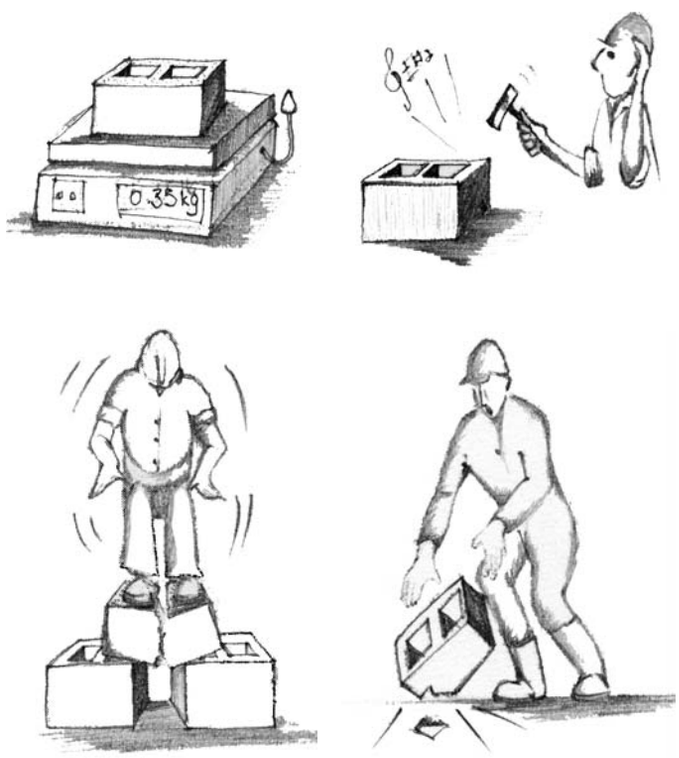


Table 8: Manufacture of precast concrete components (Watermeyer and Band, 1994)

OPERATION	ACTIVITIES	PERSONHOURS/ TON
Raw materials	Cement : production; transport to yard; pump into silo Aggregates : quarry operations; loading; transport	0,54
Mixing process	Boomscraper; weigh process; water supply	0,14
Casting of concrete	Cleaning of moulds : brushing; cleaning; carrying to cleaning area; mixing of oil; applying of oil to moulds; move to casting yard Mesh reinforcement : cutting, carrying; placing Casting and finishing : transport moulds; casting; vibrating; smoothing off Curing : cover moulds with canvas; placing of wet steamer; firing of boilers; steaming; filling of water tank; stacking Remoulding : loosen sides; strip mould; transport to stacking area; stacking; carry moulds to steaming area	4,02
Transport	Load on fork truck; drive to truck; load truck with labour; cover load with netting; transport to erection area/township; offload	1,77
Administration		0,66
Maintenance of moulds	Welding; repairing; straightening; inspecting	0,75
TOTAL		**7,82**

9. Specialist literature

MANUFACTURE OF CONCRETE MASONRY UNITS

SANS 1215: Concrete masonry units
Lane J W. The manufacture of concrete masonry units (available Cement and Concrete Institute)

MATERIALS OF MANUFACTURE

Cement

SANS 50197-1: 1996 Part 1. Common cement. Part 1. Cement – composition, specification and conformity criteria
SANS 50413-1: 1996 Masonry cements. Part 1. Specification.

Aggregates

SANS 794 Aggregates of low density
SANS 1083 Aggregates from natural sources – Aggregates for concrete
SANS 1090 Aggregates from natural sources – Fine aggregates for plaster and mortar
Cement and Concrete Institute Commentary on SANS 1083 – 1994. Aggregates from natural sources -Aggregates for concrete

USE OF MASONRY UNITS

Building regulations

National Building Regulations and Building Standards Act 1987 revised 1988
SANS 10400 – 1990 Application of the National Building Regulations
National Home Builders Registration Council's Home Building Manual, 1999
The Joint Structural Division of The South African Institution of Civil Engineering and The Institution of Structural Engineers.
Code of practice. Foundations and superstructures for single storey residential buildings of masonry construction. 1995.

STRUCTURAL DESIGN

SANS 10100:	Part 1	The structural use of concrete Part 1: Design
SANS 10160		The general procedures and loadings to be adopted for the design of buildings
SANS 10161 – 1980		The design of foundations for buildings
SANS 10164:	Part 1	The structural use of masonry Part 1 – unreinforced masonry walling
	Part 2	Part 2 – reinforced and prestressed masonry
SANS 1504		Prestressed concrete lintels
		The Joint Structural Division of The South African Institution of Civil Engineering and The Institution of Structural Engineers
		Checklist for structural design.
Crofts FS; Lane JW		Structural concrete masonry. A design guide, 2000.

CONCRETE MASONRY CONSTRUCTION

SANS 10145	Concrete masonry construction
SANS 10249	Masonry walling

MATERIALS OF CONSTRUCTION

Cement

SANS 50197-1 Part 1.	Common cement. Part 1. Cement – composition, specification and conformity criteria
SANS 50413-1	Masonry cements. Part 1. Specification.

Lime

SANS 523	Limes for use in building

Sand

SANS 1090	Aggregates from natural sources – Fine aggregate for plaster and mortar

Wall ties

SANS 28	Metal ties for cavity walls

Damp-proof courses

SANS 248	Bituminous damp-proof course
SANS 298	Mastic asphalt for damp-proofing courses and tanking
SANS 952	Polyolefin film for damp-proofing and waterproofing in buildings

REINFORCEMENT

SANS 190 – Part 2	Expanded metal. Part 2: Building products
SANS 920	Steel bars for concrete reinforcement
SANS 1024	Welded steel fabric for reinforcement of concrete

CONCRETE MANUFACTURERS ASSOCIATION PUBLICATIONS

DETAILING OF CONCRETE MASONRY:	Volume 1 Solid Units – 140
	Volume 2 Hollow Units – 140/190
	Volume 3 Cavity Wall – 240/290
FREE-STANDING WALLS	Design guide
	Technical Note: Unreinforced/Reinforced
LINTELS	Design guide
	Technical note

BUILDING YOUR HOUSE – STEP BY STEP – WITH BUILDING PLANS

ANNEX A: List of Material and Equipment Suppliers/Manufacturers

ITEM	SUPPLIER/MANUFACTURER AND TELEPHONE AND FAX NUMBERS	NOTES
ADMIXTURES	ASH RESOURCES (PTY) LTD Tel: (011) 886 6200 Fax: (011) 886 6140	
	CEMCRETE (PTY) LTD Tel: (011) 474 2415 Fax: (011) 474 2415	
	CEMENTATION CHEMICALS Tel: (011) 868 1139 Fax: (011) 868 3766	
	CHRYSO SOUTHERN AFRICA (PTY) LTD Tel: (011) 892 5726 Fax: (011) 892 5723	
	DGN MANUFACTURING Tel: (033) 344 3790 Fax: (033) 344 3790	
	DRIKON (PTY) LTD Tel: (011) 452 6890 Fax: (011) 452 7161	
	SAMSON CONSTRUCTION PRODUCTS (PTY) LTD Tel: (011) 455 5104 Fax: (011) 455 6632	
BATCHING PLANT	BIRKENMAYER (PTY) LTD Tel: (011) 970 3880 Fax: (011) 394 1681	
	CHAMBERLAIN TRADING FH (PTY) LTD Tel: (012) 329 0729 Fax: (012) 329 0740	
	DENITH ENGINEERING (PTY) LTD Tel: (012) 418 3690 Fax: (012) 419 7678	
	IAN DICKIE & CO (PTY) LTD Tel: (021) 534 3431 Fax: (021) 534 3440	
	PAN MIXERS SA (PTY) LTD Tel: (011) 397 3754 Fax: (011) 397 4721	
	PLANT TECHNOLOGY CC INCORPORATING RACKLIFT INT Tel: (011) 869 8111 Fax: (011) 869 8196	
	TURNER MORRIS (PTY) LTD Tel: (011) 618 2620 Fax: (011) 618 4313	
	VRN STEEL (PTY) LTD Tel: (011) 861 5200 Fax: (011) 861 5353	
BLOCK AND BRICK MAKING MACHINERY	CONCRETE PUMPS CC Tel: (031) 303 1397 Fax: (031) 312 0294	
	DEMS (PTY) LTD Tel: (031) 579 9300 Fax: (031) 579 5139	

ITEM	SUPPLIER/MANUFACTURER AND TELEPHONE AND FAX NUMBERS	NOTES
BLOCK AND BRICK MAKING MACHINERY	EHRENBERG ENGINEERING (PTY) LTD Tel: (011) 493 6280 Fax: (011) 493 1677	
	JACKSON INSTRUMENTS Tel: (031) 208 6656 Fax: (031) 208 6656	
	OELSCHLAEGER & PARTNERS PW (PTY) LTD Tel: (011) 396 2600 Fax: (011) 396 1412	
	PAN MIXERS SA (PTY) LTD Tel: (011) 397 3754 Fax: (011) 397 4721	
	PINETOWN MACHINE MANUFACTURERS CC Tel: (031) 701 3132 Fax: (031) 702 7820	
	Reef Construction Machinery Company (Pty) Ltd Tel: (011) 397 3754 Fax: (011) 397 4721	
CEMENT	ALPHA Tel: (011) 670 5500 Fax: (011) 670 5793	
	LAFARGE Tel: (011) 474 1323 Fax: (011) 474 3110	
	NATAL PORTLAND CEMENT Tel: (031) 450 4433 Fax: (031) 465 1774	
	PPC Tel: (011) 488 1700 Fax: (011) 726 3537	
CURING COMPOUNDS	CHRYSO SOUTHERN AFRICA (PTY) LTD Tel: (011) 892 5726 Fax: (011) 892 5723	
	CORROLEC CC Tel: (011) 465 1807 Fax: (011) 467 0458	
	CORROSION CONTROL CENTRE INTERNATIONAL CC Tel: (012) 664 1551 Fax: (012) 664 0319	
	HALL'S ADHESIVE & CHEMICALS Tel: (0333) 94 3976 Fax: (0333) 94 6075	
	JOJUN PAINTS SA (PTY) LTD Tel: (031) 709 0161 Fax: (031) 709 0166	
	SHAKA (PTY) LTD Tel: (011) 452 6890 Fax: (011) 452 7161	
	SPECIALISED SURFACE COATINGS (PTY) LTD Tel: (011) 680 1156 Fax: (011) 680 7781	

ITEM	SUPPLIER/MANUFACTURER AND TELEPHONE AND FAX NUMBERS	NOTES
MIXERS	CONDRA (PTY) LTD Tel: (011) 873 9800 Fax: (011) 873 9807	
	BABCOCK PLANT & EQUIPMENT Tel: (011) 826 6511 Fax: (011) 823 2030	
	BIRKENMAYER H (PTY) LTD Tel: (011) 970 3880 Fax: (011) 394 1681	
	BUILD PLUMB & TILE RANDBURG CC Tel: (011) 886 0734 Fax: (011) 789 6856	
	BUILDEQUIP HIRE & SALES (PTY) LTD Tel: (021) 948 8127 Fax: (021) 949 7400	
	BUILMACHINES CC Tel: (021) 981 6040 Fax: (021) 981 7120	
	CHAMBERLAIN TRADING FH (PTY) LTD Tel: (012) 329 0729 Fax: (012) 329 0740	
	CORPGRO INDUSTRIAL & BUILDING SUPPLIES (PTY) LTD Tel: (011) 315 7553 Fax: (011) 315 7589	
	DEMS (PTY) LTD Tel: (031) 579 9300 Fax: (031) 579 5139	
	FORMSCAFF (PTY) LTD (CHLOORKOP) Tel: (011) 393 4400 Fax: (011) 976 2037	
	GENQUIP CC Tel: (031) 569 2133 Fax: (031) 569 2136	
	JAYTRADE CC Tel: (021) 706 0002 Fax: (021) 706 0005	
	LIBRA-PLANT SALES & SERVICES (PTY) LTD Tel: (011) 392 6245 Fax: (011) 392 6249	
	LIEBHERR-AFRICA (PTY) LTD Tel: (011) 365 2000 Fax: (011) 817 3884	
	MACHINERY MART Tel: (031) 301 7069 Fax: (031) 301 0633	
	MALVON EQUIPMENT (CAPE) CC Tel: (021) 948 5731 Fax: (021) 945 1739	
	OELSCHLAEGER & PARTNERS PW (PTY) LTD Tel: (011) 396 2600 Fax: (011) 396 1412	
	PAN MIXERS SA (PTY) LTD Tel: (011) 397 3754 Fax: (011) 397 4721	

ITEM	SUPPLIER/MANUFACTURER AND TELEPHONE AND FAX NUMBERS	NOTES
MIXERS	PROF (PTY) LTD Tel: (011) 864 4773 Fax: (011) 864 3321	
	REEF CONSTRUCTION MACHINERY COMPANY (PTY) LTD Tel: (011) 397 3754 Fax: (011)397 4721	
	TURNER MORRIS (PTY) LTD Tel: (011) 618 2620 Fax: (011) 618 4313	
	VIBRATE SALES & SERVICES CC Tel: (011) 493 6254 Fax: (011) 493 6049	
MOULDS	DGN MANUFACTURING Tel: (033) 344 3790	
	HAWK ENGINEERING Tel: (012) 541 2660/6 Fax: (012) 541 2667	
	OLD WORLD CONCRETES (PTY) LTD Tel: (011) 626 2510 Fax: (011) 626 2209	
	PENTA CC Tel: (021) 697 4223 Fax: (021) 697 4226	
	POLYNATES (PTY) LTD Tel: (021) 691 1438 Fax: (021) 692 2891	
	PRO STEEL CONSTRUCTION CC Tel: (021) 981 4530 Fax: (021) 981 2385	
	ROEJAY EQUIPMENT & ENGINEERING Tel: (011) 442 6912 Fax: (011 788 7827	
	RUTEC Tel: (011) 402 3245 Fax: (011) 402 3246	
	TRANSVAAL RUBBER COMPANY Tel: (011) 839 2370 Fax: (011) 830 1629	
	TRIANGLE FIBREGLASS & CONSTRUCTION Tel: (016) 451 3051 Fax: (016) 451 1700	
MOULD RELEASE AGENTS	AA BALL ENGINEERING SUPPLIES (PTY) LTD Tel: (021) 425 1950 Fax: (021) 425 1489	
	ADVANCED MATERIALS TECHNOLOGY (PTY) LTD Tel: (011) 392 4232 Fax: (011) 974 4198	
	AMT DURBAN Tel: (031) 201 1319 Fax: (031) 201 2803	
MOULD RELEASE AGENTS	CHESTERTON INTERNATIONAL INCORPORATED Tel: (021) 790 6364 Fax: (021) 790 6365	

ITEM	SUPPLIER/MANUFACTURER AND TELEPHONE AND FAX NUMBERS	NOTES
MOULD RELEASE AGENTS	HA FALCHEM (SA) (PTY) LTD Tel: (011) 864 4608 Fax: (011) 864 3174	
	NFC DISTRIBUTORS (PTY) LTD Tel: (017) 647 5941 Fax: (017) 647 5330	
	REAC POLYURETHANE TECHNOLOGIES (PTY) LTD Tel: (011) 609 3013 Fax: (011) 609 3018	
	SPRANG TOOL (PTY) LTD Tel: (011) 618 3600 Fax: (011) 614 9610	
	KLUBER LUBRICATION (PTY) LTD Tel: (011) 908 2457 Fax: (011) 864 7373	
	DGN MANUFACTURING Tel: (033) 344 3790 Fax: (033) 344 3790	
	FUCHS LUBRICANTS (SOUTH AFRICA) (PTY) LTD Tel: (011) 392 5410 Fax: (011) 392 5686	
	GREEN TRADING INTERNATIONAL CC Tel: (031) 466 4106 Fax: (031) 466 4675	
	QUICKOUT TRACKING SERVICES CC Tel: (031) 301 5110 Fax: (031) 301 5110	
	ROCKFORD DEVELOPMENTS CC Tel: (012) 667 4963 Fax: (012) 667 4963	
	SPECIAL PRODUCTS Tel: (021) 854 4808 Fax: (021) 853 2366	
	PYROTEK ENGINEERING MATERIALS (PTY) LTD Tel: (035) 797 4039 Fax: (035) 797 4045	
	STEVECO (PTY) LTD Tel: (011) 334 1230 Fax: (011) 334 0548	
PIGMENTS	BAYER SA (PTY) LTD Tel: (011) 921 5238 Fax: (011) 921 5128	
	ROLFES COLOUR PIGMENTS INT. Tel: (011) 874 0600 Fax: (011) 874 0787	
	CONCOR TECHNICRETE Tel: (011) 316 2341 Fax: (011) 316 3397	
REINFORCING WELDED MESH	ALERT STEEL (PTY) LTD Tel: (012) 800 1145 Fax: (012) 800 4017	
	BRAVO STEEL CC Tel: (012) 250 2196 Fax: (012) 250 2765	

ITEM	SUPPLIER/MANUFACTURER AND TELEPHONE AND FAX NUMBERS	NOTES
REINFORCING WELDED MESH	BRC MESH REINFORCING (PTY) LTD Tel: (016) 421 3520 Fax: (016) 421 3915	
	GENERAL STEEL Tel: (011) 614 6625 Fax: (011) 614 9112	
	HENDOK (PTY) LTD Tel: (031) 507 6731 Fax: (031) 500 4353	
	NATIONAL TRADING COMPANY (PTY) LTD Tel: (011) 821 5200 Fax: (011) 824 3039	
	NFC DISTRIBUTORS (PTY) LTD Tel: (017) 647 5941 Fax: (017) 647 5330	
	NORTH-WEST STEEL & CEMENT CC Tel: (014) 596 6193 Fax: (014) 596 6323	
	POLYMESH (PTY) LTD Tel: (011) 817 1402 Fax: (011) 817 1846	
	REINFORCING & ALLIED INDUSTRIES FREE STATE Tel: (051) 435 2885 Fax: (051) 435 3833	
	REINFORCING STEEL HOLDINGS (PTY) LTD Tel: (011) 316 1035 Fax: (011) 316 4072	
	STEEL STRAIGHTENERS (PTY) LTD Tel: (011) 825 1690 Fax: (011) 873 2012	
	STEELEDALE MESH Tel: (011) 401 6300 Fax: (011) 613 3452	
	STEELMATE (PTY) LTD Tel: (011) 894 7094 Fax: (011) 918 2836	
	STOCON REINFORCING (PTY) LTD Tel: (011) 316 2227 Fax: (011) 316 1555	
	WB INDUSTRIAL SUPPLIERS CC Tel: (031) 465 4561 Fax: (031) 465 5974	
	WIREFORCE STEELBAR (PTY) LTD Tel: (011) 873 1144 Fax: (011) 873 9795	
	REINFORCING & ALLIED INDUSTRIES FREE STATE Tel: (051) 435 2885 Fax: (051) 435 3833	
	REINFORCING STEEL HOLDINGS (PTY) LTD Tel: (011) 316 1035 Fax: (011) 316 4072	
	SRICK PARADISE Tel: (011) 465 2069 Fax; (011) 465 2069	
	MERCO INDUSTRIES (PTY) LTD Tel: (011) 760 4094 Fax: (011) 760 4173	
	VAAL STEAM SUPPLIES (PTY) LTD Tel: (016) 421 1278 Fax: (016) 421 1593	

ANNEX B: Details of some precast concrete products that can be made by a small-scale manufacturer

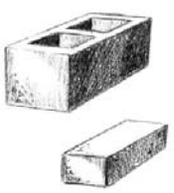
NOTE: Concrete having a strength (compressive) of 25 MPa should be used for making all units including paving blocks except for blocks and bricks.

Bird bath and stand

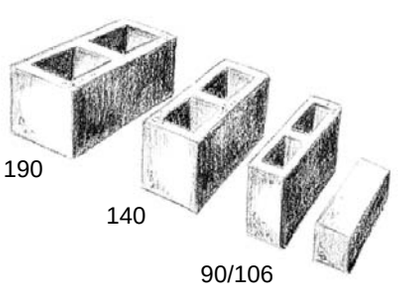
Size and shape determined by demand.

Blocks

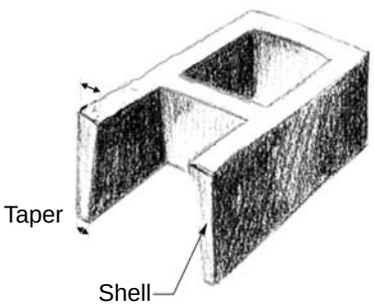
Blocks can be solid or hollow



Blocks normally are big and require two hands to lay. Length between 300 and 650mm, width between 130 and 300 mm, height between 120 and 300 mm. Normal thicknesses of wall specified are 90, 110, 140 and 190 for single leaf walls and 230 (90-50-90) or 270 (110-50-11-) for cavity walls. 140 mm thick walls are most popular for external walls of houses. Normal lengths of 140 mm units are 190, 220, 290 and 390 and heights 140 and 190 mm.



In the marketplace, there is a proliferation of sizes. Normally the minimum shell thickness of 90 and 140 mm blocks is 25 mm and for 190 mm blocks 33 mm. Normally, in practice the shell thickness is 2 to 5 mm thicker. The volume of the cores of hollow blocks should be between 25 and 60%. The minimum compressive strength for hollow and solid blocks is 3,0 MPa respectively for single storey houses but higher strength required for most other uses.

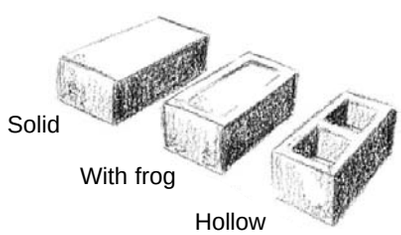


Bricks

Bricks can be solid (with or without a frog) or hollow.

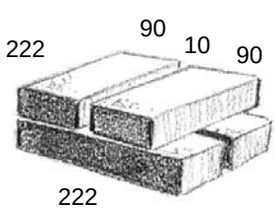
Bricks normally require one hand to lay. A brick must comply with all three of the following dimensional requirements:

length < 300 mm
width < 130 mm
height < 120 mm



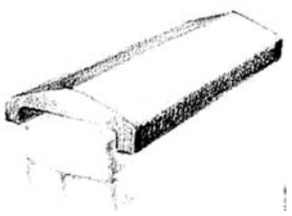
The old imperial brick size was 222 x 106 x 73 mm and the modular size brick is 190 x 90 x 90 mm. (Note: specified wall thickness is 90 and 110 mm. A 140 mm thick single leaf wall uses units for 140 mm which is a block size). In the market place, non-modular and non-imperial brick sizes are made such as 222 x 90 x 73 or 114 mm.

These units do not bond well in say brick piers or English or Flemish bond. They deviate from the basic principle that the length of a unit should be twice the width, plus the thickness of the joint, i.e. 222 = 2 x 106 + 10 but 222 π 2 x 90 + 10 (190). The minimum compressive strength for hollow and solid bricks is 3,0 and 4,0 MPa respectively.



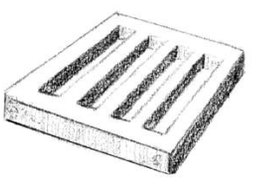
Capping or coping blocks

Capping or coping blocks are used to protect and give an attractive finish to say boundary walls.



Drainage elements

Size and shape determined by demand. Gratings and outlets are popular elements.



Fence posts

Size and shape determined by demand.

Flower bed edging

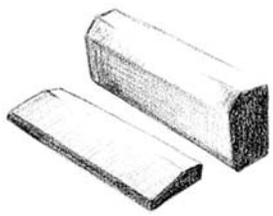
A typical type of edging is shown in the sketches.

Flower pots

Flower pots can be precast in all sorts of shapes and sizes.

Kerbs, channels and edging

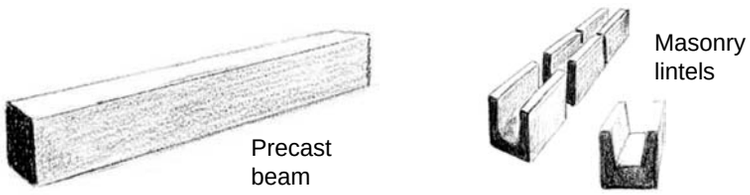
The sections of kerbs and channels shown are those in normal use. The length of each product does not exceed one metre but ease of handling will determine maximum length.



Lintels

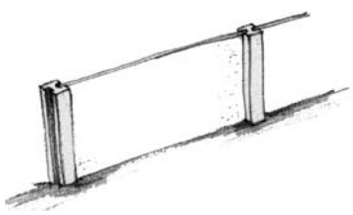
Lintels are required to span openings in walls such as windows, doors, etc. The length of pre-cast concrete lintels depends not only on the size of opening but on the ease of manufacture, handling and placing in position.

Lintels may be constructed either of a single reinforced precast concrete beam (a) or by masonry lintel blocks.



The amount of reinforcement depends on the loading, span of lintel and depth (normally related to brick and block heights).

Post and panel fences

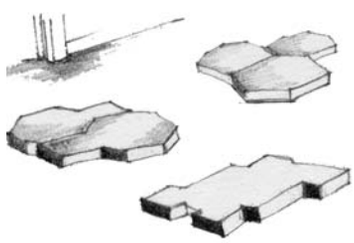


A post and panel fence consists of precast concrete posts recessed to accept precast concrete panels.

Paving blocks

Concrete block pavers can be made in a variety of shapes and sizes. Normally their plan dimensions are small so they can be laid by one hand with maximum lengths and widths of 300 and 150 mm respectively though in the market place the dimensions are around 200 and 100 mm respectively. Typical thicknesses are 50, 60 and 80 mm.

Some block shapes are patented and a check should be made with the mould manufacturer. With large sophisticated machines concrete pavers are made with semi-dry mixes. For small operators, casting into moulds to obtain the 25 MPa minimum strength is recommended.

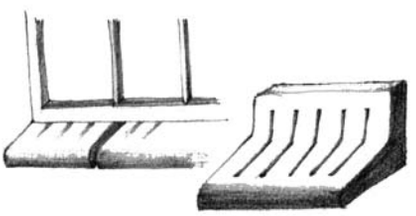


Paving slabs

Paving slabs are bigger than block pavers with dimensions up to 500 x 500 x 60 mm and are usually of square plan though sometimes rectangular and hexagon in shape.

Sculptures

Normally these are cast in rubber moulds to permit ease of de-moulding. Various mould shapes are available from suppliers though moulds can be made form positives.



Sills

Sills can be pre-cast concrete or of masonry construction, dimensions to suit the coursing of the masonry.

Sources of information and references to standards:

Sources of information on precast concrete and concrete masonry units.

Aggregate suppliers:

Alpha	Tel: (011) 670 5500 Fax: (011) 670 5793
Lafarge	Tel: (011) 474 1323 Fax: (011) 474 3110
Boutek	Tel: (012) 481 2911 Fax: (012) 481 2834
Cement and Concrete Institute	Tel: (011) 315 0300 Fax: (011) 315 0584
Concrete Manufacturers Association	Tel: (011) 805 6742 Fax: (011) 315 4683

Cement Companies

- Alpha	Tel: (011) 670 5000 Fax: (011) 670 5793
- Lafarge	Tel: (011) 474 1323 Fax: (011) 474 3110
- Natal Portland Cement	Tel: (031) 450 4433 Fax: (031) 465 1774
- PPC	Tel: (011) 488 1700 Fax: (011) 726 3537
- NHBRC	Tel: (011) 348 5715 Fax: (011) 285 4111
- Standards South Africa	Tel: (012) 428 7911 Fax: (012) 344 1568

ANNEX C: Notes on the design and construction of the concrete slab on which an egg-laying machine operates.

The minimum thickness of slab is 125 mm. However, in the case of employing a small machine, a thickness of 100 mm could be adequate. Large machines operating with intense vibration may require a thickness of 150 mm to 200 mm. Use mix proportions in accordance with the provisions of Table D1.

Table D1: Concrete mix proportions for production slab

Size of stone, mm	Proportions by volume*			Quantities per cubic metre of concrete		
	Cement	Sand	Stone	Cement,** bags	Sand, m^3	Stone, m^3
19.0 or 26.5	1 1 bag	2 75 ℓ	2 75 ℓ	8.7	0.7	0.7
13.2	1 1 bag	2 75 ℓ	1 1/3 55 ℓ	10	0.8	0.8

* Loose, uncompacted state except for cement in bags

** Complying with SANS 50197-1 CEM1 or CEMII A

The amount of water is not given in the table because it depends on the materials used. Use enough water to make a workable mix that can be properly compacted.

For concrete ordered from a ready-mix supplier or contractor, specify a strength of 30 MPa at 28 days and 19 mm stone. Slump should be 75 mm if the concrete is to be compacted by mechanical vibration and 125 mm for hand compaction. A wood-floated finish permits easier removal of blocks.

To prevent uncontrolled cracking of the slab, it should be divided into panels which should be square or as close to square as possible. A construction joint is shown in Figure D1. The halfround key prevents differential settlement of adjacent slabs.

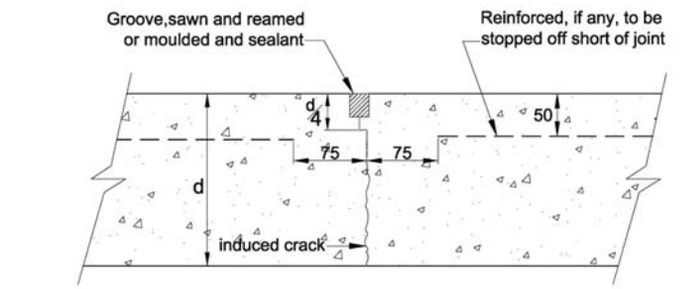
The maximum joint spacing depends on the thickness of the slab and should not exceed 3,0, 4,5 and 6 m for slab thicknesses of 100 mm, 125 mm, 150 mm and 200 mm respectively.

It is not necessary to reinforce the panels with steel rods or mesh.

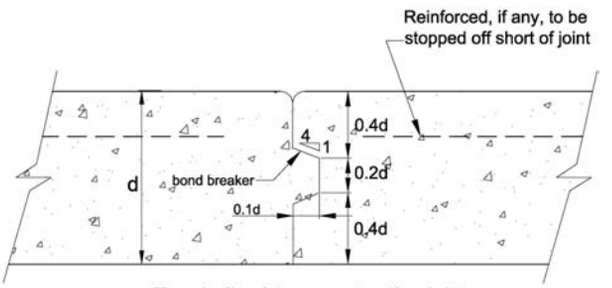
An area big enough to stack two weeks' production is needed for curing and drying blocks.

It is normally not necessary to pave this area. To avoid muddy conditions, a layer of concrete stone, about 100 mm thick, should be enough.

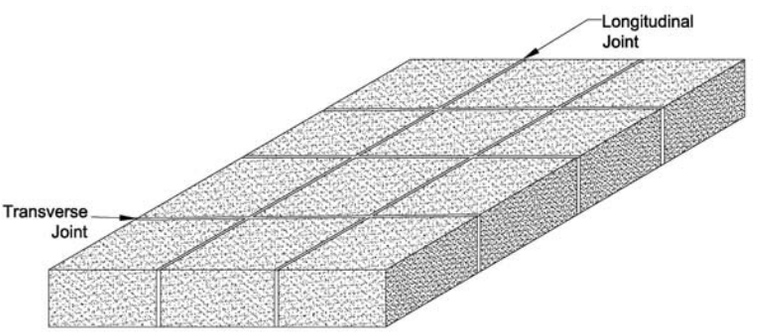
Figure D1: Construction joint



Sawn (weakened plane) contraction joint



Toggle (key) type contraction joint



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Best Practice Guideline – Part 3-2

The BESA building system

cidb
development through partnership

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A cidb guide to best practice

1ST Edition of CIDB document 1025
March 2005

Best Practice Guideline – Part 3-2

The BESA building system

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ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

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1. Introduction

The BESA Building System is a walling system comprising bitumen emulsion stabilised adobe blocks and mortar (see Figure 1) which may be used for single storey houses, schools, clinics and offices. These 200 mm thick walls incorporate a composite concrete and block ring beam that:

- stabilises the wall,
- provides an anchorage for roofs,
- spans window and door openings.

Where the horizontal span of the wall exceeds that commonly associated with houses, the walls are reinforced at regular intervals with brickforce reinforcement and incorporate full height cast in situ reinforced concrete columns and ring beams that together stabilise the structure.

External and internal wall surfaces can be finished in a variety of ways using a mortar mix or a cement/sand plaster. All other aspects of construction are conventional and utilize conventional building materials.

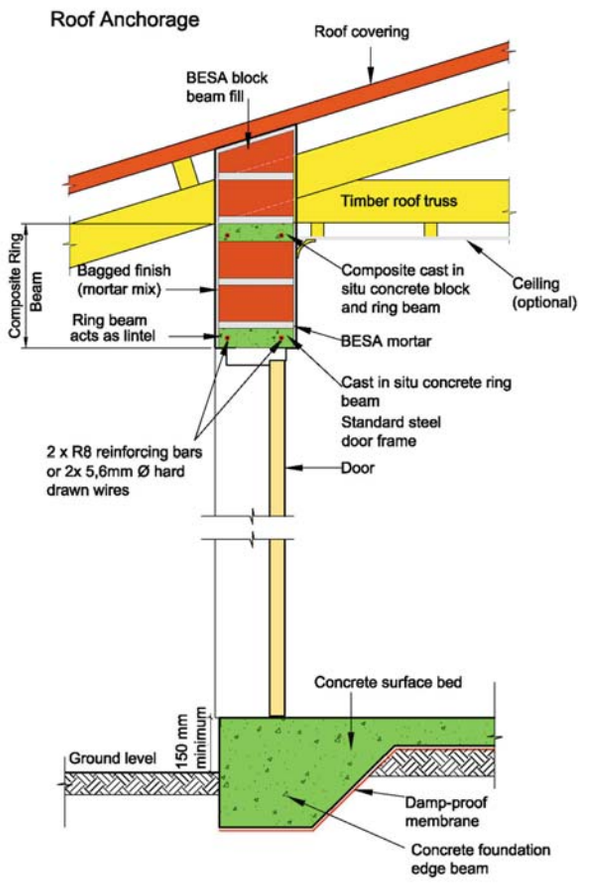
2. Satisfying legislative requirements

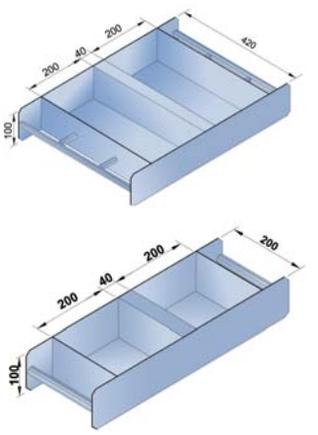
Building systems must satisfy the requirements of the National Building Regulations and, in the case of contractor-built houses, the technical requirements of the National Home Builders Registration Council. These requirements are both framed in terms of performance and can be satisfied by constructing elements and components in accordance with one or more of the following:

- a set of deemed-to-satisfy design and construction rules,
- the requirements of a suitably qualified person,
- the requirements of an Agrément certificate.

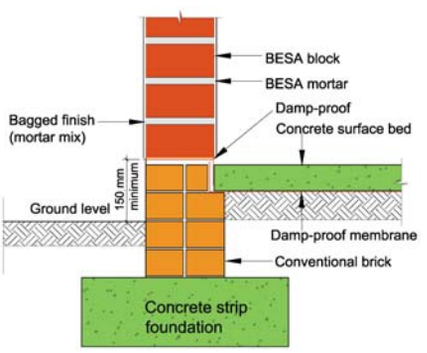
The BESA system is not covered by the deemed-to-satisfy rules provided in SANS 10400 (The application of National Building Regulations) or the NHBRC's Home Building Manual. It also cannot be rationally designed with confidence by a suitably qualified person as its material properties are relatively unknown. It can only satisfy requirements if it is the subject of an Agrément Certificate (i.e. a certificate confirming fitness-for-purpose of a non-standardised product, material or component and/or the acceptability of the related non-standardised design and the conditions pertaining thereto) issued by Agrément South Africa in terms of the powers granted to it by the Minister of Public Works.

Figure 1: Elements of the BESA system





Moulds for the manufacture of BESA Blocks



Alternative footing detail

The BESA Building System is the subject of open certificates issued by Agrèment South Africa. The concept of an open certificate is that the technology is not intellectual property of any company or individual and the information is available to anyone who wishes to use it.

Agrément Open Certificate OC-1/2001 (The BESA Building System) covers the use of the BESA system for the erection of single storey houses in all parts of South Africa for the uses (occupancy classes (SANS 10400-A; Table 1 of Regulations A(20)(1)) set out below:

- H4 Dwelling houses (detached houses and related outbuildings)
- H3 Domestic residences (semi-detached houses, row houses and related outbuildings)

Agrément Open Certificate OC-2/2003 (The BESA 2 Building System (Schools, clinic and offices) covers the use of the BESA system for the erection of single storey buildings in all parts of South Africa for the uses set out below:

- A3 Places of instruction
- G1 Offices and clinics

These certificates and Agrément South Africa's assessment applies only to BESA buildings that are designed, manufactured and erected as described and illustrated in the afore-mentioned certificates, and where the terms and conditions of certification are applied.

Who may apply?

Any competent person, company or institution who wishes to use this system to build houses, schools, clinics or offices, that comply with the National Building Regulations, or is capable of carrying out this work in accordance with the terms and conditions of certification and undertakes to do so, may apply to Agrément South Africa to be registered as a holder of these open certificates.

3. The manufacture of BESA blocks

Block manufacture

- Mix selected earth, bitumen emulsion and polypropylene fibres with water.
- Place this mix in rectangular open moulds of the requisite size.
- Remove the moulds from the blocks.
- Stack the blocks when they are sufficiently cured to be moved without distorting.
- Allow the blocks to dry and shrink naturally.

Access to sufficient quantities of suitable soil is a prerequisite to the use of the BESA Building System. It is therefore essential that a preliminary assessment is undertaken to determine the suitability of the earth that is available on the site and where borrow pits may be located. Soil that is suitable for the manufacture of BESA blocks is predominantly a sandy soil with a maximum aggregate size of 10 mm and a fines content that is preferably between 20% and 60%. Almost any well-graded soil that has the correct particle shape is worth testing in a laboratory.

The earth and other materials are normally mixed on site in a pan mixer. Moulds may be made from steel or wood and are cleaned and oiled as necessary to ensure the efficient production of accurately sized blocks. (See Figure 1.) The block mix is thrown into the moulds by hand or with a shovel. A degree of compaction is achieved by pressing the mix into the corners of the mould by hand and working the mix to remove excess air. The top surface is smoothed off with a straight edge, and a suitable mark to identify the batch is scratched or pressed into the upper surface of the wet block. The mould is then removed by lifting it straight up.

After demoulding, the blocks are left undisturbed until they are firm enough to be turned on edge without distorting. After an initial 24 hours the blocks may be exposed to full sun to encourage the curing process (in this case the drying process). If manufactured in the open air, the blocks are protected from rain until at least a week old. When sufficiently strong, the blocks are carried to a stockpile and stacked on edge with spaces between them to allow air circulation. No blocks are used until they are properly dry and at least four weeks old. This period may be extended if the drying process was delayed by cold or wet weather.

Blocks must be manufactured strictly in accordance with the provisions of Agrément South Africa's Guideline 1, The Manufacture of BESA Blocks which establishes requirements in respect of the following:

a) Materials
   - i) Earth (particle shape, soluble salt content, shrinkage product and grading)
   - ii) Water
   - iii) Bitumen emulsion
   - iv) Polypropylene fibres

b) The mix
   - i) Bitumen emulsion content
   - ii) Water content
   - iii) Typical mix for test blocks

c) The test blocks
   - i) Tests
   - ii) Acceptance criteria for BESA test blocks

d) Tests for blocks selected from production runs
   - i) Earth brick drop test
   - ii) Weight test
   - iii) Water absorption test

4. Design and erection

4.1 Design of houses and related outbuildings

The design and erection requirements are established in Agrément Open Certificate OC-1/2001 (The BESA Building System). Supporting walls are required wherever the panel length exceeds:

- 6,0 metres in general, or
- 7,5 metres where walls support tiled roofs.

Wall heights at eaves are not to exceed 2,6 metres (3,6 metres at gable wall apex). Control joints need to be provided at centres not exceeding 9,0 metres. Roof spans are not to exceed 6,0 metres.

Designs are also provided for rondavels having a diameter not exceeding 7,0 metres.

4.2 Design of schools, clinics, offices and related buildings

The design and erection requirements are established in Agrément Open Certificate OC-2/2003 (The BESA 2 Building System - schools, clinics and offices. The maximum length of wall panels between columns is 3,5 metres.

Wall heights are not to exceed 3,0 metres (4,5 at gable end). Control joints need to be provided at centres not exceeding 9,5 metres. Roof spans are not to exceed 7,5 metres in respect of tiled roofs. (No requirement in respect of sheeted roofs.)

4.3 Design of foundations for schools, clinics, offices, houses and related buildings

Foundation designs are based on residential site class designations of H, C, S or R in accordance with the provisions of the Joint Structural Division of SAICE/ IStructE Code of Practice for Foundations and Superstructures for Single Storey Residential Buildings of Masonry Construction.

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Best Practice Guideline – Part 4-1
Labour-based open channel flow technology

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1. Introduction

Stormwater drainage to overcome flooding was introduced to minimise the inconvenience and disruption of activity caused by the run-off from frequent or minor storms. It is also provided to minimise the danger to life and property by control of run-off from infrequent or major storms. This concept can be achieved by the use of two separate but inter-related systems: the minor and major drainage systems.

The minor system forms the conventional urban drainage system that collects run-off from storms of up to 10-year return periods. As the minor system is designed in conjunction with a major system, less reliance need be placed on its function and it can be designed for smaller storms, thus saving on construction costs. The design of the major system requires working with nature to provide an orderly drainage system for major flood run-off. It consists of water carrying routes that include natural watercourses, streets and servitudes. The major system is usually designed for storms of return periods of 50 years or more.

In practice, the application of the minor / major drainage concept requires the construction of overflows at critical points, where the underflow is carried by the minor system and the overflow is directed into the major system. It has also been found necessary to be generous with allocating freeboard in the design of major systems, as the calculation of storm flows for long-term flood events is imprecise.

Note

Open channel construction is by its very nature labour-based. This guideline has been compiled to present the technology, with direction for design, materials selection and construction against the background of experience gained to date in Southern Africa.

2. Design considerations

2.1 Storm flows

Comprehensive guidance can be obtained from the Roads Drainage Manual (Rooseboom, 1993) in the different design methods applicable to the calculation of storm flows. For small catchments (less than 15 km^2) the 'rational method' is recommended as it is based on simplified representative processes involved in run-off. The data collection needed to give the rational method a reasonable level of accuracy is not onerous and can be done during a site inspection, as long as the inspection can be supplemented with information found on orthophoto maps. As the maps are based on aerial photography, some catchment characteristics can be deduced from them.

Other methods of estimating run-off can be used, if sufficient data can be gathered. Most methods require large amounts of data on catchment characteristics that can be time consuming to gather and are rarely justified.

2.2 Open channel design flow

Open channels are the preferred conduits for the conveyance of storm run-off for several reasons:

- If the channel has been correctly situated in a valley line or low point, its carrying capacity is large, as the designed high water levels can be exceeded, even though some damage may occur when the banks overflow. In contrast, the carrying capacity of a pipe culvert increases steadily as the flow increases to about 70% of its maximum depth and then reduces by at least seven percent as the pipe fills and water reaches the top of the pipe. A box culvert will show a more abrupt loss of capacity as the water surface reaches the soffit, due to the additional friction. Both pipe and box culverts will then only increase in capacity after surcharging has taken place. This change to a pressurised system is not a normal design criterion for stormwater systems.

- Closed drainage systems must have access points for maintenance, normally manholes. Manholes, unless very carefully designed and constructed, are a major source of head loss due to turbulence. Unbenched manholes will collect sediment, stones and even boulders. The head lost at each manhole can severely reduce the flow capacity of the closed system. An open channel is accessible for maintenance throughout its length.

- Closed conduits conceal blockages, which only become apparent when flooding occurs, by which stage it is too late. Clearing of the blockage may then be difficult. Blockages in open channels can easily be seen and immediately cleared. Their capacity is not as critically dependent upon regular inspection as that of closed conduits.

2.3 Safety

The easy accessibility of open channels may have a negative side. Because they are so accessible, children may play in them, especially when water is flowing. In this regard, a lesson from the Laingsburg flood should be borne in mind: a person is able to wade through fast-flowing water until the depth reaches knee-deep and the flow velocity reaches three metres per second. This is the critical combination of depth and velocity at which a person is swept away. It may not be possible to design an open channel so that the depth and flow velocity are safe. Other safety measures must then be looked at. Fencing off the channel may cause more problems than it solves. A fence can act as an efficient debris filter and eventually deflect overland flows away from the drain, to cause considerable damage.

2.4 Channel lining

Flow velocities in open channels will dictate the type of channel or channel-lining required. Sensible limits to the flow velocity must be applied in order to limit erosion damage. The maximum flow velocity which can be withstood by various soil types and ditch linings is approximately as follows:

- Fine sandy soil 0,6 m/s
- Gravelly soil and stiff clays 1,2 m/s
- Cement grouted rock lining 3,0 m/s
- Concrete over 5,0 m/s

Further guidance can be found in the Road Drainage Manual (Rooseboom, 1993).

Typical roughness coefficients for various channel materials and various linings can also be found in the Road Drainage Manual (Rooseboom, 1993).

The chosen lining should be labour-friendly, in other words it should be readily amenable to construction by labour. For open channels virtually all lining materials can be laid by hand, so this requirement is hardly a restriction. However, for reasons of economy, the chosen channel lining should make maximum use of local materials.

2.5 Road crossings

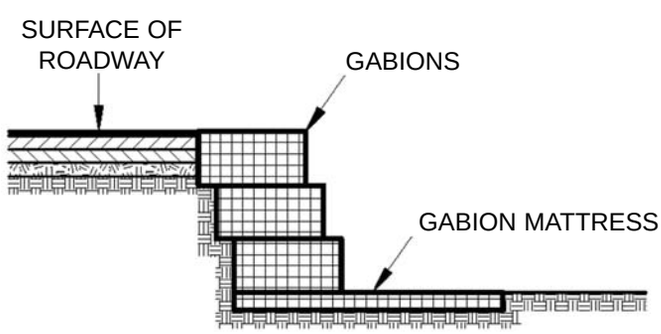
Culverts are generally chosen as the means by which open channels cross beneath roads. Adequate waterway area is probably the most important and the most difficult criterion to meet. Normally headroom is strictly limited which may severely limit the culvert waterway that can be constructed. If the traffic using the road is such that flooding can be tolerated for short periods, then a drift can provide the additional waterway needed to accommodate a long-return period

flood. The drift should be designed as a broad-crested weir. Generous freeboard should be provided to enable a larger flood to pass safely. If flow depths can be limited to 200 mm for the design flood, traffic will seldom be hindered from using the crossing. However, if space does not permit a long drift and flow depths are larger than 200 mm, consideration should be given to the placement of 200 mm high blocks or pillars at intervals along the drift edges to act as depth indicators. A sign should be erected advising that the drift should not be attempted when the depth indicators are under water. (The drift will provide a measure of safety against blockage of the culvert beneath.)

As flow velocities over a broad-crested weir at 200 mm depth are quite small, no special provision need be made to prevent scour of the road surface. However, the downstream flow velocities can increase significantly and will require armour to prevent erosion. Gabions are usually a viable solution. A major advantage of gabions is that pore-pressures cannot build up at the face, as they would upstream of a masonry wall. Gabion walls can support the edge of the roadway, can provide a hydraulic sill preventing downcutting by the floodwaters and can prevent undercutting by the falling water, provided that a gabion mattress is strategically placed for this purpose. (See Figure 1)

If a drift cannot be constructed, then the culvert should be made with openings as large as possible, with a generous allowance for blockage by debris. Storms as large as the 50-year return interval design storm frequently uproot trees and bushes and drag along large quantities of debris. A culvert can be plugged quite rapidly, causing the flow to overtop the structure and damage the road.

Figure 1: Gabions



3. Materials requirements

Open channel drains may comprise lined or unlined channels, depending on the ground conditions and the flows that have to be carried. Linings are costly and should only be used after the conditions for a channel have been properly assessed. Scour checks can control flow velocities to a limited extent and are usually cheaper than lining.

Typical channel lining materials include:

- Vegetation: low-growing vegetation - like matted grasses - is the only suitable type for channel linings. Kikuyu grass should be avoided as it needs fairly large quantities of water for its establishment and continued growth in arid climates. In wetter climates kikuyu grows too vigorously and chokes the waterway, requiring regular cutting. The preferred grass is *cynodon dactylon* variety transvaalensis, or 'transvaal kweek', which is hardy, well adapted to arid conditions and is not usually vigorous enough to present problems.

- Masonry linings are rarely appropriate for large channels carrying high flows, however, for small channels brick linings are technically adequate and can have positive aesthetic qualities that are difficult to equal in other materials.

- Precast concrete units are available in many shapes and sizes and can give a channel lining with many desirable properties. Paving units are suitable for small channels and can have positive aesthetic qualities. Vertically interlocking units are resistant to higher flow velocities and can be used to provide greater roughness by alternating blocks of different thickness. Wired interlocking units are suitable for high flow velocities and the openings between the blocks encourage the establishment of vegetation. Grass blocks (precast concrete units with openings) are often suitable for lining channel bottoms and allow the establishment of vegetation. They combine well with 'loeffel blocks' used to support the channel sides. With all such linings, care must be taken that turbulent flow does not erode the soil behind the lining or through gaps in the lining and cause the lining to collapse. Geofabrics are generally used to counter erosion behind the lining, while allowing free drainage of groundwater. Abrasion of debris-laden water requires high unit strength.

- *In situ* concrete as a lining is costly, but used in the right circumstances can be cost-effective. It can resist high flow velocities when carefully detailed and properly constructed. Drainage behind the lining must receive attention, as high ground water levels after storm run-off has been passed, can cause the lining to be lifted. The surface can be made very smooth to reduce sedimentation at low flow velocities, but it is more difficult to make the surface sufficiently rough to control high flow velocities. High flow velocities are perhaps better controlled by means of a series of steps or stepped pools, that induce a hydraulic jump at every step (Rooseboom, 1993). Abrasion of debris-laden water requires high concrete strength.

- *In situ* concrete cast into 'Hyson Cells' combines the advantages of *in situ* concrete with the flexibility of discrete blocks. (Reference should be made to the literature from the supplier.)

- Rock is an excellent channel lining material and can often be obtained locally. Rock can be used in many forms:
  - **plain stone pitching** comprises laying of hand stone onto a compacted area, the stones are driven into the earth and the gaps between the stones are filled with spalls or with topsoil and rooted grass shoots,

- **grouted stone pitching** comprises plain stone pitching with the interstices filled with a 1: 6 cement: sand mortar instead of spalls or topsoil,
- **wired and grouted stone pitching** comprises a wire net of 150 mm mesh beneath and above the stone pitching with vertical wire ties at 600 mm centres; when laid and tied together, the area is grouted with a 1: 6 cement: sand mortar. Quality of stone is required to be sound, tough and durable, generally with a 200 mm minimum dimension. (Some specifications permit stone with a diameter of up to 600 mm to be used.) Wire should be four millimetre galvanised wire.

- Various membranes are in use for channel linings, generally for waterproofing to cut infiltration into the ground. None are, however, robust enough for township or rural settlement use.

4. Plant and equipment requirements

Compaction equipment comprising hand-guided vibrating rollers or plate vibrators are adequate for all but the largest channels. Compaction with hand stampers is adequate for small areas, especially in restricted spaces, but cannot be recommended for general use. Concrete and cement mortars can be mixed by hand or by machine, depending upon the size and speed of the lining project. Hand mixing can produce high quality concrete and mortar, but requires that the mixing team receive intensive training in technique and quality control. If this is neglected the results will be poor.

Tools needed for channel linings will depend on the type of lining. Tools commonly required include spades, shovels, picks, rakes, hand stampers, garden forks, club hammers, spirit levels, straight edges, watering cans, ditch templates, string lines, measuring tapes, boning rods and wheelbarrows.

5. Construction technique

Open channels are readily constructed by hand as the requirements for accuracy and quality are generally not particularly onerous. The essential elements in the construction of open channels are the following:

- Commence work at the lower end so that any water flowing into the channel will drain away immediately and not accumulate to saturate the soil.

- Approach the final excavation level with caution so as not to over excavate. (Overbreak requires costly backfilling that seldom matches the strength and stability of undisturbed soil, especially in the case of unlined earth channels).

- Encourage the use of templates, as unskilled labour will quickly learn how to use them to ensure correct shape and side-slope of the channel excavation. Boning rods used in conjunction with profiles will ensure correct longitudinal gradients.

- When linings are to be constructed, the channel bottom and sides must be compacted to at least 90% of ModAASHTO maximum density. Poor soils exposed during excavations should be removed and replaced with better quality gravelly soils. Considerable effort is needed to ensure good preparation before lining, as uneven settlement may destroy the lining and

negate its purpose. (Remedial work is more costly than doing the job properly in the first place.)

