ROUGHTON INTERNATIONAL

In association with
THE UNIVERSITY OF BIRMINGHAM
and
THE UNIVERSITY OF NOTTINGHAM

# Materials and Borrow Pit Management for Low Cost Roads

DFID Department for International Development

February 2000

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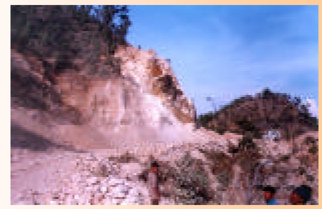
# GUIDELINES ON

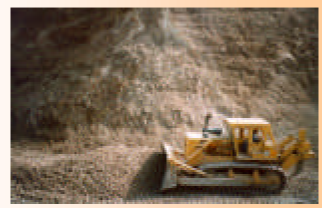
# MATERIALS AND BORROW PIT MANAGEMENT FOR LOW COST ROADS

Material Searches

Borrow Pit Site Investigation



Pit Selection and Preparation



Material Extraction

Material Processing

Material Supply

Environmental Considerations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This document is available on CD ROM and has been formatted to allow its easy use in training presentations.

# GUIDELINES ON
# MATERIALS AND BORROW PIT MANAGEMENT FOR LOW COST ROADS

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**II Review of Material Types for Use in Low Cost Paved Roads**

# Section 1
# Introduction

Identify the best sources of material supply.

Implement appropriate (low cost) processing procedures.

Implement improved economic haulage strategies.

# 1. INTRODUCTION

The production of this guideline document has followed an investigation into construction material management practices relating to the maintenance of low cost roads (unpaved and paved) in a number of developing countries. This study identified the potential for implementing more cost effective use of available maintenance funds, primarily by:

- Undertaking effective materials location studies in areas where there is a deficiency of identified natural materials suitable for low cost road construction.
- Identification of the best sources of material supply.
- Implementation of appropriate (usually low cost) extraction and processing procedures, as necessary, to significantly improve the in-service performance of pavements
- Introduction of improved record keeping and data management in relation to natural material resources and their utilisation.
- Identification and implementation of improved economic haulage strategies

Up to 70% of the construction cost of a typical low volume rural road may relate to pavement materials production and supply. Also, aggregate replacement costs are often as high as 60% of the maintenance costs of an unpaved road. There are therefore very significant cost efficiencies that can be achieved by implementing improved material management procedures and material supply strategies.

The review of current resource development practices also identified a need to improve awareness of the potential damaging effects (negative impacts) that borrow pits and quarries may have on the local environment and its inhabitants.

A comprehensive literature review revealed a large number of relevant papers and sections within existing road maintenance manuals that consider aspects of materials production and supply. For example, the practicalities of labour intensive material extraction and haulage are very well documented in a number of very good publications. However, there is no comprehensive materials management manual for low cost roads in developing countries that fully covers the subject.

It is the aim of these guidelines is to make available a concise but comprehensive and well illustrated document that:

- Provides information that will encourage cost effective selection and development of natural resources for low cost road construction.
- Encourages improved record keeping relating to material resources and their utilisation. In particular, provides guidelines on the establishment of material resource inventories and databases and promotes the benefits that may result from the use of such a database to improve materials management and design of material supply strategies.
- Highlights environmental and social issues associated with road material source development. Reviews possible negative impacts and provides guidelines in terms of measures that may be implemented to prevent or reduce adverse effects on local populations and the environment.
- Provides a document that can be a reference text and can be readily utilised as an aid in training presentations for engineering staff working in countries with large low cost road networks.

This document addresses the basic principles and aspects of borrow pit development, as well as progressing towards appropriate management strategies. As such it is hoped that it will form a useful reference for both field supervisors and highway engineers.

Figure 1.1 presents an outline of the structure and organisation of the Guidelines.


Improve road quality.


Reduce road maintenance costs.


Reduce the damaging effects of borrow pits on the local environment and its inhabitants.

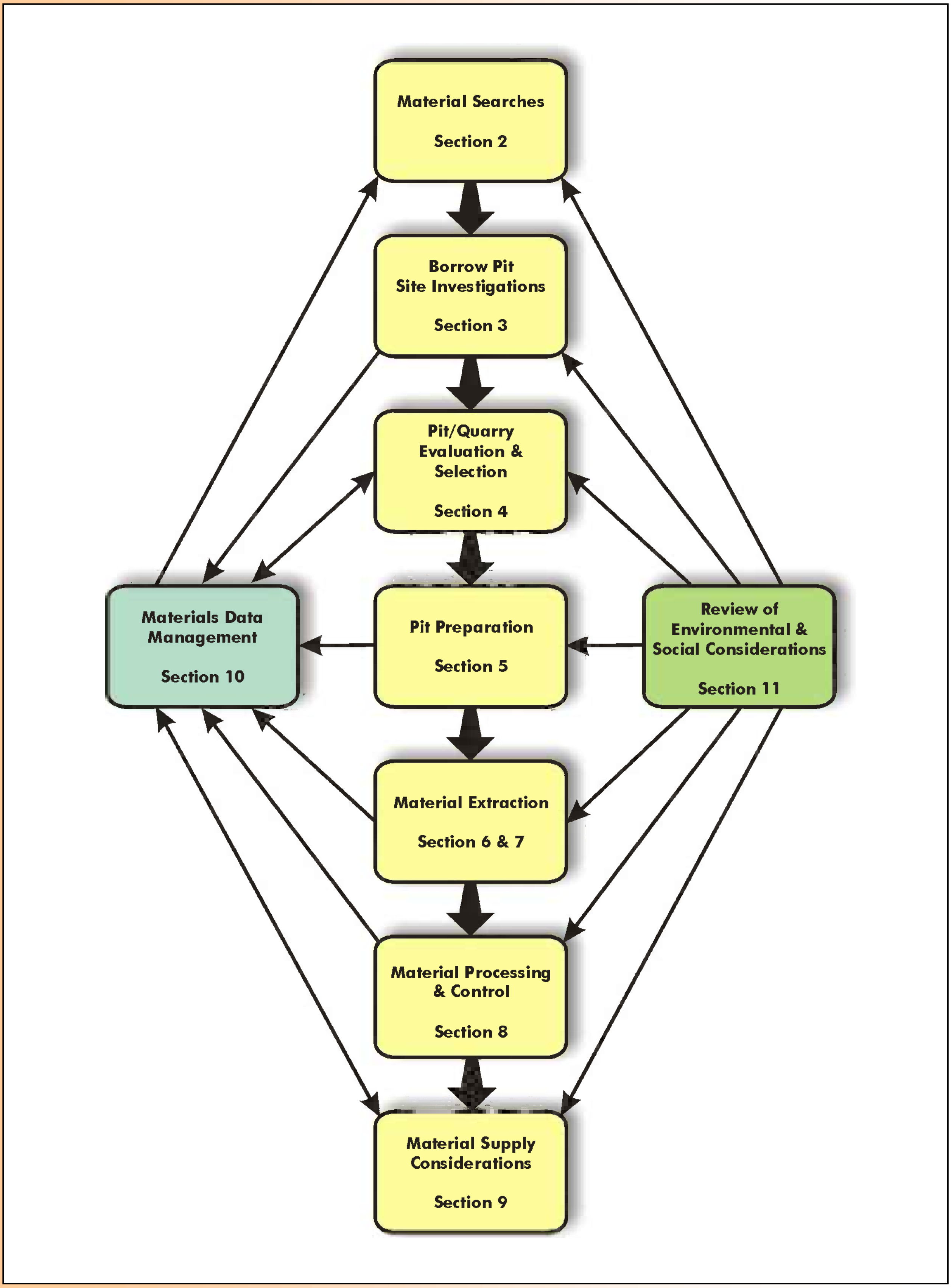
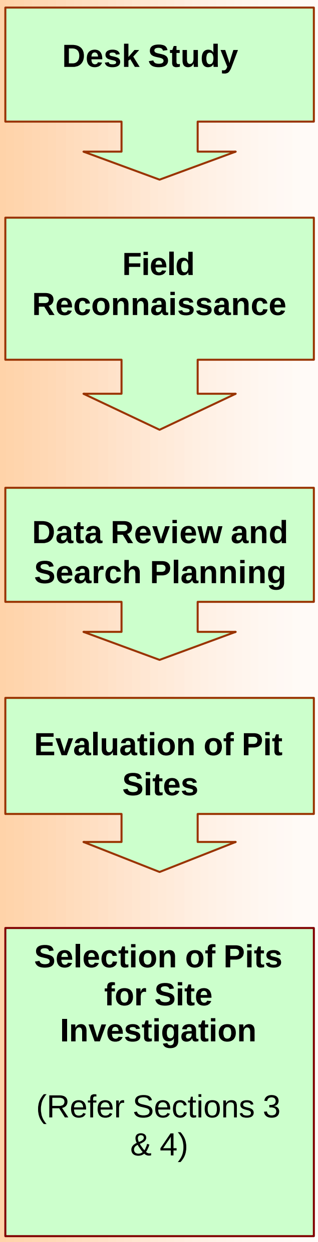



Figure 1.1 Structure and Organisation of the Guidelines

# Section 2
# Materials Searches

# 2. MATERIALS SEARCHES

## 2.1. Introduction




The identification and development of good sources of pavement construction material at regular intervals along the length of a low traffic rural road is essential to the cost effective use of construction and maintenance funds.

Materials searches will need to be carried out in the following circumstances:

- During the design of new roads.
- To identify new sources of material in areas where deficiencies exist and result in uneconomically long haulage distances from existing sources.
- To identify improved sources where existing borrow pits supply unsatisfactory materials due to cost or technical considerations.
- To replace existing traditional material sources as they become exhausted/unavailable, or are judged to be having a significantly adverse effect on the environment or local population.

The successful location of new low cost road materials tends to involve some science, some logic and a good deal of knowledge of the local area. It will often be necessary for highway engineers and road supervisors to carry out material searches in relatively remote areas, without the benefit of training in geology and without access to useful aerial photographs and geological maps.

This Section aims to provide some simple advise on the use of geological data, but aims primarily to provide some practical guidelines to assist field staff with the planning and execution of materials searches.

## 2.2. Desk Study and Field Reconnaissance

### a) Initial Data Collection and Review

Prior to any detailed field searches existing construction and materials laboratory records should be examined in order to determine the location of all existing and old material sources (even reinstated pits) in the area to be investigated. The location of these sources should be marked on the largest scale topographical and geological maps available.

Do not restrict data searches to information on the road section to be studied. In the case of material searches along feeder roads there may be existing design or feasibility study reports for the arterial roads that contain useful information on potential material resources and existing borrow sources that could be used on the roads under study.

### b) Reconnaissance Field Visit

If the staff responsible for carrying out the materials searches are not familiar with the study area or existing borrow pits then a reconnaissance visit to the site should ideally be made to locate the documented material sources and any others that are known to local residents and road supervisors.

If possible pit sites and all other outcrop sites that are visited should be accurately located with a hand held GPS (Global Positioning System – cost about US $300-1999). This instrument, which is the size of a mobile phone, will prevent any pit sites being shown in the wrong place on maps. GPS uses triangulation from navigation satellites to fix map co-ordinates on the ground.

The width of the corridor to be explored will depend on the scarcity of potential material sources and accessibility problems, but in the case of low volume roads would typically be 5 – 10 km on either side of the road to be serviced.

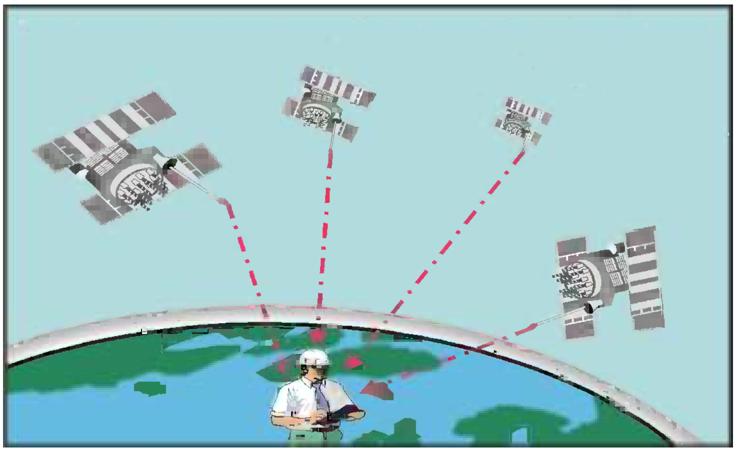


**Figure 2-1 Principle of GPS Position Fixing**

A reconnaissance survey is made to identify and investigate all known existing and potential material sources.

Landscape features often indicate the likely presence of gravel. In the centre of this photograph there is an alluvial outwash fan deposit containing an extensive resource of coarse gravel.

### c) Review of Information from Reconnaissance and Desk Study

Reconnaissance observations concerning the type of material in existing pits, road cuttings and other outcrops close to the study road should be cross referenced with plotted locations on the topography and geology maps. This exercise will show:

- The relationship between the occurrence of the existing or potential sources of material and local landforms such as hills, plateaux or valley sides (as demonstrated by field observations and indicated by contour distribution on the topography map).
- The relationship between the observed material type and its distribution as indicated on the geological map.

Once these relationships have been established an improved assessment of landform distribution may be gained from a review of stereoscopic pairs of aerial photographs, if these can be obtained at a suitably large scale (ideally 1:20,000 - 1:40,000). The interpretation of aerial photography can be a major help in defining the limits of potential material resources and providing an understanding of geological structure both regionally and locally.

During a field reconnaissance note the characteristics and GPS location of exposures and useful outcrops in existing road cuttings.

Field occurrence of laterite

- Satellite imagery may also be of assistance, but the cost of purchasing satellite images may be prohibitively high in relation to likely benefits, unless a specially funded regional resource mapping exercise is proposed.

- The process of relating landform to underlying structure is a part of "terrain evaluation". Detailed guidance on this subject is provided in UK Transport Research Laboratory's "Terrain Evaluation Manual" (State of the Art Review No 7, 1993).

- Terrain evaluation mapping already exists in some countries and may include land-system mapping which could be extremely valuable in assisting materials searches.

- Also, publications exist with respect to some commonly used low cost road materials, that provide guidance to assist in using landscape features to assist in the location of deposits. Figure 2.2 presents an extract from "Laterite in Road Pavements" (Charman, 1988) which summarises landforms commonly associated with the occurrence of laterite. Other detailed information on prospecting for laterite is contained in this reference.

| | |
|---|---|
| Land Form | Flat hilltop with sharp edge  |
| | Gentle footslope  |
| | Rounded bump on hillcrest  |
| | Edge of flat valley floor  |
| | Rounded hill on plain  |
| Drainage | Few or no streams |
| Vegetation | Poor cover, generally scrub or grassland with scattered bushes |
| Photo-tone | Dark grey. The natural strong dark red colour appears as dark grey on panchromatic air photos, but may be modified by differences in vegetation. The tonal changes may be particularly noticeable around the margin of hardpan laterite |

Source: Charman, 1998

**Figure 2-2 Landforms Indicating Possible Presence of Laterite**

- Guidelines on prospecting for calcrete road building materials are presented in several publications notably: Netterburg (1978); and Lawrance & Toole (1984).

### Identification of Potential New Material Sources

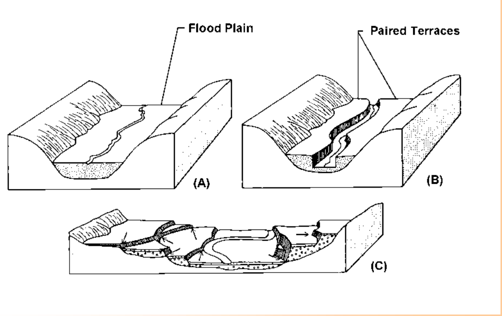
New sources of material are often located by extending existing borrow pits or by finding new sites where the presence of similar material is indicated by landform evidence supported by available mapping, surface exposures and vegetation.

However, existing borrow pits (when they are present) may not exploit all the material types that could supply low cost road building material. In this case, geological maps and references may provide evidence of the occurrence of other material types that offer potential as sources of material but have not yet been considered. For this reason a geologist should ideally be a member of any search team. If this is not possible, then the advice of someone with a good knowledge of geological materials should be obtained before any detailed field searches begin.

The natural materials that are primarily exploited to provided low cost road building aggregates are as follows:

- **Transported Sands and Gravels**. These include: water transported materials (river, lake and beach alluvium); and gravity transported deposits (ie landslide colluvium and scree deposits).
- **Pedogenic Gravels.** These are formed by the accumulation in the soil profile of chemical constituents precipitated from ground water. They include: laterite (ferricrete) gravels; calcrete and silcrete deposits.
- **Residual Gravels.** These are formed by the decomposition of solid rock through weathering. Usable materials typically comprise a mix of hard (less altered) fragments (such as quartz) in a matrix of fine grained material. Residual gravels derived from quartz rich granite and gneiss can be an important source of low cost road building material.
- **Weak or Poorly Consolidated (Rippable) Rocks**. These include weakly cemented sedimentary rocks such as conglomerates and sandstones. Relatively weak limestones and coral deposits. Unconsolidated volcanic materials including scoria and agglomerate deposits.
- **Weathered and/or Highly Fractured (Rippable) Rocks**. Any hard durable rock that is naturally closely fragmented (jointed and bedded) will form a potential source of rippable low cost road material. However, care should be taken when investigating some basic igneous rock types (ie basalt and dolerite) which may produce aggregates that are less durable than they appear, due to secondary mineralisation. Some rock types will decompose (usually along fracture plains) to form an exploitable mix of fine material and less altered core stones.

Appendix I presents a review of the advantages and disadvantages usually associated with the main material types commonly exploited to supply unpaved road gravel wearing course aggregates (adapted from Bishop & Morey, 1992).. Appendix II contains a review of material types for use in low cost paved road construction. An additional source of useful information on paved road materials is "Promoting the use of Marginal Materials" (TRL & Roughton International, 2000).

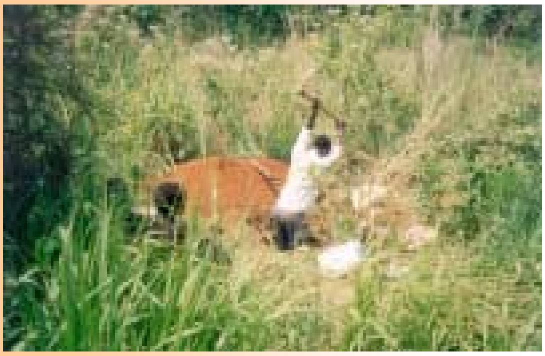



The formation of river gravel terrace deposits (Source: Leet *et al* 1978).

Rippable volcanic scoria gravel in road cutting.

Weathered fractured rippable rock.

Assemble an appropriate search team



Manual trial pitting during a materials search

## 2.3. Field Search Planning

Field searches should be carefully planned in order to ensure that a large amount of time and effort is not spent achieving disappointing results. In relation to planning the following is recommended:

- Search for and select suitable sites for development well in advance of when the material will be required (ie well before regravelling or rehabilitation is programmed).. The typical duration for materials search, testing and reporting for a 50 km road can vary from 4 months to 12 months.
- Assemble an appropriate search team that ideally includes: a materials engineer/geologist; the road supervisor most familiar with the road being supplied; representatives from local communities (who know the local soil conditions and the location of any surface exposures of possible road building aggregate); and a few labourers.
- Take some digging tools and a hand auger during initial searches so that, in the case of shallow deposits, their extent and depth of overburden cover can be immediately estimated
- Identify on field maps the sites of potential new resources (based on the findings of the desk study and field reconnaissance).
- Identify any development restrictions in the study area. For example: conservation areas; landowner opposition; intensively cultivated land; and settlements.
- Prioritise sites for initial evaluation. These will typically be those located closest to the road to be supplied. When construction of long haul roads will be expensive, prioritise investigation of sites close to existing access tracks. However, note that poor quality gravel selected because it is close to the road will result in high maintenance costs.

## 2.4. Field Evaluation of Potential Pit Sites

During a materials search study, field information needs to be collected at potential pit sites that will enable selection of the best sites to take forward for detailed site investigation.

The level of study should therefore be directed towards gaining just sufficient information to judge the relative merits of one site when compared with another. In most situations this evaluation should simply identify the best sources as those that are able to supply suitable road building material at the lowest cost.

**Economic Evaluation**

There are a large number of factors that will ultimately contribute to the relative cost of supplying aggregate from one site rather than another. Figure 2.3 presents a flow chart for the process of borrow pit evaluation during a materials search study. This Figure demonstrates the relationship between technical considerations and economic analysis.

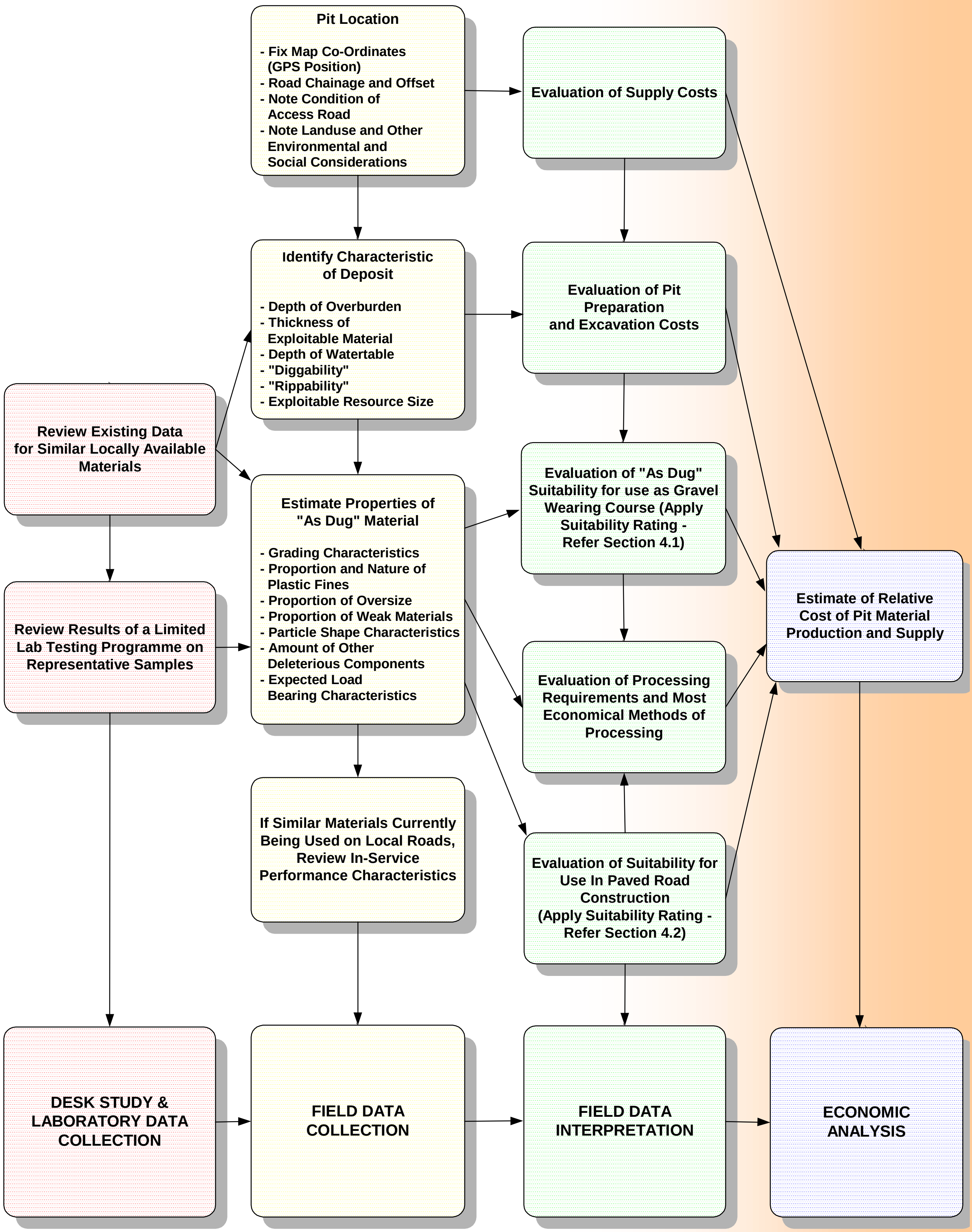



**Figure 2.3 Borrow Pit Evaluation During Material Search Studies**

Hand auger investigation during a materials search study.

**Environmental Impact Evaluation**

As noted under "Pit Location" in Figure 2.3 environmental and social influences must be considered as part of the pit evaluation made at the search stage of a resource study. The impact of a borrow pit on the environment and local population is not usually easy to quantify in a simple economic analysis, nevertheless account needs to be taken of any possible adverse effects that may result from pit development. Possible social and environmental effects to consider are shown on Figure 4.1 and reviewed in Section 11.

**Technical Evaluation**

During materials search studies, pit evaluations must usually to be based on a limited amount of information on the *in situ* (on site) characteristics of the deposit supported by a limited number of test results obtained from one or more representative samples. The value of the pit assessment must inevitably rely on the experience of the investigating staff in terms of their evaluation of:

- The likely sub-surface occurrence of the deposit.
- The expected "as dug" properties of the excavated material.
- Material processing requirements.
- Material suitabilty for various road building applications

When a high level of uncertainty exists concerning the above factors, then the scale of the preliminary site investigations may need to be increased.

The field information that needs to be collected to assist a pit evaluation at the materials search stage is shown on Figure 2.3. The field data required is similar to that needed when making a rapid assessment of a large number of existing material sources, such as is necessary during a field based materials resource inventory study. Figure 10.2 presents an example of the type of field form recommended for recording pit information during a borrow pit inventory study. A similar field form would be suitable for recording pit characteristics during a materials search and its use would allow future easy storage of the resource information on a computer database. Guidelines on completion and use of such a Field Proforma are contained in Section 10.

# Section 3
# Borrow Pit Site Investigation

Give careful consideration to the design of borrow pit site investigations.

# 3. BORROW PIT SITE INVESTIGATION

## 3.1. Planning a Site Investigation

Borrow pit site investigations are primarily carried out in order to establish reliable estimates of the quantity, quality and processing needs of potential road building materials in possible new sources that have been selected for detailed study following a materials search.

The design of the site investigation must consider the following factors:

- How much material is required. The investigation should concentrate on identifying sufficient workable material to supply expected requirements. In the case of unpaved road material investigations the site investigation should not be limited to identifying materials for just the next regravelling. Consider proving sufficient material for at least 3 regravelling operations.
- The method of site investigation will probably be influenced by the availability of suitable resources (labour, plant and test equipment).
- The hardness of the deposits may dictate the method of investigation. For example, the digging of manual trial pits may not be practical.
- The depth and nature of overburden deposits may influence choice of investigation methods

Borrow pit ground investigations should be carried out at regular intervals across the site. It is recommended that the depth of overburden, and the characteristics and thickness of the workable deposit is investigated on the basis of a 30 m to 50 m square grid. This distance should only be widened if the site is very large and the materials very similar at each test location. Unexpected changes in the ground profile should be examined locally by making additional intermediate investigation sites in the grid.

A site plan of each borrow pit to be investigated should be prepared, showing :

- The main features of the site
- The means of access and the pit location with respect to the road being supplied
- The position of each site investigation site,

An example is shown in Figure 3.1.

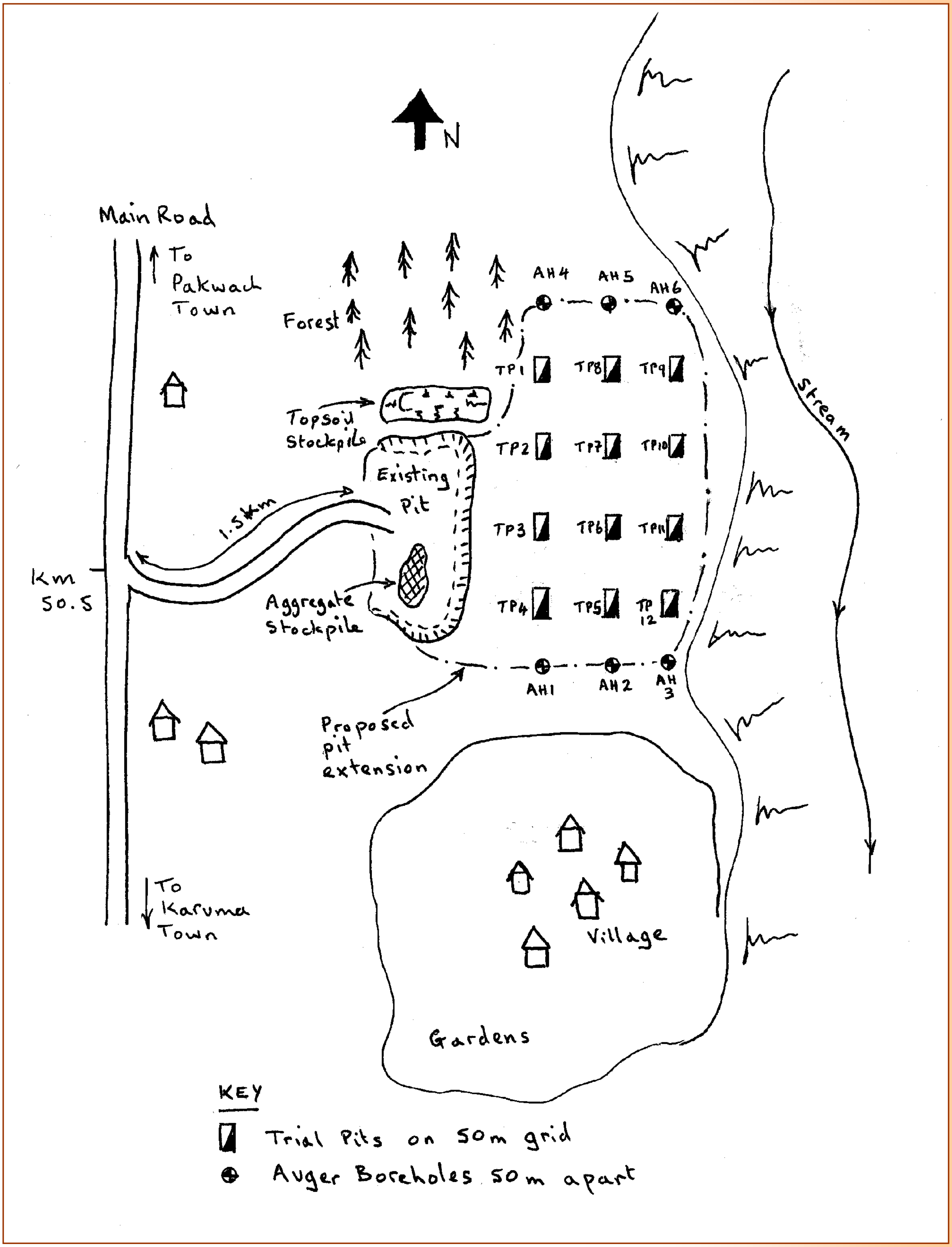



**Figure 3-1 Borrow Pit Site Investigation Sketch Plan**

In each trial pit all layers should be accurately described and measured. Materials proposed for use should be sampled and tested.


## 3.2. Trial Pits and Trenches

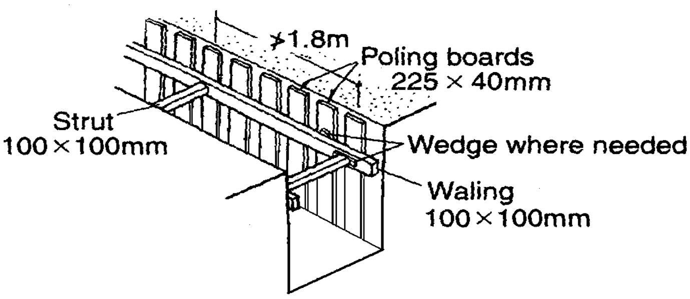
The best way to examine near surface materials is to dig inspection pits or trenches so that the usable deposits can be seen in their undisturbed state and large representative samples can be taken for testing to determine their engineering properties.

In relatively soft ground, with overburden soils not more than 1.0 to 1.5 m deep, manually excavated trial pits may be the easiest and most economical form of ground investigation. If there is any indication of excavation instability (eg by soil cracking or water inflow) then the excavation sides should be supported with timber props and shoring as shown in Figure 3.2. Auger boreholes may be made from the base of manual trial pits (such pits can rarely penetrate more than 2.5 to 3.0 m depth) or pit can be stepped to improve stability.

Trial pits and trenches can be quickly and safely excavated with a tractor backhoe or mechanical excavator when such plant is available (pits may then be excavated to a depth of 4.0 to 5.5m, depending on the machine and ground conditions encountered). The ease of excavation, stability of the sides and seepage of water should be noted. Colour photographs of side faces should be taken whenever possible, with a prominent scale marker and a method of identifying the trial pit.

Weathered and fractured hard rock deposits are best investigated by excavating a bulldozer trial trench. The change in excavation characteristics (rippability) of the material with increasing depth can then be assessed (refer Section 3.5).

Trial pits and trenches should be back-filled immediately after they have been described and sampled, otherwise they may form a serious hazard to local people and livestock (particularly when located in long grass).




Source: Davis & Lambert, 1995

**Figure 3-2 Typical Temporary Trench Support**

# 3.3. Borehole Investigations

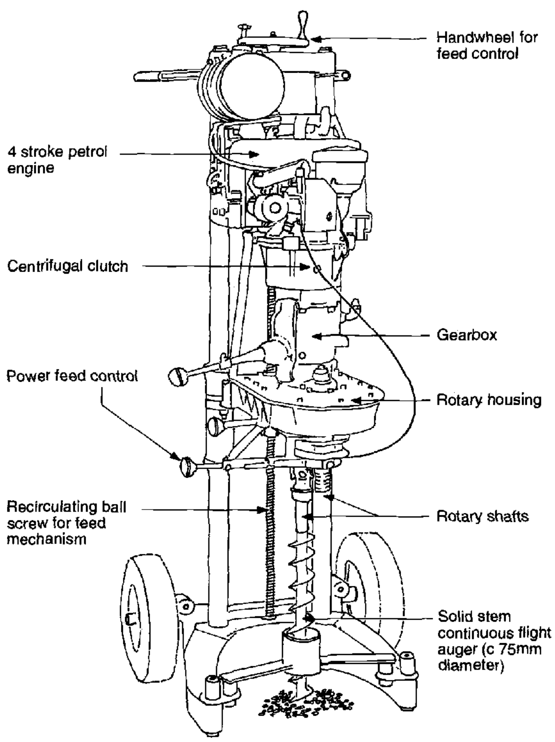
## 1. Hand and Portable Auger Boreholes

The boring of hand excavated auger boreholes may be an extremely quick and useful ground investigation method in soft or firm materials. This equipment may be used in cohesive soils or sand and gravel deposits above the water table, to a depth of 5 to 6m. Techniques exist for sinking deeper holes with temporary casing for drilling wells, but such methods would not usually be employed in ground investigations.

Various cutting heads are available up to 200 mm in diameter. The most common type is the post hole auger. Screw augers provide a quick way of penetrating clay deposits (for example, to find the thickness of overburden materials and locate the top of a gravel deposit).

