ASIST Information Service
Technical Brief No 9

Material selection and quality assurance

for labour-based unsealed road projects

International Labour Organisation
ADVISORY SUPPORT, INFORMATION SERVICES, AND TRAINING (ASIST)
Nairobi, Kenya

The Employment-Intensive Programme (EIP) is a sub-programme within the Development Policies Department (POLDEV) of the ILO. Its objective is to promote the use of local resource based technologies in infrastructure works in developing countries and to strengthen their capacity to apply such technologies.

ASIST is a sub-regional programme under the EIP, one of whose objectives is to achieve an improved effectiveness of road construction, rehabilitation and maintenance in Sub-Saharan Africa and thereby promote employment and income generation in the rural and urban areas.

The aim of ASIST Technical Briefs is to spread knowledge about labour-based technology and management amongst policy makers, planners, designers, implementers and trainers.

Material selection and quality assurance

for labour-based unsealed road projects

First edition

This publication was developed by the
ASIST technical team in Harare, Zimbabwe,
and Nairobi, Kenya.

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Acknowledgements

This document is part of an occasional series of technical briefs produced by ILO/ASIST to synthesise and summarise technical information on important aspects of labour-based technology.

The original work for this brief was undertaken under contract by Dr P Paige-Green of the Division of Roads and Transport Technology (Transportek) of the CSIR in Pretoria. He produced a report, which was subsequently edited to produce this brief.

Transportek have also put together a Gravel Road Test Kit (see Annex B) for use with this brief. This kit was demonstrated by them at the Sixth Regional Seminar for Labour-based Practitioners, held in Jinja, Uganda, in 1997. ASIST plans to evaluate the kit during 1999.

List of abbreviations and definitions

AASHTO American Association of State Highway and Transportation Officials. This association adopted a test proposed by the US War Department in 1943, to cater for larger earth moving and compaction equipment. It is now referred to as the AASHTO test.

ASIST Advisory Support, Information Services and Training for labour-based technology.

Atterberg limits Atterberg limits are measured for soil materials passing the No. 40 sieve: the shrinkage limit (SL) is the maximum water content at which a reduction in water content will not cause a decrease in the volume of the soil mass. This defines the arbitrary limit between the solid and semisolid states. The plastic limit (PL) is the water content corresponding to an arbitrary limit between the plastic and semisolid states of consistency of a soil. The liquid limit (LL) is the water content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil.

BLS bar linear shrinkage.

BS British Standard. BS 1377 defines the British Standard compaction test, introduced by R. R. Proctor in 1933. It used a compactive effort which roughly corresponded to that available in the field at the time.

CBR California Bearing Ratio. A measure of soil strength, determined from the load required to penetrate the surface of the compacted soil, expressed as a percentage of a standard value.

Clegg Hammer A simple device utilising a decelerometer, installed in a modified Proctor compaction hammer, to evaluate the stiffness of a material by measuring the deceleration encountered when the falling hammer meets the material.

DCP Dynamic Cone Penetrometer. Apparatus for estimating the *in situ* shear strength of a material by dynamically driving a standard cone through the material.

Grading Coefficient (G_c) A measure of the potential for particle interlock defined by the product of the gravel component of the material (the percentage retained between the 26.5 and 2 mm sieves) and the percentage passing the 4.75 mm sieve.

Maximum dry density (MDD) The maximum dry density which can be achieved under a specified compaction effort at the optimum moisture content.

Optimum moisture content (OMC) The moisture content at which the maximum dry density for any combination of material and compaction effort is obtained. The importance of this is particularly relevant to labour-based projects as the compaction effort using small pedestrian rollers can seldom be equated to the traditional AASHTO and BS compaction efforts. Higher OMCs will often be necessary to achieve maximum density for these efforts.

Oversize index (I_o) The stoniness as defined by the percentage of material larger than 37.5 mm.

Proctor Mr R. R. Proctor was the author of the original BS compaction standard. The compactive effort is supplied by a 2.5 kg hammer with a 50 mm diameter head falling freely from 300 mm above the top of the soil sample.

Rapid Compaction Control Device (RCCD) A simple impact penetrometer which injects a small cone into the material to estimate the shear strength of the material.

Ravelling A process where the surface material of a road is broken down by traffic to form loose material (*e.g.* gravel). The process is likely to occur where there is a deficiency of fine material, low cohesion between particles, poor particle size distribution, and inadequate compaction.

Shrinkage Product (S_p) A measure of the plasticity of the soil defined by the product of the bar linear shrinkage and the percentage passing the 0.425 mm sieve.

vpd Vehicles per day. That is, a count of the number of vehicles passing along a road in one day.

1 Background

The implementation of labour-based construction techniques for unsealed roads is beneficial in that it creates employment opportunities and assists with the development of small contractors whilst upgrading the transportation network in developing countries. Improvement in the techniques utilised during this type of construction project will result in greater cost-effectiveness and better performance of the completed product. The Advisory Support, Information Services and Training (ASIST) programme of the International Labour Organisation (ILO) has taken the lead in this. With funding from the Swedish International Development Cooperation Agency (Sida), ASIST is currently involved in the implementation of innovative technologies on various labour-based road projects in Zimbabwe and in other countries of Sub-Saharan Africa.

During an earlier visit to labour-based projects in progress in Zimbabwe, the Division of Roads and Transport Technology (Transportek) of the CSIR in Pretoria was contracted by ASIST to evaluate the procedures used regarding material selection, testing and control. In the second phase of the contract, the brief was to prepare a short guideline document on the selection and control of borrow materials, and on control of the construction process during labour-based unsealed road projects. Recommendations on the thickness design of the road are also provided.

The guidelines themselves are incorporated as an Annex to this document. The background to the decisions as to what is incorporated in the guidelines, with justification for these decisions, makes up the main text of this Technical Brief.

2 Material specifications

2.1 Recommended specifications

The performance of any unsealed road is primarily a function of the materials from which the road is constructed. It is therefore essential that the best available materials which comply with, or are as close as possible to, the appropriate material requirements be used for construction. These material requirements need, of necessity, to be simply and rapidly determined at low cost to allow sufficient samples to be tested prior to use on the road.

Numerous material specifications have been developed and utilised over time in various countries, which take into account the local material and environmental conditions. Most specifications, however, have been derived from the original AASHTO requirements which are primarily based on theoretical considerations for maximum particle packing of low plasticity materials (the dominant material derived from glacial tills in the northern United States). Experience has shown that materials with low plasticity lack adequate cohesion to resist ravelling, or the formation of corrugations, under traffic.

Regional specifications were subsequently adapted to allow for slightly higher plasticities, but in very few cases was the lower limit for plasticity specified. For this reason, variable success was obtained using the available specifications. Various projects to determine performance-related specifications for unsealed road materials were therefore carried out in South Africa and Namibia during the 1980s and early 1990s (see References 1, 2, 3, and 4). These specifications have recently been evaluated in a number of regions and countries (including Zimbabwe) and have generally been found to be more appropriate than those previously used (and in many cases more appropriate than even those currently used).

The traditional properties used in existing material specifications for unsealed roads are particle size distribution, Atterberg limits, remoulded strength, and aggregate hardness. These are similar to those found by local research to be necessary. All these parameters are critical to the performance of materials in unsealed roads, but the traditional methods of defining and evaluating them are considered to be inappropriate for labour-based projects. This is discussed further in this brief.

The material specifications recommended for the selection of borrow materials for wearing courses for unsealed roads using labour-based construction methods are given in Table 1. These should be the desired specifications for a project. Testing of all potential borrow materials for compliance with these should optimally be carried out during the borrow pit or initial materials evaluation. This should be done by a central laboratory for a Public Authority, or by a commercial laboratory, using traditional test methods, *e.g.* those contained in TMH 1 (see References 6 and 7).

If no central laboratory is available, or if the results from the laboratory are delayed, all the above testing except the soaked CBR can be determined in a simple field 'laboratory' using minimal equipment. If full testing facilities do not exist and if the road is likely to carry less than 50 vehicles per day with less than 10 per cent heavy vehicles, the Shrinkage Product and Grading Coefficient alone can be taken as the preliminary acceptance criteria. The material strength (CBR) can be evaluated during proof rolling trials as discussed in Chapter 3. Full test methods are provided in Chapter 3.

Table 2.1: Material specifications for labour-based road projects

Maximum size (mm)	37.5
Oversize Index (I_o)	Ý 5 %
Shrinkage product (S_p)	100 – 365
Grading coefficient (G_c)	16 – 34
Soaked CBR (%)	$ 15 at 95 % Modified AASHTO density
Treton Impact value (%)	20 – 65

I_o = Percentage retained on 37.5 mm sieve
S_p = Bar Linear shrinkage ´ per cent passing 0.425 mm sieve
G_c = (Per cent passing 26.5 mm - per cent passing 2.0 mm) ´ per cent passing 4.75 mm/100
Treton Impact Value (see Section 3.4.3)

The relationship between the Shrinkage Product and the Grading Coefficient is directly related to the performance as shown in Figure 1, with zones E1 and E2 being the recommended areas for best performance. This Figure shows the predicted performance and the implications (potential problems) of using material not falling within the specified limits.

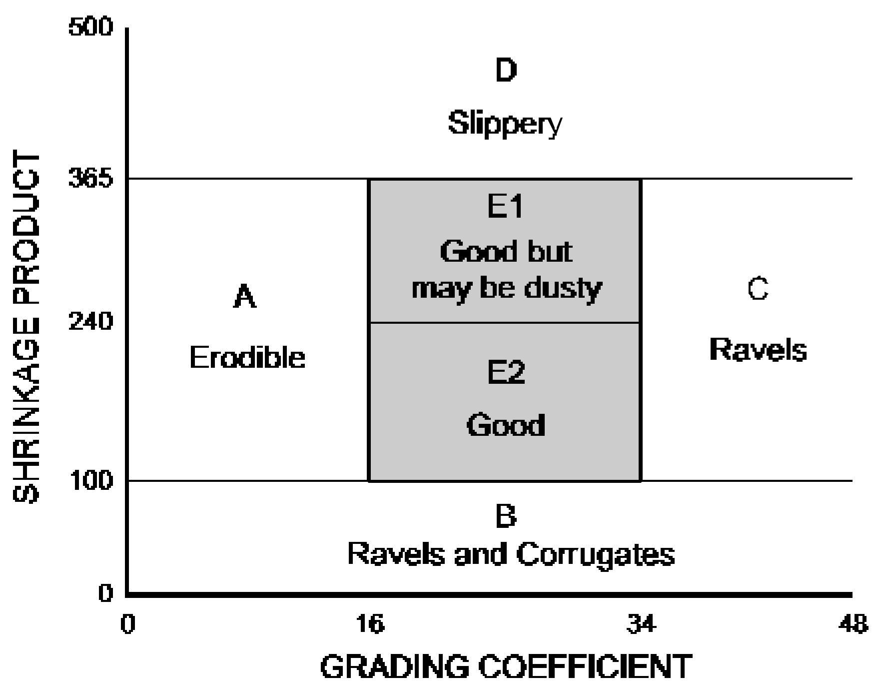

Figure 2.1: Relationship between Grading Coefficient, Shrinkage Product, and performance

3 Borrow material testing

3.1 General

It is essential that, during the initial proposal stage for any project, suitable borrow pits are located, the materials are adequately tested for compliance with the specifications given in Chapter 2, and the suitable borrow areas are carefully delineated in the field. In most cases, this should be carried out by the regional soils laboratory, as far as possible using traditional test methods and equipment as discussed in Chapter 2. Problems have, however, been encountered in the past, with the test results often only becoming available after construction has commenced. The following methods are proposed for control testing of materials during construction, but could also be used to replace or complement the initial borrow investigations where problems with obtaining results in time are encountered.