- Stone pitching and block-laying is always started at the low side and worked upstream. The units should be tightly packed.
- Grouting of stone pitching should be undertaken as the job progresses. If grouting is delayed, storm flows carrying sediments can fill the voids in the pitching. Should this happen, the pitching will have to be taken up, the sediments cleaned out and the stone re-laid.
- Attention must be given to the surface finish of linings, in order to fulfil the design requirements. If the design relies on a finished surface with absolute roughness (k) of 0,01 m to control the flow velocity, then a steel-trowelled finish is not desired.
- Drainage of the space behind the lining may be crucial and attention must be focussed on getting the details to work. Filter layers and the installation of flap-valves to relieve groundwater pressures may require specialist inputs.
- Concrete work must be properly cured for at least four days. Poorly cured concrete will not have the abrasion resistance needed to withstand high velocity debris-laden flows.
- Careful backfilling of spaces along and behind structures is essential to the correct functioning of the drain constructed. Adequate quality control measures must be in place.

6. Specialist literature

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3. Miles, L C; “Design philosophy for stormwater drainage”. Sixth Quinquennial Convention of the South African Institution of Civil Engineers, Session 2: Stormwater Hydraulics, Durban, June 1978, pp 20 to 24.
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Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour-based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major contributing organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
National Housing Forum
Congress of South African Trade Unions

Plus many individuals from construction companies

“Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings.”

Nelson Mandela, 2005 – Global Campaign for Action against Poverty

Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 4-2

Rubble masonry dam construction technology

cidb
development through partnership

Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment-intensive construction works

In this set: (colour coded)

Part 1

An overview of labour-based technologies and methods in employment-intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

3.2 The BESA building system

Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

4.2 Rubble masonry dam construction technology

4.3 Rubble masonry concrete arch bridge construction technology

4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Waterbound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

EXPANDED PUBLIC WORKS PROGRAMME

ENGINEERS AGAINST POVERTY

Labour-based methods and technologies
for employment-intensive construction works

A cidb guide to best practice

1ST Edition of CIDB document 1027 March 2005

Best Practice Guideline – Part 4-2

Rubble masonry concrete dam construction technology

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

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Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1. Introduction

1.1 Background

1.1.1 General

This section introduces the technology in broad principles and illustrates the related benefits to be gained by its application, with specific reference to a number of projects completed in South Africa.

1.1.2 The use of masonry in dam engineering

Although it has been partially washed away, the oldest dam wall still standing was constructed using stone and gravel enclosed in a skin of uncemented rubble masonry. Sadd el-Kafara Dam, constructed circa 4500 B.C. approximately 30 km to the south of Cairo in Egypt, stands over 11 m in height. In all probability, this dam failed soon after completion as a consequence of inadequate spillway capacity. Many early masonry dams have, however, stood the test of time. For example, the Alicante Dam in Spain, completed in 1594 to a height of 43 m, was the highest dam in the world for almost 300 years.

Small arch dams were constructed by the Romans as long ago as the first century BC, while the Mongols built several arches of quite large proportions during the middle ages. All of these early arches were constructed using cut (or dressed) stone, although it wasn't until the middle of the 19th century that rational stress design was applied for the first time at Zola Dam in France. In 1880, the world's first concrete arch dam was constructed in Australia and from this time on mass concrete construction gave rise to a rapid development in arch dams worldwide. Arch dams accordingly jumped from cut-stone to concrete without the transition through variations of rubble masonries that were seen for gravity dams.

With the advent of rational design methods, strong and durable masonry gravity dams were consistently being produced by the middle of the 19th century and the majority of these remain standing today. The evolution of the internal combustion engine, however, and the powerful mechanical equipment and plant that this development made possible, facilitated more efficient construction for major dams. Not only could a large dam be constructed in less time and at lower cost using crushed aggregates and sophisticated mixing plants, but the higher levels of quality and impermeability achieved, encouraged the design of more efficient structures. With the evolution of shuttered, high strength mass concrete, the horizons of the dam engineer were broadened and a new freedom to develop sophisticated three-dimensional structures was achieved.

While these developments saw the application of masonry dams on large scale diminish after the first quarter of the 20th century in what is now the developed world, masonry dam construction has remained popular in the developing world, where low-cost labour is plentiful. In China, for example, very large gravity masonry structures (up to 95 m in height) were very popular until the advent of Roller Compacted Concrete (RCC) in the early 1980s.

The majority of masonry dams constructed around the world in the past have been mass gravity structures that transfer load in a vertical plane into the foundations. It is only in Zimbabwe since the mid-1980s that more ambitious arch designs have been constructed in masonry. Requiring impermeability from thin structural members, these arch dams have necessitated the development of a

Note

The completion in 1996 of two significant Rubble Masonry Concrete (RMC) dams in South Africa heralded the arrival of a cost-effective, low-maintenance, labour-based dam technology. Since then RMC dam construction has repeatedly been demonstrated to be appropriate in the local environment where there is an overriding need for employment creation.

There is usually more than one design/construction solution for a particular dam site, not to mention the fact that by slightly moving the site, a completely different type of dam wall may provide the optimal solution. In South Africa and especially in Zimbabwe, it has been demonstrated that masonry arch dams offer a very competitive solution under certain site-specific conditions.

This best-practice guide has been compiled to present the technology of RMC dam construction, with direction for design, materials evaluation and construction and against the background of experience gained to date in constructing RMC dams in South Africa.

Rubble Masonry Concrete (RMC)

While using rubble, as opposed to dressed stone, the arch dam masonry is constructed as a monolithic matrix of large rock particles set in mortar, according to the original definition of concrete as a 'binding of loose particles into a single mass'. The term 'Rubble Masonry Concrete' differentiates between dressed and rubble stone and indicates the nature of the product of the hand-built masonry work as a concrete. Qualifying RMC with the phrase 'new generation' distances the material from historical masonries, with a view to signifying a construction material suitable for use in relatively thin arch dam structures.

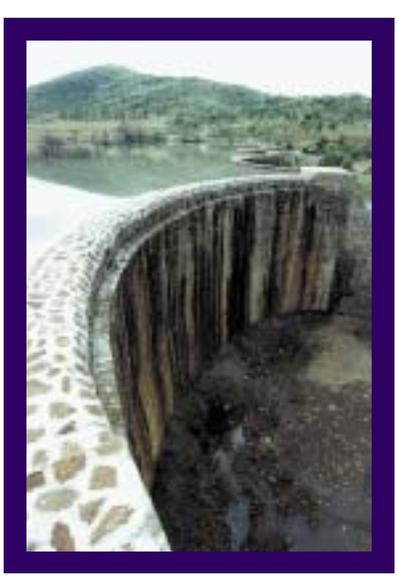
masonry of higher density and a more uniform consistency than applied on earlier gravity structures, where the seepage length to water pressure ratios are significantly higher. Furthermore, structures such as the high masonry gravity dams applied in China made use of concrete membranes to provide the necessary impermeability.

1.1.3 New generation RMC

New generation RMC was born out of a specific set of circumstances in Zimbabwe during a period of prolific dam construction in the mid-1980s. From 1980 to the mid-1990s the number of large dams in Zimbabwe increased from 76 to approximately 169, while by 1993 10 600 small dams were on record in that country.

The particular circumstances in Zimbabwe are such that a general lack of availability of ready mix concrete, particularly in rural areas, compromises the competitiveness of all types of concrete dams on a small and medium scale. For many years, masonry dam construction was accordingly applied on small dams as a matter of necessity. Since 1985, however, masonry has been applied for larger dams at which the establishment of an aggregate crushing plant would be difficult to justify. For embankment dams, spillway sills and sidewalls have often been constructed in RMC, while arch dam walls and other structure types have been built up to heights of approximately 24 m. A general availability of suitable sites, in terms of topography, geology and materials, has now promoted the universal application of RMC technology on all but major dams throughout the country.

Bringing this technology to South Africa in the 1990s, a different environment to Zimbabwe in many aspects, a dam-building material was found and a labour-based technology that could be demonstrated to be extremely cost-effective, while producing a durable, low-maintenance dam wall. When considering these factors and the training offered to previously unskilled labour in the production of dense, impermeable, high quality masonry work, the merits of the RMC technology could be seen to be quite exceptional in present day South Africa.



1.1.4 The status of the technology inherited from Zimbabwe

While Zimbabwe's experience in RMC dam construction can be drawn upon to assist in applications in South Africa, the prevalent level of understanding of the material characteristics and the lack of published data and information leave many questions unanswered. Much of the arch dam design was developed on an empirical basis and the analytical techniques used appear not to have taken full cognisance of the critical effects of temperature drop loadings.

Little, or no, large-scale materials testing has been undertaken in Zimbabwe and the materials and dam behaviour and performance can only be judged on the basis of physical inspection and verbal reports.

1.1.5 The apparent behaviour of RMC in dams

The Zimbabwe experience of the behaviour of RMC was soon confirmed in South Africa and reflects a disparate drying and thermal shrinkage performance when compared to conventional mass concrete. Structures of several hundred metres in length can be constructed in summer without ever demonstrating the cracking that would be unavoidable for an equivalent, jointless concrete structure. Whilst the lack of drying shrinkage can be easily understood, the fact that cracks do not form as a consequence of long-term thermal shrinkage cannot currently be satisfactorily justified on engineering principles.

RMC dams seep[1], rather than leak, before sealing themselves and becoming

[1] Continuous contact of concrete / mortar with water seals cracks arising from drying shrinkage. In RMC dams, autogenous healing (i.e. the closing up and disappearance of breaks or cracks in concrete where the concrete parts are kept damp and in contact) occurs on the upstream of the wall.

watertight. In this process of sealing, efflorescence and calcite are deposited in layers on the downstream face and the white streaking effect detracts from the finish of the wall. However, as the seepage diminishes, the calcite deposits dry, weather and discolour to a greenish brown, depending on the dampness and extent of attached organic growth.
South Africa is home to a broader range of climates, geologies and construction materials than is the case in Zimbabwe and greater extremes in RMC behaviour and performance are likely to be experienced in this country.

1.2 RMC dams in South Africa

1.2.2 RMC dams

Rubble Masonry Concrete technology for dams blends ancient manual construction methods with state of the art design techniques to create a dam type that history missed - the RMC arch dam. The first 'new generation' RMC arch dams were initiated in South Africa in 1995. Since then, the obvious benefits of this technology have been demonstrated on more than 10 successfully completed dams.

RMC dam construction has proved to be an efficient and highly cost-effective method for the labour-based construction of small- and medium-sized dams. With favourable conditions for a specific site, an RMC dam will usually be the lowest cost dam type up to heights of around 25 m. At the sites evaluated and exploited in South Africa to date, RMC technology has indicated a cost benefit over the closest competing dam type of generally over 30%. In every instance the component of the completed cost related directly to labour wages is significantly higher than would be the case for competing dam types, and in certain instances labour wages have represented up to 40% of the construction cost. A more usual figure might, however, be in the region of 20%. At Bakubung Dam, 8 000 person-days of employment can be directly attributed to the selection of this dam construction technology.

1.2.3 RMC composition

As a broad definition, RMC is a matrix comprising large stones, or plums, in a mortar binder. To minimise cost and optimise structural properties, it is necessary to ensure the correct rock or stone content. While a rock component content of 65 – 70% is achievable, a realistic composition is 55% rock with 45% mortar. The mortar used will generally comprise one part cement (one bag = 33 litres) and 4 – 6 parts sand (by volume), giving typical 28 day compressive strengths for the RMC of the order of 14 down to 9 MPa. Accordingly a cubic metre of 14 MPa RMC will typically comprise approximately 3,2 + pockets of cement (160 kg), 660 kg sand and 1 460 kg rock. The concrete mix has a ratio of one cement to 13,25 aggregate (sand and stone) by mass and can accordingly be described as a 'lean mix'.

Bigger can be better

Whilst economy plays a major role in promoting the objective of maximum large stone content, related secondary benefits are seen in material behaviour, as long as adequate mortar film thickness is maintained and the appropriate mortar workability is not exceeded in an effort to obtain greater rock use.

Rock used will vary in size from approximately 50 mm maximum dimension, to 300 mm, the largest dimension being dependent on the thickness of the member under construction and the obvious restrictions of manageable weight. Compromised performance is seen when too few and too large rock particles are applied, in relation to the size of the particular member under construction.

1.2.4 Construction objectives

A number of variations exist with regard to the placement and compaction of

The monolithic matrix vs. stones cemented together

In essence, this is similar in concept to the difference between brickwork and concrete. The former comprises a series of individual entities cemented to each other, while the latter comprises a body, or matrix of material made up of component constituents, in the form of cement, aggregates and water. When a 'rubble' masonry structure is built in a similar manner to brickwork, placing mortar as a receiving medium into which the surfaces of stones are embedded, the overall structural action of the final body of material is compromised. Stress transfer paths are predetermined and limited, local tension effects become significant, the mortar properties play a more dominant role and overall permeability is high.

Rough finish RMC

'Zimbabwe' finish RMC

Decorative finish RMC

RMC. Whilst the Zimbabweans have developed certain methods and standard practices, various adaptations of these methods have been made in South Africa.

The quality and durability of the final structure produced in water retaining RMC is obviously inherently sensitive to the methods applied for placement and compaction, as can be witnessed when inspecting many of the leaking masonry dam walls in certain parts of Mpumalanga. It is important to understand that RMC for arch dams must not be perceived as a series of stones cemented together using mortar, but rather as a monolithic matrix, containing large stones within a body of mortar.

1.2.5 Surface finish and appearance

The approach to surface finish applied in Zimbabwe is generally one of producing plastered external surfaces, with the occasional stone partially visible. This requires a type of flush pointing technique, which produces a relatively flat and even surface. The overall impression of such a finish is one of poorly shuttered and discoloured concrete. However, once through seepage occurs in the process of sealing, the surface becomes covered by efflorescent lime deposits and correspondingly white-streaked. In various instances in South Africa, particularly when a local stone with surface discoloration has been used, it was considered advantageous to preserve a natural rock surface appearance as far as possible. This was achieved by applying recess pointing, whereby the mortar is recessed behind the exposed surface of the stone by approximately 15 mm. The result is a structure that blends well aesthetically into its natural surroundings and takes on an 'ancient appearance' very soon after completion.

Variation in appearance for a recess pointed surface is further possible, depending on the stone-pointing method applied for the surface zones. While the surfaces of Bakubung, Welgevonden and Star Dams were finished relatively roughly, with uneven stone projections, the surface of the masonry on Genadendal and Hogsback Dams were recess-pointed very carefully, to produce a stone-pitched wall appearance. Both approaches have merit. The approach adopted at Bakubung producing a more 'ancient' appearance and that applied at Genadendal a very neat and decorative finish.

1.3 RMC dam projects completed in South Africa

1.3.1 The first two South African RMC dams

By coincidence, the first two RMC arch dams to be constructed in South Africa were initiated independently, but virtually in parallel, during 1995. Bakubung Dam in the Pilanesberg National Park, North

West Province is a 14,5 m high RMC multiple arch buttress dam, while the Maritsane Dam, near Bushbuck Ridge, Mpumalanga is an 18 m high single curvature arch dam with an embankment flank. Both dams were completed in early 1996. Maritsane Dam follows, relatively closely, the model arch with an embankment flank developed in Zimbabwe. (Zimbabwe design and construction expertise was indeed brought in to assist the local designers and contractors.) Bakubung Dam follows the broad principle of multiple arch-buttresses in Zimbabwe, although it is understood that nothing as big has been constructed in that country to date.

Bakubung Dam

Bakubung Dam comprises six 12 m radius, 120° aperture arches, with a crest thickness of 0,8 m and a maximum base thickness of 1,6 m. The width of the five buttresses varies from 1,8 m to 3 m dependent on height, and each flank is completed by a short section of gravity wall and a low embankment, where the foundation competence deteriorated. The completed structure contains 2 650 m^3 of RMC and required 9 000 person-days of labour to complete.

In this instance, a mechanical mixer was only brought in late on the construction and a shuttle dumper, with earth ramps and scaffold platforms, was used to deliver mortar to the point of placement. The dam was constructed with Walcrete masonry cement, local sand and surface rhyolite stones collected off the local hillsides and loaded by hand onto a tractor-driven trailer.

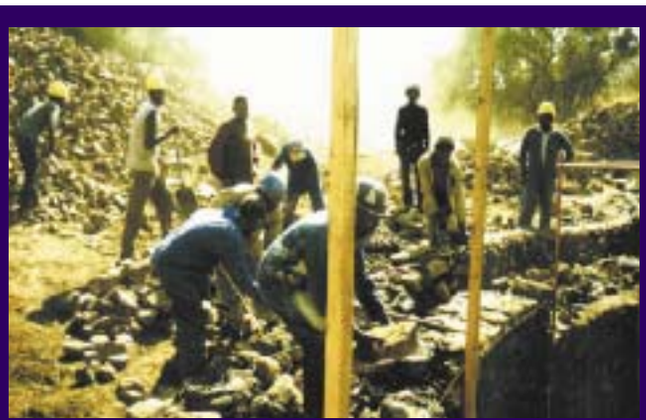
Maritsane Dam

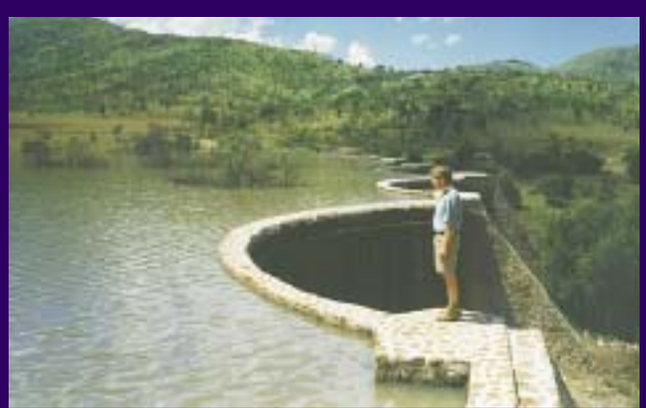
Maritsane Dam comprises a single arch on a 60 m radius with an aperture of 105°, flanked on the right side by a massive thrust block, which also acts to retain a fill embankment. The arch has a uniform thickness of 2,4 m, which is flared out to 3,5 m immediately above the foundation contact. The arch and thrust block contain 5 600 m^3 of RMC, which represents the largest quantity of RMC yet placed for a single dam in South Africa.

Scaffolding, ramps and wheelbarrows were used for the delivery of materials to the point of placement and mortar was mixed using two 300 litre mechanical concrete mixers. Granite rock particles were blasted from a dedicated quarry and sand was sourced from alluvial deposits in the dam basin. Mortar was made with PC25 Fly Ash Cement (Cem II B – V or W 32,5). 12 000 person-days of labour were required to complete the masonry construction.

1.3.2 Genadendal Dam

Genadendal Dam was built in 1996 for Bop Parks in the Madikwe Game Reserve and is a 9 m high embankment

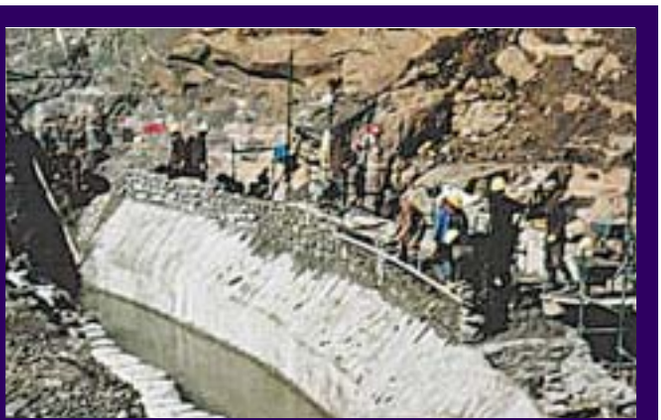


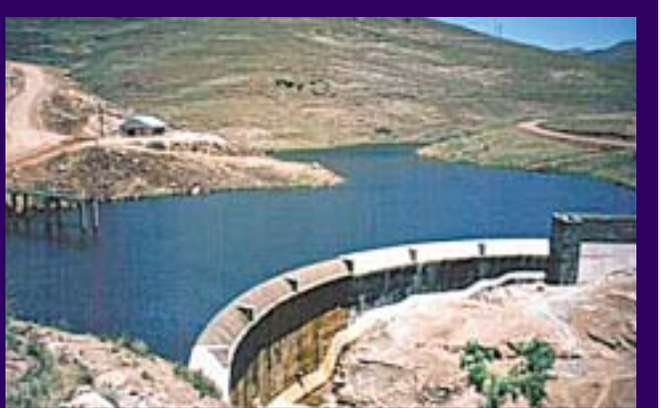


Bakubung Dam

Maritsane Dam

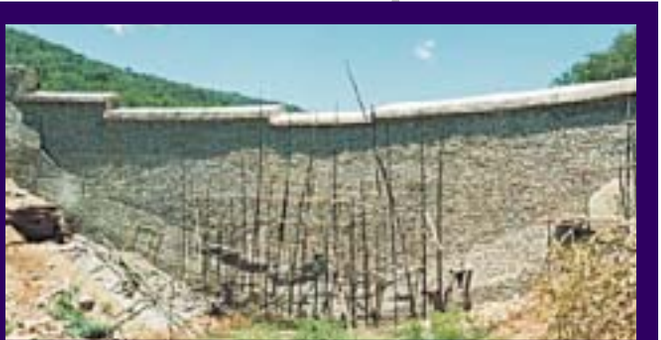
Genadendal Dam





Likalaneng Weir

Vrede/Thembalihle Dam



Welgevonden Dam

dam with a side-wash spillway, for which the sill and embankment end wall were constructed in RMC. A total of less than 200 m^3 of RMC was placed for the various components comprising this dam.

This project is of interest because of the method used for placement of RMC in the footing of the spillway overspill structure. This involved embedding very large stones in a flowable mortar, retained within an excavated trench, without external masonry shell zones. This technique proved successful and rapid, if a little costly in terms of total mortar used, save for the fact that a shrinkage crack of 5 mm width developed at a shallow section, whose foundation was locally raised by a rock outcrop.

1.3.3 Likalaneng Weir

Likalaneng Weir comprises a single arch on a 35 m radius with an aperture of 124°, flanked on the left side by a gravity thrust block. The arch has a uniform thickness of 1,7 m, which is flared out to 2,7 m immediately above the foundation contact. The arch and thrust block contain 1700 m^3 of RMC, which represents the largest quantity of RMC yet placed for a single dam in Lesotho.

Most of the construction took place in cold (snow) weather and water had to be heated for mortar batching. Blasted basalt rock particles were delivered as excavation spoil from another contract. Sand was sourced from commercial alluvial deposits in the Caledon River. Mortar was made with PC25 Fly Ash Cement (Cem II B - v or w 32,5). 6 800 person-days of labour were required to complete the masonry construction.

1.3.4 Vrede/Thembalihle Dam

Vrede/Thembalihle Dam is an 18 m high earth/rock embankment dam. The spillway is designed for a flood discharge capacity of 830 m^3/s. The spillway control structure is a 50 m long x 4,5 m high hollow gravity, Ogee-shaped RMC structure with 8 m high training walls, also constructed in RMC. The spillway structures contain 800 m^3 of RMC.

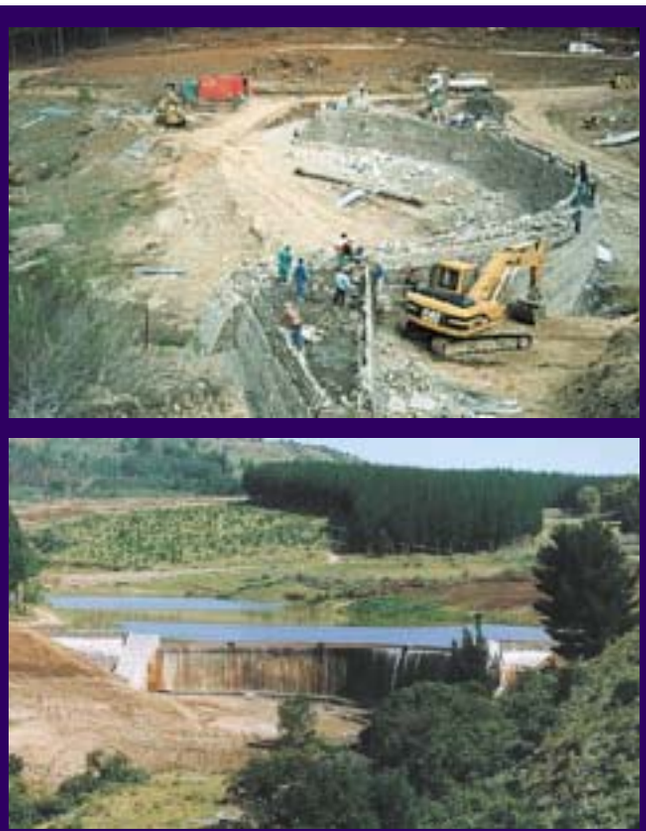
Dumpers were used for the delivery of materials to the point of placement and mortar was mixed using a 450 litre mechanical concrete mixer. Dolerite rock particles blasted from the spillway excavation and sand sourced from commercial alluvial deposits was used. Mortar was made with PC25 Fly Ash Cement (Cem II B – v or w 32,5). 500 person-days of labour were required to complete the masonry construction.

1.3.5 Welgevonden Dam

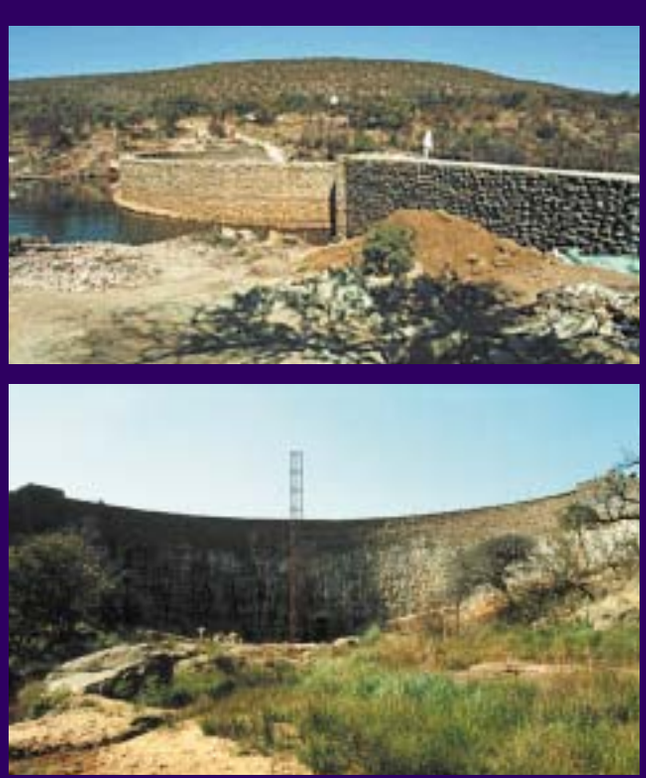
Welgevonden Dam at Mooketsi, Northern Province, was constructed in 1998 for the purpose of irrigation water

supply. The dam is a 15 m high single curvature rubble masonry arch dam with an embankment on the left flank. The arch structure comprises a single curvature, 28 m radius arch, with a uniform thickness of 1,8 m. A flaring of the arch in the vicinity of the foundation contact is provided to reduce stress concentrations.

The dam is owned by ZZ2 (Pty) Ltd, who utilised their own labour during the winter season of low farming production to construct the wall. The wall comprises 1 275 m^3 of RMC and was constructed with local river sand and Granitic 'gabion stone' imported from a quarry located at a distance of more than 80 km from site. Mortar was mixed using a 250 litre concrete mixer and transported to the point of placement using a chute and wheelbarrows. Approximately 1800 person-days of labour were utilised in the construction.



Hogsback Dam



Star Dam

1.3.6 Hogsback Dam

Hogsback Dam in the Eastern Cape was constructed in 1999 and comprises a 20 m radius central arch spillway, flanked with embankments on either side. The maximum dam height is 12 m and the masonry wall is dovetailed into the embankments using tongue walls and wrap-around fill. The arch thickness reduces from 2 m at the base to 1,1 m at the crest and the arch aperture measures 140°, with the arch thrust carried down into the foundations by means of 10 m high, 3 m wide buttresses on both flanks. The masonry portion of the dam comprised 1 750 m^3 of material, with blasted sandstone used for the rock particles and imported sand for the mortar. A team of 50 labourers from the local community was employed for the masonry construction.

1.3.7 Star Dam

Star Dam is an 11 m high single curvature arch with a 21 m radius of 120° aperture, with small gravity walls on both flanks, that was constructed on a private farm in the Waterberg, Northern Province. The dam was initiated in 1999 and left partly constructed during the floods that affected that part of the country during early 2000, to be completed later that year. The arch varies in thickness from 1,2 m at the crest to 1,8 m at the base and arch thrust is carried down by 2 m wide buttresses on both flanks. On the left flank a 16 m long gravity wall joins the buttress and the natural ground, while a gravity wall of 5 m maximum height and 40 m length completes the right flank.

1.3.8 Keta Dam

Keta Dam is a 10 m high embankment, draining a catchment of approximately 100 km^2 in the Waterberg, Northern Province. The dam, which is situated on a private game farm, was breached during intense flooding and was reconstructed with an RMC spillway on the rocky right flank. The stepped and uneven

Keta Dam

pattern of the rock of the flank resulted in the necessity for a strangely shaped spillway crest and prevented the application of an arch. The embankment end wall, gravity spillway walls and spillway channel in-fills required a total RMC volume of 1 230 m^3, which was constructed using 1 500 person days of labour. Rock particles were sourced from the local hillsides and sand from the basin of the dam.

1.4 The future of RMC for projects in South Africa

Two large RMC multiple arch buttress structures are currently under construction in South Africa to heights of 19 m and 21 m requiring 13 000 m^3 of RMC. Both dams are being financed by private initiatives as tourism features.

In view of the current growth in tourism and related developments in South Africa, a strong trend of small and medium sized dam construction is likely to continue to be seen over the next few years. With many of these developments relating to eco-tourism infrastructure, the appropriateness of and opportunity for RMC is obvious. The apparent benefits offered by RMC in terms of low construction cost, employment creation and skills development make it an extremely appropriate solution to meet this growth.

Furthermore, RMC dams will offer very cost-competitive solutions for domestic water supply projects in rural areas where deeply-incised rivers with rock foundations are available, such as in KwaZulu-Natal and along the Eastern Escarpment of South Africa.

For South Africa's northern neighbours, the opportunities for building RMC dams for water supply and for small hydropower plants are obvious, as have already been demonstrated in Zimbabwe.

2. Materials requirements

It is the intention of this sub-section to define the nature and materials requirements for Rubble Masonry Concrete for dams. In addition, some information and guidance is provided in an effort to foster a deeper understanding of the typical variations of behaviour that can be anticipated. These guidelines have been prepared for an engineer with an appropriate level of knowledge of dam design and do not attempt to cover dam design *per se*.

2.1 Materials composition

2.1.1 General

RMC is a matrix comprising large stones, or plums, in a mortar binder. To minimise cost and optimise structural properties, it is necessary to ensure the maximum realistic rock or stone content. In terms of its basic constituent materials proportions, RMC is similar in nature to a dry mix concrete, or RCC (roller compacted concrete), comprising approximately 55% large aggregate (by mass), 5,5% to 7% cement, 6% to 7% water and 30% to 35% sand. The greatest difference, of course, can be seen in the fact that the large aggregate portion of RMC comprises particles generally of 50 to 300 mm in dimension.

2.1.2 Typical mix proportions

Recent RMC dam construction has focused on two mortar mix compositions: a one part cement + 4 parts sand (by volume) mix, for use in the more critical structural members and a one part cement + 6 parts sand mix, for the more massive components[2]. The zones requiring particularly low permeability will generally be constructed in RMC with the former mortar mix while the latter mix would generally be applied where seepage paths are longer, hydrostatic pressures are lower and for non water-retaining components. These mixes were originally developed empirically in Zimbabwe and while practice in South Africa has confirmed their appropriateness and associated nominal target strengths, for realistic design, particularly when considering impermeability, it is necessary to evaluate carefully the actual composition of an RMC mix.

Mortar composition

Adopting the mortar classification system of SANS 10164 – Part 1, the 1:4 mortar mix, using a CEM 1 cement (OPC), is equivalent to a mortar Class I, displaying a 28 day preliminary (laboratory) strength of perhaps 14MPa and a works test strength of 10MPa. The nominal 1:6 mortar mix is equivalent to a mortar Class II, displaying a 28 day preliminary strength of 7MPa and a works test strength of 5MPa. In SANS 10249, a Class 1 mortar comprises 50 kg cement and approximately 130 litres sand (measured loose and damp), while a Class II mortar comprises 50 kg cement and approximately 200 litres sand.[3,4] It is very important to maintain a mortar film thickness limited to 7 to 20 mm between the rock particles within the RMC. A mortar film of this thickness should provide significantly greater strength than indicated in a 100 mm test cube.

For the purpose of evaluation, mortar mixes 1:4 and 1:6 by volume are analysed based on the following data and ignoring air content for simplicity:

Material	Loose bulk density (kg/m^3)	Relative density
Cement	1150 (1500 in bags)	2,9
Sand, dry	1620	2,65
Sand, wet	1350	

The sand is assumed to be an average sand, and has a water requirement of 330 kg/m^3 to give adequate workability to the mortar. The water requirement for a 1:4 and 1:6 mix would be similar in practice despite the higher cement content of the 1:4 mix (see Table 1).

[2] Common cement CEM I 32,5N or CEM II -A, L, S, V or W 32,5N complying with the provisions of SANS 50197-1 should be used mortar with RMC

[3] The designer should specify the minimum cement content in a cubic metre of mortar. This is more important than specifying the compressive strength of the mortar in accordance with the provisions of SANS 10164-1 : The Structural use of Masonry : Part 1: Unreinforced masonry walling as lean mixes will be permeable. The compressive strength of RMC is relatively insensitive to the strength of mortar. Compressive strength requirements can be used as a control measure to monitor uniformity in mortar. Changes in compressive strength are indicative of changes in mix proportions, water content and fine aggregate.

[4] A 'concrete' wheelbarrow has a capacity of 65l. Mortar mixes of 1 : 4 and 1 : 6 compositions are accordingly proportioned as 50 kg cement and 2, or 3 wheelbarrows of sand, respectively.

Table 1: Mortar 1:4 (dry sand)

MATERIAL	QUANTITIES					
	per 50 kg cement			per cubic metre		
	Volume (ℓ)	Absolute volume (ℓ)	Mass (kg)	Volume (ℓ)	Absolute volume (ℓ)	Mass (kg)
Cement	33,3	17,2	50	6,8 bags	117	340
Sand	133	81,4	216	905	353	1465
Water	48,5	48,5	48,5	330	330	330
Total					1000	2135
Note: cement water ratio = 0,97						

In the calculation of quantities of materials for the different mortar mixes, no allowance is made for entrapped air in the mortar (average air content 2 to 4%) and for loss of bleeding water. It is also assumed that in volume batching a full bag of cement weighing 50 kg is used, i.e. the cement is not volume batched.[5]

For dry materials, a mix of 1 cement + 6 sand and a w/c ratio by mass of 1,05 for 9MPa, assuming zero air voids, the component proportions can be determined as shown in Table 2.

When wet sand is used and volume batched, allowance must be made for the bulking of the sand otherwise the cement content will be in excess of that shown in the Tables 1 and 2.

Table 2: Mortar 1:6 (dry sand)

MATERIAL	QUANTITIES					
	per 50 kg cement			per cubic metre		
	Volume (ℓ)	Absolute volume (ℓ)	Mass (kg)	Volume (ℓ)	Absolute volume (ℓ)	Mass (kg)
Cement	33,3	17,2	50	4,8 bags	82	240
Sand	200	122.1	324	960	588	1560
Water	69	69	69	330	330	330
Total					1000	2130
Note: cement water ratio = 1,38						

A realistic mortar amount in RMC (see 2.1.2) is 40% to 45%. Accordingly, the cement content per cubic metre in RMC for a 1:4 mortar mix will vary between 136 and 153 kg/m^3 and for a 1:6 mortar mix between 96 and 108 kg/m^3.

Mortar of different water contents, and hence different consistencies, should be used for the outer and inner zones of each body of Rubble Masonry Concrete. For the external zones, which effectively form a shutter to the internal body, a drier mortar of a stiff consistency should be applied, while a wetter, more flowable mix should be used for the core zone. For surface finishing of the faces of the final structure, a one part cement to approximately four parts sand mortar of a cohesive consistency should be applied.

Rock particle content

A mass concrete might commonly contain up to 60% coarse aggregate by volume. Research and practical experience have, however, demonstrated that while a similar rock particle content is possible in RMC, and indeed of benefit in promoting economy, a content of around 50% may be more appropriate to

[5] A bag of common cement having a mass of 50 kg has a volume of approximately 33 litres when packed under air pressure at a factory. Cement, however, fluffs up (bulks) when poured into a container, with a result that 50 kg of cement cannot readily be contained in a box of 33 litres. The volume of a bag of loose (bulked) cement, depending upon its compaction, can be upto 20% more than when in a bag. For this reason, it is preferable to use whole bags of cement when volume batching.

ensure that rock particles and mortar are well and evenly distributed within the matrix. In areas of the structure where strength and impermeability are less critical, higher proportions of rock may be applied.

For a mass gravity structure, consideration can be given to the application of more traditional, historical rubble masonry techniques, where the rock particles are cemented together with mortar, as opposed to being bedded into a matrix of mortar. In such instances, the rock proportion can be increased very significantly, although it must also be understood that the contents of air voids (entrapped air) in such a 'mix' is likely to be extremely high, with concomitant potential permeability problems.

When a 1:4 mortar mix RMC is applied in areas where strength and impermeability are important, the composition of the mortar-rock matrix is particularly critical. For optimum behaviour, a 7 to 20 mm layer of mortar should evenly and uniformly separate the rock particles (see Figure 1). A variety of rock particle sizes should further be applied in order to prevent large volumes of mortar in voids between the stones.

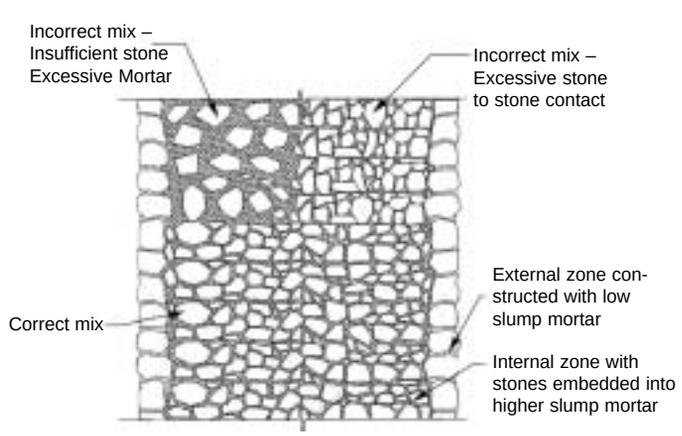
2.2 RMC behaviour as a construction material

2.2.1 General

While it is relatively simple to test, evaluate and analyse the likely strengths and performance of the mortar component of the RMC mix, the addition of large-scale rock particles complicates the picture significantly. It is not just the combination of materials that makes such analysis more involved, but the requirement for an accurate replication of the construction process to ensure representivity of the samples with the actual circumstances prevalent in prototype structures. No vibration is used for the compaction of RMC and compaction is provided in the form of the physical effort of driving large stone particles into the mortar. A further complication inherent to the strength and performance analysis of RMC is the scale of the rock particles, which limits the usefulness of small scale testing and requires specialist equipment to ensure representivity.

In RMC, particles of very different size, shape, elasticity, density and strength are combined to create a micro-behaviour environment quite different to that of concrete. Test work quoted later in this text has illustrated how mechanisms set up between the large particles within the RMC mix can be seen to dominate behaviour, if unfavourably orientated. The problem commonly experienced in RMC relates to the setting of very stiff and strong particles within a matrix of more deformable, lower strength mortar. However, in some instances of bridge construction, low strength rock particles have been used. In such cases, RMC structural performance has been demonstrated to be significantly compromised. It is not intended to discuss in this text the related performance of such RMC in dam engineering, except to say that only rock particles of higher strength and stiffness than mortar should be used in RMC for arch dams.

Figure 1: Typical RMC wall cross-section indicating zones and correct rock content



Testing mortar workability

It is suggested that site tests be carried out to establish optimum mortar workability. A test placement in a box of perhaps 1 m^2 x 0,5 m deep could be broken up a day or so after placement to establish the typical rock particle separation achieved. Repeated testing could be applied to observe and establish optimum mortar workability and the same process could serve to measure the rock and mortar mix proportion variation with mortar workability.

2.2.2 RMC mortar workability

In order to achieve the composition of RMC described in 2.2.1, mortar workability becomes critical. Too wet and flowable mortar will give rise to excessive rock particle contact and will prevent an even and uniform separation of rock particles with a thin layer of mortar. Too dry and stiff mortar will result in excessive separation of the rock particles and a higher dependence of the strength and performance properties of the mortar. Wet mortar will promote a higher rock content and dry mortar, a lower rock content. In certain non water-retaining zones of RMC, where strength requirements are minimal, a more flowable mortar can be used to increase rock content and therefore minimise cost.

2.2.3 The impact of materials variations on RMC behaviour

Recent research focussed on the mechanical properties of RMC, with particular emphasis on various aspects relevant to dam engineering. Fine and Rankine[1-4] used 500 mm cubes to test, evaluate and compare the properties of RMC, primarily in terms of crushing strength and elasticity, or deformation modulus. In this work it was demonstrated that the deformation modulus of RMC is largely determined by the elastic modulus, shape and orientation of the rock inclusions. With rock moduli varying from 24 to 120GPa, a range of RMC deformation modulus of 5 to 71GPa was demonstrated for a constant mortar deformation modulus of 18GPa.

In terms of dam engineering, the important behavioural characteristics of RMC isolated by Fine and Rankine(4) include the following:

- The orientation of the rock inclusions in relation to the main loading direction becomes critical in final materials behaviour,
- Contact between rock particles in the loading direction can result in a significantly higher deformation modulus than for loading in the perpendicular direction,
- Significantly more consistent deformation moduli are obtained when a constant covering of rock particles with mortar is ensured,
- Under load, stresses within the RMC are significantly greater and more variable when a few large particles are applied, with inter-particle contact, as compared with smaller particles separated evenly with mortar,
- It appears that specific load transfer and structural mechanisms play a significant role within an RMC cube close to and at failure. This effect is likely to be of lesser significance at lower loadings in relation to ultimate strength. The particle size in relation to member size is likely to influence the intensity of these effects,
- Poisson's Ratio of RMC can vary from 0,03 to in excess of 1,0,
- The placement method applied for RMC has a fairly significant impact on the final materials behaviour, as a consequence of the foregoing,
- Particles with soft surface weathering are not appropriate for use in RMC.

2.3 Materials requirements

2.3.1 General

In terms of materials quality and strength, the same criteria applicable for concrete are valid for RMC. For the rock particles, shape is of fundamental importance for the reasons discussed above, although workability problems that relate to the flakiness and/or angularity of coarse aggregate particles in conventional concrete are obviously less significant in RMC.

2.3.2 Rock particles

Rock particles for use in RMC can be sourced from a quarry, or from surface stone deposits (usually colluvial). When the scale of construction is small and no suitable quarry exists within the proximity of the dam site, significant economic benefit is gained from the ability to collect suitable rock from surface deposits, which frequently exist close to sites suitable for RMC construction. One obvious pre-requisite in the use of stone from surface deposits is that any weathering is insufficient to significantly compromise the mechanical properties of the parent rock. In terms of quality, rock particles must meet the related requirements of SANS 1083.

Testing rock particle strength

The strength tests applied to coarse aggregate for concrete are impractical for the size of rock particles used in RMC, although the aggregate crushing value (SANS 5841) and the 10% FACT value (SANS 5842) can be applied to smaller particles of the same source material. With the same sort of material competence required for RMC rock particles as for concrete coarse aggregate, visual inspection and handling are usually adequate to confirm density, strength, hardness and durability. Should any doubt as to the competence of a proposed rock particle exist, mechanical testing of samples must be undertaken to ensure a material of at least 2,65 specific gravity, 30MPa compressive strength and 40 GPa modulus of elasticity.

For the reasons discussed above, rock particles with weathering that affects the surface hardness are unsuitable for use in RMC and the maximum particle size must never exceed one-third of the minimum dimension of the structural element being constructed (distance between the inside faces of the surface skin zones). Elongated rock particles should be avoided and the maximum dimension of a rock particle should not exceed one half of the depth of the lift into which it is cast.

2.3.3 Fine aggregate or sand

The fine aggregate or sand must comply with the requirements of SANS 1083 (fine aggregates for concrete) or have a water requirement not greater than 10 litres with 10 kg of cement (CEM I or CEM II A) and 50 kg of air dried sand to reach a consistency suitable for the mortar in RMC.

If judgement of the suitability of the sand is based on its water requirement, then it must also comply with the requirements in the above mentioned South African National Standards for dust control, methylene blue content, clay content, organic impurities, and soluble deleterious impurities.

In general, the Fineness Modulus (FM) of the sand should lie between 2,1 and 2,8.

Where sand from a single source does not conform to the above requirements, blending of sand from different sources should be considered.

3. Plant and equipment requirements

An efficient delivery stream

The key to efficient RMC dam construction is to push the actual masonry placement with a continuous delivery stream of mortar and rock particles. If the overall construction tempo is limited by the delivery rate of construction materials, efficiency can be seen to be rapidly lost.

In the case of any labour-based construction technology, the prime objective is obviously to maximise the overall percentage of the construction cost attributable to labour wages. One of the primary successes of RMC construction for dams lies in the efficient use of labour that arises from a minimum number of component activities comprising the construction method. The basic construction can, however, be split into materials procurement, delivery and blending as one category and actual construction as another. While the latter category is entirely labour-orientated and the use of any mechanical plant would actually be relatively difficult, significant efficiencies can be gained by the use of equipment and plant for the former.

The minimum level of plant to be seen on an RMC dam construction will be a concrete mixer, a (tractor) front-end loader and a tractor and trailer. The other dam construction plant, such as an excavator for the foundation and a compressor and percussion drills for foundation dowels, are not addressed in this text.

Activities that benefit from the application of plant

On the basis that experience has demonstrated the application of plant only to be of benefit in aspects related to the constituent materials, the appropriate use of plant in RMC dam construction can be addressed under the following categories:

- Stone collection, loading and transportation
- Sand procurement and delivery
- Mortar mixing
- Mortar delivery to point of placement
- Stone delivery to point of placement

Manually collected stone

The bulk volume of stone, or rock, required for RMC construction of a dam will equate approximately to the final total volume of the structure. Accordingly, it is obvious that the procurement and management of stone for RMC construction is a significant aspect to be addressed.

When stone or rock for dam construction is collected from surface deposits, these will obviously be dispersed over a wide area and it is unlikely ever to be viable to transport such material to the dam construction using wheelbarrows. Accordingly, the provision of a tractor with a flatbed trailer has proved appropriate for stone collection and delivery. The stone collectors pile rock at a single location. The tractor and trailer are brought to that point and the stone is loaded manually. Once stockpiled on site, preferably in local piles close to the point of placement, stone can be moved to the point of placement by hand, by wheelbarrow, or using a front-end loader.

3.1 Excavation plant

Since masonry dams require rock foundations, it is necessary to have the right excavation equipment to excavate into rock and to prepare the rock foundations. As a minimum, compressed air rock breaking equipment and hand drills will be required. For larger structures where a lot of overburden material needs to be removed, it will be advisable to have at least a 20 t break-out force tracked excavator on site. Where blasting is required to form a foundation key or to remove weathered or loose rock, rock drilling and blasting equipment must be available.

3.2 Blasting equipment

Where stone for masonry construction is not available as surface rocks that can be picked up by hand, it will be necessary to develop a rock quarry. The minimum plant required for this operation will be hand drills and blasting equipment. However, for larger dams requiring substantial quantities of rock, it will be advisable to develop a quarry with tracked drill rigs.

3.3 Drilling and grouting plant

Drilling and grouting plant will be required where foundation grouting is specified to improve the water tightness or structural integrity of the foundation rock. Usually tracked drill rigs will be required, capable of drilling to depths of about 20 m and for hole sizes up to 75 mm. High speed colloidal mixers and grout pumps capable of pumping at pressures up to 100 kPa should be used for grouting.

3.4 Transportation plant

Stone or rock fragments and sand need to be transported to the dam wall site. In Zimbabwe it is common practice to use tractors and scotch carts for this purpose. However, in South Africa dumper trucks seem to be the preferred transportation plant. If large quantities need to be transported within a short period over large distances, then transportation plant could be an important element in the production scheduling.

Wheelbarrows are commonly used for transporting stones and mortar from the stockpiles and batching plants respectively, to the stone masons on the wall. For dam walls containing large volumes or where access is difficult, it may be more advantageous to use cranes on conveyor belts for this purpose. A further option is to deliver to point of placement in the bucket of a front-end loader.

3.5 Grizzly screen

Where rock fragments are mechanically loaded at a quarry and transported to the site of works in dumper trucks, the transported material will consist of a mixture of right sized stones, over-sized stones and rock dust and sand. To separate the undersized material from this mixture, it has been found that a grizzly screen works well. Railway tracks make good grizzlies and the screen size should be set for the lower stone particle size limit. Up to a point, oversized material can be broken down on site by labourers using heavy hammers. If rock fragments are far too big, they could be stored in a separate stockpile for later use in constructing plunge pool walls or other appurtenant works.

3.6 Mortar mixing and batching plant

Mortar mixing and batching plant capacity and type are determined by the production schedule. 300 litre drum mixers seem to be the preferred type of batching plant in both Zimbabwe and South Africa. The batching plant should be towable so that it can always be located at the most advantageous position for delivering mortar on the wall.

3.7 Water heating plant

When constructing masonry dams in very cold weather, it may be necessary to pre-heat the mixing water before adding it to the sand/cement mix in the drum mixer. A diesel-fired heater was used for this purpose on a project in Lesotho when day-time temperatures were typically below 10°C, night temperatures were below freezing and the mixing water temperature was about 4°C (originating from snow melt run-off).

3.8 Scaffolds

Unless mortar and stone is delivered on the dam wall with cranes or conveyor belts, it will be necessary to construct access to the wall for wheelbarrows and/or front-end loaders. In both Zimbabwe and South Africa, the method so far adopted consists of constructing a frame from steel scaffold pipes supporting running boards of construction timber. Fill ramps have been successfully used to allow a front-end loader to get close enough and high enough to deliver mortar directly to the point of placement.

Formwork and solar blankets may be required to protect green mortar against excessive cold.

3.9 Cement storage

Depending on the size of the dam under construction, it may be advantageous to dispense cement from a silo. If bagged cement is used, facilities to keep this dry at all times must be provided on site.

Sundry items

No RMC dam construction site would of course be complete without numerous wheelbarrows, spades and shovels. Tools to knock and press stones into the receiving mortar are also required.

Other temporary works

Other temporary works consist of the contractor's site facilities, which could include:

- Explosives magazine
- Laboratory facilities (mortar sand grading analysis; mortar slump test apparatus; mortar cubes and crushing apparatus; large masonry cube forms)
- Storage sheds
- Ablution facilities for the large numbers of workers
- Food preparation and dining facilities
- Protective clothing and gloves for the workers.

4. Design considerations

Performance characteristics of RMC

South African experience has confirmed the general behaviour patterns of RMC that form the basis of the empirical design approach applied for dams in Zimbabwe. This section presents the particular performance characteristics exhibited by RMC in dams, with a specific focus on the aspects in which the behaviour of RMC differs from that of conventional mass concrete.

4.1 General

These guidelines have been prepared for an engineer with an appropriate level of knowledge of dam design and do not attempt to cover dam design per se, beyond suggesting the particular analysis methods that have proved most appropriate in the case of small- and medium-size RMC structures. In view of the inherently greater design complexities of an arch dam, when compared to a gravity structure, the guideline concentrates on variants of the arch dam type. While RMC is an appropriate material for gravity dam construction, the reduced material volumes inherent to an arch configuration imply that arch dams are likely to be the preferred solution for most RMC dams of heights greater than five to seven metres.

4.1 Factors of importance in relation to RMC behaviour and performance

4.1.1 Seepage

RMC dams seep, rather than leak, before sealing themselves and becoming watertight. In this process of sealing, efflorescence and calcite are deposited in layers on the downstream face and the white streaking effect detracts from the finish of the wall. However, as the seepage diminishes, the calcite deposits dry, weather and discolour to a greenish brown, depending on the dampness and extent of attached organic growth. When particularly pure, aggressive water is impounded, self-sealing, may not occur as effectively and careful consideration should be given to appropriate section dimensions and indeed even the appropriateness of RMC in such environments.

4.1.2 Cracking

General observation indicates that RMC does not crack, or does not exhibit drying shrinkage and thermal cracking in the same manner as conventional concrete. While this property is not widely understood and cannot currently be satisfactorily fully justified on engineering principles, reliance in design is placed on the no-cracking performance of RMC. In an effort to derive an explanation for this behaviour, several hypotheses can be evaluated.

These hypotheses include the following:

- Mortar drying shrinkage is of little influence, as continuous contact between rock particles will prevent related shrinkage of the body as a whole,
- Differential stresses established during hydration and cooling are minimal, as structural elements are thin and the pace of construction is slow,
- Micro-cracking may well occur within the mortar matrix in RMC, but the large random and interlocking stone particles prevent related continuity causing single, large cracks,
- On a macro scale, the large stone particles and related interlocking produces a material of relatively high tensile strength.

Experience has shown that high mortar content RMC can crack and will undoubtedly exhibit less favourable behaviour than will a high rock content matrix.[6] Whilst conventional concretes are proportioned to ensure that all surfaces of the coarse aggregate particles are covered in mortar and paste, high rock content RMC comprises a matrix of large rock particles in contact and surrounded and in-filled by mortar. In compression, it is likely that the rock properties will play a dominant role, whilst in tension the mortar and the interlocking of rock particles are likely to be more significant.