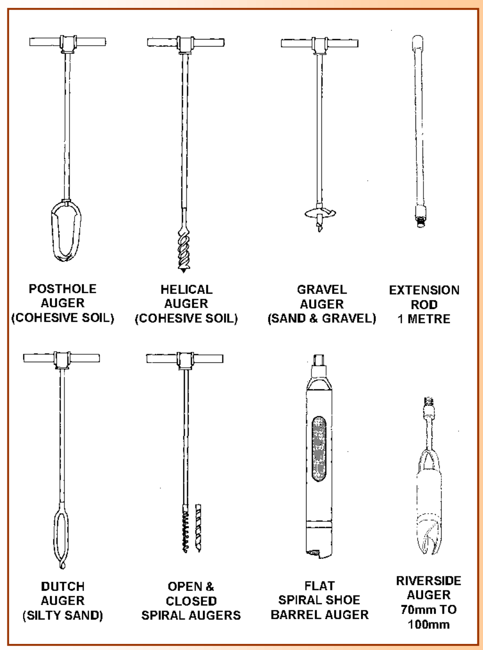
Small portable power augers, such as the "minuteman", are available but these suffer the same limitations as the hand auger. Neither are suitable where the soil is unstable, where water flows into the hole or where large stones occur. Also, it is only possible to obtain relatively small samples. As a result, auger boring is typically used to provide additional ground profile information to supplement a programme of trial pitting or large diameter machine excavated boreholes.

Using a hand auger



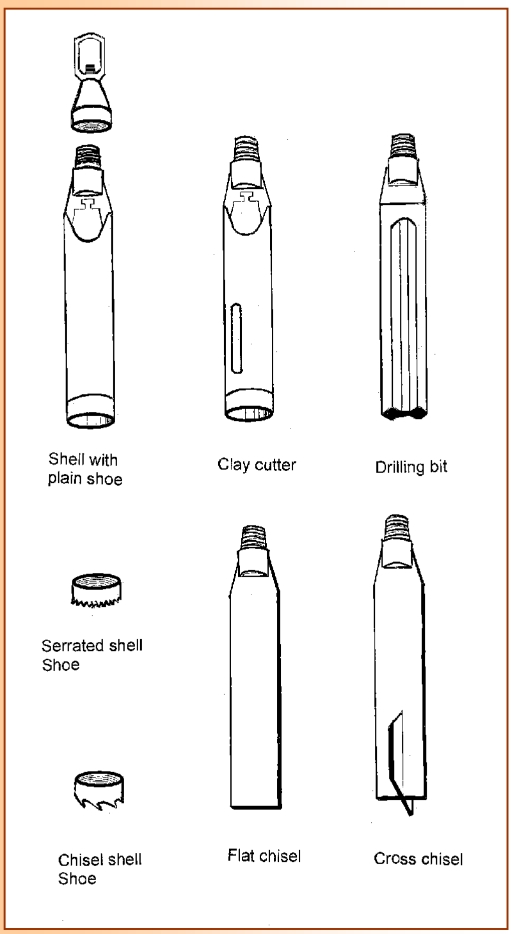

Source: Clayton *et al*, 1995

**Figure 3-3 Small Portable "Minuteman" Continuous Flight Auger Rig.**




Hand auger tools

Cable tool boring rig,. Dando 3000 Buffalo Rig shown. (Photo courtesy of Dando Drilling International)




Equipment used for cable percussion boring

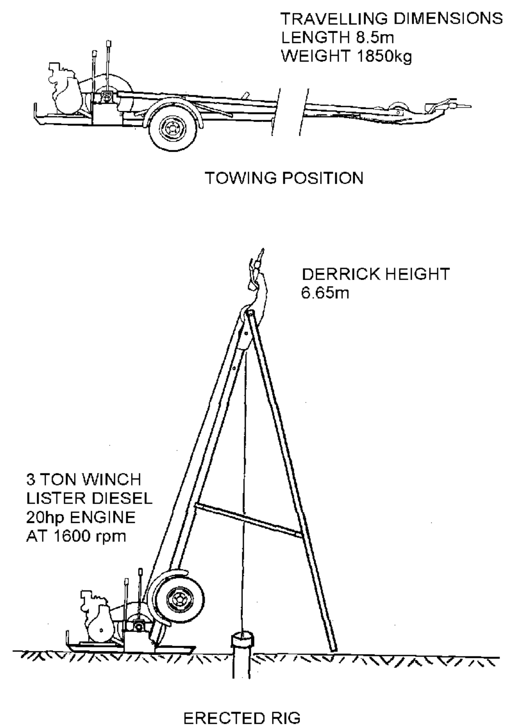
## 2. Light Percussion Boreholes

Light percussion boring, also known as cable tool boring or "shell and auger" boring, is a technique that can be used in all types of soil, above and below the water table. This method of ground investigation would only be used in borrow pits where workable gravel deposits ("bank" materials) are expected to occur to depths exceeding the reach of an excavator (4 – 5 m).

The rig consists of an engine powered winch and tripod frame that is easily collapsed for towing behind a four wheel drive vehicle. The boreholes are usually 150 to 200 mm in diameter and steel casing is typically required throughout most of the hole. Boreholes of 20 to 30m depth are commonly bored in suitable soils.

Boring is achieved by repeatedly dropping an auger, consisting of a steel tube, to the bottom of the borehole. In sands and gravels a valve is fitted to the lower end of the tube to trap the material entering it, this is a shell or sand auger. Any large stones or small boulders encountered can be broken up with a heavy chiselling tool. Large disturbed samples may be obtained, but below the water table the washing action of the shell may remove some of the fine material from sand and gravel deposits.

Attachments to the rig allow the use of light rotary drilling equipment that will enable limited investigation of the characteristics of any bedrock encountered.




Source: Dando Drilling International

**Figure 3-4 Cable Percussion Boring Rig**

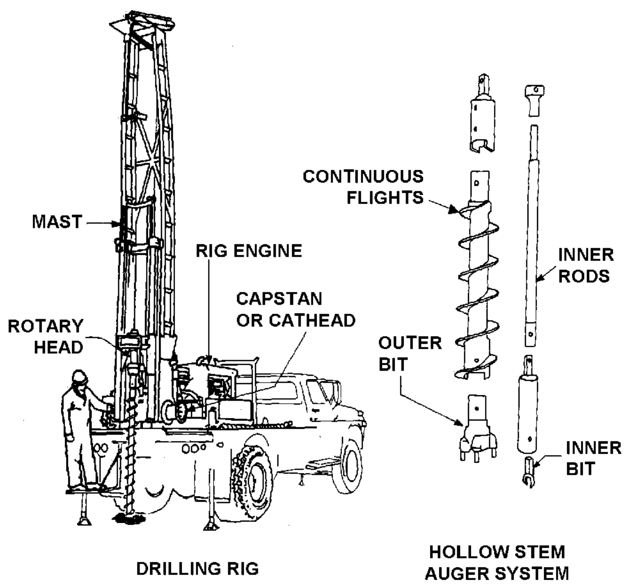
### 3. Rotary Auger Boreholes

The rotary auger rig is a heavier more powerful machine, usually truck or tractor mounted. The auger comprises a continuous helix of blades on a central shaft (continuous flight auger) which is rotated into the ground. Rapid boring may be achieved with this type of equipment, but difficulties may be encountered in sandy or silty soils that are unstable and therefore require casing.

Disturbed sampling maybe somewhat unreliable if soils from various depths become mixed during transfer to the surface via the continuous auger blade.

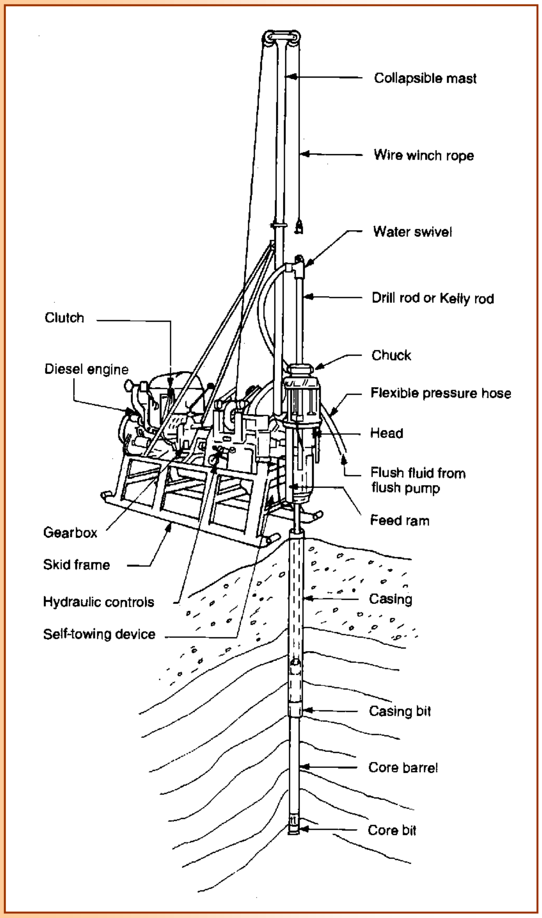
As a result of the large capital cost of this equipment and the associated sampling restrictions this technique is not widely used in borrow pit investigations.

Truck mounted rotary auger rig in operation during a borrow pit investigation.

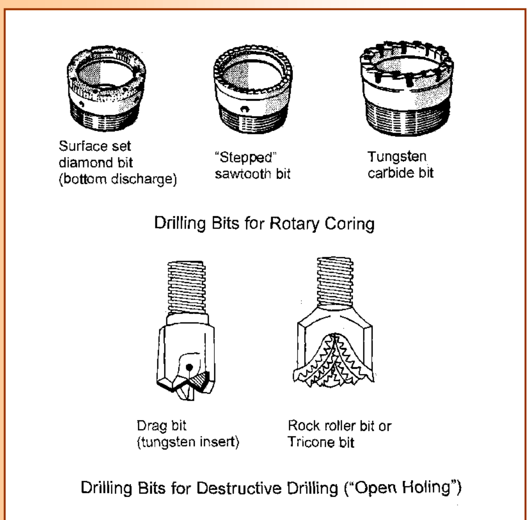



Source: Clayton *et al*, 1995 – Acker ADII

**Figure 3-5 Truck Mounted Rotary Auger Rig**




Layout for small scale rotary core drilling (source: Clayton et al ,1995)




Drilling bits for rotary drilling

### 4. Rotary Drillholes

Rotary drill rigs come in a variety of sizes from small skid mounted machines to large truck mounted machines. They use a rotary action combined with downward force to grind away the material in which the hole is made.

The primary use of rotary drilling techniques is to investigate rock quality by taking core samples. However, rotary drilling rigs can be used for non core drilling.

A destructive tricone (rock roller) drill bit is generally used to advance a non-coring hole. Only the rate of advance and characteristics of the cuttings flushed to the surface by the drilling water give any indication of the strata penetrated. This can be supplement by small disturbed samples recovered from a driven sampler (ie SPT sampler). Non core drilling is therefore of limited use, but might be employed through the overburden covering a rippable rock or quarry stone.

Rotary coring involves the use of a water lubricated diamond or tungsten tipped hollow core bit attached to a core sample recovery barrel and a series of hollow drill rods. In weak or fractured rocks better quality core are recovered from larger diameter bits. A further increase in core quality can be obtained by the use of double tube core barrels and special linings, which prevent the circulating flushing water from disturbing the cored material. The frequency of fractures in the recovered core combined with rock strength testing can provide a good guide to the excavation characteristics (rippability) of potential road building materials (refer Section 3.5).

Some ground investigation drillers have developed a technique for recovering disturbed soil samples by "dry drilling" with a single tube core barrel, but this practice is not widely used and is less successful in coarse deposits with little plastic clay binder.

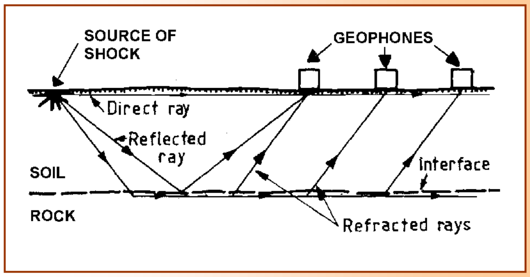
Further information on site investigation drilling and the descrition of drill cores is contained in BS 5930 "Code of Practice for Site Investigations" (1981) and "The logging of rock cores for Engineering Purposes" (Geological Society, 1977).

# 3.4. Geophysical Investigations

Geophysical surveying is a specialised subject normally requiring expert advise and interpretation. However, the two relatively simple geophysical survey techniques reviewed below can, in certain circumstances, be successfully used during the investigation of potential borrow sources.

## Seismic Refraction Surveys

The principle of seismic surveying is based on the fact that shock waves caused by an impact force on the ground travel at different speeds through different geological materials. Shock waves travel slowly through loose soils and quickly through massive rock.



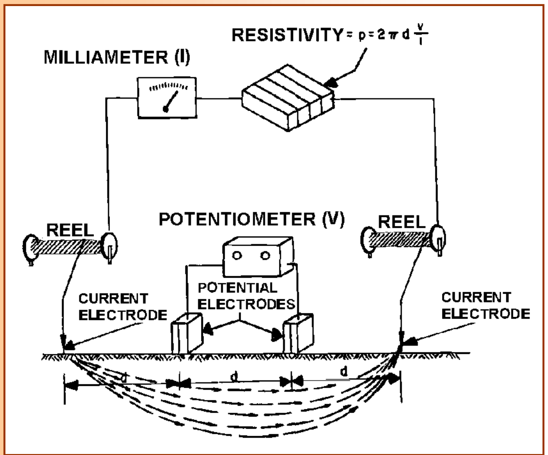

Lay out for a seismic refraction survey (source: Carter, 1983)

During the test the shock may be generated by a hammer blow on a steel plate (anvil), by a falling weight of say 50 kg from a tripod or from a small explosive charge. Larger shocks are required if the desired depth of penetration is great. The shock waves generated by the impact are detected at the surface by a series of vibration detectors (geophones) arranged at increasing distance from the source.

This method can provide information on a several layers in the ground provided that each layer is sufficiently thick and transmits the seismic shock waves at a higher speed than the one above it. That is to say, the materials are becoming harder with depth.

Seismic surveying can be used to help estimate the thickness of overburden deposits or the top and bottom of gravel beds, but some "control" from borehole information is required. Seismic surveying between boreholes can be very useful in determining the subsurface profile of large borrow deposits. It is also a material prospecting tool.

Seismic refraction surveys can also provide data on the characteristics of an individual rock strata. This may assist in determining the changing excavation characteristics of a weathered and fractured rock deposit that is "rippable" to a certain depth below the ground (see Section 3.5)




Layout for a resistivity Survey (source: Rico *et al*, 1988)

## Resistivity Surveys

The principle of resistivity surveying is based on the fact that different geological materials present differing resistance to the passage of an electric current. Some materials are good conductors (present low resistance) such as moist clay.

During the test four electrodes are placed in the ground and a current passed between the outer electrodes and the voltage recorded between the two inner electrodes is measured. Various electrode arrangements have been developed for depth probing and sub-surface profiling.

For sand and gravel deposits the Wenner electrode arrangement is often the most useful.

This method can be effective for identifying simple layer boundaries between soils, soil and rock and water-bearing strata. Detection of layers is limited to three or four with similar thicknesses. It is often rather inaccurate for depth prediction (+/- 20%), but may be used to investigate large areas economically compared to boreholes (although some borehole or trial pit "control" is required).

| Material | Resistivity (Ω m) |
|---|---|
| Clay* | 3–30 |
| Saturated organic clay or silt† | 5–20 |
| Sandy clay* | 5–40 |
| Saturated inorganic clay or silt† | 10–50 |
| Clayey sand* | 30–100 |
| Hard, partially saturated clays† and silts, saturated sands and gravels† | 50–150 |
| Shales, dry clays, silts† | 100–500 |
| Sand, gravel* | 100–4000 |
| Sandstone* | 100–8000 |
| Sandstones, dry sands and gravels† | 200–1000 |
| Crystalline rocks* | 200–10 000 |
| Sound crystalline rocks† | 1000–10 000 |
| Rocksalt, anhydrite* | >1100 |

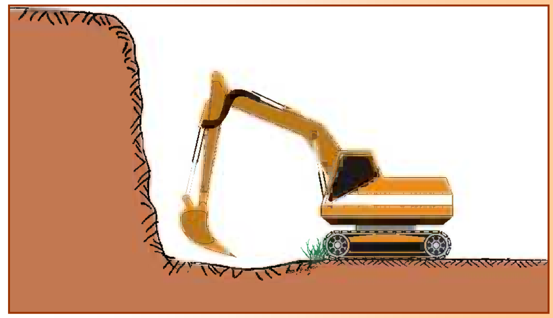
* Values from Dohr (1975).
† Values from Sowers and Sowers (1970).

**Table 3-1 Resistivity of Different Materials**

# 3.5. Investigation of Material Excavation Characteristics

## Diggability

The “diggability” of the ground is of major importance in the selection of excavating method and equipment during borrow pit development.  In soils diggability is primarily related to density, cementation and water content. In rocks, diggability is mainly determined by intact strength (compressive strength), state of alteration (weathering) and the spacing of planes of weakness (fractures, faults and bedding planes).



There is no generally accepted measure of soil diggability, assessment is usually made according to the local experience of the supervisor.  Clearly the best assessment of diggability is the excavation of trial pits or trenches with various items of equipment.  Otherwise useful information can be obtained by examining similar excavations in the locality.

A good initial guide to the diggability of fractured rock deposits has been prepared (Franklin *et al*) based on rock strength and fracture spacing (Figure 3.6).  Fracture spacing is best measured in exposures, but can also be assessed from core samples recovered from rotary drillholes.  Compressive strength and point load testing are simple and quick laboratory tests, but an experience materials engineer will be able to make a good estimate of compressive strength on site using a hammer.  Franklin’s Figure also indicates when rock is likely to require ripping or blasting to aid excavation.

Diggability of materials can be based upon the results of a seismic survey, because the speed of shock waves (seismic velocity) through the ground provides a guide to material density and fracturing.  A chart has been prepared that relates use of excavation plant and diggability to the seismic velocity of the ground (Atkinson).  Ground with a seismic velocity of lower than 1000 meters/ second may be diggable.

More detailed information on the assessment of excavatability of of rock is contained in Pettifer & Fookes (1994).  This paper notes that Franklin’s Figure 3.6 has become somewhat oudated with respect to use of the more powerful and efficient plant that has become available.

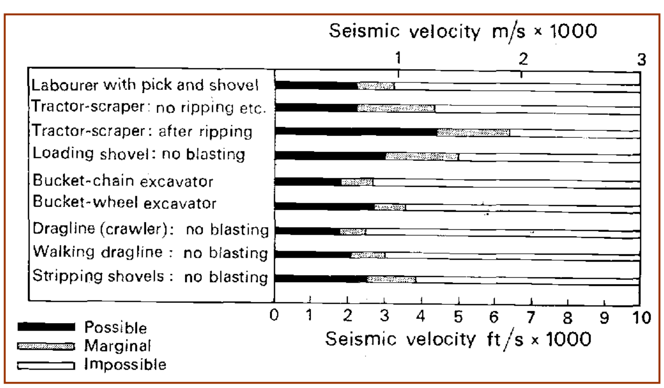



**Figure 3-6 Seismic Velocity for Determining “Diggability” (after Atkinson, 1971)**

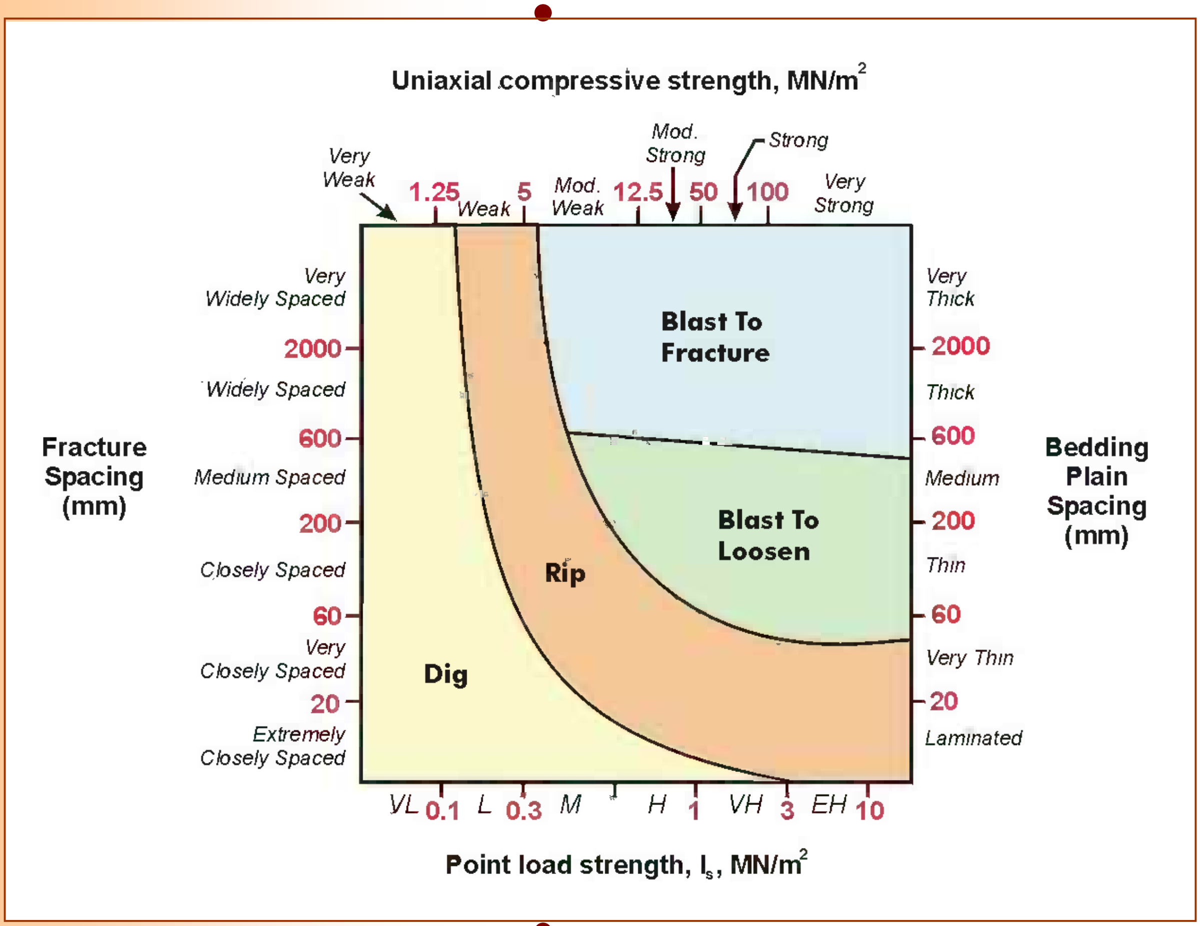



**Figure 3-7 Rock Quality Classification in Relation to Excavation (after Franklin et al, 1971)**

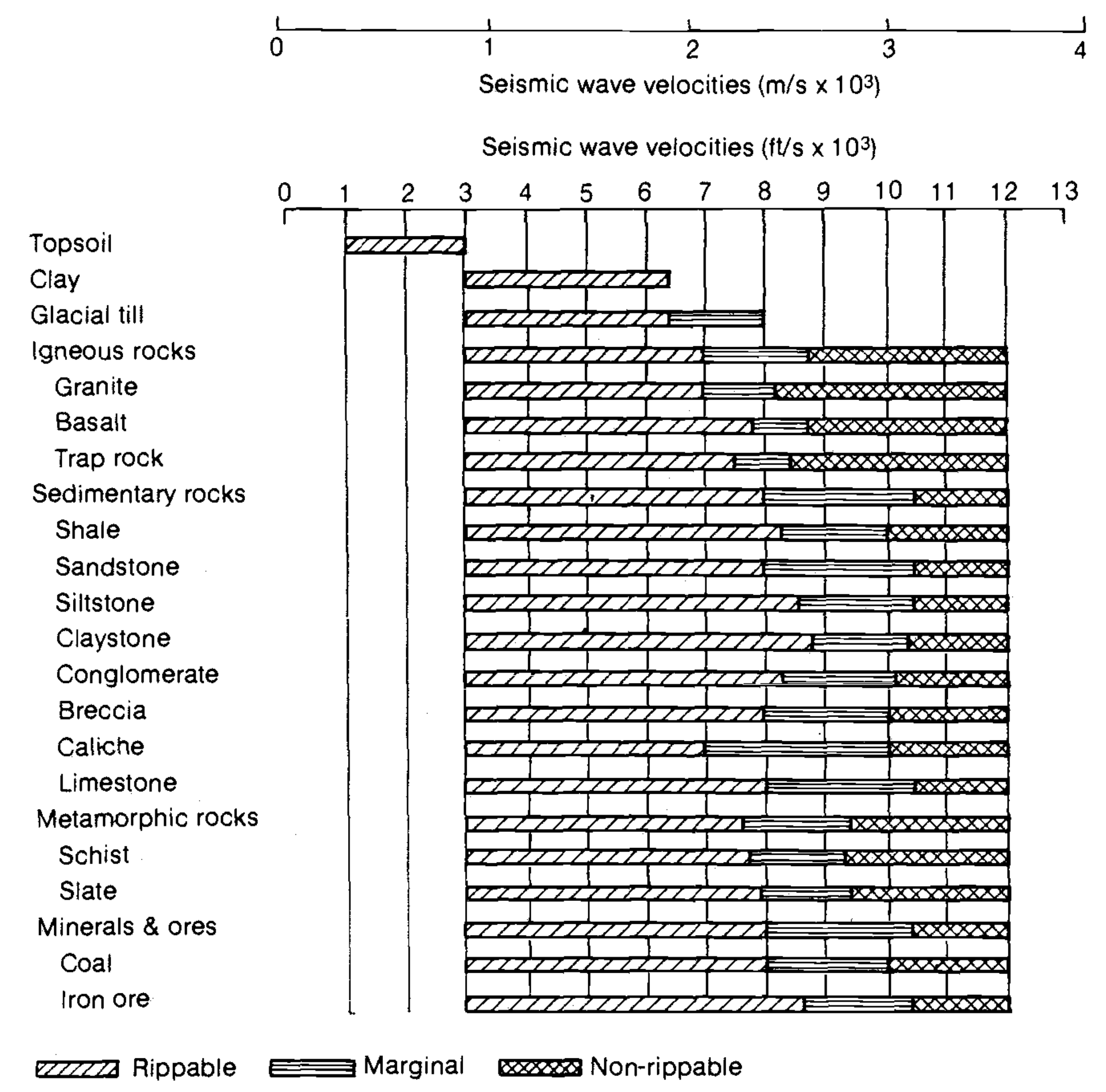



**Figure 3-8 Ripper Performance Chart for Caterpillar D9H Dozer with Multi/ Single Shank D9 Ripper (After Caterpillar Overseas S.A.)**

Three tine adjustable ripper

Single tine non adjustable ripper, suitable for very heavy ripping

## Rippability

Ripping is an inexpensive method of excavating fractured or soft rock. A ripper consists of one or more steel shanks or tines fitted to a strong frame that is mounted on the rear of a bulldozer. The ripper tines are drawn through the ground causing it to break.

The ability for a ripper tine to gain entry into a rock mass is determined by the compressive strength of the rock, its existing fracture characteristics and the power of the bulldozer. Franklin's Figure 3.6 provides an initial indication of the relationship between the fracture spacing and the strength characteristics of rocks that can be ripped with a powerful bulldozer.

When the rock to be evaluated cannot be seen in exposure, fracture logs from rotary cores can provide sufficient information when combined with compressive strength testing. The relationship between the speed of shock waves (seismic velocity) and the rippability of commonly found materials has been established and charts published by caterpillar and other manufacturers of earth-moving equipment. These charts take into account different bulldozer horsepower and the number of ripper tines used.

A relatively conservative summary of this information as a guide for initial assessment of rippability is given below:

| Seismic Velocity (p wave) m/s | Excavation Characteristics |
|---|---|
| 450 – 1200 | Easy ripping |
| 1200 - 1500 | Hard ripping |
| 1500 - 1850 | Very hard ripping |
| 1850 - 2150 | Extremely hard ripping |
| 2150 | Blasting required |

**Table 3-2 Guide to Initial Assessment of Rippability**

Additional detailed information on the assessment of rock rippability and productivity rates in various geological materials is contained in Macgregor *et al*, 1994

# 3.6. SAMPLING

## 1. Taking Representative Samples

The selection and taking of representative material samples is often the most important and difficult task to be carried out during a borrow pit site investigation.

A sample must be a small quantity of material that represents in every way a much larger quantity of material. When taking a sample the aim is not usually to select the best or worst examples of the material.

Within the identified workable deposit sampling should be carried out on a random basis. This may be from a grid of trial pits or at say 20m intervals along an existing pit face, but personal preferences must not be allowed to interfere with the selection.

It will typically be necessary to sample at least 5 locations per borrow pit (covering the full depth of the layer to be used) in order to quantify variability.

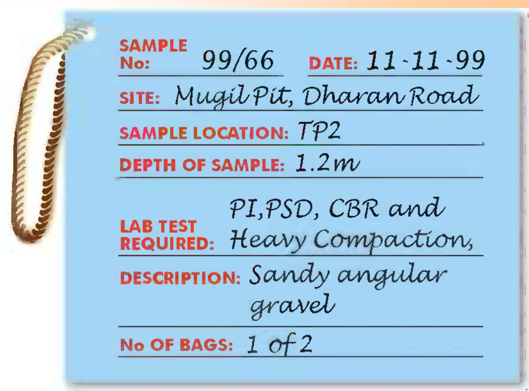
Greater care has to be taken when sampling coarse grained (gravelly) materials than when sampling fine grained (sandy and clayey) materials. In particular, it is necessary to make sure that all particle sizes are included in the sample bag – **do not remove large stones from the sample**.

The following guidelines apply to the sampling method:

- Always use a scoop or shovel with sides to take samples. If a flat spade is used the large stones will roll off the sides and the remaining sample will contain more fines than is representative.
- When sampling from a stockpile the material on the top and sides of the pile must not be taken because this material is generally coarser than the interior of the stockpile. Dig small holes in the stockpile and sample from the base of these holes. Sample various locations then thoroughly mix them together.
- Similarly when sampling river bed deposits **do not sample from the surface** where large stones collect. Dig a hole and sample from at least 500mm depth.
- If a sample obtained is too large when sub-samples are mixed together it must be reduced to the required size by quartering. This procedure is described below.
- The final sample should be placed in a hessian bag, strong polythene bag or other strong bag of suitable size (ie clean empty rice, flour or sugar sack). **Care should be taken to make sure that there are no small holes in the bag through which fine material may be lost**.

Prepare **Sample Labels** that provide the following information: Sample Reference No; Pit Name and Location; Location Sampled including depth; Date Sampled; Lab Tests Required (if known). Use of pre-printed sample record cards is recommended. Preferably place one label in the bag and attach one to the outside (or write details directly on the bag).

Sampling a small river bed gravel stockpile.




Samples drying under cover prior to testing.

### 2. Size of Sample

The size of sample is important for two main reasons:

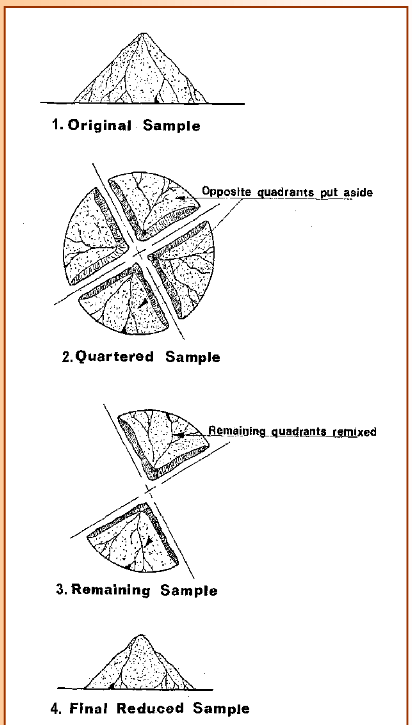
- There is a minimum size below which a sample cannot accurately represent the original material. Larger samples are required for coarse grained (gravelly) materials.
- Sufficient sample must be taken to enable the required laboratory tests to be performed (and repeated if necessary).

If transport of the samples is not a constraint then it is better to take large samples, that can be divided in the Laboratory

Recommended **minimum** sample sizes are given below:

| Tests Required | Fine grained soil (Max size 2mm) | | | | Coarse grained gravel (max size 40 mm) Not susceptible to crushing | | | | Coarse grained gravel (max size 40 mm) Susceptible to crushing | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grading | | * | * | * | * | * | * | * | * | * | * | * |
| Atterberg Limits (PI, LL & LS) | * | * | * | * | * | * | * | * | * | * | * | * |
| Compaction | | * | * | * | | * | * | * | | * | * | * |
| CBR (I point) | | * | | | | * | | | | * | | |
| CBR (3 points) | | | * | * | | | * | * | | | * | * |
| Treatment Tests | | | * | * | | | | * | | | | * |
| Minimum Sample Mass (kg) | 5 | 20 | 35 | 80 | 20 | 40 | 60 | 150 | 20 | 60 | 80 | 180 |

**Table 3-3 Recommended Minimum Mass of Sample (after Kenya Roads Dept 1987)**




### 3. Sample Quartering

If a sample obtained is too large when sub-samples are mixed together it must be reduced to the required size by a procedure called quartering:

- The original sample is placed in a neat circular pile.
- Using a shovel, this pile is then separated into quarters by making two lines at right angles through the centre of the pile. Two opposite piles quarters are then put aside and the remaining two quarters mixed together to give a smaller sample.
- If the divided sample is still too large the procedure is repeated

This will make sure that the smaller sample represents the larger sample.

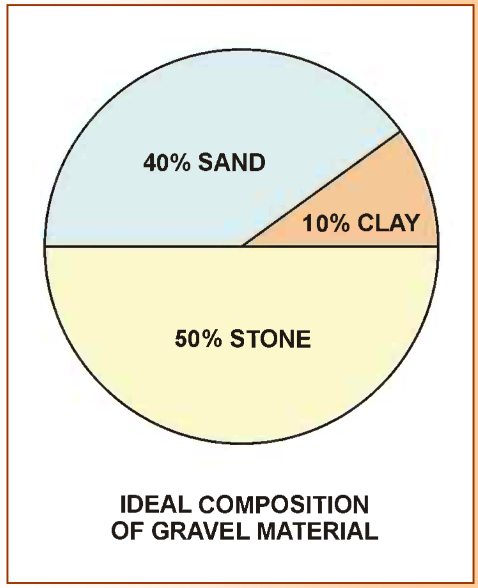
During a testing program a small sub sample should be retained, in case any repeat testing is required.

## 3.7. Materials Testing

The most suitable materials for building low cost unpaved roads consist of a well graded **gravel-sand mixture with a small proportion of clayey fines** (for details refer Section 4).

Testing of pit materials is required during a borrow pit site investigation for the following reasons:

- To determine the engineering properties of the material including:-
  - proportions of gravel, sand and fines;
  - the cohesion/plasticity characteristics of the fine material;
  - strength of the aggregate particles
  - load bearing characteristics of the compacted material
- To establish whether the materials in a pit are all of similar quality (ie determine material variability)
- To provide a documented record of pit material characteristics (for future reference)



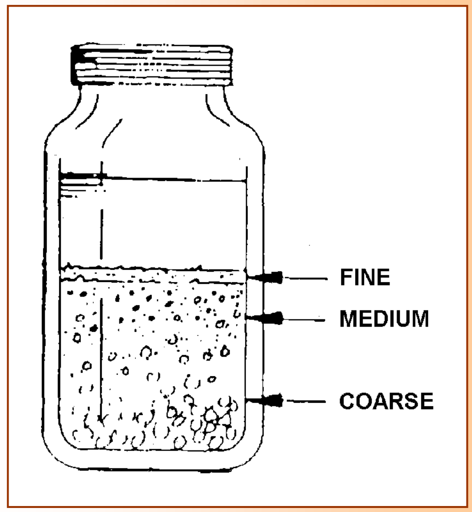

**Preliminary On-Site Testing and Evaluation**

There are a number of field tests that may be used to make an initial assessment of the quality of materials in an existing or potential material source. These are described below.