3.2 Test requirements

Traditional test techniques have been developed, based on the assumption that various basic services and facilities are available. On many labour-based projects, certain simple assumptions, such as that electricity and running water will be available, are invalid. The test techniques and methods summarised in this chapter and in Annex A allow for these. As far as possible, solar energy, local water (preferably potable), and unsophisticated equipment are utilised. It is assumed that everyday objects such as batteries are available.

The specifications discussed in the previous chapter are mostly based on simple tests which can be carried out rapidly on site using minimal equipment. The following parameters should be evaluated:

- Grading
- Shrinkage
- Aggregate hardness
- Material strength.

These tests are carried out as follows, with the complete methods of non-standard tests being presented in Section 3.4.

3.2.1 Grading

The grading requirements for the characterisation of material for unpaved roads are based on only five sieve sizes, that is 37.5 mm, 26.5 mm, 4.75 mm, 2 mm, and 0.425 mm. For the testing, the material needs first to be dried[1], the mass determined, and then the material sieved (manual shaking) through the recommended sieves above with a soft brush

[1] Air drying in direct sunlight is adequate for most materials which are potentially suitable, although the use of a solar oven is recommended.

being used where necessary. The mass of each portion is determined. The oversize index, grading coefficient and percentage passing the 0.425 mm sieve can then be determined. It should be noted that the influence of the hygroscopic moisture content on the parameters determined is negligible. The fraction passing the 0.425 mm sieve should be retained for shrinkage testing.

3.2.2 Shrinkage

The bar linear shrinkage test is carried out on the fraction passing the 0.425 mm sieve. The material should be moistened until it is at or very near the liquid limit (this can be checked with a simple fall-cone device (see Section 3.4)), placed in the mould, and oven-dried at 105°C until all shrinkage has stopped. The length of the sample is then measured and the percentage shrinkage calculated. It is recommended that the sample is dried for at least 12 hours (overnight if not done in a solar oven), but experience has shown that this can take as little as four or five hours, depending on the soil. The length of time necessary can be checked by drying to constant mass. However, preliminary research has shown that air-drying of samples is not effective for repeatable results.

3.2.3 Aggregate hardness

Aggregate hardness measurements are necessary to identify those materials which will disintegrate under rolling or traffic, as well as those which are excessively hard and will result in a rough road if too much of this type of material is included. The Treton test is used to determine this. The Treton impact value is determined by means of a simple impact hammer action on a single sized sample (obtained during the sieve analysis). This test is unnecessary if the road is unlikely to carry many buses or heavy vehicles (more than two per day) or if the material lacks a significant proportion of medium to coarse gravel (< 15 per cent retained on a 16 mm sieve).

3.2.4 Material strength

Material strength is an indication of the capacity of the material to support the wheel loads of the traffic using the road. The traditional method for determining this property is the soaked California Bearing Ratio (CBR) test. This test is routinely carried out in a central or typical site laboratory but is expensive to set up, requires a large amount of equipment, and is relatively time consuming.

As an alternative, it is considered more practical to first carefully compact a sample of the material, at the estimated optimum moisture content, to the required thickness on a subgrade prepared to the same standard as that which will be used in construction. Then to measure the resistance to penetration with a Dynamic Cone Penetrometer (DCP) (see Figure 2), a Rapid Compaction Control Device (RCCD) (see Figure 3) or a Clegg Hammer. The moisture content at the time of testing (assumed to be at or about OMC) should be taken into account (See Section 4.2.1). Acceptable values of penetration for the DCP and RCCD are given in Table 3.1.

Table 3.1: Penetration rates of DCP and RCCD for equivalent soaked CBR values of 15 % (tested at OMC)

Apparatus	Penetration rate	Penetration (3 blows)	Penetration (20 blows)
	(mm/blow)	*(mm)*	*(mm)*
DCP	Ý 5	Ý 15	Ý 100
RCCD	Ý 9	Ý 27	—

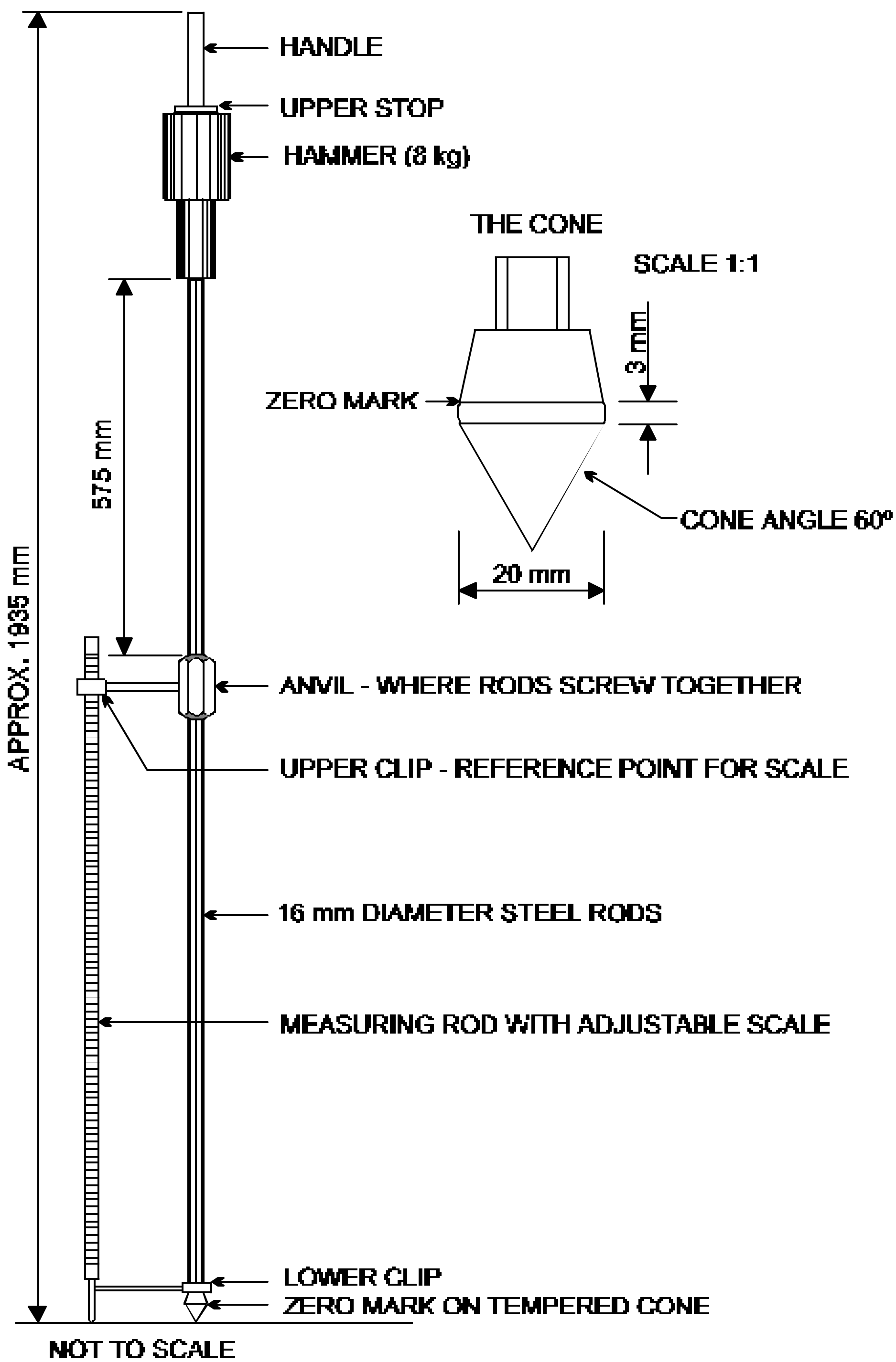

Figure 3.1: DCP test apparatus

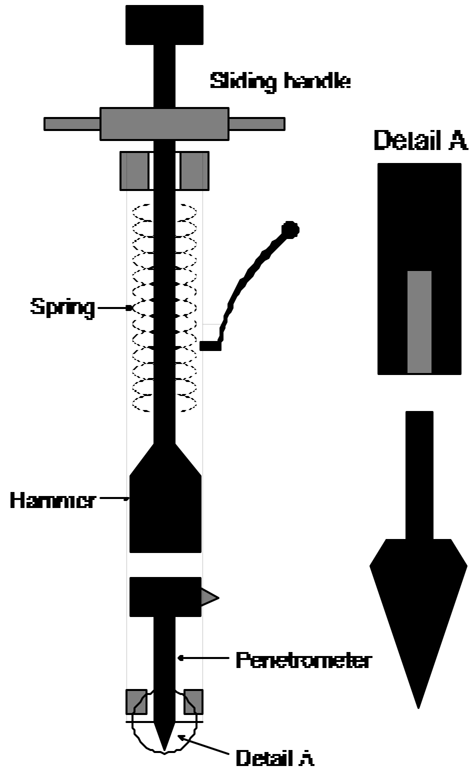

Figure 3.2: Diagram of RCCD device

The RCCD is recommended for use since the test is simpler and quicker. The apparatus is more robust (only periodic calibration of the spring is necessary), but less bulky than that required for the other two methods of control, and it has less operator variability. More tests per job lot (day's production) can be carried out more economically with the RCCD than with the other methods. However, the DCP penetration rates given in Table 3.1 can also be used for material characterisation and control purposes.

Selection of materials based on the specified G_c and S_p will in most cases exclude those which are likely to have insufficient CBR strength.

3.3 FREQUENCY OF LABORATORY TESTING

The frequency of testing of borrow pits needs to strike a balance between cost and time and statistical validity of the results. It is proposed that, even for labour-based projects, the location of borrow materials and borrow-pit testing should preferably be done according to traditional methods. If full laboratory facilities are not available, the methods described in this report can be substituted.

The frequency of testing will depend on the variability of the material: the more homogeneous the material the less the amount of testing necessary for statistical validity of the results. Unless proper testing of the borrow materials is carried out prior to commencement of the project, it is usually not possible to quantify the variability in advance of construction. For projects of this nature it is thus necessary to test samples from at least five locations per borrow pit (covering the full depth of the layer to be used) in order to quantify the variability. The sample locations should be randomly selected within the pit. This variability is used as an indication of the variation to be expected within the borrow pit, and for a simple process control technique during the construction operation.

It is recommended that at least ten RCCD or DCP tests (at least two per square metre) be carried out at points selected in a stratified random pattern when compaction is tested during proof rolling.