It is believed that a sensible evaluation of cracking in RMC, on the basis of the current level of material knowledge, might be summarised as follows:

- RMC exhibits negligible drying shrinkage,
- RMC in arch dams almost certainly does crack, under load, at the heel of the

[6]This type of cracking is normally related to drying shrinkage and thus the water requirement of sand. High cement content mortar may cause larger cracks at larger intervals than a leaner mortar which will have smaller width cracks at closer intervals.
Due to its general proportions, concrete for dams does not usually exhibit drying shrinkage in the same manner as smaller concrete members. Observed cracking in concrete in dams more usually relates to differential thermal, or long term thermal effects.

tallest cantilevers, but as is the case with other dam types, this cracking is not visible as it is only present well beneath the water level,
- Without sophisticated instrumentation and related measurement, the observance of structural deformation is not really possible, particularly on the small scale of the dams in question, and it is suggested that fairly large deformations allow the re-distribution of stresses reasonably effectively. The use of materials of a lower elastic modulus is obviously significant in this regard.

Avoid inducing high tensile stresses

Cracking of RMC can, however, occur and care should be taken to avoid typical situations that can induce high tensile stresses, such as:
- large rock particles randomly inserted into a high cement content, and/or wet mortar,
- an excessively high mortar / rock ratio, with negligible rock contact and interlocking of particles,
- construction at the warmest time of the year, particularly in an extreme climate,
- straight sections of wall with a significant length to height ratio.

4.1.3 Research into the structural behaviour of RMC under load

Structural and materials research into RMC in Southern Africa is currently rather sparse and has to date largely been pursued by Rankine[1,2,3 and 4]. While the experimentation undertaken has addressed dams peripherally, the central focus has been the application of RMC in the construction of small bridges. Furthermore, the scale of the components comprising the RMC mix, with rock particles as large as 60 kg, makes testing rather difficult and expensive, requiring specialist, large-scale equipment. Within the scale of the industry related to RMC and the works constructed in this material, it is difficult to motivate the necessary, but expensive, research required to develop a comprehensive understanding of the material.

The most recent research, however, has focussed specifically on the isolation of the mechanical properties of RMC, with particular emphasis on the relevant aspects for dam engineering. Fine and Rankine[1,2 and 4] have used 500 mm cubes to test, evaluate and compare the properties of RMC, primarily in terms of crushing strength and deformation modulus. In this work it was demonstrated that the deformation modulus of RMC is largely determined by the elastic modulus, shape and orientation of the rock inclusions. With rock moduli varying from 24 to 120GPa, a range of RMC deformation modulus of 5 to 71GPa was demonstrated for a constant mortar deformation modulus of 18GPa. The particle orientation of large rock inclusions was demonstrated to be of significant impact on the modulus for RMC comprising all rock types, with particularly detrimental effects being observed for low moduli, elongated particles orientated parallel to the loading direction. A further important aspect that was determined through testing and modelling was the respective role of particle size and inter-particle contact within the mix. If the rock inclusions are in intimate contact, the overall modulus will be higher for a large number of small particles than for a few large particles, with the latter scenario developing significantly higher local stresses in transferring stress through the matrix. If, however, all particles are surrounded by mortar, the stiffness modulus is independent of particle size and transfer stresses are significantly reduced.

Hard rock particles with soft surface weathering have been used in the past in RMC bridges. Research has demonstrated this rock type to produce particularly low strength RMC. This is not only a function of the particle strength, but also the associated complete lack of surface bond between mortar and rock. (Refer also to 2.3.)

Review of the structural implications of RMC research findings

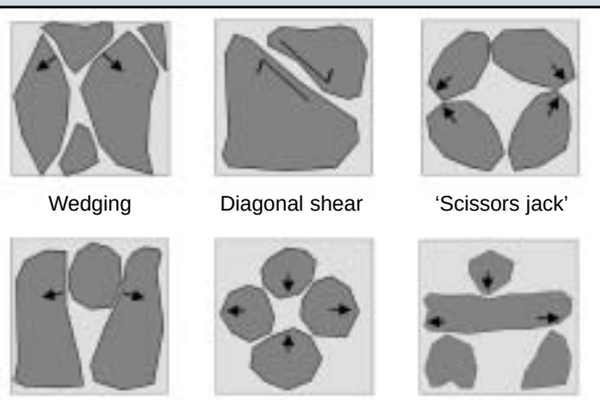
The findings of the RMC research completed to date have been presented in a largely factual format, with very little analysis and review of associated causative mechanisms, or related structural implications. It is, however, possible to draw a great deal more out of these results and there is significant value to be gained in reviewing the impact of such inferences against the performance requirements inherent to arch dam engineering. It must, however, be recognised that test cubes containing large rock particles, which are pressed using extremely hard, un-deformable surfaces, will tend to reproduce the extremes of behaviour in RMC. While the dominant stress paths tend to be relatively localised in dam structures, plenty of room for a spreading and redistribution of stress exists and some of the effects revealed through the research to date will certainly be mitigated in this process.

Key aspects may be summarised as follows:

Particle orientation and mortar separation

In dam engineering, placement of RMC in horizontal layers tends to ensure that any particle to particle contact is predominantly vertical and that the longer dimension of particles is orientated vertically. This suggests that RMC in dams is likely to exhibit a higher deformation modulus in the vertical direction than in the horizontal direction. In an arch dam this can be seen to be of some advantage, as cantilevers become stiffer, creating lower overall displacement and arch action allows more yielding, which lowers overall maximum stresses. In the arch structures typically constructed in RMC, the largest compressive stresses are furthermore orientated in a predominantly horizontal direction, suiting the better performance axis of the RMC. While no related testing has yet been completed, it is quite likely that such particle orientation will also give rise to greater tensile strength in a vertical direction, where this is required.

Figure 2: Possible structural mechanisms within RMC cube



The improved performance of RMC when the rock particles are evenly distributed and evenly separated by mortar of 7 mm to 20 mm thickness tends to reflect the importance of mortar workability and construction technique on the final structural performance characteristics and these must be given careful consideration in the compilation of construction specifications.

Structural mechanisms and Poisson's ratio

The research of Fine and Rankine[4] suggested the possible existence of a number of structural mechanisms within the 500 mm test cubes. These are illustrated in Figure 2 and each of the mechanisms postulated serve to suggest the possible modes of cube failure and explain why some cubes might exhibit particularly high poisson's ratios.

The mechanisms suggested are likely to be particularly influenced by scale effects. When the size of the stone particles is smaller in relation to the member under stress, it is very likely that the influence of the identified mechanisms will be significantly reduced. Furthermore, some measure of three dimensional restraint will also assist in distributing stresses more evenly through any member that is relatively massive in relation to its constituent components.

RMC – the nature of material

While the broad behaviour of RMC in dams can most closely be likened to that of conventional mass concrete, there are specific differences that must be addressed in the process of design. To understand the important factors of influence on design and the approach applied to the design and construction of RMC structures, it is first necessary to understand the nature of the material itself. While the general composition, mixes and behaviour variations of the material are discussed in subsection 2.2 of this guideline (Materials requirements), the structural characteristics and performance of RMC are addressed in this sub-section.

4.2 Dam design influences

4.2.1 The development of RMC in dam engineering

Whilst RMC arch dams have seen broad application in Zimbabwe since 1985, distinct differences exist between the application of RMC for dams in that country and in South Africa. These various differences require that engineers in South Africa create and develop a greater understanding of the material and its behaviour, and indeed its likely variations in behaviour, before implementation on ambitious designs. The dams constructed in Zimbabwe to date have apparently universally demonstrated exemplary behaviour. However, it cannot be considered sensible to blindly apply an empirical design approach, developed for different circumstances, without a full and comprehensive

understanding of all related important factors of influence on design and construction.

While the history in Zimbabwe of more than 15 years of 'new generation' RMC arch dam construction provides very useful reference, the prevalent level of knowledge of the material characteristics and the lack of published data and information leave many questions unanswered. Construction in Zimbabwe has seen the almost exclusive use of granitic aggregates, on granitic foundations, while in South Africa. There is a significantly broader range of geologies and construction material characteristics. Furthermore, climatic variations across Zimbabwe are less significant than across the breadth of South Africa and accordingly, while temperature related effects have been rather inadequately addressed previously in RMC arch dam design, information concerning successful precedents exposed to environments as extreme climatically as certain parts of South Africa is sparse.

4.2.2 Construction without contraction joints

RMC dams, particularly arch dams, are usually constructed without contraction joints, to allow for the effects of thermal shrinkage. While the consequences of thermal effects on arch action within a dam wall are addressed later in this section, it is important that the designer consider very carefully the necessity to include contraction joints and the structural implications, should they be omitted.

Multiple arch buttress dams of well over 200 m in length and arch dams of up to 150 m in length have been constructed in RMC without suffering any cracks. On the basis of past experience it is considered that joints within arch sections can and should be avoided, if possible, as a joint in an arch would require grouting to re-establish structural continuity. A single joint, or widely spaced joints in an arch, if left un-grouted, may well result in greater stress concentrations than would occur in a structure with no joints.

When to include contraction joints

There are certain circumstances for which the inclusion of contraction joints is considered advisable, including:

- when differential foundation settlement, or movement is possible,
- when the length to height ratio of a straight section of wall becomes excessive,
- in extreme climatic conditions.

4.2.3 Construction without shutters

RMC dams will generally be constructed without shutters, as the drier external zones are placed first to contain the more flowable mortar matrix into which the rock particles are embedded. Construction in such a manner, however, implies that different structural characteristics can be anticipated for the internal and external zones of the dam wall. Whilst the mass of both zones will contribute to the overall structural stability, only the internal zone will be capable of carrying the full design compression, shear and tension stresses and only this zone will contribute to the water-tightness of the structure.

If the technique of placing a flowable RMC within drier external walls is used, careful attention should be given to the possibility of rapid drawdown of the reservoir, when considering rendering (plastering) of the upstream face. If the dam design allows the impounded reservoir to be drawn down rapidly and a permeable zone exists within the dam wall between the plastered upstream face and the impermeable central RMC zone, an unbalanced water pressure can develop that may result in bursting of the upstream face surface.

In colder placement temperatures and in some instances when a cement with a retarded set is used, problems may be experienced in movement of the external wall zones during placement of the internal, structural masonry. Such a phenomenon can obviously compromise the integrity of the structure and when it is observed, remedial measures should be taken. Such measures might include widening the surface zone, constructing in lower lifts, the use of steel reinforcement in the surface zone, or the use of facing shutters.

4.2.4 Practical construction constraints

A large part of the success of RMC dam construction to date has been found in its simplicity and an ability to utilise low skill labour. The need for simplicity and the nature of this shutterless construction, however, limits the practicality of more complex dam geometries and arch shapes. Above a certain height, significant benefit is derived in creating additional sliding resistance for a concrete multiple arch dam by sloping the arch forward, to mobilise the weight of the water and develop additional vertical load on the foundation. To date, no economical solution has been found to allow inclination of the arches of an RMC multiple arch dam.

4.2.5 Ineffective self-sealing

When particularly pure, aggressive water is impounded, self-sealing may not occur as effectively and careful consideration should be given to appropriate section dimensions and indeed even the appropriateness of RMC in such environments.

4.3 Dam design considerations

4.3.1 RMC elastic modulus and thermal expansivity

It is likely that a relatively low elastic modulus and the use of material with a low thermal expansivity in relatively temperate climates are important factors in the apparently successful behaviour of RMC to date. When investigating higher RMC arch dams, for which higher strength RMC is necessary, it is very possible that increased cement contents and/or the use of very hard rock aggregate could compromise RMC behaviour, producing a material more closely emulating concrete.

Testing essential

In considering the construction of a high (above perhaps 16 m) RMC arch dam in South Africa, it is suggested that the establishment of actual RMC mechanical properties through realistic testing is essential for any constitutive materials save for granite applied in a mild climate.

The relative sensitivity of RMC arch dam performance to thermal expansivity and elastic modulus can be illustrated through the typical effects indicated in a study of stresses for a typical RMC arch dam when subjected to a uniform structural temperature drop of 6°C. Table 3 below presents an indicative summary of the impact of typical materials variations on stress and displacement for this relatively mild drop in body temperature. Obviously, neither thermal expansivity, nor elastic modulus variations are of any influence on structural stress levels if no temperature variation load is applied; only displacements being affected.

Table 3: The effect of materials properties on arch dam stress levels under a 6ºC temperature drop load

Modulus of Elasticity	Thermal Expansivity	Compression	Shear	Displacement	Indicated Tension
Low	Low	6,5	1,2	8,6	4,0
Low	High	8,1	1,4	12,2	5,6
High	Low	8,4	1,5	4,8	5,9
High	High	12,6	2,7	8,4	10,5

4.3.2 Climatic- and environment-specific conditions

In observing an empirical approach to RMC dam design, on the basis of Zimbabwe experience, we must bear in mind that elsewhere in southern Africa, we can experience a significantly wider range of construction material types, foundation geologies, climatic conditions and site specific circumstances. For instance, it is significantly possible that surface freeze-thaw conditions within RMC, in through seepage water, could occur in the colder areas of South Africa and Lesotho. Furthermore, aggressive, ion hungry water may not allow the process of seepage self-sealing to occur as effectively as has been the case to date.

It is accordingly important that the designer weigh fully the consequences and implications of the climate and the materials of the environment in which it is intended to build an RMC dam, as well as any other circumstances of specific relevance. In a climate where surface freeze-thaw conditions can occur, great care should be taken in relying on the RMC as the impermeable barrier, as ongoing degradation of the downstream surface zone could eventually compromise the overall structural integrity.

Understanding range boundaries is important

Analysis of RMC arch dams for a range of climatic conditions and constituent rock materials characteristics serves to illustrate clearly the specific conditions where RMC should be used with great caution. For example, a dam of 20 m height, constructed predominantly in winter using granitic aggregate in an area of temperate climate (6°C structural temperature drop), might indicate maximum compressive stresses of 6,5MPa and maximum total shear of 1,2MPa. The equivalent structure constructed with a competent quartzitic aggregate in an area of more extreme climate (10°C structural temperature drop) might indicate maximum compressions of up to 15,8MPa, together with total shear of up to 4,1MPa. Whilst the former stress levels may be considered acceptable in design, the latter would not even be acceptable for a 30MPa RCC, for which cohesions in excess of 5MPa can be developed.

4.4 Dam design approach

4.4.1 Gravity dams

Many masonry gravity dams were constructed in what is now the developed world during the latter part of the 19th century and the early 20th century. In developing countries, such as China and India, the construction of masonry gravity dams remained commonplace until relatively recently, with the advent of Roller Compacted Concrete (RCC) being seen to have had a dramatic impact on the number of high masonry gravity dams constructed since 1980 in China. It is possible to construct a conservatively proportioned masonry gravity dam to a height of well over 50 m before stresses reach critical levels. For example, Zhuzuang Dam in China was completed in 1979 to a height of 95 m, while the 93 m Baoquan Dam, which was completed in 1976, contains over one million m^3 of masonry. For such high masonry dams, concrete face slabs have been applied to ensure impermeability.

On the scale likely to be applicable in South Africa, design and materials strength considerations for masonry gravity dams are accordingly significantly less critical than is the case for arch dams, where critical stress levels are reached for much smaller structures.

4.4.2 Stress criteria for arch dams

Setting design stress criteria for any 3D arch dam is highly inadvisable without first defining the method of analysis. However, one should bear in mind the basic principles and material safety factors typically applied in dam design and consider this against the levels of quality control and the final variation in material properties achieved using the RMC method of labour construction. Compressive stresses should only really be evaluated once associated tensions and shears are within acceptable ranges. Furthermore, to arrive at a fully optimal wide valley arch dam design, non-linear analysis will be required to allow cracking under cantilever tensile stresses.

Significant attention should be given to shear stresses within an arch dam toward the higher end of the range of RMC dam heights, particularly in the case of a wide valley site, where a tendency for cantilever base translations will be evident. The effects of shear are specifically critical in RMC arches of simple geometry that do not benefit from the related advantages of double curvature. A secondary effect of the inability to stiffen the cantilevers by means of vertical curvature is the development of vertical bending (bursting) tensions in the middle of the downstream face.

4.4.3 Design

In view of the various design uncertainties that will undoubtedly be present in relation to RMC materials behaviour and the final applicable structural

temperature drop, it is suggested that the best design tools possible be applied where ambitious arch configurations are proposed. By using a finite element (FE) model, and varying material properties, it is relatively simple to isolate anticipated performance and stress levels within an envelope and accordingly at least the structural effectiveness of the proposed structure may be confirmed with some degree of confidence. For a small RMC arch, or multiple arch buttress, practical construction limitations become the dominant factor and thermal stresses and effects are small and/or of limited consequence on structural function. In such instances general principles and hand calculations can represent an adequate design approach and FE analysis will not necessarily always be required. It should be possible to analyse and construct straightforward dam designs confidently on relatively small scale without any surprises. In light of the fact that RMC arch dams are constructed without groutable joints, temperature drop analyses must always be included in the process of design.

4.4.4 Temperature-related factors

Temperature effects were apparently only superficially addressed in early RMC arch dam design and it is considered of critical importance that this situation be redressed, as shrinkage effects relating to cold temperatures have significant effects on the overall structural function of arch dams, particularly those in wide valleys. This effect is obviously of even greater significance when the dam in question is constructed without joints, which can be filled with grout when shrinkage occurs. RMC dams are constructed without contraction joints and the final structure effectively forms a single monolith from one abutment to the other. All thermal effects, expansion as a result of hot temperatures and contraction as a result of cold, must be accommodated within the body of the structure itself. In relatively thin structures, such as arch and arch buttress dams on the scale applicable to RMC, the entire wall will be largely subject to surface temperature effects, with significant insulation from external temperatures typically only occurring at depths in excess of three to four metres from surface[8]. Similar thermal phenomena and consequential effects have been studied in some depth for other concrete dam types and specifically for RCC dams [7, 8 and 13]. RCC arch dams suffer similar effects, particularly in respect of the fact that both RCC and RMC dams are constructed as continuous bodies, usually in horizontal placement layers from one flank to the other, and not monolithic blocks as is the case for conventional concrete. Although placement rates and hydration heat related problems are significantly different in each case, parallels may be drawn and much experience gained in thermal and related structural analysis of RCC and concrete arches may be applied to RMC arches.

A typical South African climate might see effective RMC placement temperatures averaging perhaps 22°C, final minimum winter water temperatures of perhaps 10°C and a minimum average daily winter air temperature of around 8°C. Assuming some insu-

Figure 3: Typical stress movement through arch dam

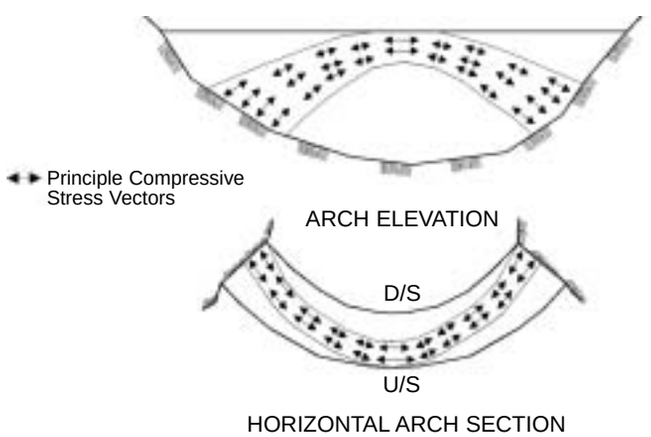
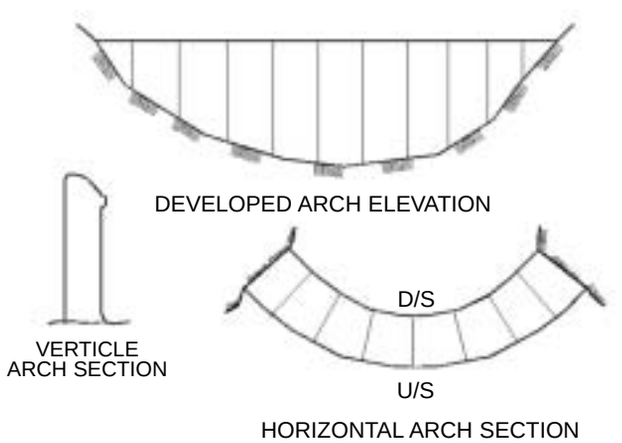


Figure 4: Arch represented as a series of blocks



lation and temperature time lag, and remembering the thin sections typical of RMC arches, an effective temperature drop of the RMC from placement to minimum winter temperature might very easily be as much as 10°C. On the optimistic side, an RMC structure in such an environment might accordingly be required to accommodate temperature variations of the order of at least 6°C above and 8°C below placement, 'zero stress' temperature. Assuming typical concrete properties for RMC, the structure would be subject to direct temperature compressions and tensions of at least 800kPa and 1,2MPa respectively.

All variants of the concrete arch dam are inherently susceptible to temperature related effects, although very efficient arches, such as those in tight V shaped valleys where arch stresses are high, are less sensitive than those in wider, open valleys, where cantilever stresses are more pronounced. Whilst an arch dam is an inherently safe structure which can generally be pushed way beyond design loadings before failure, nevertheless it is considered important that efficient function is preserved and that the mode of structural function is well understood by the designer.

In the case of an arch dam in a wide open valley, the water load develops arch stresses that are transferred internally through the top of the dam in the centre down into the lower portion of the abutment on each flank (see Figure 3). Very little lateral compression is developed in the lower portion of the central section of the wall. When subjected to low temperatures, the wall structure effectively shrinks, although its foundation remains unaffected, causing tension across the structure, from one abutment to the other. To accommodate the water load, the structure must take up these tensions through movement, which occurs by a general deflection of the crest downstream and an associated tipping forward of the dam wall, which causes increased tensions at the upstream heel and increased compressions at the downstream toe. In addition, the area of effective arch compression, through the upper portion of the dam in the centre (between abutments), decreases and associated levels of compression over this smaller area correspondingly increase. In broad and general terms, less of the structure functions to transfer water load into the foundations, stress within the effective areas increases and the structure becomes less efficient in function, with a significant portion of its volume no longer carrying structural load.

This effect can be described by imagining the dam wall as a series of monolithic blocks as pictured in Figures 4 to 7.

Temperature shrinkage of the wall would cause each of these blocks to reduce in size and shrink away from each other as illustrated in Figure 5, the most significant opening between blocks occurring farther away from the restraining points (abutments).

Figure 5: Arch represented as a series of blocks

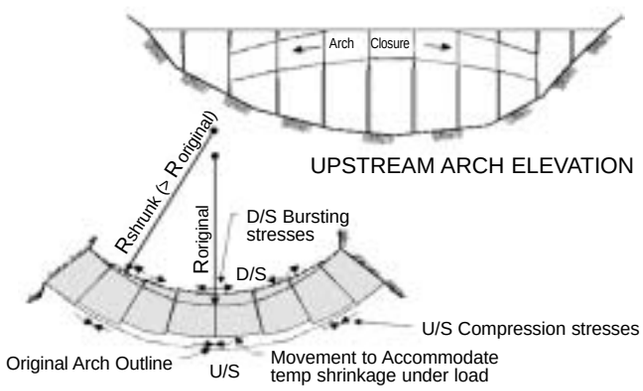


Figure 6: 'Shrunk blocks' after temperature loss

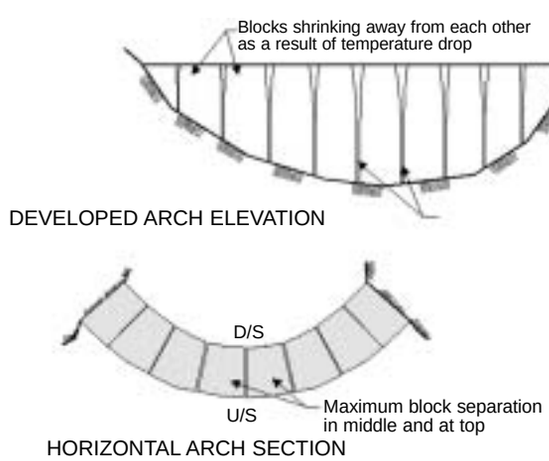
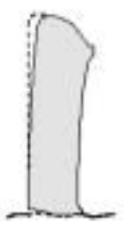


Figure 7: Deflection of cantilever (Temp. + Water)



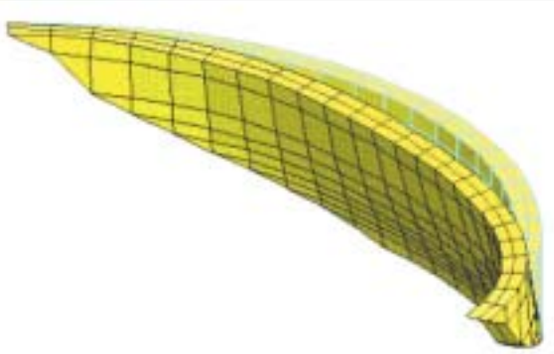
VERTICLE
ARCH SECTION

To accommodate the water load and associated arching stresses, the blocks deflect as cantilevers in a downstream direction until closure between blocks occurs at the crest. As a result of the restraint of the wall against the abutment on either flank, and the higher flexibility of the taller cantilevers, the central portion of the crest moves furthest, with each successive block to the sides moving less. The consequence of this effect is a final arch with a larger effective radius (see Figure 6). The alignment of the sides of each block remains oriented on the original radius and accordingly the wedge shaped blocks are effectively too narrow at their downstream faces to form complete and even contact with each other on the larger, deflected radius. This in turn implies that the blocks will make contact with each other initially only over the upstream side of their respective surfaces and the arch will accordingly display a 'bursting' effect. In this process horizontal compressive stresses in the central upstream portion of the arch increase, as do horizontal tensions in the downstream portion and tensions in the heel and compressions in the toe at the abutments. Looking at the wall in terms of a series of cantilevers, this effect is seen as a tipping forward of the upper portion, as shown in Figure 7.

In the described process a great deal of the efficiency of the arch is lost, with only the portions of the structure illustrated in Figure 5 actually being effective. If a zero tensile stress is assumed for the RMC, all areas of tension will be subject to cracking and compressive stresses in the remainder of the wall will correspondingly increase to redistribute structural load.

In the case of a conventional concrete arch dam, these temperature effects are mitigated by construction in monolithic blocks, with subsequent grouting at low temperature to re-establish structural continuity between the blocks, on the original arch radius. In the case of an RMC dam, it is not possible to re-establish structural continuity by grouting and the design must accommodate these effects; in virtually every case, the most severe loading case being hydrostatic, gravity, uplift and temperature drop loads. (See Figure 8 and Table 4)

Figure 8: Exaggerated temperature and water structural wall deflection

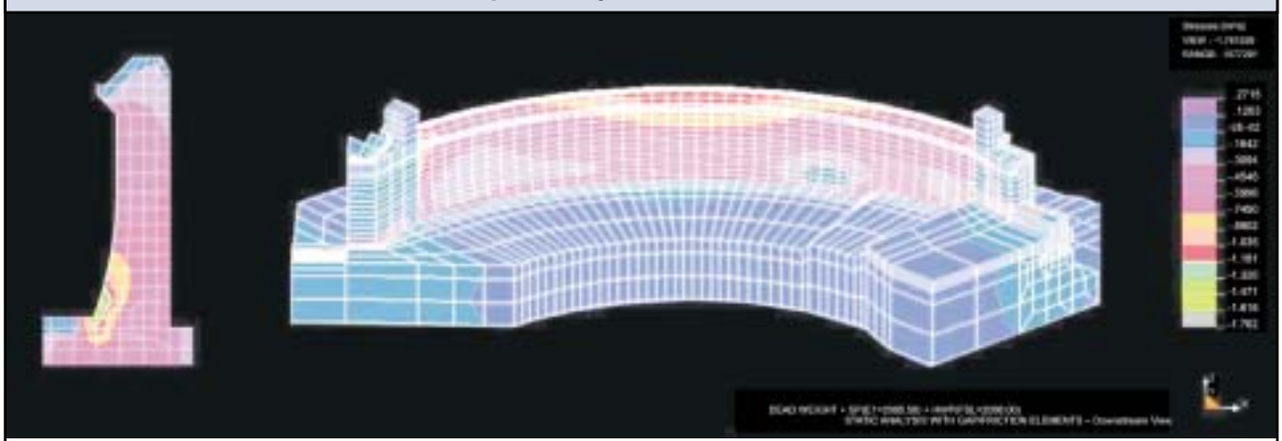


It is, however, valid to note that the only manifestation of the above effects that might be visibly obvious is the downstream face bursting tension, if cracking results. As has been demonstrated through FE modelling and investigation, using an RMC of relatively low elastic modulus significantly reduces the level of these tensions. (See Figure 8.)

The important temperature-related factors of influence can be summarised as follows:

- Thermal effects are critical in the design of RMC arch dams and may not be ignored,
- Thermal effects are highly dependent on RMC material properties, specifically thermal expansivity and elastic modulus,

Figure 9: An example of the stress display of a non-linear static-elastic finite element model of an arch dam with thrust blocks in a wide U-shaped valley.



A friction gap element is modeled on the upstream foundation contact. Temperature drop and temperature differentials between the upstream and downstream faces were modeled for both winter and summer conditions.

- Even in ideal climatic conditions, temperature drop related stresses are significant in relation to hydrostatic structural stresses, irrespective of RMC material properties,
- A low thermal expansivity in RMC is of significant advantage in lowering temperature related structural stresses,
- RMC with a low modulus of elasticity displays greater deformation, but lower critical stress levels, as the more malleable structure deforms and re-develops arching more effectively than a stiffer structure, in which stress is passed through smaller contact areas,
- It appears that the Zimbabweans have been very fortunate to date in their application of RMC in arch dams using granite, as this material's low thermal expansivity and lowish elastic modulus appear to be ideal in producing low stress levels in a wide valley arch dam,
- Where RMC of relatively high thermal expansivity and high elastic modulus is constructed in an extreme climate, temperature effects are critical and stresses may very easily reach dangerous levels.

Specifications

It is always possible to mitigate deleterious circumstances through clever specifications and careful, sensible construction planning. Minimising the 'built-in' RMC temperature will obviously be of benefit in reducing the differential between the 'zero stress' state and the lowest, cold winter temperatures, or the final structural temperature drop.

Table 4: The Effect of temperature on arch dam stress levels

Environment and materials	Compression (MPa)	Shear (MPa)	Maximum Crest Displacement mm	Indicated Tension (MPa)
Good Materials * Ignoring Temp.	5,4	1,1	6,1	0,5
Good Materials + cold climate (10°C temp.drop)	7,3	1,3	10,3	4,8

*- For RMC, good materials = low thermal expansivity and lowish modulus of elasticity.

4.4.5 Foundation dowels

It is usually considered wise to include dowels into the foundation for an RMC arch. With a small dam / foundation contact surface area for an RMC arch, the level of cohesion achieved cannot always be reliably assured and these dowels serve to promote a greater structural mobilisation of the foundation rock-mass beneath the dam. As a general rule, dowels of this nature are only used to increase the factor of safety against sliding and a reasonable factor of safety must anyway be ensured ignoring the effect of the dowels.

5. Construction technique

5.1 Materials procurement

5.1.1 Stone

A number of variations exist with regard to procuring masonry stone.

If suitable surface stones are available in sufficient quantity, then the masonry stone can be collected and stockpiled by hand, from where it can be hand-loaded and transported to the dam wall, usually with a tractor and low-bed trailer.

If suitable surface stones are not available, then quarrying the masonry rock may be the next best option. The technique used for quarrying the rock is to fragmentation-blast the rock so that the largest proportion of the rock fragments break up into the size range 100 mm – 300 mm. In Zimbabwe it is common practice to blast the rock so that it is dispersed over a wide area from where it can be hand-loaded onto scotch carts. This technique is mostly not acceptable in South Africa, for environmental and safety reasons. The most common practice here is to develop a face in the quarry where the blast is contained. The blasted mixture of rock and dust is mechanically loaded onto dumper trucks for transportation to the dam wall. At the dam wall the rock mixture is dumped onto a sloping grizzly screen where the undersized material is screened out. As far as is practically possible, oversized rocks in the building stockpile are broken down with heavy hammers.

Commercial sources for stone

When no rock is available on site, or if small quantities are required, it may be best to procure masonry rock from a commercial source such as a crusher. Stone of a suitable size for use in RMC for dams is usually sold commercially as either Gabion stone, or dumped rock.

5.1.2 Sand

Sand is the most important ingredient in producing good quality masonry. It is therefore necessary to locate and test sufficient deposits of mortar sand sources early in the project phase. The most desirable situation is if suitable mortar sand can be sourced from within the future dam basin or within the river reach near the dam wall. When sourcing alluvial sand adjacent to a river, seasonal flooding should be taken into account as this may prevent accessing the sand at a crucial time during construction.

Alluvial sand derived from the erosion of many sedimentary rock types, is not suitable for use in mortar, as a result of a non-continuous single-size grading that can result in high permeability, bleeding and low mortar strengths. It has been found that this problem can usually be solved by blending such sand with crusher sand.

Standards for sand

The blended sand should comply with the requirements of SANS 1083, or SANS 1090. If available sands do not comply with these standards, their suitability for use in RMC should be evaluated and certified by a recognised testing laboratory.

In Zimbabwe and in large parts of South Africa, granites make up the base geology from which good quality concrete sands are derived. Sand is usually deposited according to particle sizes, namely coarse sand under fast flowing conditions and fine sand under slow flowing conditions. This often necessitates sourcing sand from two locations and then blending the 'concrete sand' and the 'pit sand' to achieve the desired grading.

5.1.3 Cement and cement storage

Cement which is stored on site shall be adequately protected against moisture and other factors that may cause it to deteriorate.

Cement for masonry mortar in dams is usually specified to contain filler agents such as Fly Ash, Granulated Blast Furnace Slag or Hydraulic Lime. The purpose of these filler agents is to improve water tightness, to delay set, to decrease the rate of hydration and total heat created, to increase strength gain over time and/or to improve workability of the mortar. It is desirable to procure cement pre-blended in pockets, or in bulk if a silo is provided. Cement blends are often cheaper when pre-blended and there is no chance of getting the mix proportions wrong (like

leaving out the cement!). Cement should be stored and kept dry until it is placed in the drum mixer.

5.2 Preparatory activities

5.2.1 Foundation excavations and treatment

The general approach applicable for the foundations of a concrete dam should be applied for the rock foundation of a masonry dam. When excavating into rock foundations by blasting, care should be taken to avoid consequential damage. This can be achieved by line drilling and pre-splitting to form the sides of the foundation key and by decreasing the burden and spacing inside the foundation key. Light blasting or no blasting (i.e. using non-explosive excavation methods) is the key to creating a sound foundation excavation.

5.2.2 Material storage

Care should be taken to avoid contamination of materials during storage and particular care is necessary when sands of different gradings are to be blended. The typical arrangements and procedures of good concrete practice should be observed for all aspects related to the materials to be used in RMC dam construction.

Assumptions re dam size

The nature and extent of the necessary river diversion for an RMC dam will, as always, depend on the size and hydrology of the river to be dammed and the size and construction duration of the dam itself. However, in this guideline only small to medium sized RMC dams are addressed within the context of southern Africa and accordingly certain assumptions can be considered generally valid.

5.2.3 River diversion

For small to medium sized RMC dams, where catchment size is not excessive, as will generally be the case, river diversion and flood handling during construction are very straightforward. As RMC dams are constructed as monolithic structures, without joints, if the arches are constructed in relatively horizontal layers, then the structural integrity is assured at all times. Whilst early loading of RMC might be undesirable, hydraulic pressures incurred during the passage of a relatively short-lived flood event can be handled with ease and without any detrimental consequences.

Normal flow can be handled through a permanent bottom outlet installed at a low point in the wall. Alternatively, a dedicated river diversion facility can be installed as described below.

Construct a low (± 2 m high) masonry cofferdam on the upstream side of the weir, ± 2 m away from the upstream face of the arch wall. A large diameter (± 1.5 m diameter) pre-formed pipe (spun concrete or AC sewer pipes are ideal) must be cast into the cofferdam so that it will extend through the upstream face of the weir and beyond, by about one metre. This pipe must be installed in the lowest section of the riverbed and will be bedded in and surrounded by concrete. A ± 600 mm diameter preformed manhole must be attached to the soffit of the diversion pipe, adjacent to the upstream face of the arch wall. Upon completion of the dam wall, first closure will be affected by fixing the permanent bottom outlet inside the diversion pipe and by closing the upstream and downstream annulus with formwork, thereby forcing river flow through the bottom outlet. The annulus between the diversion pipe and the bottom outlet must then be concreted up through the upstream manhole. Closure must take place when flow in the river is less than the outlet capacity of the bottom outlet.

Quality of mortar crucial

The quality of the mortar will ultimately determine the quality of the masonry, both in terms of strength and water tightness. It is therefore more crucial to attend to this aspect of the construction than anything else.

5.2.4 Mortar batching and mixing

It is usual to complete batching for RMC dam construction by volume. If mass batching can be achieved without excessive additional cost, the related accuracy and increased control is advantageous. Batching plants should be accurate and

regularly checked. In instances when volume batching is carried out using wheelbarrows, etc, great care should be taken to ensure adherence to correct materials proportioning and regular checking and intelligent supervision is necessary. Cement should not , however, be measured by volume but by mass, typically per 50 kg bag.

Mortar is made by mixing sand, pre-blended cement and water in a drum mixer. On smaller projects, mixing can be accomplished manually, although experience has shown that better results and greater overall efficiencies are achieved using a mechanical mixer. (The quantity of water added to the mix cannot be controlled when mortar is mixed manually.) Mixing should ensure that the mortar produced is of an even consistency, the correct slump and in compliance with the prescribed mix design and strength requirements. Care should be taken to regularly measure and/or assess the moisture content of the sand prior to mixing. This is very necessary to ensure that the correct amount of mixing water is added to the mix.

If the mixing water is very cold and/or the ambient temperature is too low, the mixing water should be pre-heated. In extremely warm ambient conditions, cooling the batching water by the addition of ice may be necessary, although this is not considered viable on anything but the largest projects for which RMC is likely to be used. Mortar should be placed within two hours of having been batched.

5.3 RMC construction

5.3.1 Stone preparation

Masonry stones should be thoroughly cleaned from all dust, mud and weathered scale. Stones should be wetted before being transported to the wall for placement. Jetting down stones with a high-pressure water jet, usually accomplishes both objectives of cleaning and wetting.

The exposure of stockpiled stones to direct sunlight should be avoided during warmer periods. If this exposure is unavoidable, stones should be selected for use only from the shaded side of the stockpile, or by selecting from sub-surface. Water jetting will also assist in cooling stockpiled stone.

5.3.2 Mortar and stone transportation

Mortar and masonry stones can be delivered to the dam wall mechanically using cranes, conveyor belts, or a front-end loader or alternatively manually, using wheelbarrows. Either way, it is important to ensure that stones of mixed sizes are delivered continuously. In Zimbabwe, manual transportation has been used to convey stones and mortar for a masonry dam of 16 000 m^3 body volume, while in South Africa a 5 600 m^3 masonry body was the largest constructed to date by conveying material with wheelbarrows. It is however anticipated that two dams about to be built, with masonry volumes of about 13 000m^3 each, will be built by using cranes to convey stones and mortar onto the wall.

5.3.3 Surface preparation

Before placing mortar and masonry stones on a previous lift, the surface should be cleaned of all laitance, loose rocks, dust and debris. The surface should then be watered down. If the surface is very dry, such as can be the case when the construction site is abandoned for the year-end builder's break or for phased construction, then special treatment of the surface will be required in order to ensure proper adhesion of subsequent lifts.

5.3.4 Placement and compaction

A number of variations exist with regard to the placement and compaction of

RMC. Whilst the Zimbabweans have developed certain methods and standard practices, various adaptations of these methods have been applied in South Africa.

The quality and durability of the final structure produced in water retaining RMC is obviously inherently sensitive to the methods applied for placement and compaction, as can be witnessed when inspecting many of the leaking masonry dam walls in places such as Mpumalanga.

It is important to understand that RMC for arch dams must not be perceived as a series of stones cemented together using mortar, but rather as a monolithic matrix, containing large stone within a body of mortar. In essence, this is similar in concept to the difference between brickwork and concrete. The former comprises a series of individual entities cemented to each other, while the latter comprises a body, or matrix of material made up of component constituents, in the form of cement, aggregates and water. When a 'rubble' masonry structure is built in a similar manner to brickwork, placing mortar as a receiving medium into which the surfaces of stones are embedded, the overall structural action of the final body of material is compromised. Stress transfer paths are predetermined and limited, local tension effects become significant, the mortar properties play a more dominant role and overall permeability is high.

Optimum structural performance

The optimal structural performance of RMC would seem to be achieved when the stone content is maximised without compromising the uniform and even separation of rock particles with 7 mm to 20 mm of mortar. Typical stone content will accordingly be approximately 55% of the masonry body by volume, with the balance (45%) comprising mortar.

Accordingly, the method adopted successfully for the construction of several dams in South Africa has involved the initial construction of dry stone walls on either side of a particular structural member to a height of approximately 200 mm, followed by the filling of the trough created with a relatively flowable mortar, into which large stone plums are embedded. The stone plums are forced deep into the mortar by being stood on and by being pressed in using a customised hammer tool created from a length of reinforcing steel bar, which actions further served effectively to compact the receiving mortar. Some stones are left projecting slightly above the top surface of each lift, to allow keying into the subsequent lift, and the receiving placement surface is cleaned thoroughly and dampened between lifts, as this surface tends to be damaged and dirtied by pedestrian movement. The 'dry' facing walls are constructed much like conventional brick wall, using stiff mortar as bedding for the facing stones, which are usually carefully selected for the purpose.

5.3.5 Surface finishes

Where RMC end walls must retain earth fill embankments, the surface against which the fill is to be compacted, must be plastered on completion to create a relatively smooth receiving surface with no overhangs or distinct discontinuities.

Surfaces in permanent contact with water must be flush jointed by plastering mortar into the grooves between surface (facing) stones. This results in less chemical and physical erosion. This measure is of particular importance for all surfaces exposed to freeze-thaw conditions, where ice can develop in surface grooves and then 'crack out' the surface mortar and rocks, in the same way as rocks are weathered.

In mild climates where the surface is not continually in contact with water and where a certain aesthetic finish is required, joints between the facing stones can be accentuated by raking out mortar to a specified depth.

5.4 Quality control and testing

It is important to address quality in RMC dam construction and whilst mortar cube crushing tests are a useful reference, the specification and regular encouragement of correct procedures and methods of construction to be observed is of greater importance. The labour and the contractor to be employed on small dams typically suitable to RMC will generally not be highly sophisticated and the repeated reinforcement of quality requirements and related appropriate procedures and construction methods will not be wasted.

The following quality control procedures should be implemented:

- Double-check all setting-out. Arch dams rely on their shape for strength and therefore the overall structural stability and integrity can be severely compromised if not constructed in accordance with the design dimensions,
- Count cement bags for each mortar batch (to ensure that the right amount of cement went into the mix),
- Keep a written record of mortar batches for each day and the amount of cement used,
- Calculate the volume of masonry batched over a period and compare it with the measured increase in the masonry volume. This is a good indicator of the relative volume of mortar in a unit of masonry,
- Check that each lift is cleaned and watered before placing the next lift,
- Keep placed masonry wet for proper curing.

Useful tests

The following tests are nevertheless useful and should be undertaken on a continuous basis:

- Sand grading analysis,
- Slump measurement on mortar,
- Manufacture and crushing of mortar cubes (crush at least half at seven days),
- On larger projects, some larger masonry cubes should be manufactured for crushing as a strength reference.

5.5 Dealing with inclement weather

Masonry construction can continue in very light rain, but should be stopped in heavy rain.

When constructing masonry in conditions of persistent extreme cold, such as during the winter in the mountains of Lesotho, a variety of measures may have to be implemented. Firstly, the mixing water drawn from the rivers will have a maximum temperature of about 6°C. This water will have to be pre-heated to about 60°C, resulting in a mortar temperature of about 25°C when discharged from the drum mixer. With day-time temperatures below 10°C and night-time temperatures below freezing, it is also necessary to protect the placed masonry mortar against freezing. The most effective way identified is to use plywood formwork to protect the side faces of the masonry structure and to cover the top surface with thermal blankets during the night.

5.6 Labour

5.6.1 Success factors for employment-intensive masonry construction

Labour productivity determines whether a masonry dam can be constructed at lower cost and within the same time frame as a plant-intensive design/construction solution. It is therefore important to pay attention to the labour-related issues that can make the difference in whether this type of dam construction is a success or not. Experience has shown that there are only two key determinants with respect to labour productivity, i.e. the type of labour recruited and the manner in which labour is employed. These two issues can be addressed through a range of strategies and measures, i.e. effective recruiting methods; good training; skills/leadership spotting/development; setting up appropriate task teams; and creating a productive environment (e.g. transport arrangements, site facilities, food, communication channels, etc). To develop task-based measurement criteria and setting productivity targets for remuneration purposes, require intensive initial experimentation on each project.

5.6.2 Management and skilled technical staff

The requirements for site management staff and skilled technical staff on masonry dam projects are the same as for any other dam construction project of similar size and these staff requirements will therefore not be discussed here. Only the labour requirements peculiar to masonry dam construction will be listed below.

Skilled masons: Skilled masons are required for building the facing surfaces of the structure in advance of the core or hearting. Ideally these masons should have demonstrated their skills on a previous project. They will report directly to the foreman. Their responsibilities will include the training of new masons and managing and directing their own support team who deliver material on the wall and who construct the hearting.

Heavy manual labour: Heavy manual labour can only be done by healthy and physically strong persons. This work typically includes the pushing of heavily loaded wheelbarrows up ramps, the handling of large rock particles, etc.

Light manual labour: Light manual labour includes such tasks as pointing or plastering the facing surfaces of the structures. This work does not place specific reliance on physical strength.

Mortar batching: Because of the high importance of this activity, it is essential to place a reliable person with the appropriate technical knowledge in charge of the mortar batching operations at each and every batching plant. His support staff must be able to do heavy manual labour.

Laboratory staff: At least one technically competent and very reliable person should be in charge of quality control. He should have one or two assistants. His principal functions will be to screen sand, do slump tests on mortar, make mortar cubes for testing, report results daily to the Site Agent and immediately raise the alarm if tests indicate that technical specifications are not being met.

Typical construction teams: A masonry construction team typically comprises five workers as follows:

- One mason,
- Two assistants (for the mason). They place the hearting masonry and move mortar and stones on the wall,
- Two wheelbarrow labourers (one for mortar and the other stone transportation).

One 300 litre drum mixer manned by a team of three can supply mortar at an adequate rate for three five-person masonry construction teams as described above. A team of two labourers can attend to cleaning and conveying masonry stones from the stockpile on site to convenient collection points for the masonry teams.

5.6.3 Productivity

When referring to productivity rates, it becomes necessary to agree on some definitions. In this document, productivity rates will always refer to the volume of masonry placed per day per worker.

Factors influencing productivity

A wide range of site specific, construction methodology and labour-related factors can affect productivity rates. Specific factors that influence productivity are:

- The skills, attitude and experience of the work force,
- Remuneration incentives,
- Leadership on the site,
- Working conditions (both social and physical),
- Weather conditions,
- Access and working space (better access and lots of working space increase productivity),
- Total volume (the greater the volume, generally the higher the productivity due to the relatively short learning curve in relation to the overall duration of the project),
- Availability of construction materials (a bottleneck in material deliveries can severely hamper productivity and can cause the work force to become demoralised),
- Construction methods and material delivery onto the wall (the more mechanised, generally the higher the productivity rates, but the additional costs of mechanisation must be weighed up).

'Worker' means all construction staff directly involved in the production and placement of masonry. Site management staff, technical staff and laboratory staff are excluded. Their costs should be included under Preliminary and General items. All workers employed in the sourcing and delivery of construction materials to the site of works, are also excluded. Their costs should be reflected in the material procurement costs, which in turn will later be incorporated in the masonry cost.

Productivity rates vary widely, from as little as 0.3 m^3 per person per day to as much as five cubic metres per person per day. The latter productivity rate can only be achieved if the manual transportation of masonry rock and mortar onto the wall is replaced with mechanical delivery systems. The cost of mechanical delivery systems should then be separately calculated and converted into a cost per cubic meter of masonry placed. If the entire process from rock stockpile and mortar batching plant to construction of masonry walls are done with manual labour, then typical productivity varies between 0.5 m^3 per person per day to 1.0 m^3 per person per day.

5.7 Costing of rubble masonry construction

The only element of masonry dams that should be costed differently from say a comparable concrete dam is the unit cost of placed masonry. The technique for determining the unit cost of masonry is not significantly different to that of costing concrete. As with concrete, it should be decided what portion of the temporary works and plant will be costed under preliminary and general items and what portion will be costed into the unit volume of material placed. To simplify calculations and to better illustrate the costing principles, all temporary works and plant costs will be left out of the masonry unit cost in this document.

The costing and scheduling methodology is illustrated in Tables 5 and 6, respectively.

Table 5: Typical costing for RMC

Item Description	Unit	Rate (R-c)	Qty./m^3 masonry	Masonry unit cost (R/m^3)
Loose masonry rock delivered	m^3			
Sand delivered	m^3			
Cement	pockets			
Sub-Total Materials	m^3			
Labour Wages	person-day			
Total Nett Cost	m^3			
Waste and Risk	%			
Mark-up	%			
Total Masonry Unit Price	m^3			

Clearly, all of the costs illustrated in Table 5 can be further refined, for example the labour cost can be disaggregated into the various categories of labour rates and the actual cost of materials delivered to site can be calculated according to standard methods. It has been found that rates can vary between R200 and R400 per m^3 masonry placed. In addition to this rate, must be added the fixed and time-related costs of head office overheads, insurances, site facilities, plant, temporary works, site supervision, etc. These prices are adjusted for year 2 000 and are applicable for masonry arch dam projects where masonry quantities ranged from 1 000 m^3 to 5 600 m^3. The project locations varied from the Western

Cape, Lesotho, Free State, Limpopo Province and Mpumalanga.

The cost of employment per unit of expenditure typically ranges from about R20 to R100 per hour.

Table 6 : Typical scheduling of RMC

RUBBLE ROCK MASONRY CONCRETE CONSTRUCTION – BILL OF QUANTITIES						
ITEM NO	SPEC	DESCRIPTION	UNIT	QTY	RATE	AMOUNT
	PSRM	SECTION PSRM				
		ROCK MASONRY (p1)				
PSRM 1		ROCK MASONRY CONSTRUCTION				
		a. External faces of vertical walls (300 mm thick)	m^3			
		b. Hearting or core between external faces	m^3			
		c. Bulk constructions (sections > 4m minimum dimension)	m^3			
PSRM 2		SURFACE FINISHES				
		a. Decorative finish with specially selected rock	m^3			
		b. Recess pointed finish	m^3			
		c. Smooth plastered finish	m^3			
PSRM 3		MORTAR BATCHING (45% of nett structure volume)				
PSRM 3.1		Strength Mortar Using …….. Cement				
		a. 15 Mpa	m^3			
		b. 10 Mpa	m^3			
		c. 7 Mpa	m^3			
PSRM 3.2		Extra-over PSRM 3.1 to Blend Sand from different stockpiles	m^3			
PSRM 4		MATERIALS SOURCING AND DELIVERY TO SITE				
PSRM 4.1		Masonry Rock (50mm – 300mm size, measured as nett				
		volume of structure, i.e. allow for bulking & waste)				
		a. Loose surface rocks collected by hand	m^3			
		b. Fragmentation-blasted from designated quarry site	m^3			
		c. Purchased from designated commercial source	m^3			
		d. Purchased from source located by the contractor	m^3			
PSRM 4.2		Mortar Sand, measured as 45% nett volume of structure				
		a. Alluvium from designated sources on site	m^3			
		b. Alluvium from designated commercial sources	m^3			
		c. Crusher material from designated commercial sources	m^3			
		d. Sand from sources to be located by the contractor	m^3			
		CARRIED FORWARD TO SUMMARY PAGE				

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Notes

Notes

Notes

Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour-based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major contributing organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
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Plus many individuals from construction companies

“Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings.”

Nelson Mandela, 2005 – Global Campaign for Action against Poverty

Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 4-3

Rubble masonry concrete arch bridge construction technology

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Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment-intensive construction works

In this set: (colour coded)

Part 1

An overview of labour-based technologies and methods in employment-intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

3.2 The BESA building system

Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

4.2 Rubble masonry dam construction technology

4.3 Rubble masonry concrete arch bridge construction technology

4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Waterbound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

EXPANDED PUBLIC WORKS PROGRAMME
Creating opportunities towards human fulfilment

ENGINEERS AGAINST POVERTY

Labour-based methods and technologies
for employment-intensive construction works

A cidb guide to best practice

1ST Edition of CIDB document 1028 March 2005

Best Practice Guideline – Part 4-3
Rubble masonry concrete arch bridge construction technology

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

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Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1. Introducing RMC arch bridge construction technology

This section introduces the technology in broad principles and illustrates the related benefits to be gained by its application with specific reference to research performed and experience gained to date in Southern Africa.

Note

Whilst Rubble Masonry Concrete (RMC) Arch bridges have been constructed for around 3 000 years, the technology has, to a large extent been replaced by steel and concrete construction technologies.

In recent times, there has been a resurgence in the construction of small RMC Arch bridges, in areas of Africa where the technology is appropriate.