**1. On- site Grading Tests**

Settlement Test - place a sample in a glass jar, add water and shake hard. Then leave to allow the particles to settle. Gravel, sand and coarse silt will settle within a few minutes. Any clay and fine silt will remain in suspension for several hours.

The approximate quantities of each particle size will be seen as layers in the sample. The finer material usually being a different colour. Settling will be clearer if a little salt is added to the water before shaking.

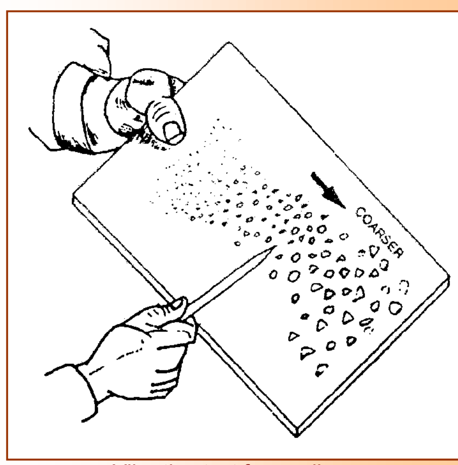



Settlement test for grading

A good gravel road surfacing material should have a mixture of gravel, sand and clay in about the following proportions:

| | |
|---|---|
| Gravel (>2mm) | 50% |
| Sand | 40% |
| Silt & Clay | 10% |

Vibration Test - dry materials can be tested by placing a broken up sample on a slightly inclined board and tapping it lightly with a stick or penil. The coarser materials will move down slope more quickly than the fine material.




Vibration test for grading

If there is a good range of different sized particles between the largest and smallest then the sample is said to be “Well Graded” and it will compact well. If only a few sizes can be seen it is single sized or Poorly Graded (refer Figure 4.2).

**2. On- site Cohesion/Plasticity Evaluation**

Take a hand full of damp material (moisten if necessary) and mould it into a ball to check for the presence of cohesive fine material (binder material).

If cohesive fines are present the material will stick together when placed on a flat surface. Silts and Clays will also stain the hands.

**3. On- site Aggregate Strength Evaluation**

Take dry sample of material and break it up. Test the gravel particles by tapping lightly with a hammer. If they disintegrate easily the material is unlikely to be suitable for road gravelling as the same disintegration is likely to occur under traffic. However, some materials with relatively weak particles may perform satisfactorily (ie laterite and calcarenite gravels).

The Aggregate Pliers Test is a simple field test developed in South Africa for quantifying particle strength of relatively weak materials. The test involves obtaining 100 to 200 pieces of the air-dry 19.1 to 12.7 mm aggregate portion of the material. The first step is to try and break the pieces between the thumb and forefinger, using both hands simultaneously. The unbroken pieces are them tested with an ordinary pair of 180mm pliers in the concave serrated portion of the jaws. In both cases maximum strength should be exerted, although this aspect does not seem to be the particularly critical. The total percentage passing the fingers test is called the Aggregate Fingers Value (AFV) and the percentage passing the pliers test is the Aggregate Pliers Value (APV).

A fair correlation between the Aggregate Pliers Test and the Laboratory 10% Fines Aggregate Crushing Test (10% FACT - refer Section 3.7.3) has been found to exist. Material unbroken by the pliers tends to have a 10% FACT value of more than 100 kN while that unbroken by the fingers tends to have a 10% FACT value of more than 50 kN. The test is only useful on materials whose crushing strength is less than about 150 kN (Netterberg 1978).

## Laboratory Testing

In order to fully assess the engineering properties of a borrow pit material it is necessary to have samples tested in a Materials Laboratory. The laboratory will use standard testing procedures to classify the samples taken. The results obtained can then be compared with appropriate material specifications that define the desirable properties of gravel road materials (refer Section 4)

### 1) Laboratory Grading Tests

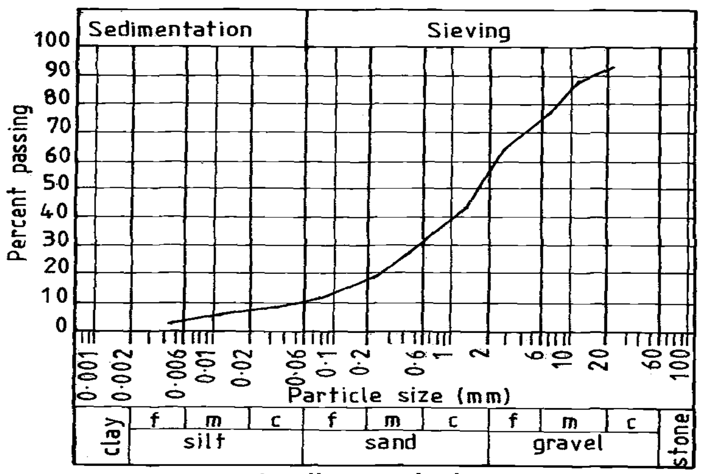
The particle size distribution grading of a road surfacing material is an essential guide to the suitability of the material since the engineering properties are very dependant on grading.

Grading analysis involves the separation of the various particle sizes through a series of circular test sieves, so that the proportion of each size fraction may be established. The proportion of gravel, sand, silt and clay is defined by the particle sizes shown opposite (British Standard definitions)

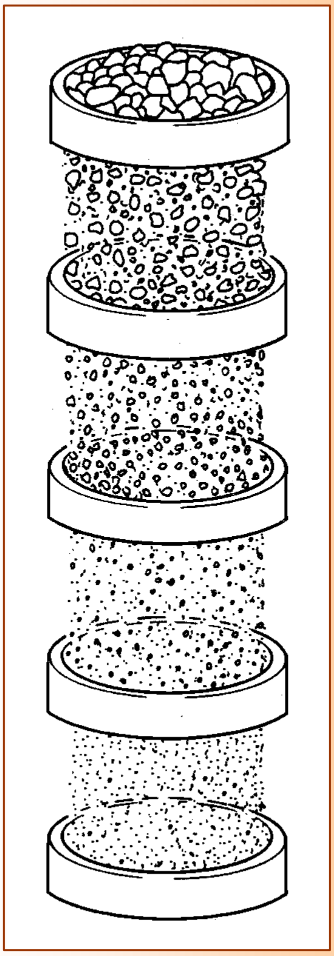
Particle size gradings can be carried out by dry sieving or by wet sieving. Dry sieving is most suitable for relatively clean free running sand and gravel materials. Samples containing more than 10 to 15% of silt and clay are more accurately tested by wet sieving. In a well equipped laboratory a set of about 8 or 9 different sieves would be used to analyse road building materials.

However, the grading requirements for the characterisation of material for unpaved low traffic volume roads can be simplified so that the test can be carried out on site with a minimum of equipment. The simplified procedure is based on only 5 sieve sizes: 37.5 mm, 26.5 mm, 4.75 mm, 2.00 mm and 0.425mm.

The material is air dried and broken up, the mass determined and then it is sieved (manually shaken) through the recommended sieves with a soft brush being used as necessary. The mass of each proportion is determined. The Oversize Index, Grading Coefficient and percentage passing the 0.425 sieves can then be determined to assess material suitability (refer Section 4).



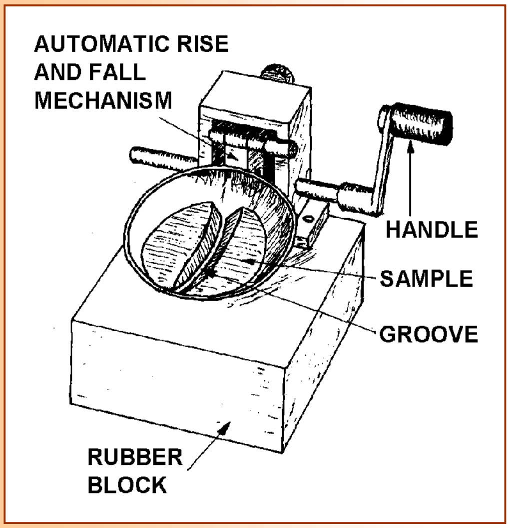

**Grading Analysis**



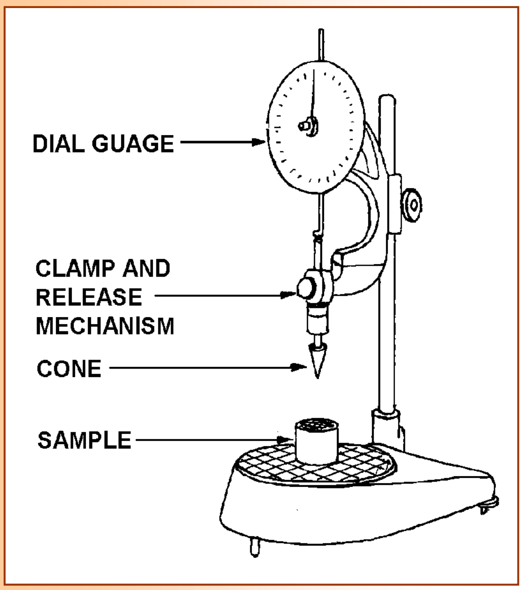
Particle size distribution analysis using sieves (Source Bomag 1983)

| Description | | Particle Size |
|---|---|---|
| Boulders | | Greater than 200 mm |
| Cobbles | | 60 – 200 mm |
| Gravel | Coarse | 20 – 60 mm |
| | Medium | 6 – 20 mm |
| | Fine | 2 – 6 mm |
| Sand | Coarse | 0.6 – 2 mm |
| | Medium | 0.2 – 0.6 mm |
| | Fine | 0.06 – 0.2 mm |
| Silt | | 0.002 – 0.06 mm |
| Clay | | Less than 0.002 mm |

Grading Classification (After British Standards)




Casagrande apparatus for determination of Liquid Limit (LL) of soils.




Cone penetrometer apparatus for determination of Liquid Limit (LL) of soils.

**2. Laboratory Cohesion/Plasticity Evaluation**

Material for surfacing unpaved roads requires some clayey fines to act as "binder". The cohesion associated with clay soils helps to hold the aggregate particles in place on the road. Cohesion is related to plasticity and is measured in the laboratory by three test procedures, namely:

- Liquid Limit Testing
- Plastic Limit Testing
- Linear Shrinkage Testing

The **Liquid Limit (LL)** is an indication of the percentage moisture content at which soil changes from a firm plastic state to a soft liquid state. The test is carried out on the fine material which passes the 0.425mm test sieve. About 200 grams of material is required for the test.

Two methods are available for determining the liquid limit: the "traditional" method using the Casagrande apparatus and the more recently developed cone penetrometer method.

In the Casagrande test the moisture content at which the soil groove would be just closed by 25blows along a 13mm length is the liquid limit.

In the cone penetrometer test the moisture content at which the test cone penetrates the cup of soil 20mm is the liquid limit.

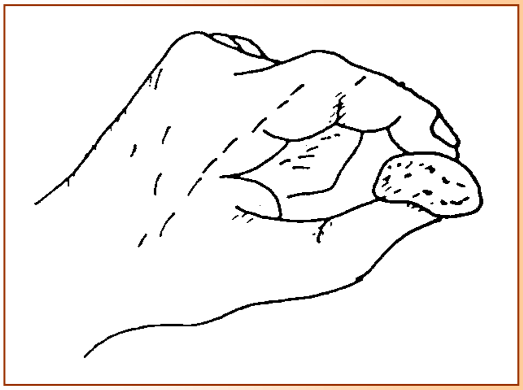
A certain amount of skill and judgement is required when carrying out these tests and estimating the amounts of water needed. The two test give broadly similar results but the cone penetrometer is quicker and gives more consistent results.

The **Plastic Limit (PL)** is an indication of the percentage moisture content at which the soil fines change from a semi solid to a plastic state. In this test a 20 gram sample of material passing the O.425 mm sieve is mixed with a little water until it becomes plastic enough to be formed into a ball. The soil is then moulded between the fingers until the surface begins to crack. It is then repeatedly rolled on a glass plate into 3mm diameter threads until longitudinal cracking causes the tread to start to break up. This moisture content is the plastic limit.

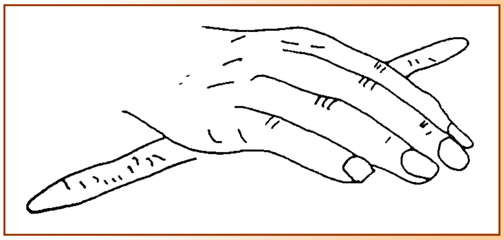
The difference between the Liquid Limit and the Plastic Limit is called the **Plasticity Index (PI)**. This index provides a good guide to the cohesive properties of a road building aggregate. A high PI may indicate the presence of an undesirable amount or type of clay.

In the **Linear Shrinkage (LS)** Test a 150 gram sample of material passing the 425 mm sieve is mixed with water to bring the moisture content to about the Liquid Limit. The sample is then placed in a standard mould (usually 140 mm long) and dried in an oven. The sample length after drying is measured. The Linear Shrinkage is expressed as the original length minus the final length divided by the original length. There is typically a close relationship between Linear Shrinkage and Plasticity Index **(PI = 2.13 x LS).**

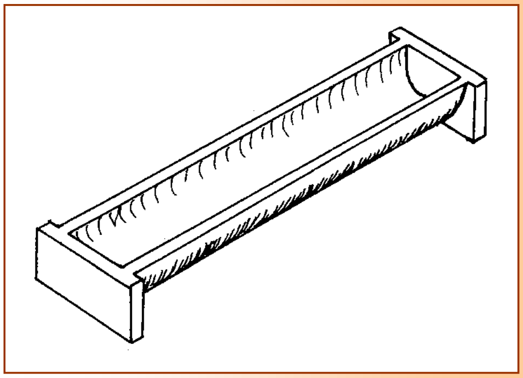
Unfortunately, preliminary research has shown that air drying of Linear Shrinkage samples is not effective for repeatable results.



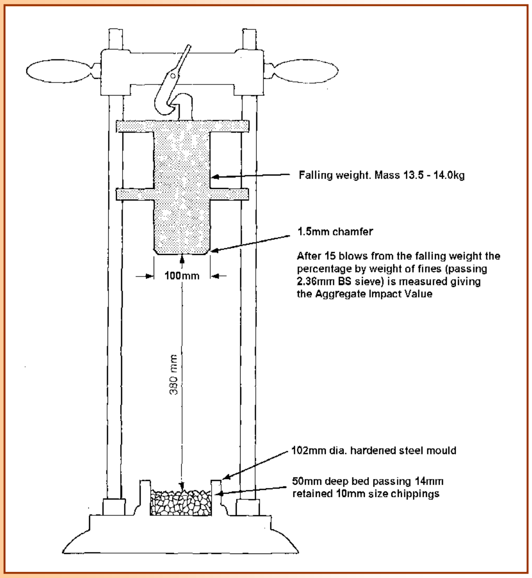
Plastic Limit (PL) determination of fine soil



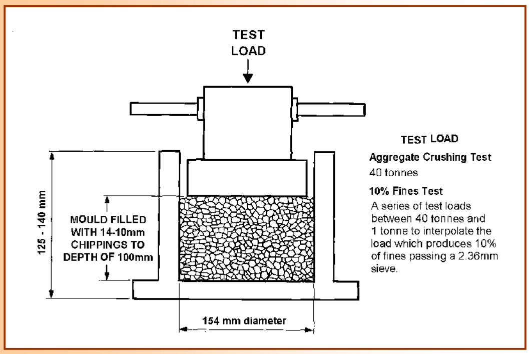
**PI = LL - PL**



Mould for determination of Linear Shrinkage (LS)




Aggregate Impact Value Test Apparatus (after R.S. Millard 1993)




Aggregate Crushing Value and Ten Percent Fines Test Apparatus (after R.S. Millard 1993)

### 3. Laboratory Aggregate Strength Evaluation

Aggregate hardness testing is necessary to identify those materials which will disintegrate during compaction or under traffic, as well as those which are excessively hard and will result in a rough unpaved road if too much of this type of material is included.

There are a range of methods for testing aggregate strength. With the more common tests, the results obtained by one method can typically be related to results expected from another. Two common strength tests, the **Aggregate Crushing Value (ACV**) Test and **Ten Percent Fines Test (10% FACT**) are made in a concrete compression machine by applying load to aggregate particles and measuring the change in particle size grading (Refer BS 812). The **Los Angeles Abrasion (LAA) Te**st, is an impact test in which steel balls are rotated in a drum with the aggregate sample (Refer AASHTO Test Procedures). This test is tending to be replaced by the ACV and 10%FACT tests because they require less investment in specialist equipment.

The **Aggregate Impact Value (AIV**) apparatus has been developed in Britain to provide a more portable testing apparatus that can be used on site. In this test an aggregate sample in the size range 14 to 10mm is subjected to 15 blows from a hammer (13.5 – 14.1 Kg) falling through 380 mm. With weak aggregates the number of blows may be reduced in accordance with the modified procedure. AIV results have a good correlation with ACV results.

In South Africa the **Treton Impact Value (TIV)** Test (refer TMHI 1979) has been designed as a portable aggregate strength testing apparatus. It is a hammer impact test similar to the AIV test.

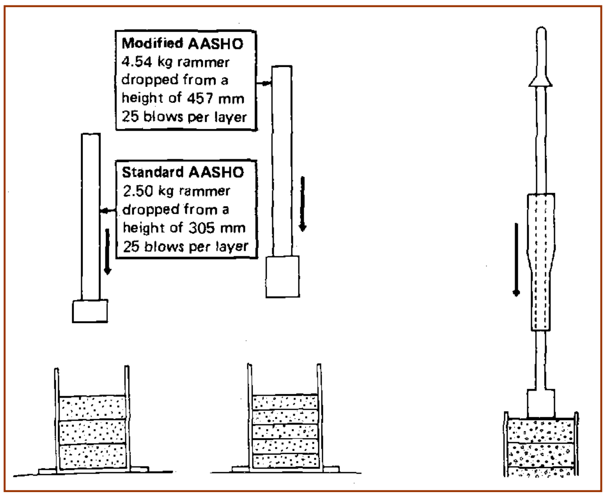
### 4. Laboratory Compaction Tests

The in-service performance of any road material is strongly influenced by its compacted density. Compaction on site is usually carried out by rolling. Control of compaction is necessary to ensure that a satisfactory density is achieved. Laboratory compaction tests provide the basis for control procedures used on site.

Compaction tests provide the following basic data for granular road building materials (Head 1992):

- The relationship between dry density and moisture content for a given amount of compaction.
- The moisture content required for the most efficient compaction. That is the moisture content at which the maximum dry density is achieved under a particular amount of compaction.
- The value of the maximum dry density.

There are several different standard laboratory compaction tests. The two methods most commonly used are those defined in the AASHTO/ASTM (USA) test procedures and those defined by the BS (British) Test Procedures. The tests makes use of a rammer and a cylindrical mould as illustrated in Figure 3.9 below:



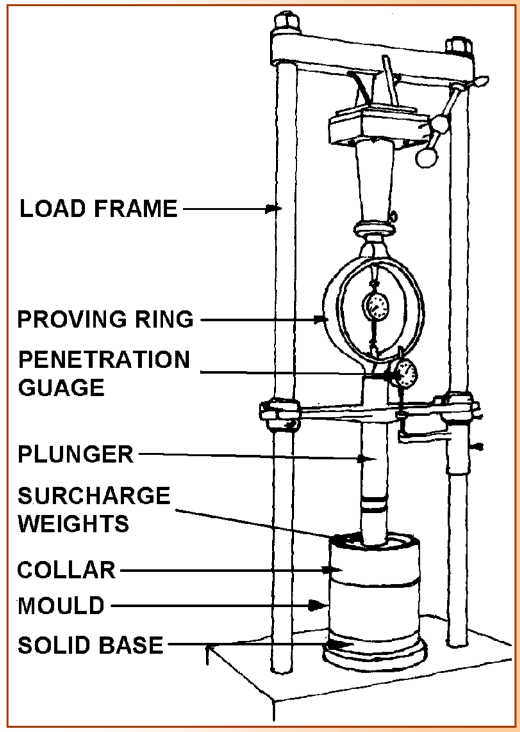

Source: Forssblad 1981

**Figure 3-9 AASHTO Compaction Tests**

### 5. Laboratory Testing of Load Bearing Characteristics

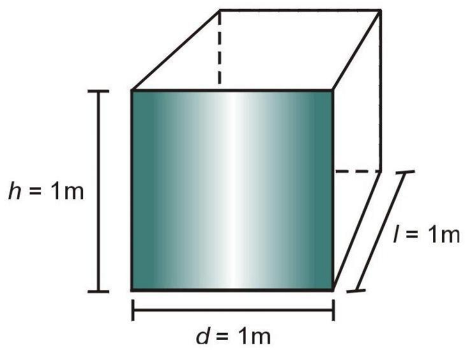
The standard laboratory test for establishing the load bearing capacity of a compacted road building aggregate is the **California Bearing Ratio Test (CBR).** This test consists of measuring the force required to push a cylindrical plunger of 49.6 mm diameter at a rate of 1mm per minute, 2.5 mm and 5 mm into the laboratory compacted material.

Tests are carried out either unsoaked or soaked. Unpaved road materials would normally be tested according to the 4 day soaked test procedure.Full CBR testing of aggregates for use in lightly trafficked unpaved roads is not often carried out because of time and cost. An estimated CBR value may be derived from the results of grading and plasticity tests.

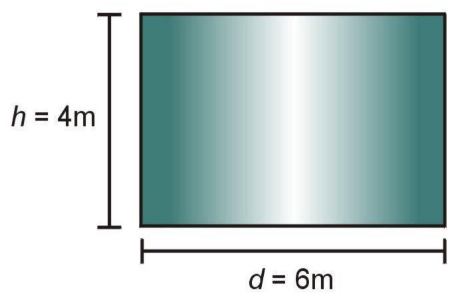



California Bearing Ratio Test Apparatus

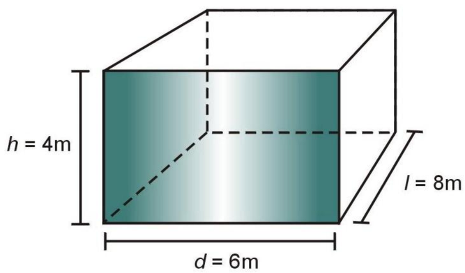
CBR test in progress, using a simple manually operated apparatus.




Definition:
$1m^3$ is the volume of a cube with a length of side 1m.




Area of rectangle
= depth x height
= 6 x 4
= $24m^2$




Volume of a rectangular prism
= depth x height x length
= 6 x 4 x 8
= $192m^3$

## 3.8. Resource Estimation

One primary objective of a borrow pit investigation is usually to establish the extent of a workable deposit and prepare an estimate of the quantity of material that can be extracted from the site.

The potential quantity of material that can be extracted from a borrow pit should always be calculated in cubic metres ($m^3$). A cubic metre should be seen as a box of material with a length (*l*) of 1 metre a height (*h*) of 1 metre and a depth (*d*) of 1metre.

Several terms might be applied to a borrow pit material estimate:

Total Resource Size – an estimate of the maximum volume of exploitable material that is believed to exist at a particular location

Partial Resource Estimate – an estimate of the material which is expected to occur in for example, a proposed pit extension.

Material Reserve Estimate – use of the term reserve implies that a given volume of material has been proven to exist within a defined area.

It is desirable to prepare an estimate of the total resource size of all borrow pits used to supply a road network, in order to assist with the planning of future road maintenance and construction. However, it may not be practical to undertake a detailed site investigation of the deposit to confirm such an estimate. As a result, considerable judgement and local knowledge may be required to ensure that a realistic resource estimate is made. In general, it is better to be conservative when making estimates rather than too generous. In respect of borrow pits for gravel supply to unpaved roads the following simple classification of total resource size is recommended:

| Term | Volume Range, $m^3$ |
|---|---|
| Very Limited | Less than 5,000 |
| Limited | 5,000 to 15,000 |
| Moderate | 15,000 to 35,000 |
| Large | 35,000 to 75,000 |
| Extensive | Greater than 75,000 |

**Table 3-4 Recommended Categories of Total Resource Size**

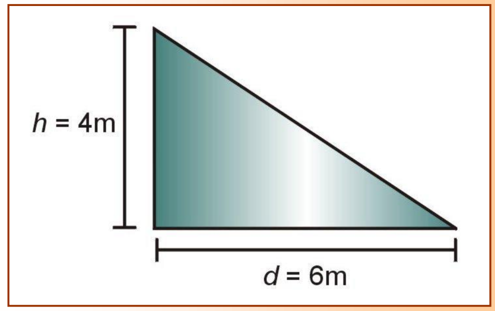
When there is some uncertainty regarding the extent of the workable deposit the descriptive term need not be supported by a specific volume estimate. However, when site investigations provide some certainty as to available material resources the estimate should be reported to the following levels of accuracy

- Report to the nearest 500 $m^3$ up to 15,000 $m^3$
- Report to the nearest 1,000 $m^3$ between 15,000 and 75,000 $m^3$
- Report to the nearest 5,000 $m^3$ when greater than 75,000 $m^3$

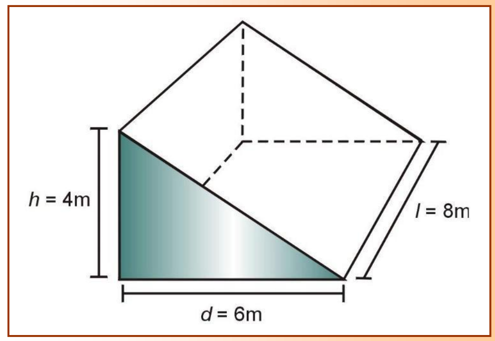
There are several factors, in addition to the actual size of the deposit, that should influence the total resource estimate prepared, these include:

- The quantity of material that is expected to be required. For example, there is no benefit in carrying out site investigations over an area that is so large that it locates more material than is ever likely to be required.
- Sensible limitations on land take. For example, it is unlikely to be either practical or environmentally acceptable to expect to obtain large quantities of gravel from a deposit that is only 500 mm thick. Losses associated with overburden removal and contamination with underlying material could effectively reduce the workable thickness in terms of quantity estimation to 300mm.
- Restrictions associated with existing land-use. For example, unless there are severe resource deficiencies it would not be acceptable to require removal of buildings and resettlement.
- Restrictions associated with land ownership. Some land may not be available for development.
- Restrictions associated with ground water. Available extraction equipment may not be able to extract materials from below the water table.

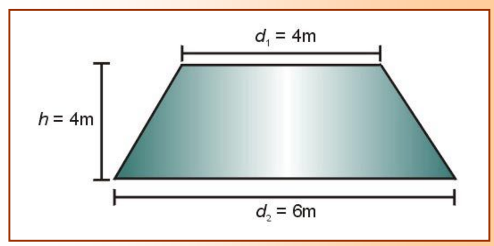
The size of hillside pits is often controlled by slope stability considerations and visual impact on the local environment.



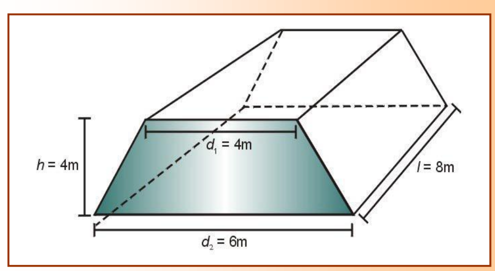

Area of triangle
= depth x half height
= 6 x 4/2
= $12m^2$



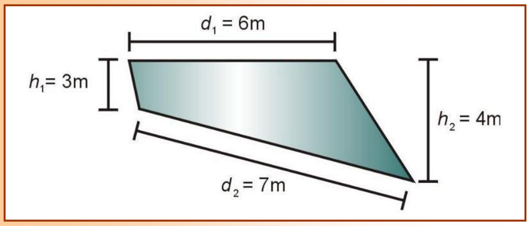

Volume of a triangular prism
= depth x half height x length
= 6 x 4/2 x 8
= $96m^3$



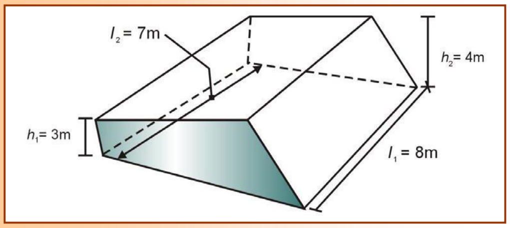

Area of a trapezoid
= Average depth x vertical height
= $(d_1+d_2)$ /2 x 4
= $20m^2$



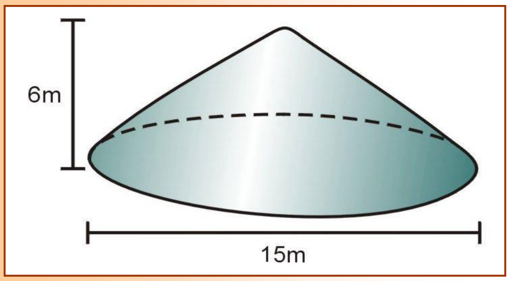

Volume of a quadrilateral prism
= Average trapezoid x length
= $(d_1+d_2)$ /2 x 4 x 8
= $160m^3$



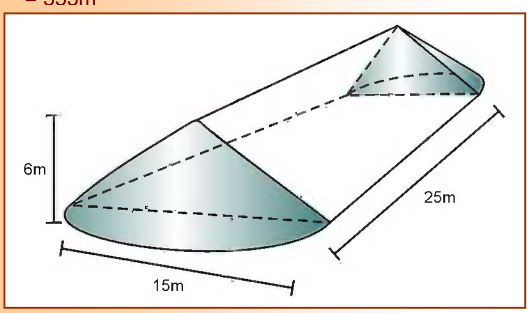

Area of irregular rhombus
= Average vertical height x average depth
= $d_1 + d_2$ /2 x $h_1 + h_2$ /2 = 6.5 x 3.5
= 22.75m$^2$



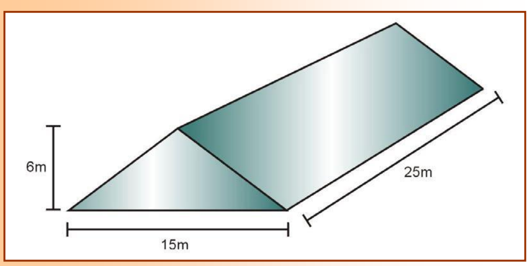

Volume of irregular rhombic prism
= Average vertical height x average length
= 22.75 x $l_1$+$l_2$ /2
= 170.6m$^3$




Volume of conical stockpile
= Area of base x height divided by 3
= $\pi r^2$ x (6/3)
= 3.14 x (7.5)$^2$ x 2 = 176.71 x 2
= 353m$^3$




Volume of extended conical stockpile
= Volume of ends (353m$^3$) + Centre



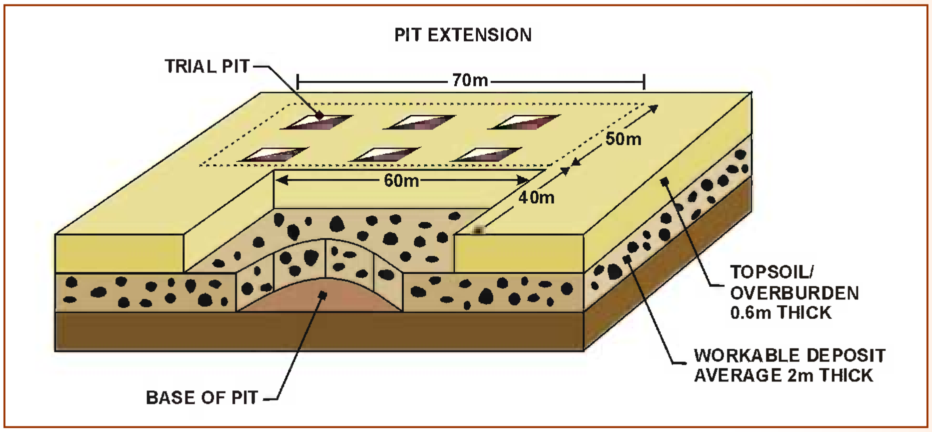

Volume of extended conical stockpile
Centre = 6/2 x 15 x 25 + (353m$^3$)
= 1125 + 353 = 1478m$^3$

## Calculating Resource Estimates

Volumes of material existing in a borrow pit should be visualised as one simple shape or a number of simple shapes such as rectangular prisms or triangular prisms. The volume of material in these shapes is estimated by first calculating a representative area in square meters (m$^2$). and then multiplying this area by its depth or a length (in metres). It may need to be an average depth or length if the pit is irregular in shape or the deposit has a variable thickness. Formula for calculating the area of shapes often found in pit developments are shown.

Two examples of partial resource estimates for borrow pit extensions are presented to illustrate the procedure.

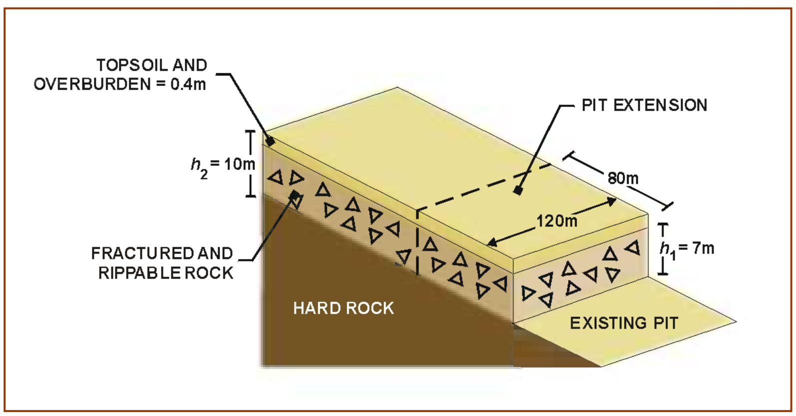
### Resource Estimate - Example 1 (flat terrain):




| | | |
|---|---|---|
| Gravel in stripped area | = 40 x 60 x 2 | = 4,800 $m^3$ |
| Less 20% for wastage | = 4,800 – (4,800 x 0.2) | = 3,840$m^3$ |
| Proposed extension | = 50 x 70m | = 3,500$m^2$ |
| Overburden clearance | = 3,500$m^2$ x 0.6m | = 2,100$m^3$ |
| Gravel in extension | = 3,500$m^3$ x 2 | = 7,000$m^3$ |
| Allow for 20% wastage | = 7,000 – (7,000 x 0.2) | = 5,600$m^3$ |
| Total resource in stripped area and in extension | = 3,840 + 5,600 | = 9,440 Say 9,000$m^3$ |

Note: The material reserves identified are required to supply 150mm of compacted gravel surfacing material for regravelling a 6m wide road (ie: 0.15m x 6m x 1000m = 900$m^3$ required per km). 9,000$m^3$ will therefore supply about 10km of road (assuming compacted gravel at similar density to gravel in pit face). Bulking of material in stockpile likely to be 1.20 (ie: 100$m^3$ excavated = 120$m^3$ in stockpile for haulage).

### Resource Estimate - Example 2 (hill terrain):




| | | |
|---|---|---|
| Volume of Overburden in Extension | = 80 x 120 x 0.4 | = 3,840$m^3$ to stockpile in pit base |
| Rippable rock in Pit Extension | = $h_1$+$h_2$ /2 x80 x120 | = 8.5 x 80 x 120 = 81,600$m^3$ |
| Assume 30% of rock will be oversize and removed by screening then resource in extension | = 81,600 – (81,600 x 30/100) | = approximately 57,000$m^3$ gravel |
| Assume bulking of material will be 1.25 | eg: 100$m^3$ excavated | = 125$m^3$ in stockpile for haulage |

## Material Wastage, Shrinkage and Bulking

It is important to make an appropriate allowance for wastage when making resource estimates. The main causes of wastage or loss of excavated road building material are as follows:

- Loss from the upper surface of the workable deposit or "bank" during overburden clearance
- Contamination of the lower surface of the bank by over excavation
- Removal of oversize material or excess fines Use of the excavated material to construct the base to stockpiles and construct haulage roads
- Loss associated with over placement of material on the road

When accurately calculating volumes of "bank" excavation required for a specific construction task, such as regravelling 10km of road, it is necessary to make an allowance for wastage. The amount of wastage will depend on many factors including: thickness and uniformity of the "bank"; method of extraction and processing; need for stockpiling etc. Wastage may typically vary from 5 to 30%. In addition to wastage there may be a significant "shrinkage" of material volume from the "bank" to the compacted road, if the bank deposits exist in a loose condition.