3.4 FULL TEST METHODS

3.4.1 Sieve analysis for grading coefficient

SCOPE

In this method, a soil, sand or gravel sample is separated by dry sieving for determination of the grading coefficient and to prepare fine material for the bar linear shrinkage test.

APPARATUS

- Sheet of canvas 1 metre by 1 metre for coning and quartering of the material
- The following test sieves: 37.5 mm, 26.5 mm, 4.75 mm, 2 mm and 0.425 mm with pan and cover
- Balance with pan, accurate to 1 g, to weigh up to 5 kg
- Various pans of 250 to 300 mm diameter and 20 mm deep
- Drying oven (Solar) to maintain a temperature between 105 and 110°C
- Various stiff brushes
- Thermometer (0 to 120°C)

METHOD

Size of sample The size of the test sample should be such that at least 100 g of material passes the 0.425 mm sieve, but not less than 2 kg in all. This should be prepared from a bulk sample of at least 5 kg by coning and quartering on the canvas sheet.

Preparation of the sample Air-dry the sample until it is friable and particles separate with ease. If the sample is still too wet, it should be dried in an oven at a temperature not exceeding 50°C.

Dry sieving Dry sieve the material as follows: shake the material through each sieve in turn, starting at the 37.5 mm sieve, until further shaking results in minimal additional material passing each sieve. The larger particles (> 4.75 mm) should be brushed with a stiff bristle brush to remove all fines adhering to them. Determine the mass of the soil fines (< 0.425 mm) and transfer these to a marked paper bag. It is recommended that they are dried in a solar oven prior to being weighed but, if this will delay the testing, this step may be omitted since the use of air-dried weights will not affect the results unduly.

Determination of the particle size distribution The masses of the individual fractions retained on each sieve should be determined (preferably after being oven-dried but after air-drying if necessary). The masses of these fractions should be determined to the nearest 1 g. Record the masses retained on each sieve and that of the material passing the 0.425 mm sieve.

CALCULATIONS

1 Calculate the total mass of material as the sum of the masses retained on the individual sieves as well as of that passing the 0.425 mm sieve.

2 Calculate the cumulative percentages passing each sieve (by mass of the total dry sample) accurately to the nearest 1 per cent. All results should be normalised to 100 per cent passing the 37.5 mm sieve by multiplying the percentage passing each sieve by the percentage passing the 37.5 mm sieve (P37) divided by 100. If 100 per cent passes the 37.5 mm sieve, this step is not necessary.

3 Calculate the grading coefficient. This is the percentage material passing the 26.5 mm sieve and retained on the 2 mm sieve, multiplied by the percentage passing the 4.75 mm sieve, as follows:

$$GC = (P26 - P2) \times P475/100$$

where *P26 = cumulative percentage passing the 26.5 mm sieve*
P2 = cumulative percentage passing the 2 mm sieve
P475 = cumulative percentage passing the 4.75 mm sieve

3.4.2 Determination of the linear shrinkage of soils

SCOPE

This method covers the determination of the linear shrinkage of soil when it is dried from a moisture content equivalent to the liquid limit to the oven-dry state.

Definition
The linear shrinkage of a soil, for the moisture content equivalent to the liquid limit, is the decrease in one dimension, expressed as a percentage of the original dimension of the soil mass, when the moisture content is reduced from the liquid limit to an oven-dry state.

APPARATUS

- A shrinkage mould made from 10 mm stainless steel bar with internal dimensions of 150 mm ± 0.25 mm long × 10 mm ± 0.25 mm wide × 10 mm ± 0.25 mm deep, and open on two sides (see Figure 3.3)
- A stainless steel plate to fit under the shrinkage mould

- A small thick-bristle paint brush, about 5 mm wide
- Silicone lubricant spray (*e.g.* Q20 or WD 40)
- A spatula with a slightly flexible blade about 100 mm long and 20 mm wide
- A solar drying oven
- A pair of dividers and a millimetre scale
- A standard cup, drop cone and guide-tube for estimating the liquid limit
- A thermometer (0 to 120 °C).

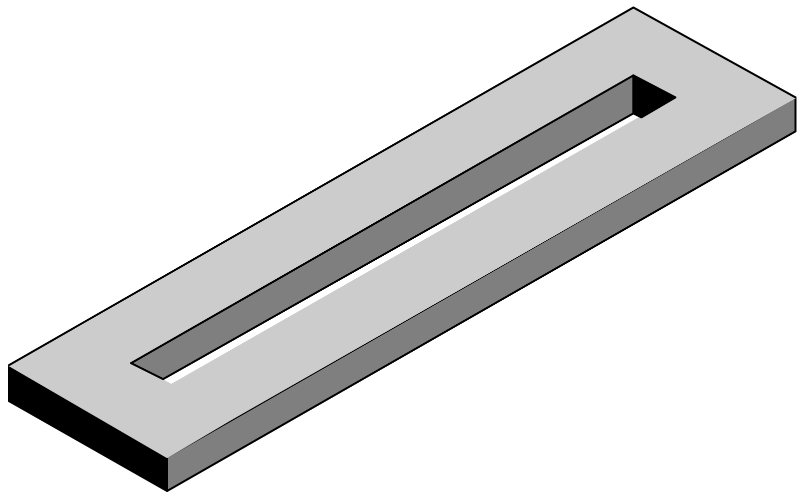

Figure 3.3: Mould for bar linear shrinkage test

METHOD

Waxing the mould The interior of a clean, dry shrinkage mould is sprayed evenly with the silicone lubricant

Filling the mould The moisture content at which the test is carried out must be as close to the liquid limit as practically possible. A simplified drop-cone device based on the British Standard liquid limit method is used to ensure that the moisture content is correct. Sufficient material to fill the cup provided should be mixed up and placed evenly in the cup to a level between 2 and 5 mm below the rim of the cup. The cone should be placed in the guide tube on the surface of the soil in the cup and allowed to penetrate for five seconds. The cone should penetrate to a depth of 20 mm, equivalent to the calibration mark on the cone. If the penetration is below this mark, the material is too dry and additional water is required. The material would then need thorough re-mixing before the penetration test is repeated. If the penetration is too high (*i.e.* the cone sinks into the material to a depth above the calibration mark), the material is too wet and needs to be dried out by mixing in sunlight until repetition of the penetration test gives a result within the defined limits.

The lubricated mould should be placed on the plate provided, and one half should be filled with the moist soil by taking small pieces of soil on the spatula and pressing the soil down against one end of the mould. Then work along the mould until the whole side is filled and the soil forms a diagonal surface from the top of one side to the bottom of the opposite side (see Figure 3.4(a)).

The mould is now turned round and the other portion is filled in the same manner (see Figure 3.4(b)). The hollow along the top of the soil in the mould is now filled so that the soil is raised slightly above the sides of the mould (see Figure 3.4(c)). The excess material is removed by drawing the blade of the spatula once only from one end of the mould to the other. The index finger is pressed down on the blade so that the blade moves along the sides of the mould (see Figure 3.4(d)). During this process the wet soil may pull away from the end of the mould, in which case it should be pushed back gently with the spatula.

NB The soil surface should on no account be smoothed or finished off with a wet spatula.

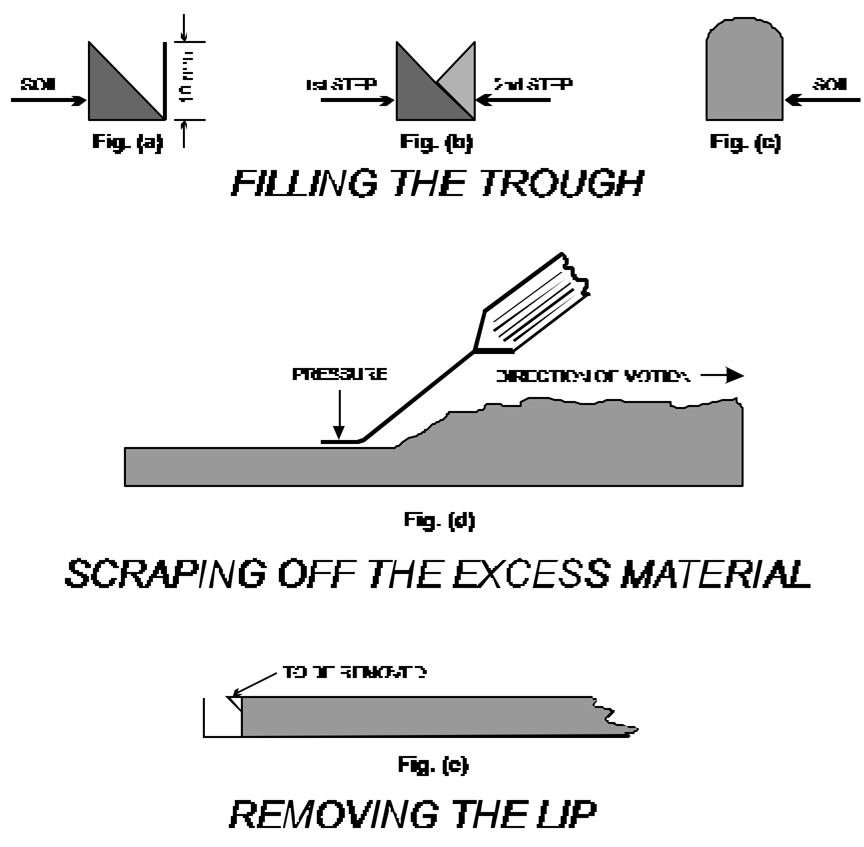

Figure 3.4: Preparation of material for shrinkage test

Drying the wet material The mould with wet material is now placed in the solar oven and dried at a temperature of between 105 and 110°C (the lid may need to be partially opened to maintain a reasonably constant temperature) until no further shrinkage can be detected. As a rule, the material is dried out for 12 hours, although three hours should be sufficient time in the oven. The mould (with the material) is taken out of the oven and allowed to cool in the air.

Measuring the shrinkage It may be found that the ends of the dry soil bar have a slight lip or projecting piece at the top. These lips must be removed by abrading with a sharp, narrow spatula, so that the end of the soil bar is parallel to the end of the mould (see Figure 3.4 (e)). If the soil bar is curved, it should be pressed back into the mould with the fingertips so as to make the top surface as level as possible.

The loose dust and sand removed from the ends, as well as any loose material between cracks, should be emptied out of the mould by carefully inverting it whilst the material is held in position with the fingers. The soil bar is then pressed tightly against one end of the mould. It will be noticed that the soil bar fits better at one end than at the other end. The bar should be pressed tightly against the end at which there is a better fit. The distance between the other end of the soil bar and the respective end of the mould, is measured by means of a good pair of dividers, measuring on a millimetre scale, to the nearest 0.5 mm, and recorded.

CALCULATIONS

The bar linear shrinkage (BLS) is calculated as follows:

$BLS = LS \times 0.67$ (%)

where LS = linear shrinkage in mm.

NOTES

After being tested, the soil bar should be examined to ensure that the corners of the mould were filled properly and that no air pockets were contained in the soil bar. If there are air pockets, the test should be repeated.