This guideline has been compiled to present the technology of RMC arch bridge construction, with direction for design, site selection, materials evaluation and construction against the background of experience gained to date in Southern Africa.

1.1 Background

Masonry Arch Bridge construction first appeared in ancient civilisation in Mesopotamia between the Tigris and Euphrates Rivers, some 3 000 years ago. The oldest surviving masonry arch bridge is at Smyrna, in Turkey. It was built around 900 BC. Numerous masonry arch bridges have subsequently been constructed all around the world (see Figure 1). As the construction technology developed, bridges started to show evidence of an effort to shape and fit the stones to minimise the joint thickness between them and to orientate the stones so that the principal stresses would be at right angles to the joints. This showed an inherent comprehension of the basics of arch action.

Based on the above principles, numerous masonry arch bridges have survived, indicating considerable durability as a result of the mechanical distribution of loads within the arch structure that tends to ensure that the loads are transferred internally in such a manner as to ensure that the integrity of the structure is maintained.

1.2 Recent interest in RMC bridges

In recent times, the construction of RMC arch bridges was pioneered in Zimbabwe, during the liberation struggle between 1973 and 1980. As a result of a shortage of materials that were needed to construct bridges using modern methods, such as reinforced concrete and steel, local engineers built numerous RMC arch bridges. Their methods of design and construction evolved empirically, often at the expense of structures being washed away or bypassed. Unfortunately, their experience was not carefully documented.

In South Africa, during the 1990s, use was made of RMC Arch technology for the construction of simple stone structures, such as fords (drifts), culvert, outlets, small bridge abutments and piers as well as stone arch culverts, with areas from approximately 0,75 m^2 (equivalent to a one metre diameter pipe) to 2,26 m^2 (equivalent to 2 x 1,2 m diameter pipes).

In 1992, the then Lebowa Government commenced a programme of bridge construction, intending to use structural corrugated steel sheet arch formers, as well as simply supported reinforced concrete decks, as part of its road management system. It was found that placement of the corrugated steel arch rings required cranes to handle them. Subsequently, these formers were backfilled using earth-moving plant and compaction equipment. As a result the desire to increase the labour component of the project and also due to supply problems relating to the corrugated sheets, the engineers explored alternative construction techniques in order not to delay the project. A labour-based technique using rubble masonry was successfully implemented.

Figure 1: Old masonry arch bridge in the Lake District, England

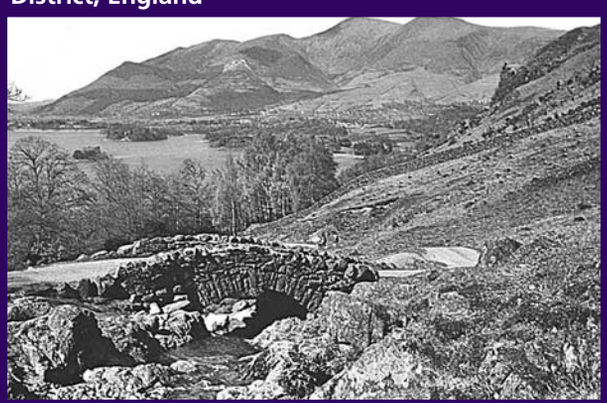
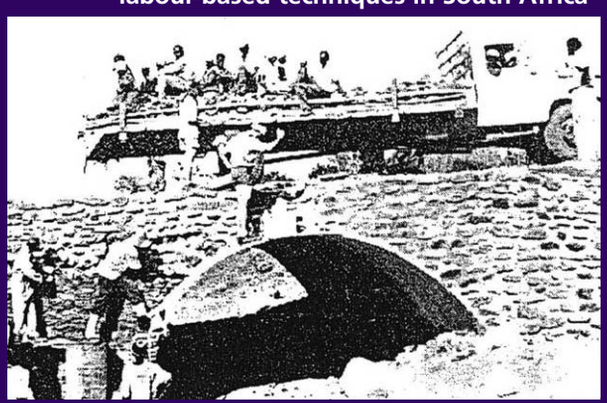


Figure 2: RMC arch bridge constructed using labour-based techniques in South Africa



2. Materials requirements

Typical RMC composition

RMC as used in arch bridge and culvert construction is a matrix comprising large stones in a mortar binder. To minimise cost, and to optimise structural properties, it is desirable to maximise the stone content. RMC is similar in nature to a dry mix concrete, typically comprising approximately 55% large aggregate (by mass), 6% cement, 6% water and 33% sand. The greatest difference, of course, can be seen in the fact that the large aggregate portion of RMC comprises particles generally of 50 to 300 mm in dimension[1].

2.1 Typical mix proportions

2.1.1 General

RMC used in arch bridges typically uses two mortar mix compositions, a 1:4 cement: sand mix for the critical zones of the structure, such as the arch rings and spandrel walls, and other areas exposed alternate wetting and drying or the erosive effects of flowing water and 1:6 cement: sand for the massive infill sections. The mixes are prepared to a consistency that is just fluid enough to fill the interstices between the underlying stones.

2.1.2 Mortar composition

Adopting the mortar classification system of SANS 10164 – Part 1, the 1:4 mortar mix, using a CEM 1 cement (OPC), is equivalent to a mortar Class I, displaying a 28-day preliminary (laboratory) strength of perhaps 14MPa and a works test strength of 10MPa. The nominal 1:6 mortar mix is equivalent to a mortar Class II, displaying a 28-day preliminary strength of 7MPa and a works test strength of 5MPa. In SANS 10249, a Class 1 mortar comprises 50 kg cement and approximately 130 litres sand (measured loose and damp), while a Class II mortar comprises 50 kg cement and approximately 200 litres sand.[2,3] It is very important to maintain a mortar film thickness limited to 7 to 20mm between the rock particles within the RMC. A mortar film of this thickness should provide significantly greater strength than indicated in a 100mm test cube.

For the purpose of evaluation, mortar mixes 1:4 and 1:6 by volume are analysed based on the following data and ignoring air content for simplicity:

Material	Loose bulk density (kg/m^3)	Relative density
Cement	1150 (1500 in bags)	2,9
Sand, dry	1620	2,65
Sand, wet	1350	

The sand is assumed to be an average sand and has a water requirement of 330 kg/m^3 to give adequate workability to the mortar. The water requirement for a 1:4 and 1:6 mix would be similar in practice despite the higher cement content of the 1:4 mix (see Table 1).

[1] This is effectively controlled by the mass of the individual stones to ensure that they can be placed by hand. The mass of a stone with a nominal diameter of 300 mm varies from between 30-40 kg.

[2] The designer should specify the minimum cement content in a cubic metre of mortar. This is more important than specifying the compressive strength of the mortar in accordance with the provisions of SANS 10164-1 : The Structural use of Masonry : Part 1: Unreinforced masonry walling as lean mixes will be permeable. The compressive strength of RMC is relatively insensitive to the strength of mortar. Compressive strength requirements can be used as a control measure to monitor uniformity in mortar. Changes in compressive strength are indicative of changes in mix proportions, water content and fine aggregate.

[3] A 'concrete' wheelbarrow has a capacity of 65ℓ. Mortar mixes of 1 : 4 and 1 : 6 compositions are accordingly proportioned as 50 kg cement and 2, or 3 wheelbarrows of sand, respectively.

[4] A bag of common cement having a mass of 50kg has a volume of approximately 33 litres when packed under air pressure at a factory. Cement, however, fluffs up (bulks) when poured into a container, with a result that 50 kg of cement cannot readily be contained in a box of 33 litres. The volume of a bag of loose (bulked) cement, depending upon its compaction, can be upto 20% more than when in a bag. For this reason, it is preferable to use whole bags of cement when volume batching.

Table 1: Mortar 1:4 (dry sand)

MATERIAL	QUANTITIES					
	per 50 kg cement			per cubic metre		
	Volume (ℓ)	Absolute volume (ℓ)	Mass (kg)	Volume (ℓ)	Absolute volume (ℓ)	Mass (kg)
Cement	33,3	17,2	50	6,8 bags	117	340
Sand	133	81,4	216	905	353	1465
Water	48,5	48,5	48,5	330	330	330
Total					1000	2135
Note: cement water ratio = 0,97						

In the calculation of quantities of materials for the different mortar mixes, no allowance is made for entrapped air in the mortar (average air content 2 to 4%) and for loss of bleeding water. It is also assumed that in volume batching a full bag of cement weighing 50 kg is used, i.e. the cement is not volume batched[4].

For dry materials, a mix of 1 cement + 6 sand and a w/c ratio by mass of 1,05 for 9MPa, assuming zero air voids, the component proportions can be determined as shown in Table 2.

When wet sand is used and volume batched, allowance must be made for the bulking of the sand otherwise the cement content will be in excess of that shown in the Tables 1 and 2.

Table 2: Mortar 1:6 (dry sand)

MATERIAL	QUANTITIES					
	per 50 kg cement			per cubic metre		
	Volume (ℓ)	Absolute volume (ℓ)	Mass (kg)	Volume (ℓ)	Absolute volume (ℓ)	Mass (kg)
Cement	33,3	17,2	50	4,8 bags	82	240
Sand	200	122.1	324	960	588	1560
Water	69	69	69	330	330	330
Total					1000	2130
Note: cement water ratio = 1,38						

A realistic mortar amount in RMC is 40 – 45%. Accordingly, the cement content per cubic metre in RMC for a 1:4 mortar mix will vary between 136 and 153 kg/m^3 and for a 1:6 mortar mix between 96 and 108 kg/m^3.

2.1.3 Rock particle content

A mass concrete might commonly contain up to 60% coarse aggregate by volume. Research and practical experience have, however, demonstrated that while a similar rock particle content is possible in RMC, and indeed of benefit in promoting economy, a content of around 50% may be more appropriate to ensure that rock particles and mortar are well and evenly distributed within the matrix. In areas of the structure where strength and impermeability are less critical, higher proportions of rock may be applied. For a mass gravity structure, consideration can be given to the application of more traditional, historical rubble masonry techniques, where the rock particles are cemented together with mortar, as opposed to being bedded into a matrix of mortar. In such instances, the rock proportion can be increased very significantly, although it must also be understood that the contents of air voids (entrapped air) in such a 'mix' is likely to be extremely high, with concomitant potential permeability problems.

2.2 RMC behaviour as a construction material

2.2.1 General

While it is relatively simple to test, evaluate and analyse the likely strengths and performance of the mortar component of the RMC mix, the addition of large scale rock particles complicates the picture significantly. It is not just the combination of materials that makes such analysis more involved, but the requirement for an accurate replication of the construction process to ensure representivity of the samples with the actual circumstances prevalent in prototype structures. No vibration is used for the compaction of RMC and compaction is provided in the form of the physical effort of driving large stone particles into the mortar. A further complication inherent to the strength and performance analysis of RMC is the scale of the rock particles, which limits the usefulness of small scale testing and requires specialist equipment to ensure representivity.

In RMC, components of very different size, shape, elasticity, density and strength are combined to create a behaviour environment quite different to that of concrete. Test work as described below has illustrated how mechanisms set up between the large particles within the RMC mix can be seen to dominate behaviour, if unfavourably orientated. The problem commonly experienced in RMC relates to the setting of very stiff and strong particles within a matrix of more de-formable, lower strength mortar. However, in some instances of bridge construction, low strength rock particles have been used. In such cases, RMC structural performance has been demonstrated to be significantly compromised.

Testing mortar workability

It is suggested that site tests be carried out to establish optimum mortar workability. A test placement in a box of perhaps 1 m^2 x 0,5 m deep could be broken up a day or so after placement to establish the typical rock particle separation achieved. Repeated testing could be applied to observe and establish optimum mortar workability and the same process could serve to measure the rock and mortar mix proportion variation with mortar workability.

2.2.2 RMC mortar workability

In order to achieve the composition of RMC, mortar workability becomes critical. Too wet and flowable mortar will give rise to excessive rock particle contact and will prevent an even and uniform separation of rock particles with a thin layer of mortar. Too dry and stiff mortar will result in excessive separation of the rock particles and a higher dependence of the strength and performance properties of the mortar. Wet mortar will promote a higher rock content and dry mortar, a lower rock content.

2.2.3 The impact of materials variations on RMC behaviour

Recent research by Fine and Rankine used 500 mm cubes to test, evaluate and compare the properties of RMC, primarily in terms of crushing strength and elasticity, or deformation modulus. In this works it was demonstrated that the deformation modulus of RMC is largely determined by the elastic modulus, shape and orientation of the rock inclusions. With rock moduli varying from 24 to 120 GPa, a range of RMC deformation modulus of 5 to 71 GPa was demonstrated for a constant mortar deformation modulus of 18 GPa.

Relating to arch bridges, the important characteristics of RMC identified in the research include the following:

- The orientation of the rock inclusions in relation to the direction of load transfer is critical in final materials behaviour,
- Under load, stresses within the RMC are significantly greater and more variable when a few large particles are applied, with inter-particle contact, as compared with smaller particles separated evenly with mortar,
- It appears that specific load transfer and structural mechanisms play a significant role within an RMC cube close to and at failure. This effect is likely to be of lesser significance at lower loadings in relation to ultimate strength. The particle size in relation to member size is likely to influence the intensity of these effects,
- Poisson's Ratio of RMC can vary from 0,03 to in excess of 1,0,
- The placement method applied for RMC has a fairly significant impact on the final materials behaviour, as a consequence of the foregoing,
- Particles with surface weathering are not appropriate for use in RMC.

2.3 Materials requirements

2.3.1 General

In terms of materials quality and strength, the same criteria applicable for concrete are valid for RMC. For the rock particles, shape is of importance for the reasons discussed above, although workability problems that relate to the flakiness and/or angularity of coarse aggregate particles in conventional concrete are obviously not relevant in RMC arch bridge construction (see Figure 7).

2.3.2 Rock particles

Rock particles for use in RMC can be sourced from a quarry, or from surface stone deposits (usually colluvial). When the scale of construction is small and no suitable quarry exists within the proximity of the dam site, significant economic benefit is gained from the ability to collect suitable rock from local surface deposits which frequently exist close to sites suitable for RMC construction. One obvious prerequisite in the use of stone from local surface deposits is that any weathering is insufficient to significantly compromise the mechanical properties of the parent rock. In terms of quality, rock particles must meet the related requirements of SANS 1083.

For the reasons discussed above, rock particles with weathering that affects the surface hardness are unsuitable for use in RMC and the maximum nominal particle size should not exceed a of the minimum dimension of the structural element being constructed (distance between the inside faces of the surface skin zones). Elongated rock particles should be avoided and the maximum dimension of a rock particle should not exceed half of the depth of the lift into which it is cast.

Testing rock particle strength

The strength tests applied to coarse aggregate for concrete are impractical for the size of rock particles used in RMC, although the aggregate crushing value (SANS 5841) and the 10% FACT value (SANS 5842) can be applied to smaller particles of the same source material. With the same sort of material competence required for RMC rock particles as for concrete coarse aggregate, visual inspection and handling are usually adequate to confirm density, strength, hardness and durability. Should any doubt as to the competence of a proposed rock particle exist, mechanical testing of samples must be undertaken to ensure a material of at least 2,65 specific gravity, 30 MPa compressive strength and 40 GPa modulus of elasticity.

2.3.3 Fine aggregate or sand

The fine aggregate or sand must comply with the requirements of SANS 1083 (fine aggregate for concrete) or SANS 1090 (fine aggregates for mortar) or have a water requirement not greater than 10 litres with 10 kg of cement (CEM I or CEM II A) and 50 kg of air dry sand to reach a consistency suitable for the mortar that is used in RMC.

If judgement of the suitability of a sand is based on its water requirement then it must also comply with the requirements in the above South African National Standards for dust content, methylene blue content, clay content, organic impurities, and soluble deleterious impurities.

In general, the Fineness Modulus (FM) of the sand should lie between 2,1 and 2,8.

Where sand from a single source does not conform to the above requirements, blending of sand from different sources should be considered.

3. Plant and equipment requirements

Activities that benefit from the application of plant

On the basis that experience has demonstrated the application of plant only to be of benefit in aspects related to the constituent materials, the appropriate use of plant in RMC construction can be addressed under the following categories:

- stone collection, loading and transportation
- sand procurement and delivery
- mortar mixing
- mortar delivery to point of placement
- stone delivery to point of placement

3.1 Goal – to maximise labour usage

In the case of any labour-based construction technology, the prime objective is obviously to maximise the overall percentage of the construction cost attributable to labour wages. One of the primary successes of RMC construction is the efficient use of labour that arises from a minimum number of component activities comprising the construction method. The basic construction can, however, be split into materials procurement, delivery and blending as one category and actual construction as another. While the latter category is entirely labour-orientated and the use of any mechanical plant would actually be relatively difficult, significant efficiencies can be gained by the use of equipment and plant for the former.

3.2 Construction plant

Blasting and quarrying equipment

RMC arch bridges are generally of small scale. Should it be found necessary to quarry for stone, RMC may not necessarily be an economical solution.

3.2.1 Excavation plant

RMC arch bridges generally require sound foundations. It is often necessary to expose suitable rock by the removal of overburden, and in some cases to trim and shape the rock. Whilst the size of an average RMC arch bridge is not normally large it may be necessary to use air or rock breaking equipment to trim and shape foundation surfaces.

3.2.2 Manual collection of stone

The bulk volume of stone, or rock, required for RMC construction of a bridge will equate approximately to the final total volume of the structure. Accordingly, it is obvious that the procurement and management of stone for RMC construction is a significant aspect to be addressed.

When stone or rock for arch bridge construction is collected from surface deposits, these may obviously be dispersed over a wide area and it may not to be viable to transport such material to the construction site using wheelbarrows. Accordingly, the provision of a tractor with a flatbed trailer has proved appropriate for stone collection and delivery. Stone collectors pile rock at a specified location. The tractor and trailer are brought to that point and the stone is loaded manually. Once stockpiled on site, preferably in piles close to the point of placement by hand, by wheelbarrow or using sledges.

3.2.3 Transportation plant

Stone or rock fragments and sand need to be transported to the bridge site. In Zimbabwe it is common practice to use tractors and scotch carts for this purpose. However, in South Africa dumper trucks seem to be the preferred transportation plant. If large quantities need to be transported within a short period over large distances, then transportation plant could be an important element in the production scheduling.

Wheelbarrows are commonly used for transporting stones and mortar from the stockpiles and batching plants respectively, to the stone masons on the bridge. Wooden sledges or stretches can also be effectively employed for this purpose.

3.2.4 Mortar mixing and batching plant

For the construction of small arch bridges, mortar may be mixed by hand. Suitable gauge boxes or other measuring equipment should be provided to ensure the correct proportioning of the constituent materials.

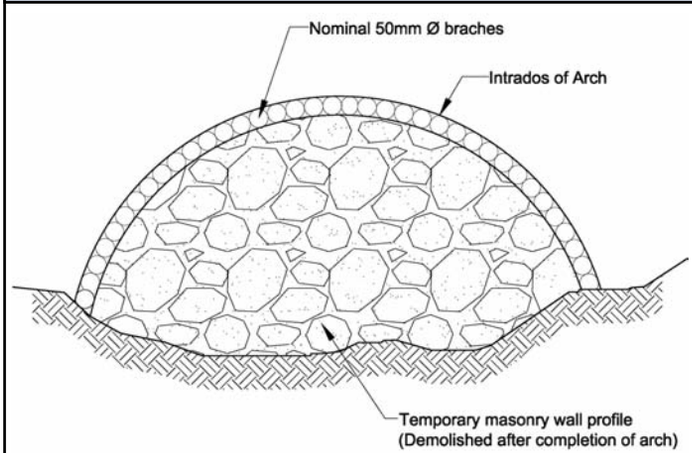
Hand mixing should always be done on a close-boarded mixing platform, to prevent contamination of the mix by materials picked up off the surface.

Where the scale of bridge construction justifies it, mechanical mixers can be employed. Typical plant used is a 300 litre drum-type cement mixer, powered by a small petrol or diesel engine. Mixing plants should not be too large, so that it can be moved around to suit construction requirements.

3.2.5 Scaffolds and formwork or centring

Traditionally, timber has been used as arch centring. Due to the high price of timber and difficulty in transporting it to remote sites, alternatives may have to be sought. One alternative is the use of corrugated steel roof sheeting which has been pre-cranked to the radius of the inner shell of the arch, or intrados. Where spans are large, the sheets may require propping until the arch is self-supporting. Such centring may however distort asymmetrically when construction loads are applied. In this case, arch formers made from boarding, cut to the profile of the arch may be used under the sheeting to help maintain the arch shape.

Figure 3: Arch centring using tree branches and temporary masonry profiles



Another alternative is to use 50 mm diameter tree branches, as shown in Figure 3, that are placed to span between temporary masonry wall profiles. The gaps between the saplings are sealed with old cement sacks or similar bags. Whilst this has worked in the past, the finish of the arch tends to be very rough and sagging of the saplings can result in considerable distortion of the arch.

In Zimbabwe, proprietary precast concrete shell formers have been developed, that require no additional support after erection. These are however, subject to patent, and their use may only be justified if sufficient construction is undertaken.

3.2.6 Compaction equipment

In an RMC arch bridge, the backfill between the spandrel walls interacts with the arch ring of the structure, providing a degree of composite action. It is therefore essential that the backfill over the arch is properly placed and compacted. Generally it will be found that the use of hand compaction equipment such as tampers will not provide a sufficiently uniform dense compaction. The use of light-powered compaction equipment such as plate compactors, impact rammers or walk-behind tandem rollers should be considered.

3.2.7 Materials storage

Cement should be kept dry at all times. Sand and stone should be stored in firm dry areas, where they are not likely to be flooded.

3.2.8 Sundry builder's tools

Normal builders tools, such as wheelbarrows, picks, spades and shovels, various hammers (large sledge bricklayers and carpenter's types) and trowels for pointing and trimming of mortar will be required.

4. Design considerations

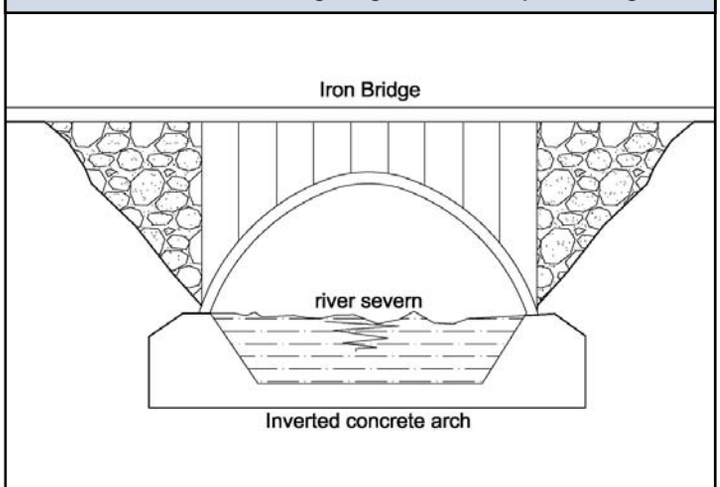
This section provides guidance for the application of Rubble Masonry Concrete in small arch bridge construction. These guidelines have been prepared for an engineer with an appropriate level of knowledge of bridge design and do not attempt to cover bridge dam design per se, beyond suggesting the particular analysis methods that have proved most appropriate in the case of small and medium size RMC structures.

4.1 Factors relating to design of RMC arch bridges

4.1.1 Hydraulic adequacy

Experience in the construction of small RMC arch bridges in Zimbabwe has shown that the most common cause of failure is as a result of hydraulic inadequacy. Bridges have either been washed away during severe storms, because of inadequate waterway area, have had their approaches washed away or have been bypassed as a result of the stream creating a new channel. Poor placement of arch bridges has resulted in structures being left high and dry when the stream or river has changed course during floods. It is this essential that the site for an RMC arch bridge be chosen carefully, taking the stream characteristics into consideration.

Figure 4: Diagramme of inverted concrete arch used to tie abutments of the iron bridge together in Shropshire, England



4.1.2 Foundations

In order for RMC arch bridges to function as designed, the foundations must be capable of resisting the loads due to the self-weight of the structure as well as the horizontal thrusts generated by arch action. Not only is the competence of the neck important, but the orientation of the rock surfaces and bedding planes in relation to the thrusts. If the material is sound, the rock can often be trimmed to the appropriate shape and orientation.

Where rock is not available but where the founding material is considered capable of resisting the loads and unlikely to be subject to scour during storms, concrete bases may be viable. Consideration should be given to ensuring that resistance to the horizontal thrusts can be maintained. A horizontal reinforced-concrete tie-beam may be used below the scour level of the stream bed to tie the bases together. A classic example of this is the use of an inverted concrete arch as a remedial measure, to tie the abutments of the iron-bridge gorge bride in Shropshire, England, across the river Severn (see Figure 4).

Whilst piled foundations may be used, it is unlikely that the cost associated therewith would be appropriate for use in small RMC arch bride construction.

Various loads

Arch bridges and their foundations need to withstand transient water loads during floods, self-weight, traffic loads, internally generated arch thrust and possibly load redistributions caused by foundation distortions.

4.2 Forces to be resisted

4.2.1 Transient loading

Bridges with a small aperture fraction produce an appreciable obstruction to a river's flow, frequently aggravated by driftwood blocking the flow through the apertures, effectively forming a weir. Overtopping must therefore be considered as an important loading condition, since it will cause significant lateral load and possibly overturning of the structure. Flood loading is defined as a transient load and must be considered in combination with buoyed-up self-weight, but not with traffic loads. Data concerning actual values of flood-water pressures may be sought form other sources or from an assessment of water depth provided by the

Department of Transport guidelines. The required moment, to restore stability against overturning may be calculated by taking moments about the base of the downstream face, assuming the buoyed-up weight of masonry to be no more than 1 400 kg/m^2. Tall single-lane bridges are more likely to require anchorage to resist this.

4.2.2 Traffic loading

An assessment of appropriate standards for rural roads (CSIR Report No. 92/466/1) has considered the traffic that is likely to use the rural roads for which most RMC bridges are designed. The recommendation is made that NA and NB24 vehicle loads, as defined by TMH7 (1981), should be used. The maximum vehicle loads that the bridges are required to withstand are thus 16 wheel loads of 60 kN each, consisting of four rows in two pairs. Each row of wheels is separated by a minimum of two metres, and each row has four wheels paced one metre apart across the bridge. The wheel contact area may be defined by a square with a 240 mm side. If more ambitious structural designs are attempted, for example bridges to carry traffic on national roads, then NB36 loading would be appropriate. Where a structure is to be covered with fill and/or a sub-base, the compaction equipment used may subject the structure to a more severe point load, particularly if a steel roller acts directly on the rough rubble finish.

4.3 Methods of structural analysis

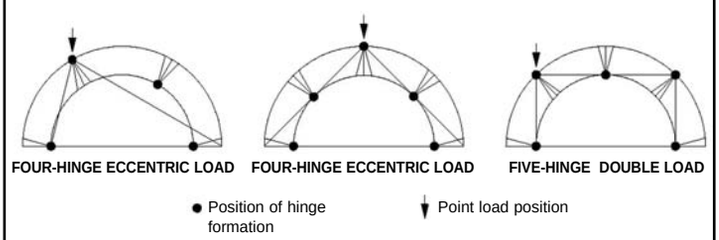
4.3.1 General

Although there appear to be no reported incidents of live-load-induced RMC bridge failures, their reliable analysis is a prerequisite for optimal design solutions for given locations and the construction of more ambitious structures in future. Numerous authorities including Tellett, Hendry, Page and de Bruin have reviewed a variety of methods of structural analysis of arch bridges, both simple and complex, with which arch bridge designers ought to be acquainted. Traditional design philosophy assumes that arch masonry possesses good compressive strength but zero-tensile strength, and aims to prevent the formation of tension within the masonry by limiting the resultant line of thrust to lie within the middle third of the arch ring.

This is easily achieved in arches that carry either a pure uniformly distributed load or a pure point load. In the former case, for example, where the arch is required only to support its own weight, it would always meet these conditions, provided it approximated the shape of an inverted catenary. The inverted catenary arch perfectly traces its line of self-weight-induced thrust, just as a chain sags reciprocally in perfect tension. In the latter case, where the arch has only to support a point load, it would qualify for these conditions if it had a triangular shape whose apex coincided with the load.

However, upon the application of point loads to catenary arch, tensions quickly develop. Where the point load is static, such tensions can easily be alleviated by distorting the catenary arch shape towards that of a triangle. However, when the point load may be dynamic, as is always the case in bridges, the solution is rather more complex since the arch ring must be capable of accommodating each unique shape of line thrust as the load moves across its deck. This is achieved in practice by thickening the arch ring, by increasing the dead weight of the structure itself, and/or by tolerating a small amount of tension within the arch. It is generally assumed that the material is infinitely strong in compression and that, provided the reaction to thrust is maintained, a failure condition is reached when the line of thrust reaches the outer faces of the masonry at no fewer than four points, converting the structure into a kinematic mechanism by the formation of

Figure 5: Formation of 3 possible kinematic mechanisms under elementary point loads



hinge points where the line of thrust alternately coincides with the intrados and extrados of the arch.

Three possible kinematic mechanisms are illustrated in Figure 5 for elementary point loads, from which it can be seen that hinge points are always formed on alternate sides of the arch. The diagrammes show the lines of thrust originating from the point loads as straight lines. This is not only conservative, but unrealistic, since the line can be straight only if the structure itself is weightless. The true line of thrust is defined by the path followed by the resultant of all the forces acting on the arch across its span, including self-weight and external actions. Hence, the true lines of thrust will be bent favourably away from the intrados. However, the greater the point load in relation to the weight of the structure, the straighter the line of thrust will become. Determination of the position of this true line of thrust may be obtained by calculation or by graphical method of analysis.

4.3.2 Calculation of the position of the line of thrust

The arch is divided into equal segments with point loads emanating from their centres representing the self-weight of the structure, including the road and fill. Reactions are determined by taking moments about assumed hinges, and the position of the line of thrust relative to the intrados (measured vertically) is determined accordingly. A value that falls outside of the arch ring indicates an incorrect assumption of hinge position.

4.3.3 Graphical determination of the position of the line of thrust

Ideally, this method of analysis is best performed with a CAD programme to ensure graphical accuracy. The practice of performing the analysis provides the arch designer with an 'intuitive feel' with which to anticipate the consequences of future modifications to various arch design parameters, particularly regarding the contribution of self-weight in maintaining equilibrium. A worked example is contained in Fine and Rankine's proposed guidelines for the design and construction of rubble masonry concrete arch bridges.

Model limitations

Model limitations include a restriction to assumed linear homogeneous material response and its inability to model independent behaviour in compression and tension, thus precluding automatically allowing cracks to develop. Furthermore, the assumption are made that the foundations are infinitely stiff, which perhaps realistic when founding upon rock, but questionable in soils. Required input includes estimation of material properties, namely density stiffness and Poisson's ratio, as well as imposed point loads and UDLs. Normally they assume the materials to be homogeneous and allow the user to manipulate the mesh size to achieve an acceptable compromise between detail and processing time. The output data can include quantified maximum compressive and tensile stresses, together with their co-ordinates and stress vectors, as well as deflections and co-ordinates.

4.3.4 Finite element analysis and the evaluation of a simple model

Until recently, finite element computer models for the analysis of arch bridges were too sophisticated for most designers. They typically required expensive computer hardware and software and the finite mesh had to be generated manually, a process that took much longer than graphical arch design methods. Reasonably priced two-dimensional plane strain programs such as Prokon, are now available for the analysis of RMC arches. Given a grid spacing within the limitations of its capacity, the model are able to quickly generate their own mesh and therefore easily accommodate design changes. Moreover they are able to model structures comprising more than one type of material and can therefore accommodate additional overburden layers such as fill, sub-grade and base-course and, in so doing, distribute concentrated wheel loads over the masonry. However, additional overburden layers do not normally

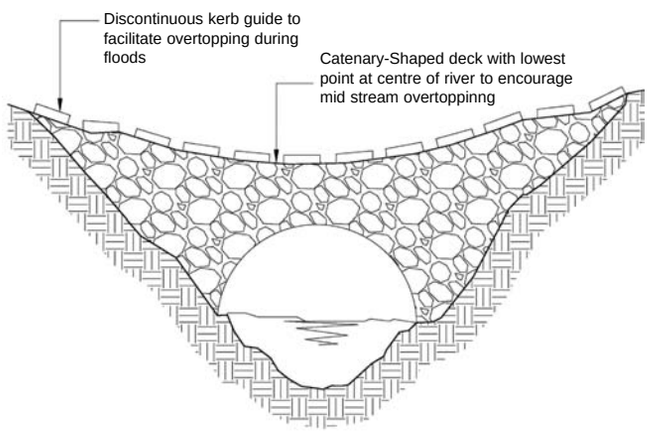
form part of an RMC bridge structure and there may be better ways of modelling the resistance of fill.

4.4 Geometrical considerations and failure mechanisms

Every effort should be made to minimize the bridge's obstruction to the flowing river, particularly when it is in flood. Large apertures are less likely to become blocked and require maintenance. The arch designer should therefore always aim to make apertures as big as possible.

Zimbabwean experience indicates that inclining the upstream elevation of the bridge, with a wedge of additional masonry, assists in lifting debris over the top of the structure and clear of its openings and a catenary bridge deck (with the lowest point at the centre of the river) to encourage overtopping of the structure at midstream and to prevent scour form eroding the approaches and abutments. Kerbs and guide-blocks should be kept discontinuous to decrease obstruction to debris and flood water (see Figure 6).

Figure 6: Protection of erosion of approaches by providing a catenary-shaped bridge deck



4.5 Anchorage and resistance to transient loading

Anchorage against sliding and overturning from transient flood-loading may best be achieved by socketing into bedrock and/or grouting pre-cranked anchor bars into pre-drilled holes. Although standard jackhammer drill steels may be capable of forming a hole sufficiently large to accommodate 25 mm nominal diameter reinforcing bars, it may be preferable to use a lesser diameter bar to ensure a good grout surround. Bar spacers obviously help to achieve this cover. The projecting bars should be sufficiently long and amply embedded into the structure to preclude masonry tensile failure immediately above the proximal end. Furthermore, the projecting bar should not be embedded directly in RMC; a cavity (of about 20 mm in diameter) should be left around the bar and subsequently filled with a cement-rich high slump concrete to increase the bar/aggregate interlock, thereby affording greater pullout resistance. Anchorage may be further improved by linking the anchor bars with transverse reinforcing steel cast into the RMC arch structure.

4.6 Structural behaviour

4.6.1 Research

Structural and materials research into RMC in Southern Africa is currently rather sparse and has to date largely been pursued by Rankine. The experimentation undertaken has been relating to the application of RMC in the construction of small bridges. Furthermore, the scale of the components comprising the RMC mix, with rock particles as large as 60 kg, makes testing rather difficult and expensive, requiring specialist, large-scale equipment. Within the scale of the industry related to RMC and the works constructed in this material, it is difficult to motivate the necessary, but expensive, research required to develop a comprehensive understanding of the material.

The most recent research has focussed specifically on the isolation of the mechanical properties of RMC. Fine and Rankine have used 500 mm cubes to test,

evaluate and compare the properties of RMC, primarily in terms of crushing strength and deformation modulus. In this work it is demonstrated that the deformation modulus of RMC is largely determined by the elastic modulus, shape and orientation of the rock inclusions. With rock moduli varying from 24 to 120GPa, a range of RMC deformation modulus of 5 to 71GPa was demonstrated for a constant mortar deformation modulus of 18GPa. The particle orientation of large rock inclusions was demonstrated to be of significant impact on the modulus for RMC comprising all rock types, with particularly detrimental effects being observed for low moduli, elongated particles orientated parallel to the loading direction. A further important aspect that was determined through testing and modelling was the respective role of particle size and inter-particle contact within the mix. If the rock inclusions are in intimate contact, the overall modulus will be higher for a large number of small particles than for a few large particles, with the latter scenario developing significantly higher local stresses in transferring stress through the matrix. If, however, all particles are surrounded by mortar, the stiffness modulus is independent of particle size and transfer stresses are significantly reduced.

Hard rock particles with soft surface weathering have been used in the past in RMC bridges. Research has demonstrated this rock type to produce particularly low strength RMC. This is not only a function of the particle strength, but also the associated complete lack of surface bond between mortar and rock. (Refer also to 2.3.3.)

4.6.2 Review of the structural Implications of RMC research findings

The findings for the RMC research completed to date have been presented in a largely factual format, with very little analysis and review of associated causative mechanisms, or related structural implications. It is, however, possible to draw a great deal more out of these results and there is significant value to be gained in reviewing the impact of such inferences against the performance requirements inherent to arch dam engineering. It must, however, be recognised that test cubes containing large rock particles, which are pressed using extremely hard, un-deformable surfaces, will tend to reproduce the extremes of behaviour in RMC.

Key aspects may be summarised as follows:

Particle orientation and mortar separation

The improved performance of RMC when the rock particles are evenly distributed and evenly separated by mortar tends to reflect the importance of construction technique on the final structural performance characteristics and this must be given careful consideration in the compilation of construction specifications.

Structural mechanisms and Poisson's ratio

The research of Fine and Rankine suggested the possible existence of a number of structural mechanisms within the 500 mm test cubes. These are illustrated in Figure 3.7 and each of the mechanisms postulated serve to suggest the possible modes of cube failure and explain why some cubes might exhibit particularly high Poisson's ratios.

The mechanisms suggested are likely to be particularly influenced by scale effects. When the size of the stone particles is smaller in relation to the member under stress, it is very likely that the influence of the identified mechanisms will be significantly reduced. Furthermore, some measure of three-dimensional restraint will also assist in distributing stresses more evenly through any member that is relatively massive in relation to its constituent components.

5. Construction technique, labour and costing

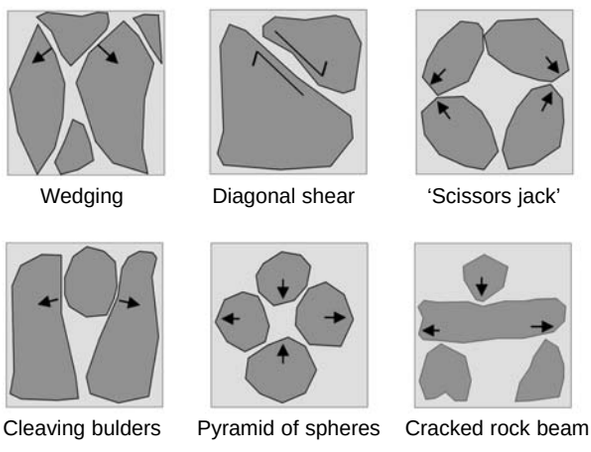
5.1 Materials procurement

5.1.1 Stone

If suitable surfaces stones are available in sufficient quantity on or near the site, then the masonry stone can be collected and stockpiled by hand, from where it can be hand-loaded and transported to the bridge usually with a tractor and low-bed trailer.

When no rock is available on site, or if small quantities are required, it may be best to procure masonry rock from a commercial source such as a crusher. Stone of a suitable size for use in RMC is usually sold commercially as dump rock.

Figure 7: Possible structural mechanisms within RMC cube



5.1.2 Sand

Sand is the most important ingredient in producing good quality masonry. It is therefore necessary to locate and test sufficient deposits of mortar sand sources early in the project phase. The most desirable situation is if suitable mortar sand can be sourced from the river near the site. When sourcing alluvial sand adjacent to a river, seasonal flooding should be taken into account as this may prevent accessing the sand at a crucial time during construction. The removal of large quantities of sand may also be subject to environmental management constraints.

Alluvial sand derived from the erosion of many sedimentary rock types, is not suitable for use in mortar, as a result of a non-continuous single-size grading that can result in high permeability, bleeding and low mortar strengths. It has been found that this problem can usually be solved by blending such sand with crusher sand.

In Zimbabwe, and in large parts of South Africa, granites make up the base geology from which good quality concrete sands are derived. Sand is usually deposited according to particle sizes, namely coarse sand under fast flowing conditions and fine sand under slow flowing conditions. This often necessitates sourcing sand from two locations, one yielding fine sand and the other coarse sand and then blending the 'concrete sand' and the 'pit sand' to achieve the desired grading.

5.1.3 Cement and cement storage

Cement should be stored and kept dry until it is used.

5.2 Preparatory activities

5.2.1 Foundation excavations and treatment

Foundations should be excavated and trimmed to the lines shown on drawing. When excavating into rock by blasting, care should be taken to avoid consequential damage. Light blasting or non-explosive excavation methods are the key to creating a sound foundation excavation.

5.2.2 Material storage

Care should be taken to avoid contamination of materials during storage and particular care is necessary when sands of different gradings are to be blended. The typical arrangements and procedures of good concrete practice should be observed for all aspects related to the materials to be used in RMC bridge construction.

Mortar quality is crucial

The quality of the mortar will ultimately determine the quality of the masonry, both in terms of strength and durability. It is therefore more crucial to attend to this aspect of the construction.

5.2.3 Mortar batching and mixing

Normally, batching for RMC arch bridge construction is done by volume. If mass batching can be achieved without excessive additional cost, the related accuracy and increased control may be advantageous. Batching plants should be accurate and regularly checked. In instances when volume batching is carried out using wheelbarrows, etc, great care should be taken to ensure adherence to correct materials proportioning and regular checking and supervision is necessary. Cement should not, however, be measured by volume but by mass, typically per 50 kg bag.

Mortar is normally made by mixing sand, cement and water in a drum mixer. On smaller projects, mixing can be accomplished manually, although better results and efficiencies are achieved using a mechanical mixer. Mixing should ensure that the mortar produced is of an even consistency with the correct slump and in compliance with the prescribed mix design and strength requirements. Care should be taken to regularly assess the moisture content of the sand prior to mixing. This is necessary to ensure that the right amount of mixing water will be added to the mix. A useful indirect check on the water : cement ratio is to perform regular slump tests on the mortar batches.

If the mixing water is very cold and/or the ambient temperature is too low, the mixing water should be pre-heated. Mortar should be placed within two hours of having been batched.

5.3 RMC construction

5.3.1 Stone preparation

Masonry stones should be thoroughly cleaned from all dust, mud and weathered scale. Stones should be wetted before being transported to the structure for placement. Jetting down stones with a high-pressure water jet, usually accomplishes both objectives of cleaning and wetting.

5.3.2 Surface preparation

Before placing mortar and masonry stones on a previous lift, the surface should be cleaned of all laitance, loose rocks, dust and debris. The surface should then be watered down. If the surface is very dry, as can be the case when the construction site closed for a period of time, special treatment of the surface will be required in order to ensure proper adhesion of subsequent placement of RMC.

The monolithic matrix

It is important to understand that RMC for arch bridges must not be perceived as a series of stones cemented together using mortar, but rather as a monolithic matrix, containing large stone within a body of mortar. In essence, this is similar in concept to the difference between brickwork and concrete. The former comprises a series of individual entities cemented to each other, while the latter comprises a body, or matrix of material made up of component constituents, in the form of cement, aggregates and water. When a 'rubble' masonry structure is built in a similar manner to brickwork, placing mortar as a receiving medium into which the surfaces of stones are embedded, the overall structural action of the final body of material is compromised.

5.3.3 Placement and compaction

A number of variations exist with regard to the placement and compaction of RMC. Whilst the Zimbabweans have developed certain methods and standard practices, various adaptations of these methods have been applied in South Africa.

The optimal structural performance of RMC would seem to be achieved when the stone content is maximised without compromising the uniform and even separation of rock particles with 7 to 20 mm of mortar. Typical stone content will accordingly be approximately 55% of the masonry body by volume, with the balance (45%) comprising mortar.

Accordingly, the method adopted successfully for the construction has involved the initial construction of dry stone walls on either side of a particular structural

member to a height of approximately 200 mm, followed by the filling of the trough created with a relatively flowable mortar, into which large stone plums are embedded. The stone plums are forced deep into the mortar by being stood on and by being pressed in using a customised hammer tool created from a length of reinforcing steel bar, which actions further served effectively to compact the receiving mortar. Some stones are left projecting slightly above the top surface of each lift, to allow keying into the subsequent lift, and the receiving placement surface is cleaned thoroughly and dampened between lifts, as this surface tends to be damaged and dirtied by pedestrian movement. The 'dry' facing walls are constructed much like conventional brick wall, using stiff mortar as bedding for the facing stones, which are usually carefully selected for the purpose.

5.3.4 Surface finishes

Where RMC end-walls retain earth-fill embankments, the surface against which the fill is to be compacted, should be plastered on completion to reduce soil-wall friction.

Surfaces in permanent contact with water should be flush jointed by plastering mortar into the grooves between surface (facing) stones. The reason for this is that the specific surface area is reduced, resulting in less chemical and physical erosion. This is of particular importance for all surfaces exposed to freeze-thaw conditions, where ice can develop in surface grooves and then 'crack out' the surface mortar and rocks.

5.4 Quality control and testing

It is important to address quality in RMC bridge construction and whilst mortar cube crushing test are a useful reference, the specification and regular encouragement of correct procedures and methods of construction to be observed is of greater importance. The labour and the contractor to be employed on RMC bridge construction will generally not be highly sophisticated and the repeated reinforcement for quality requirements and related appropriate procedures and construction methods will not be wasted.

The following tests are nevertheless useful and should be undertaken on a continuous basis, commensurate with the scale of the works:

- Sand grading analysis
- Slump measurement on mortar
- Manufacture and crushing of mortar cubes (crush at least half at seven days)
- On larger projects, some larger masonry cubes may be manufactured for crushing as a strength reference

The following quality control procedures should be implemented:

- Double-check all setting-out of formwork. Arch bridges rely on their shape for strength – thus the overall structural stability and integrity can be severely compromised if not constructed in accordance with the design dimensions,
- Count cement bags for each mortar batch (to ensure that the right amount of cement went into the mix),
- Keep a written record of mortar batches for each day and the amount of cement used,
- Calculate the volume of masonry batched over a period and compare it with the measured increase in the masonry volume. This is a good indicator of the relative volume of mortar in a unit of masonry,
- Check that surfaces are properly prepared before placing subsequent masonry,
- Keep placed masonry wet for proper curing.

5.5 Dealing with inclement weather

Masonry construction can continue in very light rain, but should be stopped in heavy rain.

When constructing masonry in conditions of persistent extreme cold, such as during the winter in the mountains of Lesotho, a variety of measures may have to be implemented. Firstly, the mixing water drawn from the rivers will have a maximum temperature of about 6°C. This water will have to be pre-heated to about 60°C, resulting in a mortar temperature of about 25°C when discharged from the drum mixer.

With day-time temperatures below 10°C and night-time temperatures below freezing, it is also necessary to protect the placed masonry mortar against freezing. The most effective way identified is to use plywood formwork to protect the side faces of the masonry structure and to cover the top surface with thermal blankets during the night.

5.6 Labour

5.6.1 Why labour?

Unlike many other 'plant-replacement' construction techniques, masonry bridges require construction by manual labour. This is of course a major spin-off for employment creation, especially considering that the bulk of the labour force is usually recruited from the local community.

5.6.2 Labour requirements

The requirements for site management staff and skilled staff on masonry arch bridge projects are the same as for any other construction project of similar size. Only the labour requirements peculiar to masonry arch bridge construction will be listed below.

Skilled masons: Skilled masons are required for building the facing surfaces of the structure in advance of the core or hearting. Ideally these masons should have demonstrated their skills on a previous project. They will report directly to the foreman. Their responsibilities will include the training of new masons and managing and directing their own support team who deliver material on the wall and who construct the hearting.

Heavy manual labour: Heavy manual labour can only be done by healthy and physically strong persons. This work typically includes the pushing of heavily loaded wheelbarrows up ramps, the handling of large rock particles, etc.

Light manual labour: Light manual labour includes such tasks as pointing or plastering the facing surfaces of the structures. This work does not place specific reliance on physical strength.

Mortar batching: Because of its importance, it is essential to place a reliable person with the appropriate technical knowledge in charge of the mortar batching operations at each and every batching plant. His support staff must be able to do heavy manual labour.

Laboratory staff: At least one technically competent and very reliable person should be in charge of quality control. He should have one or two assistants. His principal functions will be to screen sand, do slump tests on mortar, make mortar cubes for testing, report results daily to the Site Agent and immediately raise the alarm if test indicate that technical specifications are not being met.

Typical construction teams: A masonry construction team would typically comprise five workers, as follows:

- One mason
- One assistant (for the mason)
- Two wheelbarrow labourers (one for mortar and the other stone transportation).

One 300-litre drum mixer manned by a team of three can supply mortar at an adequate rate for three/four-person masonry construction teams as described above. A team of two labourers can attend to cleaning and conveying masonry stones from the stockpile on site to convenient collection points for the masonry teams.

5.6.3 Productivity

Definitions

When referring to productivity rates, it becomes necessary to agree on some definitions. In this document, productivity rates will always refer to the volume of masonry placed per day per worker. 'Worker' means all construction staff directly involved in the production and placement of masonry. Site management staff, technical staff and laboratory staff are excluded. Their costs should be included under Preliminary and General items. All workers employed in the sourcing and delivery of construction materials to the site of works, are also excluded. Their costs should be reflected in the material procurement costs, which in turn will later be incorporated in the masonry cost.

Factors influencing productivity

A wide range of site specific, construction methodology and labour-related factors can affect productivity rates. Specific factors that influence productivity are:

- The skills, attitude and experience of the work force
- Remuneration incentives
- Leadership on the site
- Working conditions (both social and physical)
- Weather conditions
- Access and working space (better access and lots of working space increase productivity)
- Total volume (the greater the volume, generally the higher the productivity due to the relatively short learning curve in relation to the overall duration of the project)
- Availability of construction materials (a bottleneck in material deliveries can severely hamper productivity and can cause the work force to become demoralised)
- Construction methods and material delivery onto the wall (the more mechanised, generally the higher the productivity rates, but the additional costs of mechanisation must be weighed up)

Productivity rates

Productivity rates vary widely, from as little as 0.3 m^3 per person per day to as much as 5 m^3 per person per day. The latter productivity rate can only be achieved if the manual transportation of masonry rock and mortar onto the formwork is replaced with mechanical delivery systems.The cost of mechanical delivery systems should then be separately calculated and converted into a cost per cubic meter of masonry placed. If the entire process from rock stockpile and mortar batching plant to construction of masonry arches are done with manual labour, then typical productivity varies between 0.5 m^3 per person per day to 1.0 m^3 per person per day.

5.6.4 Costing of rubble masonry construction (RMC)

The only element of masonry arch bridges that should be costed differently from say a comparable concrete structure is the unit cost of placed masonry. The technique for determining the unit cost of masonry is not significantly different to that of costing concrete. As with concrete, it should be decided what portion of the temporary works and plant will be costed under preliminary and general items and what portion will be costed into the unit volume of material placed. To simplify calculations and to better illustrate the costing principles, all temporary works and plant costs will be left out of the masonry unit cost in this document.

The costing and scheduling methodology is illustrated in Tables 4 and 5, respectively.

Table 4: Typical costing for RMC

Item Description	Unit	Rate (R-c)	Qty./m^3 masonry	Masonry unit cost (R/m^3)
Loose masonry rock delivered	m^3			
Sand delivered	m^3			
Cement	pockets			
Sub-Total Materials	m^3			
Labour Wages	man-day			
Total Nett Cost	m^3			
Waste and Risk	%			
Mark-up	%			
Total Masonry Unit Price	m^3			

Clearly, all of the costs illustrated in Table 4 can be further refined, for example the labour cost can be disaggregated into the various categories of labour rates and the actual cost of materials delivered to site can be calculated according to standard methods

The cost of employment per unit of expenditure typically ranges from about R20 to R100 per hour.

6. Specialist literature

6.1 General

The scope of literature relating to the application of Rubble Masonry Concrete (RMC) in arch bridge construction can be divided into two categories: recent research and technical papers relating to RMC in bridges in South Africa and publications discussing historical bridges construction. High level technical information concerning the behaviour and strength characteristics of masonry and RMC is not easily accessible.

Table 5: Typical scheduling of RMC

RUBBLE ROCK MASONRY CONCRETE CONSTRUCTION – BILL OF QUANTITIES						
ITEM NO	SPEC	DESCRIPTION	UNIT	QTY	RATE	AMOUNT
	PSRM	SECTION PSRM				
		ROCK MASONRY (p1)				
PSRM 1		ROCK MASONRY CONSTRUCTION				
		a. External faces of vertical walls (300 mm thick)	m^3			
		b. Hearting or core between external faces	m^3			
PSRM 2		SURFACE FINISHES				
		a. Decorative finish with specially selected rock	m^3			
		b. Recess pointed finish	m^3			
		c. Smooth plastered finish	m^3			
PSRM 3		MORTAR BATCHING (45% of nett structure volume)				
PSRM 3.1		**Strength Mortar Using …….. Cement**				
		a. 15 Mpa	m^3			
		b. 10 Mpa	m^3			
		c. 7 Mpa	m^3			
PSRM 3.2		Extra-over PSRM 3.1 to Blend Sand from different stockpiles	m^3			
PSRM 4		MATERIALS SOURCING AND DELIVERY TO SITE				
PSRM 4.1		**Masonry Rock (50 mm – 300 mm size, measured as nett volume of structure, i.e. allow for bulking & waste)**				
		a. Loose surface rocks collected by hand	m^3			
		b. Fragmentation-blasted from designated quarry site	m^3			
		c. Purchased from designated commercial source	m^3			
		d. Purchased from source located by the contractor	m^3			
PSRM 4.2		**Mortar Sand, measured as 45% nett volume of structure**				
		a. Alluvium from designated sources on site	m^3			
		b. Alluvium from designated commercial sources	m^3			
		c. Crusher material from designated commercial sources	m^3			
		d. Sand from sources to be located by the contractor	m^3			
		CARRIED FORWARD TO SUMMARY PAGE				

6.2 Recent technical publications on RMC in South Africa and Zimbabwe

The relevant publications addressing 'new generation' rubble masonry concrete include:

1) Fine, B, Rankine, RGD and McCutcheon. Deformation mechanics of rubble masonry concrete. Journal of the South African Institution of Civil Engineers. Volume 41, No. 1, First Quarter 1999.