Also to be taken into account when hauling material from the borrow pit to the road is "bulking-up". When materials are excavated they are loosened and sometimes broken down, this results in an increase in volume per unit weight known as "bulking". The bulking factor of a material is the bulk density in the pit face (bank) divided by the loose bulk density. A bulking factor of 1.25 indicates that 100 $m^3$ of bank material will become 125 $m^3$ of loose material in the stockpile.

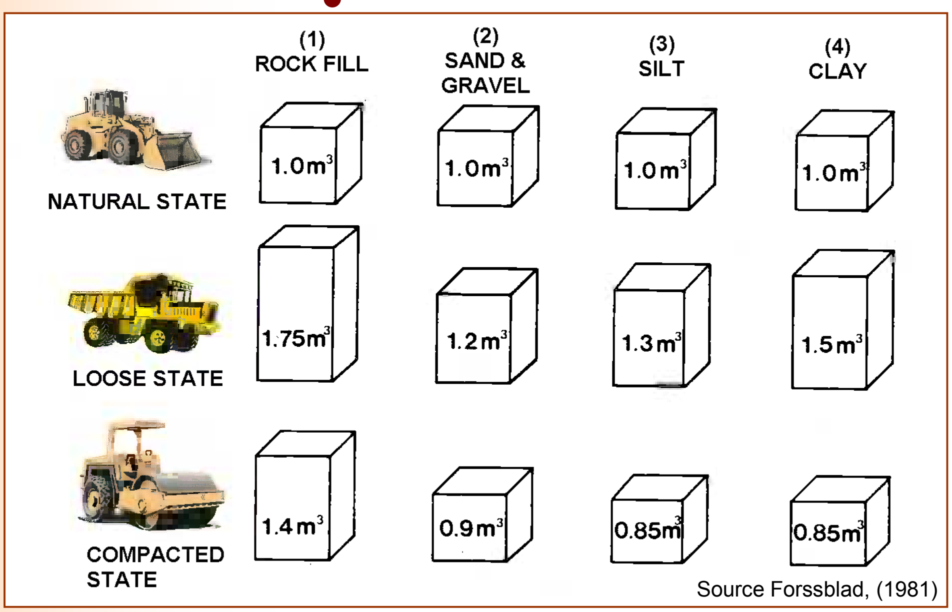



**Figure 3-10 Material Volumes in Natural, Loose and Compacted States**

The bulking and shrinkage factors of a deposit can be estimated from the results of density and compaction tests made on site and in the laboratory. The Table below provides typical density relationships.

| MATERIAL | MOISTURE CONDITION | BULK DENSITY (Tonne/m3) | | | SWELL (%) | SHRINKAGE(%) |
|---|---|---|---|---|---|---|
| | | Bank | Stockpile | Compacted | (Bank to Stockpile) | (Bank to Compacted) |
| TOPSOIL & fine OVERBURDEN | Dry<br>Moist<br>Saturated | 1.5 – 1.6<br>1.6 – 1.8<br>1.9 – 2.0 | 1.2 – 1.3<br>1.3 – 1.5<br>1.4 – 1.6 | 1,6 – 1.9 | 20 - 25 | 5 - 10 |
| SAND & GRAVEL | Dry<br>Moist<br>Saturated | 1.9 - 2.1<br>2.0 – 2.2<br>2.2 – 2.4 | 1.6 – 1.8<br>1.8 – 1.9<br>1.9 – 2.0 | 2.2 – 2.4 | 10 - 15 | 8 - 12 |
| SAND & GRAVEL + Fines | Dry<br>Moist<br>Saturated | 1.8 – 2.0<br>2.0 – 2.1<br>2.1 – 2.3 | 1.6 – 1.8<br>1.7 –1.8<br>1.8 – 2.0 | 2.1 - 2.3 | 12 - 20 | 8 - 12 |
| Gravelly CLAY | Dry<br>Moist<br>Saturated | 1.4 – 1.8<br>1.6 - 2.2<br>1.8 – 2.3 | 1.2 – 1.4<br>1.3 - 1.6<br>1.5 – 1.9 | 2.0 - 2.4 | 20 - 40 | 8 - 12 |
| SANDS | Dry<br>Moist<br>Saturated | 1.5 – 1.9<br>1.8 – 2.0<br>1.9 - 2.1 | 1.4 – 1.7<br>1.6 – 1.8<br>1.8 – 1.9 | 1.9 – 2.3 | 10- 15 | 5 - 15 |
| Fractured/Weathered (rippable) ROCK | Moist | 1.8 – 2.4 | 1.4 – 1.6 | 2.0 – 2.4 | 25 - 60 | 0 - 12 |

**Table 3-5 Typical Material Densities, Bulking and Shrinkage Factors**

# Section 4
# Pit/Quarry Evaluation & Selection

# 4. PIT / QUARRY EVALUATION AND SELECTION

After potential sources of road building material have been identified and site investigations carried out, the next activity is to establish which are the best sites to develop. The main influences that have to be evaluated include:

- Technical Considerations
- Economic Considerations
- Social and Environmental Considerations

A summary of all the main factors to be taken into account is presented in Figure 4.1. This Figure illustrates the large number of potential influences and their interrelationship. The decision to develop one material source rather than an alternative will often require engineering judgement in order to adequately balance the technical, economic, social and environmental considerations.

This Section provides guidelines for carrying out an evaluation of technical considerations and presents an introduction to economic influences. Detailed consideration of economic influences associated with developing a material supply strategy for sections of road are reviewed in Section 9. The detailed review of potential social and environmental impacts associated with material resource development is also presented separately, in Section 11.

High quality gravel wearing course

## 4.1. Desirable Characteristics of Unpaved Road Surfacing Gravel

Desirable material characteristics are considered below along with recommended methods of establishing the relative quality of one deposit as compared to another, based on the results of the standard laboratory tests described in Section 3.

### Material Performance Requirements

The in service performance requirements of an ideal gravel road surfacing material (wearing course gravel) can be listed as follows (Netterberg & Paige-Green 1988):

- Ability to provide an acceptable smooth and safe ride without excessive maintenance (ie freedom from corrugations, potholes, ruts and oversize material).
- Stability, in terms of resistance to deformation under both wet and dry conditions
- Ability to shed water without excessive scouring.
- Resistance to the abrasive action of traffic and erosion by water and wind.
- Freedom from excessive dust in dry weather.
- Freedom from excessive slipperyness in wet conditions without excessive tyre wear.
- Low cost and ease of maintenance.

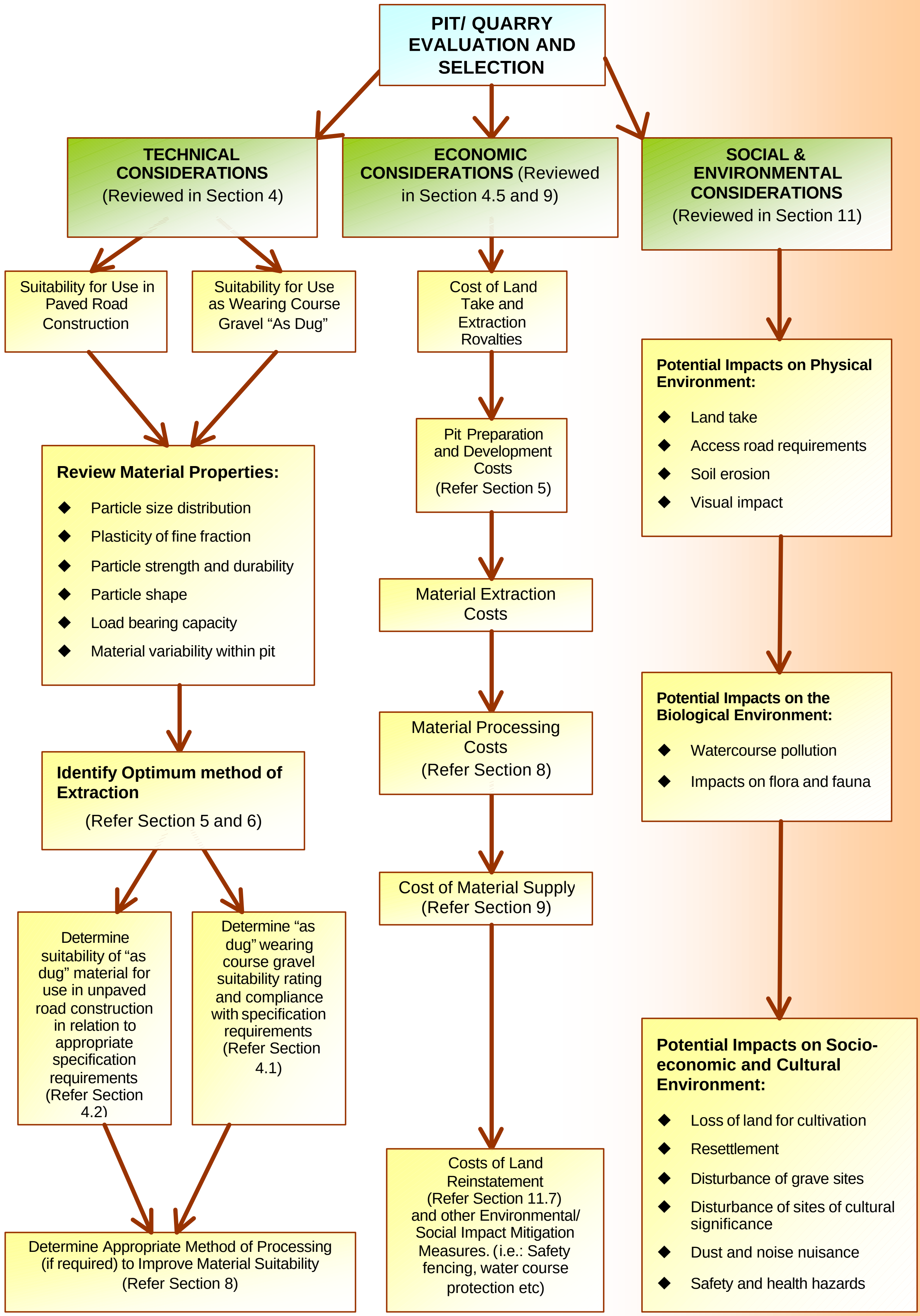



**Figure 4.1 Factors Influencing Pit/ Quarry Evaluation and Selection**

## Material Property Requirements

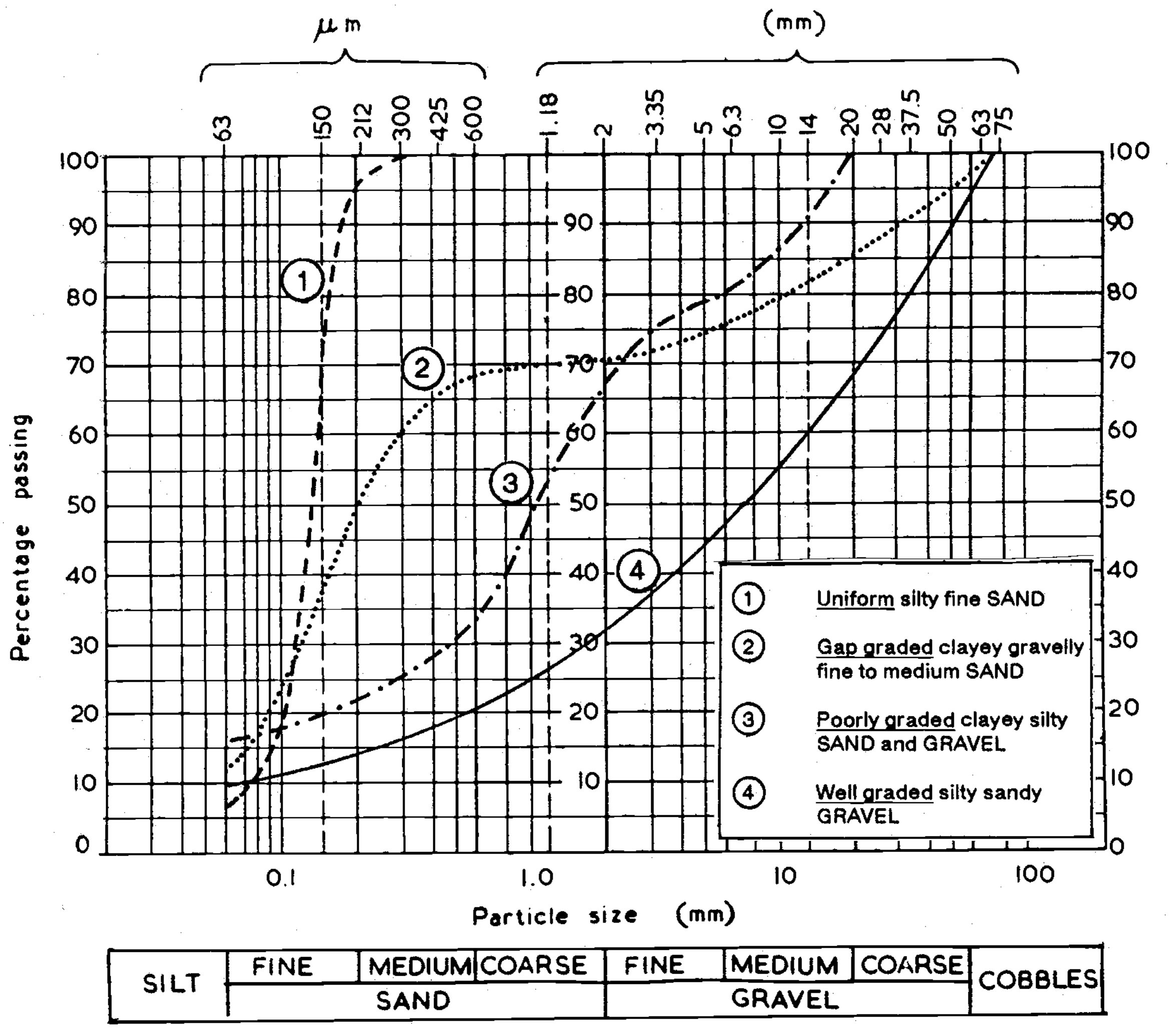
The relative quality and in-service performance characteristics of a gravel road surfacing material will be determined by the properties of the individual components (aggregate particles) and the engineering characteristics of the natural or manufactured mix.

The quality of any granular road material will be largely determined by five fundamental properties as listed below:

| | Material Characteristic | Description of the Material Property | Main Laboratory Tests Designed to Evaluate the Property. |
|---|---|---|---|
| 1 | Particle Size Grading | The relative proportions of each size fraction from gravel to clay size | Sieve Analysis |
| 2 | Plasticity of Fine Fraction | The characteristics of the particles smaller than 0.425mm to behave as a plastic/ cohesive material at different moisture contents | Liquid Limit Test<br>Plastic Limit Test<br>Linear Shrinkage Test |
| 3 | Particle Strength and Durability | The existing strength of individual particles and the ability of the particles to maintain this strength during the life of the road. | Aggregate Crushing Value Test (ACV)<br>10 % Fines Aggregate Crushing Test (10% FACT)<br>Los Angeles Abrasion Test (LAA)<br>Aggregate Impact Value Test (AIV)<br>Magnesium or Sodium Sulphate Soundness Test |
| 4 | Particle Shape | The angularity and flakiness of the aggregate particles and their ability to interlock together. | Visual description<br>Flakiness Index Test<br>Elongation Index Test |
| 5 | Load Bearing Capacity of the Aggregate Mix | The capacity of the compacted aggregate mix to support loads imposed by road vehicles | California Bearing Ratio (CBR)<br>Triaxial test (not practical for use as specification test) |

**Table 4-1 Material Characteristics Influencing Material Performance**

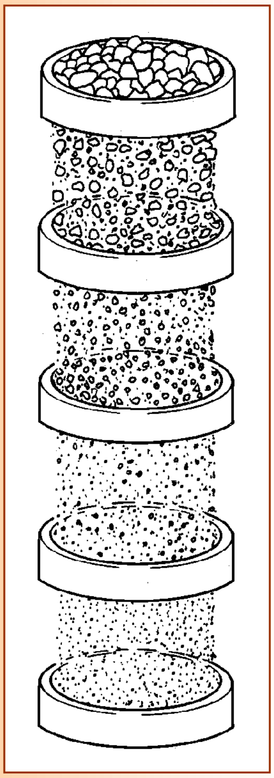
The majority of material specifications for gravel road surfacing materials place limits on particle size grading, plasticity of the fine fraction and CBR strength. The significance of particle strength and shape is typically assessed through the ability of the material to satisfy the CBR requirement. The durability of unpaved road materials is usually not a critical parameter (TRH 20 1990) except in the case of materials such as mudrocks that may be subject to rapid disintegration during the short design life of the unsurfaced pavement.




**Description of Material Grading**

| | | |
|---|---|---|
| Well Graded | - | Wide range of grain sizes, well distributed. |
| Moderately Graded | - | Wide range of grain sizes, moderately well distributed. |
| Poorly Graded | - | Uneven or ill proportioned distribution of particle sizes (giving poor compaction characteristics). |
| Uniform | - | Poorly graded material in which the size of most particles lies between narrow limits. |
| Gap Graded | - | Poorly graded material in which an intermediate size of particle is markedly under represented. |

**Figure 4-2 Material Grading Characteristics**



Sieve analysis for determination of particle size distribution grading (source Bomag 1983).

Sampling a stockpile of gravel road paving material

### i) Desirable Grading Characteristics for Unpaved Road Materials

Good wearing course gravels are "well graded", that is they have a wide range of grain sizes well distributed (refer Figure 4.2). The maximum size should ideally be 20 to 40mm. A small quantity (5 – 15%) of particles up to 50mm or 75mm in size may be tolerable. However, the presence of particles larger than 50 mm will make reshaping the surface with a grader difficult.

It is usually cost effective to crush or screen out particles larger than 38mm when producing wearing course gravels for roads carrying more than 50 vehicles a day. In practice gravel roads are often constructed with "as dug" aggregates that include a significant quantity of oversize which results in unnecessarily rough roads. Methods of dealing with oversize material are reviewed in Section 9.1.

All graded road materials can be divided into three basic classes after compaction (Yoder & Witczak 1975) as follows:

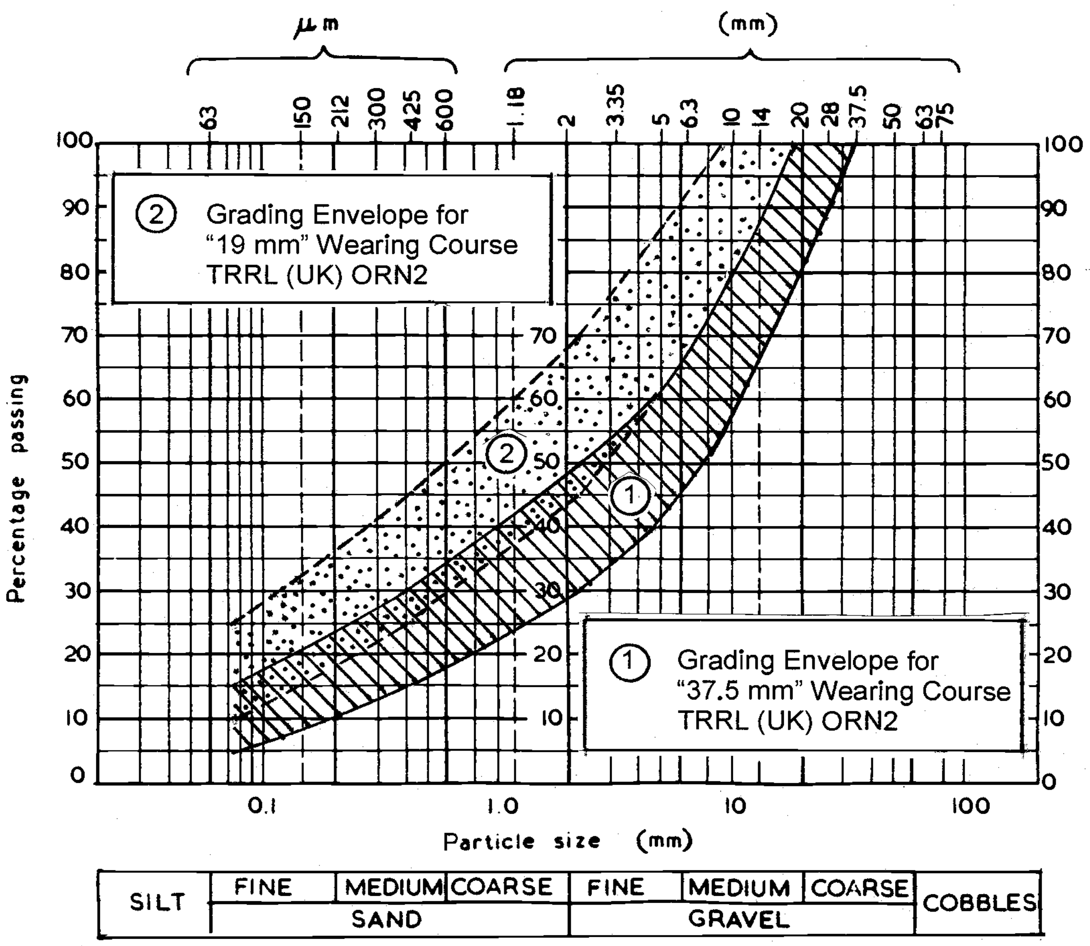
- Aggregate with just sufficient fines to fill the voids
- Aggregate with a deficiency of fines
- Aggregate with excess fines

Natural materials rarely contain the precise quantity of fines required to just fill the voids between the coarser particles. The grading characteristics of such materials may be defined by a formula such as "Fuller's" (RRL 1952). The particle size distribution envelopes recommended by UK TRRL, as shown in Figure 4.3, define a range of particle sizes close to the theoretical ideal "Fuller's" curve. Materials within and approximately parallel to such a grading envelope can typically be compacted to produce high *in situ* densities. It has been observed that materials with high *in situ* densities provide the greatest bearing capacity, lowest permeability and best long term performance.

Materials with a deficiency of fines derive their strength from grain to grain contact. In which case, compacted density, particle interlock, aggregate shape and strength become more important. Such materials are stony, porous, permeable, difficult to shape and compact, and as a result have low shear strength (Netterberg & Paige Green 1988).

When excess fines are present in a wearing course gravel then the coarse particles begin to "float" within the fine matrix. In this case, it is the properties of the fines that largely determine the engineering characteristics of the material and the nature of the coarse particles becomes of secondary importance. Surfacing materials containing excess fines may be easy to shape and compact and may be practically impermeable but their strength and skid resistance is likely to be greatly affected by moisture.

Grading specifications such as those illustrated in Figure 4.3 exclude "poorly graded" and excessively "gap graded" materials (with poor compaction characteristics) by specifying a certain percentage retained between successive pairs of sieves. This ensures that the grading curve of the material lies approximately parallel to the limits of the envelope.




| B S sieve size | Percentage passing (*) | | |
|---|---|---|---|
| | Nominal maximum size | | |
| | 37.5mm | 19mm | 9.5mm |
| 37.5 | 100 | – | – |
| 19 | 80–100 | 100 | – |
| 9.5 | 55– 80 | 80–100 | 100 |
| 4.75 | 40– 60 | 60– 85 | 80–100 |
| 2.36 | 30– 50 | 45– 70 | 50– 80 |
| 425μm | 15– 30 | 25– 45 | 25– 45 |
| 75μm | 5– 15 | 10– 25 | 10– 25 |

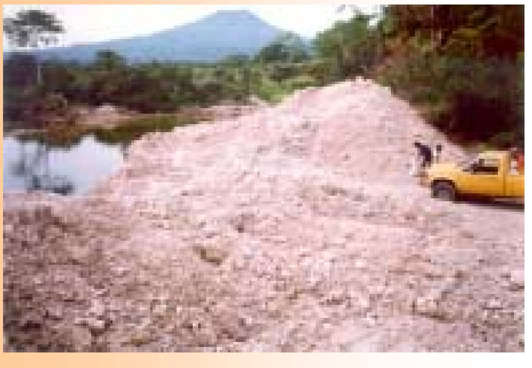
(*) Not less than 10% should be retained between each pair of such successive sieves specified for use, excepting the largest pair.

**Figure 4-3 Recommended Grading Specifications For Wearing Course Gravel (After TRRL UK ORN3)**

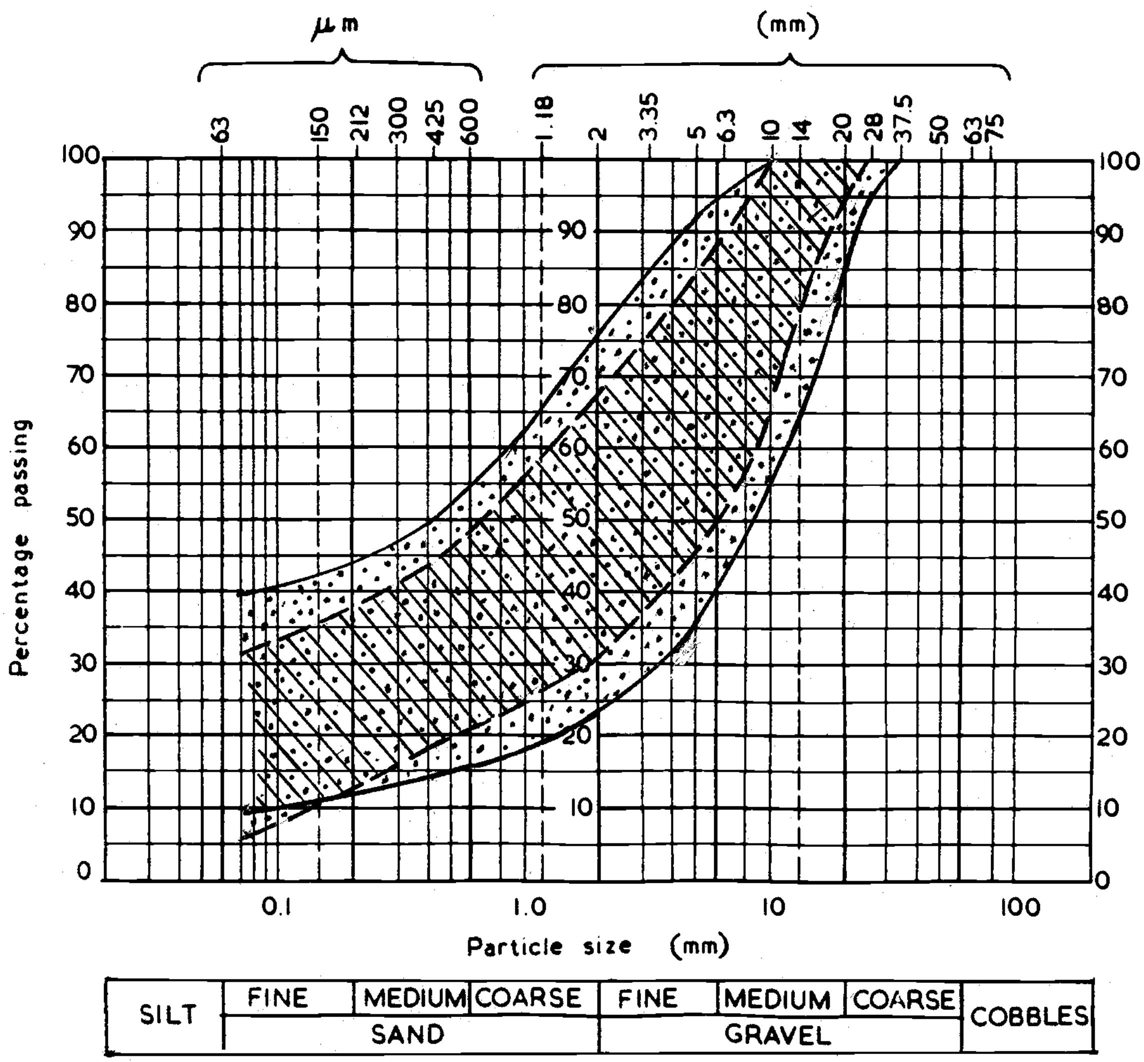
Laterite gravel pit
(photo courtesy of P Larcher, Univ. of Loughborough

Some materials with apparently poor grading characteristics (when compared with Figure 4.3 recommendations) give good in-service performance characteristics when used as gravel surfacing material despite relatively high fines contents. Such non standard materials include laterite gravels, coral gravels and calcrete gravels.

Research on the performance characteristics of such natural gravel materials has resulted in the development of modified grading envelopes. The Kenya Road Design Manual (1987) grading recommendations, as illustrated in Figure 4.4, have been designed to provide guidance appropriate for a wide range of locally occurring natural gravel materials, including laterite ("murram") and quartz gravels. As a result, a much higher fines content is allowable. However, experience has shown that some materials (ie alluvial gravels and weathered rock gravels) will not perform well if fines contents are close to the upper limits indicated by the Kenya recommendations. Some materials may generate a significant amount of additional fines during compaction, in which case grading characteristics before and after compaction testing should be investigated.



Coral gravel pit




**Class 1 Wearing Course Gravel**
(required where initial daily number of commercial vehicles > 150)

**Class 2 Wearing Course Gravel**
(may be used when initial daily number of commercial vehicles < 150)

**Figure 4-4 Recommended Grading Specifications for Wearing Course Gravel (After Kenya Road Design Manual 1987)**

Nodular calcrete deposits

Grading recommendations specifically for calcrete wearing course gravels have been defined (Netterberg 1971), as shown in Figure 4.5. These guidelines have been applied in several countries since publication and have been found to be appropriate (when combined with other material property limits).

Problems associated with applying a single restrictive grading envelope to a wide range of locally available natural materials has led to the development of several formulae to assist in the appraisal of the particle size distribution characteristics of potential gravel road surfacing materials. Two useful grading evaluation formula include: the "Grading Modulus" (TRH 14 1989); and the "Grading Coefficient" (TRH 20 1990) :

$$\textbf{Grading Modulus} = P_{2.00} + P_{0.425} + P_{0.075} \, / \, 100$$

Where $P_{2.00}$ is % passing 2mm sieve

$P_{0.425}$ is % passing 0.425 mm sieve

$P_{0.075}$ is % passing 0.075 mm sieve

$$\textbf{Grading Coefficient} = (P_{26.5} - P_{2.00}) \times P_{4.74} \, / \, 100$$

Where $P_{2.6.5}$ is % passing 26.5mm sieve

$P_{2.00.}$ is % passing 2.00 mm sieve

$P_{4.74}$ is % passing 4.74 mm sieve

These formulae allow a broad range of material gradings to be considered for use in gravel road surfacing and enable the more suitably graded materials to be numerically defined. This approach to the grading assessment gravel road materials is a significant advance, because in the case of low cost road construction available materials may have to be used despite some defects in their engineering properties.

The Committee of State Road Authorities in South Africa (TRH 20 1990) recommends that wearing course gravel for unpaved rural roads should have a Grading Coefficient in the range 16 – 34 and should have no more than 5% of particles larger than 37.5 mm.

The Botswana Road Design Manual recommends minimum Grading Modulus (GM) values of 1.6 for 19mm maximum size wearing course gravels reducing to GM 1.3 for 4.75mm maximum size surfacing gravels. However these recommendations do not apply to calcrete gravels. The desirable particle size distribution range for calcretes is illustrated in Figure 4.5.

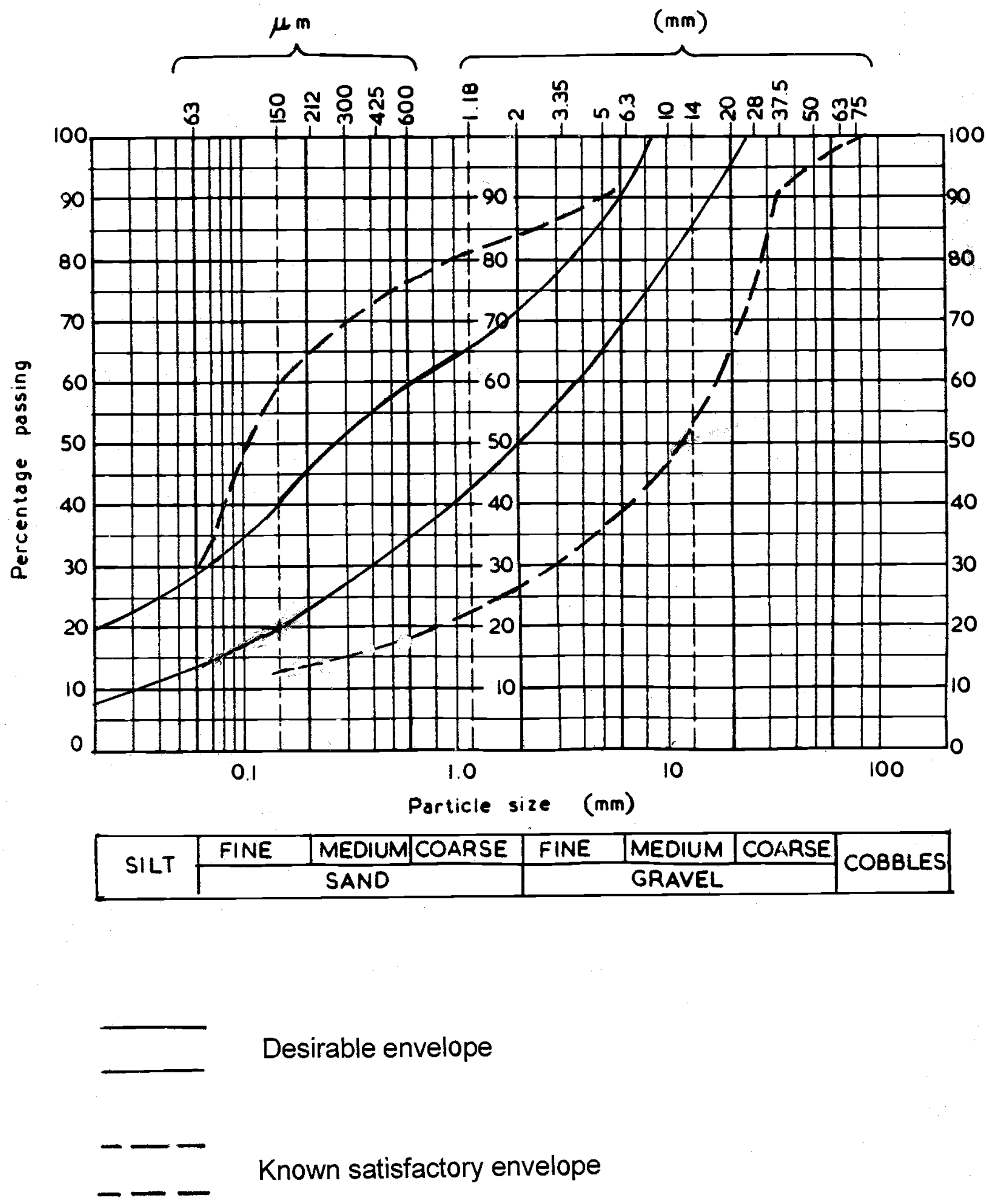
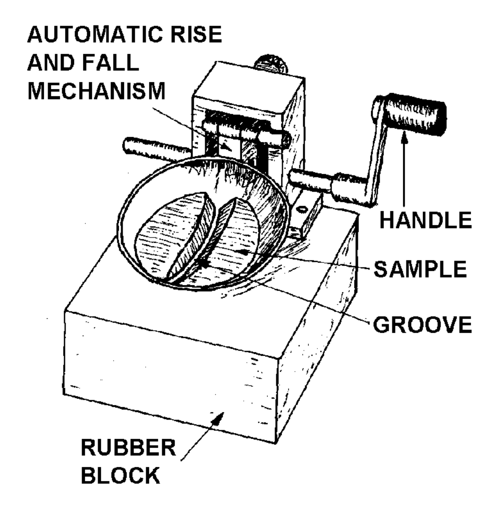
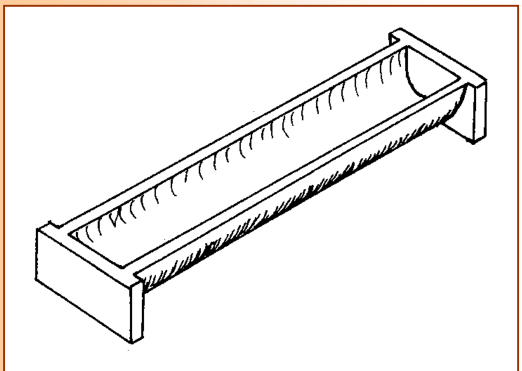



**Figure 4-5 Desirable Grading Envelope for Calcrete Wearing Course Gravel (after Netterberg 1971)**




Casagrande apparatus for determination of Liquid Limit of soils



Linear Shrinkage Mould

## ii) Desirable Plasticity Characteristics for Unpaved Road Materials

Good gravel road surfacing materials contain plastic fines, which are required to act as binder material. This plastic binder provides the compacted surface with resistance to natural erosion and excessive wear under traffic, prevents excessive dustiness and also reduces the permeability of the pavement.