3.4.3 The determination of the Treton impact value of aggregate

SCOPE

The Treton value is an indication of the resistance of aggregate to impact. The aggregate is subjected to ten blows of a falling hammer and the resulting disintegration is measured in terms of the quantity passing the 2 mm sieve, which is then expressed as a percentage of the mass of the test sample. This is called the Treton value.

APPARATUS

- A Treton apparatus consisting of a base plate, anvil, cylinder, and a hammer weighing 15 kg ± 50 g (see Figure 3.5). The base plate should be placed on a firm concrete block.
- The following test sieves, all 200 mm in diameter: 19.0 mm, 16.0 mm and 2 mm. The bigger sieves should be made of perforated plate and the 2 mm sieve of wire mesh.
- A balance to weigh up to 200 g, accurate to 1 g.

METHOD

From the field sample, screen out a sufficient quantity (at least 200 g) of the fraction between 19 mm and 16 mm (see Note (i)). Select a sample of 15 to 20 of the most cubical pieces, so that their total mass (in grams) will be as close as possible to 50 times the relative density of the aggregate in grams (it is not necessary to determine the relative density. An estimate will be satisfactory (2.65 for granitic and sedimentary materials and 2.9 for dark basaltic and metamorphic materials)). Weigh the sample accurately to 1 g, and place the particles as evenly spaced as possible on the anvil in such a manner that their tops are approximately in the same horizontal plane.

Place the cylinder over the anvil and tighten the clamp screws. Place the hammer in the cylinder so that the top of the hammer is level with the top of the cylinder and let it drop ten times from this position.

Remove the cylinder, and sieve all the aggregate on the anvil and base plate thoroughly through a 2 mm sieve. Weigh the aggregate retained on the sieve to the nearest 1 g, and record the mass. The test should be carried out in triplicate (see Note (ii)).

CALCULATIONS

Calculate the Treton value to the first decimal place as follows and report to the nearest whole number:

Treton value = $(A - B)/A \times 100$

where A = *the mass of the stone particles before tamping (g)*
B = *the mass of the stone particles retained on the 2 mm sieve after tamping (g).*

NOTES

(i) If the aggregate is noticeably variable as regards type or hardness, each type should be tested and reported separately. In this case an estimate should be made of the percentage of each type and a weighted average determined.

(ii) The Treton value, as reported, should be the average of three determinations. If any individual result differs from the others by more than five units, further tests should be carried out.

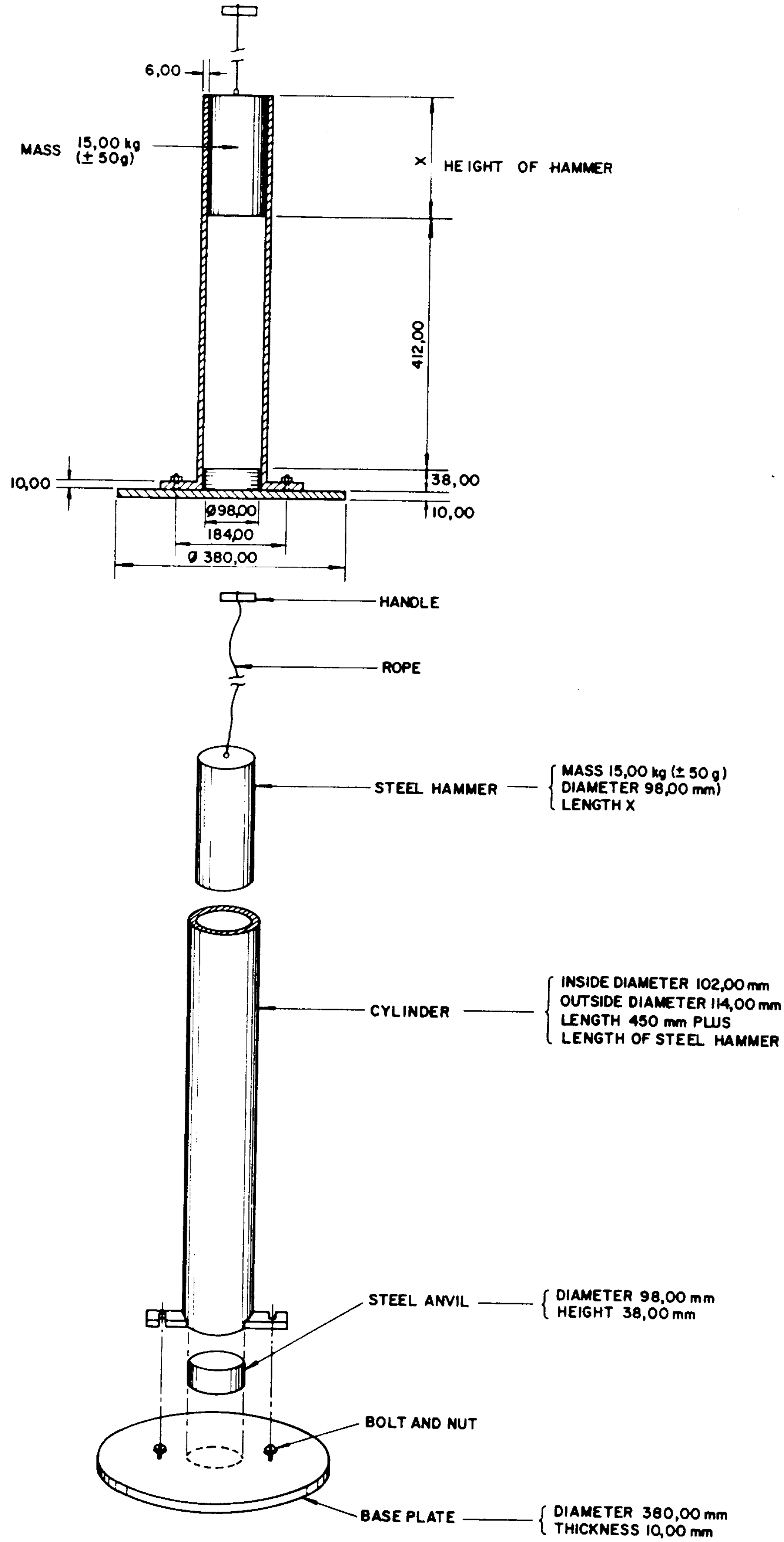

Figure 3.5: Treton apparatus

4 Construction quality assurance testing

4.1 MATERIAL TESTING AND CONTROL

The properties of the material should be tested on a regular basis during construction to ensure that they do not differ from the accepted specification. For control testing purposes, only the grading coefficient and shrinkage product need be tested.

This testing shall be done daily to ensure that the material to be used for the following job lot complies with the specifications. It is recommended that samples of the material to be used the next day (or for the next job lot if a weekend follows) be taken during the morning and tested so that the material can be approved first thing in the morning before use. The test techniques are such that this is possible. The individual results of the borrow pit testing should be plotted on Figure 2.1 with the mean and standard deviations of the two parameters which can be used to define a rectangle. At least 90 per cent of the routine daily test results should plot in this rectangle as work in the borrow pit progresses. The test results should be plotted on this figure on an ongoing basis. If there is a trend to move out of the rectangle towards the limits of the E1/E2 block (in Figure 2.1), this would be indicative of a change in the material properties. Additional testing should then be carried out to determine the cause of this and to identify remedial action, *e.g.* blending of different materials, redefinition of the boundaries of the borrow pit, or adjustment of the depth of excavation, *etc.*

4.2 CONSTRUCTION QUALITY ASSURANCE

A number of factors should be controlled during construction. These include:

- Moisture content
- Thickness
- Compaction
- General finish.

4.2.1 Moisture content

One of the principal factors in the construction process, and which affects the final compaction, is the moisture content. In most soil materials the natural variation in optimum moisture content (OMC) is wider than the limits around OMC permitted for successful compaction. In addition, the actual process of adding and mixing water to soil materials, particularly in labour-based projects, often leads to significant variation of the moisture content within the material. In addition, most moisture content determinations are slow (except for nuclear methods, but these are often unreliable for moisture contents of natural gravels) and the results are frequently only available after compaction is completed. For this reason, the manual control of the moisture after laboratory calibration of the "feel" of the material at various moisture contents at and around optimum is considered the most practical and effective solution.

In most cases, the test techniques for moisture content render the results practically meaningless in the context of labour-based construction. The process of moistening the material, (whether this is done in the borrow-pit or on the road) is not discussed in this report.

The control of moisture during construction should be carried out visually by squeezing a sample of the material as tightly as possible in the hand. The material should be moist enough to stick together when squeezed without any visible sign of free water on the surface. If the material disintegrates, it is too dry for compaction. If free water is ejected or if the soil sticks to the hand, it is too wet. If the "sausage" formed by squeezing in the hand is squeezed diametrically between the thumb and forefinger, it should break with some crumbling. It should not break by deformation under the finger pressure, nor should there be excessive crumbling. It should be noted that non-cohesive soils behave differently, but that all materials for wearing courses should have some cohesion. The above technique is considered most practical and suitable for the purpose. If possible, this method should be practised in the laboratory with material at various known moisture contents, and correlated with the laboratory determined optimum moisture content to "get the feel" prior to commencement of compaction.

It is currently difficult to correct the field strength for any deviation from the expected moisture content at the time of testing. The following approximate model is based on the combination of various parameters (soaked CBR (CBR_s) and optimum moisture content (OMC)) and models. It has been developed to assist with evaluating whether the results are in the right range for the DCP and RCCD penetration rates (DN_c and $RCCD_c$) immediately after compaction at compaction moisture content (CMC):

$$DN_c = 0 \cdot 144 \left(e^{-1 \cdot 33 \frac{CMC}{OMC}} \right) \left(CBR_s^{0 \cdot 46} \right)^{-0 \cdot 787}$$

$$RCCD_c = 0 \cdot 0735 \left(e^{-1 \cdot 33 \frac{CMC}{OMC}} \right) \left(CBR_s^{0 \cdot 46} \right)^{-0 \cdot 775}$$

4.2.2 Thickness

It is important that the thickness of the material be closely controlled. This should be controlled prior to compaction, with allowance for the bulking factor. Spreading of the material should be as consistent as possible to ensure that all material is placed at a similar loose density. The bulking factor is usually between 25 and 35 per cent, depending on the gradation of the material and on the compaction effort, but this should be determined accurately during the initial proof rolling of the material.

Control of the thickness during construction is carried out by inserting a calibrated probe (Figure 4.1) through the uncompacted material to confirm that the thickness prior to compaction is equivalent to the required final layer thickness plus a correction for bulking. The bulking factor should be determined during the proof rolling by measurement of the thickness before and after rolling. It can also be estimated by comparison of the mass of a known volume (best done in a large measuring cylinder) with the maximum dry density of the material determined in the laboratory. In most cases a bulking value of 30 to 35 per cent may be assumed. One advantage of knowing the bulking factor accurately is that this can be used to ensure that adequate compaction has been achieved by monitoring the initial and final thickness of the layer.

Thickness before compaction = design thickness $\times$ (1 + BF (%) / 100)

where BF is the percentage bulking factor for the material.