2) Rankine, RGD, Gohnert, M and McCutcheon, RT. Proposed Guidelines for the design and construction of rubble masonry concrete arch bridges. Journal of the South African Institution of Civil Engineers. Volume 40, No. 3. Third Quarter 1998.

3) Shaw, QHW. "Rubble Masonry Concrete Dam Design and Construction. Part 2: Proposed Design Standards and Related influences". SAICE Journal - April 1998

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Notes

Notes

Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour-based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major contributing organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
National Housing Forum
Congress of South African Trade Unions

Plus many individuals from construction companies

"Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings."

Nelson Mandela, 2005 – Global Campaign for Action against Poverty

Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 4-4

Foamed bitumen gravel

development through partnership

Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment-intensive construction works

In this set: (colour coded)

Part 1

An overview of labour-based technologies and methods in employment-intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

3.2 The BESA building system

Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

4.2 Rubble masonry dam construction technology

4.3 Rubble masonry concrete arch bridge construction technology

4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Waterbound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

EXPANDED PUBLIC WORKS PROGRAMME
Creating opportunities towards human fulfilment

ENGINEERS AGAINST POVERTY

Labour-based methods and technologies
for employment-intensive construction works

A cidb guide to best practice

1ST Edition of CIDB document 1029
March 2005

Best Practice Guideline – Part 4-4

Foamed bitumen gravel

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

cidb
development through partnership

Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1. Introduction

The potential of foamed bitumen for use as a soil binder was first realised in 1956 by Dr. Ladis H. Csanyi, at the Engineering Experiment Station in Iowa State University. Since then, foamed asphalt technology has been used successfully in many countries, with corresponding evolution of the original bitumen foaming process as experience was gained in its use. The original process consisted of injecting steam into hot bitumen. The steam foaming system was very convenient for asphalt plants where steam was readily available but it proved to be impractical for *in situ* foaming operations, because of the need for special equipment such as steam boilers. In 1968, Mobil Oil Australia, which had acquired the patent rights for Csanyi's invention, modified the original process by adding cold water rather than steam into the hot bitumen. The bitumen foaming process thus became much more practical and economical for general use.

Definition

The term 'foamed asphalt', as used in this document, refers to a mixture of pavement construction aggregates and foamed bitumen. The foamed bitumen, or expanded bitumen, is produced by a process in which water is injected into the hot bitumen, resulting in spontaneous foaming. The physical properties of the bitumen are temporarily altered when the injected water, on contact with the hot bitumen, is turned into vapour which is trapped in thousands of tiny bitumen bubbles. However, the foam dissipates in less than a minute and the bitumen resumes its original properties. In order to produce foamed asphalt, the bitumen has to be incorporated into the aggregates while still in its foamed state.

Foaming increases the surface area of the bitumen and considerably reduces its viscosity, making it well suited for mixing with cold and moist aggregates. Foamed bitumen can be used with a variety of materials, ranging from conventional high-quality graded materials and recycled pavement materials to marginal materials such as those having a high plasticity index. Foamed asphalt can be manufactured *in situ* or in a central plant. Binder contents are based on the mix design, and are determined as percentage (by weight) required for the mix to have optimum properties.

The use of foamed asphalt, an alternative cold-mix procedure, has had limited application in the construction of road pavements in South Africa especially for the rehabilitation of low volume roads in rural areas of KwaZulu-Natal. Recent interest in the material has resulted in several research projects that have generated mix design procedures and general guidelines on the use of foamed asphalt. The common usage of the material in the last few years has been in the *in situ* recycling method of construction using specialised deep-milling machinery whereby the old pavement is ripped, pulverised, treated with foamed bitumen and repaved in one continuous process. Foamed asphalt can be produced successfully in an asphalt plant, with suitable modifications, as well as on-site using a mobile batch plant as described by Hefer (1995).

The properties of foamed asphalt that make it very suitable for employment-intensive type of road construction are:

- Foamed asphalt can be manufactured from a variety of aggregates including possibly marginal materials,
- Foamed asphalt remains workable for long periods (months) and hence can be stockpiled.

Advantages of foamed asphalt

The following advantages of foamed asphalt have been noted in previous research:

- The foamed binder increases the shear strength and reduces the moisture susceptibility of granular materials,
- The strength characteristics of foamed asphalt approach those of cemented materials, but foamed asphalt is flexible and fatigue resistant,
- Foam treatment can be used with a wider range of aggregate types than other cold mix processes,
- Reduced binder and transportation costs, as foamed asphalt requires less binder and water than other types of cold mixing,
- Saving in time, because foamed asphalt can be compacted immediately and can carry traffic almost immediately after compaction is completed,
- Energy conservation, because only the bitumen needs to be heated while the aggregates are mixed in while cold and damp (no need for drying),
- Environmental side effects resulting from the evaporation of volatiles from the mix are avoided since curing does not result in the release of volatiles,
- Foamed asphalt can be stockpiled with no risk of binder runoff or leaching. Since foamed asphalt remains workable for extended periods, the usual time constraints for achieving compaction, shaping and finishing of the layer are avoided,
- Foamed asphalt layers can be constructed even in some adverse weather conditions, such as in cold weather or light rain, without significantly affecting the workability or the quality of the finished layer.

2. Overall considerations and planning

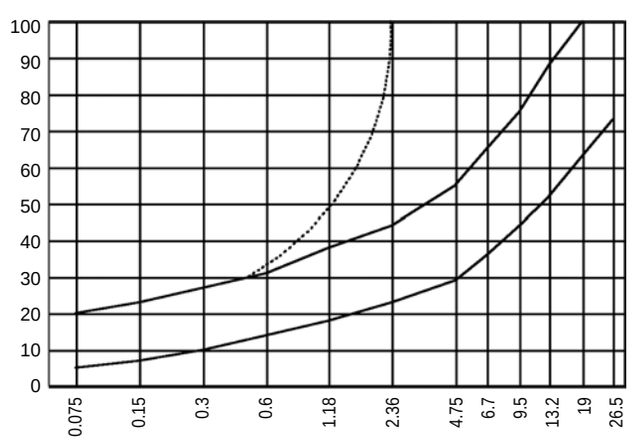
2.1 Mix design

The laboratory design of foamed asphalt materials is required to select the proper proportions and quality of the materials in order to optimise the properties of the mix. The binder content selected for foamed asphalt mixes is based on the Indirect Tensile Strength test.

2.2 Binder characterisation and preparation

The foaming characteristics of a particular bitumen type need to be optimised for producing foamed asphalt mixes. The foamed bitumen is characterised in terms of expansion ratio and half life. The expansion ratio of the foam is defined as the ratio between the maximum volume achieved in the foam state and the final volume of the binder once the foam has dissipated. The half life is the time, in seconds, between the moment the foam achieves maximum volume and the time it dissipates to half of the maximum volume. This is achieved by measuring the half-life and the expansion ratio of foamed bitumen produced using various percentages of water. Usually five tests are conducted with the foaming water content varying from 1% to 3% at 0,5% increments. The temperature of the bitumen before foaming should be in the range 180°C to 200°C. It is recommended that the half-life of the foamed bitumen be at least 12 seconds and the expansion ratio be at least 10:1. Additives may be used to catalyse the foaming. However, the use of these has a significant cost implication.

Figure 1: Aggregate grading requirements for foam treatment



2.3 Aggregate characterisation and preparation

Foamed bitumen is compatible with a variety of material types and is usually limited only by the grading of the material. The following guidelines should be followed. The grading and the PI of the aggregates should be determined. The grading is adjusted, if required, by adding fine or coarse material so that the final grading conforms to the grading envelope shown Figure 1. For low volume roads, aggregate gradings which lie above the target grading (finer), on sieves larger than 0,06 mm, may be acceptable. Materials which have a PI greater than 12 should be treated with lime to reduce the PI. In addition, it is common practice to add 1% to 2% cement to the mix to aid in bitumen adhesion. The Modified AASHTO optimum moisture content of the aggregates is determined.

Table 1: Guidelines in appropriate foamed binder contents by mass of dry aggregate

% passing 4,75 mm sieve	% passing 0,075 mm sieve	% Foamed bitumen
< 50 (gravels)	3 - 5	3
	5 - 7,5	3,5
	7,5 - 10	4
	> 10	4,5
> 50 (sands)	3 - 5	3,5
	5 - 7,5	4
	7,5 - 10	4,5
	> 10	5

The aggregates should be oven dried to a constant mass. The dried aggregates are riffled into five batches of 10 kg each. These will be used to produce five batches of foamed asphalt samples at various binder contents.

2.4 Binder content (BC) for trial mixes

An appropriate range of foamed bitumen contents, using Tables 1 and 2 as a guide, is selected for the trial mixes. Five batches of trial mixes are normally prepared at binder contents differing by one percent.

2.5 Moisture content

The moisture content for mixing and compaction is a crucial mix design parameter, which has traditionally been selected at the 'fluff' point of the aggregates (70% to 80% modified AASHTO OMC). However, it is recommended that the moisture content for mixing and compaction be selected at the greater of 'OMC minus the BC' and the 'fluff point'.

2.6 Mixing and compaction

Each 10kg sample of aggregate and the required mass of foamed bitumen (and lime or cement if required) are mixed in a mechanical mixer at the moisture content prescribed above. The foamed asphalt is stored in sealed containers to prevent moisture loss, until all five batches have been mixed. Duplicate samples are removed from each foamed asphalt batch for the determination of moisture content and bitumen content. The remaining foamed asphalt will be used to prepare compacted foamed asphalt specimens for further testing.

Table 2: Appropriate foamed binder contents by mass of dry aggregate

Soil type	Optimum range of binder contents (%)	Additional requirements
Well graded clean gravel	2 - 2,5	
Well graded marginally clayey / silty gravel	2 - 4,5	
Poorly graded marginally clayey gravel	2,5 - 3	
Clayey gravel	4 - 6	lime modification
Well graded clean sand	4 - 5	filler
Well graded marginally silty sand	2,5 - 4	
Poorly graded marginally silty sand	3 - 4,5	low pen bitumen; filler
Poorly graded clean sand	2,5 - 5	filler
Silty sand	2,5 - 4,5	
Silty clayey sand	4	possibly lime
Clayey sand	3 - 4	lime modification

For further foamed asphalt testing, it is suggested that eight samples be prepared from each batch: six samples for indirect tensile tests and two samples for volumetric evaluation. Specimens are compacted, using the Marshall hammer, to a 100 mm nominal diameter and 65 mm nominal height. Specimens of this size normally require about 1,15 kg of material. A compactive effort of 75 blows on each face is recommended.

2.7 Curing, testing and design binder content determination

The foamed asphalt samples should be subjected to an accelerated curing procedure before undergoing any tests. The widely used procedure of three days' oven curing at 60°C is recommended. Indirect tensile strength testing (ITS) is conducted to determine the ultimate strengths of both dry and soaked samples. The design binder content should be selected as the binder content at which the soaked indirect tensile strength is at a maximum.

Resilient modulus testing at the design binder content is recommended for dry and soaked samples, to determine adequate structural capacity of the material. The specifications in Table 3 should be used as minimum acceptance criteria.

Dynamic Creep testing at the design binder content is suggested in order to evaluate the permanent deformation characteristics of the foamed asphalt mixes.

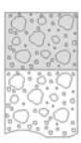
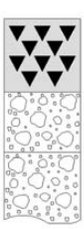
The mix produced should generally conform to the specifications in Table 3 in order to provide acceptable structural performance.

Table 3: Mix design criteria for foam-treated aggregate

Property	E0 - E2 Traffic	E3 - E4 Traffic
Retained (wet) ITS (25°C)	60% of dry ITS	70% of dry ITS
Min. Indirect Tensile Strength (dry)	100 kPa	150 kPa
Resilient Modulus (25°C)	900 MPa	1500 MPa
Dynamic Creep	10 MPa	15 MPa
Voids in mix	5 - 15 %	5 - 15 %

3. Structural design

Figure 2: Estimated structural bearing capacities for pavements with foamed bitumen treated gravel base layers

Estimated Design Bearing Capacity (Standard axles)	Pavement Structure
100 000 to 300 000	 100 mm weathered sandstone or granite with 3% binder In-situ weathered granite or sandstone, CBR 26%
300 000 to 1 million	175 mm weathered granite with 1% road lime and 4,5 to 5% binder. 100 mm weathered granite at 95% mod AASHTO compaction, CBR 27% In-situ weathered granite at 93% mod AASHTO compaction, CBR 23 %
1 to 3 million	 175 mm of 80% recycled asphalt, 20% crusher dust and 5,5 to 6% residual binder. 100 mm weathered granite at 95% mod AASHTO compaction, CBR 27 % *In situ* weathered granite at 93% mod AASHTO compaction, CBR 23 %

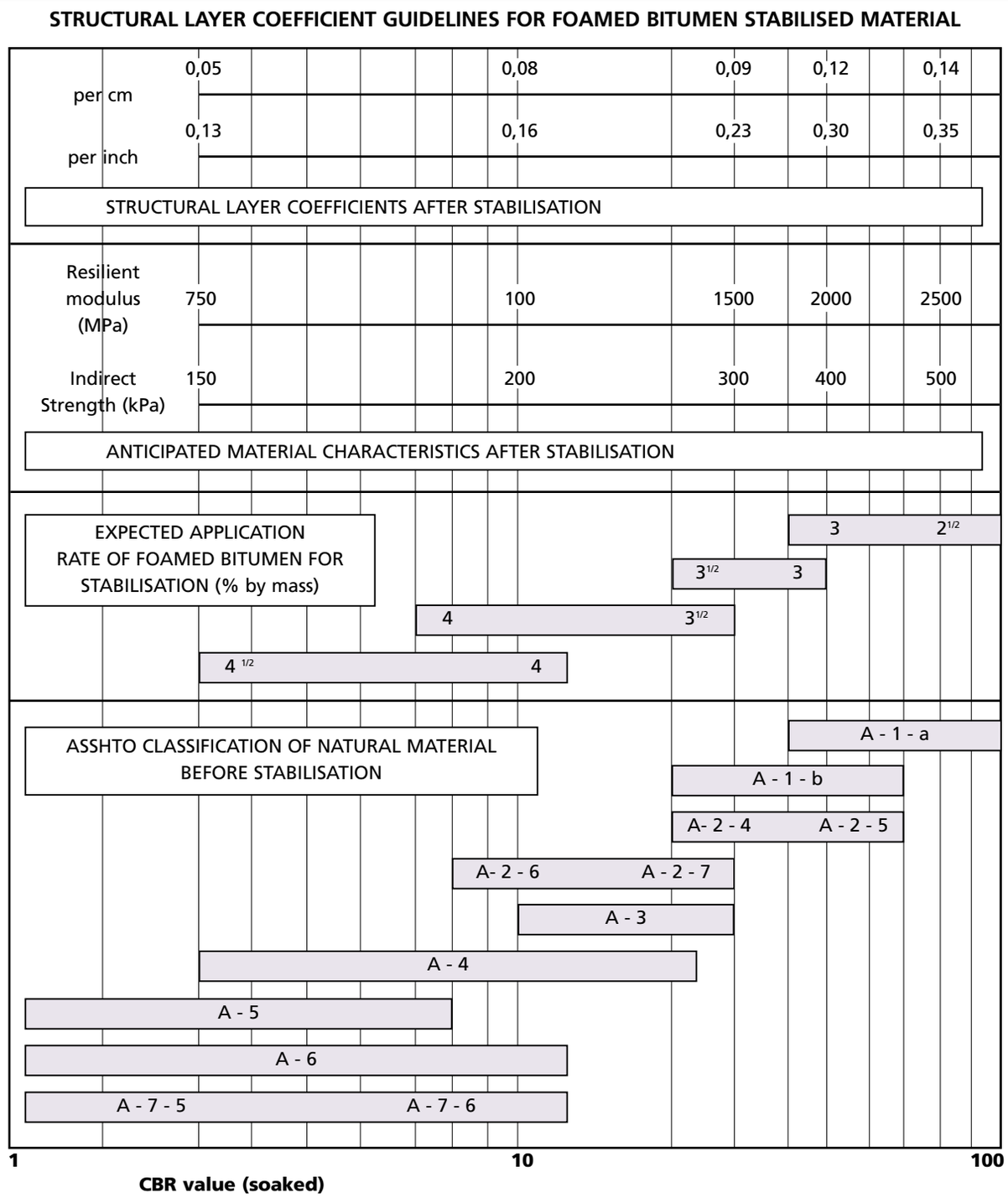
Foamed bitumen is relatively new to South Africa and as such, proper structural design procedures are still lacking for this material. Figure 3 provides guidelines on the Structural Number (SN) of foamed asphalt to be used in the AASHTO Structural Number Design Method (ASNDM). This chart was developed using mechanistic pavement design procedures but it should be kept in mind that the ASNDM is an empirical design method relating the SN to the bearing capacity of the pavement.

Transportek (Theyse, 1997) was also involved in a field study of the performance of foamed bitumen gravel mixes in South Africa. The output from this study in terms of the structural bearing capacity of low-volume roads constructed by using foamed bitumen treatment is given in Figure 2. The bearing capacities indicated in Figure 2 may be used as a reference for new designs.

Foam-treated gravel is essentially a brittle, bonded material. The retention of the cohesive bond depends largely on the flexibility of the material and the amount of support provided by the pavement structure below the base layer. It is therefore recommended that the pavement foundation should be well prepared even for the labour-intensive construction of access roads. Relatively good performance has been achieved on such roads in KwaZulu-Natal where the *in situ* material when properly compacted provided a sub-base layer of G6 (CBR>25 at 95 % mod AASHTO) quality that should typically have a resilient modulus of 250 MPa.

Although a foam-treated base layer may successfully be opened to traffic temporarily, the base layer must be surfaced with a bituminous surfacing in order to ensure long-term functional and structural performance.

Figure 3: Interim structural number (SN) input values for foam-treated gravel

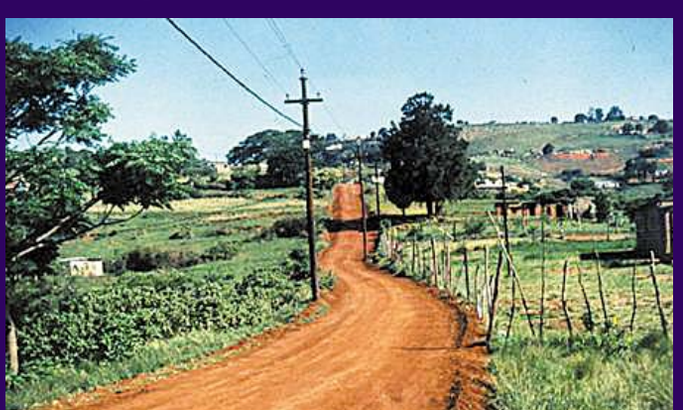


Notes
1. All materials classified as A - 4 or lower to be pretreated with hydrated lime.
2. Cement at nominal 1% to be added to all materials with P < 10 and CBR < 45.
3. Where required, non-plastic fine material to be added to increase the percentage passing the 0,75 mm sieve to achieve a minimum of 5%.
4. Where the mean annual rainfall is less than 100 mm and the risk of the pavement layers becoming saturated is negligible, the soaked ITS test may be omitted and the design foamed bitumen content determined using only dry ITS values.

4. Construction

Figure 4: Roadbed preparation

(a) An existing access road



(b) Bladed and compacted access road foundation for the foam-treated base layer

4.1 Plant and equipment

An asphalt plant with bitumen foaming capability is required to produce the foamed asphalt mix, as this cannot be produced on site, unless the deep *in situ* recycling method is selected. However the deep *in situ* recycling method is not suited to labour-intensive work.

Suitable provision must be made on site for the stockpiling of foam bitumen treated materials, i.e. protection from sunlight, rain, etc., by covering with a plastic sheeting. The height of the stockpile should not exceed three metres in order to prevent self compaction.

Compaction equipment: Pedestrian roller; Bomag 65.

Steel shuttering: Steel shuttering should be used for edge restraint and thickness control during construction. 3 m, 2 m and 1 m lengths should be supplied.

Steel squeegees, rakes, shovels and wheelbarrows: Steel squeegees are preferred to rakes for levelling the mix. Rakes tend to segregate the mix, whereas the steel squeegees distribute the material uniformly without segregation.

Screeds: Steel screeds are used between the top of the steel shuttering and the top of the side drain or the top of the inside edge of the concrete gutter to obtain the pre-compaction level of the foamed asphalt.

Steel gauges: Steel gauges are placed on top of the steel shuttering and edge of concrete curbs to obtain the uniform loose level before compaction and to ensure that the correct final compacted level is obtained. The first layer of mix is placed level with the shuttering and top of drain and compacted. The second layer of mix is placed level with the tops of gauges when placed on top of the shuttering and on top of the drain and then compacted. This ensures a uniform constructed level of the final base.

Plastic sheeting: Rolls of standard construction sheeting for protection of uncompacted layers and stockpiled materials.

Spirit level and straight edge and measuring tape

Water tank and hoses

4.2 Construction process

4.2.1 Roadbed preparation

As mentioned under the structural design section, a foam-treated base layer requires proper support from the sub-base layer. The *in situ* material should be bladed with a grader to create an even surface free of vegetation and compacted. If the *in situ* material is of insufficient quality, material should be imported and compacted for the sub-base layer.

4.2.2 Placing of steel shuttering

It is advisable to use steel shuttering as temporary edge-restraints for the construction of the foam-treated base layer. The steel shuttering that is available has one leg 150 mm in height and the other 100 mm. The required thickness of the base layer will dictate which leg to use as the edge-restraint when placing the steel shuttering, i.e. where a 150 mm thick layer is needed use the 150 mm leg as the height. Short 1m lengths of shuttering should be used for small curves. Make sure that the quantity of shuttering matches the amount of asphalt to be placed in one day.

The shuttering that is to be placed at the outside edge of the street/road must be securely fixed onto the prepared sub-base. If the foamed asphalt is placed in half-widths, place the shuttering on the centre line of the street/road. The levels of the top of the base can be checked using a reference line from the top of the drain to the outside edge of the street/road.

4.2.3 Placing of material and compaction

Remove material from the stockpile and mix with a shovel. The material must be sufficiently moist to achieve the desired compaction. Water can be added to the mix if it is suspected that there is insufficient moisture for compaction. In this case the exact moisture content of the mix and the water to be added must be determined carefully as follows:

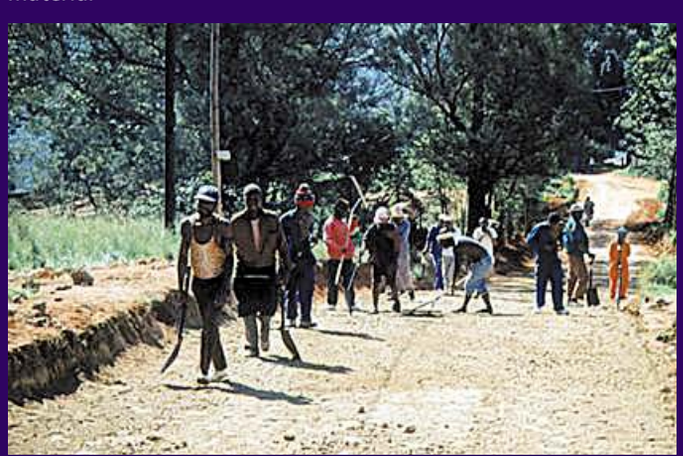
- The optimum moisture content (OMC) and binder content (BC) must be obtained from the materials laboratory, e.g. OMC of 7% and BC of 2%,
- For the best workability the amount of fluid (i.e. bitumen + water) to be added is OMC + BC = LL,
- The amount of moisture in the mix must be determined by weighing the gravel in four 25 litre containers (fill mix level with top of container) in its wet condition = LW,
- Then dry this material in the sun (spread the aggregate out of container) and reweigh it = LD,
- The weight of the moisture in the mix (LM) = LD – LW,
- The weight of the aggregate in the mix (LA) = LD ÷ (1+BC/100),
- Then the amount of water to be added = (OMC – BC) x LA /100 – LW i.e. added water = Total fluid – bitumen – moisture in the mix.

Experience will tell how much water should be added to make the mixture suitable for compaction without it being too dry or too wet. It is better to be on the wet side than the dry side.

Figure 5: Placement and spreading of the foam-treated material

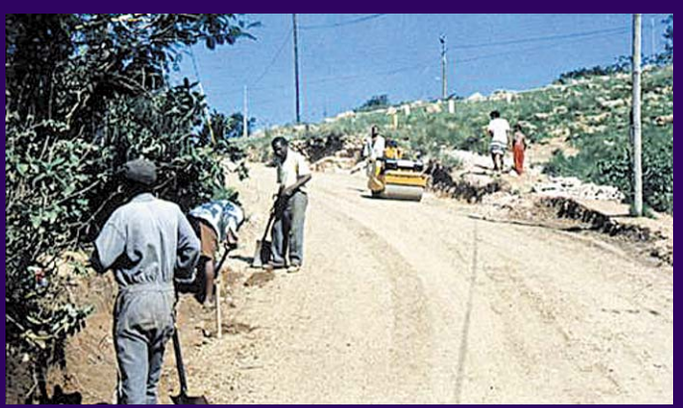
(a) Delivery of foam-treated material from a central plant

(b) Moving the material from the stock-pile and spreading the material



(c) Spreading of the foam-treated material

Figure 6: Placement and spreading of the foam-treated material



(a) Compaction of the foam-treated base layer

(b) The finished foam-treated gravel base layer

To prevent the material from drying out prematurely, the newly spread foamed asphalt should be covered systematically with a plastic cover as work progresses, until a sufficiently long (eight to ten metres) section is completed for the compaction to commence.

During the compaction process, there will always be a certain amount of spillage of loose material on the top of the steel gauges, which must be systematically removed with a flat shovel in order not to inhibit the roller from eventually compacting the material to the required level above the sub-base.

In order to obtain a smooth level of the base, i.e. to ensure that the surface of the foamed asphalt does not undulate, the method of hand rolling should be carefully controlled. This problem is induced by the roller initially moving onto the newly placed mix in a straight line parallel to the line of the steel shutters, causing surging and 'pushing' of the material. The roller should approach the strip at an angle with the roller drum over the edge of the shutter and existing surface, which automatically controls the level. This process should be repeated for each shutter, thus forming a triangle of uncompacted material, which could then be compacted at an angle with quarter wheel rolling. The rolling of the strip is then done by commencing the rolling with part of the roller over the shuttering which controls the uniformity of the surface levels. This process is repeated on the alternate shutter and alternatively moved in half-rolls to the centre.

4.3 Quality control

In order to ensure that the foamed asphalt designed in the laboratory is constructed to specification and that its structural performance is to the employer's satisfaction, the quality of the layer both during and after construction should be evaluated.

During the execution of the work, the contractor should ascertain that the composition of the mix is always close to the composition which was decided jointly by the contractor, the employer and his representative, within predetermined tolerances. In addition, he should ensure that the laying operations result in a finished layer of adequate density.

The degree of compaction can be controlled directly by means of conventional methods (such as a nuclear density gauge) or, indirectly, through the use of the Rapid Compaction Control Device (RCCD).

The RCCD could be used to calibrate the results obtained in the laboratory with those obtained in the field in order for the RCCD to be used for the following purposes during and after construction:

- to monitor the degree of compaction of the ETB during construction,

- to monitor the gain in strength during curing,
- as a decision tool, to establish when the layer can be opened to traffic.

The following procedure is proposed for calibration of the RCCD:

- Determine the optimum binder content in the laboratory,
- Compact four samples at optimum fluid content and optimum binder content, using a vibratory table,
- Determine the three-blow RCCD penetration (mm) on two unsoaked samples immediately after compaction in their moulds (three blows on four points per sample),
- Cure the remaining two samples in their moulds for one day at ambient temperature, followed by two days' curing at 40°C if the optimum moisture content is less than 8%, or for 45 hours at 60°C if the optimum moisture content is greater than 8%,
- Determine the three-blow RCCD penetration (mm) on the two remaining unsoaked samples after curing in their moulds (three blows on four points per sample),
- Calculate the average three-blow RCCD penetrations (mm) immediately after compaction and after curing.

The average RCCD penetration measured immediately after compaction can be used to evaluate the degree of compaction on the road. The average RCCD penetration measured after curing can be used to determine when the road can be opened to traffic. Generally, the road can be opened to traffic when the RCCD penetration (mm per three blows) is less than 18 mm. Generally, a section can be opened to traffic within 24 hours of construction.

5. Specialist literature

1. Muthen KM, Contract Report CR-98/077: Foamed Asphalt Mixes, Mix Design Procedure, CSIR Transportek for SABITA Ltd. Pretoria, 1998.

2. Theyse HL, Contract Report CR-97/087:Preliminary Assessment of the Structural Properties of Pavements with Foamed Bitumen Base Layers, CSIR Transportek for KZN DOT, Pretoria, 1997.

3. Lewis AJN and DC Collings, Cold In Place Recycling: A Relevant Process For Road Rehabilitation And Upgrading: In: Proceedings Of The 7th Conference On Asphalt Pavements For Southern Africa, Victoria Falls, 1999

4. De Beer, M., Kalombo, D.K. & Horak, E. 1993. Rapid compaction control for trench re instatements and pavement layers. In: Proceedings of the 13th Annual Transportation Convention. Pretoria: University of Pretoria, Vol. 2B, paper 7, pp 1-19.

Notes

Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour-based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major contributing organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
National Housing Forum
Congress of South African Trade Unions

Plus many individuals from construction companies

"Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings."

Nelson Mandela, 2005 – Global Campaign for Action against Poverty

Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 4-5

Cast *in situ* block pavement

cidb
development through partnership

Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment-intensive construction works

In this set: (colour coded)

Part 1

An overview of labour-based technologies and methods in employment-intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

3.2 The BESA building system

Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

4.2 Rubble masonry dam construction technology

4.3 Rubble masonry concrete arch bridge construction technology

4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Waterbound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

EXPANDED PUBLIC WORKS PROGRAMME
Creating opportunities towards human fulfilment

ENGINEERS AGAINST POVERTY

Labour-based methods and technologies
for employment-intensive construction works

A cidb guide to best practice

1ST Edition of CIDB document 1030 March 2005

Best Practice Guideline – Part 4-5

Cast *in-situ* block pavement

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

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development through partnership

Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1. Background

The use of the cast *in-situ* block pavement resulted from a need to develop a road construction method that would provide an all-weather road without the disruptions associated with traditional construction, while at the same time was labour intensive.

Cast *in-situ* block paving refers to the locally developed technology of welded plastic geocells, commonly known by the proprietary name Hyson-cells. The cells, when filled with concrete, form an interlocking 'cell slab' (see Figure 1). The hollow cell matrix acts as vast sacrificial formwork, which is left embedded in the concrete to serve as jointing. While there has been some experience with this technology, it is still relatively unknown. However, the supplier offers labour training and site supervision services in the use of the product and the concept has won acclaim at international conferences.

The benefits of cast *in-situ* block pavements include:

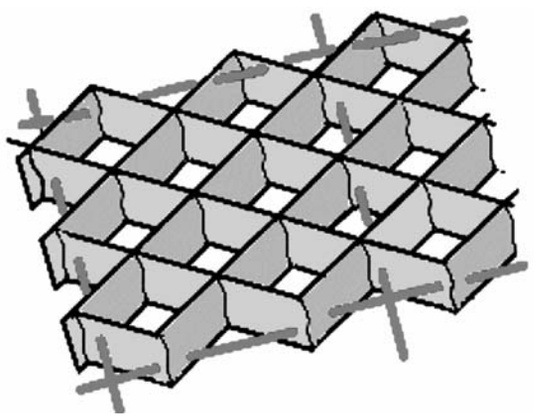
- By first placing the course aggregate, only 40% of the slab volume has to be mixed and handled,
- The cells reduce the amount of shrinkage cracking and provide a jointing as well as a self-keying (see Figure 1) mechanism for load transfer,
- Very low maintenance is required for the pavement over the design period,
- The construction is an integral process in which the road can be cast in any desired profile, and side drains or drains down the centre of the road can be constructed with the cells (see Figure 2).

Figure 1: Core of Hyson-cells block showing self-keyed joint

Figure 2 : Hyson-cells road with integral side drains

2. Materials

Figure 3: Hyson-Cells



2.1. Material components

2.1.1. Hyson-Cells

Hyson-Cells (see Figure 3) are packaged in one cubic metre bags which contain 200 m^3 of expanded cells. One cell of extra material along each side of the road, which is not butted to a kerb or drain, should be allowed for tuck-in of cells into an anchor trench.

2.1.2. Anchoring pegs

Y10 Steel reinforcing bars, of variable length depending on nature of the in-situ material, but typically 250 mm at a rate of one peg per square metre, and 1 peg in every second cell in the anchor trenches. (Note: smooth R10 bars are not suitable). Do not pre-cut the Y10 bars, as the required length may vary.

2.1.3. Stone fill

The stone fill for the cells should be sieved stone between 27-37 mm with no fines. The aggregate does not have to be crushed, but should be essentially single sized, as a graded aggregate could inhibit the penetration of the grout. For 75 mm slabs and smaller, the aggregate should pass the 26,5 mm sieve and be retained on the 19 mm sieve. A maximum flakiness index of 30% is required.

2.1.4. Sand

It is essential to use good quality plaster sand for the grout as coarser sands may prevent effective grout penetration. The typical requirements for concrete with respect to cleanliness and absence of organic materials should be followed.

2.1.5. Cement

Common Cement CEM II B-V complying with SANS 50197-1 gives a good workability. In built-up areas the use of quick setting cements may be advantageous.

2.2 Grout mix guidelines

0.4 Cubic metres of grout is required per cubic metre of cells (i.e. to fill 40% voids in the stone). Increase this to 0.5 cubic metres per cubic metre of cells if the stone is uncompacted. The following table shows mix ratios for different strength requirements. The amount of water added depends on the aggregate, but controls the consistency of the grout which should be a thick paste. If the grout is too thin, then its strength could be severely impaired, but if it is too thick then insufficient penetration will occur.

Typical grout mix proportions are presented in Table 1.

Table 1: Grout mix proportions

Strength required	10 MPa	20 MPa	40 MPa
Sand : cement ratio	3:1	2:1	1:1
Pockets of cement	2.78	4.1	6.15
Volume of sand	0.29 m^3	0.266 m^3	0.2 m^3
Volume of grout	0.4 m^3	0.4 m^3	0.4 m^3
Total volume	1 m^3	1 m^3	1 m^3

3. Equipment

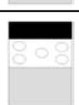
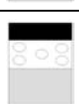
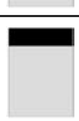
The equipment required for the construction of the cast *in-situ* block paving includes:

- Wheelbarrows
- Concrete mixer
- Hand vibratory roller and/or plate vibratory compactor
- Brooms
- Water supply for mixing concrete grout
- Shovels
- Straight edges and spirit levels

4. Structural design

The design procedure for cast *in situ* block paving should be based on the industry-accepted practice as given in TRH4 and UTG3. The catalogue given in Figure 4, after Visser (1994), can be used to select an appropriate structure for the block paving for low-volume streets. The 10th percentile of the four-day soaked CBR of the in-situ material is used as the design criteria. If the soaked CBR of the *in-situ* material is less than 3% then special treatment of these sections will be required. Expert advice must be consulted in this case, as well as in the case of problem soils such as active clays, dispersive and collapsing soils etc.

Figure 4: Catalogue of structural designs (after Visser, 1994)

Pavement Code	Pavement Structure
A	75/1: 1 Cell Slab 150 G5 or 150 C4 In-Situ*
B	 75/1: 1 Cell Slab 150 G5 or 125 C4 In-Situ*
C	 75/1: 1 Cell Slab 125 G5 or 100 C4 In-Situ*
D	75/2: 1 Cell Slab In-Situ*
E	 50/2: 1 Cell Slab In-Situ*

* Note requirements for *in-situ* preperation

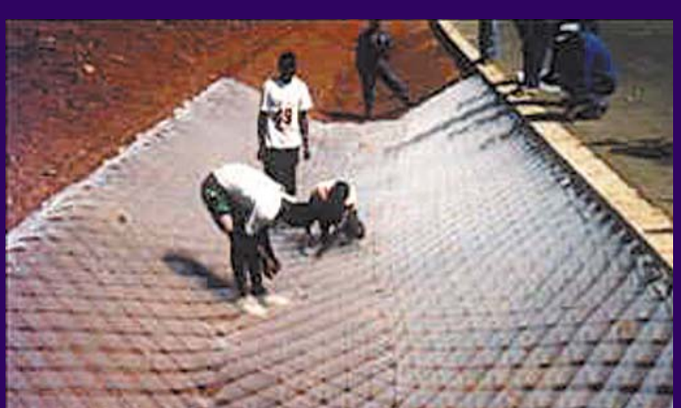
Route and environment Classification	Design traffic during structural life (EBO)		
	<0,2x10^6	0,2-0,8x10^6	0,8-3,0x10^6
Minor arterial, wet Climate, 3 - 7 CBR*		A	A
Minor arterial, wet Climate, CBR > 7		A	A
Minor arterial, dry Climate, 3 - 7 CBR		B	B
Minor arterial, dry Climate, CBR > 7		C	A
Access street, wet Climate, 3 - 7 CBR	D	C	B
Access street, wet Climate, CBR > 7	E	C	B
Access street, dry Climate, 3 - 7 CBR	D	C	B
Access street, dry Climate, CBR > 7	E	C	B

* Special precautions have to be taken if the design CBR < 3

5. Construction technique

Figure 5: A placed cell mat showing the edge anchor trenches and transverse key trenches

Figure 6: Expanded cells in a road side-drain application



5.1. Construction specification

Prepare earthworks to required levels, shape and densities, according to the required specifications. The prepared surface must be very smooth as any irregularities will show up in the final surface. Apply a thin blinding layer of sand over the prepared surface. Excavate anchorage trenches (200 mm wide x 200 mm deep) at the position specified (see Figure 5). The trenches should be positioned at the sides and parallel to the road and across the road as required. An anchorage trench is recommended at all edges that do not butt against a kerb to serve as anchorage and to prevent potential edge damage to the cast slab. The edge trenches also prevent undermining by water and provide extra load bearing along the edge. On steep slopes it is recommended that key trenches be cut across the width of the road, to prevent slab slippage and to cut off water from flowing under the slab.

Expand the cells and rig them taut to the securing Y10 steel bars using the anchoring strings that are an integral part of the Hyson-Cells mat. The cells must be stretched in the direction of the road and not across the road. The cells must be extended extremely tautly into a square shape. Packs of cells may be joined as required by using galvanized pins or by threading a string through alternate cells. The anchoring pegs must be driven to at least 50 mm below the surface level of the cell. After tying the rigging strings to the pegs, drive the peg a further 10 mm to distort the cells. The ends of the cells must be tucked into the anchor trenches and anchored with pegs. The cells must not be tucked into the key-trenches cut across the road, as these will be cast integrally with the slab. Figure 5 shows an example of a placed mat with the anchorage and key trenches.

Place the stone fill in the cells using wheelbarrows. Brush the stones flush with the top of the cells using a stiff broom. Compact the stone, if required, with 2-3 passes of the vibrating drum roller. The finish on the street is highly dependent on the evenness of the compacted coarse aggregate, and it is recommended that a straight edge be used to ensure evenness. The grout is ineffective in removing unevenness.

Mix the grout using the concrete mixer and place in the cells using wheelbarrows. Dampen the stone before placing the grout, but do not leave any standing water. Start grouting from the highest point on the road and proceed downhill. Place the grout in an even layer about 50% above the height of the cell depth.

Use the vibratory roller to vibrate the grout into the stone voids. Use a plastic sheet over the surface to prevent the grout from adhering to the roller. Compaction should continue until the tops of the cell walls are visible on the surface.

Brush the surface to form a rough texture. Keep the paving damp for the curing period as specified by the engineer. Protect the paving by covering in a thin sheet of plastic.

As a quality control measure, take cubes of stone and grout mix and determine the strength in the laboratory. Also, inspect cells to determine if the grout has penetrated over the full depth of the cell. Cells that are sampled in this way must be refilled immediately.

The cast *in-situ* block system may also be used in surface drainage applications as illustrated by Figure 6.

5.2. Labour

It is possible to construct cast *in situ* block pavements as illustrated in Table 2 using a number of construction techniques which range from being plant-based to fully employment-intensive techniques. In Option 1, plant is used to place the stones and mix the concrete, whereas in Option 3, the grout is mixed in a hippo drum, i.e. a drum which contains internal vanes which is rolled along the ground for a mixing period of 90 seconds. In Option 4, the stone is crushed on site by means of a small mechanical crusher. The labour component can increase by a factor of nearly 5, between Option 1 and Option 4.

Table 2: Person-hours required to provide and construct an *in-situ* paved block pavement (Watermeyer and Band, 1994)

PRIVATE OPERATION	PERSON-HOURS/m^2			
	OPTION NUMBER			
	1	2	3	4
	Concrete pump mixer and front-end loader	Concrete pump mixer and wheelbarrows to place grout	Hippo drums and wheelbarrows	With crushing own stone and sieving sand
Laying of cells	0,06	0,06	0,06	0,06
Place stones and compact	0,10	0,37	0,37	0,99
Mix and place grout	0,10	0,19	0,37	0,72
Finishing	0,03	0,03	0,03	0,03
TOTAL	0,38	0,65	0,83	1,80

6. Specialist literature

1. Committee of Urban Transport Authorities, Structural Design of Urban Roads, Draft UTG3, Pretoria, 1988.
2. Hyson-cells Technical Literature and Product Guides
3. Visser AT, A Cast In-Situ Block Pavement For Labour Enhanced Construction, Technical Paper in Concrete Beton No 71, February 1994
4. Watermeyer RB and Band NG. The Development of Small Scale Enterprises, Skills, Entrepreneurship and Employment Opportunities through the Provision of Housing. Working Group 3, National Housing Forum, November 1994.

Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour-based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major contributing organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
National Housing Forum
Congress of South African Trade Unions

Plus many individuals from construction companies

"Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings."

Nelson Mandela, 2005 – Global Campaign for Action against Poverty

Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 4-6

Emulsion-treated gravel

cidb
development through partnership

Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment intensive construction works

In this set: (colour coded)

Part 1

An overview of labour-based technologies and methods in employment intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

3.2 The BESA building system

Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

4.2 Rubble masonry dam construction technology

4.3 Rubble masonry concrete arch bridge construction technology

4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Waterbound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

EXPANDED PUBLIC WORKS PROGRAMME
Creating opportunities towards human fulfilment

ENGINEERS AGAINST POVERTY

Labour-based methods and technologies
for employment-intensive construction works

A cidb guide to best practice

1ST Edition of CIDB document 1031 March 2005

Best Practice Guideline – Part 4-6

Emulsion-treated gravel

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

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Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1. Introduction

1.1 Background

Heavy Vehicle Simulator (HVS) tests and other research activities on the relative performance of ETB compared to untreated gravels showed the following:

- deflection reduction of up to 30% in the ETB,
- lower permanent deformation(rutting), greater bearing capacity and greater resistance to shear forces were measured,
- considerable reduction in the moisture sensitivity as a result of lower permeabilities and the binding of the fines,
- improved resistance to reflective cracking,
- compared to a crushed stone base, G1, (although not necessarily in the same bearing capacity category), construction time and costs would be reduced by reducing the compactive effort and by eliminating the slushing process and the need for priming,
- prior to being sealed, the ETB layer could withstand heavy traffic for extended periods.

Between 1988 and 1992, the Southern African Bitumen Association (Sabita) sponsored a research programme, the objective of which was the development of nationally acceptable mixing, testing and evaluation methodologies for Granular Emulsion Mixes (GEMs). Whereas the emphasis of this project was on the upgrading of sub-standard materials (for the particular pavement category) to base standards by the addition of relatively high percentages of emulsion (residual bitumen contents in excess of two percent), the project nevertheless attempted to formalize the design procedures of ETBs. In October 1993, Sabita (Sabita, 1993) launched a design manual for GEMs with recommended design procedures for both stabilised GEMs (high emulsion contents) and modified GEMs (low emulsion contents; similar in concept to ETBs).

The publication of the GEMs design manual, however, did not address all the needs identified by the road building industry. Although the ETB technology had proved itself in the field, there were still a number of unknown factors which made it difficult for road agencies or their representatives to specify ETBs as part of their works.

Because of this, Sabita launched a project in 1996 with the objective of broadening the range of application of ETBs as a competitive base course material in both rural and urban applications by extending the design scope of the current technology and entrenching it in practice. The aim of the above project was, based on best practice, to provide:

- guidelines on structural design
- economic guidelines
- guidelines on material design
- guidelines on constructability

At the same time, the technology was refined. This project culminated in the publication of Sabita Manual 21 on the Design and Use of Emulsion Treated Bases.

Note

Bitumen emulsion is a widely used product in the road construction industry. Over the past 30 years, great success has been achieved by South African road engineers with the technique of adding small quantities of bitumen emulsion to gravels of fair to good quality, even for the rehabilitation of national roads. The application of using bitumen emulsion treated gravels for labour-based construction is fairly recent development, but has quickly been refined into a technically sound method. In low volume roads, the emulsion treated gravel is usually used to form the road-base layer, and hence the term Emulsion Treated Base (ETB) is commonly used.

The SABITA Manual 21: The Design and use of Emulsion Treated Bases published by the Southern African Bitumen Association has informed much of the content of this section.

Unknowns hampering adoption of ETB technology

- the shift between properties at the design stage and those in the field,
- the lack of reliable performance indicators,
- constructability issues and acceptance criteria were not well developed/ documented,
- potential advantages of the use of emulsions relative to other materials and their advantages were not adequately addressed.

1.2 Definition of ETBs

ETBs are defined as new or reclaimed gravels (often of a quality not suitable for use as a base course for the particular application) treated with a small percentage of bitumen emulsion (usually less than 2,5% depending on the quality of the parent material) so as to produce the required base course quality type of material.

Bitumen emulsion is made up of minute droplets of bitumen suspended in water. The bitumen, in emulsified form, can be easily mixed with aggregates after which the bitumen adheres to the aggregates, and the water evaporates.

1.3 Advantages of ETBs

The addition of bitumen emulsion to new or reclaimed gravels offers the following advantages:

- it reduces the internal friction of the gravel, crusher run or crushed stone during construction, thus improving its compacted density and its workability (without having to resort to slushing in the case of crushed stone),
- it reduces water susceptibility and improves cohesion by binding the fine aggregate,
- the addition of a fairly small amount of emulsion can significantly increase the CBR and UCS of the material,
- its strength and stiffness are similar to those of lightly cemented materials,
- rutting of a gravel type base course can be reduced significantly,
- if the ETB base does crack at the end of its life cycle, the transportation of fines is considerably reduced, which reduces the possibility of 'pumping' problems and the resultant secondary cracking,
- it reduces the development of potholes in the base when the surfacing is damaged,
- by enrichment of the upper ETB layer during construction, it usually eliminates the need for priming,
- when using crushed stone aggregate (as for G1 base), the risk of segregation of the aggregate matrix is reduced during construction.
- it allows the layer to be trafficked sooner than most other base layers - as soon as the emulsion has broken and no pick-up is evident under traffic,
- its use results in savings in fuel consumption required for heating, as emulsions are used at ambient temperatures (cold mix),
- gravels do not need to be dried, as emulsions adhere readily to damp aggregate,
- it is usually possible to core ETBs and to recover complete cores, which facilitates easy and speedy testing for quality control purposes.

The above benefits, together with the ability to use local or *in-situ* materials, thus obviating the need to haul in suitable base course material over long distances, make the addition of small percentages of emulsion attractive from the point of view of costs, as well as highly suitable for use as an employment-intensive construction material.

2. Materials and specifications

2.1 Material components

2.1.1 Cement

The cement is added to the mix as a catalyst to induce the emulsion to break after compaction of the layer. Normally only one percent cement is added.

2.1.2 Lime

If the material has a PI > 6, it is advisable to add lime to the material to reduce the PI. The effect of the lime on the material must be established, with emulsion added.

2.1.3 Emulsion

The emulsion to be used must be an anionic stable grade 60% emulsion. Normally for labour-enhanced work the emulsion will be supplied in 210 litre drums

2.1.4 Aggregate

The following natural gravels may be considered for construction of ETBs:

- decomposed granites
- decomposed dolerites
- decomposed basalts
- quartzitic gravels
- laterite/ferricrete gravels
- chert gravels
- sandstone gravels
- calcretes

2.2 Material design in four steps

STEP 1: Characterisation of the parent material

A sieve analysis should be carried out and the Atterberg limits determined on the parent material. If the re-use of cement-treated (CTB) or lime-treated (LTB) materials is considered for the manufacture of ETBs, such materials should be crushed in the laboratory prior to the determination of grading and Atterberg limits to produce a grading similar to that obtained from field processes.

The parent material should be classified in accordance with the classification given in Draft TRH14 (COLTO, 1989). Preference should be given to G1 to G3 or CTB type materials, as these would seldom require more than one percent residual bitumen. This, however, should not be interpreted to indicate that relatively expensive crushed stone (G1 or G2) material should necessarily be acquired if it is not already available on site (such as in an existing pavement). It also does not exclude materials of a lower class. G4 or G5 type materials may be used successfully in ETBs, provided that the required amount of residual bitumen does not exceed two percent. (If it is greater than two percent, the stabilisation approach – Sabita 1993 – should be considered for the design of the ETB.) Also, the grading properties of sub-grade quality materials could be improved by mixing in coarse gravels or crusher run/crushed stone. This would allow the use of lower emulsion contents.

Both the grading of the parent material and the material properties obtained after addition of the emulsion will determine whether the ETB would be suitable

The design procedure

The material design process for gravels treated with small percentages of emulsion (less than 3%) is based on the following procedure:

- characterisation of materials to be used in ETBs;
- determination of the optimum fluid content;
- preparation of samples, in which the amount of residual bitumen varies from 0-2% in increments of 0,5%, but where the optimum fluid content (hydroscopic water, emulsion and compaction water) remains unchanged;
- compaction in accordance with the standard modified AASHTO method at room temperature;
- curing of samples (24 hours at ambient temperature followed by 48 hours' oven curing at 40°C if the optimum moisture content is less than 8%, or 45 hours at 60°C if the optimum moisture content is greater than 8%);
- determination of CBR and UCS after 4 days and 6 hours soaking, respectively; and
- determination of optimum residual bitumen content.

Adding lime to swelling clays

For some materials such as dolerites (G1 or G2 quality) with a PI of, say, 3 to 4, but which may contain montmorillonite clays, it is recommended that lime be added to the material. In order to quantify the presence of such clays (smectite), the PI test should be conducted on material passing the 0,075mm sieve.

for the intended pavement structure and design traffic. A high traffic category would require sound material with a good continuous grading (such as that obtained from crusher run/crushed stone) to achieve proper aggregate interlock. (Note that crusher run and crushed stone materials are normally delivered with an excess of fines, which are slushed out in the final aggregate interlocking phase). Certain natural gravels could be used on medium to high traffic category roads (bearing capacity > 300 000 Standard Axle Loads), but usually their application would be limited to Category C and Category D roads (bearing capacity <300 000 Standard Axle Loads), unless larger amounts of emulsion are used.

Both the PI and the shrinkage product (product of the linear shrinkage and the percentage of material passing the 0,425 mm sieve) may be used to verify whether or not natural gravels would be suitable for use in ETBs. Material with a PI greater than 6 should not be considered for use in its natural state. Lime should be added to reduce the PI to below 6. Similarly, for high-volume roads, the shrinkage product should not exceed 50. If it exceeds 50, lime should be added and/or the grading modified (for instance, by mixing in coarse aggregate) in order to reduce the shrinkage product to below 50.

The quantity of stable grade emulsion to be used in ETBs is governed by the type of gravel used and its grading modulus (e.g. certain decomposed granites react well with emulsion; coarse-graded materials would require less emulsion than fine-graded materials).

It is recommended that one percent of cement be added to the parent material to assist the breaking process and adhesion of the emulsion and to increase the early strength which is required to allow the layer to be trafficked soon after completion of construction.

Using the grading modulus

The grading modulus (together with PI; see above) could be used as an alternative to the shrinkage product. For high volume roads, it is recommended that the grading modulus be greater than 2,1. If the grading modulus is less than 2,1 and the soaked CBRs of the untreated material exceed 50 at 95 to 97% mod. AASHTO compaction, the grading of the material could be improved by the addition of between 15 and 20% crushed -19 mm +6,7 mm aggregate.

Key definitions

The following definitions are given for fluid content, maximum density and optimum fluid content:

- Fluid content is the total quantity of fluid in the mix, including hygroscopic moisture, the bitumen and water within the emulsion and moisture added for compaction.
- The maximum density of a material at a specific compactive effort is the highest density obtainable when compaction is carried out on the material at a various fluid contents.
- The optimum fluid content for a specific compactive effort is the fluid content at which the maximum density is obtained.

STEP 2: Determination of the optimum fluid content

The maximum dry density and optimum fluid content are determined by establishing the fluid-density relationship of the material when prepared and compacted at the Modified AASHTO compaction effort at different fluid contents.