The desirable characteristics of the binder fraction are dependent on climatic conditions. Dry environments can tolerate higher quantities of plastic binder and higher plasticity characteristics as determined by Atterberg limit testing. In the case of seasonally wet tropical environments the selection of gravel surfacing material is most often a compromise between a material which possesses sufficiently high plasticity to prevent gravel loss in the dry season and sufficiently low plasticity to prevent serious rutting and deformation in the wet season.

The relationship between the plasticity of the binder and the total quantity of binder has been found to be critical to performance of wearing course gravels. As a result, specifications have been developed that include desirable limits for “Plasticity Modulus”, “Plasticity Product” or “Shrinkage Product” (also sometimes called “Shrinkage Modulus”). These parameters are defined below:

**Plasticity Modulus**
**= Plasticity Index x % passing 0.425 mm sieve**

**Plasticity Product**
**= Plasticity Index x % passing 0.075mm sieve**

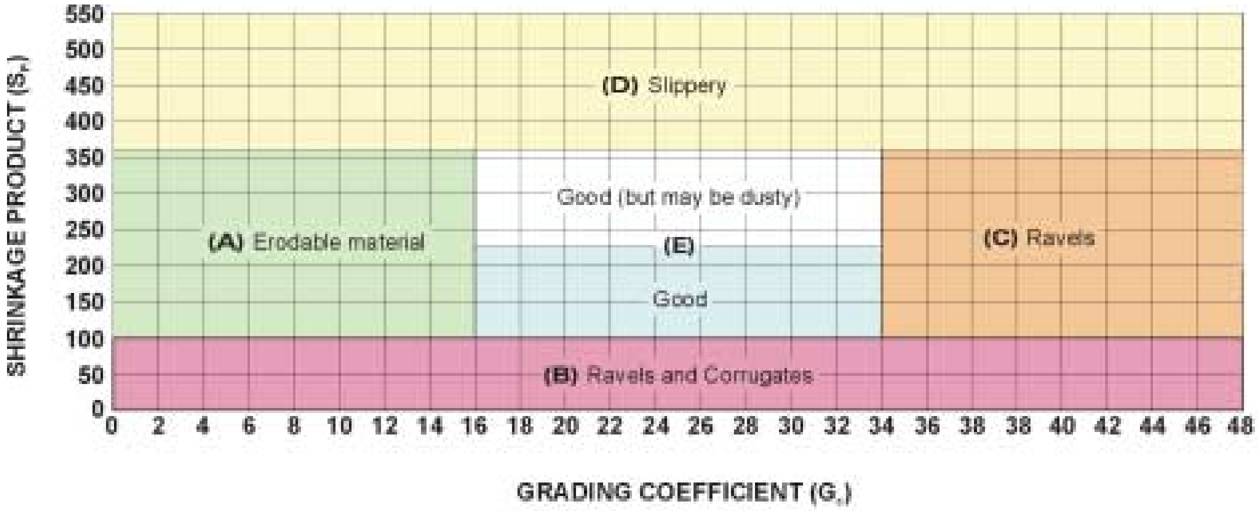
**Shrinkage Product**
**= Bar Linear shrinkage x % passing 0.425mm sieve**

The South African Committee of State Road Authorities (TRH 20 1990) has published a chart that uses the relationship between Shrinkage Product and Grading Coefficient to predict the performance of wearing course gravels as shown in Figure 4.6.

| | TRRL (UK) ORN2 (1985) | | | MOTC (Kenya) 1987 | | CSRA (S. Africa) TRH 14/20 1989/90) | AASHTO (USA) M 147-65 1996 |
|---|---|---|---|---|---|---|---|
| Climatic Category | Moist wet tropical | Seasonal wet tropical | Arid & semi arid | Wet | Dry | n.s. | n.s |
| Liquid Limit % (LL) | Max 35 | Max 45 | Max 55 | n.s. | n.s. | | Max 35 |
| Plasticity Index % (PI) | 4-9 | 6-20 | 15–30 | 5-20 | 10-30 | 8-20 | 4-9 |
| Linear Shrinkage % (LS) | 2 - 5 | 3 - 10 | 8 - 15 | n.s | n.s. | n.s. | n.s. |
| Plasticity Modulus (Sp) | n.s. | n.s. | n.s. | 200 - 1200 | | n.s. | n.s. |
| Shrinkage Product (Sp) | n.s. | n.s. | n.s. | n.s. | n.s. | 100 - 365 (Max 240 preferred) | n.s. |

Note: n.s = not specified

**Table 4-2 Specifications for the Plasticity Characteristics of Wearing Course Gravels**




**Notes:**

1. Shrinkage Product ($S_p$) = Bar Linear shrinkage from liquid limit x % passing 0.425mm sieve.
2. Grading Coefficient ($G_c$) = (% passing 26.5mm - % passing 2.0mm) x % passing 4.74mm/100

**Material Performance Characteristics Associated with Each Zone:**

**A** Materials in this area generally perform satisfactorily but are finely graded and particularly prone to erosion by water: they should be avoided if possible, especially on steep grades and sections with steep cross-falls and super- elevations. Most roads constructed from these materials perform satisfactorily but may require periodic labour-intensive maintenance over short lengths and have high gravel losses due to water erosion.

**B** "These materials generally lack cohesion and are highly susceptible to the formation of loose material (ravelling) and corrugations. Regular maintenance is necessary if these materials are used and the roughness is to be restricted to reasonable levels.

**C** Materials in this zone generally comprise fine, gap-graded gravels lacking adequate cohesion, resulting in ravelling and the production of loose material.

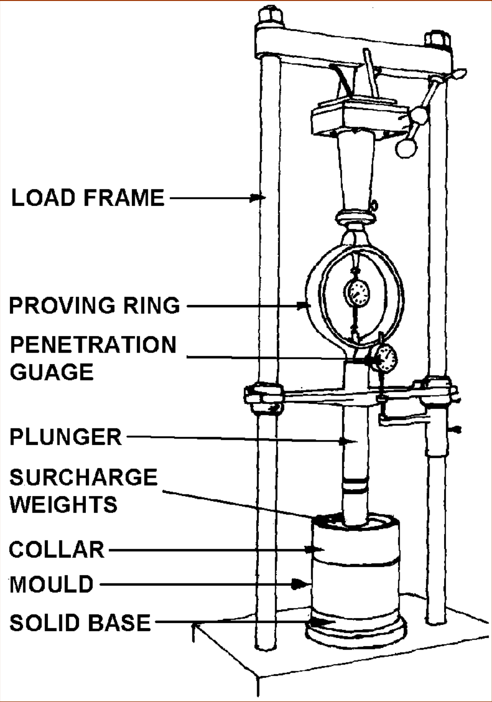
**D** Materials with a shrinkage product in excess of 365 tend to be slippery when wet.

**E** Materials in this zone perform well in general, provided the oversize material is restricted to the recommended limits.

**Figure 4-6 Relationship Between Shrinkage Product, Grading Coefficient and Performance of Wearing Course Gravels (After TRH 20 1990)**

The Ministry of Roads and Road Traffic in Zimbabwe (MRRT 1975) identified relationships between Plasticity Product and percentage retained on 2.36 mm sieve and Plasticity Index and percentage passing 0.075mm sieve that may also be used to predict the performance of wearing course gravels. These are presented as Figures 4.7.

The best gravel road surfacing materials have a Plasticity Product of 400 to 950 (zone C Figure 4.7a) and should lie within the shaded are in Figure 4.7b. In terms of grading the Zimbabwe chart discourages using materials with a nominal maximum size of greater than 19mm, this is often impractical and uneconomical.

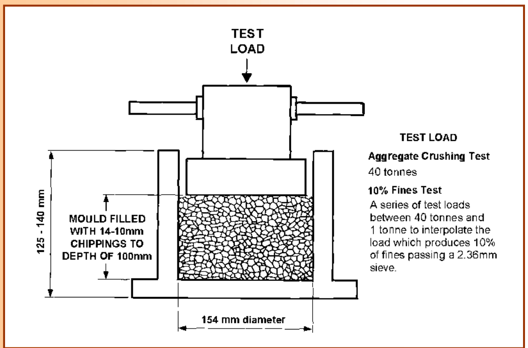



California Bearing Ratio Test Apparatus

**iii) Desirable CBR Characteristics for Unpaved Road Materials**

Existing specifications for gravel road surfacing materials show considerable variation with respect to recommended CBR characteristics. Many specifications provide no guidance on CBR, relying on restricted grading and plasticity requirements to provide adequate bearing capacity. The lowest published minimum CBR requirements is 15% at 95% modified AASHTO (TRH 20 1990) after 4 days soaking but values of greater than 30% have been specified.

It is recommended that a target soaked CBR of 20% is adopted, this is in accordance with the Kenya Road Design Manual. Most materials complying with published grading and plasticity limits will have no difficulty in complying with this requirement when compacted to 95% mod AASHTO (or equivalent). As a result, CBR testing need not be a routine quality control test except in the case of suspect materials (ie materials that have some property outside of recommended limits).




Aggregate Crushing Value and Ten Percent Fines Test Apparatus (after R.S. Millard 1993)

**iv) Desirable Particle Strength Characteristics for Unpaved Road Materials**

The presence of a high proportion of weak particles will result in a pavement prone to break-down in service. Such break-down will lead to rutting and potholing and may produce an excess of fines, which are dusty in dry weather and may lead to corrugations in the pavement surface.

Published aggregate strength requirements for gravel road materials vary widely and are generally only important for the coarser graded materials. Experience in South Africa (Netterberg & Paige-Green 1988) has lead to the conclusion that whilst a 10% FACT of about 110 kN is required to prevent any aggregate degradation under traffic, much lower values down to about 20 have been found to be satisfactory. Indeed, the presence of some weak particles may be desirable in order to improve the grading of some materials during compaction and in service.

Specific particle strength recommendations exist for some non standard aggregates such as laterite and calcrete and may make use of tests such as the Aggregate Finger Value Test and Aggregate Pliers Value Test

It is recommended that the following target strength properties are adopted for gravel road surfacing materials: minimum 10% FACT of 50 kN or maximum modified (soaked) aggregate impact value of 40% (after Botswana Road Design Manual 1982).

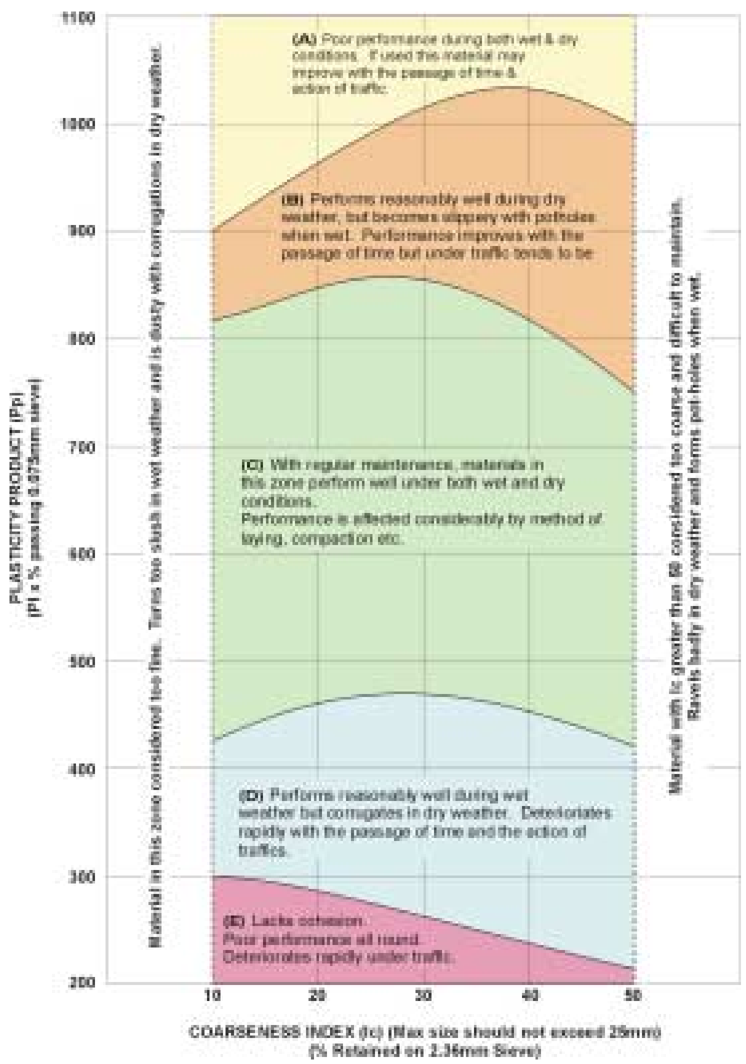



**Figure 4.7a**
**Wearing Course Gravel**
**Performance Guide**

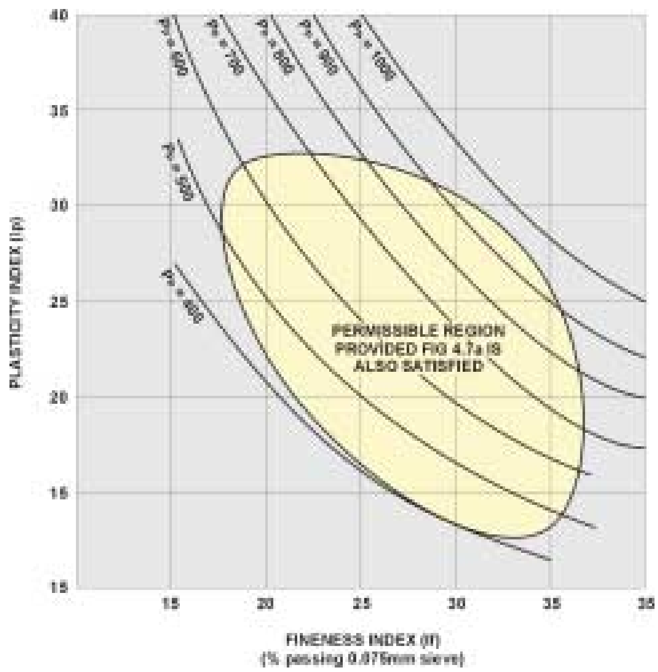



**Figure 4.7b**
**Zone of Potentially Suitable**
**Wearing Course Gravel**

**Figure 4-7 Performance Guide for Wearing Course Gravels (After Zimbabawe MRRT 1975)**

### v) Desirable Particle Shape Characteristics for Unpaved Road Materials

Particle shape influences the compaction characteristics of wearing course pavement materials. Angular particles are preferred because they have better interlocking capability and may therefore produce high density resistant pavements.

Conversely, rounded particles have poor interlocking capability and are difficult to compact into a high density pavement. As a result, the surface will be prone to ravelling and erosion under the action of traffic and weather.

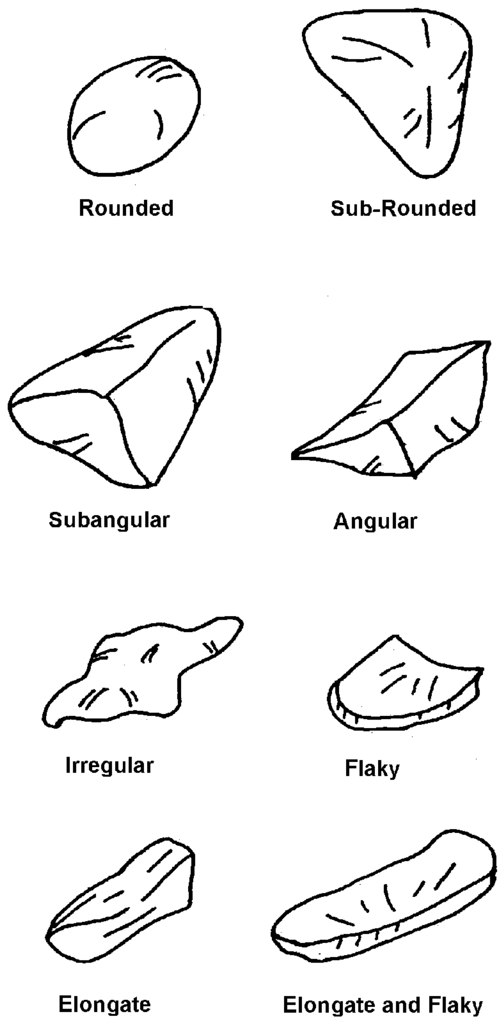



**Figure 4-8 Description of Particle Shape**

## Evaluation of "As Dug" Wearing Course Gravel Suitability Rating

In many cases there is the possibility of supplying gravel for surfacing a section of unpaved road from one of several potential sources. In order to assess the relative suitability of materials from different sites it is recommended that an "as dug" ("pit-run") wearing course gravel "suitability rating" is assigned to each source under evaluation.

Table 4.3 presents a rating system developed during the National Material Resources Study undertaken in Papua New Guinea. During this study more than 1000 material sources, serving about 3900 km of gravel road were evaluated and rated in terms of "as dug" wearing course gravel suitability. The resulting database of information was used to aid pit selection and develop an economic material supply strategy.

| Rating | Definition | Characteristics |
|---|---|---|
| 1 | *Very Good* | The material is well graded and has an appropriate proportion of suitable plastic binder coupled with good particle shape and strength. Similar materials have a good performance history. |
| 2 | *Good* | Similar characteristics to very good materials, but exhibits some minor deficiencies or excesses. |
| 3 | *Moderate* | Exhibits one or more easily recognisable deficiencies or excesses. Such as high proportion of oversize particles; a deficiency of plastic binder; significant percentage of weak material. |
| 4 | *Poor* | Exhibits several undesirable characteristics which will lead to unsatisfactory or poor pavement performance unless measures taken to improve material suitability |
| 5 | *Very Poor /Unsuitable* | These materials are either inherently unsuitable for use as gravel road surfacing material (*i.e.* slaking shale) or produce a pit-run product which requires significant processing (*i.e.* poorly fractured 'blocky' rock or 'hard rock' source). |

Source Bishop & Morey, 1992

**Table 4-3 Rating System for "As Dug" Suitability of Gravel Wearing Course Sourses**

The assigned rating should be based on an evaluation of the five material properties reviewed above and should take into account of any experience relating to the in-service performance characteristics of similar materials.

The rating is designed to be a numerical classification that can be easily and consistently applied by different materials engineers/engineering geologists and readily input onto a materials resources database (refer Section 10).

Although a 5 point system, it can be refined into what is essentially a 9 point system, since deposits which are considered marginal between two ratings may be reported as 2-3 (good to moderate quality). Similarly, the rating system can account for lack of uniformity in the quality of the deposit. This is important because whilst river bed gravels may have similar characteristics over a large area (homogeneous deposits), pits exploiting weathered rock tend to expose materials of varying quality, or the suitability of the deposit may vary with increasing depth away from exposed surfaces.

Appendix I presents a review of the main material types that are commonly exploited to supply unpaved road gravel wearing course aggregates (adapted from Bishop & Morey, 1992).

## 4.2. Paved Road Material Evaluation

### Introduction

Typical lightly trafficked bitumen surfaced rural road.

Gravel surfaced roads will require paving when maintenance costs increase to unacceptable levels or when other economic or social benefits become significant.

Consideration is typically given to upgrading to bitumen standard when the average number of vehicles ranges between 100 and 400 per day. At these traffic flows upgrading may be viable if the traffic includes a high proportion of commercial vehicles.

However, bitumen surfacing may be economic for problem road sections, such as where steep gradients occur or when gravel haulage distances/costs are excessive, when traffic flows are as low 40 vehicles a day

When bitumen surfaced roads are to be constructed to carry only low volumes of traffic (less than about 1million Equivalent Standard Axles - ESA) economic pressures typically dictate that optimum use must be made of locally available road building materials. If possible maximum use should be made of natural gravel deposits and these should be used either “as dug” or with the minimum of processing.

Investigating construction materials in a low volume paved road.

Standard granular pavement material specifications that have been developed for general application over a wide range of design traffic volumes (ie from 0.25 to 10 million ESA) in tropical and subtropical countries are clearly defined in a number of existing publications (ie TRL ORN31, 1993). These specifications are briefly reviewed and form a good target quality standard to aim for in the case of low trafficked roads. However for the very lightly trafficked roads, it is widely accepted that such material specifications may be unnecessarily conservative.

For example, the normal bearing strength requirement for natural gravel base materials is CBR 80%. However, experience has shown that where bitumen surfaced roads will carry only light traffic then lower strength gravels may be used, provided that the pavement is well drained under all circumstances (Kenya Design Manual 1987).

A review of some of the published recommendations with respect to reduced property standards for low volume paved roads is therefore presented, with the warning that their adoption must be dependent on the existence of a satisfactory road environment.

## Standard Material Requirements for Paved Roads

The material selection guidelines contained in the UK Transport Research Laboratory's Overseas Road Note 31 ("A guide to the structural design of bitumen-surfaced roads in tropical and sub-tropical countries") are representative of paved road material specifications that are suitable for general application over a wide range of design traffic volumes (ie from 0.25 to 10 million esa).

Pavement trial pit exposing construction materials in a lightly trafficked bitumen surfaced road

### a) Roadbase Materials

ORN 31 presents property guidelines for both crushed stone base materials and for naturally occurring granular materials. Natural gravels that can be successfully used as roadbase include: laterite; calcrete; quartzitic gravels; alluvial gravels and fractured/ weathered rock deposits. The ORN31 requirements for natural gravel roadbase are summarised below.

Table 4.4 presents three recommended roadbase grading envelopes for material characteristics after compaction. Only the two larger sizes should be considered for traffic in excess of 1.5 million ESA.

| BS Test Sieve (mm) | % by mass of total aggregate passing test sieve<br>Nominal maximum Particle size | | |
|---|---|---|---|
| | 37.5 mm | 20 mm | 10 mm |
| 50 | 100 | - | - |
| 37.5 | 80 – 100 | 100 | - |
| 20 | 60 – 80 | 80 – 100 | 100 |
| 10 | 45 – 65 | 55 – 80 | 80 – 100 |
| 5 | 30 – 50 | 40 – 60 | 50 – 70 |
| 2.36 | 20 – 40 | 30 – 50 | 35 – 50 |
| 0.425 | 10 – 25 | 12 – 27 | 12 – 30 |
| 0.075 | 5 - 15 | 5 - 15 | 5 - 15 |

**Table 4-4 Recommended Gradings for Natural Gravel Bases (after ORN 31)**

Natural gravels will typically require screening and/or crushing in order to produce an aggregate grading that lies approximately parallel to the limits of the envelopes in Table 4.4. The mixing of different sources may also be carried out in order to improve grading characteristics. The fraction larger than 10 mm in size should consist of more than 40 % of particles with angular, irregular or crushed faces (if soaked CBR 80% is to be achieved).

For materials whose stability may decrease with particle break-down, aggregate hardness criteria may be based on a minimum soaked Ten Per Cent Fines Value of 50 kN or a maximum soaked Modified Aggregate Impact Value of 40% (BS 812 Part 112 1990).

- The fine fraction of natural gravel base materials should preferably be non plastic but should normally never exceed a Plasticity Index (PI) of 6%. As an alternative to PI a Linear Shrinkage of not exceeding 3% may be applied.

Plasticity Modulus (PM)
= Plasticity Index x % passing 0.425 mm sieve

Plasticity Product (PP)
= Plasticity Index x % passing 0.075mm sieve

- ORN 31 advises that if the PI approaches the upper limit of 6% it is desirable that the fines content be restricted to the lower end of the range. To ensure this, a maximum Plasticity Product of 60 is recommended or alternatively a maximum Plasticity Modulus of 90.

- Plasticity criteria may be improved during construction by adding a small percentage of hydrated lime or cement.

- ORN 31 requires roadbase material to have a minimum CBR 80% after 4 days soaking at 98% maximum dry density achieved in the British Standard (Heavy) compaction test, 4.5 kg rammer (BS 1377 Part 4 1990). However, in arid and semi arid areas (annual rainfall less than 500 mm) ORN 31 advises that for traffic volumes up to 0.7 million ESA, consideration may be given to relaxing the maximum allowable PI from 6% to 12% and reducing the minimum CBR from 80% to 60%.

**b) Sub-base Materials**

- General materials specifications, such as ORN 31 (1993), that are suitable for a wide range of design traffic volumes typically require that the sub-base layer in paved road construction provides a minimum CBR of 30%. This result is required at the highest anticipated moisture content when compacted to the specified field density, usually a minimum of 95% of the maximum dry density achieved in the BS Heavy Compaction Test, 4.5 kg rammer. The CBR value should be obtained after 4 days soaking, unless conditions of good road drainage and low rainfall are guaranteed, then unsoaked testing will be acceptable.

| BS Sieve Size | % passing |
|---|---|
| 50 | 100 |
| 37.5 | 80 – 100 |
| 20 | 60 – 100 |
| 5 | 30 – 100 |
| 1.18 | 17 – 75 |
| 0.425 | 9 – 50 |
| 0.075 | 5 - 25 |

Grading for Sub-base (ORN 31,1993)

- ORN 31 advises that a broad range of particle size distribution gradings may be satisfactory for sub-base materials (refer grading envelope table). Sub-base material plasticity limits recommended by ORN 31 are shown below:

| Climate | Liquid Limit | Plasticity Index | Linear Shrinkage |
|---|---|---|---|
| Moist tropical and wet tropical | <35 | <6 | <3 |
| Seasonally wet tropical | <45 | <12 | <6 |
| Arid and semi-arid | <55 | <20 | <10 |

**Table 4-5 Recommended Plasticity Characteristics for Granular Sub-base (after ORN 31)**

- Some “marginal“ or non standard materials will provide satisfactory soaked CBR values and in–service performance characteristics when plasticity properties exceed those recommended above, as reviewed in the following sub-section.

### c) Aggregates for Bituminous Surfacing

On lightly to medium trafficked rural roads surface dressing is the most common form of bituminous surfacing. A surface dressing typically comprises a thin film of sprayed bitumen that is covered with a layer of stone chippings. A single surface dressing may be used as the initial surfacing on a lightly trafficked new road, but a double surface dressing is more often used to increase durability. Recommendations for surface dressing in tropical and sub-tropical countries are contained in UK TRRL Overseas Road Note 3 (1982-currently undergoing revision). Other useful documents include the South African CSRA TRH 3 and the specifications issued by the Australian State Highway Departments.

Poor materials can seriously reduce the life of a surface dressing, therefore great care needs to be taken in the selection of sources of sealing aggregate. Recommendations in ORSN 3 for aggregate properties are summarised below.

Measuring the skid resistance properties of a bitumenous surface dressing.

The main requirements of sealing chippings is that they should be strong enough to resist break down under the passage of traffic and provide resistance to vehicle skidding. Chippings of single nominal size are used (typically 6,10,14 or 20 mm). Ideally, they should be cubical and not susceptible to polishing by vehicles. Flaky and elongated chippings are to be avoided since these move about under the roller and under subsequent traffic, and do not remain in the closely packed mosaic which is the objective in good surface dressing (Millard, 1993). Maximum permissible Flakiness Index (FI) values for 10,14 and 20 mm chips is 35 according to ORN 3. Ideally all sealing aggregates should have a FI of less than 30.

Sample chippings produced from potential surfacing aggregate sources should be tested to determine: grading, flakiness index, aggregate crushing value (ACV), and sodium sulphate (SSS) or magnesian sulphate soundness (MSS). When appropriate, the polished stone value (PSV) and aggregate abrasion value (AAV). Test methods are described in BS 812. The testing of PSV and AAV is usually not carried out in the case of low traffic volume roads, when aggregate strength testing is normally sufficient.

ORN 3 states that the specification for maximum ACV for surface dressing chippings typically lie in the range 20 – 35. For lightly trafficked roads the higher value is likely to be adequate but on more heavily trafficked roads a maximum ACV of 20 is recommended.

It is recommended that SSS should not normally exceed 12% and MSS should not exceed 18%, unless field trials indicate that acceptable in-service performance is associated with chipping exhibiting higher values. For example, some sealing aggregates from alluvial gravel sources, comprising a mixture of rock types may perform satisfactory on lightly trafficked roads with SSS values up to 20%.

Some alternatives to surface dressing exist for lightly trafficked roads, particularly when suitable sources of strong sealing chippings are not available, these alternative bituminous surface treatments are considered in the following sub-section.


Paved road built with "as dug" laterite and sand.

Volcanic scoria gravel represents a source of lower standard paved road material

## Lower Standard Paved Road Materials

Considerable research is still in progress to develop appropriate minimum road design standards and pavement materials specifications for low trafficked rural roads (less than about 1million Equivalent Standard Axles – esa) located in the developing world.

This research includes the investigation of the properties and in-service performance characteristics of various "marginal" or "non standard" materials. In general, marginal materials are natural gravels that do not wholly comply with the standard road material specifications in use in a country, but which can be used successfully in appropriate conditions.

The identification of appropriate selection criteria for potential sources of granular material for low volume paved road construction requires specific knowledge of the road environment including the following variables:

- Proposed road design standards (ie road crossfall)
- Local climate and topography (ie annual rainfall)
- Composition of traffic (ie is overloading a problem?)
- Efficiency of maintenance
- In-service performance characteristics of locally available materials

It is beyond the scope of this manual to attempt to provide selection criteria for all natural materials that may be considered for the supply of low volume paved road materials. However, a general review of existing published specification limits is presented, but their adoption must be dependent on the existence of a satisfactory road environment.

Guidelines and specification limits for the use of materials in low volume roads that have been developed in several counties are reviewed below as an introduction to selection procedures. However, interested readers are strongly advised to refer back to the quoted references before adopting any of the test property specifications quoted here.

**a) Kenya**

The Kenya Road Design Manual (1987) contains a Chapter on Low Standard Bitumen Surfaced Roads. This document contains relaxed specifications (refer Table 4.6) for roads expected to carry less than 0.5 million esa. In Kenya laterite and quartzitic marginal materials are widespread and their low volume road standards are designed to allow use of these materials within a relaxed specification that has been shown to identify materials with satisfactory in-service performance.

Relaxed base course requirements apply up to 0.7 million esa Base course material in Kenya may have a reduced CBR of 50% with maximum PI of 15% in wet areas (annual rainfall greater than 500 mm) and PI of 20% in dry areas (annual rainfall less than 500mm). Maximum particle size is 40 mm and no particle strength requirements are stated.

| Specification Source | | CEBT France 1987 | RHD Bangladesh (1990) | MOW&C Botswana (1982) | NITRR South Africa (Richards 1978) | | MOTC Kenya (1987) | |
|---|---|---|---|---|---|---|---|---|
| Traffic Category (Million esa or vehicles/day) | | Max 3 esa | n.s | Max 0.2 esa | < 300 vpd | 300–600 vpd | Max 0.7 esa | |
| Climate-Annual Rainfall | | Tropical | Monsoon | Semi-arid | n.s | | <500 mm | >500 mm |
| Type of Material | | Natural Gravel | Gravel or Brick & Sand | Natural Gravel | Natural Gravel | | Natural Gravel | |
| Grading | Max Particle Size | 40 | 50 | 37.5 | n.s | | 40 mm | |
| | Grading Modulus | | | Min 1.9 | Min 1.5 | Min 1.5 | | |
| Plasticity | Liquid Limit | n.s | Max 20 | Max 30 | | | | |
| | Plasticity Index | Max 6 (Max 15 Laterite) | Max 5 | 10 or 15 | Max 10 (Max 15 for Pedogenic) | Max 8 (Max 15 for Pedogenic) | 20 | 15 |
| | Linear Shrinkage (%) | n.s. | n.s | Max 5 | Max 6 Pedogenic | Max 6 for Pedogenic | n.s | n.s |
| | Plasticity Product | | | n.s | n.s. | | | |
| | Shrinkage Modulus | | | Max 170 | | | | |
| CBR | Unsoaked (%) | n.s | | n.s | | | n.s. | |
| | 4 day Soaked (%) | Min 60 | Min 50 | Min 45 | 50 - 60 | 60 - 70 | Min 50 | |
| | Swell (%) | Max 10 | | Max 0.5 | n.s. | | n.s | |
| Durability | Los Angeles Abrasion Value (%) | Max 50 | n.s | n.s | | | | |
| | Aggregate Crushing Value (%) | Max 35 | Max 35 | | | | | |
| | Micro Deval (%) | Max 20 | n.s. | | | | | |
| | 10% Fines (kN) | n.s | Min 90 | Min 50 | | | | |

n.s.=not stated

**Table 4-6 Review of Some Base Course Standards for Low Volume Roads**

Layer thicknesses for lower standard construction are as for "standard" construction. However, this is based on the principle that the thicknesses of the road base and surfacing, which are made of the most expensive material, should be kept constant and as low as possible, for each class of traffic. Minimum base thickness is 150 mm up to 1 million esa design traffic. Sub-base beneath non standard bases is of the same quality as for "standard" sub-base (minimum CBR of 30%, max PI of 15 in wet areas and plasticity modulus of 250).

Pavement trial pit exposing lower standard, but satiasfactory, natural gravel construction materials.

### b) Southern Africa

A review of pavement materials for low volume roads in Southern Africa was prepared by Netterberg and Paige Green (1988). This paper concludes that in the selection of base and lower layers more weight should probably be attached to the CBR or triaxial strength attained in the road rather than to grading or plasticity.

It is recognised in South Africa that documented experimentation with local materials of varying quality is required. Richards (1978) presented recommendations for lightly trafficked roads that are included in Table 4.6. Pedogenic calcrete and laterite gravels are a widely used road building material in Southern Africa, Richards applies higher plasticity limits to pedogenic materials.

The Committee of State Road Authorities (TRH 4, 1985) has provision for the construction of special pavements (Category D) for roads designed for less than 0.2 million esa per lane. These roads may be constructed with "G5" natural gravel base. The G5 materials have, among other limitations a minimum soaked CBR value of 45% and Maximum PI of 10.

### c) Botswana

The Botswana Road Design Manual has a Section on Low Traffic Roads (LTR), which are defined as roads designed to carry less than 0.2 million esa. It is intended that these roads would have 3.5 to 5.0m wide bituminous surfacing and would normally carry less than 150 vehicles per day. Relaxed specification limits for the base course of LTRs are shown on Table 4.6. Separate reduced standard specifications are applicable to calcrete gravels, but are not shown on Table 4.6.