4.2.3 Compaction

The compaction achieved in the field is arguably the most important aspect of the construction process. It is neither economically nor practically possible to determine sufficient densities on labour-based projects for construction quality control, to take into account the natural variability of the material. It is thus recommended that a simple device such as the Rapid Compaction Control Device (RCCD) or DCP be used for this purpose. Both tests are quick and repeatable and many tests can be done at little cost.

Should the test results show up areas which are unacceptable, the reasons for this should be investigated. Poor results can be attributed to the use of material that is too wet, material that has not received adequate compaction effort, or to the presence of a pocket of poor quality material. The actual cause should be identified and corrective action taken. This may involve scarifying and drying out prior to recompaction if the material is too wet, additional compaction if necessary, or replacement of poor material where appropriate.

A simple method of sand replacement density determination can be carried out, but it is difficult to relate this to a standard for the evaluation of relative compaction in highly variable natural materials. To determine relative compaction, the density in the road should be compared with the actual laboratory maximum dry density (MDD) for that material. This would require an MDD test to be done on the identical material tested *in situ*. This is neither practical nor economical.

4.2.4 Visual inspection

It is imperative that supervisors are trained to carry out a comprehensive visual inspection of the completed layer prior to excessive drying out of the material. This inspection should be carried out during the latter part of the shift prior to demobilisation of staff and plant for the day. It should be extremely thorough and should cover the total job lot completed in the shift. During this inspection, large stones, excessively moist areas, poorly compacted areas, bumps and depressions, areas of thin material, material segregation, *etc*. should be located and the appropriate remedial action taken.

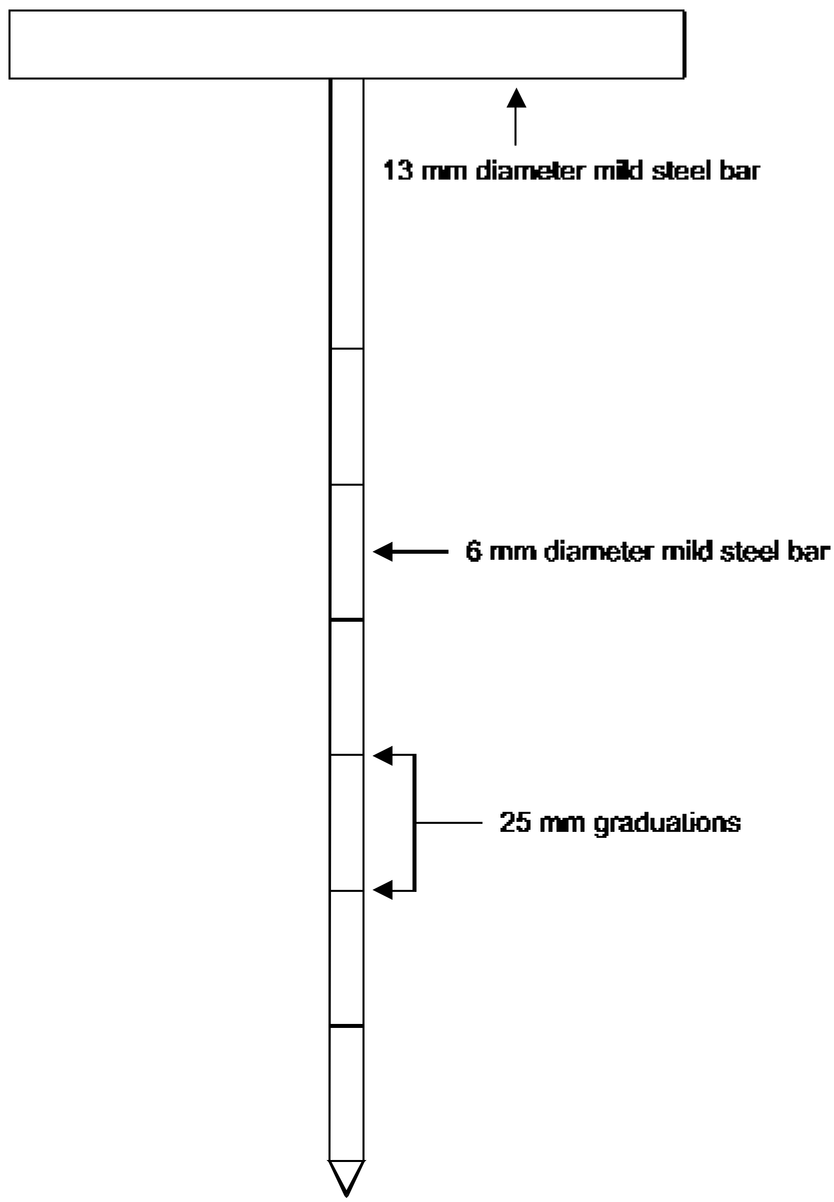

Figure 4.1: Thickness probe

5 Thickness design

Considerable debate has been held and continues to be held regarding the need for a full structural design for unsealed roads. The fact is that wearing courses seldom fail as a result of punching into the subgrade (*i.e.* shear failure of either the wearing course or subgrade material). Failure is typically either the result of continued slippage of the vehicle tyre against the soil when a high moisture content prevails (lack of frictional resistance leading to plastic failure) resulting in settlement of the tyre into the material; or shear failure of the upper portion of the wearing course with lateral displacement. The former situation is confirmed by the fitting of chains to a vehicle wheel to increase this friction which restores passability to the vehicle without excessive additional deformation of the wearing course. The latter situation is manifested by ruts in the wearing course with lateral displacement of the wearing course material. Only when the wearing course becomes excessively thin does shearing of the underlying subgrade material become possible when this is soaked.

The thickness design should take into account the fact that most deformation which may occur in unpaved roads is rectified during routine maintenance, and that with time, all roads lose material through environmental factors and traffic wear. It is thus necessary in terms of thickness design to allow for these two aspects and for a minimum remaining thickness to prevent the subgrade being exposed at the surface.

The rate of gravel loss under traffic is typically greater than that resulting from environmental influences and is mostly related to traffic volume. Other factors such as climate, material properties and, to a lesser extent, geometrics affect the rate of gravel loss. As for most roads, the primary design criterion should be the life before major maintenance (regravelling) is required.

For roads carrying less than 100 vehicles per day (vpd) on a subgrade material with a minimum soaked CBR of 3 per cent, a wearing course 150 mm thick of material with a minimum soaked CBR value of 15 will provide an adequate structure. In areas where the subgrade (or wearing course) is likely to become soaked (*i.e.* to be under standing water for more than 24 hours) resulting in the CBR of the subgrade and base decreasing to less than 3 or 15 per cent respectively, the application of two layers of wearing course quality material (each 150 mm thick) is recommended. The standard thickness of 150 mm of material as proposed in the specification has been shown to be adequate to resist excessive deformation under most conditions, even persistent rainfall, provided the shape of the road is such that excessive ponding on the road structure cannot occur. The necessity for proper maintenance of unsealed roads cannot be overemphasised. Extended periods of poor or no maintenance will always result in significant deterioration of the road, loss of gravel, and in extreme difficulty in restoring the condition of the road.

In addition to the subgrade being compacted to a high density to provide a platform for compaction of the wearing course, it is equally important that the subgrade density is such that loss of wearing course by being punched into the subgrade or by taking up significant rutting which may occur in the subgrade, is minimised. This type of “gravel loss” is typically made up during routine maintenance but results in a premature need for regravelling.

Thinner layers (not less than 100 mm) can be placed to reduce the cost of material and construction, but in the long term this is generally not cost-effective. Once about 50 to 75 mm of material has been lost, the wearing course will need to be replaced, resulting in a premature regravelling operation. Layers thicker than 150 mm are not recommended as it then becomes difficult to obtain adequate compaction, particularly through the full depth, but also at the surface. It should be remembered that, as the layer of uncompacted material becomes thicker, the distance from the firm platform required to compact against becomes greater and more energy is absorbed by the loose material. This is particularly relevant when light rollers are utilised.

If the traffic is likely to be higher than 100 vehicles per day, including more than ten heavies, it may be necessary to increase the thickness of the wearing course over those areas with low subgrade strengths (soaked CBR of less than 5 per cent); or else to include a 150 mm thick selected layer with a minimum soaked CBR of 10 per cent. Recommended thicknesses and wearing course material strengths are summarised in Table 5.1.

Table 5.1: Recommended thicknesses and material strengths for different subgrade and traffic conditions

Subgrade CBR	Traffic (vpd)	Layers/thickness	Min. soaked CBR
> 3	< 100	150 wearing course	15
< 3	< 100	150 wearing course 150 selected layer	15 5
< 5	> 100 (> 10% heavy)	150 wearing course 150 sub-base	15 10

It is possible to scientifically and mechanistically design the layer thickness in which aspects, such as subgrade strength and stiffness, wearing course material strength and stiffness, annual gravel loss through traffic and environmental factors, traffic compaction, *etc*., are taken into account. However, these all require additional testing and environmental data, much of which are not available in remote locations. In general, the design proposed above will, with routine maintenance, provide a road which will last between 5 to 10 years without requiring major maintenance other than periodic grader blading.

6 Conclusions and recommendations

6.1 Conclusions

The construction of labour-based unsealed roads, if done with the correct materials and appropriate quality assurance, will result in roads which will perform as well as those built conventionally using plant-based methods. Particular attention should be paid to material selection and control, as well as to construction control.

6.2 Recommendations

It is recommended that these guidelines be implemented and augmented where necessary. Although every project will have certain unique characteristics and problems, these guidelines are seen as a generally applicable solution for routine labour-based construction.

As a consequence of this assignment, Transportek is currently producing a labour-based construction test kit which will include all the necessary testing and analysis equipment to carry out the testing recommended in this Brief. Copies of the test methods to meet the requirements of these guidelines will also be included (a summary of the contents of the kit is provided in Annex B). It is recommended that this be presented at appropriate venues and seminars.

As these techniques are applied, any problems which may be encountered in practice, and improvements in the methods identified with experience, can be incorporated into the Guidelines.

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WHERE THERE IS NO SOILS LAB!

Material selection and tests for labour-based gravel roads

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1 Introduction

These guidelines describe a step-by-step method of evaluating borrow materials for use as the wearing course in labour-based unsealed roads, and for ensuring that the quality of the construction is appropriate.

The guidelines assume that all the required testing apparatus has been provided for the project and that potable water and normal day-to-day requirements such as batteries are available. They also assume that supervisors have been given adequate training in the use of these guidelines.

It will also be noted that the test methods given in this section are a simplification of those described in the main document, for ease of use in the field. The effect of this simplification is considered to be insignificant in terms of the repeatability and reproducibility of the tests and their implications on the use of the materials.

2 Material properties

2.1 MATERIAL GRADING

In order to achieve good particle interlock from the wearing course material, a good particle size distribution is necessary. This is defined by the Grading Coefficient. In addition, it is important to limit the quantity of large stones in the material by specifying the Oversize Index. These parameters are simply determined as described below.

2.1.1 Determination of the grading coefficient and oversize index

SCOPE

In this method, a soil, sand or gravel sample is separated by dry sieving for determination of the grading coefficient and to prepare fine material for the bar linear shrinkage test.