The optimum fluid content is approximately equal to the optimum moisture content of the untreated material (as determined according to Method A7 of TMH1 (COLTO, 1986) plus the residual bitumen within the quantity of emulsion to be added (expressed as a percentage of the mass of the dry material). Although it is not essential, it is advisable to determine the optimum moisture content before the optimum fluid content is determined, especially if several different emulsion contents are to be investigated.

Apparatus and preparation prior to mixing

These are identical to those described in Method A7 of TMH1 (COLTO, 1986). Any material larger than 19 mm should be crushed until it passes this size prior to treatment and compaction.

Mixing

The sample in each basin should be weighed accurately to the nearest five grams and transferred to the mixing basin. The quantity of emulsion to be added (as a percentage of the mass of dry material) should be known, and hence the residual bitumen content (e.g. 60% for a 60% anionic emulsion) can be determined. The approximate optimum fluid content can be derived by adding the percentage residual bitumen to the optimum moisture content of the untreated material if this is known.

The percentage of compaction water required can be determined by subtracting the percentage emulsion (and the approximate hygroscopic moisture content if this is known) from the required fluid content. The volume of water required should then be determined and measured into a suitable container. The required mass of emulsion should also be determined and measured into another suitable container.

If cement or any other stabilising agent is to be added, it should be thoroughly mixed with the dry material at this stage.

A portion of the compaction water (equivalent to the moisture absorption) should then be added to the dry sample until, in the opinion of the operator, the material is damp. While the water is being added, the material should be mixed continuously with a trowel. This should normally continue until dust is no longer generated by the mixing.

The remaining compaction water should then be thoroughly mixed with the emulsion and added to the damp material. Under no circumstances should diluted emulsion be added to dry porous material. The mixing of the moist material should be continued for another few minutes. The moist material should now be covered with a damp sack to prevent evaporation and should be allowed to stand for half an hour so that the fluid may become evenly distributed throughout. (In the meantime another basin of material may be treated by mixing at a fluid content of one percent lower or higher than the first fluid content.) If the material has been moistened beforehand, it is not necessary to wait for half an hour and compaction may therefore commence immediately after the fluid has been mixed in.

Determination of fluid content

After the second layer has been compacted, a representative sample should be taken from the material in the basin and placed in a suitable container for determination of the moisture content.

The sample should be between 500 and 1 000 g. The more coarsely graded the material, the larger the sample should be. The moist sample should be weighed immediately to the nearest 0,1 g and dried to constant mass in an oven at 105 to 110 °C. The moisture content should be determined to the nearest 0,1%.

The fluid content should then be determined by adding the percentage residual bitumen (determined earlier) to this value.

Calculations

The moisture content of the material at each point should be calculated to the nearest 0,1% as follows:
$d = (a - b) / (b - c) \times 100$

Where:
d = moisture content expressed as a percentage of the dry soil
a = mass of container and wet material (g)
b = mass of container and dry material (g)
c = mass of container only (g)
The fluid content (f) should be calculated by adding the percentage residual bitumen (e) as follows:
$f = d + e$

Recommended procedures contained in TMH1

The recommended procedures are identical to those described in Method A7 of TMH1 (COLTO, 1986) for:

- Preparation of the mould and compaction,
- Removal of excess material, mass of mould and establishing additional points for the fluid-density relationship curve.

The dry density at each point should be calculated to the nearest one kg/m^3 as follows:
D = W / (d + 100) x (100 / V) x 1000.

Where:
D = dry density (kg/m^3)
W = mass of wet material (g)
V = volume of mould (ml)

Fluid-density relationship

After the calculations have been completed, the fluid contents should be plotted graphically against the respective dry densities (see Figure A7/2 of TMH1; COLTO, 1986). The peak of the curve indicates the optimum fluid content and the maximum density of the material when compacted under this particular effort.

Reporting of results

The maximum density should be reported to the nearest whole number on forms such as Form A10(a)/1 (TMH1; COLTO, 1986) if the results are required to be used as a reference for field densities, or on Form A8/1 (TMH1; COLTO, 1986) or a similar form if required for CBR determinations (see Method A8 of TMH1; COLTO, 1986).

The optimum fluid content should be reported to the first decimal figure.

Note

- The material should be compacted within one hour of mixing, since the emulsion must not have broken at the time of compaction.
- Once material has been compacted, it cannot be used for another compaction.

STEP 3: Manufacturing and curing of specimens

Sample manufacturing

The sample manufacturing procedure is described in the procedure for the determination of optimum fluid content (Step 2). It is recommended that samples be prepared over a range of emulsion contents, where the amount of residual bitumen varies from 0% to 2% in increments of 0,5%, but where the optimum fluid content (hygroscopic water, emulsion and compaction water) remains unchanged. Samples prepared at various residual binder contents should be compacted at room temperature according to the standard modified AASHTO method. Any material larger than 19 mm should be crushed prior to treatment and compacted until it passes this size.

It is recommended that samples prepared for UCS testing be manufactured at a moisture content of 0,5 to 1,0% above optimum moisture content. If samples are compacted at optimum moisture content, the UCS results often underestimate the strength of the material because of their dryness.

Replacing oversized material

If over-size material is encountered in the field, such over-size material should be removed and replaced with -19 mm +13 mm fractions of coated (treated) material obtained from field samples prior to compaction. The crushing of over-size material after emulsion treatment and the use of such material for compaction would detract from the strength of the ETB, as some faces of the aggregate would be uncoated.

Curing and soaking of specimens

After compaction, the specimens are cured in their moulds for 24 hours at ambient temperature, followed by 48 hours' curing in an oven set to a temperature of 40 °C, if the optimum moisture content is less than eight percent. If the optimum moisture content is greater than eight percent, the specimens are cured for 45 hours at 60 °C. Alternatively, specimens can be cured for seven days at ambient temperature (when cement has been added) or 28 days at ambient temperature (when no cement has been added). The purpose of curing is to induce breaking of the emulsion. This limiting moisture content of eight percent is only a guide and should be used with discretion.

Before CBR and UCS testing, the cured specimens should be cooled, weighed and submerged in water at ambient temperature for four days and six hours

respectively. After removal from the soaking baths, it is recommended that the samples be surface-dried with a towel and weighed again to establish the amount of water, if any, which has been absorbed.

STEP 4: Testing of specimens

California Bearing Ratio (CBR)

With due attention to the requirements for pavement balance and depth, applicable to the situation, the CBR values obtained are used for the determination of:

- the optimum residual bitumen content,
- whether the material is suitable for the traffic class envisaged,
- whether the material is suitable for use in the base layer,
- cover requirements (i.e. type and thickness of the overlay).

After curing and four days' soaking, the CBR values of the various specimens, each prepared at a given residual bitumen content, are determined to a penetration depth of 2,54 mm. The optimum residual bitumen content is defined as the residual bitumen content at which the CBR requirements defined in Table 1 are met.

E1 type materials would typically consist of parent materials of G1 to G3 or CTB quality with a residual bitumen content of less than 1,0% (CTB, G1 or G2) or less than 1,5% (G3). E1 type materials would be suitable for use on Category A and Category B roads (in excess of 300,000 E80s).

Table 1: Mix design criteria for ETBs in terms of CBR

Material Code	Minimum CBR
E1	150% at 100% Mod. AASHTO compaction
E2	100% at 100% Mod. AASHTO compaction

E2 type materials would typically consist of parent materials of G4 to G5 quality with a residual bitumen content of less than 1,8%. E2 type materials would be suitable for use on Category C and Category D roads (up to 300,000 E80s).

Unconfined compressive strength

After curing and six hours' soaking, the UCS values of the various specimens, each prepared at a given residual bitumen content, are determined in order to establish whether or not the material complies with base standards. The optimum residual bitumen content is defined as the residual bitumen content at which the minimum UCS requirements defined in Table 2 are met.

Table 2: Mix design criteria for ETBs in terms of UCS

Material Code	Minimum UCS
E1	1 200 kPa
E2	700 kPa

3. Structural design

The principles of structural pavement design as described in Draft TRH4 (COLTO, 1996) and Draft TRH12 (COLTO, 1983) should be used in conjunction with this document during the pavement design process. There are, however, a few pavement design principles of particular importance to the design (initial as well as rehabilitation) of a pavement structure with an emulsion-treated base layer.

The concept and importance of designing a deep, well balanced pavement structure is well established. Emulsion-treated material is essentially a fairly stiff and brittle material if compared with granular materials. This, on the one hand, improves the deformation resistance of the material but increases the load sensitivity of the material if not well supported. The designer should therefore guard against using a thin emulsion-treated base layer on a granular support as this may lead to a shallow and/or unbalanced pavement structure sensitive to overloading. Although these designs are included in the catalogue, they are only intended for applications with a low load-bearing capacity demand where few heavy and overloaded vehicles are expected in the traffic spectrum such as for residential access streets. In general it is suggested that a lightly cemented sub-base be used for pavements with emulsion-treated base layers - of course, depending on the required total bearing capacity.

Although, in terms of initial strength, stiffness and behaviour under repeated loading, the behaviour of emulsion-treated material closely resembles that of lightly cemented material, this does not imply that the performance of these two material types will be the same under similar conditions and/or pavement structures. Both materials start off at more or less the same level of strength and with a similar deterioration pattern, but the time scale during which this deterioration takes place, will differ. Experience has shown that an emulsion-treated material will not pump fines to the road surface under traffic when wet. On the other hand, experience has shown that this may well happen once a cement-treated base has cracked.

The relatively high stiffness of an emulsion-treated material compared to that of a natural gravel or a crusher run (G2 to G3) should improve the fatigue resistance of bituminous surfacings since the fatigue of the latter layers is highly dependent on the stiffness of the immediate support layer (a well balanced and relatively deep structure is necessary).

Due to the nature of emulsion-treated materials, a base layer constructed of ETB must be surfaced with a bituminous surfacing in order to ensure long-term structural performance.

The design catalogue (after SABITA Manual 21) presented in Figure 1 can be used to determine the structure of the pavement required for a certain traffic level.

Figure 1: Design catalogue for determining a range of pavement structures

ROAD CATEGORY	PAVEMENT CLASS AND DESIGN BEARING CAPACITY (80 KN AXLES/LANE)										
	ESO.003 0.1-0.3x10^4	ESO.01 0.3-1.0x10^4	ESO.003 1.0-3.0x10^4	ESO.01 3.0-10x10^4	ESO.003 0.1-0.3x10^6	ES1 0.3-1.0x10^6	ES3 1.0-3.0x10^6	ES10 3.0-10x10^6	ES30 10-130x10^6	ES100 30-100x10^6	Foundation
A: Major interurban freeways and roads. (95% approximate design reliability)								40A 125E1 250C4	40A 150E1 150C3 150C4		
B: Interurban collectors and major rural roads. (90% approximate Design reliability)						S 100E1 150C4 S 125E1 150G5	S*/30A 125E1 150C4 S*/30A 150E1 150G5	40A 125E1 200C4 40A 150E1 150C4			150G7 150G9 G10
C: Lightly trafficked rural roads and strategic roads. Design reliability)				S 100E2 150G6	S 100E2 150G6	S 100E2 125C4					
D: Light pavement structures, rural access roads. (50% approximate design reliability)			S1 100E2 100G6	S1 100E2 125G6							150G9 G10

Symbol A denotes AG. AC. or AS.
AO, AP may be recommended as a surfacing measure for improved skid resistance when wet or to reduce water spray
S denotes Double Surface Treatment (seal or combinations of seal and slurry)
S1 denotes Single Surface Treatment
* If seal is used, increase C4 and G5 subbase thickness to 200 mm.

Most likely combinations of road category and design bearing capacity.

4. Construction

4.1 Plant and equipment

Concrete mixer

Concrete mixer 200/250 litre (or bigger if readily available). It is advisable to use a concrete mixer equipped with a diesel engine as the stoppages are minimal and labour-friendly.

Pedestrian roller

The Bomag 65 is efficient and economical and can compact layers up to 75 mm thick to the specified densities.

Steel shuttering

Steel shuttering should be used for edge restraint and thickness control during construction. It will be noted that the one leg of the shuttering is 150 mm and the other 100 mm, so that where required a 150 mm layer of ETB can be placed. It is advisable to have different lengths of shuttering, i.e. three, two and one metre shuttering, the latter being particularly useful for small radius curves. The quantity of shuttering will depend on the volume of ETB that can be placed in one day.

Steel squeegees, rakes, shovels and wheelbarrows

Steel squeegees are preferred to rakes for levelling the mixed ETB. Rakes tend to segregate the mix, whereas the steel squeegees distribute the material uniformly without segregation. However, rakes can be used with the finer materials.

Screeds

Steel screeds are used between the top of the steel shuttering and the top of the side drain or the top of the inside edge of the concrete gutter to obtain the pre-compaction level of the ETB. The length of the screed will depend on the width of the ETB being laid, but two metres is about the maximum width that can be efficiently handled with two labour units working the screed.

Steel gauges

Steel gauges are placed on top of the steel shuttering and edge of concrete to obtain the uniform loose level of the ETB before compaction and to ensure that the correct final compacted level is obtained.

The first layer of ETB is placed level with the shuttering and top of drain and compacted. The second layer of ETB is placed level with the tops of gauges when placed on top of the shuttering and on top of the drain and then compacted. This ensures a uniform constructed level of the final base.

Heavy duty hose and fittings

100 m of heavy duty hose of 13 mm diameter, with fittings, makes the handling of the water supply easy and efficient, with minimum wastage of the water.

Watering cans

20 litre watering cans with a modified shower 'rose' attached. The diameter of the holes in the 'rose' must be increased to three millimetres so that diluted emulsion can be applied before the ETB is laid.

Plastic sheeting

Rolls of standard construction sheeting are required.

Spirit levels, straight edge and measuring tape

Spirit levels, straight edge and measuring tape are required.

4.2 Construction techniques

4.2.1 Handling of emulsion

The following precautions must be observed when handling bitumen emulsion:

- When unloading the drums from the delivery truck it must be ensured that the drums are not dropped from the truck but rolled off the truck using steel or timber ramps. This process will ensure that the drums do not break and prevent premature breaking of the emulsion in the drum.
- Before the drums of emulsion are used, they must be rolled backwards and forwards to ensure that the emulsion is properly mixed, as when they are stockpiled for any length of time the bitumen in the emulsion tends to settle to the bottom of the drum. (Note: Full drums must be stored flat and empty drums vertically.)
- It is essential for accurate and neat workmanship that the drums be placed on a steel frame and a hand operated ball valve be fitted to the drum.

Measuring containers, with calibrated steel dip sticks, must be available for measuring accurately the required amount of emulsion for each mix.

Figure 2: Batching of chemicals

(a) Measuring off the required volume of emulsion

b) Weighing the required mass of cement

4.2.2 Batching and mixing

The mixing of the materials can either be done by hand labour or with a concrete mixer (see Figure 2). The latter is quicker and more effective for larger quantities while the former is quite practical for smaller quantities and most effective for road repair work.

Before mixing make sure that the specification of the mix is correct, i.e. the percentage of emulsion, cement and/or lime that must be added to the gravel or aggregate.

Calculate the weight of the loose material as follows:

- Using 4 x 25 litre measuring cans, weigh the cans empty.

  W_{01} = -------kg weight of can 1 empty
  W_{02} = -------kg weight of can 2 empty
  W_{03} = -------kg weight of can 3 empty
  W_{04} = -------kg weight of can 4 empty

- Paint a number on each of the cans, viz. 1, 2, 3, 4.
- Fill the cans with the gravel to be used. Strike off the can so that the gravel is level with the top of the can and weigh the can and gravel. Repeat the exercise with all 4 cans.

  W_1 = -------kg weight of can 1 plus gravel
  W_2 = -------kg weight of can 2 plus gravel
  W_3 = -------kg weight of can 3 plus gravel
  W_4 = -------kg weight of can 4 plus gravel

Note

1 litre of cement weighs 1,5 kg
1 litre of lime weighs 1,065 kg

Therefore to measure the lime or cement in litres:

Kg of lime
1,065 = litres lime

Kg of cement
1,5 = litres cement

- Calculate the weight of the gravel in each can.

  $W_1 - W_{01} = W_{g1}$ kg weight of gravel for can 1
  $W_2 - W_{02} = W_{g2}$ kg weight of gravel for can 2
  $W_3 - W_{03} = W_{g3}$ kg weight of gravel for can 3
  $W_4 - W_{04} = W_{g4}$ kg weight of gravel for can 4

- Calculate the weight of 100 litres of gravel by adding W_{g1}, W_{g2}, W_{g3} and W_{g4}.
- Calculate the amount of emulsion in kg to add to 100 litres of gravel. If the specification calls for 1,67% of emulsion, then the amount of emulsion to be added to 100 litres of gravel is:

  $$\frac{1{,}67}{100} \times (W_{g1} + W_{g2} + W_{g3} + W_{g4}) \quad \text{kg}$$

- Calculate the amount of lime and/or cement in kg to add to 100 litres of gravel in the same way. If one percent of lime and/or cement is required, exactly the same calculation is done, i.e.

  $$\frac{1}{100} \times (W_{g1} + W_{g2} + W_{g3} + W_{g4}) \quad \text{kg}$$

Figure 3: Temporary shutters placed on the sub-base

The optimum moisture content must be obtained from the materials laboratory, e.g. seven percent. For the best workability the amount of liquid (i.e. emulsion + water) to be added is 7% + 1,5% = L_L. The amount of emulsion to be added is 1,67% of the weight of the gravel = L_E. The amount of water to be added is = $L_L - L_E$. If the gravel is moist or wet the amount of liquid in the gravel must be determined by weighing the gravel in four 25 litre containers in its wet condition = L_W. Then dry this material in the sun and reweigh it = L_D. The weight of the moisture in the gravel is:

$L_M = L_D - L_W$

Then the amount of water to be added is L_L-L_E-L_M. Added water = Total liquid – emulsion – moisture in the gravel.

4.2.3 Placing of steel shuttering

The steel shuttering that is available has one leg

Figure 4: Mixing of emulsion-treated gravel

(a) Any cement must be mixed to the dry aggregate

(b) Mechanical mixers can be used to good effect on labour-intensive projects

150 mm in height and the other 100 mm. The angle that you will use as your height when placing the steel shuttering depends on the thickness of the ETB, i.e. where a 150 mm thick ETB is needed use the 150 mm leg as the height. The shorter 1 metre lengths of shuttering should be used for small curves (see Figure 3).

4.2.4 Mixing

If the material for road construction can only be mixed by hand then the work must be planned and organised to reduce the physical work involved to a minimum (see Figure 4).
It is advisable to start with 1 part of emulsion to 3 or 4 parts of water. It will be observed after the first mix whether the water should be increased or decreased. The amount of water in the gravel will also affect the degree of dilution. The amount of liquid to be added must be approximately 1 to 1½% above the optimum moisture content required for the Mod. AASHTO density. (This must be checked with the laboratory tests.)

4.2.5 Placing and compaction

Because hand work progresses slowly, the problem of evaporation and premature breaking of the emulsion will affect the efficiency of compaction. To prevent the material from drying out prematurely, the newly spread ETB should be covered systematically with a plastic cover as work progresses, until a sufficiently long (8 to 10 m) section is completed for the compaction to commence (see Figure 5).

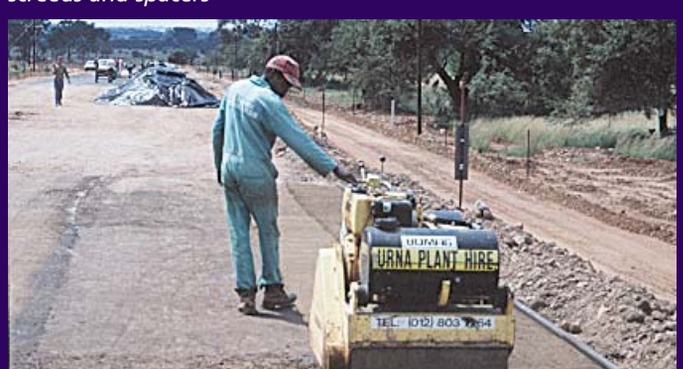
During the compaction process, there will always be a certain amount of spillage of loose material on the top of the steel gauges, which must be systematically removed with a flat shovel in order not to inhibit the roller from eventually compacting the material to the required level above the sub-base.

In the case of 150 mm ETBs, the surface of the first layer of compacted material should be 'watered' with diluted emulsion (1:6 - emulsion : water), using the watering can. The diluted emulsion can be spread with brooms to even out the application.

Figure 5: Placing and compaction of emulsion-treated material

(a) The surface of the subbase is sprayed with diluted emulsion and the loose emulsion-treated material is tipped between the edge-restraints

(b) The loose emulsion-treated material is levelled off at the required height using the temporary edge-restraints, steel screeds and spacers



(c) Emulsion-treated natural gravel compacts well using only light compaction equipment

In order to obtain a smooth level of the base, i.e. to ensure that the surface of the ETB does not undulate, the method of hand rolling should be carefully controlled. This problem is induced by the roller initially moving onto the newly placed ETB in a straight line parallel to the line of the steel shutters, causing surging and 'pushing' of the material. The roller should approach the strip at an angle with the roller drum over the edge of the shutter and existing surface, which automatically controls the level. This process should be repeated for each shutter, thus forming a triangle of uncompacted material, which could then be compacted at an angle with quarter wheel rolling. The rolling of the strip is then

The methodology in brief

- The optimum moisture content (OMC) must be obtained from the materials laboratory, e.g. OMC of 7%.
- For the best workability the amount of liquid (i.e. emulsion + water) to be added is 7% + 1,0% = L_L (1,0 to 1,5% above OMC).
- The amount of emulsion to be added is 1,67% of the weight of the gravel = L_E.
- The amount of water to be added is = $L_L - L_E$.
- If the gravel is moist or wet, the amount of liquid in the gravel must be determined by weighing the gravel in four 25 litre containers in its wet condition = L_W.
- Then dry this material in the sun and reweigh it = L_D.
- The weight of the moisture in the gravel (L_M) = $L_D - L_W$.
- Then the amount of water to be added is $L_L - L_E - L_M$ (i.e. Added water = Total liquid – emulsion – moisture in the gravel. Experience will tell how much water should be added to make the mixture suitable for compaction without it being too dry or too wet. It is better to be on the wet side than the dry side.)

done by commencing the rolling with part of the roller over the shuttering which controls the uniformity of the surface levels. This process is repeated on the alternate shutter and alternatively moved in half-rolls to the centre.

The problem of poor workmanship causing the construction of slacks, bumps, over-coarse sections, etc. will always be present. These can be rectified by chipping out the bumps to level, filling in the slacks by roughening and tacking the surface with diluted emulsion, applying the ETB and compacting it. Over-coarse sections can be tacked with diluted emulsion, raking selected ETB (coarse gravel removed) over the area and compacting it. The sooner this rectification work is done after placement of the ETB, the easier and more effective it is.

If there is going to be a delay between application of the surfacing and the time the road is to be opened to traffic, a light application of emulsion must be applied to the surface with the watering can once the compaction has been completed.

4.2.6 Quality control

In order to ensure that the ETB designed in the laboratory is constructed to specification and that its structural performance is to the employer's satisfaction, the quality of the ETB both during and after construction should be evaluated.

During the execution of the work, the contractor should ascertain that the composition of the ETB is always close to the composition which was decided jointly by the contractor, the employer and his representative, within predetermined tolerances. In addition, he should ensure that the laying operations result in a finished layer of adequate density.

The degree of compaction can be controlled directly by means of conventional methods (such as a nuclear density gauge) or, indirectly, through the use of the Rapid Compaction Control Device (RCCD).

The RCCD could be used to calibrate the results obtained in the laboratory with those obtained in the field in order for the RCCD to be used for the following purposes during and after construction:

- to monitor the degree of compaction of the ETB during construction,
- to monitor the gain in strength during curing,
- as a decision tool, to establish when the layer can be opened to traffic (i.e. if the parent material is finely graded. If the material is coarsely graded, the layer, once the emulsion has broken, can be opened to traffic within 24 hours).

The following procedure is proposed for calibration of the RCCD:

- Determine the optimum emulsion content based on CBR and UCS results,
- Compact four samples at optimum fluid content and optimum emulsion content, using a vibratory table,
- Determine the three-blow RCCD penetration (mm) on two unsoaked samples immediately after compaction in their moulds (three blows on four points per sample),
- Cure the remaining two samples in their moulds for one day at ambient

temperature, followed by two days' curing at 40 °C if the optimum moisture content is less than 8%, or for 45 hours at 60 °C if the optimum moisture content is greater than 8%,
- Determine the three-blow RCCD penetration (mm) on the two remaining unsoaked samples after curing in their moulds (three blows on four points per sample),
- Calculate the average three-blow RCCD penetrations (mm) immediately after compaction and after curing.

The average RCCD penetration measured immediately after compaction can be used to evaluate the degree of compaction on the road. The average RCCD penetration measured after curing can be used to determine when the road can be opened to traffic. Generally, the road can be opened to traffic when the RCCD penetration (mm per three blows) is less than 18 mm.

Generally, a section can be opened to traffic within 24 hours of construction. This, however, would depend on the climate, the rate of breaking of the emulsion in the top layer of the ETB and the grading of the parent material (i.e. whether it is coarse or fine).

5. Specialist literature

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Notes

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Notes

Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour-based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major Contributing Organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
National Housing Forum
Congress of South African Trade Unions

Plus many individuals from construction companies

"Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings."

Nelson Mandela, 2005 – Global Campaign for Action against Poverty

Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 4-7

Water-bound Macadam

cidb
development through partnership

Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment-intensive construction works

In this set: (colour coded)

Part 1

An overview of labour-based technologies and methods in employment-intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

3.2 The BESA building system

Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

4.2 Rubble masonry dam construction technology

4.3 Rubble masonry concrete arch bridge construction technology

4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Water-bound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

EXPANDED PUBLIC WORKS PROGRAMME

ENGINEERS AGAINST POVERTY

Labour-based methods and technologies
for employment-intensive construction works

A cidb guide to best practice

1ST Edition of CIDB document 1032 March 2005

Best Practice Guideline – Part 4-7

Water-bound Macadam

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

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Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1. Introduction

1.1 Background

Macadam-type pavement layers have been used successfully in South Africa for many decades. Macadam-type pavement layers traditionally refer to a layer of almost single-sized stone (usually 53mm nominal size for recent projects) in which the voids are filled with a dry, cohesionless fine aggregate filler. With the growing need for superior performance, a variety of modifications have been introduced, which include filling the voids with bitumen, slurry, etc.

A macadam layer essentially consists of a stone skeleton of which the voids are filled with another material. The stone skeleton, because of its single size, has large amounts of voids but has a high shear strength. If confined properly, a crucial requirement for macadam base courses, the stone skeleton forms the 'backbone' of the macadam and is largely responsible for the strength of the constructed layer. The material used to fill the voids provides lateral stability to the stone skeleton but adds little bearing capacity. This structure also gives water-bound macadam its good resistance to water as it drains well and the stone skeleton is less susceptible to the water present in the layer.

A water-bound macadam (WM) refers to a method of construction whereby water is used to force fine material into the voids during compaction. With proper construction control, and a phased construction procedure, the water-bound macadam offers a suitable labour intensive method for road construction.

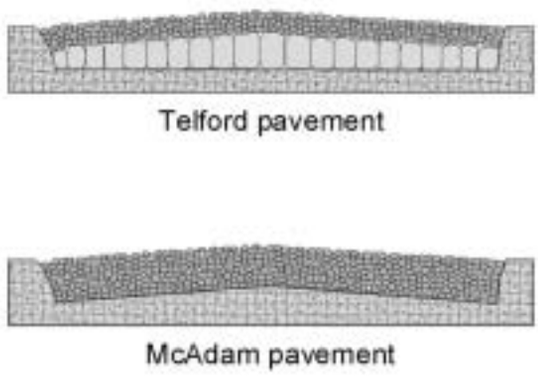
Note

This document is mainly compiled from: Guidelines for the Selection, Design and Construction of Water-bound Macadam Base Layers, Guideline Document DP-2000/5, published by Transportek CSIR. The development of this guideline document was sponsored by the Gauteng Department of Transport and Public Works, Directorate Design and the South African National Road Agency Limited.

1.2 Origins of macadam construction (Hefer, 1997)

The origins of macadam-type pavement construction can be traced back to a period between 1750 and 1830 during which two Scottish engineers, Thomas Telford and John Louden McAdam were active in developing and promoting their respective road-building techniques in England. Telford used fairly large stones (75 mm long, 125 mm wide and 325 mm high) to build a foundation layer on a level roadbed. The heights of these large stones decreased from the centre-line to the edge of the roadway to create a slight camber. Smaller stones were driven into the open voids on the surface of this layer and any projecting points were broken off. A 100 – 200 mm thick layer of small broken stone was then placed on top of the foundation layer. McAdam simply used layers of broken stones, none of whose dimensions exceeded 25 mm and these layers were placed directly on the roadbed. The broken stone was angular and consolidated under traffic. McAdam recommended that the road be raised above the surrounding ground to improve drainage. A layer of small broken stones, spread on the surface of the road, was used by both road-builders. These stones were broken down further and compacted by traffic to produce a solid, smooth riding surface. Figure 1 illustrates the difference between the approaches used by Telford and McAdam.

Figure 1: Telford and McAdam pavements



Neither Telford nor McAdam used any fine filler in the voids of the stone layer and it is not clear when this practice originated. Macadam construction was boosted by the invention of the stone crusher and steamroller in the 1860s but, in essence, the process remained labour-intensive.

Increased motorised-vehicle traffic at the turn of the century created dust and surface disintegration problems because of higher vehicle speeds and increased

friction between tyre and pavement. This led to the development of tar penetration macadams.

1.3 The history of macadam pavements in South Africa

Macadam pavement construction went through various phases in South Africa. Several provincial road authorities and major municipalities constructed macadam pavements until the 1960s and even as late as the 1970s. Thereafter the use of water-bound macadam declined in favour of materials which were more easily placed by machine.

Why mechanisation gained favour

Mechanised construction of pavement layers using continuously graded crushed stone gained favour for a number of reasons listed by Horak (1983), and influenced by the following:

- a trend to emulate the mechanisation of the industry in Europe and the USA where labour was scarce. In part this was prompted by the belief that progress resulted from mechanisation. This in turn led to policies and regulations designed to foster mechanisation;
- the large tax incentives that were allowed in respect of the purchase of new plant (Cohen, 1989; Lansdown, 1988);
- the introduction of a wage determination for the construction industry, which caused a substantial increase in the cost of labour;
- the difficulty which was experienced in mechanisation of the water-bound macadam process (Horak, 1983:10s); and
- government policy which actively discouraged the use of labour in urban South Africa.

However, the use of water-bound macadam did not only decline in South Africa, but did so all over the world. In the developed world where wages increased dramatically, the use of water-bound macadam has practically disappeared. But even in other developing countries, the mechanisation trend has also lead to much reduced use of this technique.

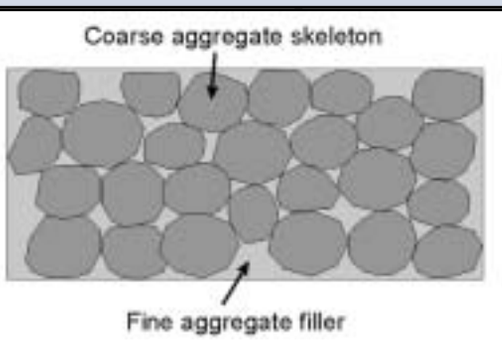
The good in-service record of macadam pavements in the former Transvaal (Burrow, 1975) and in the wet climate of Natal caused the interest in this type of construction to be retained and gave rise to several attempts during the 1980s to mechanise the construction of macadam layers. These attempts varied from using motorised graders to spread and level the coarse aggregate and sand spreaders and mechanical brooms to spread and cause the fine aggregate filler to penetrate (Horak, 1983), to laying the coarse aggregate with modified pavers (Roux and Otte, 1993, McCall et al, 1990).

A new generation of macadam-type materials evolved in South Africa during the late 1980s and 1990s. The process started with the development of partially penetrated macadams (Roux and Otte, 1993) in Natal. The need for job creation and empowerment through labour-intensive road construction projects and contractor development led to the development of slurry-bound and composite macadams that were used on several pilot projects by the Greater Johannesburg Metropolitan Council (Horak et al, 1995). A distinction is therefore made between the macadam material types outlined in 1.4 and 1.5.

1.4 Conventional types of macadam

Dry-bound macadam (DM): The voids in a layer of almost single-sized stone (usually 53 mm nominal size for recent projects) are filled with a dry, cohesionless fine aggregate filler. The voids are filled with filler through the use of compaction equipment only, and no water is used (see Figure 2).

Figure 2: Dry and water-bound macadam



Water-bound macadam (WM): Two water-bound processes have been identified in literature. It seems that the term 'water-bound' is generally used to describe a dry-bound macadam which has been 'slushed' after all the voids have been filled with dry filler. The slushing process consists of saturating the macadam layer (coarse and fine aggregate) by

spraying it with water, after which a number of passes are made with a steel drum roller, forcing the excess fines to the surface of the layer, from which they are then swept away (see Figure 2).

A completely wet process has been used in KwaZulu-Natal in cases where the climate did not allow the fine filler to dry out sufficiently to flow into the voids of the macadam layer (Roux and Otte, 1993; McCall et al, 1990). The fines were spread using a chip spreader and washed into the coarse aggregate layer with water-jets from a spray-bar.

Penetration macadam (PM): Fine aggregate is not used to fill the voids between the coarse aggregate of a penetration macadam layer. Hot tar is poured over the coarse aggregate layer and flows into the voids, coating the large aggregate in the process. The voids are, however, not filled completely by the tar (see Figure 3).

1.5 New generation macadam

Partially penetrated macadam (PPM): A dry- or water-bound macadam layer is constructed in the usual way but, instead of the excess fines being swept off the surface of the layer, some of the filler in the open voids at the top of the layer is also swept away. A very rough surface, with the coarse aggregate projecting from the layer, is obtained. Slurry is then applied with a slurry-box to fill these open voids on the surface of the layer. Slurry penetration is normally relatively shallow for this type of macadam (see Figure 4).

Slurry-bound macadam (SM): As in the case of penetration macadam, no fines are used to fill the voids of slurry-bound macadam. A slurry, produced from crusher sand (or a mixture of crusher sand and natural sand) and emulsion, is forced into the voids between the coarse aggregate of this type of macadam layer. (see Figure 5).

The slurry therefore performs the function of the tar in a penetration macadam. All the voids are filled with slurry in the case of a slurry-bound macadam, in contrast to the partial filling of the voids in a penetration macadam layer.

Composite macadam (CM): Composite macadam consists of a lower portion of dry- or water-bound macadam (usually of a nominal 53 mm stone size) and of a top portion consisting of a slurry-bound macadam (usually of a nominal 26 or 37 mm stone size) (see Figure 6).

Figure 3: Penetration macadam

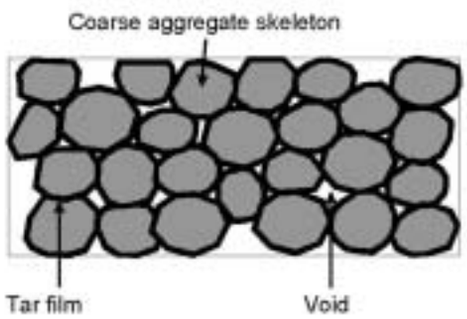


Figure 4: Partially penetrated macadam

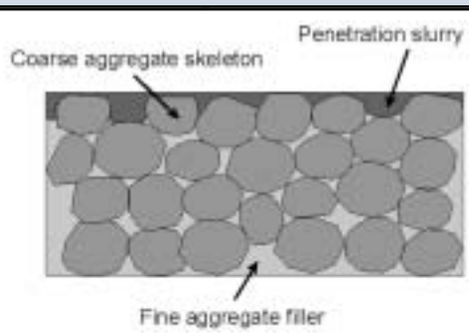


Figure 5: Slurry-bound macadam

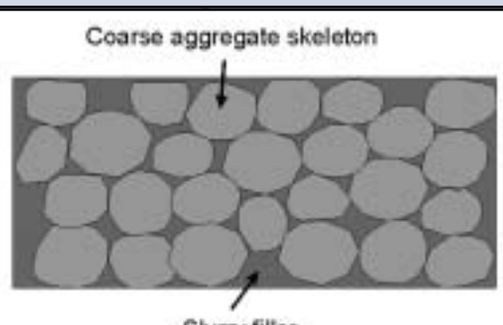
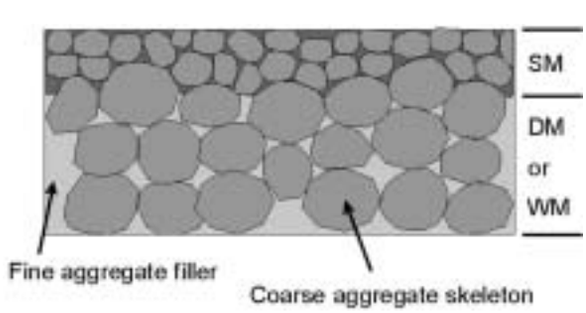


Figure 6: Composite macadam



2. Materials and specifications

Table 1: Grading requirements for the coarse and fine fractions of a water-bound macadam material (CSRA, 1985)

Sieve size (mm)	Cumulative percentage passing by mass	
	Coarse aggregate	
75,0	100	100
53,0	85 – 100	85 – 100
37,5	35 – 70	0 – 30
26,5	0 – 15	0 – 5
19,0	0 – 5	–
	Fine aggregate	
9,5	100	
4,75	85 – 100	
0,075	10 – 25	

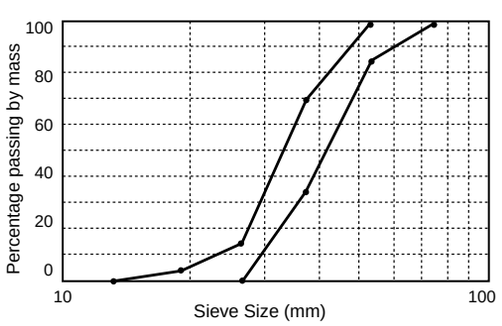
Table 2: Durability, shape and Atterberg limits specification for water-bound macadam base layers (CSRA, 1985)

Parameter		Value
Crushing strength:	Minimum dry 10 % FACT (kN)*	110**
	Maximum ACV (%)	29
Maximum weighted average Flakiness Index (%) determined on the -26,5 mm; +19,0 mm and -19,0 mm; +13,2 mm fractions		35
Atterberg limits:	maximum Liquid Limit (LL)	25
	maximum Plasticity Index (PI)	6
	maximum Linear Shrinkage, % (LS)	3

Notes: * The wet 10% FACT should be 75% of the dry value.
** Minimum dry 10% FACT for tillite should be 200 kN and the wet value 70% of the dry value.

Figure 7: Grading requirement for the coarse aggregate

(a) TRH14 grading specification (CSRA, 1985) for 53 mm nominal size coarse aggregate



(b) Indian grading specification (Horak, 1983) for 63,5 mm nominal size coarse aggregate

2.1 Aggregate specification

The material specifications for the coarse aggregate used for water-bound macadam construction consist of grading and durability requirements. Table 1 and Figures 7 and 8 provide specifications for the grading of the coarse and fine aggregate used for water-bound macadam construction. Table 2 provides the specification for the durability and shape of the coarse aggregate and for the Atterberg limits of the fine aggregate according to TRH14.

The grading envelopes in Figures 7(a) and 8(a) are from TRH14. The grading envelopes in Figures 7(b) and 8(b) are additional to the TRH14 criteria and allow for the use of a wider selection of material in water-bound macadam construction.

The grading envelopes for the coarse aggregate have the common characteristic of an almost single particle size distribution. The Cape Town municipality grading envelope for the fine aggregate also shows a tendency towards a more single-sized particle size distribution. The TRH14 grading envelope for the fine aggregate clearly requires a continuously graded material. The Cape Town municipality criteria are incorporated in this document to allow for the use of natural sand as a fine aggregate for water-bound macadam. A crusher sand grading would be more typical of the TRH14 grading requirement.

2.2 Rock types suitable for producing coarse aggregate

The coarse aggregate for a water-bound macadam material should be obtained from the crushing of unweathered, hard rock. There are, however, certain rock types that are likely to be more suitable for use in a water-bound macadam material.

Basic crystalline rocks

Some basic crystalline rocks may be prone to decomposition in wet climates. These include:

- Andesite
- Basalt
- Diabase/dolerite
- Diorite
- Gabbro/norite

Acid crystalline rocks

- Granite
- Rhyolite

High silica rocks

- Quartzite

Arenaceous rocks

• Quartzitic sandstone

Argillaceous rocks

Only sufficiently 'baked' argillaceous rocks, such as Malmesbury shale, will probably be suitable ('Malmesbury Shale' is in fact a misnomer, as this rock is actually hornfels and neither shale nor mudstone). In general, rocks from this group are not strong enough for use in base layers and are seldom crushed commercially.

Carbonate rocks

• Dolomite

Diamictites

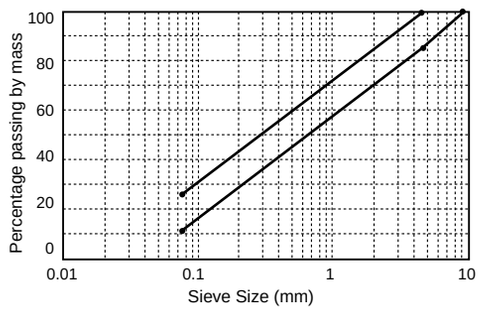
• Tillite

Granite and quartzite, especially if they come from mine dump-rock, could contain excessive quantities of sulphide minerals. These minerals have a distinctive shiny appearance and colour, such as iron pyrite, which is gold-coloured; marcasite, which is silver-coloured and copper pyrite, which has an iridescent gold, red and green colour. These minerals decompose easily in the presence of water and air to form mainly sulphuric acid. The acid products are not stable and change into sulphate salts which may cause blistering of the surfacing. If a relatively pervious water-bound macadam is built with clearly visible quantities of these minerals present in the coarse aggregate, it is recommended that expert opinion be obtained, should the use of this material be contemplated.

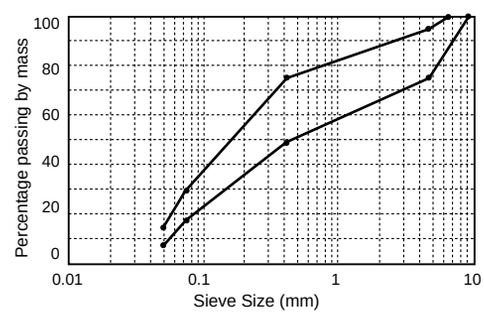
Although tillites have performed well in water-bound macadam base layers under Heavy Vehicle Simulator (HVS) testing in KwaZulu-Natal (Roux and Otte, 1993; Wright and Hess, 1988), the strength requirement for the use of this material in base layers is increased to a minimum dry 10 per cent FACT of 200 kN, the wet 10% FACT being 70% of the dry value (CSRA, 1985).

Figure 8: Grading requirement for the fine aggregate

(a) TRH14 grading specification (CSRA, 1985) for the fine aggregate



(b) Cape Town municipality grading specification (Horak, 1983) for the fine aggregate



2.3 Material suitable for use as fine aggregate

There are basically two sources of the fine aggregate for water-bound macadam. The first option, which seems to be recommended in most of the literature, is to obtain the fines from the crushing of the same parent material used for producing the coarse aggregate. In this case, a continuous particle size distribution is obtained and the TRH14 grading curve envelope for the fine aggregate shown in Figure 8 (a) will apply.

There are, however, also a number of sources of natural fine sands which may be used for water-bound macadam construction. These sands should be screened for PI and salt content before they are used in water-bound macadam construction. The particle size distribution of these and other natural sands will tend towards an almost single-size distribution and the Cape Town municipality grading envelope (Horak, 1983) for fine aggregate shown in Figure 8(b) will apply.

A blend of crusher dust and natural sand may also be used to achieve the required particle size distribution for the fine aggregate.

Permeability of waterbound macadam

Although no confirmation could be found in the literature, it is anticipated that the use of continuously graded crusher dust will reduce the permeability of water-bound macadam and the use of an almost single-size natural sand will increase its permeability. Water-bound macadam with crusher dust and natural sand fine aggregate have shown similar behaviour under the HVS and in laboratory testing (Theyse, 1999) and the effect on the performance of the material of the type of fine aggregate that is used seems to be overshadowed by other parameters, such as the field density that is achieved.

2.4 Relaxation of the TRH14 material specifications

The relaxation of the TRH14 material specifications may be viewed in terms of deviations from the grading requirements for the coarse and fine aggregates and/or deviations from the strength and plasticity requirements for the coarse and fine aggregates respectively. Such relaxations should only be considered for low volume roads. Expert opinion should be consulted whenever the use of marginal materials is considered.

In terms of deviations from the grading requirements for the coarse aggregate, the grading envelopes specified by most institutions seem to agree to a great extent. The impetus for deviating from this basic grading specification seems to be small, as the coarse aggregate is basically a manufactured material whose particle size distribution can be controlled. The grading specifications for the fine aggregate seem to have been adapted by local road authorities to suit the natural sands available in specific areas. In view of the previous comment on the relatively small effect that the grading of the fine aggregate has on the behaviour of the water-bound macadam under repeated loading, a deviation from the grading requirement for the fine aggregate does not seem critical. Adjustment of the grading envelope for the fine aggregate, such as the example shown in Figure 8, to suit locally available sands may therefore be allowed, with due consideration being given to the effect that this may have on the permeability of the composite material.

Although it has been suggested that the strength requirement for the large aggregate may be too stringent (Roux and Otte, 1993), Horak (1983) reported a change in the grading of the coarse aggregate under HVS testing and Philips (1994) reported that fracturing of the coarse aggregate occurred under vibratory compaction. It is therefore recommended that the TRH14 strength requirements for the coarse aggregate be adhered to.

Hefer (1997) investigated the performance of seven water-bound macadam pavements in the Johannesburg area, all of which performed well. Of these, the fine aggregate in five of the water-bound macadam base layers had PI values in excess of the specified value of 6, with values as high as 9 and 11 in some cases. Horak (1983) recommended a range of values for the PI of the fine aggregate between 4 and 9, the intention being that the higher PI material should be used to reduce the water permeability of the top portion of the water-bound macadam base layer.

3. Practical aspects

3.1 The use of water-bound macadam in wet areas

Water-bound macadam is one of the preferred base layer types in the wet climate of the eastern part of South Africa. HVS test results (Roux and Otte, 1989) and recent laboratory test results (Theyse, 1999) indicate that water-bound macadam loses static shear strength and deforms to a significantly greater extent at high saturation levels than at low saturation levels. It is therefore desirable to keep the saturation level of even a water-bound macadam base layer as low as possible in order to ensure best performance.

Although this has not been confirmed by experimental results, the permeability of water-bound macadam should presumably be a function of the particle size distribution of the fine aggregate. A water-bound macadam layer with a continuously graded fine aggregate such as crusher sand should have a lower permeability than a water-bound macadam layer with an almost single-sized fine aggregate filler. It is therefore recommended that a continuously graded fine aggregate should be used as far as possible to prevent water from entering the base layer. If, on the other hand, it is foreseen that, despite all precautions, the water-bound macadam layer will have to perform some drainage function, the permeability of the water-bound macadam should be sufficient to allow the water to drain away, but not high enough to cause the transportation of the fines from the layer. A natural sand filler is the appropriate choice in this case.

Complete saturation of the layer with the associated high pore-pressure under traffic loading should be avoided at all cost. Side-drains provided for draining away construction water should be able to accommodate the in-service drainage of the layer but these must be maintained properly.

TRH15 (CSRA, 1984) should be consulted for general subsurface drainage aspects in addition to the water-bound macadam specific drainage systems discussed in this document. Figure 9 shows the detail of a side-drain design (McCall et al,1990) that is incorporated in the concrete edge-restraint of a water-bound macadam base layer. A 50 mm slotted pipe wrapped in geotextile is laid on the completed subbase parallel to the front face of the edge-restraint. The geotextile is wrapped around the slotted pipe from the front face of the edge-restraint over and then under the pipe and the geotextile overlap is laid flat on the subbase. The shuttering for the concrete edge-restraint is then placed in position and the pipe and geotextile are fixed to the shutters. Care should be taken not to contaminate the geotextile overlap which is lying on the sub-base outside the shutters when pouring the concrete edge-restraint. The drainage of the water-bound macadam layer will be through this portion of the geotextile. The geotextile overlap is lifted and glued onto the front face of the concrete edge-restraint after removal of the shutters. Extreme care should be exercised in the construction of the edge-restraint drain, as McCall reported problems with the contamination and tearing of the geotextile, the blocking of the slots in the pipe by concrete fines and the separation of the pipe from the front face of the edge-restraint. Modifications to make the system more robust should be considered.

Figure 9: Concrete edge-restraint and side-drain detail

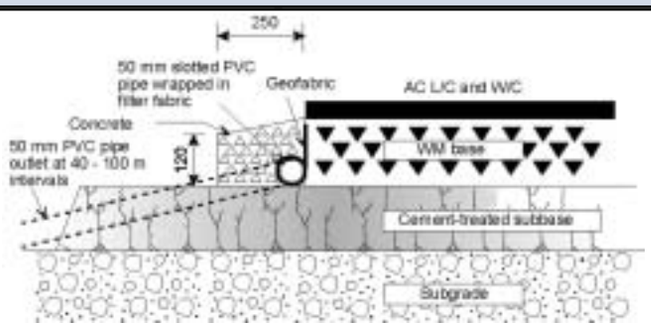


Figure 10: Transverse, no-fines concrete subbase drain

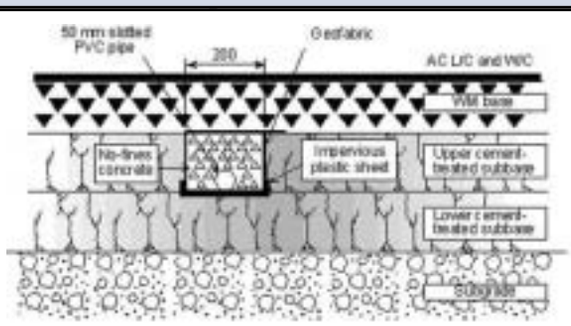


Figure 11: Modified VKE edge-restraint and side-drain design

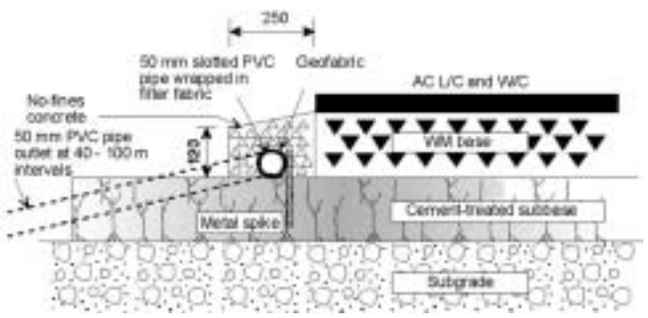


Figure 12: Block paving type edge-restraint and side-drain design

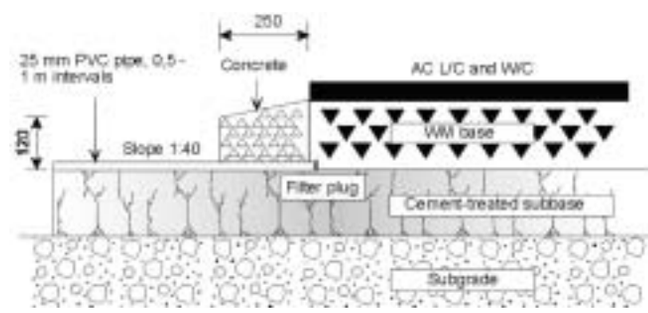


Figure 10 shows a section through a sub-base drain for a water-bound macadam base layer consisting of a transverse no-fines concrete strip, wrapped in filter fabric. The sub-base drain is easier to construct and more robust than the edge-restraint drain. This type of no-fines concrete drain should not be used in the base layer, as crushing of the concrete will occur during compaction of the water-bound macadam base layer.

The side-drain and concrete edge-restraint shown in Figure 9 has been used successfully in KwaZulu-Natal (VKE, 1987) with a slight modification. The drainage pipe was moved to the bottom centre part of the concrete edge-restraint and no-fines concrete was used for the edge-restraint. As the drainage pipe and geotextile did not become clogged with concrete fines, this system performed exceptionally well, allowing all the construction water to drain away under saturated conditions. The only problem with this design was that the no-fines concrete did not bond well to the cemented sub-base and that the edge-restraints moved laterally during placement of the base layer. It is suggested that metal spikes be driven into the sub-base and that the no-fines concrete be poured around the protruding spikes. The suggested modified design is shown in Figure 11. Although this design performed reasonably well during construction, there is concern that the no-fines concrete will be crushed if it is exposed to traffic loading. Figure 12 shows another alternative for the design of the edge-restraint drain normally used with block paving (Visser, personal communication).

3.2 Field density specification, compaction and quality control

The purpose of setting a certain minimum level for the density of a pavement layer is to ensure that an adequate bearing strength is achieved. Although bearing strength is the desired parameter, density is a convenient parameter to measure under field conditions and in the laboratory and the relationship between bearing strength and density can easily be confirmed from laboratory test results. The field density specifications for water-bound macadam are based on the apparent density of the coarse and fine aggregate combined. TRH14 (CSRA 1985) makes provision for two water-bound macadam classes whose density requirements are:

- WM1 88 – 90% of apparent density
- WM2 86 – 88% of apparent density

Potgieter, Hattingh and Schultz (1997) described the four stages of water-bound macadam compaction summarised in the list below and described how these levels of densification could be achieved.