Successful field trials have been carried out using lower quality materials (mostly calcretes, latertites and weathered granite) than those provided for under the exceeding specification (which is about to be revised). As a result valuable information applicable to semi-arid conditions is becoming available.

### d) Bangladesh

Bangladesh suffers from a severe deficiency of good road building aggregates combined with a monsoonal climate. As a result, the Roads and Highways Department has developed a specification that allows mixtures of crushed rock or brick with sand to be utilised in the construction of base course for lower trafficked roads. This base material has a minimum soaked CBR of 50% and maximum plasticity index of 5%

**e) CEBTP France**

The Centre Expéimental de Recherches et d'Etudes du Bâtiment des Travaux Publics (CEBTP, 1984) has published a practical guide to pavement design for tropical counties. This document provides recommendations on the use of various types of road material and provides some guideline specifications for the use lower standard aggregates in roads designed to carry less than 3 million esa. Their recommendation with respect to granular base material are included in Table 4.6.

**f) Queensland Australia**

Australia has developed standards for lower trafficked roads (designed for less than 1 million esa) located in low rainfall areas (less than 500mm/annum). Queensland Transport's Pavement Design manual includes design charts for roads build with "non standard" granular base course aggregates ranging in strength from CBR 40 to CBR 50. Also in Queensland the CBR requirement for Standard Granular base materials may be reduced from 80% to 60% when design traffic is less than 1 million esa.

The key features of their use of lower standard materials, include:

- Constant minimum thickness (125 mm) of the base (CBR 45-50%) and upper subbase (CBR 30-40%)
- Variable depth of a relatively strong lower subbase (CBR 25 - 35%)

The principles applied involve making maximum use of the available non standard materials. Use of the strongest material is minimised, whilst protection from subgrade deformation may be achieved at higher traffic levels by the construction of a thick high strength lower subbase layer.

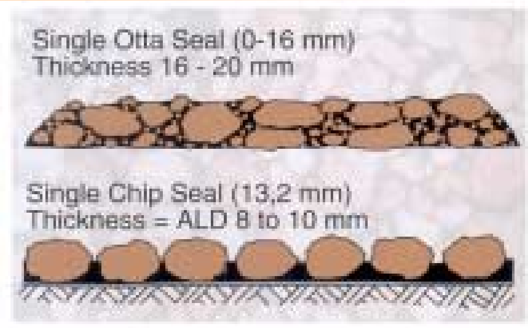
**g) Bituminous Surfacing Using Lower Standard Aggegates**

When the only available or economic sources of aggregate for bituminous surfacing are relatively low strength (ACV 30 – 35%) then consideration should be given to alternative constructions from single or double chip surface dressings.

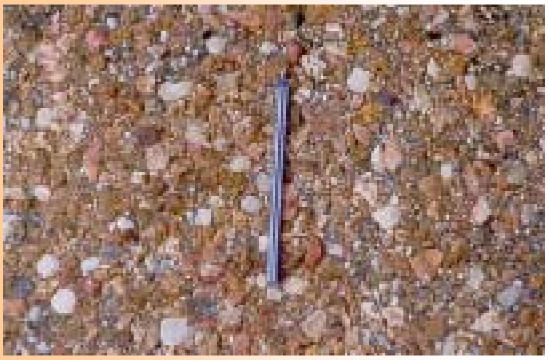
The two main options for bituminous surfacing using lower standard aggregates are:

- "Otta" Seal or Gravel Seal
- Sand Seal

"Otta" Seal under Construction (photo courtesy of Botswana Roads Department)




Sketch courtesy of Republic of Botswana Roads Department



Close up of Otta Seal Texture (Photograph courtesy of Botswana Roads Department)

Otta seals provide a durable low cost surfacing that is relatively insensitive to standards of workmanship. Labour intensive methods of construction may be used.

**"Otta" Seal or Gravel Seal**

A guide to the design, construction and maintenance of Otta seals has been published by the Republic of Botswana Roads Department (1999). This publication is the result of many years of successful field trials utilising lower quality aggregate in bituminous surfacing in Botswana, Kenya, Zimbabwe, Bangladesh and Scandinavia.

This type of seal is formed by placing graded aggregate (crushed or uncrushed, fines included) on a relatively thick film of comparatively soft binder (150/200 penetration grade or MC 3000 or MC800 cutback bitumen). During rolling and under traffic the bitumen works upwards through the aggregate instices. The graded aggregate relies both on mechanical interlock and bitumen binding for its strength.

A large variety of materials can be used as aggregate in Otta seals. The aggregate grading specified forms a wide grading envelope and strength requirements are relatively low. The amount of fines (<0.075 mm) should preferably not exceed 10%. It is desirable that the material be non plastic but Plasticity Indexes of up to 10% are acceptable.

| Aggregate Strength Requirement | Vehicles per day at the time of Construction | | BS Test Designation |
|---|---|---|---|
| | <100 | >100 | |
| Min. Dry 10% FACT | 90 kN | 110 kN | BS 812 |
| Min Wet/Dry strength ratio | 0.60 | 0.75 | |

**Table 4-7 Otta Seal Aggregate Strength Requirements**

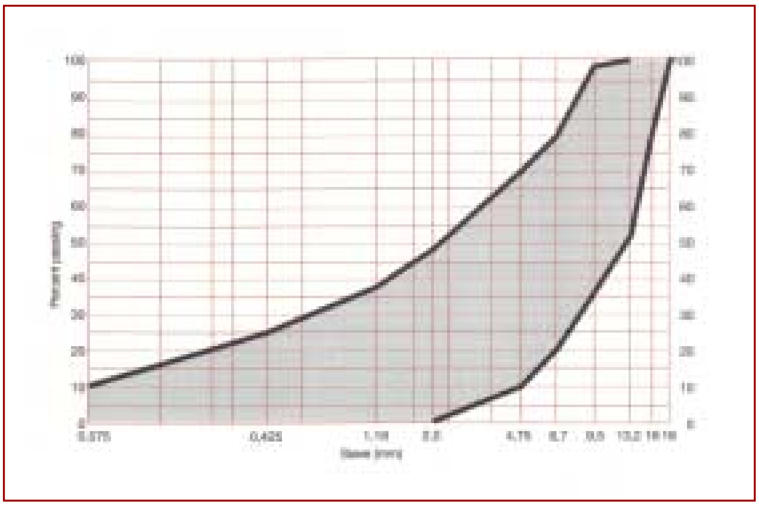


**Figure 4-9 General Grading Requirement for "Otta" Seal Aggregate**

**Sand Seal**

A sand seal is a layer of bitumen binder covered with sand or fine aggregate. The Kenya Design Manual (1987) recommends the grading envelope shown below.

| Sieve Size mm | % passing |
|---|---|
| 6.3 | 100 |
| 5.0 | 95 – 100 |
| 4.0 | 90 – 100 |
| 2.0 | 50 – 95 |
| 1.0 | 20 – 80 |
| 0.6 | 10 - 50 |
| 0.425 | 3 - 25 |
| 0.3 | 0 - 15 |
| 0.150 | 0 - 8 |
| 0.075 | 0 - 5 |

**Table 4-8 Grading Envelope for Sand Seal Aggregate (after Kenya Road Design Manual)**

The fines (passing 0.425) must be non plastic and the Sand Equivalent must be greater than 40. Suitable binders are cationic emulsion K1-60 and medium curing cut-backs MC800, MC 3000 or 800/1400. Kenya Manual notes that sands are generally siliceous in which case it is necessary to employ either cationic emulsion or an adhesion agent with cut-back. The amount of bitumen required is normally between 0.9 and 1.2 litres/$m^2$.

An excessive amount of sand is deliberately spread (6-7 litres/$m^2$). The sand particles penetrate into the binder and the whipped off sand is broomed several times back on to the road until it is held. Usually 4 to 5 litres/ $m^2$ of sand can be fixed in a single layer.

In Kenya it is recommended to routinely apply double sand seals to ensure imperviousness. The service life of a double sand seal is should be at least five years under traffic not exceeding 200 vehicles/day.

## Evaluation of Paved Road Material Suitability Rating

For future planning and record purposes it is recommended that during all borrow pit evaluations the materials are classified in terms of their suitability for use in paved road construction and for the supply of other road construction materials.

A suitability classification may be applied to the potential of the material source to supply:

- Road base
- Sub-base
- Sealing aggregate
- Gabion stone/ pitching stone
- Armour stone/ rip rap
- Coarse concrete aggregate
- Fine concrete aggregate

The following 4 point classification system (Bishop & Morey, 1992) allows a material source to be reliably classified based on information currently available to the engineer or technician making the pit evaluation:

| Rating | Definition | Characteristics |
|---|---|---|
| 1 | Proven to be suitable | Sufficient laboratory testing undertaken to prove the deposit conforms to specification requirements and/or has a good in-service performance history. |
| 2 | Likely to be Suitable | Insufficient laboratory testing undertaken to prove the deposit conforms to specification requirements but available test data and field observations indicate that the material would be suitable |
| 3 | Unlikely to be Suitable | Available data and field observations indicate that the material will be unsuitable, but further testing is required to confirm this conclusion. |
| 4 | Unsuitable | Field observations and/or available test results indicate that the deposits will be unable to conform to specification limits |

**Table 4-9 Rating System to Classify Material Suitability for Use in Various Road Construction Applications**

This suitability rating, when combined with the "As dug" Gravel Wearing Course Suitability Rating (refer Table 4.3) can form the basis of a simple and very informative Materials inventory Database Report (refer Section 10.4).

Appendix II contains a review of material types for use in low cost paved road construction.

## 4.3. Desirable Pit Characteristics

In simple terms, the best pit or quarry site is one that will be able to supply suitable road building materials at the lowest cost and with the least damaging effect on the environment and local population (refer Section 11).

The main factors contributing to desirable characteristics include:

**Pit Location**

Ideally pits should be:

- Located close to the road being supplied, preferably within a few hundred metres or adjacent to an existing feeder track.
- They should not require construction of long haul roads.
- Pits and quarries should preferably be located on land that has low agricultural potential and should not be located close to settlements if it can be avoided.

**Nature of the Deposit**

The desirable properties of any potential resource are:

- Relatively thin overburden or good overburden to workable deposit (bank) ratio.
- Uniformity of material characteristics within the “gravel bank” or “payrock”
- Predictable and preferably large sub-surface occurrence.
- High quailty excavated material requiring minimum, preferably low cost, processing to achieve a suitable standard for use in the desired construction application.

## 4.4. Economic and Haulage Considerations

When assessing whether to develop one pit site as opposed to an alternative potential source then selection must always fully consider the interrelationship between the quality of the extracted materials and the associated the economic influences (as identified in Figure 4.1).

Full consideration of economic influences requires a review of how a potential pit may be economically integrated into the **material supply strategy** for the road it may serve.

Material supply strategies are developed to ensure that **minimum costs** are associated with supplying suitable quality materials at the particular location on the road where they are required.

To design a material supply strategy the following factors need to be quantified:

- **The cost per cubic metre** of extracting and processing (if necessary) the aggregate to comply with quality requirements.
- **The cost of hauling the aggregate** to its destination on the road. **The availability of the material for use**, as determined by the estimated resource size.
- **The relative quality of the material**, if all pit material is not processed to the same standard.
- **Negative environmental impacts** and mitigation costs.

Detailed consideration of factors that influence the design of a materials supply strategy is presented in Section 9.4.

# Section 5
# Pit Preparation

# 5. PIT PREPARATION

This section considers the preparations and arrangements that are typically necessary prior to material excavation. These include administrative/planning activities and physical site preparations.

## 5.1. Pit Planning and Approval for Development

Engineering, social and environmental consideration are all very important in Pit Planning. Section 11 specifically addresses the social and environmental considerations associated with pit planning and development.

### Pit Working Plan

A pit working plan should be prepared and approved before any excavation begins.

Borrow pits should never be opened and operated in an uncontrolled manner. A working plan should be prepared before any excavation begins. Each plan should include consideration of the following:

- Arrangements for consultation with affected people so that a compensation agreement may be reached with the users/ owners and access arrangements agreed.
- The extent of each pit/ quarry (or extension) should be clearly marked on the ground, and a site survey undertaken for record purposes (refer following sub-section) to define agreed limits of working.
- An outline of the direction, timing and depth of working should be defined.
- When determining the size of a borrow area, allowance should be made for separate stockpiling of top-soil, overburden and borrow materials. A separate area for stockpiling future maintenance materials may be required outside the borrow pit (but within the borrow area).
- Borrow pits should be excavated to a regular width and shape. As far as possible, all existing trees, hedges fences etc should be preserved.
- Appropriate drainage and safety requirements should be determined
- A reinstatement plan, giving details of final shape, method of achieving it, drainage and sediment control, re-soiling and re-vegetation measures should also be prepared
- In all cases land taken for material sources should be minimised and fair compensation should be promptly paid to the user.

Borrow pits for the supply of low cost road materials are usually not in continuous use. In the case of gravel wearing course sources, 3 to 5 years will typically occur between regravelling operations and paved roads will usually only require rehabilitation after more than 10 years. This should be taken into account during planning. The area stripped should only be large enough to provide aggregate for immediate needs, with some stockpiling of maintenance aggregates.

When possible, areas of a pit that are worked out should be reinstated at the end of a particular supply operation. Such progressive restoration is beneficial because:

- Deterioration of top-soil and sub-soil material is minimised.
- Loss of productive land is minimised.
- Visual impact of the pit development is minimised.

## Site Survey

In the case of small borrow pits in remote uncultivated areas it may be sufficient to prepare pit sketches with important dimensions determined by tape measure. When a borrow pit will affect cultivated land and local inhabitants then an accurate site survey should usually be made and a large scale plan prepared at a scale of about 1:500 to 1:1000 depending on the size of the proposed working and nature of the site.

The site survey should include such details as:

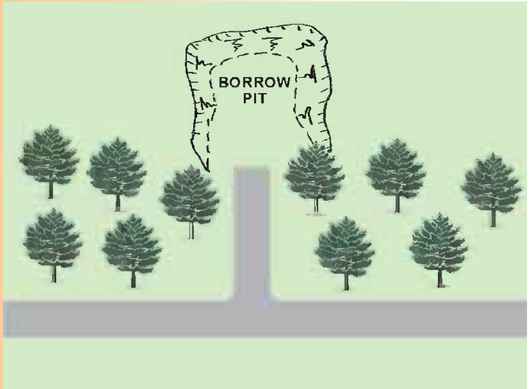
- Property boundaries
- Areas of cultivation
- Drainage lines and directions
- Location of specimen trees or fruit trees, dwellings, grave sites etc.
- Soils profile information (ie depth of top-soil and subsoil layers)
- Limit of area of agreed development.

Trial pit dug through borrow area showing soil profile:

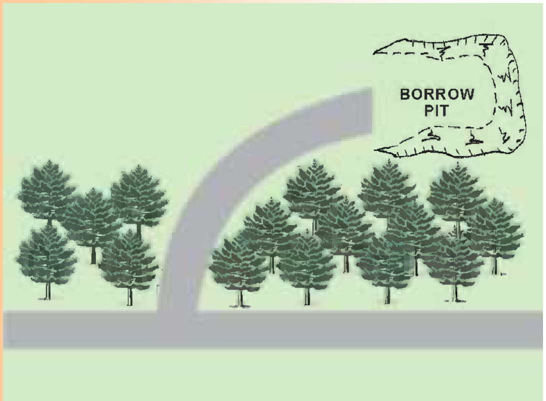
1 Top-soil
2 & 3 Sub-soils
4 Laterite Gravel

This ground profile information should be reported on the site survey plans

(Photo Source TRL 1999)




Undesirable access route




Preferred access route

## 5.2. Access Roads

The following recommendations relate to the provision of access tracks to borrow pits:

- Access tracks should be designed to be strong enough to carry the expected haulage traffic without significant deformation. Economies of construction may easily be outweighed by increased haulage costs (refer Section 9.3).
- Adequate provision should be made for cross drainage and for side drainage in order to prevent soil erosion, sediment pollution or road closure due to flooding.
- Pit access tracks should be aligned in such a way that they cause minimum disturbance to the local population and the environment. They should be located at a safe distance from permanent dwellings and if necessary fencing should be provided to protect local people and livestock.
- The route of an access track may be used to reduce the visual intrusion of pit located close the road being supplied.

## 5.3. Site Clearance

In flat to rolling terrain low cost road building materials often occur as thin (1.0 – 1.5 m) gravel deposits beneath a similar depth of topsoil and subsoil. As a result, extraction of the gravel will involve a relatively large area of site clearance to obtain quite a small quantity of construction material.

In hilly to mountainous terrain exploitable deposits are often fractured rock materials occurring beneath a very thin topsoil layer that rests on a variable depth of residual soil and highly weathered rock.

In both situations great care needs to be taken during the site clearance operations to expose the gravel bank or payrock materials, otherwise effective pit reinstatement may not be possible and significant environmental damage will result.

Current practices employed in respect of site clearance for borrow pits supplying low cost road materials are typically very poor. In particular, the following problems and bad practices often occur:

- Bush clearing is often achieved by burning prior to topsoil stripping. This practice removes organic matter and kills useful bacteria in the soil that help to produce additional nutrients (TRL 1999). If uncontrolled extensive damage may occur to the surrounding countryside.
- The removal of topsoil and sub-soils is often carried out as one operation. This results in complete destruction of the fragile topsoil.
- Heavy plant is frequently used to remove and stockpile surface soils. This causes soil compaction that will reduce future agricultural productivity.

- If any reinstatement takes place, it often involves bulldozing the mixed surface soils back into the excavation. This practice can result in rocks and boulders being strewn across the surface. The overall effect is severe degradation of the agricultural potential of the land.
- In mountainous terrain disposal of overburden soils is sometimes carried out by side tipping downslope. This degrades the agricultural potential of the hillslope and frequently leads to slope instability (landslides that may just involve the spoil, or the spoil and the underlying weak soils).
- Topsoil is frequently left in stockpiles for unnecessarily long periods. The longer the soil is stockpiled the greater will be the change in soil structure and nutrient available due to rapid decline in soil organic matter (TRL 1999).

Recommended procedures for site clearance are presented in the following paragraphs. They have frequently been based on procedures contained in "Environmental Reinstatement of Road Building Borrow Pits in Southern Africa" (TRL,1999).

Side tipping of overburden in mountainous terrain is unsightly and frequently leads to severe slope instability problems.

## Removal of Vegetation

Vegetation clearance is often carried out by dozer when site growth comprises bush and trees. This will cause over compaction of the surface soils and so should be avoided if possible. Manual vegetation removal is the least damaging form of site clearance and should be used when manpower resources are available.

During site clearance any shubs that would be suitable for transplanting back onto the site during reinstatement should be identified and protected. Similarly cuttings of some shrubs might be preserved for future replanting..

Manual methods of site clearance are encouraged, because they reduce damage to fragile tops-soil and sub-soil materials (Sketch after ILO/ASIST Bulletin No 9, 1999)

Manual methods of site clearance are encouraged, because they reduce damage to fragile tops-soil and sub-soil materials (Sketch after ILO/ASIST Bulletin No 9, 1999)

Tractor excavator carrying out top-soil stripping (photo courtesy of JCB)

## Removal of Top-soil, Sub-soil and Other Overburden

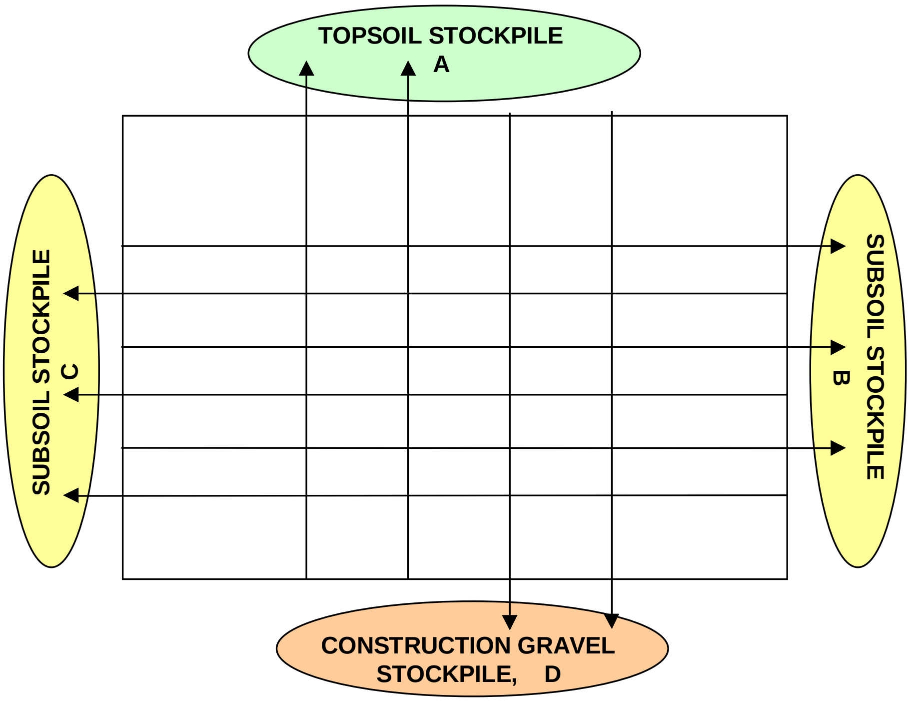
Guidelines on appropriate procedures for topsoil removal, overburden soil stripping and pit reinstatement have been prepared by TRL (1999). Figure 5.1 shows diagrammatically their recommended procedure, which comprises careful removal of topsoil and it stockpiling followed by extraction of identified subsoil layers separately into stockpiles followed by borrow extraction.

Some specific recommendations on good practice are given below.

### Top-soil

Top-soil is the organic soil typically occurring as a surface layer 150 – 200 mm thick. It is essential that the topsoil is carefully removed and stockpiled for use during reinstatement of the excavation. The future productivity of the restored land is totally dependent on its careful replacement. The following recommendations apply to top-soil stripping:

- The top-soil stripping operation should normally be carried out at the same time as the removal of vegetation.
- Top-soil can usually be distinguished by a change in colour. If not, then the surface layer should be removed to a depth of 150mm and stockpiled separately from the underlying layers and in such a way that it does not interfere with the drainage of the adjacent land area.
- Top-soil stockpiles should be shaped to minimise the erosive action of rainfall.
- Removal of top-soil by labour intensive methods is encouraged when practical and economically viable (labour based excavation productivity norms are given in Table 6.2, and outputs for soil haulage by wheel barrow and tractor and trailer are presented in Section 9). Manual methods will minimise compaction of the soil.
- If top-soil is to be removed by mechanic plant, this should ideally be selected to cause least compaction of the material. Tracked backhoe excavators (with special buckets) or scrapers are most suitable. In the absence of earth scrapers, a combination of dozer, grader and wheel loader may be most effective on relatively large sites.
- The borrow pit top-soil should only be used for borrow pit restoration, and should not be used to supplement materials required for side-slope cover or other road project purposes.




**PROFILE**

A TOPSOIL APPROX. -150mm THICK

B SUBSOIL APPROX. 300mm THICK

C SUBSOIL APPROX. 400mm THICK

D GRAVEL USUALLY 750-2000mm DEPTH THICK

EXTRACTION ROUTINE A →B→C→D
REHABILITATION ROUTINE C →B→A

Source: TRL. 1999

**Figure 5-1 Recommended Procedure for Removal of Overburden and Stockpiling**

**Subsoil and Other Overburden**

The following recommendations apply to sub-soil and overburden stripping:

- The average and range of thickness of overburden soils should be accurately known from site investigations and shown on the pit plans.
- Sub-soil layers should be identified, removed in sequence and stockpiled in shaped berms separately from the top-soil and in such a way that it does not interfere with the drainage of the adjacent land area.
- In mountainous terrain where there is no space for storage of overburden materials, they should be hauled to a suitable disposal site or stockpile area located in stable terrain. Side tipping of overburden soils on steep slopes beside the road should never be permitted.
- Overburden stripping may be carried out with any suitable plant.

## 5.4. Layout of Working

**Shallow Gravel Pits**

The layout of a borrow pit exploiting near surface deposits will be strongly influenced by whether it is to be worked by labour intensive methods or by using mechanised equipment.

Intensive labour extraction methods are considered in Section 6. Figures 6.1 and 6.2 show the ideal pit arrangement for the labour based extraction of gravel on a flat site.

The following considerations should be taken into account when planning borrow pit development using manual methods (PIARC 1994):

- Optimum height of face to be worked with a pick is about 700mm.
- The most efficient layout will avoid multiple handling. Where possible excavate bays about 3.5m wide so that trailers can be backed in for loading.
- Provide sufficient space to allow tractors and trailers to manoeuvre into and out of loading positions without difficulty. It may be desirable to have both access and exit routes into the working.
- Ensure that the pit layout will avoid poor drainage and the development of soil erosion problems.
- In hillside pits excavate material to allow easy loading and ensure safety of workers.

When mechanised extraction methods are employed the main influences on pit layout may be somewhat different, as follows:

- The working face should be arranged to allow efficient operation of the excavation plant being utilised (refer Section 7.3). For example, dozers work best down a slightly inclined face, whilst backhoes may operate most efficiently in a near vertical face several metres high.
- The need to promote or prevent mixing of slightly different deposits, may influence both pit layout and selection of appropriate excavation plant.
- Some stockpiling of excavated materials is typically associated with plant based extraction therefore careful consideration needs to be given to the location of stockpile areas. They should not interfere with future development of the pit and need to be arranged so that there is sufficient space for the efficient operation of loading plant and trucks.
- Processing of materials, if required, will also require considerable space and careful siting with respect to the excavation and stockpile areas.
- Fencing will be required, to protect the local population and livestock, when pit development will produce potentially hazardous steep faces.

The working of relatively thin near surface deposits involves a poor ratio between land take and resource size, hence these pits have the potential to create significant adverse effects on the environment. Pit layout and method of pit operation can help to reduce these negative impacts and such environmental considerations are examined further in Section 11.

### Deep Pits and Hard Rock Sources

The planning of deep excavations requires adequate knowledge of expected subsurface geological conditions (obtained from the site investigations), combined with an understanding of safe cut slope design and good quarrying practice.

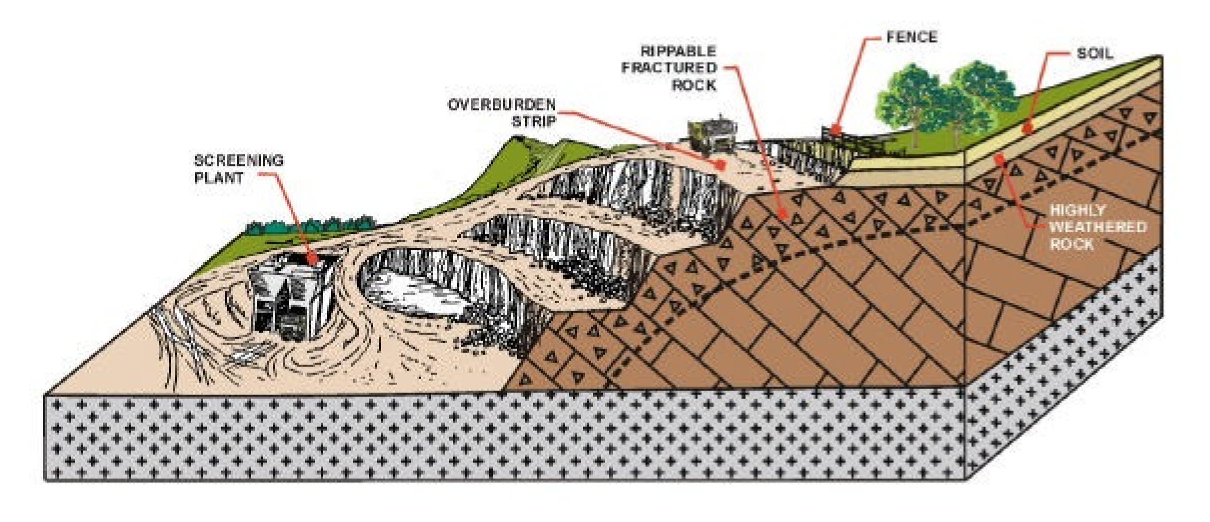



**Figure 5-2 Recommended General Layout of a Hillside Quarry (Modified after Ferry, 1986)**

- Figure 5.2 illustrates the recommended general layout of a hillside quarry in hard rock (requiring drilling and blasting). Such an excavation should be developed in a series of benches separating steep quarry faces. Processing and stockpile areas should be located in a flat area, which provides sufficient space for aggregate handling. In the case of hillside quarries processing plant may have to be located some distance from the excavation.

Cut slope stability and detailed quarry layout is determined by the characteristics of the soil and rock materials that are exposed. Typically increasing excavation depth is associated with increasing material strength and decreasing rock weathering or alteration.

Figure 5.3 presents a guide to good quarrying practice in weathered rock, which provides recommendations on slope design in materials subject to a standard weathering profile. In such a situation pit planning will need to take account of the suitability of different weathering grade materials for different applications in road construction. Grade I and II materials may be suitable for base production, whilst Grade III rock may only provide subbase aggregates and Grade IV deposits may only be useful in selected fill layers. As far as possible, the quarry should be designed to exploit required quantities of each material type, while minimising extraction of unusable material.

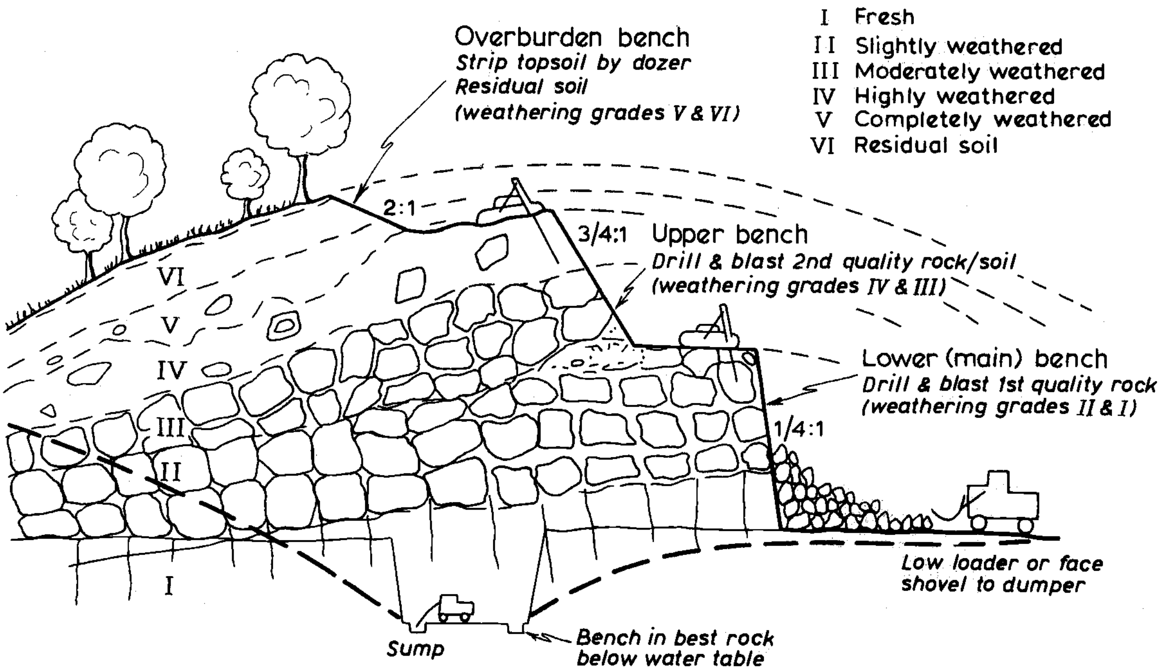



**Figure 5-3 Good Quarrying Practice in Weathered Rock Overlain by Residual Soil (Fookes, 1991)**

A good indication of subsurface conditions, gained from site investigations, is essential for the development of quarry layouts. However, the amount of information that can be gained on rock quality from drillhole and geophysical investigations is limited. As a result, it is necessary to constantly review planned layouts in the light of actual ground conditions exposed, particularly with respect to safe cut slope design.

Detailed guidelines on the design of cut slope in rock may be found in "Rock Slope Engineering" by Hoek E and Bray JW (1977).

# Section 6
# Material Extraction
# (Labour Intensive)

# 6. MATERIAL EXTRACTION (LABOUR INTENSIVE)

## 6.1. Introduction

In most developing countries the purchase and maintenance of equipment for materials extraction requires major foreign currency expenditure. Mechanised extraction can be relatively expensive when labour is readily available and inexpensive. In addition, unemployment is a serious problem in the rural communities of many developing countries, therefore it is often in the national interest to utilise manual labour power as much as possible.

In such circumstances, the use of labour based methods has been encouraged by agencies funding civil engineering works and in particular by the International Labour Organisation (ILO). As a result, there exists a good selection of manuals and advisory notes dealing with labour intensive road construction.

A list of selected references providing details on various aspects of labour based road construction is presented in the bibliography. In view of the availability of information on this subject, this Section gives greatest consideration to when labour based methods may be appropriate for materials extraction and reviews rates of production that might be expected.

Labour based gravel pit development
(Photo courtesy of P Larcher, Univ. Of Loughborough)

## 6.2. When Labour Intensive Methods are Appropriate

Often even when social and economic factors indicate that labour intensive methods of construction material supply would be beneficial, other factors may show that it is either not viable, inefficient or undesirable.

**1. Geological Considerations**

In many developing countries the geological conditions required for efficient labour intensive gravel road material supply may only occur rarely. Labour intensive material extraction and supply may only be viable when:

- Uncemented gravel occurs beneath a relatively thin overburden cover
- Exploitable deposits occur at frequent intervals close to the road. Typically it is more efficient to haul materials by tipper truck when distances exceed 5-10 km, due to travel time and because it is difficult to load tipper trucks efficiently by hand labour.

Labour intensive methods of gravel road material supply have been most successful in areas where:

- There is a widespread occurrence of near surface weakly cemented laterite (murram) deposits, calcrete deposits or silcrete deposits
- There are frequent exploitable river bed or river terrace gravel deposits

**2. Environmental Considerations**

Labour intensive methods are sometimes used in mountainous terrain where there are roadside occurrences of suitably fractured rock. However, the development of frequent small borrow pits in terrain which is prone to soil erosion and slope instability is not supported. In mountainous terrain it is better to open a limited number of carefully selected borrow pits in order to limit environmental damage. Large pit size and longer haulage distances then favour mechanised extraction and loading, and tipper truck haulage.

Labour based extraction is most viable when overburden soils are thin and bank deposits uncemented

Development of numerous small pits/quarries in mountainous terrain for labour based extraction will often be associated with serious adverse environmental impacts that outweigh any economic and social benefits.

## 6.3. Resources and Work Methods

Labour intensive extraction makes maximum use of hand tools. A pit labour gang will require: picks; crow bars; hoes; shovels; and sledge hammers. In addition, labour gangs should be provided with a jerry can of drinking water, a first aid kit and head and foot protection.