APPARATUS

- Sheet of canvas 1 metre by 1 metre for coning and quartering material
- The following test sieves: 37.5 mm, 26.5 mm, 4.75 mm, 2 mm and 0.425 mm with pan and cover
- Balance with pan, accurate to 1 g, to weigh up to 5 kg
- Various pans of 250 to 300 mm diameter and 20 mm deep
- Drying oven (Solar) to maintain a temperature between 105 and 110°C
- Various stiff brushes
- Thermometer (0 to 120 °C)

METHOD

STEP 1 A test sample such that at least 100 g of material passes the 0.425 mm sieve, but not less than 2 kg in total, should be prepared from a bulk sample of at least 5 kg by coning and quartering using a canvas sheet.

STEP 2 Air dry the sample until it is friable and the particles can be separated with ease. If the sample is still too wet, it should be dried in a solar oven at a temperature not exceeding 50°C.

STEP 3 Dry sieve the material as follows: shake the material through each sieve (37.5, 26.5, 4.75, 2.0 and 0.425 mm) in turn, starting at the 37.5 mm sieve, until further shaking results in minimal additional material passing the sieve. Brush the larger particles (> 4.75 mm) with a stiff bristle brush to remove all fines adhering to these. Determine the mass of the soil fines (< 0.425 mm) and transfer them to a marked paper bag for subsequent testing. (It is recommended that they be dried in a solar oven prior to being weighed, but if this will delay testing, this step may be omitted, since the use of air-dried weights will not affect the results unduly.)

STEP 4 The masses of the individual fractions retained on each sieve should be determined (preferably after being oven-dried but after air-drying if necessary). The masses should be determined to the nearest 1 g. Record the masses retained on each sieve and that passing the 0.425 mm sieve. A form for recording and calculating the results is included at the end of this document.

RESULTS

Calculate the total mass of material as the sum of the fractions retained on the individual sieves as well as that passing the 0.425 mm sieve. Determine the percentage of each of these as a percentage of the total mass of (dry) material tested.

Calculate the cumulative percentages passing each sieve to the nearest 1 per cent by summing the percentage passing each sieve, starting from the finest sieve. All results should first be corrected for the percentage retained on the 37.5 mm sieve by multiplying the percentage passing each sieve by the percentage passing the 37.5 mm sieve (P37) divided by 100. If all the material passes the 37.5 mm sieve, this step is not necessary.

Calculate the **grading coefficient** as the percentage material passing the 26.5 mm sieve and retained on the 2 mm sieve (P26 and P2 respectively) multiplied by the percentage passing the 4.75 mm sieve (P475) using the following formula:

$$GC = (P26 - P2) \times P475/100$$

The **oversize index** is defined as the percentage of the total material retained on the 37.5 mm sieve.

INTERPRETATION

The limits for the grading coefficient are shown in Figure A.3 and should be between 16 and 34. A maximum oversize index of 5 per cent is permitted to retain a good riding quality over time.

2.2 MATERIAL COHESION

In order to minimise the loosening of the surfacing material and the formation of corrugations, it is necessary that the materials should have some plasticity. This is determined using the bar linear shrinkage test described below by measuring the linear shrinkage of a soil dried from a moisture content equivalent to the liquid limit to the oven-dry state.

2.2.1 Determination of the linear shrinkage of soils

SCOPE

This method covers the determination of the linear shrinkage of soil when it is dried from a moisture content equivalent to the liquid limit to the oven-dry state.

Definition *The linear shrinkage of a soil for the moisture content equivalent to the liquid limit, is the decrease in one dimension, expressed as a percentage of the original dimension of the soil mass, when the moisture content is reduced from the liquid limit to an oven-dry state.*

APPARATUS

- A shrinkage mould made from 10 mm stainless steel bar with internal dimensions of 150 mm ± 0.25 mm long × 10 mm ± 0.25 mm wide × 10 mm ± 0.25 mm deep, and open on two sides (see Figure 3.3)
- A stainless steel plate to fit under the shrinkage mould
- A small thick-bristle paint brush, about 5 mm wide
- Silicone lubricant spray (*e.g.* Q20 or WD 40)
- A spatula with a slightly flexible blade about 100 mm long and 20 mm wide
- A solar drying oven capable of maintaining a temperature of 105 to 110°C
- A pair of dividers and a millimetre scale
- A standard cup, drop cone and guide-tube for estimating the liquid limit
- A thermometer (0 to 120 °C).

METHOD

STEP 1 The interior of a clean, dry shrinkage mould is sprayed evenly with the silicone lubricant.

STEP 2 The fines (*i.e.* the fraction passing the 0.425 mm sieve) saved during the grading analysis are used for this test. Add water to the fines and mix thoroughly until the consistency is at the liquid limit. The drop-cone device is used to ensure that this initial moisture content is correct. Sufficient material to fill the cup provided should be mixed up and placed evenly in the cup to a level between 2 and 5 mm below the rim of the cup. The cone should be placed in the guide tube on the surface of the soil in the cup and allowed to penetrate for 5 seconds. The cone should penetrate to a depth of 20 mm, equivalent to the calibration mark on the cone. If the penetration is below this mark, the material is too dry and additional water is required. The material would then need thorough re-mixing before the penetration test is repeated. If the penetration is too high (*i.e.* the cone sinks into the material to a depth above the calibration mark), the material is too wet and needs to be dried out by additional mixing until repetition of the penetration test gives a result within the defined limits.

STEP 3 The lubricated mould should be placed on the plate provided and one half should be filled with the moist soil by taking small pieces of soil on the spatula and pressing the soil down against one end of the mould and working along the mould until the whole side is filled and the soil forms a diagonal surface from the top of one side to the bottom of the opposite side (see Figure A1(a)).

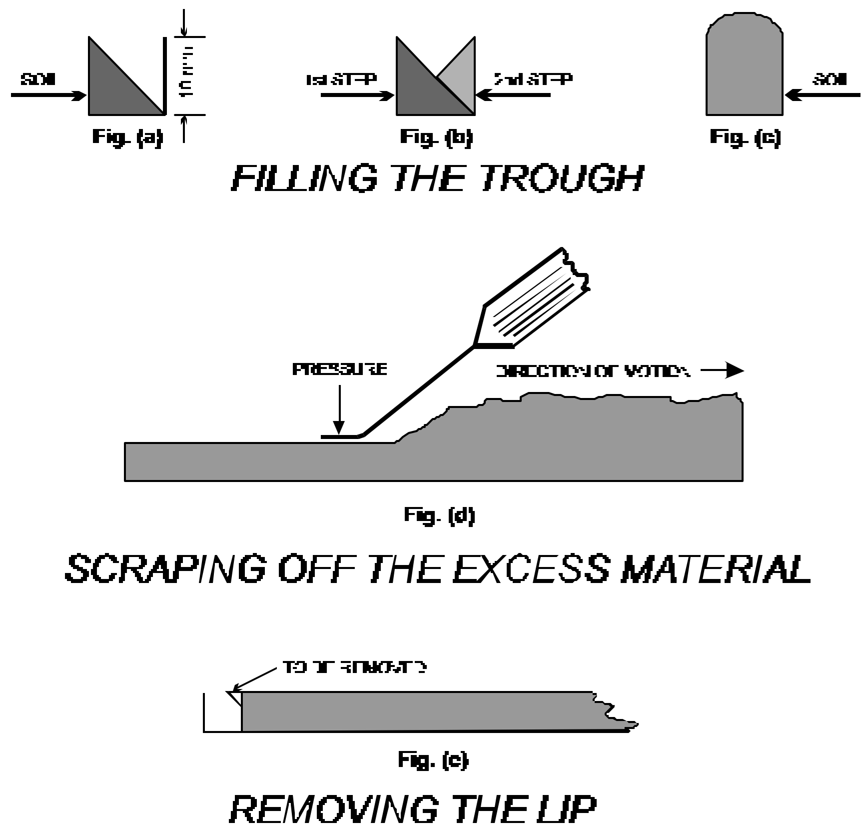


Figure A1: Preparation of material for the linear shrinkage test

The mould is now turned round and the other portion is filled in the same manner (see Figure A1 (b)). The hollow along the top of the soil in the mould is now filled so that the soil is raised slightly above the sides of the mould (see Figure A1 (c)). The excess material is removed by drawing the blade of the spatula once only from one end of the mould to the other. The index finger is pressed down on the blade so that the blade moves along the sides of the mould (see Figure A1 (d)). During this process the wet soil may pull away from the end of the mould, in which case it should be pushed back gently with the spatula. *On no account should the surface of the soil be smoothed or finished off with a wet spatula.*

STEP 4 The filled mould is now placed in the drying oven and dried at a temperature of between 105 and 110°C until no further shrinkage can be detected. As a rule, the material is dried out overnight, although three hours in the oven should be sufficient. The mould with the material is taken out of the oven and allowed to cool.

STEP 5 It may be found that the ends of the dry soil bar have a slight lip or projecting piece at the top. These lips should be removed by abrading with a sharp, narrow spatula, so that the end of the soil bar is parallel to the end of the mould (see Figure A1 (e)). If the soil bar is curved, it should be pressed back into the mould with the fingertips so as to make the top surface as level as possible.

The loose dust and sand, removed from the ends, as well as any loose material between cracks, should be emptied out of the mould by carefully inverting the mould whilst the material is held in position with the fingers. The soil bar is then pressed tightly against one end of the mould. It may be noticed that the soil bar fits better at one end than at the other end. The bar should be pressed tightly against the end at which there is a better fit. The gap between the soil bar and the end of the mould is measured by means of a good pair of dividers, measuring on a millimetre scale, to the nearest 0.5 mm and recorded on the form included with this document.

RESULTS

The bar linear shrinkage (BLS) is calculated from the measured shrinkage LS (in mm) as follows:

$BLS = LS \times 0.67$ (%)

NOTE

After the test, the soil bar should be examined to ensure that the corners of the mould were filled properly and that no air pockets were contained in the soil bar. If air pockets were contained, the material should be tested again.

INTERPRETATION

A value for the shrinkage product in excess of 100 is required but it should not exceed 365, otherwise slipperiness will result when the material is wet.

2.3 MATERIAL STRENGTH

In order to support the loads applied by vehicles, the material should have an adequate strength at the density at which it will perform in the field. The soaked California Bearing Ratio is typically specified for this parameter but its measurement requires bulky, expensive equipment. For labour-based projects, the following simple but equivalent method is, however, recommended. For this, a small section of road equivalent to that of the full scale construction is processed. This should be five metres long and one metre wide (or the width of the roller if wider than one metre), with one metre of material surrounding the central section to be tested.

2.3.1 The determination of the compacted strength of material

SCOPE

The objective of this procedure is to ensure that the compacted strength of the borrowed material as placed in the field complies with the acceptance testing carried out on the borrow material. Secondary objectives of this procedure are to identify the limit to be used for control testing after compaction and to identify the number of roller passes for optimum compaction.

APPARATUS

- Compactor equivalent to that proposed for use
- DCP or RCCD apparatus.