Loose: Loose material after placement.

Orientated: The orientation of the large aggregate is adjusted to achieve an optimum packing pattern of the coarse and fine aggregates. This level may be achieved with light rollers.

Interlocked: The large aggregate is locked into an optimum packing pattern. According to Potgieter, Hattingh and Schultz, this is the highest level of densification that can be achieved during construction by using heavy (12 tonne) rollers.

Densified: The air voids in the layer are minimised through the optimum packing pattern of the coarse and fine aggregates. According to Potgieter, Hattingh and Schultz, this condition will be achieved for water-bound macadam under traffic loading.

It has often been said that the large aggregate provides the bearing strength of water-bound macadam and that the fine aggregate provides stability to the material. The bearing strength is achieved through the normal forces acting at the contact points between the large aggregate particles. Maximisation of the number of contact points by achieving an optimal packing pattern of the coarse aggregate in an interlocked state will therefore result in maximisation of the bearing strength. This optimal packing pattern with its associated maximum number of contact points and normal contact forces is, however, only maintained through the frictional forces at the contact points and the stabilising effect of the fine aggregate. It is therefore essential to the performance of the water-bound macadam that an interlocked condition be achieved with a dense filling of the voids with the fine aggregate. The current general consensus (Visser and Hattingh, 1999) is that only the use of conventional heavy compaction equipment (12-tonne flat wheel roller) will ensure the desired interlocked and stable condition of water-bound macadam.

The use of these heavy rollers also enables the slushing of the water-bound macadam layer to remove excess fines from the layer. The slushing process is similar to the slushing process for a G1 crushed stone base layer and will be discussed under the construction section of this document.

Horak (1982) investigated the effect of slushing on the density of water-bound macadam at one HVS test site. The maximum density achieved by rolling alone was 86,5% of apparent density, while the density increased to 88,6% after slushing and to 89,5% after trafficking. These results seem to confirm the hypothesis by Potgieter, Hattingh and Schultz and emphasise the need to achieve the maximum possible density of the water-bound macadam layer during construction before the road is opened to traffic. It is therefore recommended that, except in areas with water shortages, water-bound macadam should be slushed to achieve the highest possible density during construction so as to avoid post-construction compaction and deformation of the material.

Density is crucial

The density of water-bound macadam is the single most important factor governing the performance of the material. There can therefore be no compromise on the density specification for water-bound macadam and the use of conventional, heavy compaction equipment is imperative.

The construction quality of nine roads with labour-intensively constructed water-bound macadam base layers was evaluated for the Central Witwatersrand Regional Services Council in 1994 (van Huyssteen, 1994). Only one of the 10 density samples taken from these roads complied with the density specification of 88% of apparent density for a WM1 material and one sample met the density specification of 86% of apparent density for a WM2 material. It is not stated what compaction equipment was used on these base layers, but the field density of the water-bound macadam clearly did not meet the specifications and Van Huyssteen concluded that inadequate inclusion of fines in the large aggregate skeleton was the cause of the low field density. A localised failure occurred on one of these roads. The fines settled to the bottom of the water-bound macadam layer under the vibratory action of traffic. The asphalt surfacing had a cobblestone appearance (seemingly spanning from one large stone to the next) and a dense crack pattern. This same type of localised failure has been noted on several

Achieving uniform density

Inadequate filling of the voids in the water-bound macadam layer with fine aggregate and subsequent failure of the layer to meet the density specification therefore seem to be a significant problem resulting in the localized failure of the water-bound macadam base layer. The construction process of water-bound macadam may itself lead to high spatial variability in density. The uneven spreading of the fine aggregate can result in lean patches with a lower density than that of the surrounding area and even below the specified density. A density test that can be applied at a large number of points on the layer is therefore required. The rondavel density test (Horak, 1983) is regarded as the most appropriate type of density test for water-bound macadam. Unfortunately, this test, which is a type of sand replacement test, is cumbersome and not suited to frequent application. Nuclear density readings are quicker and easier to obtain. It is therefore suggested that a nuclear density device be calibrated against the rondavel test for each specific project. The nuclear density readings could then be done at short intervals, with rondavel control tests being carried out at longer intervals. The holes for the nuclear probe should be drilled through a metal footplate to prevent the macadam layer from being disturbed.

recently constructed water-bound macadam base layers in the Gauteng Province (Sadzik, personal communication).

3.3 Selection of a surfacing type

The selection of a surfacing type for water-bound macadam is largely dictated by the riding quality of water-bound macadam rather than by structural requirements. From previous studies the following riding qualities are typical:

- Water-bound and slurry penetration macadam: 1,5 - 2,0 PSI
- Asphalt wearing course on a slurry penetration layer: 3,0 - 3,5 PSI
- Asphalt wearing course on an asphalt levelling course: 3,5 - 4,0 PSI.

According to the constructed riding quality requirement from TRH4, a water-bound and slurry penetration macadam with a single or double seal will therefore not even satisfy the riding quality requirement for a Category D road in a rural environment. Single or double seal surface treatments are therefore not recommended for water-bound macadam pavements.

Slurry penetration macadam has been applied successfully as a stage construction option to accommodate construction traffic without disturbing the base layer (Roux and Otte, 1993). An asphalt wearing course on a slurry penetration macadam may be applied to category D, C and less important category B roads. Important category B roads and category A roads require both asphalt levelling and wearing courses.

Although the riding quality of a water-bound or slurry penetration macadam with a single or double seal may be sufficient for application on streets in urban areas, an asphalt surfacing is still recommended. The turning, breaking and accelerating motion of traffic in the urban environment may damage surface treatments and expose the water-bound macadam to the scouring effects of stormwater run-off. The placement of water-bound macadam with a paver does not have a significantly beneficial effect on the riding quality of the material, an acceptable riding quality only being achieved when a correction layer (hot-mix asphalt or penetration slurry) and a wearing course layer are applied.

4. Structural design

The purpose of structural pavement design is to make an unbiased estimate of the bearing capacity of layered pavement systems of different types. If the bearing capacity of a specific design is under- or overestimated in relation to the bearing capacity of alternative designs, the particular design will respectively be unfairly penalised or promoted during the economic analysis. A structural design method that will assess the bearing capacity of different pavement types according to the same set of rules is therefore required. A mechanistic-empirical design method has the potential to do this. SANRA (2000) presents a mechanistic-empirical design model for water-bound macadam material based on Heavy Vehicle Simulator (HVS) and laboratory test results. This design model was used for the design of the structural pavement layers shown in the pavement design catalogue in Figure 13.

Figure 13: Structural design catalogue for waterbound macadam bases

ROAD CATEGORY	PAVEMENT CLASS AND DESIGN BEARING CAPACITY (80 KN AXLES/LANE)										
	ESO.003 0.1-0.3x10^4	ESO.01 0.3-1.0x10^4	ESO.003 1.0-3.0x10^4	ESO.01 3.0-10x10^4	ESO.003 0.1-0.3x10^6	ES1 0.3-1.0x10^6	ES3 1.0-3.0x10^6	ES10 3.0-10x10^6	ES30 10-130x10^6	ES100 30-100x10^6	Foundation
A: Major interurban freeways and roads. (95% approximate design reliability)							30A 125 150C3	30A 125 125C3 125C3	50A 150 150C3 150C3		
B: Interurban collectors and major rural roads. (90% approximate design reliability)					S 100 150G6	S 125 125C4 S 125 150G5	30A 125 150C4	30A 125 125C4 125C4			150G7 150G9 G10
C: Lightly trafficked rural roads and strategic roads. design reliability)				S 100 100G6	S 100 100C4 S 100 125G6	S 100 125C4 S 100 150G5	30A 125 125C4 30A 125 150G5				
D: Light pavement structures, rural access roads. (50% approximate design reliability)			S 100 100G7	S 75WM2* 100C4` S 100 100G6	S 100 100C4 S 100 125G6						150G9 G10

Symbol A denotes AG. AC. or AS.
AO, AP may be recommended as a surfacing measure for improved skid resistance when wet or to reduce water spray
S denotes Double Surface Treatment (seal or combinations of seal and slurry)
S1 denotes Single Surface Treatment
* If seal is used, increase C4 and G5 subbase thickness to 200 mm.

Most likely combinations of road category and design bearing capacity.

The catalogue indicates the minimum material quality and layer thickness requirement for each combination of road category and design bearing capacity. Construction tolerances should be added to these minimum requirements to ensure that the constructed layers are never thinner than the minimum requirement given in the catalogue. The catalogue also allows the use of double and Cape Seals for combinations of low design-bearing capacity and for less important road categories. This reflects the minimum requirement from a structural design viewpoint. A hot-mix asphalt surfacing may be required from functional considerations and the reader is referred to the previous section of this document for selection of an appropriate surfacing.

Designs were developed for two design cases. The first case consists of a WM2 water-bound macadam base layer constructed on a granular sub-base or relatively thin or weak cement-treated sub-base. The base layer is at 84% of apparent density because of the relatively weak compaction anvil provided by the sub-base. The second case consists of a WM1 water-bound macadam base layer constructed on a sufficiently strong compaction anvil consisting of at least 125mm of cement-treated material and the base density is 88% of apparent density.

5. Plant and equipment

The following plant and equipment is required:

- 12 ton steel wheel roller compactor: for compacting aggregate and working fines into voids,
- Steel shuttering:for edge-restraint and thickness control during construction,
- Steel rakes and shovels and wheelbarrows: for transporting, levelling and placing aggregate,
- Screeds which are used between the top of the steel shuttering and the top of the side drain or the top of the inside edge of the concrete gutter to obtain the pre-compaction level,
- Steel gauges which are placed on top of the steel shuttering and edge of concrete to obtain the uniform loose level before compaction and to ensure that the correct final compacted level is obtained,
- Water tank and heavy duty hose and fittings for the supply of water and slushing of fines.

6. Construction

6.1 Loss of previous generation skills

The success of early water-bound macadam construction in South Africa depended largely on the skills of the road-builders of the time. Meticulous attention was paid to the detail of each step of the construction process. With time and as a result of the increasing use of continuously graded crushed stone for base layer construction, these skills were lost to the road-building industry. The interest in water-bound macadam construction was revived when job-creation became a national priority because water-bound macadam construction is well suited to labour-intensive methods. By this time, however, the earlier skill of water-bound macadam construction had faded and with new, inexperienced emerging contractors entering the road-building industry, the risk associated with water-bound macadam construction increased. It is therefore strongly recommended that the construction process for water-bound macadam construction be broken down into as many steps as possible, with the contractor and consultant paying the greatest attention to every detail of each step. As many checks as possible should also be built into the process to enable the quality of the product to be monitored continuously. It is not possible to go through the steps of water-bound macadam construction carelessly and still achieve a high quality product.

The construction of water-bound macadam may be divided into two components, namely the placement of the large aggregate, and the filling of the voids in

Three processes for filling the voids

Three processes have been identified from the literature for filling the voids in the large aggregate matrix:

- dry method (hence the name dry-bound macadam),
- a dry method, with slushing of the layer to remove excess fines once all the voids have been filled,
- a wet method, by which the fines are actually washed into the full depth of the base layer with water.

the large aggregate skeleton with a fine filler. Manual labour may be used to varying extents in each of these components but the principles of construction should remain the same for labour-intensive or plant-intensive construction. The following steps in the construction process will be discussed individually:

- Sub-base and edge-restraint preparation,
- Placement of the large aggregate,
- Filling of the voids in the coarse aggregate skeleton with a fine filler.

6.2 Sub-base and edge-restraint preparation

The catalogue of pavement designs in Figure 13 indicates that both unbound natural gravel or lightly cemented natural gravel sub-base layers may be used for pavements with water-bound macadam base layers. The use of lightly cemented sub-base layers is, however, strongly recommended if the wet method of construction is used and should be considered if the slushing process is to be used.

Permanent and temporary edge-restraints serve a dual purpose during water-bound macadam construction. Firstly, they act as an edge-restraint to box-in the large aggregate during the construction process and secondly, they are used without exception to provide a reference for the control of the levels on the water-bound macadam base layer. The option to construct a permanent concrete edge-restraint incorporating a side drain seems to be preferred in the wetter, eastern coastal areas of South Africa (VKE, 1987, McCall et al, 1990). These edge-restraints provide confinement of the water-bound macadam layer and the side drains drain away excess water during construction and the service life of the pavement. The use of temporary steel shutters in combination with gravel shoulders seems to be preferred in the dryer parts of the country to provide the edge-restraint for the water-bound macadam base layer.

If concrete edge-restraints are used, the line and level of the shutters on the front face of the edge-restraint are surveyed at 20 m intervals on straights and 10 m on curves (McCall et al, 1990). String lines and dipsticks are then used from the top of the completed concrete edge-restraints for level control on the water-bound macadam base. The problem with string lines is that they sag towards the centre-line of a wide carriageway. Modern laser levels should not suffer from this problem.

If temporary steel shutters are used on the centre-line and at the edges of a carriageway, the coarse aggregate for the water-bound macadam may be levelled against a screed rail placed on spacers on top of the steel shutters. The problem with this method is that, because of the fixed height of the shutters, any undulation at the top of the sub-base is reflected to the top of the base layer. It is therefore recommended that the steel shutters should only be used as an initial thickness guide and should be removed before any compaction is applied to the coarse aggregate layer. Final level control should then be done by string line and dip stick from levelled survey pegs. If temporary steel or wooden edge-restraints are used during the construction, care should be taken that the shoulders are constructed and compacted properly so that they can provide the confinement that is essential to the long term performance of the water-bound macadam layer.

Edge-restraints, either permanent or temporary, are the first step in the process of level control of the water-bound macadam base layer and should receive attention accordingly.

6.3 The placement of the coarse aggregate

The placement of the coarse aggregate may be done from stockpiles by hand labour using coal forks (Horak, 1983) (see Figures 14 and 15), with a heavy grader (VKE, 1987) if the coarse aggregate is dumped on the sub-base or by mechanical paver (McCall et al, 1990). The use of a mechanical paver in the case study reported by McCall resulted in slightly better riding qualities on the surfaced road than the labour-intensive and plant-intensive methods.

Several authors (Horak, 1983; VKE, 1987; McCall, 1990 and VKE & McCutcheon and Associates, 1999) agree that about 33% reduction in the thickness of the loose, coarse aggregate should be allowed for during compaction. Spacers of the required height are therefore placed on the edge-restraints and the coarse aggregate is spread to the top of the spacers by the preferred method. Before any compaction is done on the coarse aggregate layer, a level surface finish should be obtained. This is done by filling in lean spots by hand labour and by removing excess material from high spots. An uneven surface of the loose coarse aggregate layer before compaction will result in an uneven surface after compaction.

If the coarse aggregate stockpile is dumped directly onto the sub-base, on delivery, it is desirable to move the entire stockpile during spreading, as otherwise the partial compaction at the bottom of the stockpile heap will lead to greater undulations of the final surface. Also there may be some fines within the coarse material that will fall to the bottom of the heap and interfere with the bedding of the coarse aggregate onto the sub-base.

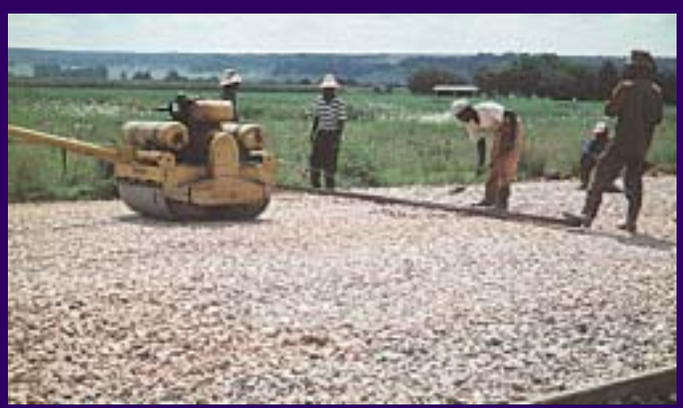
One of the aspects of early water-bound macadam construction which was highlighted by Horak (1983) was that the maximum layer thickness constructed in one lift should not exceed twice the size of the coarse aggregate. This was done to assist in the proper penetration of the layer with the fine aggregate.

Once a level surface is achieved on the loose, coarse aggregate layer, the spacers are removed from the concrete edge-restraints or the temporary shutters are removed totally. The furrows left by the temporary shutters are then filled with loose aggregate. The coarse aggregate layer is now ready for compaction. Horak (1983) often referred to the use of 12 ton, 3-wheel rollers for the compaction of the coarse aggregate layer. Other sources (VKE, 1987 and McCall et al, 1990) mention the use of 8 ton tandem rollers and McCall specifically mentioned the breaking of an unweathered dolerite coarse aggregate with an Aggregate

Figure 14: Spreading of the coarse aggregate between temporary edge restraints

Crushing Value (ACV) of 14,4% under a 12 ton, 3-wheel roller. Phillips (1994) also reported the crushing of the coarse aggregate under a vibratory roller. Ideally, trial sections should be constructed to determine the degradation of the coarse aggregate under 12 ton or vibratory compaction. If degradation of the coarse aggregate proves to be a problem, 8 ton tandem rollers should be used.

Figure 15: Levelling the loose coarse aggregate before compaction



Rolling should always be towards the higher side: if cambered, rolling starts at the sides and progresses towards the centre; if super-elevated, it starts at the low side and progresses upwards. If gravel shoulders are used, the drum of the roller should overlap onto the shoulder to ensure proper confinement. After the initial compaction passes the surface of the layer is again rectified by hand. Rolling is continued until no movement of the coarse aggregate is visible under the rollers and the coarse aggregate is keyed in. The stone layer is then 'locked up'. It should be note that if lock-up is not achieved and the fines are spread and slushed, the shape and level of the base will be distorted by each subsequent operation. Lock-up ensures higher stability of the coarse aggregate and less distortion of the final surface.

6.4 Filling of the voids in the coarse aggregate with fine aggregate

The fine aggregate is spread on the keyed-in coarse aggregate layer by hand using shovels or by mechanical chip-spreader (see Figure 16). The thickness of the loose filler placed in one application should not exceed 25mm and should be evenly distributed. If the material is slightly moist, it should be left to dry before vibratory compaction is applied to enable the fine aggregate to filter down into the coarse aggregate layer. The process of successive applications of fine aggregate and vibratory compaction is continued until the layer is choked with fine aggregate. If the dry process is selected, the construction process stops at this point. The dry method is appropriate for arid areas where very little water is available for construction. In this case, water-bound macadam construction should compare favourably with the construction of a continuously graded material which will require compaction water.

If slushing is selected, the choked layer is watered and compaction should then resume, working from the highest to the lowest point. Drainage outlets should be inspected to ensure that the construction water drains freely from the layer. The excess fines should be slushed from the layer and broomed to the side of the layer (see Figure 17). After completion of the slushing process, the layer should be left to dry and then broomed again.

Figure 16: Spreading of the fine aggregate

McCall et al (1990) mentioned the use of a 24 ton pneumatic roller for the slushing process and VKE (1987) indicated that the use of a 24 ton pneumatic roller had no significant effect on the slushing process. Density results (Horak, 1982) from water-bound macadam base layers seem to indicate that a density of 84% to 86% of apparent density may be

Figure 17: Washing-in of the fines during the completely wet process

A completely wet process – KwaZulu-Natal

A completely wet process has been used in KwaZulu-Natal on two occasions (VKE, 1987 and McCall et al 1990) when the fine aggregate would not dry sufficiently to flow freely into the coarse aggregate layer. A water cart with a modified spray bar was used to blast the fine aggregate into the voids with water jets. Again, if this technique is used, the drainage outlets should be inspected to ensure that the construction water drains from the base layer.

achieved with vibratory compaction using the dry method and that a density up to 88% may be achieved if the layer is slushed and that this will be further increased by trafficking to between 88% and 90% of apparent density. This seems to correspond well with Potgieter, Hattingh and Schultz's theory of orientation, interlock and densification.

After the fine aggregate is applied to fill the voids, the layer is then ready to be primed. A blanket of loose filler may be left on top of the layer to prevent kick-out of the coarse aggregate under construction traffic but all loose material must be broomed off before the prime is applied. In general it is not recommended that traffic is allowed on the water-bound macadam layer before the surfacing layer is applied. This can be costly and difficult under some circumstances. If it is foreseen that it will be difficult to prevent traffic (including construction traffic) using the road, the possibility of applying a slurry layer across the water-bound macadam should be considered. This is also costly but will be cheaper than having to do major reconstruction of the water-bound macadam layer. McCall et al (1990) reported on the use of a slurry penetration layer in the top portion of a water-bound macadam base layer that was opened to construction traffic within four hours of construction with no damage to the base layer.

To summarise, the following list of important aspects which should be monitored closely during the construction process, is provided:

- The edge-restraints, either permanent or temporary, form the first step in the process of level control of the water-bound macadam base layer and should receive attention accordingly,
- The maximum layer thickness constructed in one lift should not exceed twice the size of the coarse aggregate,
- If the surface of the loose coarse aggregate layer is uneven before compaction, this will result in an uneven surface after compaction,

Figure 18: A completed road, showing the waterbound macadam layer after compaction, priming and surfaced with a thin asphalt

- After the initial compaction passes, the surface of the coarse aggregate layer is again rectified by hand,
- Rolling is continued until no movement of the coarse aggregate is visible under the rollers and the coarse aggregate is keyed-in.
- The thickness of the loose filler placed in one application should not exceed 25 mm and should be evenly distributed,
- If a slushing process is used, compaction should start from the highest point, working to the lowest point,
- If a slushing or completely wet process is used, drainage outlets should be inspected to ensure that the construction water drains freely from the base layer,
- The layer must dry out completely before it is sealed,
- A layer of loose filler material or a slurry penetration layer may be used if the newly constructed water-bound macadam layer has to be opened to construction traffic,
- All loose material must be broomed off before a prime is applied.

Figure 18: continued

7. Quality control

The density of the layer can be checked against the following requirements from TRH 14:

- WM1 88-90% of apparent density
- WM2 86-88% of apparent density

Sand replacement tests or nuclear density measurements can be used to determine density. However, as these tests can only be performed after the fine aggregate has been placed and the base slushed, it may be very difficult to improve the density if the coarse aggregate was not compacted properly. If additional slushing does not bring the density up to specification, then the layer will have to be scrapped and new material brought in. It is generally very costly to separate the coarse and fine materials for re-use. It is therefore important that measures are in place to ensure that the coarse aggregate is sufficiently compacted before the fine materials are placed. One important means of doing this is using levels to ensure that the 33% reduction in thickness of the loose layer was achieved.

All the geometric requirements of the specification must be checked and met: level, layer thickness, and eveness (with straight-edge tests). The cleanliness of the mosaic must also be checked carefully. Poor brooming will leave fines on the stone surface, which will lead to delamination of the surfacing.

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Notes

Notes

Notes

Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour-based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major contributing organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
National Housing Forum
Congress of South African Trade Unions

Plus many individuals from construction companies

“Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings.”

Nelson Mandela, 2005 – Global Campaign for Action against Poverty

Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 4-8

Slurrybound and composite Macadam construction

cidb
development through partnership

Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment-intensive construction works

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Part 1

An overview of labour-based technologies and methods in employment-intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

3.2 The BESA building system

Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

4.2 Rubble masonry dam construction technology

4.3 Rubble masonry concrete arch bridge construction technology

4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Water-bound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

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Labour-based methods and technologies
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A cidb guide to best practice

1ST Edition of CIDB document 1033 March 2005

Best Practice Guideline – Part 4-8

Slurry bound and composite Macadam construction

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

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Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1. Introduction

A new generation macadam-type pavements evolved during the late 1980s and 1990s. The need for job creation and improvement through employment-intensive road construction projects led to the development of the composite and slurry-bound macadam construction techniques. Although the traditional water-bound macadam techniques were employment-intensive, they were constructed to density specifications which could only be achieved through employment of heavy rollers. As such they partially satisfied the empowerment criteria. The new generation macadams were designed to have a low mechanisation level in order to improve the labour / small scale enterprise-friendliness of the technology. As such, the technology has low skills-level requirements and with appropriate management, high production rates can be achieved at attractive profit margins.

Macadam pavements comprise high quality layers constructed with single-sized 13 mm to 53 mm aggregate, which is stabilised by filling the voids with a suitable material. Terms commonly used to describe different types of macadams are described in Table 1. Figure 1 gives a schematic representation of the macadam types.

Note

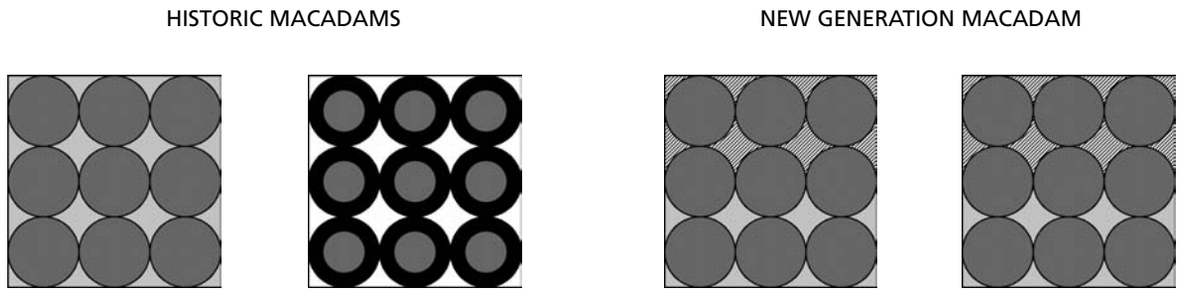
Macadam pavements comprise high quality layers constructed with single-sized 13mm to 53mm aggregate, which is stabilised by filling the voids with a suitable material. There are a number of macadam pavement types. This section, however, deals only with slurry-bound macadam and the composite macadam construction.

The design procedures for the construction covered in this section is typical of South African pavement design methods such as that embodied in TRH4:1996 (COLTO, 1996) and UTG3:1988 (CUTA, 1988). As a result, the design process is merely summarised. Those unfamiliar with pavement design procedures are encouraged to review the specialist literature on the subject.

Table 1: Descriptions of various types of macadam

Type of macadam	Description
Dry-bound macadam (DM)	The coarse aggregate first needs to be interlocked using appropriate rollers. Cohesionless fine filler is then vibrated into the voids without the use of water.
Water-bound macadam (WM)	The coarse aggregate also needs to be interlocked using the appropriate rollers whereafter water may be used to slush the filler into the voids. The filler may be slightly plastic.
Penetration macadam (PM)	Interlock of the coarse aggregate needs to be achieved using the appropriate rollers whereafter a hot tar or bitumen is poured over the coarse aggregate layer coating the large aggregates. The voids are not filled completely by the tar or bitumen.
Slurry-bound macadam (SM)	The coarse aggregates are only orientated by means of light pedestrian type rollers or plate compactors. A slurry, produced from sand and bitumen emulsion, is forced into the voids between the coarse aggregate until the voids are filled using the same light pedestrian type rollers.
Composite macadam (CM)	Consists of a lower portion of dry- or waterbound macadam and a top portion of slurry-bound macadam.

Figure 1: Schematic representation of macadam types



2. Material requirements

Table 2: Composite macadam: recommended grading for selected layer thickness

Layer thickness of 75 mm			
Bottom (45 mm)	Grading : Nominal size (mm)	53	Sand filler•
	ALD (mm)	32	
Top (30mm)	Grading : Nominal size (mm)	19 or 16	Slurry filler
	ALD (mm)	12 or 10	

• Sand may be replaced by slurry. Costs may not be excessive for large areas. Suitable for smaller areas like bus/taxi ranks.

Table 3: Slurry-bound macadam: recommended grading for various layer thicknesses

Layer thickness (mm)	50	40	30	25
Nominal size (mm)	26,5-19	19	16	13,2
ALD (mm)	16-12	12	10	7

Table 4: Recommended gradings

Sieve size (mm)	Percentage by mass passing				
	53 mm	37 mm	26,5 mm	19,0 mm	13,2 mm
75	100				
53	85 - 100	100			
37,5	35 - 70	85 - 100	100		
26,5	0 – 15	0 - 50	85 - 100	100	
19,0	0 - 5	0 - 25	0 - 30	85 - 100	100
13,2		0 - 5	0 - 5	0 - 30	85 - 100
9,5				0 - 5	0 - 30
4,75					0 - 5
0,075					

Table 5: Recommended grading for the slurry filler

Sieve size (mm)	Percentage by mass passing					
	Fine grade			Medium grade		
6,7				100		
4,75	100			82 – 100		
2,36	90 – 100			56 – 95		
1,18	65 – 95			37 – 75		
0,6	42 – 72			22 – 50		
0,3	23 – 48			15 – 37		
0,15	10 – 27			7 – 20		
0,075	4 – 12			4 – 12		
Appropriate layer thickness (mm)	25	30	75 (top part)	40	50	75 (bottom part)

The coarse aggregate forms the skeleton that carries the whole load through direct stone-to-stone contact to the supporting layers. This structure provides high load bearing capacity. The fine aggregate or slurry stabilises the layer. This section sets out the requirements for each important element, including: grading, crushing strength, shape of aggregate, aggregate for slurry, cement and lime, and slurry mix design.

2.1 Grading

2.1.1 Coarse aggregate

In general the average least dimension (ALD) of the coarse aggregate must not exceed one third of the layer thickness. In addition the grading must be such that the sufficient voids remain to be filled with filler sand or slurry. The gradings contained in Tables 2 and 3 are recommended for the various layer thicknesses.

Grading envelopes of the respective nominal sizes are tabulated in Table 4.

2.1.2 Aggregate for slurry

The specified grading limits for the filler slurry are also a function of the layer thickness. The gradings as set out in Table 5 are recommended for the various layer thicknesses.

2.2 Crushing strength

TRH14 (CSRA, 1985) specifies the crushing strength of the coarse aggregate in terms of the 10% Fines Aggregate Crushing Value (FACT) and the Aggregate Crushing Value (ACV). A minimum 10% FACT of 110 kN or maximum ACV of 29% is specified. Composite macadam (CM) layers are ideally suited to accommodate lower quality aggregate in the lower part of the layer and an ACV below 33 is recommended. Hand-picked or screened natural aggregate nodules such as calcrete can be used provided it meets the strength requirements.

2.3 Shape of aggregate

The shape of the aggregate is expressed as the Flakiness Index, which should be less than 35 for the –26,5 + 19mm and –19 + 13,2mm according to the TRH14. Results found in traditional macadam layers confirmed the applicability of this criterion and values ranged from 8 to 32. The importance of this specification should not be overlooked in the light of compaction methods used on labour intensive projects, as flaky aggregate slithers tend to bridge over voids and intimate stone-to-stone contact is not achieved.

2.4 Aggregate for slurry

The aggregate for slurry seals should comprise crusher sand obtained from a parent rock having an ACV not exceeding 30 or a mixture of such crusher sand and an approved clean natural sand, where the mixture does not contain more than 25% of natural sand. The aggregate shall be clean, tough, durable, angular in shape, and shall comply with the grading requirements given in Table 5 for the slurry.

2.5 Cement and lime

Common cement should comply with the requirements of SANS 50197-1. Road lime shall comply with the requirements of SANS 824 (Lime for Soil Stabilisation).

Only one of the abovementioned materials should be used throughout the construction in order to prevent undesirable colour differences in the surface.

2.6 Slurry mix design

The slurry mix design is of utmost importance as the level of compaction specified on the coarse aggregate is reduced to accommodate the smaller equipment. The optimum slurry stability must be achieved to embed to the stone framework after a light compaction effort.

An anionic 60% stable-grade emulsion is recommended. An immersion index of not less than 75% (Method C5: TMH1, CSRA, 1986) for briquettes made with slurry aggregate and 80/100 penetration-grade bitumen are recommended. Gradings for the slurry aggregate are given in Table 5. These gradings should conform to a sand equivalent of not less than 35 according to TMH1 method B19. An emulsion content of 250 litre/m^3 and cement content of 1% by aggregate mass are the proportions given as guidance for nominal rates. The Cape Cone Slump test is used to control workability (Method CPA/C1; CPARD, 1993). A flow between 30 mm and 40 mm should be adequate for slurry mixes to be placed by hand. Slight adjustment of slurry material proportions may be needed to suit site conditions. Trial mixes are recommended.

3. Plant and equipment requirements

The slurry-bound and composite macadam layers are constructed at very low mechanisation levels. A typical construction team of eight to ten workers need to be equipped with the following:

- 1 Pedestrian roller or plate compactor
- 2 Shovels
- 4 Ballast forks
- 4 Wheelbarrows
- 4 Squeegees
- 2 Rakes
- 1 x 3 m Straight edge (Screed Board)
- 2 Bass brooms
- 3m x 2 m Hessian cloth
- 4 Measuring containers

The material does not require any heating and is used at ambient temperatures.

The following protective clothing also needs to be provided:

- Gloves
- Overalls
- Gumboots

4. Design considerations

4.1 General

Due to the simplicity and flexibility of the new generation macadams, it can be applied to wide ranging of surfacing applications including:

- Walkways
- Driveways
- Parking areas
- Roads/streets
- Road rehabilitation using slurry-bound macadam as overlay
- Pothole patching
- Assembly areas
- Tennis courts
- Taxi/bus bays

In two particular applications the unique properties of the slurry-bound macadam will offer the optimum solution in comparison with alternatives, namely:

- In inaccessible or mountainous terrain where large construction equipment is costly to operate, whereas the equipment necessary to construct a slurry-bound macadam layer or overlay is light and easy to manoeuvre in difficult terrains,
- In a phased construction approach where the problem of mechanical damage to new asphaltic layers during construction is overcome by using a slurry-bound macadam as base layer with only a thin slurry seal as initial surfacing. (This may be sufficient surfacing for a period of eight years. The required asphalt overlay may then follow once construction activities for the total development are complete. This may also suit the cashflow requirements of developers awaiting remuneration from tenants or buyers.)

4.2 Macadam selection charts for roads or streets

Several construction-related factors that need to be considered in the selection of the appropriate technology are:

- The riding quality required
- The type / class of road
- The experience of the targeted contractors

A smooth-riding quality is achieved by maintaining a strict tolerance on surface irregularities and level undulations. However, surface irregularities within a strict tolerance of say 6 mm can only be achieved at a cost premium or through asphalt machine overlays. The designer therefore needs to carefully select the appropriate specified surface irregularity and should base his decisions on the contents of Table 6.

Table 6: Guidelines on macadam selection

Road class	Specified base surface irregularities (mm)	Minimum Surfacing option	Base type	Contractor Profile
Class 5 : Access Roads	15	6mm slurry	Slurry-bound macadam	Inexperienced/ low skills
Class 4 : Local distributors	12	6mm slurry	Slurry-bound macadam / Composite macadam	Moderately experienced/ skilled
Class 3 : District distributors	12	25mm asphalt	Slurry-bound macadam / Composite macadam/ Waterbound macadam*	Moderately experienced / skilled
Class 2 : Primary District distributors	6	25mm Asphalt Overlay	SM/CM/WM*	Experienced/ skilled

*Water-bound macadam must not be used with thin surface treatment types.

4.3 The design process

4.3.1 Design philosophy and process

The first decision relates to what type of road and service level the design has to satisfy. Macadam base layers are covered in this manual and other pavement types should be considered if the requirements cannot be met by macadam pavements. The guidelines provided in Table 6 provide important information in addressing employment issues that favour the use of macadam construction.

Typically urban streets are designed to carry the traffic loads anticipated over a 20-year period, the so-called structural design period. The additional structural strength required for a 20-year design period compared with a 10 or 15-year period is usually minimal and cost-effective. Urban street layouts are relatively fixed and remain the same over periods much longer than the structural design period.

4.3.2 Design traffic

The design traffic is expressed as the equivalent damage caused by the design axle load of 80kN during the structural design period and is denoted by E80. Damage caused by any axle load PkN is related to the standard axle load by an exponential relation as follows:

$F = (p/80)^n$

Where the exponent, n, can vary between 2 and 5 depending on the pavement structure, but for macadam pavements an exponent of 4 can be used.

The design traffic then consists of the summation of the damage of all the axles during the structural design period. TRH4:1996 gives guidance about damage which different vehicles cause.

4.3.3 Material availability

Consider the availability of materials and their unit cost, as well as previous experience with these materials. Sources of naturally occurring aggregates, particularly in remote rural areas may enhance the employment-intensiveness of aspects of macadam alternatives.

4.3.4 Practical considerations

It is accepted that proper drainage will be provided both for surface run-off and to guard against wetting up of the pavement layers. In cases where problem sub-grades, such as swelling clays, collapsing soils or dolomites exist, specialist engineering input would be essential. Construction considerations also need to be taken into account.

4.3.5 Economic analysis

Road and street infrastructure are primarily funded by the public sector. Great care must be taken with the application of public funds and transparency at all times, and thorough economic analyses must be performed to justify the recommended actions.

A comparison of material costs between various macadam construction types show that slurry-bound macadam is the most costly macadam type. However, it is relatively easy to construct, which reduces labour costs. The machine component required is the lowest, which makes the construction technique more accessible to new contractors. The labour component of a slurry-bound macadam is approximately one-third of the construction costs. The specified surface smoothness also has a marked influence on costs. A macadam-base type can be constructed within a 10% range of other types of equivalent structural value base.

The typical cost structures of some labour-intensive construction techniques are shown in Table 7. It should be noted that the actual cost structure may be influenced by several factors, such as:

- Affordability of machinery and equipment
- Labour component

Structural design

Structural designs for different design traffic groups should be approached as set out in 4.4.

Socio-economic analysis

The economic analysis includes consideration of the socio-economic benefits to the region or community and a comparison of life-cycle costs of alternative pavement types over a given analysis period, which would typically be the same as the structural design period. The socio-economic issues include the percentage of the contract value that will be earned by the community, the extent of local job creation and the extent to which the project will serve as a vehicle for small, medium and micro-enterprise (SMME) development.

- Production rate
- Cost of materials (availability of natural materials)
- Life/cycle costs

4.4 Structural design

A detailed laboratory study indicated that the stiffness, or structural strength, of all the different macadam layers referred to in Section 1 could be considered the same. Therefore structurally there is no difference between the macadam layer materials and the choice is made according to the capabilities of the contractor, the level of employment intensity that is required and the level of service that needs to be provided.

Table 7: Cost structure of some labour-intensive construction techniques

Construction type	Relative rating of total costs (%)	Cost of plant & equipment (%)	Labour Component (%)	Material component (%)	Production rate	Dominant features
Conventional (crushed stone layer)	1	40 – 45	7 - 12	40 – 45	Fast	
Water-bound macadam	1 – 1,10	35 – 45	20 – 30	20 – 30	Medium	High plant costs
Slurry-bound macadam	1 – 1,20	25 – 30	25 – 35	30 – 40	Medium	Low equipment costs
Composite macadam	0,9 – 115	25 – 30	30 – 35	25 – 35	Slow	Low equipment & material costs
Foam gravel	0,9 – 1,2	40 – 45	10 – 15	35 – 45	Fast	Fast construction
Emulsion treated bases	0,7 – 1,2	30 – 40	30 – 35	20 – 30	Slow	Low materials cost

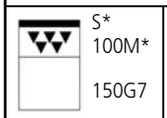
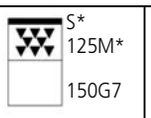
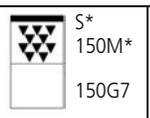
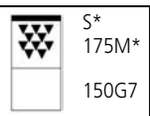
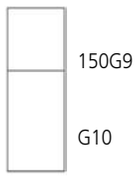
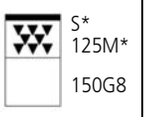
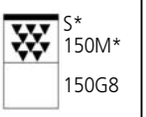
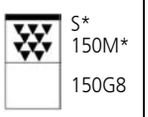
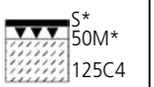
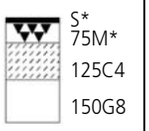
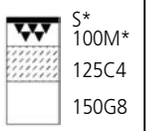
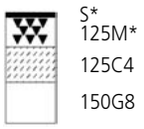
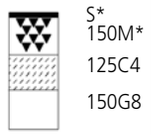
Note

It should be noted that the foundation layers in Table 8 would only be required if the sub-grade conditions are weak. If a G9 material exists in the field, the G10 material would be dispensed with. In the wetter region, i.e. N-value less than 2, two G9 layers are required compared with the one shown on the catalogue for dry and moderate regions.

The catalogue of designs presented in Table 8 was developed by using a mechanistic analysis approach combined with the performance results of in-service pavements. The mechanistic analysis considered the vertical compressive strain on the soil and granular layers and the horizontal tensile strains in the stabilised layers, as recommended by the SA Mechanistic Design Procedure (Theyse et al, 1996). A terminal rut of 20 mm was used as the design criterion. This procedure is similar to that used to develop TRH4:1996 and is therefore complementary to that document for D category pavements. No design criterion was applied to the macadam layer, as laboratory evaluation has consistently shown high shear resistance and field performance showed that the macadam layer disintegrates when the supporting layers are unable to support the loads and causes significant deformations.

In certain cases designers would wish to carry out a mechanistic structural analysis. Table 9 gives guidance for the moduli or stiffness values that should be used for macadam layers in addition to the materials given in the SA Mechanistic Design Method (Theyse et al, 1996). These stiffness values were determined by back-calculating Falling Weight Deflectometer results. Stiffnesses determined in the K-mould in the laboratory were lower than the mean field value and

Table 8: Design catalogue for macadam pavements

DESIGN BEARING CAPACITY (MILLION EQUIVALENT STANDARD 80 KN AXLES/LANE)							
<0.003	0.003 – 0.01	0.01 – 0.03	0.03 – 0.1	0.1 – 0.3	0.3 – 1.0	1.0 – 3.0	Foundation
 S* 100M* 150G7	 S* 125M* 150G7	S* 125M* 150G7	S* 150M* 150G7	 S* 150M* 150G7	 S* 175M* 150G7		 150G9 G10
 S* 125M* 150G8	 S* 150M* 150G8	 S* 150M* 150G8	S* 175M* 150G8	S* 175M* 150G8			
S* 50M* 125C4	 S* 50M* 125C4	S* 75M* 125C4	 S* 75M* 125C4 150G8	 S* 100M* 125C4 150G8	 S* 125M* 125C4 150G8	 S* 150M* 125C4 150G8	

Material codes are as defined in TRH4 (CSRA, 1985)
M* denotes SM, CM, DM or WM
S* denotes Cape seal or fine or course slurry for Cm and Sm
S* denotes Cape seal for WM and DM

corresponded with the 20th percentile value. This means that if the laboratory stiffness values were used they would relate to a confidence level of 80%.

Table 9: Moduli for macadam layers back-calculated from FWD deflection basins

Value Description	Over strong cemented layers (C1, C2, C3) MPa	Over Weak cemented (C4) MPa	Over gravel soils MPa
Mean	860	580	490
Range	450 – 1500	260 – 950	150 – 900
Median	720	600	460
20th percentile	550	420	360

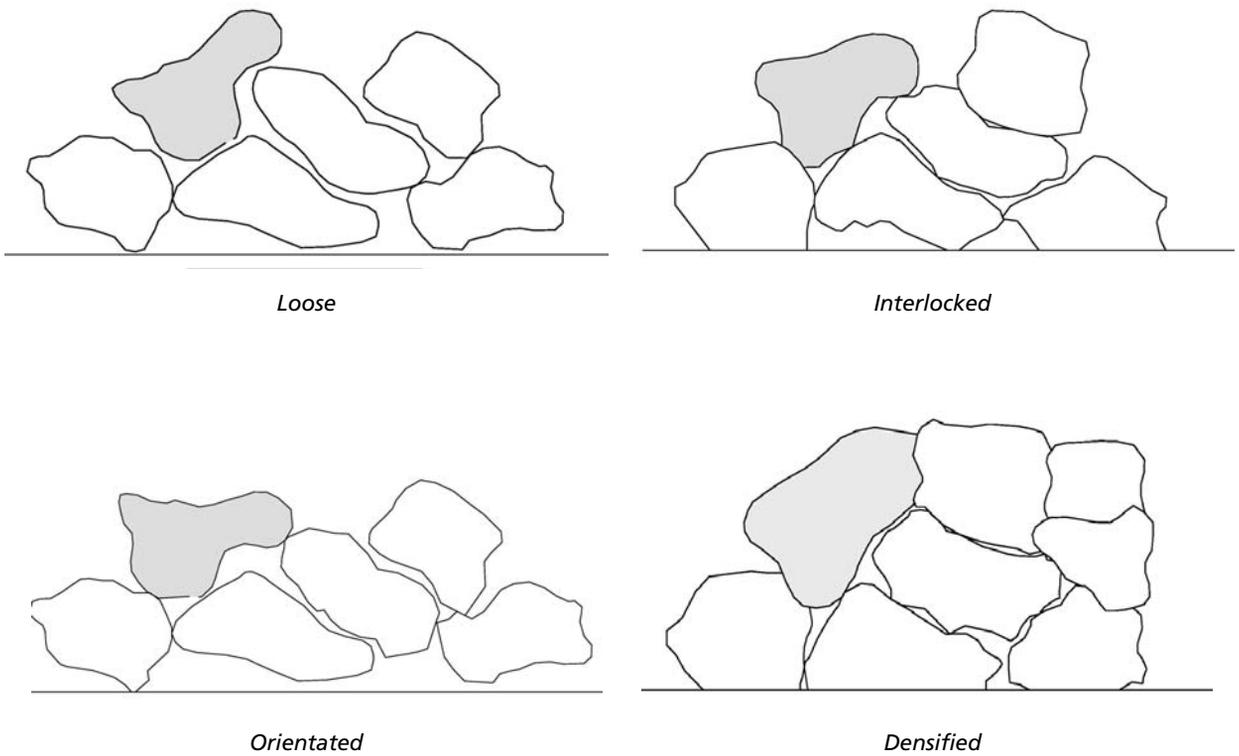
4.5 Density requirements

Compaction of a macadam layer occurs in three distinct phases, namely orientation, interlock and densification as shown in Figure 2. The energy required to 'orientate' the coarse aggregate in a layer with limited thickness can be achieved with light compaction equipment.

To achieve 'interlock' requires much more energy and a heavy flat wheel (12 ton) roller would be required. Densification takes place during normal trafficking. The coarse aggregate in a composite macadam and the slurry-bound macadam can be considered as being in the orientation phase and the slurry provides the stiffness to ensure adequate interlock.

The density measurements will depend largely on the extent to which the voids are filled with fine material and the number and size of coarse aggregates in the test hole. If there is less than full penetration of the fine material through the layer, the density will be low, but provided that the voids in the upper portion of the layer are well filled, the lower coarse aggregate is fully constrained and cannot move. TRH14:1958 for example requires a density of 86% to 88% of bulk density for water-bound macadam. Rather than specifying density, it is recommended that a method specification be followed. For water-bound macadam and dry-bound macadam layers compaction of the coarse aggregate should continue until full interlock, as indicated by no movement under the heavy (12 ton) roller, and the condition of the layer is acceptable. Thereafter the

Figure 2: Level of densification for macadam layers



fine material is either washed in (water-bound macadam) or vibrated dry (dry-bound macadam) until the voids are full. The same technique applies to composite macadam and the slurry-bound macadam, except that the roller may be lighter and the bituminous slurry is worked into the voids with squeegees.

If in doubt, then, for water-bound macadam the 86% to 88% of bulk density should be the norm. In the case of composite macadams, the layer should be tested against a specified density of 86% of the rice density determined in the laboratory according to TMH1 Method C4 (CSRA, 1986). The field density should be determined with the rondavel test (NITRR Technical Note TP 52/83).

5. Construction technique

5.1 Composite macadam

The composite macadam is constructed in two lifts namely the bottom part and the top part.

Construction of the bottom part

i) Spread the coarse aggregate to the required thickness (initially the layer is placed 30% thicker than the final thickness to allow for bulking) and level using ballast forks and a three metre straight edge. In the case of a composite macadam the coarser aggregate is spread to give a final thickness of two-thirds of the layer thickness.

ii) A thin layer (about 20 mm) of dry natural plaster sand is spread evenly over the coarse aggregate by means of a stiff broom and worked into the voids of the coarse aggregate. This action is repeated until no more sand penetrates into the voids.

iii) The surface of the layer is then thoroughly wetted and the roller is used to compact the layer and additional fine material and water are added to fill the voids until the sand is about 15 mm below the tops of the stones.

Construction of the top part

i) Spread the smaller size coarse aggregate, typically a 26,5 mm size, to the required level, and ensure evenness with the 3m straight edge.

ii) Compact the aggregate with the roller to achieve aggregate interlock and correct unevenness by adding additional coarse aggregate.

iii) The fine slurry is mixed to the specified proportions, spread with squeegees and worked into the voids. The soft slurry is then vibrated into the voids with the vibrating roller or plate vibrator until all the voids are filled and no further penetration will take place. The slurry is then worked even with the tops of the coarse aggregate to provide the wearing surface.

5.2 Slurry-bound macadam

In the case of the slurry-bound macadam a bituminous slurry seal is used to fill the voids instead of the fine sand. The steps to construct this type of macadam are as follows:

i) Spread the coarse aggregate to the required thickness (initially the layer is placed 30% thicker than the final layer to allow for bulking) and levels using ballast forks and a three metre straight edge.

ii) Use the roller to achieve aggregate orientation, and correct local depressions by working with the ballast forks. Pedestrian rollers or plate vibrators can be successfully used. Rolling normally starts on the outer edge, which is supported either by the gravel shoulder in a box-type construction or by wooden forms, until the outer part is stable, and then compaction of the centre takes place.

iii) The fine slurry is then mixed to the specified proportions, spread with squeegees and worked into the voids. The liquid slurry is then vibrated into the voids with the vibrating roller or plate vibrator, until all the voids are filled and no further penetration can be observed. The slurry is then worked even with the tops of the coarse aggregate to provide the wearing surface.

6. Specialist literature

1 A Design Manual : Labour-intensive construction guidelines for macadam pavements

University of Pretoria – Potgieter Hattingh & Raspi Inc. – TOSAS

2 Committee of Land Transport Officials (COLTO)

Standard Specifications for Road and Bridge Works for State Road Authorities

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5 Committee of Transport Authorities (CUTA). 1988. DRAFT UTG3 – Structural Design of Urban Roads. Department of Transport, Pretoria.

6 Labour-Intensive Construction Techniques - LICT 7 - Upgrading techniques for low volume roads/streets. August 1996. CSIR.

7 S A Bitumen and Tar Association – SABITA – Methods and Procedures – Labour-enhanced construction for

Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour-based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major contributing organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
National Housing Forum
Congress of South African Trade Unions

Plus many individuals from construction companies

"Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings."

Nelson Mandela, 2005 – Global Campaign for Action against Poverty

Labour-based methods and technologies for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 4-9

Labour-based construction methods for unsealed roads

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development through partnership

Confronting joblessness

This set of best practice guidelines for labour-based construction represents a significant investment of leadership by the South African Construction Industry *"to spearhead job creation and skills development so that our growing economy is increasingly accessible to all citizens"*

(Minister Stella Sigcau, SA Construction Industry – Status Report 2004).

In finalising this set as a tool for designers and practitioners, the Construction Industry Development Board (cidb) has assembled the knowledge and experience given freely by industry through a consultative process that commenced in 1996.

Taking forward this process, the cidb has published these guidelines in fulfilment of its mandate to "establish and promote best practice… and the improved performance of… participants in the construction delivery process".

"We have made the firm commitment to confront the challenges of poverty and joblessness. We have made the solemn pledge that we will do everything possible to achieve the goal of a better life for all our people."

President Thabo Mbeki, 18 May 2004 – launch of the Expanded Public Works Programme.

Labour-based methods and technologies for employment-intensive construction works

In this set: (colour coded)

Part 1

An overview of labour-based technologies and methods in employment-intensive works

Part 2

Labour-based construction methods

2.1 Labour-based construction methods for earthworks

Part 3

Labour-based methods for materials manufacture

3.1 Precast concrete products, bricks and block making

3.2 The BESA building system

Part 4

Labour-based construction technologies

4.1 Labour-based open channel flow technology

4.2 Rubble masonry dam construction technology

4.3 Rubble masonry concrete arch bridge construction technology

4.4 Foamed bitumen gravel

4.5 Cast *in situ* block pavement

4.6 Emulsion-treated gravel

4.7 Water-bound Macadam

4.8 Slurrybound and composite Macadam construction

4.9 Labour-based construction methods for unsealed roads

These best practice guidelines are supported by the Expanded Public Works Programme (EPWP), which directs a significant and increasing proportion of South Africa's public investment towards a labour-intensive programme of construction, drawing the unemployed into productive work and providing access to skills development.

The guidelines draw on international experience and are endorsed by Engineers Against Poverty (EAP), an international development NGO established by leading UK engineering institutions. EAP is working to ensure that the engineering industry remains at the forefront of efforts to reduce and eventually eliminate global poverty.

EXPANDED PUBLIC WORKS PROGRAMME
Creating opportunities towards human fulfilment

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Labour-based methods and technologies
for employment-intensive construction works

A cidb guide to best practice

Best Practice Guideline – Part 4-9

Labour-based construction methods for unsealed roads

1ST Edition of CIDB document 1034
March 2005

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cidb is a public entity established in terms of the CIDB Act, 2000 to provide strategic direction for sustainable growth, reform and improvement of the construction sector and its enhanced role in the country's economy. In pursuit of this aim cidb partners with stakeholders and regulates the construction industry around a common development agenda underpinned by best practice procurement and project processes.