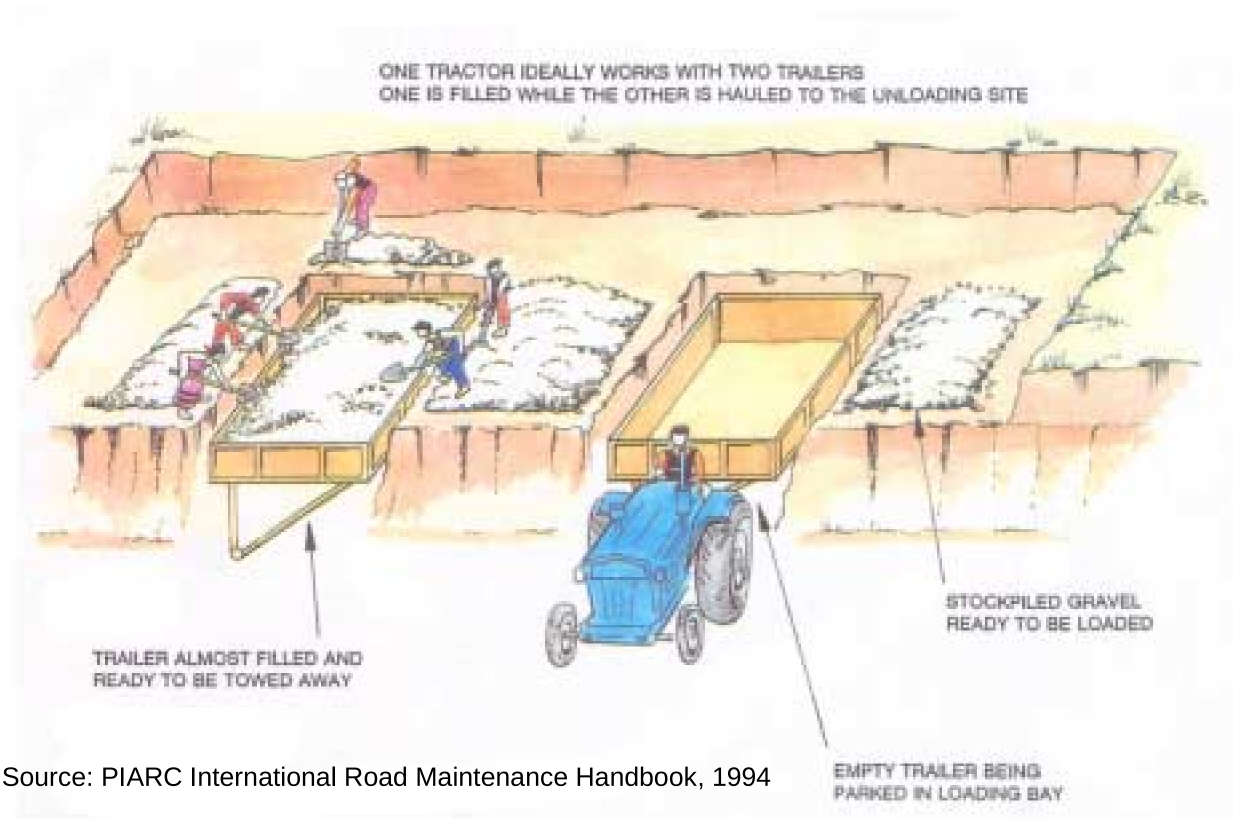
Careful pit planning and preparation is particularly important in the case of labour intensive material extraction (refer Section 5.3).

Figures 6.1 and 6.2 Indicate some of the most important aspects of work to be considered when excavating and stockpiling in the pit.

The minimum size of pit labour gang will depend on:

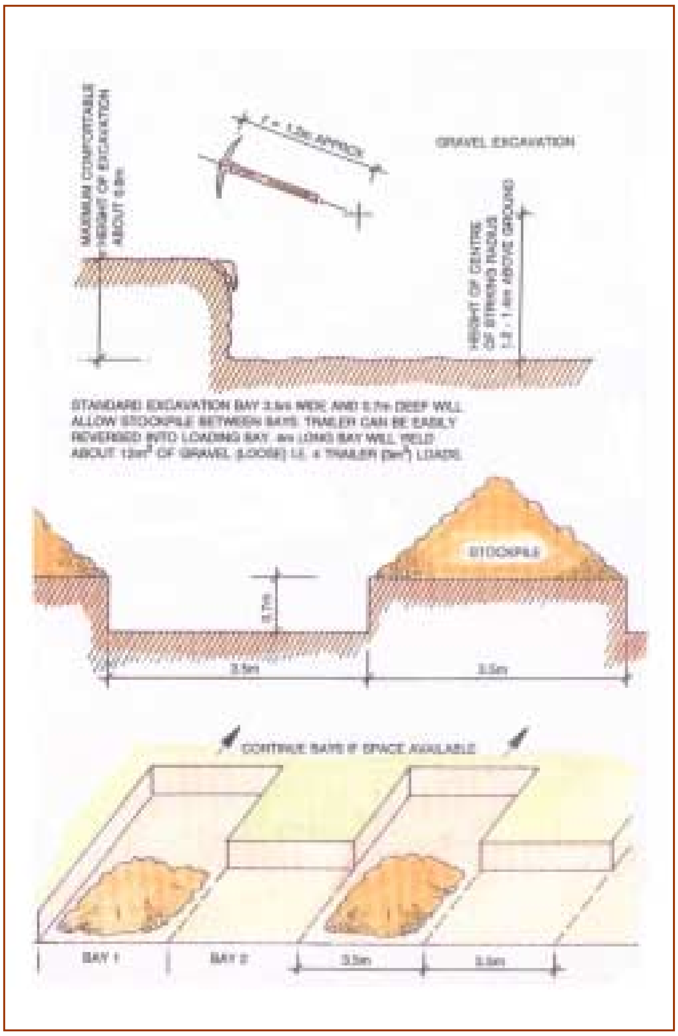
- Size of the pit site and amount of overburden to be cleared
- Availability and capacity of the hauling equipment
- Productivity rates, which will be influenced by the hardness of the *in-situ* bank material (refer Section 6.4.

Large pit operations may require between 40 to 60 labourers both for site preparation and subsequent extraction.




Source: PIARC International Road Maintenance Handbook, 1994

**Figure 6-1 Ideal Pit Arrangement for Labour Intensive Extraction**




Source PIARC International Road Maintenance Handbook, 1994

**Figure 6-2 Development of a Gravel Pit on Flat Ground**

Labour based gravel pit development
(Photo courtesy of P Larcher, Univ. of Loughborough)

## 6.4. Work Outputs

As would be expected the most important parameter in the assessment of outputs from labour based extraction is the hardness of the material. This can alter the expected productivity by a factor of four or greater (ILO/ASIST Tech. Brief No 2 1996). The World Bank in a definitive study produced a comprehensive classification of soil strengths in relation to manual excavation. Table 6.1 reproduces a simplified classification based on soil type and tool penetration. This classification provides a useful way for projects to assess their individual needs.

| | Soil Description | | |
|---|---|---|---|
| | Cohesive | Non cohesive | |
| Soft | Soft | Very loose | Easily excavated with a shovel or hoe |
| Medium | Firm | Loose | Can be dug with a shovel |
| Hard | Stiff | Compact | Mattock, pick or other swung tool required |
| Very Hard | Very Stiff or Hard | Dense or Very Dense | Crowbar required in addition to pick |
| Rock | - | Rock | Sledge hammer and Chisel required |

(Extract from ILO/ASIST TB No2 – after World Bank)

**Table 6-1 Soil Classification for Manual Excavation**

Productivity norms for labour based extraction have recently been reviewed by ILO/ASIST. The results of their findings are summarised in Table 6.2. It is noticeable that the data from the trials for soft, medium and hard soils are very scattered, with improbably high figures for very hard soils. This probably reflects a lack of attention to site conditions among supervisors. In general, the median rates form a reasonable basis for productivity estimation.

| | Average Productivity by Soil Classification $M^3$ / Worker Day | | | | |
|---|---|---|---|---|---|
| | Soft Soil | Medium Soil | Hard Material | Very Hard Material | Rock |
| Botswana | 4.2 | 3.8 | 2.5 | 1.9 | - |
| Cambodia | 2.8 | 2.0 | 1.3 | 0.8 | - |
| China | 9.0 | 7.0 | 3.0 | 2.0 | - |
| Ghana | 3.8 | 3.8 | 3.8 | 3.8 | - |
| Indonesia | - | - | 2.5 | - | - |
| Kenya | 5.0 | 3.5 | 2.3 | 1.8 | 0.8 |
| Lesotho | 4.5 | 3.5 | 2.8 | 1.0 | 0.5 |
| Nepal | - | 3.3 | 2.5 | - | 0.6 |
| Tanzania | 5.5 | 4.5 | 4.0 | 2.5 | - |
| Zimbabwe | 5.5 | 5.5 | 4.0 | 3.5 | 2.0 |
| WB Study | 6.7 | 2.1 | 3.0 | 2.0 | 1.7 |
| **Median** | **5.0** | **3.5** | **2.8** | **2.0** | **0.8** |

(Extract from ILO/ASIST TB No2)

**Table 6-2 Labour Based Excavation Productivity Norms**

# Section 7
# Material Extraction
# (Mechanised)

# 7. MATERIAL EXTRACTION (MECHANISED)

## 7.1. Excavation Planning and Plant Selection

The economic extraction and production of borrow pit materials for low cost road construction, may depend largely on the correct selection of plant and the careful programming of its use.

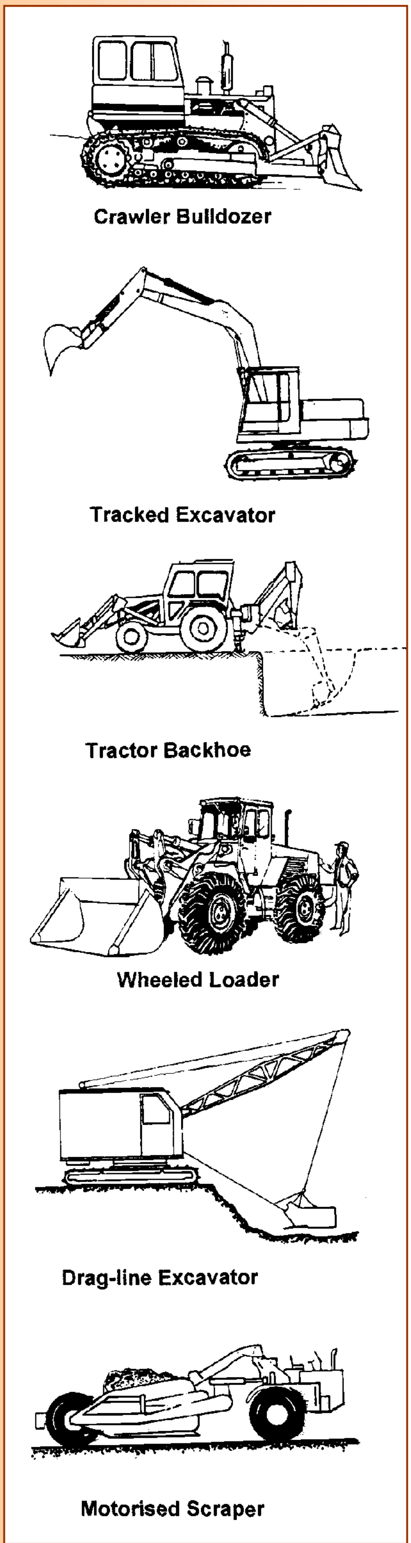
Table 7.1 summarises the types of plant suitable for heavy, medium and light excavation work.

Section 3 has provided guidance on the assessment of the diggability and rippability of geological materials. Factors to consider when planning material excavation and use of plant include:

- Choose a method of extraction that produces the best quality "as dug" materials (ie does not generate a large proportion of oversize material).
- If pit materials are variable or inter-bedded, use plant and excavation methods that can produce a suitably mixed aggregate.
- Select plant that achieves an acceptable rate of material production or programme stockpiling ahead of aggregate supply.
- When possible use plant that can both excavate and load the aggregate.
- If aggregates are likely to deteriorate in stockpile, try to combine excavation and supply activities.
- Carefully programme plant and pit activities that require more than one type of plant (ie dozer to strip overburden and excavator to dig gravel for loading or stockpiling).
- Programme activities so that plant does not stand idle in a pit.

To ensure satisfactory plant output:

- All plant should be in sound mechanical condition and well maintained.
- All operators should be adequately trained and experienced.
- All items of plant should be worked within the normal limits of their capacity. They should not be overworked.
- There must be adequate site supervision to ensure that appropriate extraction methods and procedures are being followed by all concerned.




Extraction Equipment
(Source: Aggregates, 1993)

| | Excavation | | | Comments |
|---|---|---|---|---|
| | Heavy | Medium | Light | |
| Drill and Blast | ♦ | | | Pneumatic, top-hammer rotary percussive methods can be used for drilling small diameter blast holes. |
| Bulldozer Ripping | ♦ | ♦ | | Single tine used for very heavy ripping (poorly fractured rock) and multiple tines for medium ripping (fractured or weak rock). The correct selection of tine, ripper arrangement and method of use will all affect the efficiency of excavation and the characteristics of the excavated material. |
| Bulldozer | | ♦ | ♦ | Blade excavation of fractured rock may reduce oversize associated with ripping (when feasible). However, when ripping is not required, then use of plant that can excavate and load is desirable |
| Grader | | | ♦ | Typically not efficient for excavation, but may be required for mixing material in the pit or on the road |
| Excavator | | ♦ | ♦ | Versatile method of excavation and loading. Large selection of plant produced. Face excavation may allow effective mixing of beds. |
| Tractor Backhoe | | | ♦ | Rate of production may be limited, but might be adequate particularly if material is stockpiled. |
| Drag-line Excavator | | | ♦ | May be required for excavating gravel from below the water table |
| Wheel Loader | | | ♦ | Ideal for excavating and loading loose gravels (after pit preparation) |
| Crawler Loader | | | ♦ | Usually not ideal due to lack of manoeuvrability on the tracks |
| Scraper | | | ♦ | Best suited for large scale earthworks operations, will rarely be economical in low cost road construction |

**Table 7-1 Suitability of Plant for Extraction**

## 7.2. Efficient Use of Plant

The following descriptions of plant and notes on their appropriate and efficient use in borrow pit excavation includes a number of selected extracts from the Fiji Road Maintenance Training Manual Section 4.4 (Public Works Department, Fiji 1997).

### Bulldozers

Bulldozer with single tine parallelogram type ripper.

Crawler "dozers" will be required when poorly fractured rock, weak compact rock or cemented gravel is to be extracted.

Cutting and pushing down hill invariably improves the operating efficiency of bulldozer excavation, because the weight of the machine will assist the process. Cutting materials down an incline may have the added advantage that different horizontal layers are mixed during the excavation process. Blades should be pitched back for heavy cutting and penetration work.

With softer materials, use of a dozer may be 'overkill'. Transport of dozers between sites is slow and this may incur lost time and extra costs (ARRB 1997).

Three tine adjustable parallelogram type ripper (Source: Chelyabinsk).

In some situations a better "as dug" rock gravel will be obtained by making maximum use of the blade rather than resorting to the use of rippers to aid extraction. If the ripping process produces a significant quantity of oversize material that is not readily broken up by tracking, then use of the blade to "shave" off material would be a better method when feasible. However, blade excavation may require a very powerful machine and may result in considerable machine wear. In which case it could be more economical to rip and either screen out or crush the oversize produced (refer Section 8).

Bulldozers may be used to push material up to about 150m into stockpile, but their use is unlikely to be efficient over longer distances. The output of bulldozers depends on a number of different factors such as machine size, type of material, whether operating on the level or on a grade and so on. However as a general guide, a dozer of about 10 tonne weight (ie Caterpillar D4) will shift around $100m^3$ of loose material per hour over a 100 m distance. While a dozer of about 20 tonnes (ie Caterpillar D7) will shift around $200^3$ of loose material per hour over 100m.

### Bulldozer Ripping

Bulldozers may be fitted with one or more ripper tines (shanks). The correct selection of tine, ripper arrangement and method of use will all affect the efficiency of excavation and the characteristics of the excavated material.

There are two basic types of ripper and several types of ripper tine (shank) and tip as shown in the Figures and described below:

### 1. Radial Ripper

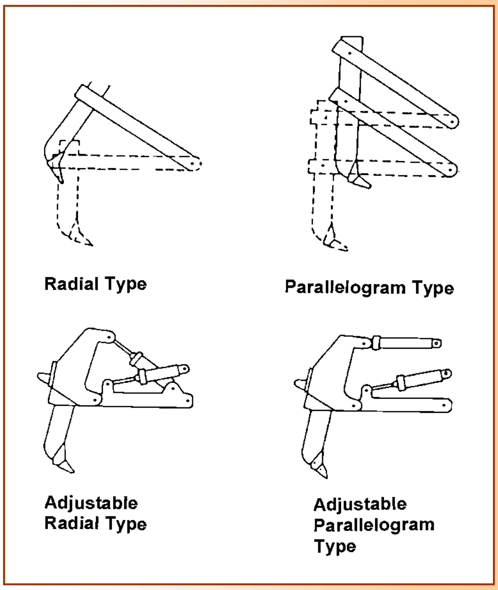
This type of ripper is hinged on the bulldozer frame and the depth of penetration is controlled through a hydraulic arm. The tip angle varies as the shank is raised or lowered. A manual adjustment enables the angle of the shank to be varied. Small angles are used for soft materials and large angles for hard material

### 2. Parallelogram Ripper

This type of ripper has two parallel link arms that allow the tip angle to remain constant when the shank is raised or lowered. This type has the advantage of a constant tip angle irrespective of ripping depth, but the disadvantage that the angle cannot be altered to give better penetration in hard material.

Refinements of the above two types of ripper are the adjustable radial and the adjustable parallelogram. These rippers have hydraulic controls to enable the operator to vary the tip angle while ripping.

In very hard ground a single tine parallelogram ripper is usually the most effective arrangement.




Ripper Arrangements

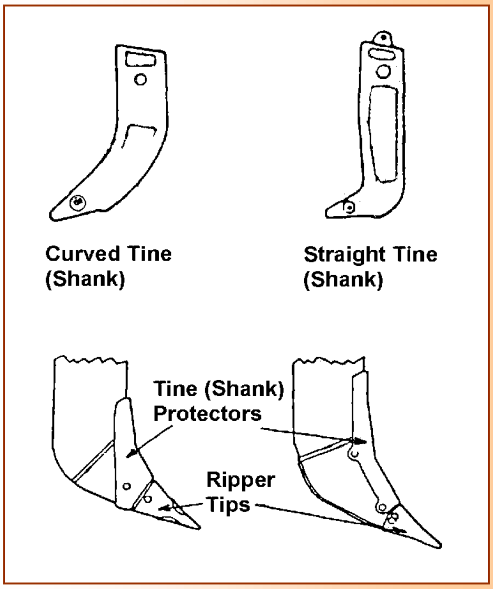
### 3. Ripper Tines and Tips

There are two basic types of ripper tine, the straight and the curved. Straight tines provide the lifting action needed in tight, laminated materials plus the ripping ability in thick or slab type material. Curved tines work well in less dense material and produce less ripping distance. With the curved tine, material is lifted and further broken before passing the vertical portion of the tine. This tine therefore has an advantage when winning borrow material.

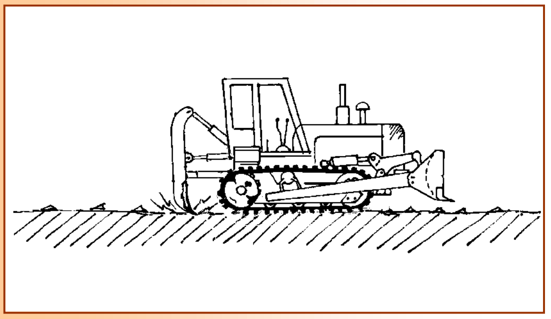
The penetrating end of the tine is fitted with a hardened tip to protect it from wear. Ripper tips must be able to withstand abrasion and breakage and to penetrate into the material to be ripped. Three types of tip are available as follows:

- Short tips, for use when penetration is difficult
- Intermediate tips, for use when the material is abrasive and a long tip is likely to break
- Long tips

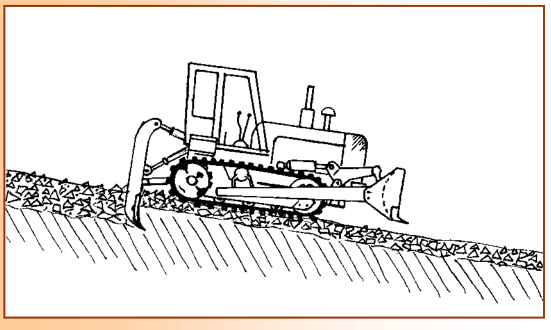
As a general rule, it is good practice to use the longest tip that will rip without excessive breakage. A shank protector may be pinned to the leading edge of the shank to protect it from excessive wear.




Ripper Tines and Tips



Poor arrangement for effective ripping.



Optimum arrangement for ripping.

## Efficient Ripping for Borrow

In order to maximise efficiency in ripping to produce road aggregate the following points should be kept in mind:

- First gear should be used because optimum ripping speed is about 2 to 3 km/h. Machine maintenance costs tend to increase rapidly for small increases in speed.
- As far as possible rip downhill to obtain the benefit from the weight of the machine.
- Care should be taken to arrange for ripping to make optimum use of natural fracture orientation. Ripping will be most effective when carried out in the direction of inclined fracture planes (or bedding) as this tends to pull the tine into the ground.
- If the materials contain vertical laminations that run parallel to the cut, it is sometimes necessary to rip across the cut to obtain proper material break-up, as ripping along the laminations may only produce deep channels in the material.
- The spacing of ripper passes will influence the final size of material produced. Close spacing will produce less oversize material. Cross ripping may also limit oversize.
- Ripping as deep as possible will loosen the maximum amount of material, but ripping to partial depth may reduce the proportion of oversize material produced.
- Use of a second dozer to pull the ripper dozer may extend the range of the ripper into harder material, thus avoiding the need to blast.
- Rock that is too difficult to rip initially may sometimes be pre-blasted with light explosive charges and then ripped.
- Never remove all the ripped material before ripping deeper. Always leave a layer of at least 100 to 150 mm of ripped material to provide better traction, reduce track wear and crush the surface materials.

## Excavators

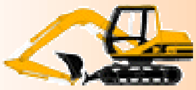
Excavators are very versatile digging machines that are now produced in a great variety of forms. All excavators have boom arm hydraulically operated digger buckets and are turntable mounted on either a crawler track or wheeled chassis. The turntable can be horizontally rotated on the fixed chassis by a full circle 360 degrees. The reach of the boom arm for digging operations, either upwards or downwards, may be up to 6m.

Excavator classification is generally by machine operating weight and power rating – typically 6 to 15 tonne and 60 to 150 KW power. Unlike backhoes, excavators do not require stabilising rams whilst being operated. In built counterweights are incorporated, which act as stabilisers. Heaped bucket capacities typically range from 0.5 to $2m^3$. The hourly output of an excavator will depend on many factors including the size of the bucket, the type of material, the site conditions and skill of the operator.

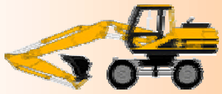
As a general guide, for sands and gravels, possible outputs vary from 125 $m^3$/ hour for a 0.5 $m^3$ heaped capacity bucket to $360m^3$/ hour for a 2.0 $m^3$ heaped capacity bucket. For well blasted or naturally fractured rock, comparable figures are 80 and 200 $m^3$/ hour. However actual outputs may be below these possible values because of particular site conditions that apply in the borrow pit.

In order to maximise efficiency in excavator digging and loading operations the following guidelines apply:

- Greatest efficiency will be achieved if borrow materials can be loaded for haulage as they are excavated. In which case the excavator and trucks should be arranged so that the operating cycle is minimised. Ensure that there are sufficient trucks so that the excavator does not have to wait.
- The size of the bucket should be suitable for the particular conditions, such as the quantity and type of material to be loaded.
- For each bucket size there is an optimum bank or face height at which it can be filled in minimum time. If the height is small it may be necessary to push harder or make two passes. However, the face height may need to be influenced by the need to mix layers with different material characteristics.
- The rake or angle of the bucket should be adjusted to suit the particular material. For easy digging and low cuts, maximum rake should be used. While, for harder digging and higher faces a smaller rake should be adopted.
- Where possible the excavator should be arranged so that the working area is well drained in order to keep the excavator and trucks on a firm and dry base.



Tracked excavator (Source: JCB)



Wheeled excavator (Source: JCB)

Excavator digging river gravel from below water level

Excavator (Source: JCB)

Hydraulic Hammer Attachment (Source: Maberly)

Backhoe (Source: JCB)

Backhoe (Source: JCB)

## Hydraulic Hammer Attachments

When hydraulic hammers are attached to excavator booms (replacing the bucket) the machines can be used for secondary breaking of large stones and boulders produced by blasting or ripping. This will allow stone to be broken for feeding into a crusher, but will rarely be suitable for reducing oversize in aggregate otherwise suitable for use as gravel road surfacing material.

Recently excavation from the rock face by hydraulic hammer has been introduced in Europe, and has advantages where noise restrictions prevent blasting.

## Backhoes

A backhoe comprises a bucket or shovel mounted on a hydraulic boom and attached to the rear of a crawler or rubber tyred tractor. Backhoes are well suited to excavating relatively loose material from above or below the level of its wheels into trucks. The reach for digging and loading is controlled by the length of the boom, but is usually up to 4m.

Heaped bucket capacities range from 0.5 $m^3$ to 1.00 $m^3$. The figures given for smaller excavators can be used as a guide to hourly output capacities. In order to optimise backhoe operation, the guidelines listed for excavators should be taken into account when relevant.

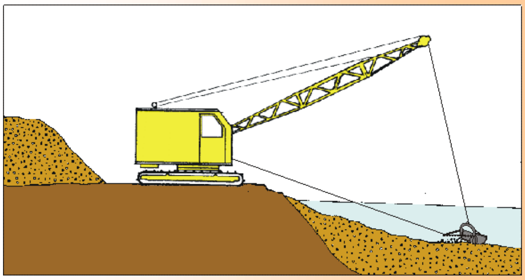
The horizontal arc that the bucket of a backhoe can be rotated through is a half circle 180 degrees. As a result backhoes are not nearly so versatile or manoeuvrable as an excavator. For stability rubber tyred backhoes require rams. Set up times are therefore considerably longer than for excavators.

Backhoes are easy to move between material sources and can be useful for carrying out trial pit investigations during material prospecting.

## Dragline Excavators

Dragline excavators are typically modified crawler cranes with an additional winch and clutch gearing. Long side tracks reduce bearing pressure and increase stability. The superstructure can rotate through 360 degrees.

The machine is usually situated on a bank and is able to excavate gravel materials to a considerable depth depending on the boom length and slope angle. Owing to the boom length the machine is able to extract material from one set up over a large area. A skilled operator may cast the bucket beyond the reach of the boom.



Dragline excavator recovering gravel from below water level.

Draglines can be operated "wet" or "dry" and can excavate soils, unconsolidated overburden, sand and gravel and well fragmented rock although it is not suitable for the selective recovery of thinly bedded materials (Aggregates, Geological Society 1993). Dragline excavators are particularly useful for excavating sand and gravel deposits from water filled excavations. When excavating from below water level it is usual to create a stockpile to permit drainage before haulage.

When fitted with a large steel ball dragline equipment can be used as an alternative to excavator mounted hydraulic hammers for breaking oversize boulders. The ball is dropped from the top of the boom on the rock. This method of secondary breakage is slow but highly effective in most rock types. However, it will create a safety hazard due to flying rock pieces that will require special precautions.

## Graders

A grader comprises an adjustable steel blade mounted on a rubber tyred vehicle. The blade can be raised or lowered, rotated or tilted. Blades vary from about 3.6 to 4.9 m long and from about 600 to 800 mm high depending on the engine power of the machine (range 92 to 200 KW). The blade is slightly curved enabling it to cut into a surface and then impart a rolling motion on the material removed, which assists lateral movement and mixing.

Typical motor grader used during low cost road construction and maintenance.

In borrow pits graders will normally only be used for: topsoil and loose overburden stripping; mixing extracted materials (by windrowing); maintenance of access roads; and reinstatement of topsoil. Typical operating speeds for stripping are 4-6 km/hr, while for mixing a speed of 6—13km/hr is appropriate. For mixing purposes the blade is leaned at the top edge to enable the material to flow and rise freely.

Graders are frequently fitted with tines to allow hard road surfaces to be ripped to shallow depth, but graders are not generally efficient for pit excavation work. Use of the ripping tines to aid extraction of pit materials is liable to overwork the machine and result in serious tyre wear.

Operator training, efficiency and competency is always a key factor in effective grader operations.

## Front End Loaders

A loader is a bucket mounted on the front of a rubber tyred or crawler tractor. Loaders are often used to excavate loose materials, such as river gravel. Tyres are likely to suffer excessive wear excavating hard materials. Their main use in borrow pits is usually to load from stockpile into trucks. Loaders may also be used to transport small quantities of material over short distances (up to 200 to 300m). For instance, loaders may be used to transport ripped materials to the grizzly feed of a screen or crusher.

Crawler tractors may be used when loading broken rock or when ground conditions are unsuitable for rubber tyred loaders. However they are slower and less mobile than rubber tyred loaders, their screwing action usually damages the loading area and they must be transported from site to site.

Wheeled front end loaders are ideal for excavating and handling loose soils and gravels in borrow and stockpile areas.

Rubber tyred loaders may be two or four wheel drive with rigid or articulated frames. In addition they may have an oscillating frame which provides greater flexibility and manoeuvrability as well as stability when operating on uneven ground.

The general purpose loader bucket has a hardened cutting edge and optional teeth or tines. The rock bucket is heavier and may have a see through grill at the rear. Bucket sizes range from 1 to 3 $m^3$ heaped capacity (struck or level capacities are about 80% of heaped).

Hourly loader outputs range from 80 $m^3$ /hr per $m^3$ of struck bucket capacity for sand and gravel to about 50 $m^3$ /hr per $m^3$ of struck bucket capacity for well blasted rock, under good operating conditions. In poor operating conditions the hourly outputs may be significantly less.

The following guidelines apply to the efficient use of loaders:

- Loaders are usually not efficient at winning material and loading at the same time. Loading from stockpiles is normal
- Position trucks to minimise loader turning and travel. Load from the side or rear of a truck, never over the cabin
- Match the size and capacity of the loader to the trucks they are working with
- Ensure the loader is operating on a level and firm surface so that it and the trucks do not bog or skid
- Ensure that sufficient trucks are available so that the loader does not have to wait.
- Move the bucket up and down to force load material
- Do not work under an overhang
- On loose sandy ground, use minimum tyre inflation for maximum flotation and traction
- Material should be stockpiled in such a condition that a full bucket may be readily obtained.

## 7.3. Stockpiling and Segregation

It is often necessary to extract and store quantities of aggregate either in the borrow pit or at a location close to the section of road that is to be constructed or maintained. Handling and stockpiling of aggregate needs to be undertaken with care to ensure that wastage of material is minimised and particle segregation does not occur.

Segregation is the grouping together of similar sized particles that will result in there being pockets of coarse material with no fines in one place and pockets of fine material in another. Segregation most often occurs when:

- relatively dry aggregate is deposited from a conveyor belt into a tall conical stockpile. The large particles will tend to roll down the outside of the heap to concentrate at the base.
- aggregates are end tipped into a high stockpile

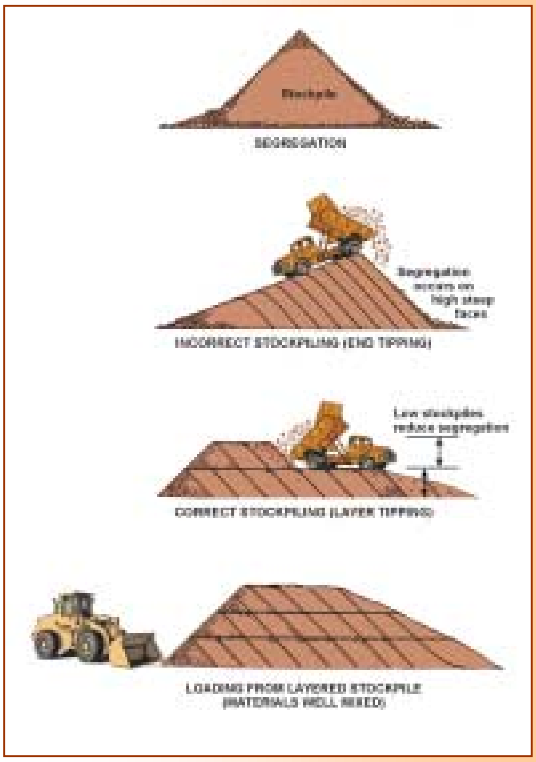
Segregation due to conveyor systems is best prevented in the first instance by spraying the aggregate with water as it leaves the conveyor. Then the heap should be kept as small as possible. The higher the heap the greater the segregation because the large stones will roll further. Conveyor heaps are usually kept small by a loader constantly removing material to a separate stockpile or by the loader regularly flattening the heap. Apart from the segregation problem, this work is often required to prevent the feed from backing up into the conveyor. In the case of a small scale screening operation a team of labourers may be able to spread the material arriving from the conveyor before the loader comes to remove the heap (as shown in the photograph).

End tipping by loaders or trucks should never be used to create aggregate stockpiles. Layer tipping, preferably from alternate ends of the heap, should be carried out. Then loading from the layered heap should be done in a way that promotes layer mixing.

Materials delivered to the road should always be well mixed (generally by grader windrowing) before compaction on the road. If segregated materials are delivered and used, not only will the resulting pavement construction be poor, but considerable difficult will be associated with material placement and compaction.

Other factors to consider when handling and storing aggregates include:

- Never load from below the base of the stockpile as this will result in aggregate contamination
- Plan all activities to minimise double handling of aggregate, this is costly and provides additional opportunities for segregation.
- Shape stockpiles in the best way to protect the material from damage by the action of wind and rainfall.
- Avoid stockpiling clayey materials during a wet season.




Correct stockpiling to avoid segregation (modified after Ferry 1986)

Mobile screening plant producing road material. Note team of men flattening the stockpile and reducing segregation

# Section 8
# Material Processing and Control

# 8. MATERIAL PROCESSING AND CONTROL

High quality screened gravel wearing course.

This section reviews the possible methods of improving the quality of "as dug" gravel road construction materials. Common defects include the presence of oversize particles and too much or too little fine grained "binder" material. Various procedures and treatments can be used to improve the engineering characteristics of "as dug" materials. The selection of the appropriate treatment will be strongly influenced by the severity of the problem and is usually a balance of economic considerations.

Typically it is cost effective to use appropriate quality materials, because good performance on the road will result in significant cost savings that will out weigh the expense associated with processing. Unfortunately, some of the cost benefits are not easy to quantify and to take account of. The **main benefits from using satisfactory quality material include**:

- **Reduced construction and maintenance costs,** resulting from reduction in the time required for compaction and reduction in amount of material hauled (if for example, oversize material is removed during material placement).
- **Reduced gravel loss**, resulting in prolonged intervals between grading and regravelling. For example, if a surfacing material lacks plastic binder the road may require regravelling every 2 years, but with addition of binder the resulting road surface may not require regravelling for 4 years and the regrading interval can also be extended.
- **Improved riding surface and reduction in vehicle operating costs.** Poor quality materials quickly develop into rough roads that lead to significantly higher vehicle maintenance costs for road users.
- **Reduction in accidents and other adverse environmental and social effects**. Poor quality materials may produce slippery roads, bumpy roads and dusty surfaces. Such conditions cause an increased occurrence of road accidents and may have a significant social and environmental impact (ie dust causes health problems in roadside communities).

Material with too much plastic fines producing a slippery dangerous surface.

Typically more than half the cost of maintaining an unsealed road goes towards the supply and spreading of material to replace that which has been lost by a combination of erosion by wind and water and traffic wear. **There is often scope for considerable cost savings by using better quality materials** that are resistant to wear.

Dusty rough surface containing oversize and not enough plastic binder material

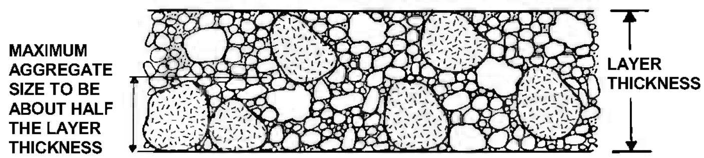
# 8.1. Dealing with Oversize Material

The presence of oversize particles in "as dug" materials is a very common defect. It is also a problem that is quite often not properly corrected.