METHOD

STEP 1 A sufficient quantity of the proposed material (between 4.0 and 4.5 cubic metres) should be dumped on a section of the proposed subgrade prepared to the same standard as that of the proposed road. Water should be added to bring this material to its estimated optimum moisture content.

STEP 2 The moist material should be spread to a thickness which will provide a compacted thickness equivalent to the design thickness of the layer.

STEP 3 Using the compaction method and plant which will be used during full construction, a complete roller pass should be given to the layer. The strength of the layer is then determined using a DCP or RCCD and the results recorded on the field test data form provided.

STEP 4 Repeat Step 3, plotting the penetration rate obtained from testing against the number of roller passes until no further strengthening of the material occurs (*i.e.* until the measured penetration rate reaches a minimum). This identifies both the number of passes above which no additional benefit from rolling is obtained, and the final maximum strength of the material at compaction moisture content.

INTERPRETATION

The maximum strength of the material should comply with the requirements given in Table A1 below:

Table A1: Penetration rates of DCP and RCCD and equivalent soaked CBR (tested at OMC)

Apparatus	Penetration rate	Penetration (3 blows)	Penetration (20 blows)	Equivalent soaked CBR
	(mm/blow)	*(mm)*	*(mm)*	*(%)*
DCP	Ý 5	Ý 15	Ý 100	15

RCCD	Ý 9	Ý 27	—	15

STEP 6

If the above requirements are not met, either the material has inadequate strength to resist deformation or to avoid becoming slippery when wet, or additional compaction energy is required in order to achieve a higher density and increase the strength of the material.

A minimum soaked equivalent CBR strength of 15 per cent is required for acceptable passability and trafficability. This is related to the DCP and RCCD results as indicated in the table above.

2.4 AGGREGATE STRENGTH

In order to ensure that the aggregate particle strength is sufficient to avoid this component of the material breaking down excessively under rolling and traffic, a simple strength test (Treton Impact Value test (Figure A2)) is recommended, as described below. This test also identifies those materials which are too hard to break down and which could result in excessive stoniness of the road. A sample of the aggregate is subjected to ten blows of a falling hammer and the resulting disintegration is measured in terms of the quantity passing the 2 mm sieve.

2.4.1 Determination of the Treton impact value of aggregate

SCOPE

The Treton value is an indication of the resistance of aggregate to impact. The aggregate is subjected to ten blows of a falling hammer and the resulting disintegration is measured in terms of the quantity passing the 2 mm sieve, which is then expressed as a percentage of the mass of the test sample. This is called the Treton value.

APPARATUS

- A Treton apparatus consisting of a base plate, anvil, cylinder and a hammer weighing 15 kg ± 50 g (Figure A2). The base plate should be placed on a firm concrete block.
- The following test sieves, 200 mm in diameter: 19.0 mm, 16.0 mm and 2 mm. The bigger sieves should be made of perforated plate and the 2 mm sieve of wire mesh.
- A balance to weigh up to 200 g, accurate to 1 g.

METHOD

STEP 1 From the field sample, screen out a sufficient quantity (at least 200 g) of the – 19.0 + 16.0 mm fraction. If the aggregate is noticeably variable as regards type or hardness, each type should be tested and reported separately. In this case an estimate should be made of the percentage of each type.

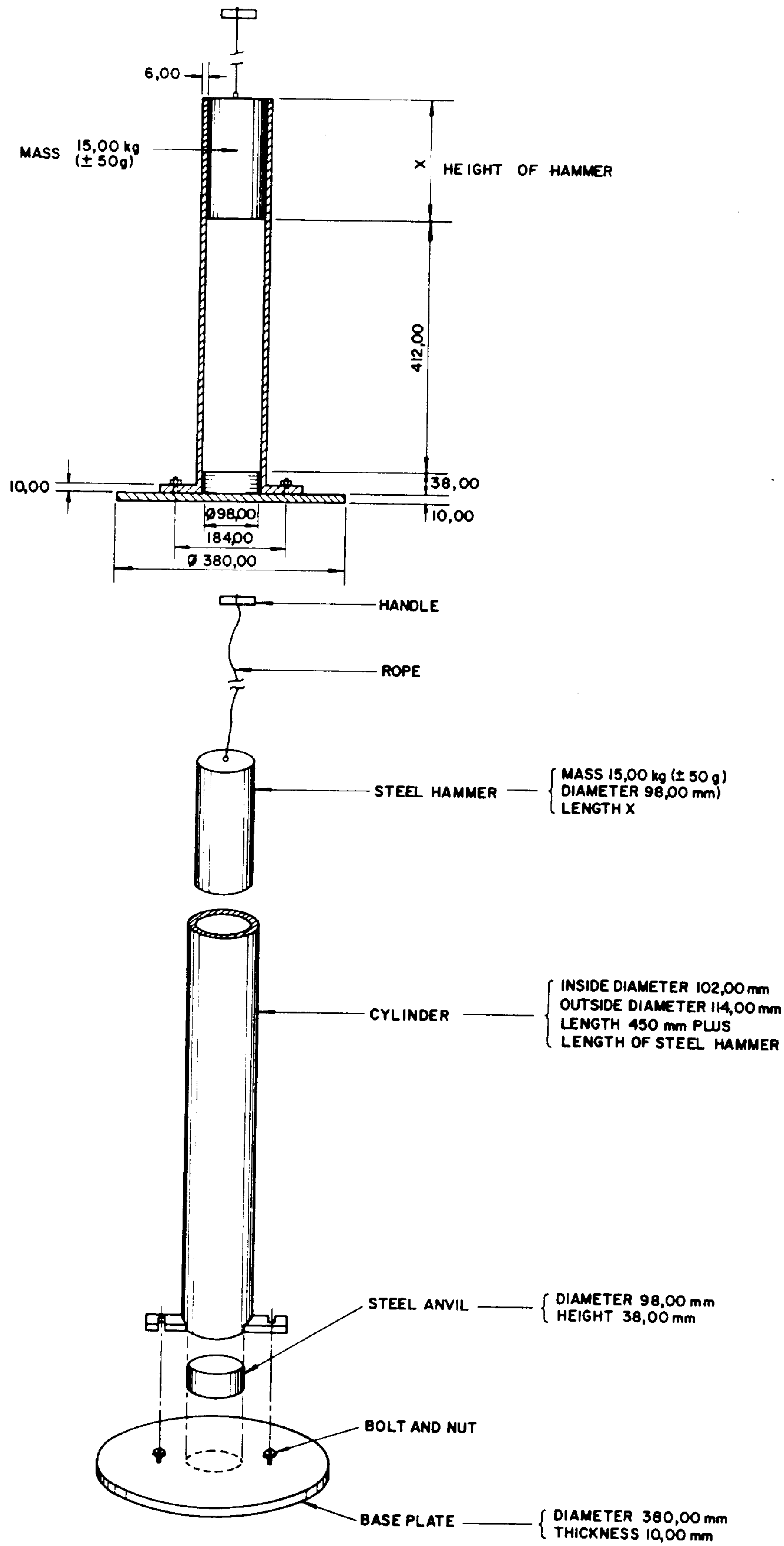


Figure A2: Treton apparatus

STEP 2 Select 15 to 20 of the most cubical pieces. Weigh the aggregate pieces to an accuracy of 1 g, and place them as evenly spaced as possible on the anvil in such a manner that their tops are approximately in the same horizontal plane.

STEP 3 Place the cylinder over the anvil and tighten the clamp screws. Place the hammer in the cylinder so that the top of the hammer is level with the top of the cylinder and let it drop ten times from this position.

STEP 4 Remove the cylinder and sieve all the aggregate on the anvil and base plate thoroughly through a 2 mm sieve. Weigh the aggregate retained on the sieve to the nearest 1 g, and record the mass. The test should be carried out in triplicate. (If any individual result differs from the others by more than five units, further tests should be carried out.)

RESULTS

Calculate the Treton value to the first decimal place as follows:

Treton value = $(A - B)/A \times 100$

where A = *the total mass of the stone particles before tamping (g)*
B = *the total mass of the stone particles retained on the 2 mm sieve after tamping (g).*

Report the value to the nearest whole number.

INTERPRETATION

Recommended Treton impact values should lie between 20 and 65. Materials with values less than 20 will be too hard and cause excessive roughness whilst those with values higher than 65 will be too soft and break down under traffic.

2.5 APPLICATION

The results obtained from the grading and linear shrinkage testing are evaluated using Figure A-3

For the best performance, the results should plot in zone E1 or E2 of the diagram. The potential problems associated with materials plotting in the other zones are identified in the zones. To reduce dust, materials should preferably plot in the E2 zone.

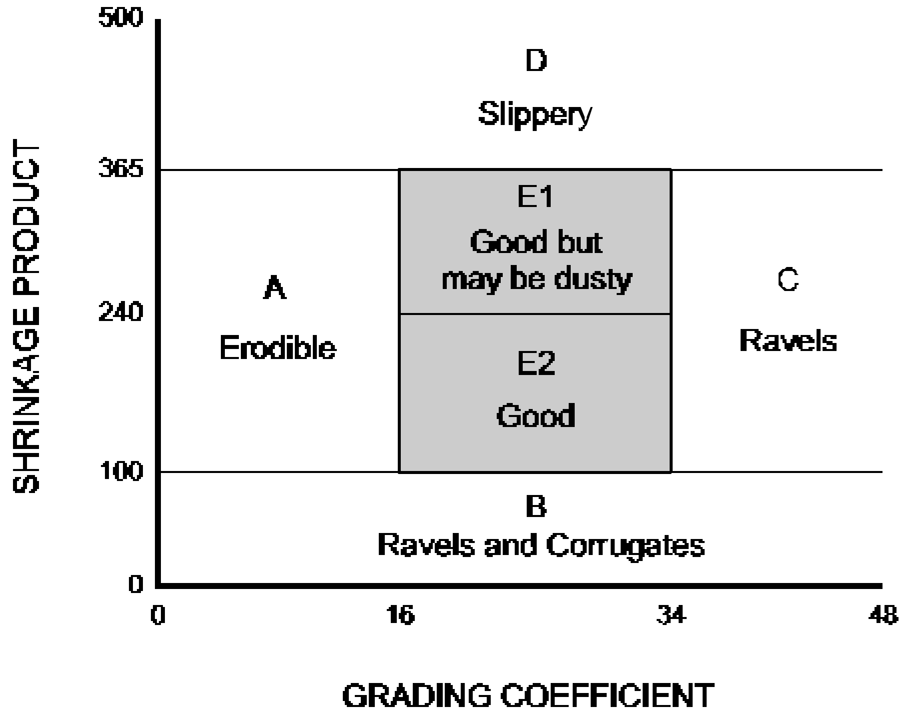


Figure A3: Relationship between Grading Coefficient, Shrinkage Product and performance

3 Quality assurance during construction

3.1 MATERIAL TESTING AND CONTROL

The quality of the borrow material should be controlled on a regular basis during construction to ensure that its properties do not differ from the accepted specification. For this purpose, only the grading coefficient and shrinkage product need be tested.