ISBN: 0-621-35565-8 Printed March, 2005

Construction Industry Development Board
Private Bag X14, Brooklyn Square, 0075
Tel: 27 12-481 9030 Fax: 27 12-343 7153
E-mail: cidb@cidb.org.za Website www.cidb.org.za

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Overview of the best practice labour-based guidelines

The South African White Paper *Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry* (1999) expresses a vision for public-sector delivery aimed at optimising employment opportunities through labour-intensive construction. This can be realised in the delivery of infrastructure through the adoption, where technically and economically feasible, of:

- labour-based methods of construction and manufacture where labour, utilising hand tools and light equipment, is preferred to the use of heavy equipment for specific activities; and
- labour-based technologies where there is a shift in balance between labour and equipment in the way the work is specified and executed for selected works components.

Appropriate specifications and labour-based technologies are required to optimise employment opportunities generated per unit of expenditure. The absence of adequate design information on labour-based technologies frequently limits the choices available in project design. As a result labour-based technologies are often approached circumspectly and conservatively.

These best practice guidelines present current state-of-the-art practices in a wide range of labour-based construction methods, manufacturing methods and technologies which have been successfully utilised in South Africa in recent years. They are intended to provide sufficient technical information on such methods and technologies to enable those responsible for the design of projects to make confident and informed choices on their use in projects.

The cidb best practice guidelines establish desirable and appropriate standards, processes, procedures and methods relating to the implementation of employment-intensive works using:

- labour-based construction methods for earthworks;
- labour-based methods for materials manufacture; and
- labour-based construction technologies.

Following a process of peer review and public comment cidb has published the guidelines in Government Gazette No 27352 on 11 March 2005.

The guidelines can be downloaded from the cidb website www.cidb.org.za free of charge and can be obtained in hard-copy from cidb or the South African Institution of Civil Engineering (SAICE), website www.civils.org.za, at the cost of printing and postage.

1. Introduction

1.1 Background

Unsealed roads were the first roads constructed by man when the operators of the earliest wagons and carts encountered difficulties traversing poor materials. Localised troublesome areas would have been made passable by the addition of local materials that provided improved bearing capacity and trafficability. As the use of wheeled vehicles increased, it became more important to provide acceptable passability over the entire length of road and appropriate materials were selected and placed with some "engineering" input. These roads would probably have been constructed using entirely labour-based methods. As time progressed, more automation was used until the present, when most unsealed roads are constructed using predominantly heavy plant.

Note

Unsealed roads include all roads constructed without the use of bitumen, concrete, blocks or other durable surfaces interfacing with wheels of vehicles. They include earth tracks, earth roads, gravel roads and roads treated with a dust palliative or chemical stabiliser. The term unsealed roads is generally used internationally as a replacement for the older terms, "dirt" or 'gravel' roads. In order to provide the expected level of service, unsealed roads must be constructed from suitable materials, must be constructed to the specified quality and must be maintained to an appropriate standard. As the majority of roads in rural and developing areas are unsealed, are not stabilised and carry relatively light traffic, these roads provide excellent opportunities for the use of labour-based construction and maintenance methods.

Unsealed roads are still the principal type of road making up more than 90% of the road network in many developing countries and over 50% in some of the world's most developed countries. These are generally the least expensive roads to construct, but unlike sealed roads, the surface is not protected from environmental or traffic stresses and deteriorates rapidly. Ongoing maintenance is thus an essential and costly necessity for unsealed roads. This of course does provide an excellent opportunity for sustained local employment using labour-based construction and maintenance technologies.

1.2 Definition

Unsealed roads include all roads with no waterproof or structural surfacing, i.e. bitumen, concrete, interlocking blocks, etc. In their simplest form, unsealed roads usually consist of two tracks resulting from the compaction of the *in situ* material and destruction of vegetation following the passage of a few vehicles or carts along the same alignment. Once the traffic increases to a certain point (this will vary depending on the *in situ* material and nature of the traffic), the wheel tracks become wider and eventually the full width of a road is cleared, usually by grader or bulldozer. Traffic still rides on the *in situ* materials and the road is classified as an earth road. This type of road obviously has shortcomings in that the material properties are dictated by the local material and may or may not be suitable for sustained use as a wearing course. In addition, wear of the road results in general lowering with respect to the surrounding natural ground level, resulting in poor drainage and an eventual need for importing material to provide some type of formation and shape to the road.

When a selected material is imported and the road is shaped, it then becomes a gravel road.

2. Materials and specification

2.1 Aggregate specification

The properties of the materials used as gravel road wearing courses have a significant impact on both the performance and maintenance needs of the road, far more so than in sealed roads. Gravel wearing course materials require:

- Adequate cohesion to avoid ravelling and corrugation of the surface under traffic,
- A grading that produces a tightly bound, interlocked layer with sufficient strength to avoid erosion and shear failure,
- A limited plasticity such that the road does not become excessively slippery when wet,
- Sufficient gravel to provide a skeleton for the fine material and adequate skid resistance, but not enough to cause excessive tyre wear or large particles that will affect riding quality.

Table 1: Recommended material specification for unsealed roads

Property	Specification limit
Maximum size (mm)	37.5
Maximum Oversize Index (I_o) (%)[a]	5
Shrinkage Product (S_p)[b]	100 – 365 (max of 240 preferable)
Grading Coefficient (G_c)[c]	16 – 34
Minimum CBR (%)[d]	15 at 95 % Mod AASHTO
Treton Impact Value (%)	20 – 65

[a] – I_o = Percent retained on 37.5 mm sieve
[b] – S_p = Linear shrinkage x percent passing 0.425 mm sieve
[c] – G_c = (Percent passing 26.5 mm sieve –% passing 2 mm sieve) x % passing 4.75 mm sieve
[d] – Conventional soaked CBR unlike the unsoaked CBR originally specified in TRH 20

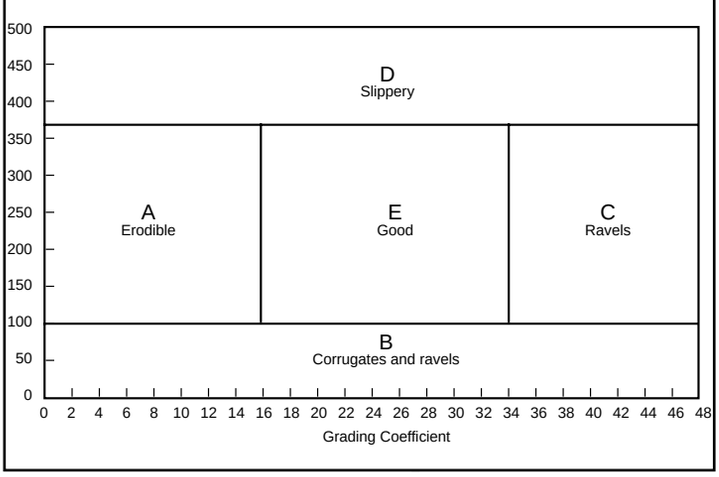
Research and experience have shown that materials complying with the requirements in Table 1 are generally adequate (TRH 20, 1990).

The grading and plasticity components of these specifications can be plotted as shown in Figure 1 as an aid to predict the likely performance of materials not complying with the requirements of Table 1.

Materials falling into Zone E will provide the best performance, provided the oversize content and strength are correct. Materials falling into Zones A, B, C and D can be expected to be erodible, to corrugate and ravel, to ravel or to become slippery, respectively. The degree of the expected defect will generally increase as the material plots further away from Zone E.

Materials must be located and tested prior to initiation of construction. Initial testing and material acceptance needs to be carried out in a conventional soil testing laboratory, but quality control on site can use simplified techniques (Paige-Green, 1998).

Figure 1: Gravel road specification and performance



The use of geological, engineering geological or engineering material classification systems is generally unsuitable for the identification of suitable wearing course materials: only the individual material properties can be effectively used. Dolerites for example could be excessively stony, highly plastic or very granular with a low plasticity, none of which would perform satisfactorily. Depending, however, on their stages of weathering and the prevailing environmental conditions, other dolerites could perform very well. It is thus essential to determine the actual properties of every potential material source.

Provided certain conditions are accepted, it is possible to make use of materials not complying fully with the requirements of Table 1. For example, a material with

a very low shrinkage product could perform satisfactorily in a moist area with low traffic as moisture will provide an effective cohesion for long periods reducing the tendency for the material to corrugate (which will take longer under low traffic). Such material may be used provided that the periodic need to provide increased maintenance (light grading or dragging to remove corrugations) is accepted. In a dry area with relatively high traffic, the maintenance needs on this type of material will be very high resulting in high costs and significant disruption of traffic flow, making the use of the material impractical.

Similar constraints are found when labour-based construction and maintenance techniques are employed. The degree of compaction attained may not be as high as that from conventional plant, resulting in poorer performance of low plasticity material or highly plastic material. These aspects must be considered when using materials not complying with the requirements of Table 1.

3. Practical aspects

3.1 Impact on performance

The specifications described above were developed over a wide range of materials, climate and traffic conditions and can be applied generally. It has, however, been found that they can be fine-tuned for local conditions but this can only be done with experience in certain areas. It is more important to ensure that certain aspects such as material homogeneity, stoniness, compaction and drainage are carefully controlled and supervised, during both construction and maintenance.

3.2 Material homogeneity

The use of variable or heterogeneous materials on unsealed roads results in localised problems, particularly in relation to passability and drainage. It is thus essential that the material is as homogeneous as a natural material can be and this is best achieved by stockpiling the materials for use on the road. The actions of excavation, loading, haulage, stockpiling, reloading, haulage and dumping, although involving double handling, creates a significant degree of mixing and homogenisation of the material.

3.3 Stoniness

One of the major contributors to poor performance of gravel roads is the presence of excessive oversize material. The presence of large stones in the wearing course results in extreme roughness and severe difficulties in maintaining the road.

Material containing significant oversize particles should be processed at source, especially in labour-based projects, where the haulage of unwanted material can have a major impact on productivity. Processing of the material through a series of small grizzlies or mesh screens should form a part of the excavation to stockpile process.

Removal of oversize material from the road during mixing and compaction is seldom successful, and results in wastage and unnecessary haulage. Manual breaking of oversize material can be carried out using large hammers, but this needs very close supervision, as hammers tend to bury the problem rather than break the cobbles and boulders, with the result that they are exposed some time

More detail on ELHUS activities

Further information on excavating, loading, hauling, unloading and spreading activities (ELHUS) may be found in Section 3 (ELHUS and compaction) of Part 2.1: Labour-based construction methods for earthworks.

later in the service-life of the road. If this is carried out, it is important that the fractured particles are separated from each other so that they do not behave as an integral particle. This requires careful mixing in the area of the broken particles.

3.4 Compaction

The act of compacting soils and gravels improves their quality/performance by improving particle interlock and thus shear strength and reducing permeability. These aspects are all necessary to ensure a road that fulfils its social and economic needs.

To achieve any reasonable degree of compaction, the material should be at a specific moisture content related to the compaction effort available on site. Material that is too wet will become spongy and will not compact, whereas material that is too dry requires an excessive effort to overcome the friction between the particles and achieve any reasonable density. Some sandy materials can be compacted successfully when dry, but they do not achieve the same strength as when wet compacted as the suction forces created between the particles on drying out do not develop.

Traditionally, construction specifications require materials to be compacted to a specific (although arbitrary) density, which may or may not be achievable with the available plant or be necessary for that material and the prevailing conditions. The control of compaction is difficult, relying on either sophisticated nuclear equipment or time-consuming labour-based methods, which are carried out at very few points on the road. A method specification, based on proof rolling trials allows for much better control and the results can be assessed at many more points on the road using simple equipment as discussed in 4.

3.5 Drainage

3.5.1 General

The uncontrolled passage of water on and adjacent to unsealed roads can cause significant damage to the road and seriously affect the movement and safety of traffic using the road. Rain falling on the road must be removed from the road surface as rapidly as possible whilst that falling adjacent to the road must not be allowed to accumulate on or close to the road structure.

3.5.2 Road surface drainage

In order to ensure that precipitation does not remain on the road surface, a good shape needs to be maintained. This requires a central crown and a camber, preferably of about 4%, towards each side of the road. Cambers greater than 5% result in erosion and unsafe driving conditions, whilst those less than about 2.5% allow the water to permeate into the road and usually result in ponding on the road. This camber must be carefully maintained during routine maintenance activities. On mono-camber sections of road, the cross-fall or super-elevation should not exceed 4% to avoid excessive erosion and to facilitate maintenance.

Fix potholes

Potholes and depressions in the road will hold water and gradually increase in size and severity under traffic. These should be repaired manually on a regular basis.

It is important that windrows, which will disrupt the flow of water from the road surface, do not remain along the road after maintenance. Any material retained for maintenance activities should be off the road shoulder and must not block the entrance to side or mitre-drains.

3.5.3 Side drains

Water drained from the road surface will inevitably be collected in side drains adjacent to the road shoulder. These must be well-maintained and effective at all times, and provide unhindered paths for the removal of the water into adjacent

fields (by way of properly designed mitre drains or across the road through effective culverts). For this to be effective in flat terrain, it is essential that the road is constructed on an adequate formation. The spacing of mitre-drains (particularly on steeper grades) should be such that high water velocities are not achieved and scouring is minimised.

Side drains should be wide and deep enough to handle the expected water without flooding the road, but also to facilitate maintenance. Maintenance using labour allows much narrower and deeper drains than that using motor graders.

4. Structural design

The pavement structure of sealed roads is designed to carry a finite number of vehicles over a specific period under the prevailing environmental conditions. This is achieved by providing a series of pavement layers each distributing applied stresses so that no part of the pavement is overstressed, but the cumulative infinitesimal damage that occurs under each vehicle pass reaches a defined terminal condition at the end of the design life. Any premature damage due to overstressing or inadequate layers results in localised damage requiring unscheduled maintenance (e.g. crack filling, pothole patching, rut filling) or possibly even rehabilitation or reconstruction.

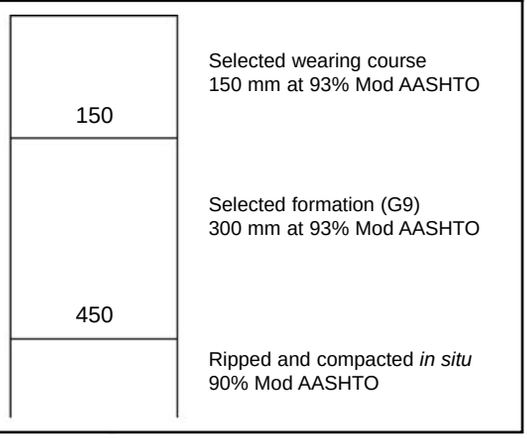
Although similar forces (in addition to environmental stresses) affect unsealed roads, most damage that occurs is usually corrected during scheduled routine maintenance, i.e. potholes or ruts are filled during grader blading or spot re-gravelling. In comparison with equivalent damage to sealed roads, any other maintenance that may be needed is relatively inexpensive and less disruptive to traffic. For this reason, the structural design of unsealed roads requires significantly less input.

Unlike sealed roads, structural design decisions for unsealed roads are generally more labour-friendly. All unsealed road materials are usually natural, so labour-unfriendly decisions, e.g. to stabilise the materials, as would be the case for many sealed roads, do not affect the outcome.

One of the main components of the structural design is to ensure that a formation with appropriate dimensions is designed with a suitable specified material and compaction. The sub-grade must be cleared and grubbed and then rolled to refusal with the available equipment in preparation for placement of the formation. At least 300 mm of material with a minimum soaked CBR of 7% (G9) should be placed as formation in order to raise the road prior to placement of the wearing course. This should be compacted to refusal ensuring that a minimum density of 93% Mod AASHTO is achieved. Typically, 150mm of material complying with the specification described in Section 2 and compacted to refusal for the available equipment or plant (but not less than 95% Mod AASHTO) should be placed as the wearing course.

This pavement structure is illustrated in Figure 2.

Figure 2: Pavement structure



This structure has been found to be appropriate for most gravel roads. In drier areas, the height of the formation can be reduced although the side drains must be at least 300mm beneath the road crown. The placement of pipe culverts requires adequate formation and cover and often dictates the formation thickness. Care must be taken to ensure that culverts and pipes do not result in 'speed humps' along the road.

5. Plant and equipment

Typical tools that are needed for labour-based gravel road projects are:

- Axe, panga, machete, etc. for removal of vegetation
- Shovel
- Pick
- Wheelbarrow: typically 50 to 70 litres
- Donkey cart
- Setting out profiles and/or templates
- String, dip sticks, stakes, pegs, etc.
- Water tanks and spraying equipment
- Rake
- Levelling beam
- Hand stampers

Mechanical compaction equipment may also be required to complement manual activities. Mechanical hauling equipment (tractors and trailers) should be available where necessary.

Apparatus for carrying out a Dynamic Cone Penetrometer (DCP) test and quality control testing should also be available.

6. Construction

6.1 Earthworks

New unsealed roads will result either from the upgrading of an existing earth track or less commonly on a totally new alignment. In either case, the centre-line of the proposed road should be staked out (stakes at 20 to 50 m intervals, depending on topography and vegetation) and the proposed vertical alignment/ final road levels marked on these stakes. This is most easily done using ranging roads and an Abney Level, but where steep grades prevail, more sophisticated levelling surveys may be necessary (see Annexure A).

The crown height, layer thicknesses and cross-falls are then transferred to offset stakes or pegs adjacent to the edge of the road and side drain, prior to clearing and grubbing, which will usually result in loss of the centre-line stakes. This should be done using string, tape measures, calibrated dip sticks and levelling beams.

Clearing and grubbing can then commence. Traditionally this is done with a bulldozer or grader, but labour-based methods can be equally effective. Labourers should initially remove all vegetation above ground level using the appropriate equipment. Trees should be cut down, bushes hacked back and grass

For more detail

See Part 2.1: Labour-based construction methods for earthworks

cut as described in Section 2 (clearing and Grubbing) of Part 2.1: Labour-based construction methods for earthworks . The root and organic rich topsoil must then be removed and disposed of as instructed. Grubbing should be done using shovels and picks where necessary, ensuring that the absolute minimum soil material is removed. Where isolated rock outcrops or large boulders occur, dry wood removed during the bush and tree clearing should be collected and retained for use in fires to break the rock as described in Part 2 (Labour-based Methods for Earthworks).

The cleared and grubbed roadbed must then be levelled and compacted to as high a density as practically possible using available plant. On small projects, use can be made of hand tampers but generally, small pedestrian or sit-on rollers are necessary. The addition of water to the roadbed material will usually be necessary to assist compaction, unless this is carried out in the wet season. On certain materials it may be necessary to loosen the roadbed material with forks prior to compaction in order to break up loosely cemented particles and possible collapsible soil structures. It is also recommended that, where possible, a camber towards the side-drains is applied to the top of the sub-grade to assist with drainage of water that may seep through the pavement structure.

6.2 Formation

The formation should be constructed of selected material that is excavated, loaded, hauled, unloaded and spread as described in Part 2 (Labour-based Methods for Earthworks). Suitable material should be obtained from the relevant stockpiles and dumped and spread according to Part 2 (Labour-based Methods for Earthworks). Dip-sticking of string lines, which allow for the bulking of the material, should be carried out during spreading to ensure an even distribution of material. It is also possible to use pegs or pins marking the top of the layer for spreading, but these should be removed prior to compaction (see Figure 3).

For more detail

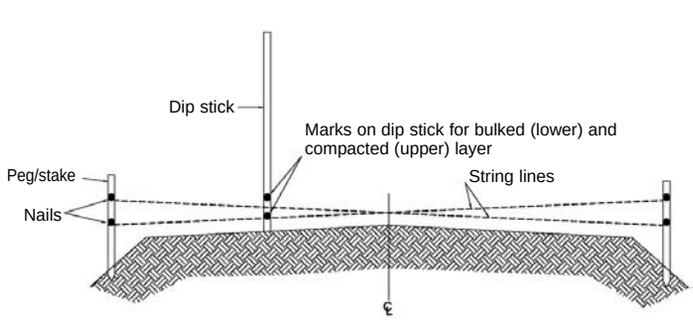
See Part 2.1: Labour-based constuction methods for earthworks

The top of the formation should be constructed to the same shape as the proposed wearing course to maintain a constant wearing course thickness and to assist in internal drainage of the layers. As the formation is typically 300 mm thick (compacted), it is impracticable to compact this material with light equipment in one layer. Compaction should thus be carried out in three 100 mm layers.

It is useful to determine the typical bulking factor of the material and to place marks for both this and the compacted layer on the dip stick. This provides additional control for spreading and compaction. It is also usual to require stakes or pegs more frequently than one every 20 m during actual labour-based construction.

For very light pavement structures, it is possible to use only very light compaction and not to be too concerned with the actual compaction. The result of this will typically be significant rutting during early trafficking (as a result of traffic compaction), which can be corrected during surface maintenance. The implication of this is that additional wearing course material will be required earlier in the life of the road. This is not recommended if heavy trucks are expected to use the road as early potholing and shear failures in the uncompacted formation are likely.

Figure 3: Level control during spreading and compaction



6.3 Wearing course

The gravel wearing course will be constructed of selected material that is excavated, stockpiled, loaded, hauled, unloaded and spread as described in Part 2 (Labour-based Methods for Earthworks). The material for the wearing course should preferably be moistened to just above optimum moisture content at the stockpile prior to hauling so that segregation is minimised and the loading, hauling, unloading and spreading process homogenises the material as far as possible. Traditionally, the gravel is tipped along the side of the road and then spread by grader (with simultaneous watering and mixing) across the road. On labour-based projects, however, the material will typically be spread with forks and/or rakes and should thus be dumped on the road to accelerate the spreading procedure. During spreading, all oversize material that may have been 'accidentally' incorporated into the wearing course gravel must be removed. It is important that oversize particles are not just buried in the layer, as they will appear over time as the gravel is worn away by traffic and environmental effects.

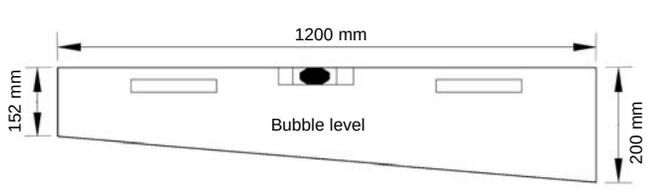
As it is very difficult to trim the final levels using only labour, it is important that the surface is as even and as well shaped as possible prior to compaction. The use of string lines and dip sticks is the most practical method of ensuring this on labour-based projects, although it is useful for each labourer to have a suitable camber board (planks with a spirit level on the upper surface and a 4% slope on the lower surface – Figure 4) for checking his individual work. (Levels can also be estimated using a calibrated probe as described in Paige-Green, 1998.) This process should be carried out as rapidly as possible to avoid excessive loss of moisture from the material and compaction must commence as soon as possible.

Never use pins for the wearing course

The use of pins in the road carriageway to mark the top of the layer should never be considered for the wearing course as any that may be inadvertently left in the layer can cause potentially unsafe conditions as they become exposed to vehicle tyres.

Compaction will normally be done using a small pedestrian or sit-on roller. Density testing is notoriously difficult and poorly repeatable on this type of project and other techniques should be used to control the construction. It is recommended that the use of controlled dip-sticking using the bulking/compacted relationship determined in a laboratory (usually during the initial material characterisation and evaluation process) should be the first check on compaction. The use of a method specification based on proof rolling as discussed in Section 7 should always be considered. This provides a target DCP penetration rate as well as permitting a much larger number of tests to be carried out and enhancing overall quality. The testing must be done immediately after compaction (i.e. at OMC) and where the DCP penetration rate is unsatisfactory, additional compaction must be applied as soon as practically possible. A calibrated probe can also indicate whether compaction has been achieved, provided the layer thickness before compaction is correct (Paige-Green, 1998).

Figure 4: Four percent camber board



On small projects, the use of hand stampers for compaction can be considered but it is difficult to obtain a consistent density and uniform surface. If this technique is used, the optimum number of blows should be determined by trial and error and this number used consistently over the layer, ensuring that all parts of the

layer are compacted.

6.4 Drainage

Side drains will be excavated manually to a defined profile. An appropriate cross section should be identified during the design phase (side slopes usually about 1 vertical : 1.5 horizontal with the ditch bottom at least 0.5 metres below sub-grade level) and templates manufactured (typically from wooden planks). These should be used on an ongoing basis to ensure that the drainage shape is correct. Cross sections of typical side drains are shown in Figure 5. The longitudinal slope of the drain should compromise between effective water removal without silting and avoidance of scouring and erosion. Where erosion is likely, check dams (Figure 6) or other erosion protection measures should be implemented. It is equally important that the mitre drains are properly graded to ensure that water carried into them is effectively removed from the road area (Figure 7). They must also remain effective under the silt that will build up between maintenance activities.

The geometry of the drains must be consistent with labour-based maintenance. Mitre drains and flat bottomed side drains are frequently cleaned and maintained by grader and are designed for this. Labour-based drainage maintenance will be facilitated by a much smaller invert width or a V-drain.

Culverts and pipe drains must fit within the formation to avoid humps in the road. Where this is not possible, the thickness of the formation must be increased to accommodate the drainage structures. Care must also be taken to ensure that the pipe inverts are not below the natural drainage level, so as to become ineffective.

Figure 5: Cross-sections of typical drains

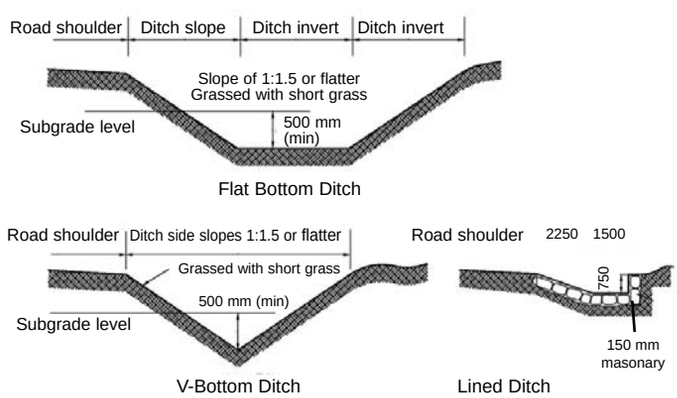


Figure 6: Erosion control measures and check dams

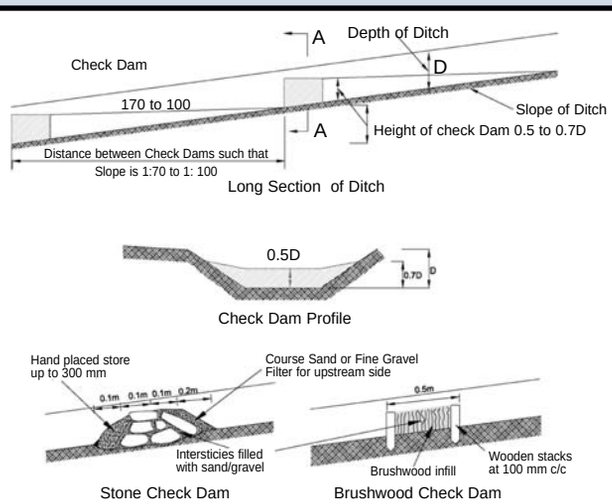
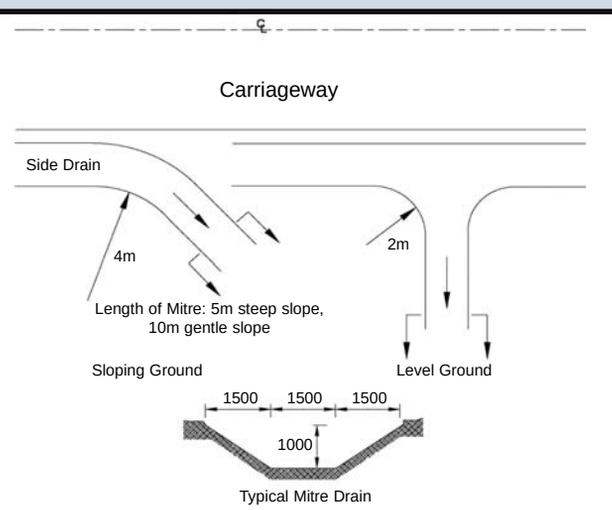


Figure 7: Typical mitre-drain layout and cross-section



7. Quality control

Quality is vital

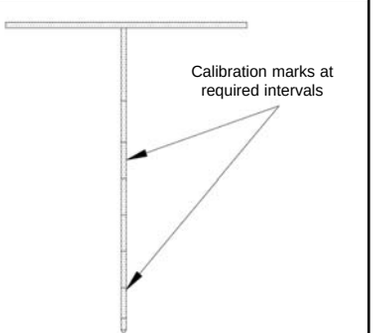
It is essential that the quality of construction is controlled fully (Paige-Green, 1998).

7.1 Road shape

Obtaining the correct shape of the road surface during labour-based construction is imperative, as it is difficult to correct any significant problems after construction using manual techniques. The provision and use of an adequate number of camber boards or carefully set out string lines is essential.

These camber boards should be used regularly and frequently during the spreading and compaction of the wearing course.

Figure 8: Probe for assessing layer thickness



7.2 Material thickness

Control of the material thickness must start during the unloading phase of the project. It is imperative that the material is dumped at the required spacing and frequency, so that it can be evenly spread out at a consistent density. A simple hand probe similar to that illustrated in Figure 8 can be used to judge the thickness of both the spread (uncompacted) and compacted layer. By simply pressing the probe into the layer, the thickness can be observed from the exposed calibration marks. Typically, the underlying layer will have dried out since compaction and a greater resistance to penetration will be easily felt as the probe is pressed into the layer.

7.3 Compaction

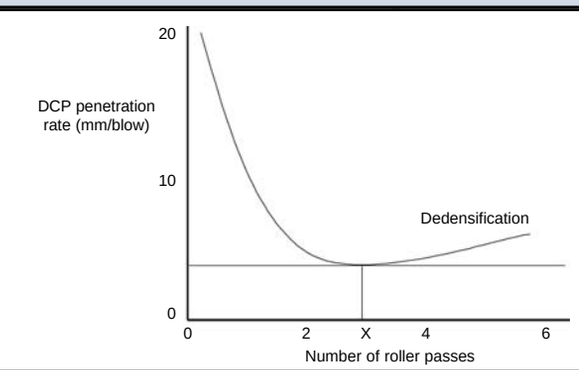
Compaction of road pavement layers is traditionally controlled by density measurement. This requires knowledge of the density of the material at a specified compaction effort (usually 95% of mod AASHTO for a gravel wearing course). The density is usually controlled using an *in situ* replacement method (sand replacement) or a nuclear measuring device. Both of these techniques have inherent problems and are considered inefficient for labour-based projects.

The simplest method for checking compaction of labour-based projects is by measuring the height of the material before and after compaction. This can be done using a number of techniques as discussed (dip stick, string lines, calibrated probe, etc.). Although not entirely accurate, a good indication of the overall quality of compaction can be obtained.

It is suggested, however, that a method specification, based on proof rolling, be implemented and controlled using a DCP or Rapid Compaction Control Device (RCCD) apparatus. The suggested process for this is as follows:

After the material has been spread and is ready for compaction, a short section of road should be given one 'pass' with the available compaction plant, i.e., forwards and backwards. A DCP test (or RCCD) is carried out to a depth of 150 mm (or the layer thickness if less), and further passes are applied with a DCP test being carried out after each pass. The DCP penetration rate is plotted against the number of passes (Figure 9) and the number of passes after which no beneficial compaction occurs is identified (point X or 3 passes in Figure 9). The DCP tests should be carried out in close enough proximity to allow direct comparison of the results but not so close that the result is affected by previous tests. The minimum DCP penetration rate obtained (at compaction moisture content) is also the target rate for quality control of the layer after compaction. A statistical judgement scheme (example COLTO, 1996 or TRH5, 1977) or some simplified version of this (e.g. Annexure B) can be applied for acceptance

Figure 9: Proof rolling example



8. Maintenance

testing.

8.1 Surface maintenance

Road surface maintenance using conventional plant includes light grading, heavy grading and occasionally ripping and recompaction. Where only labour is used for maintenance, only the light grading activity can be effectively simulated. Heavy grading and ripping and recompaction require a grader at least and the relevant techniques are described in LICT 4 (1997). The process of light grading can be substituted by labour-based techniques on small projects but is usually not cost effective on projects more than between 3 km and 5 km long.

The frequency of maintenance will depend primarily on the traffic and the precipitation and should be such that the state of the road does not deteriorate significantly. It is practically impossible without heavy grading to restore a reasonable riding quality to a badly deteriorated road. Similarly, the presence of excessive oversize material results in serious maintenance difficulties. Where a labour-based unit or local contractor is available and a routine maintenance contract can be awarded, the road surface can be maintained without a grader.

The process will usually involve a combination of pothole patching as described in section 8.2 and light scarification of surface irregularities, including protruding stones, corrugations and compacted windrows using rakes or forks. The loosened material will be spread to fill depressions and even out the surface, ensuring that the crown and camber of the road are retained. Any large stones must be removed from the road surface. This can often be combined with surface dragging using a small tyre or steel drag (LICT 4, 1997). These drags can be drawn by labourers, animals or small vehicles and assist in retaining the shape of the road. The shape of the road during dragging should be controlled using camber boards. The use of bush or tree drags is not recommended as these invariably result in dishing of the road with a severe effect on the surface drainage of the road.

It is important that during surface maintenance, windrows of material that will affect the drainage of water from the road surface are not left adjacent to the carriageway.

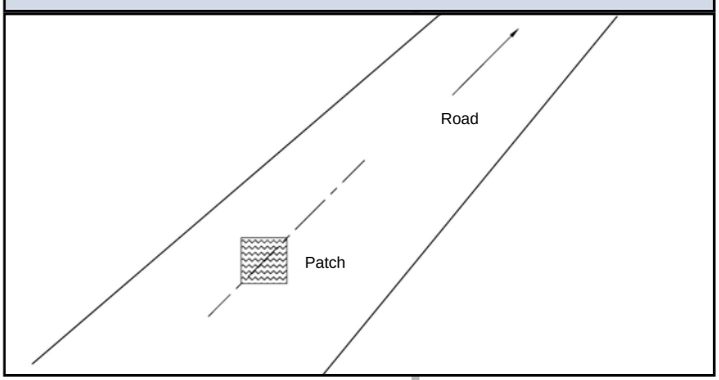
8.2 Patching

Early repair of potholes and depressions is essential as they can cause significant damage to vehicles and result in unsafe driving conditions. This may be defined as patching or spot re-gravelling. On materials that form a crust or 'blad' (including many calcretes and ferricretes), conventional grading can cause extensive damage to the hard surface and patching is the most appropriate maintenance technique.

Potholes can vary in diameter from 100 mm to in excess of 1 500 mm and when more than 50 or 75 mm deep have the greatest impact on vehicles. They arise through a number of processes, including poor road shape and drainage, poor maintenance, corrugations, rutting, excessive stoniness, weak wearing course materials, formation or sub-grades, poor compaction, etc. Potholes can seldom be repaired during normal grader maintenance and the following procedure is suggested:

Remove all unstable or weak material, preferably in a diamond shape as seen when driving along the road (Figure 10) and clean the hole by brooming. It is not necessary to produce a hole with smooth vertical sides for unsealed roads: a rough surface finish in fact results in better bonding of the patch material.

Figure 10: Pothole repair using diamond-shaped patch



The sides and base of the hole should be watered to enhance the bond between the hole and the patch material. It is important, however, to avoid the addition of too much water, such that the material becomes soggy.

The patch material should come from the same source (and have similar properties) as the original wearing course material. It should be moistened until it can be squeezed in one hand into a tight 'ball' without excess water being expelled. It must then be compacted, using a hand stamper or rammer, into the hole in layers about 60 to 75 mm thick, ensuring that the material adjacent to the edge of the hole is well compacted. This should continue until the material is about 15 mm proud of the road surface. Compaction in layers thinner than about 40 mm will result in lamination, which will often disintegrate under traffic on drying out.

A similar process is necessary to repair damage to the road caused by water flow and erosion, but it is not practical to excavate diamond shaped holes – the erosion channels must just be cleaned out and repaired as described above. It is important to identify, and attempt to rectify, the cause of such distress where possible.

Never patch with windrow material

Under no circumstances should material from windrows on the carriageway be used for patching as these materials have generally lost the majority of their fines and thus lack adequate cohesion.

8.3 Re-gravelling

Depending on the traffic the full thickness of the gravel wearing course will be lost over time. This can take from 4 or 5 years for heavily trafficked roads to in excess of 10 years for roads carrying only light traffic. It is recommended, however, that the road be re-gravelled before the entire wearing course is lost, in order to avoid deterioration of the formation. This material is neither designed nor constructed to support traffic and a minimum cover of 25 to 50 mm of wearing course gravel should be retained on the road to avoid excessive deformation of the surface prior to re-gravelling.

Re-gravelling will generally follow the construction procedure described earlier for construction of the wearing course, including the material location, ELHUS, compaction and quality control requirements outlined.

Spot improvement

Spot improvement can be described as an activity somewhere between pothole patching on a large scale and re-gravelling on a small scale. This operation is usually necessary in the following circumstances:

- where serious damage has been done by water (erosion on grades or adjacent to culverts);
- where deficiencies in gravel or construction quality occur; and
- on flat sections or in sag curves where drainage is impeded.

A successful spot improvement operation makes use of those principles described under patching and re-gravelling or wearing course construction.

8.4 Drainage maintenance

The regular maintenance of side drains and culverts is traditionally a labour-based activity. This involves the clearing of bush and cutting of grass as well as the de-silting of culverts and other drainage structures. It is essential that this is carried out meticulously, all of the debris removed from the drains and structures being disposed of well away from the drainage systems. Silt from drains should never be used for filling depressions or potholes on the road surface.

9. Safety

The construction, maintenance and repair of unsealed roads using labour-based techniques, like any other road, require stringent safety measures. Labour on these projects often has little experience of conventional safety measures. As described in Section 4 of Part 2.1: Labour-based construction methods for earthworks, safety should be an inherent component of any project. It is essential that adequate warning and control be provided for labour working both on and adjacent to the road. Extensive use of warning signs, demarcation cones and barriers and flagman following conventional practice is a prerequisite for a safe project.

Fortunately, the majority of unsealed road projects on which labour-based techniques are used have light and often slow-moving traffic.

10. Specialist literature

1 The design, construction and maintenance of unpaved roads. 1990. Pretoria: Department of Transport. (Technical Recommendations for Highways: Draft TRH 20).

2 Paige-Green, P. 1998. Material selection and quality assurance for labour-based unsealed road projects. Nairobi, Kenya: ILO/ASIST (Technical Brief No 9).

3 Maintenance of unsurfaced roads/streets. 1997. Pretoria: South African National Roads Agency. (Labour-Intensive Construction Techniques: LICT 4).

4 Statistical concepts of quality assurance and their application in road construction. 1977. Pretoria: Department of Transport. (Technical Recommendations for Highways: Draft TRH 5).

5 McCutcheon, RT and Marshall J. Labour-intensive construction and maintenance of rural roads: Guidelines for the training of road builders. Construction and Development Series, Number 14. Development Bank of Southern Africa. November, 1996.

Annexure A: Setting out the road alignment and cross-section

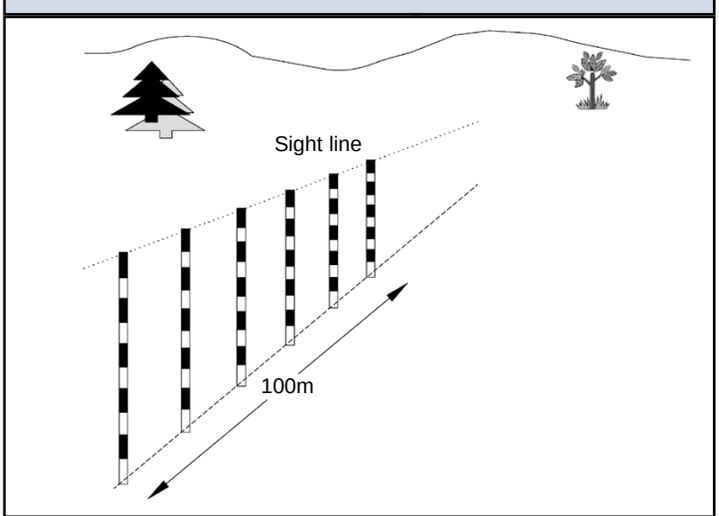
A1 Equipment

String line
Tape measure (3 and 50 m)
Line level
Ranging rods
Adjustable profile boards
Hammer
Steel spikes

A2 Centre line

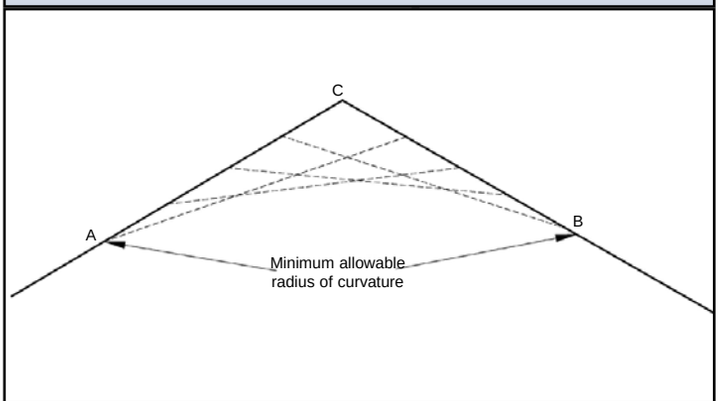
On existing roads, the centre line and alignment will usually be followed. On new alignments it is necessary to set out the centre line and off-set pegs marking the road edge and drainage.

Figure A1: Setting out centre line



The centre line is marked by placing ranging rods into the ground at 10 to 20 metre intervals (further apart on flatter more uniform alignments). In order to ensure straight sections of road, ranging rods are installed at 100 m frequencies and the intermediate rods are then installed at the appropriate points making sure that they are all directly in line and the same height to facilitate later setting out of cross section profiles (Figure A1). Each stake should be marked with the chainage/kilometre length from the start.

Figure A2: Setting out curves



Straight sections of road are easy to set out but horizontal curves require significantly more input. These should be smooth and large radius curves can be set out by eye with practice. Smaller radius curves are more difficult to set out by eye and string can be used to assist in this operation as indicated in Figure A2. At the point of curvature, the road is divided into two straight sections based on the approach and exit angles, meeting at point O. This can be done by using ranging rods. Points A and B are located on the basis of the minimum allowable radius of curvature. These are easiest located by measuring AO and BO as the specified minimum radius of curvature (Figure A2). AO and BO are then divided into four or five equal sections and string lines placed between the points on AO and the opposite points on BO, i.e. the point on AO closest to O is joined to the point on BO furthest from O. The outermost inter-sections of these lines provides the required horizontal curve.

Once the road centre line has been set out, and the horizontal alignment fixed, the vertical alignment should be set. This will usually follow that of an existing road with minor smoothing out or require a full setting out. The aim is to provide a smooth surface and this can be achieved by ensuring that the ranging rods shown in Figure A1 are all at the same height along the sight line. They should thus be placed into the ground (or existing road) to ensure this. Ranging rods can usually be hammered into soft ground but in harder material or rocky terrain, a steel

spike should be knocked into the ground first to avoid damage to the ranging rods. Where it is difficult to achieve the correct levels at the tops of the ranging rods, profile boards can be used. These are flat steel plates attached to a clampable sliding device such that they can be adjusted and clamped at the required heights using sight lines.

At this stage of the project, the centre line of the proposed road should be marked out with ranging rods at regular intervals (or appropriately marked stakes replacing the ranging rods). The pavement/drain cross sections are then located at the site of each ranging rod/stake. These must be perpendicular to the centre line at the respective points. Ensuring that the profiles are perpendicular to the centre line can be done using tape measures or marked strings and the 3-4-5 method as shown in Figure A3.

On these perpendiculars, the road profile should be pegged out using a tape measure and the pegs (or stakes) placed at the edge of the formation, and marking the drain break points on each side of the road. In order to ensure adequate drainage, however, the drains require a small grade and this should be ensured using ranging rods and profile boards. The grade of the drains can be determined from the spacing between ranging rods and their heights (assuming they have been correctly placed with a horizontal sight line or one with a known grade). Profile boards on these rods can then be used to establish stakes marked at the correct heights for construction control (Figure A4).

Figure A3: Setting out right angles

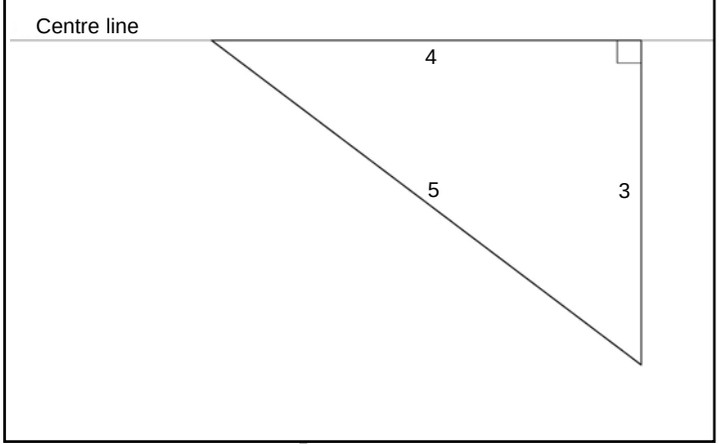
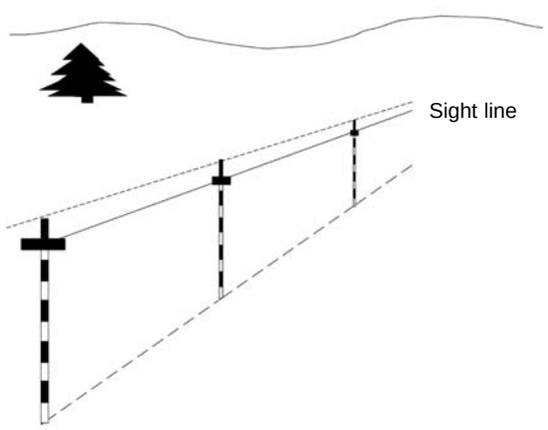


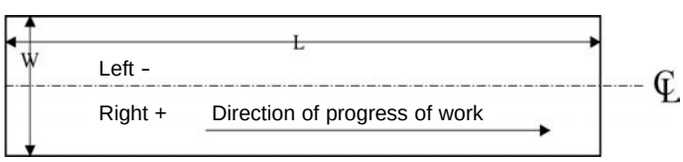
Figure A4: Using ranging rods and profile boards to set grades for drains



Annexure B: Simple statistical quality control technique

The testing of construction quality should be carried out at the end of every day for a lot (i.e. one day's production). This would usually comprise about 100 metres of new layer, depending on resources available. The properties to be tested would be compaction (or a proxy thereof) and layer thickness.

Figure B1: Definition of a surface lot



A minimum sample size of six is considered to be sufficient although a greater number of samples would be desirable. Sampling should be carried out in a random manner and a stratified random system as follows has been found to be effective:

The section to be evaluated must be defined by an area of width, W, and length, L, separated by the centre line as shown in Figure B1. Both the length and width are reduced by 400 mm compared with the actual construction.

Table B1: Random selection of sampling plan

Minutes past hour	Sampling plan
0-10	1
10-20	2
20-30	3
30-40	4
40-50	5
50-60	6

Random numbers for various sampling plans are provided in Table B1. A sampling plan is randomly selected – one way of doing this is by taking the minute reading on a watch at the time of the assessment:

The coordinates of the sampling points are determined from Table B2 and transferred to the road by measurements along the road centre line (f1L) and offset from the centre line (+ or – f2W) as shown in the example below.

Table B2: Factors for determining co-ordinates of random sampling positions on a surface lot

	Sampling plan 1		Sampling plan 2		Sampling plan 3		Sampling plan 4		Sampling plan 5		Sampling plan 6	
n	f_1	f_2	f_1	f_2	f_1	f_2	f_1	f_2	f_1	f_2	f_1	f_2
1	0.075	0.225 (-)	0.825	0.125(+)	0.275	0.225(-)	0.675	0.425(+)	0.375	0.125(-)	0.525	0.375(+)
2	0.925	0.275(-)	0.425	0.525(-)	0.925	0.375(+)	0.225	0.075(-)	0.925	0.425(+)	0.225	0.125(-)
3	0.275	0.375(+)	0.925	0.125(-)	0.175	0.425(+)	0.825	0.025(-)	0.275	0.475(+)	0.725	0.475(-)
4	0.575	0.325(-)	0.275	0.425(+)	0.975	0.275(-)	0.125	0.175(+)	0.925	0.225(-)	0.075	0.025(+)
5	0.075	0.475(-)	0.525	0.375(+)	0.175	0.175(-)	0.775	0.075(+)	0.025	0.025(-)	0.825	0.425(+)
6	0.525	0.275(+)	0.075	0.325(-)	0.975	0.275(+)	0.025	0.275(-)	0.575	0.275(+)	0.325	0.375(-)
7	0.325	0.275(+)	0.625	0.125(-)	0.475	0.075(+)	0.975	0.175(-)	0.325	0.375(+)	0.875	0.025(-)
8	0.775	0.025(-)	0.175	0.475(+)	0.625	0.025(-)	0.075	0.075(+)	0.675	0.075(-)	0.375	0.325(+)
9	0.175	0.425(-)	0.675	0.275(+)	0.375	0.475(-)	0.675	0.125(+)	0.425	0.125(-)	0.575	0.475(+)
10	0.975	0.075(+)	0.375	0.275(-)	0.975	0.075(+)	0.325	0.375(-)	0.775	0.275(+)	0.075	0.275(-)

The testing at each point will require a DCP penetration to 150 mm depth and a determination of the thickness (using the probe or excavating a small hole).

Example:

Sampling

A lot needs to be checked for compaction (DCP penetration rate) and thickness. Six samples are to be taken. The time is 16:25 (i.e. sampling plan 3 is to be used).

The length of the lot is measured as 98 m and the width is 6.5 m.

The nett length, L of the lot = 98 - 0.4 = 97.6m
The nett width, W of the lot = 6.5 – 0.4 = 6.1m

The zero point for the longitudinal measurements is 200 mm from the start of the lot in the direction of progress and on the centre line for the transverse measurements.

The nett co-ordinates of the sampling positions are as follows:

Sample	f1	f1L (m)	f2	f2W (m)
1	0.275	26.84	-0.225	-1.37
2	0.925	90.28	+0.375	+2.29
3	0.175	17.08	+0.425	+2.59
4	0.975	95.16	-0.275	-1.68
5	0.175	17.08	-0.175	-1.07
6	0.275	26.84	+0.275	+1.68

Thus, test 1 will be at 26.84 + 0.2 = 27.04 m from the start of the section and 1.37 m to the left of the centre line, etc.

The tests will be interpreted as follows:

Compaction (DCP penetration):

The target value will be that obtained from the proof rolling usually in the range 6 to 12 mm penetration per blow. A maximum mean value and an absolute maximum value as shown will be required.

Target value (mm/blow)	Maximum mean	Maximum for single test
6	5.4	8
8	7.4	10
10	9.4	11.5
12	11.4	13

Where the maximum mean value is not achieved, additional rolling should be applied to the entire section, until the value is achieved. At areas with values higher than the target value and where the maximum for the single test is obtained, additional rolling should also be provided. The results should obviously be assessed in terms of the overall visual impression of the section.

Layer thickness

Typically, a layer thickness of 150 mm will be specified. The results of the random thickness testing will be assessed in terms of the following:

Target thickness (mm)	Minimum 90th percentile thickness	Minimum mean thickness
150	140	134

Notes

Acknowledgements

This guide to best practice would not have been possible without the contribution of all sectors of SA Construction and its stakeholders, a contribution of time and leadership made in the interests of a better industry.

It is impossible to list all those who have made an input to this product since the 1996 initiative between the Minister of Public Works and Captains of Industry. The "Captains' Initiative" kick-started a number of key interventions towards a transforming industry including a focus on labour based construction.

Initial conceptual work was taken forward by the Inter-ministerial Task on Construction Industry Development, which established a focus group under the leadership of Graham Power. The Focus Group built on the experience of pilot public works projects to develop a preliminary set of guidelines.

Building on the work of the Task Team, the cidb has expanded the application of technologies and methods to increase the employment generated per unit of expenditure. A focus group of industry specialists and stakeholders has further reviewed and refined these guidelines, which are now recommended by the Expanded Public Works Programme in the delivery of national, provincial and municipal infrastructure,

cidb wishes to thank the many individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally.

A special thanks is due to Ron Watermeyer (past President of the SA Institution of Civil Engineers) whose involvement has ensured a continuity of focus throughout the process.

Major contributing organisations

Department of Public Works
Department of Transport
Department of Water Affairs and Forestry
Gautrans
South African National Roads Agency Limited
Soweto City Council
Johannesburg City Council
eThekwini Metro
Tshwane Metro
South African Federation of Civil Engineering Contractors
South African Association of Consulting Engineers
South African Institution of Civil Engineering
University of the Witwatersrand
University of Pretoria
International Labour Organisation (Asist Programme)
CSIR Boutek and Transportek
Development Bank of Southern Africa
The South African Roads Board
Agrément South Africa
Standards South Africa
Cement and Concrete Institute
South African Bitumen Association
South African Black Technical and Allied Careers Organisation
Concrete Manufacturing Association
Building Industries Federation of South Africa
National Economic Forum
National Housing Forum
Congress of South African Trade Unions

Plus many individuals from construction companies

"Like slavery and apartheid, poverty is not natural. It is man made and it can be overcome and eradicated by the actions of human beings."

Nelson Mandela, 2005 – Global Campaign for Action against Poverty