



# LABOUR-BASED TECHNOLOGIES AND METHODS FOR EMPLOYMENT INTENSIVE CONSTRUCTION WORKS

## BEST PRACTICE GUIDELINE 2

### Labour-Based Construction Methods for Earthworks

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**Note:** 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 activities that are very difficult to do with labour and are thus 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 that are based on current practice.

## 1 Introduction

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### 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 have 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.

### 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**

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**Note:** SANS 1921-5 requirement for clearing and grubbing is:

*Grass and small bushes shall be cleared by hand.*

### **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 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

### **2.3 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 1 metre. Removal and grubbing of large trees is paid by individual number of trees, categorised into girth steps of 1 m.

#### **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 1 metre. Removal and grubbing of large trees is paid by individual number of trees, categorised into girth steps of 1 m. 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<sup>3</sup>.

## 2.4 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 5 m 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.

## 2.5 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 <sup>2</sup> )	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 are:

#### **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, or
- 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..

#### **Off-loading**

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.

### **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 team's 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 sites. 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

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

Team balancing exercise:

**Table 3: Team balancing exercise**

	<b>Activity</b>	<b>Productivity (worker/day)</b>	<b>Quantity</b>	<b>Mandays required</b>
1	Excavation of soft material	3m <sup>3</sup>	150	50
2	Loading of soft material	5m <sup>3</sup>	150	30
3&4	Hauling & Unloading (100m)	6 m <sup>3</sup>	150	25
5	Spreading	15m <sup>3</sup>	150	10

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 though, it just means that it was poorly planned.

The ELHUS activities will now all 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.

### **3.3.3 Classification of material and effect on productivity for each activity**

One very important aspect that has large influence on the 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 workstudy done to be able to accurately 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 of a material 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 layerworks 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.

### **3.3.4 Tools and plant**

#### **3.3.4.1 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 1% 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.

#### 3.3.4.2 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  
                         Setting out profiles and/or templates

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 compliment manual activities. Apparatus for carrying out a Dynamic Cone Penetrometer (DCP) test should also be available.

#### 3.3.4.3 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.

### 3.3.5 Practical guidelines for excavation

#### 3.3.5.1 Methods of classifying earthworks

**Note:** 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; or
  - 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; or
- 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**

1		2	
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

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 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 <sup>+</sup>	
	GRANULAR SOIL	COHESIVE SOIL	GRANULAR SOIL	COHESIVE SOIL <sup>++</sup>
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 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.

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 1.4. 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 1.5 and 1.6. 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]

NOTE: The numbering of the clauses follows the numbering of SANS 1200 DM.

**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.*

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

Dynamic cone penetrometer - minimum number of blows required to penetrate 100 mm	Granular materials	Cohesive materials
	7-15 <sup>+</sup>	6 to 8 <sup>+,**</sup>
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.

+ 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

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.

### 3.3.5.2 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 overwatered as it is almost equally difficult working with excessively sticky materials.

Bedrock or large residual boulders are frequently encountered in the subgrade. 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.

### **3.3.5.3 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.

### **3.3.5.4 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 2000 m<sup>2</sup> (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.

Stockpiled materials should be tested to ensure the correct quality for their intended purpose. Generally four samples per 1000 m<sup>3</sup> 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.

### **3.3.5.5 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 (m3)			
	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 <sup>3</sup> /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

### 3.3.5.6 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.

### 3.3.6 Practical guidelines for loading

#### 3.3.6.1 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, eg, 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 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.

### 3.3.6.2 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.

**Table 10: Loading productivities**

LOADING	TOOLS	TASKS m <sup>3</sup> /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 manday, m3
Below Level	5.88
0.5 m above ground level	5.26
1.0 m above	4.55
1.5 m above	3.85
2.0 m above	3.23
	2.70

### 3.3.7 Practical guidelines for Hauling

#### 3.3.7.1 Introduction

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.

#### 3.3.7.2 Practical tips

**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.

**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 where-ever 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 loses 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<sup>3</sup> and 2.0 m<sup>3</sup>. 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<sup>3</sup> up to 5 m<sup>3</sup> 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.

**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 2 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.

### 3.3.7.3 Productivities

**Table 12: Wheel barrow productivity**

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

Note that haul distance = horizontal distance + 10 x vertical rise

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.

### 3.3.8 Practical guidelines for Unloading

#### 3.3.8.1 Practical tips

Unloading of construction materials requires planning to eliminate excessive double handling. Road gravels should be offloaded down the middle of the roadway, unless the layerwork 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.

**Table 13: Donkey cart haulage productivity (based on 0,5 m<sup>3</sup> 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).

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 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.

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.

### 3.3.8.2 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 m<sup>3</sup>/m-d can be assumed.

### 3.3.9 Practical guidelines and productivities for Spreading

#### 3.3.9.1 Practical tips

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 nor longitudinally, as would be the case with a grader. The resulting material and its moisture content is 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 bower. 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 crossfall. 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.

### 3.3.9.2 Productivities

Typical productivities for spreading and related activities are:

- Spreading only 12 m<sup>3</sup> per worker per day
- Water, mix, spread and level 3 m<sup>3</sup> per worker per day
- 

### 3.3.10 Practical guidelines for Compaction

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

*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*

- d) a Proctor density of 90 % is achieved,*
- e) 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, or*
- f) the density of the compacted trench backfill is not less than that of the surrounding undisturbed soil when tested comparatively with a dcp.*

### 3.3.10.1 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.

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 5 blows / 100 mm of material at compaction moisture content can be used to specify the compaction requirements.

### 3.3.10.2 Existing Standards

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, flatwheel 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 150mm and the material shall be compacted by means of mechanical equipment to 90% of mod AASHTO density.

### **3.3.10.3 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. The problem is put into perspective when one realizes that a large self-propelled vibrating roller can compact up to 300 m<sup>3</sup> 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.

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.

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.

### **3.3.10.4 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.

A common problem in the compaction of earthworks is the control of moisture content. (see 1.3.9.1). 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 method outlined in 1.3.9.1 is recommended, viz

- 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 crossfall. 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.

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 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.

### **3.3.10.5 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.

### **3.3.10.6 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 are 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.

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).

## **4 Safety**

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### **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 a 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.

- 1 Implement the Occupational Health and Safety Act provisions, rules and regulations.
- 2 Talk about safety.
- 3 Implement "Behaviour Based Safety" or "pro-active control of safety" [Strydom, 1999]
- 4 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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