This testing is required on a routine basis to ensure that the material to be used for the following job lots comply with the specifications. It is recommended that samples of the material to be used should be taken two or three days prior to that material being used and tested so that the material can be approved at least the day before it is processed in the borrow pit, loaded and hauled. The test techniques described in the section on Material Properties above are such that this is possible.

The individual results of the borrow pit testing should be plotted on Figure A3. The test results should be plotted on this figure on an ongoing basis and if there is a trend to move out of Zone E, it is indicative of a change in the material properties. Additional testing should be carried out to determine the cause of this and to identify remedial action, *e.g.* blending of material, redefining of boundaries of the borrow pit, adjustment of depth of excavation, *etc.*

3.2 CONSTRUCTION QUALITY ASSURANCE

A number of factors should be controlled during construction. These are:

- Moisture content
- Thickness
- Compaction
- General finish.

3.2.1 Moisture content

It is very difficult to get a high degree of compaction if the moisture content is not close to the Optimum Moisture Content (OMC) for that material. As it is difficult to get an accurate, usable determination of the moisture content quickly, the visual determination of this in the field is recommended.

The control of moisture during construction must be carried out by squeezing a sample of the material as tightly as possible in the hand.

The material should be moist enough to stick together when squeezed, with no visible sign of free water on the surface.

If the material disintegrates, it is too dry for compaction. If free water is ejected or if the soil sticks to the hand, it is too wet.

If the "sausage" formed by squeezing in the hand is squeezed diametrically between the thumb and forefinger, it should break with some crumbling. It should not break by deformation under the finger pressure, nor should there be excessive crumbling.

3.2.2 Thickness

The thickness of the layer should be closely controlled prior to compaction, with allowance for the bulking factor. Spreading of the material should be as consistent as possible to ensure that all material is placed at a similar loose density.

To produce a 150 mm thick compacted layer, 190 to 200 mm of loose material is typically required.

Control of the thickness during construction is carried out by inserting a calibrated probe (Figure A4) through the uncompacted material to confirm that the thickness prior to compaction is within the required limits.

This should be checked in at least 25 locations and, where the thickness is deficient, more material should be added.

3.2.3 Compaction

The compaction achieved in the field is the most important aspect of the construction process. It is recommended that a simple device such as the Rapid Compaction Control Device (RCCD) or DCP is used for this purpose. Both tests are quick and repeatable, and many tests can be done rapidly and at little cost.

Not less than six tests should be done on any job lot and in no case should the penetration rate exceed the specified maximum permissible penetration rate.

Should the tests show up areas which are unacceptable, the reasons for this should be investigated. Poor results can be attributed to the material being too wet, material that has not received adequate compaction effort, or to a pocket of poor quality material.

The actual cause needs to be identified and corrective action taken. This may involve scarifying and drying out prior to recompaction if the material is too wet, additional compaction if necessary, or replacement of poor material where appropriate.

3.2.4 Visual inspection

Supervisors should be trained to carry out a comprehensive visual inspection of the completed layer prior to excessive drying out of the material. This inspection should be carried out during the latter part of the shift prior to demobilisation of staff and plant for the day, should be extremely thorough and should cover the total job lot completed in the shift. During this inspection the following should be evaluated:

- the presence of large stones
- excessively moist areas
- poorly compacted areas
- bumps and depressions
- areas of thin material
- material segregation.

Appropriate action to rectify the problems should be taken before the material has dried out.

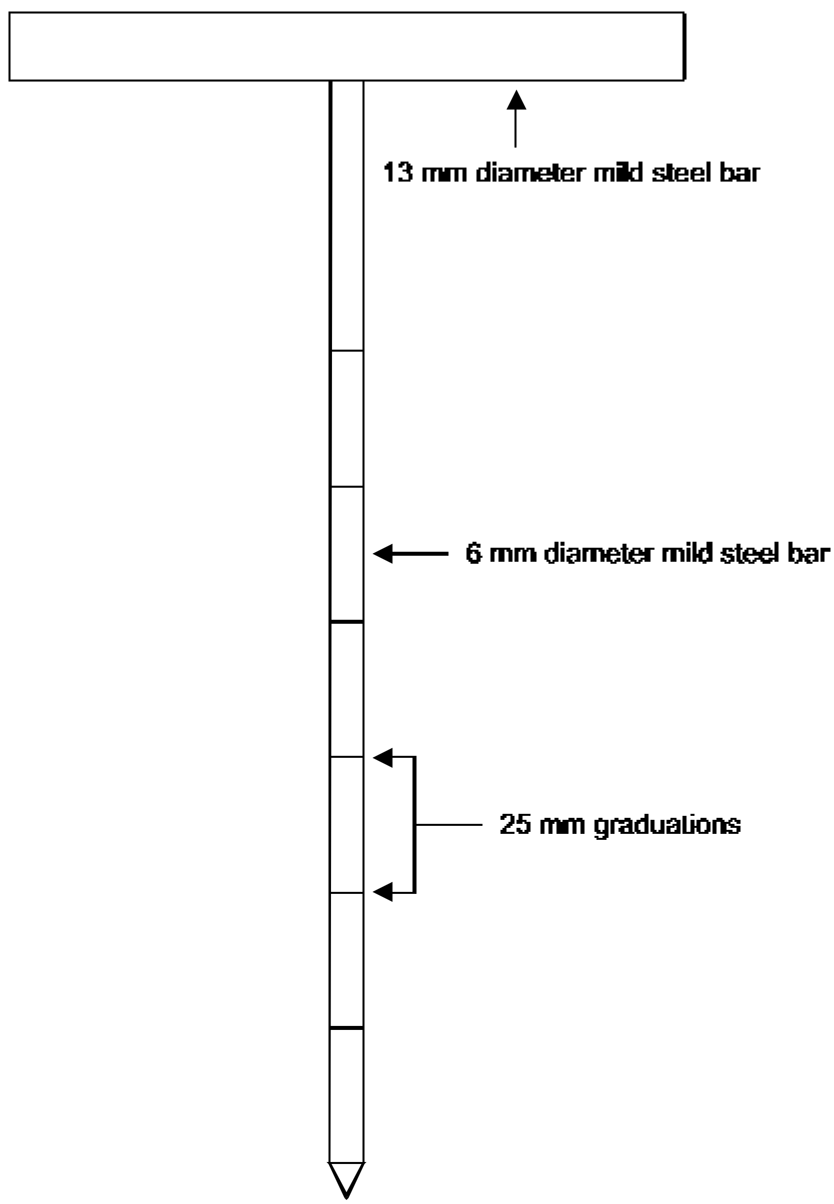


Figure A4: Thickness probe

LABORATORY TEST RESULTS

PROJECT: ____ DATE: ____________

SAMPLE NUMBER: ______________________________ OVEN DRIED: YES ☐ NO ☐

SAMPLE LOCATION: ____

GRADING ANALYSIS

Sieve size mm	Mass retained (g)	% of total retained	Cumulative % passing		Normalised cumulative % passing	
37.5				D		
26.5				A		A
4.75				C		C
2.0				B		B
0.425						
< 0.425						

G_C = (A – B) x C/100 = (........ – ....) x (......./100) =.................

I_O = 100 – D = (100 – ....) = ...

LINEAR SHRINKAGE

Mould Number	Linear shrinkage (LS) mm	Bar linear shrinkage (BLS)* mm	Shrinkage product (SP)**

* BLS = LS x 0.67
** SP = Mean BLS x Percent passing 0.425 mm

TRETON IMPACT VALUE

Test Number	Total Mass (A) g	Mass Retained on 2 mm Sieve (B) g	Treton value*

* Treton value = ((A – B)/A) x 100

Operator: ____

FIELD TEST RESULTS

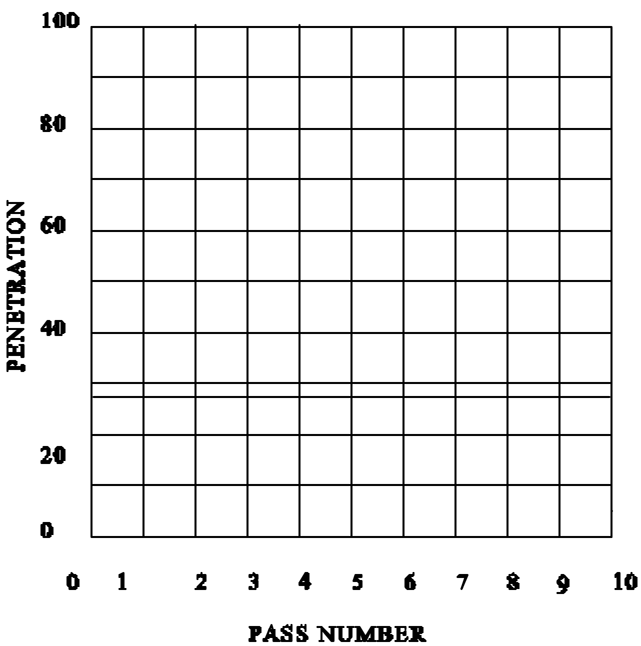
PROJECT: ____ DATE: ______________

TEST NUMBER: ____

TEST LOCATION: ____

COMPACTED STRENGTH

Pass number	1	2	3	4	5	6	7	8	9	10
RCCD reading (3 blows)										
DCP penetration (mm/blow)										



THICKNESS

(25 readings in mm from the probe per job lot)

Operator: ____

Annex B: Contents of CSIR testing kit

The following are the basic contents of the CSIR field testing kit. Certain items (*e.g.* balance and oven), which are necessary in one test, are not repeated in the requirements for subsequent tests.

Grading

- Sheets of canvas 1 metre by 1 metre for coning and quartering material.
- Test sieves: 37.5 mm, 26.5 mm, 4.75 mm, 2 mm and 0.425 mm with pan and cover.
- Balance with pan, accurate to 1 g, to weigh up to 5 kg.
- Various pans of 250 to 300 mm diameter and 20 mm deep.
- Drying oven (Solar) to maintain a temperature between 105 and 110°C.
- Various stiff brushes.
- Electronic calculator (Solar powered).
- Wind shield for balance.
- Levelling platform for balance.
- Thermometer (0 to 120°C).

Linear shrinkage

- Shrinkage moulds with internal dimensions of 150 ± 0.25 mm long × 10 ± 0.25 mm wide × 10 ± 0.25 mm deep and made of 10 mm thick stainless steel bar, open on two sides.
- A steel plate to fit underneath the shrinkage moulds.
- Silicone lubricant spray (*e.g.* Q20 or WD 40).
- A spatula with a slightly flexible blade about 100 mm long and 20 mm wide.
- A pair of dividers and a millimetre scale.
- A standard drop cone and calibrated tube for estimating the liquid limit.

Material strength

- RCCD or DCP test apparatus.

Aggregate strength (Treton)

- A Treton apparatus consisting of a base plate, anvil, cylinder and a hammer weighing 15 kg ± 50 g (Figure A2). The baseplate should be placed on a firm concrete block.
- The following test sieves, 200 mm in diameter: 19.0 mm, 16.0 mm and 2 mm. The larger sieves should be made of perforated plate and the 2 mm sieve of wire mesh.

Thickness

- Thickness probe.