The definition of what is "oversize" (or the acceptable maximum particle size), may depend on the volume of traffic that will use the road. Ideally, any unpaved road carrying more than 100 vehicles a day should comprise material with a maximum particle size of 40 mm. This is sometimes relaxed to 60mm or even 75mm in remote areas where only a few vehicles a day will use the road.

Rippable weathered hard basalt that will produce a significant proportion of hard oversize material

The presence of oversize quickly produces rough roads that are difficult to rework and reshape. It is also important to recognise the need for the maximum aggregate size to be no greater than half the layer thickness. This ensures that all large particles can be bound up tightly in an interlocking structure.




The various methods of dealing with oversize material either in the borrow pit or on the road (during material placement) are shown on Figure 8.1. Each method is briefly reviewed in the following paragraphs.

High proportion of oversize being supplied to the road

## Manual Removal or Breakage of Oversize Material

Where the proportion of oversize material is relatively small it may be effectively treated by manual removal or breakage either at the pit or at the construction site or even at both locations.

Field experience has indicated that manual treatment of oversize may not be successful where the proportion exceeds about 20%, even when large teams of labourers are employed for this purpose. However, the upper limit will depend on the diligence of the labourers and the ease with which the particles can be broken down. In the case of weaker materials if a few large particles are not manually removed it may not be a problem if further breakdown occurs during compaction.

The removal of hard oversize fragments at the construction site leads to considerable wastage and potential obstruction of side drains.

It is therefore recommended that whenever possible oversize is treated or removed in the pit, unless special plant is to be used to break down large particles during construction (ie a mobile hammer mill or grid roller is to be used during pavement laying).

Small mobile screening plant producing gravel wearing course

Grid roller treating oversize material on the road (Photos courtesy of Broons Hire (SA) Pty Ltd)


## Screening

Screening to remove oversize particles at the pit can be a low cost solution, when the proportion of oversize is in the range 15 to 40%. A screen comprises a frame supporting a mesh or slotted panel with an aperture designed to prevent large particles passing through.

The oversize material removed by screening is just rejected unless crushing plant is available. In areas where road building materials are scarce it may be inefficient and wasteful not to utilise the oversize fragments if they form a significant proportion.

Various methods of screening exist and each method is appropriate for use in different situations. Screening is an important material processing technique and is therefore reviewed in detail in Section 8.4

## Treatment by Grid Roller

Grid rollers are often successfully used to break down oversize materials on the construction site, before use of standard compaction plant. The surface of the drum consists of a grid or woven mesh made of steel bars that form squares with about 100 mm side length. They are usually ballasted with blocks of concrete or wet sand and may be very heavy. Typically they are 7 to 15 tonnes when ballasted and exert high contact pressures. Grid rollers are usually towed by a relatively fast tractor at up to 25 km/h in order to provide a crushing action by impact.

Grid rollers can treat windrows of coarse material that comprise particles up to about 300 mm in size. Two problems are often reported with the use of grid rollers for management of oversize in unpaved roads:

- Hard oversize particles may be pushed under the surface in situations where the underlying materials provide little resistance. Then as the surface wears away the oversize material is exposed.
- Grid rollers give little control over the particle size grading of the material produced. Maintenance teams sometimes report difficulty with reshaping (grading) and compacting “gridded” materials.

Road authorities that have carried out trials using both grid rollers and mobile hammer mills to treat oversize material on the road have concluded that a mobile hammer mill (such as the “rockbuster”) is sometimes the more cost effective method and produces better materials.

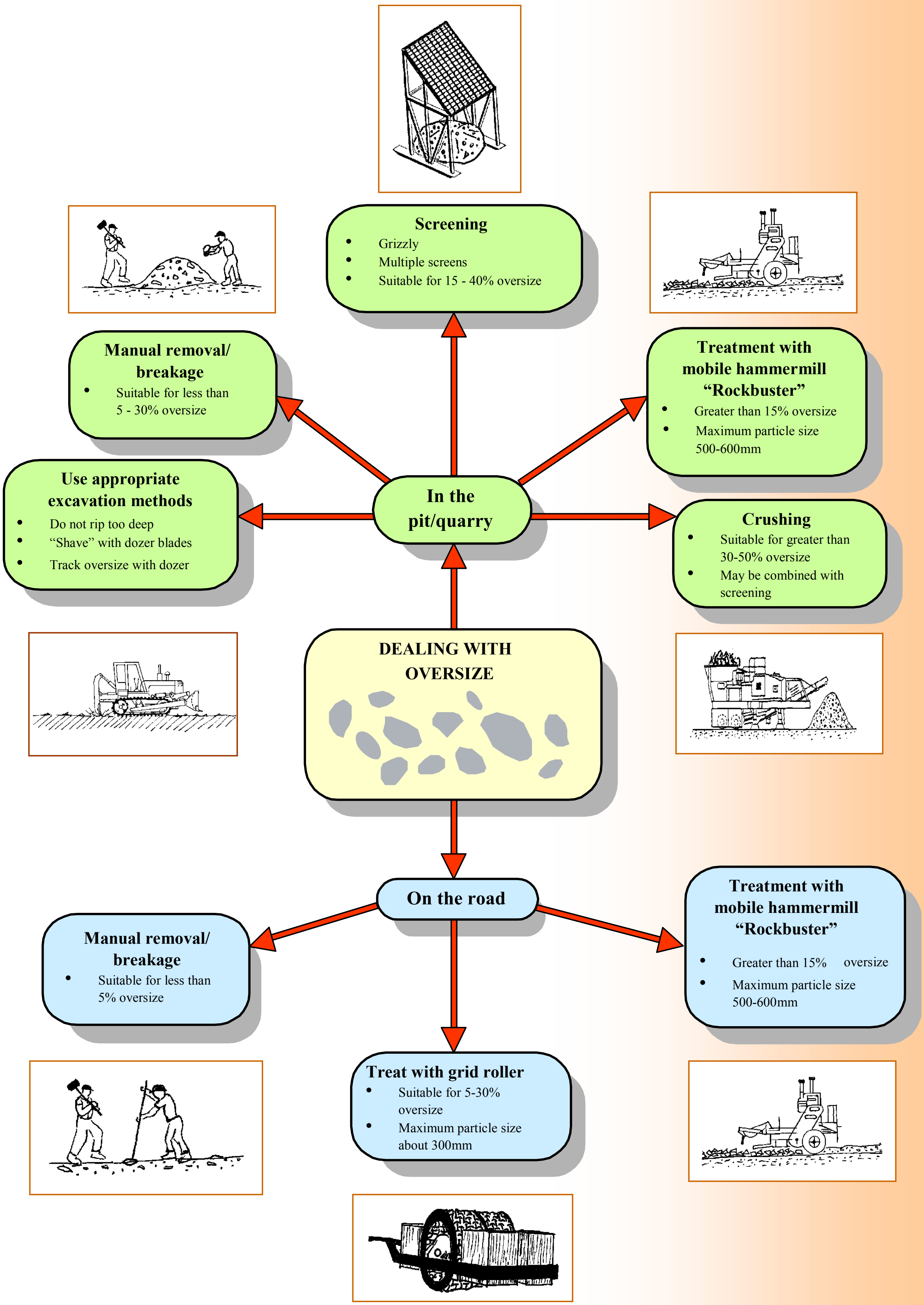



Figure 8-1 Dealing with Oversize Material

## Treatment with Mobile Hammer Mill "Rockbuster"

A mobile hammer mill consists of a horizontally mounted crushing chamber with rotating hammers which impact downwards and smash underlying oversize rocks. This hammer mill is towed over a windrow or rill of material at slow speed and typically achieved adequate crushing in a single pass of the machine.

Mobile hammer mills may be used in a pit processing area or on the road during construction. If treatment is required in the pit then sufficient space is required to allow a windrow of reasonable length to be formed, otherwise the time taken in turning the machine will seriously effect efficiency.

The production output of a mobile hammer mill is dependant on the hardness and degree of weathering of the oversize as well as the proportion of oversize to be treated.

Machines such as the "Rockbuster" produced by Broons Hire in Australia and South Africa have been found to be extremely effective at dealing with oversize in many situations. The machine is very versatile. It can handle oversize rocks up to 500 – 600 mm in size and can produce 40mm minus graded crushed stone at the rate of 120 $m^3$ per hour on some materials

Initial purchase cost equates to a medium sized grader, whilst the cost of crushing oversize with a Rockbuster can be half that associated with the use of a conventional crusher in some cases. The attributes of the mobile hammer mill appear not to be well known in many developing countries, where this equipment could be of major benefit. A review of the possible applications and performance characteristics of this type of equipment is therefore presented in some detail in Section 8.5


Rockbuster mobile hammermill treating oversize on the road (Photos Courtesy of Broons Hire (SA) pty Ltd)

## Crushing

Production of crushed aggregates for unpaved road construction is an expensive option. Even primary crushing of rippable materials with a small mobile crushing machine may lead to aggregates that cost more than three times as much as "pit run" materials.

As a result, production of high cost crushed gravel road surfacing materials may only be viable in clearly identified circumstances. Factors that should be reviewed before committing to the production of crushed aggregates include:

- Cost of hauling natural gravels from outside the area compared with the cost of producing crushed local materials
- Relative quality of crushed stone compared with alternatives
- Alternative of using a mobile hammer mill rather than conventional crushing equipment.
- Viability of stabilising local fine grained materials with, for example, lime or cement.
- Climate and topography may influence the viability of using materials that might in certain circumstances be considered unsuitable
- The crushing of oversize produced by screening may be cost effective and have significant environmental benefits in some circumstances

In steep hill country with high rainfall well graded angular gravels will stand up considerably well to scour and traffic abrasion due to their good mechanical interlock. Hence, use of crushed river gravel as opposed to rounded gravel may be justifiable due to resulting reduction in maintenance costs.

When suitable "as dug" materials are so rare that it is necessary to produce crushed gravel wearing course material, then consideration should be given to the economics of extending the life of the road surface by the application of a low cost bitumen seal, such as an "otta" seal (refer Section 4.2).

A full review of crushing methods and equipment is presented in Section 8.6

Mobile Crushing Plant in operation
(Photo courtesy of Pegson).

## 8.2. Dealing with Incorrect Fines Content

An essential component of any good quality gravel road surfacing material is the presence of a small quantity of plastic fines material to act as "binder".

The presence of excess fines will result in roads that are slippery in wet weather and dusty in dry weather. Roads that lack plastic fines are prone to ravelling, that is to say they easily wear away under traffic and when subjected to scour from surface water.

### Lack of Plastic Binder

The most effective method of dealing with a lack of plastic fines content is usually to mix together two different materials, one which has a high binder content with one that lacks plastic fines. Such mixing may be referred to as **"mechanical stabilisation"**.

The proportions of each material that need to be mixed together should be determined from the results of laboratory tests made to establish the particle size of each material. There are then various simple procedures that can be used for calculating the effect of mixing differently graded materials together. If it is impractical to wait for such testing, then some experimentation (trial and error) in the field will soon indicate suitable mix proportions.

When searching for a binder source avoid using clayey materials which show cracking when dry

The mixing of materials may be carried out in the pit or on the road. The choice is usually dependent on the location of the two material sources with respect to the section of road being constructed.

In the pit it may be possible to mix gravels that lack binder material with clayey overburden materials, but great care and effort must be taken to ensure that a uniform material is produced. This may involve thoroughly mixing materials on the pit floor with a grader.

Sandy clay binder source

Blending of materials is usually easier and more successful when the binder rich material is a clayey gravel rather than for instance a sandy clay. For example, the best material to mix with a binder deficient river gravel may be a clayey ripped weathered rock gravel. In this case not only will the cohesion of the material be improved but also the particle shape if the river gravel is rounded and the ripped material angular. In this example, when mixing on the road it may be found to be appropriate to mix two loads of river gravel with one of ripped rock as shown in Figure 8.2 opposite.

Two points to note when considering mechanical stabilisation are: mixing is best achieved with dry aggregates; and avoid using clayey materials which show cracking when dry.

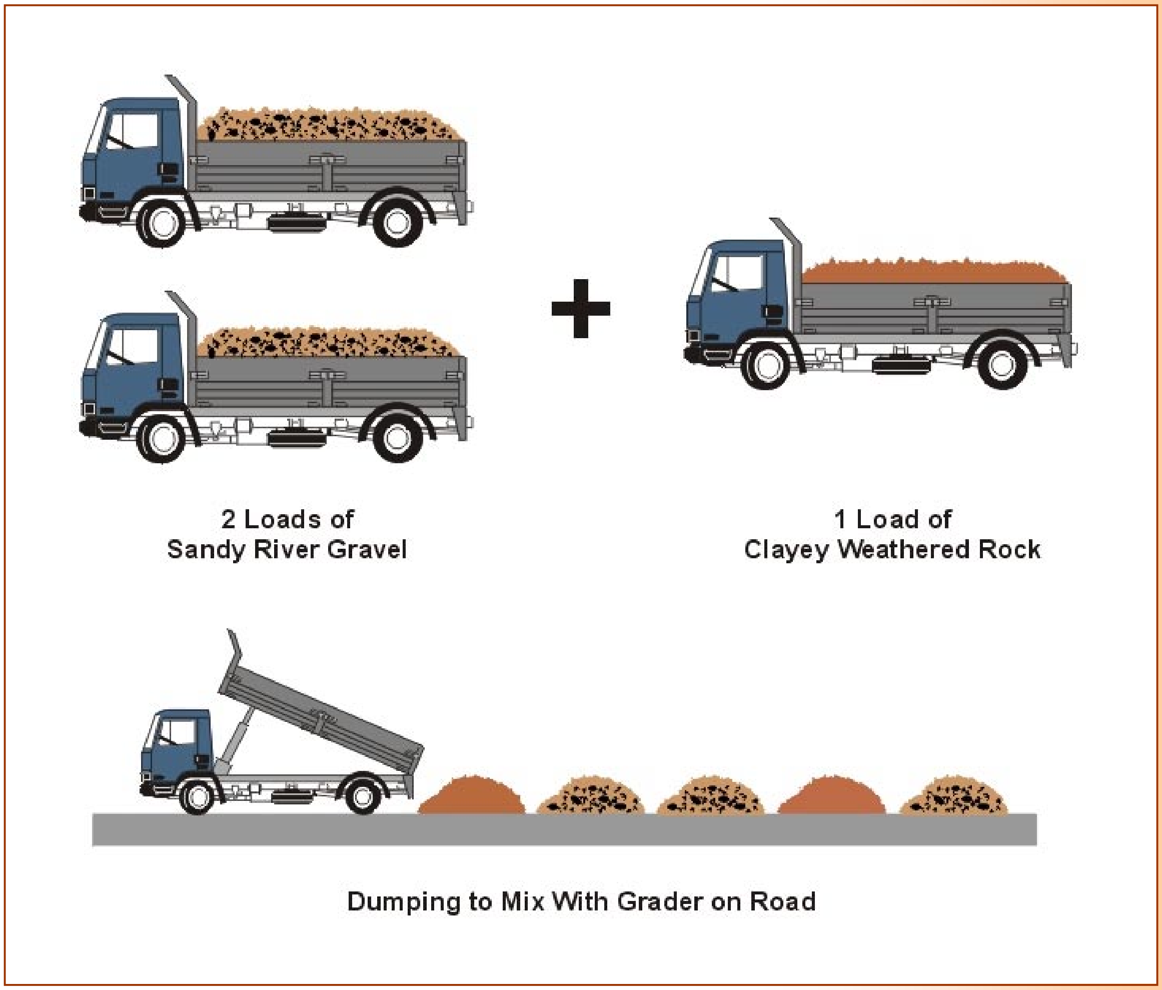



**Figure 8-2 Mixing Material on the Road**

Serious performance problems will result if materials containing either too much or too little plastic fines are used in gravel road surfacing..

### Too Much Plastic Fines

Materials containing an excess of plastic fines are typically best treated by mixing with a non plastic well graded sand or sandy gravel. Suitable blending materials are usually river, lake or beach deposits (either recent deposits or ancient terrace deposits). Some weathered sandstones and conglomerates may break down to become low fines gravelly sands that can be used for the mechanical stabilisation of very clayey materials. Stabilisation can also be used to treat materials with an excess of clayey fines (or a lack of plastic fines). Methods of aggregate modification and chemical stabilisation are briefly introduced in Section 8.7

## 8.3. Correcting Materials Defects During Road Maintenance

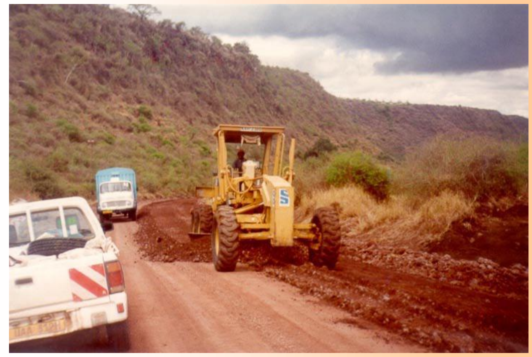
Regrading and regravelling operations provide a good opportunity to improve the grading and plasticity characteristics of existing gravel surfacing materials. This opportunity is often overlooked.

After a year or so of trafficking it is usually easy to identify what characteristics of a gravel road pavement are causing poor performance. A particular section of road may be rutting badly (ravelling - associated with lack of binder) another section may be excessively rough or dusty. It is recommended that where such defects are apparent and are clearly causing significant increase in maintenance activities consideration should be given to improving the pavement material during routine and periodic maintenance activities.

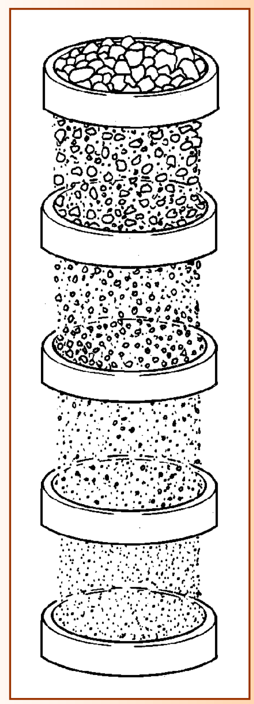
Some of the activities that should be considered include:

- A simple low cost remedy for severe lack of plastic binder may be to grade some plastic subgrade materials from the side of the road onto the pavement prior to scarifying and reshaping. Test the suitability (plasticity characteristics) of such binder sources before implementing this procedure.
- When "heavy grading" and patching is necessary, ensure when possible that the new material has properties which improve the characteristics of the existing materials. If significant improvement in overall material quality will be achieved by hauling from a borrow source that is not necessarily the nearest to the maintenance work this may well be justified, because of the resulting improved performance of the materials.
- Road surfaces that have become rough due to exposure of oversize particles can be greatly improved by treatment with a mobile hammer mill as part of a heavy grading operation. Indeed, large particles that have collected at the side of the road (and would normally be graded to waste) can be graded back onto the road, broken down and reincorporated in the pavement.
- Whenever regravelling is required, review the characteristics of the existing materials and their origin. If poor particle size grading properties or binder problems are apparent then investigate the possibility of producing a better quality material by mixing material from more than one borrow source.

It is much easier to identify gravel road material defects and develop appropriate improvement options when material classification test results (particle size gradings and plasticity index test values) are available for both the existing pavement gravels and the available borrow sources.



The binder content of wearing course gravels may be improved during regrading by bringing some plastic subgrade soil from the side of the road.



Development of good pavement maintenance strategies requires support form a materials laboratory.

## 8.4. Screening

Aggregate screening may involve primary screening to simply remove oversize material or primary and secondary screening. During secondary screening the "as dug" material becomes separated into several size fractions which may then be recombined in proportions that produces a material that closely conforms with the desired grading envelope for unpaved road material.

Primary screening is a process that could benefit a great many "as dug" aggregates. It can be a simple, quick and inexpensive procedure that significantly improves the quality of an unpaved road surfacing material. Secondary screening requires more sophisticated equipment and its use will significantly increases the cost of material production and so may only be justifiable when there is a need to exploit relatively large quantities of very poorly graded "as dug" material.

### Grizzly Screens

A grizzly is a primary screen with coarse openings to reject large fragments. Several types of grizzly screen exist as follows:

**1. Portable Gravity Grizzly.**

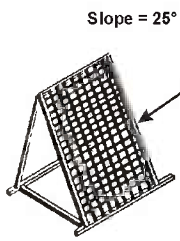
In its simplest form a grizzly is a portable inclined screen with no moving parts that relies on gravity to move the material over its surface.

A simple light frame can be constructed for placing on the ground or directly on a truck body before loading. Gravel is deposited from a loader on the top of the slope and rolls down along the surface, the smaller material falls through the screen and the oversize rolls clear over the rear end of the tipper truck. When the truck is full the loader picks up the grizzly and places it on the next one. A helper is needed to steady the grizzly during placement.

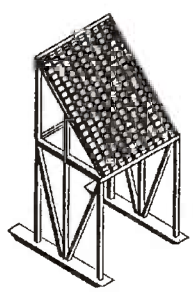
When used for stockpiling, the grizzly can be bolted to the tipper body. In which case, the screen must not be so high or so heavy as to over-balance the truck body when tipping.

A similar grizzly may be built on a skid frame. Then the truck reverses under it to be loaded. It will often become partly buried, therefore the frame should be strong enough to withstand heavy pulls. It may be braced between the skids to provide extra strength.

A portable grizzly frame can be easily manufactured using suitable angle iron and box section steel, that is often lying around plant depots. The screen itself may be a purchased woven mesh (perhaps 50 or 60 mm square) or could be fabricated from 10-15 mm welded steel reinforcing bars.




Light Portable Grizzly That May be Used on the Ground or Placed on a Truck Body Before Loading



Skid Mounted Grizzly. Truck Backs Under it to be Loaded.

### 2. Fixed Gravity Grizzly

A simple fixed gravity grizzly is shown in the border. Such a unit may have screen surfaces of parallel steel bars or coarse mesh supported by cross members.

A strong screen could be manufactured locally using 25-30mm steel reinforcing bars in an arrangement as shown. A problem with this type of screen may be that slightly oversize rocks stick between the bars. The gradual increase in slot width towards the bottom of the screen helps to alleviate this problem. However, two men are typically required to man the screen and remove any jammed rocks after each loads is tipped. **Blockages are also more easily cleared if the screen bars are triangular (flat side up) or inverted rails.**

For a given material and bar spacing the amount of material passing through the grizzly will be increased by lengthening the screen or by reducing the slope. A long screen occupies more space both vertically and horizontally. A slope that is too flat will allow material to rest on the surface and clog the slots. An over steepened or short slope will reject undersize material.

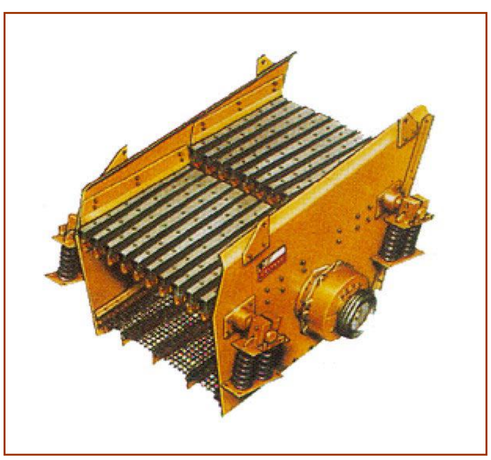
Loose dry aggregate will separate satisfactorily at a grade of 30 to 40 degrees. Wet gravel or binder rich material is likely to require a slope of up to 50 degrees. **Wet sticky materials cannot be satisfactorily processed**

### 3. Cantilever Grizzly

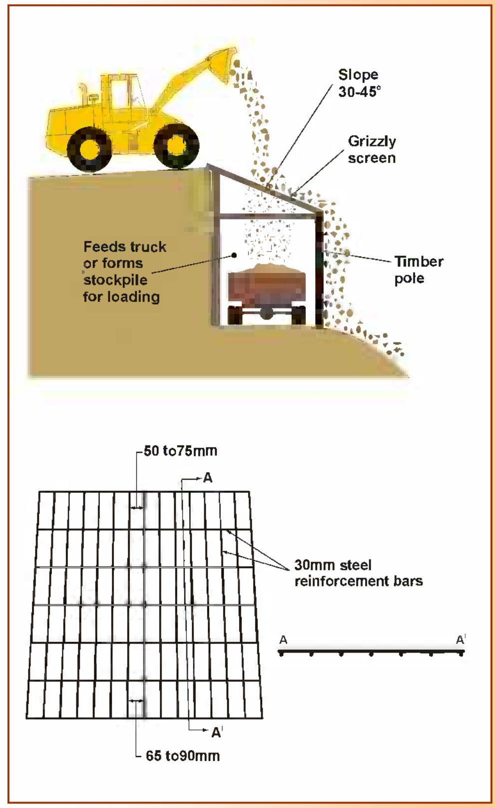
The cantiliver grizzley has rigid bars held only by two tie rods near the top end. In this case stones are not blocked by cross supports and the projecting bars vibrate under impact, thus speeding the flow of material and freeing wedged stones. This requires less slope than the soild grizzly and can be used with narrower spacing. It is not suitable for use with material containing heavy boulders.

### 4. Vibrating Bar Grizzly

The slope of a grizzly can be reduced and the accuracy of sizing increased by shaking or vibrating the screen. Best results are obtained by purchasing a manufactured unit such as that shown below



Vibrating bar grizzly screen
(Photo courtesy of Parker Plant)

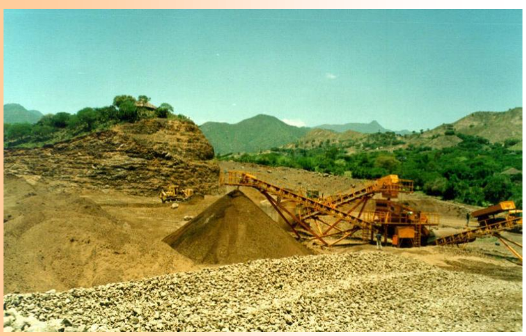



A simple fixed grizzly screen


A mobile screening plant with a vibrating bar mechanism. Equipment shown is a 595 Hydratrak (Photo courtesy of Finlay Hydrascreens, Omagh Ltd.)


Simple vibrating screen in operation. Note team of men shifting the stockpile and trying to prevent segregation.


Vibrating multiple deck secondary screen (Screenranger photo courtesy of Parker Plant Ltd


Small multiple deck vibrating screen forming stockpiles of gravel wearing course from ripped weathered rock (note outcrop on left)

## Shaking and Vibrating Secondary Screens

Secondary mechanical screens are typically rectangular in shape, may be suspended on loose flexible attachments and are usually shaken or vibrated by connecting rods or some form of eccentric rotation device. The slope may be horizontal or up to 20 degrees.

This equipment may be used to form a stand alone screening plant or as a component in a screening and crushing operation. If the "as dug material are very coarse, it may be fed with material from a primary grizzly screen.

Screening plants can be set up to provide several sizes of output from a stack of vibrating screens. The top deck has the coarsest grid. Material that passes through it is further separated into sizes according to each succeeding screen. The separated materials can then be recombined in proportions that produces an aggregate that conforms with the desired grading envelope for unpaved road material.

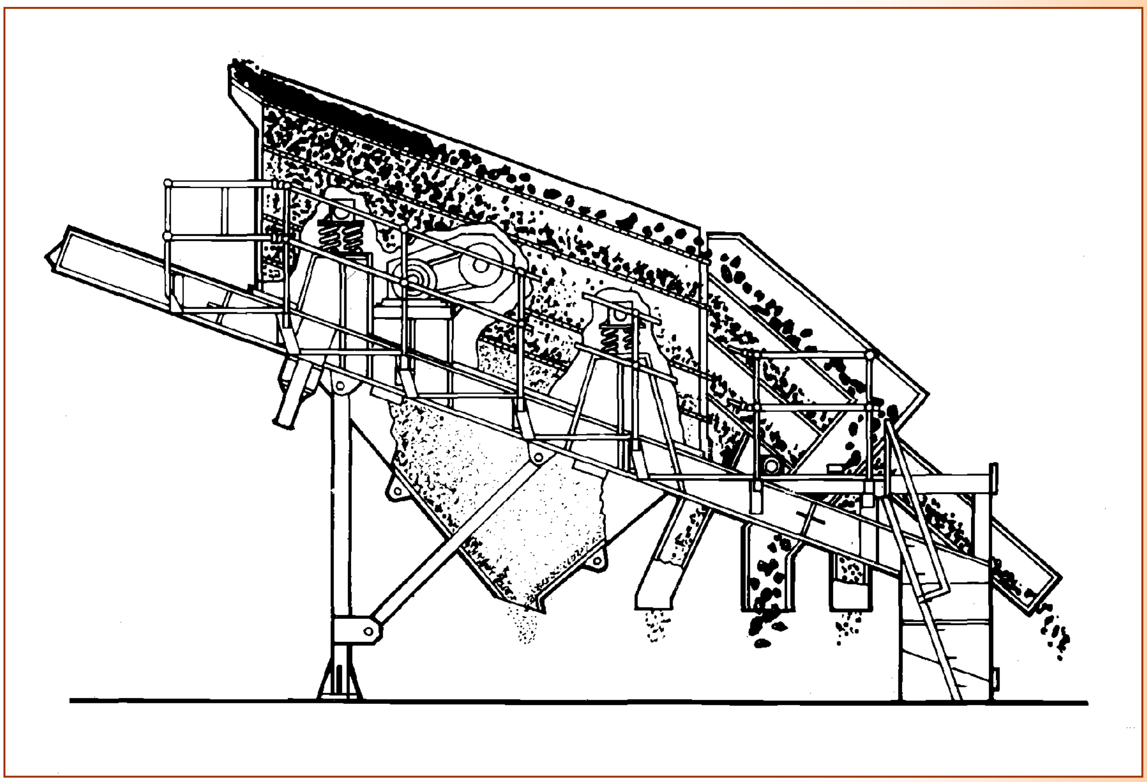
Materials containing excess fines can be processed by such a screening procedure, provided that the fines are not sticky, in which case the screens may clog or "blind".

The establishment and operation of a multiple deck screening plant will involve a major cost investment therefore it is only likely to be economically viable when materials are scarce, poorly graded and occur as isolated large resources. Then there may be a requirement for relatively large quantities of screened material from a few sources.

Screened oversize material may be useful for the construction of subgrade capping layers, stockpile foundations and pit access road foundations

Source: Svedala Industri

**Figure 8-3 Svedala Inclined Vibrating Screen**



Source: Parker Plant Ltd

**Figure 8-4 Parker Screenranger**

The Rockbuster Mobile Hammer Mill (BH-1220)

Effect of One Pass Rockbuster Treatment. One pass with the Rockbuster type of mobile hammer mill will typically be enough to achieve sufficient material break down to allow its use in unpaved gravel road construction. Caldwell reports the before and after treatment particle size gradings of materials crushed by one pass during field trails, these results are summarised in Table 8.1. In all cases satisfactory surfacing gravel was produced at a cost which compared favourably with alternative treatment options.

The particle size distribution produced can be varied dramatically by altering the towing speed, hammer clearances and hammers

(Photos courtesy of Broons Hire (S.A. PTY Ltd).

## 8.5. Use of Mobile Hammer Mill

The use of mobile hammer mills to crush oversize rocks in unpaved road materials has been widely and successfully practised in the outback of Australia for several decades. It is also an accepted treatment method in South Africa. However, mobile hammer mills have rarely been used in many developing countries where they could often provide major benefits to authorities that maintain a large unpaved road network.

### Details of the Machine

The "Rockbuster" manufactured by Broons Hire of Australia is probably the most widely known and best tested small mobile hammer mill suitable for the treatment of road materials. This towed impact crushing machine weighs approximately seven tons and comprises a hammer chamber with a breaking width of about 1.2 m, together with a throat opening of 0.6 m. The hammer assembly has a working rotating speed of 1000 rpm and contains 18 impactors made of heat treated manganese steel. Power for the hammer mill is provided by a reliable 190 hp Caterpillar (3306 TA) six-cylinder engine.

**Figure 8-5 Rockbuster Hammers)**

A double row of heat treated chain curtains prevents rock fragments flying from the front of the hammer mill when it is operating. A full length baffle at the rear, which rests on top of the crushed material, prevents flying fragments leaving the back of the crushing chamber. Replacement of a set of hammers takes three men about one hour. The "Rockbuster" can be towed by a 65 hp tractor.

### Production Rates

Details of production rates for the rockbuster, recorded during tests in Australia on three different materials have been reported by Caldwell and are summarised in Table8.2.

It was found that the towing speed while crushing a windrow 600mm wide by 375 mm high is between 500m and 1100m per hour, depending on the nature and proportion of oversize in the material being treated.

| Material Type | Silcrete-Ironstone | Weathered Basalt | River Gravel/ Loam mix (70/30 mix) |
|---|---|---|---|
| Total quantity Treated | 15,300 $m^3$ | 8,000 $m^3$ | 5,500 |
| % Oversize | 10 – 15% (up to 250 mm cube) | 30% (up to 300 mm cube) | 60% (mainly up to 200 mm |
| Max size after one pass | 45 – 50 mm | 45 mm | |
| Towing speed | 1100 m/hr | 600 m/hr | 500 m/hr |
| Production Rate per Working Hour | 170 $m^3$ | 90 $m^3$ | 73 $m^3$ |
| No of Hammer Replacements – light duty (Sets) | 7.5 (1 set per 2070 $m^3$) | 4.7 (1 set per 1700 $m^3$) | 7.3 (1 set per 750 $m^3$) |

**Table 8-1 Details of Rockbuster Production Rates (after Caldwell, 1985)**

| | Silcrete-Ironstone | | Weathered Basalt | | River Gravel/ Loam Mix | | Target Grading "B" |
|---|---|---|---|---|---|---|---|
| | Before Crush | After Crush | Before Crush | After Crush | Before Crush* | After Crush* (Mix) | |
| Sieve % Pass 75mm | 97 | | 90 | | 84 | | |
| 53mm | 96 | 100 | 85 | 100 | 78 | (100) | 100 |
| 37.5mm | 94 | 99 | 78 | 92 | 69 | 100 (98) | 85 - 100 |
| 26.5mm | 93 | 97 | 64 | 83 | 60 | 88 (88) | |
| 19mm | 92 | 96 | 52 | 68 | 52 | 80 (82) | 55 - 90 |
| 9.5mm | 75 | 77 | 32 | 41 | 38 | 58 (67) | 40 - 70 |
| 4.75mm | 42 | 52 | 20 | 25 | 24 | 37 (54) | 28 - 55 |
| 2.36mm | 25 | 36 | 16 | 18 | 14 | 24 (47) | 20 - 45 |
| 0.425mm | 19 | 25 | 9 | 11 | 3 | 7 (21) | 10 - 25 |
| 0.075mm | 14 | 15 | 6 | 9 | 2 | 4 (12) | 4 - 15 |
| Plasticity Index | 6.9 | 7.4 | 19 | 14 | | | |

*River gravel only

**Table 8-2 Effects of One Pass Rockbuster Treatment (after Caldwell,1985)**

The Rockbuster has been successfully used in PNG for many years used to treat oversize in coralline materials.

The Rockbuster (BH-1220) being used in a borrow pit. (Photo courtesy of Broons Hire (S.A.) PTY LTD)

## Procedure for Rockbuster Crushing in the Pit

The Rockbuster is safe to operate on the road without the need to stop or divert traffic provided the road has adequate width. When used correctly chips of rock will not be ejected from the crushing chamber.

However, on narrow roads where it is necessary to avoid disruption to traffic, the Rockbuster can be use to treat material at the pit site or at any other suitable road side location. Some Contractors prefer to carry out treatment off road. However, operating efficiency may be significantly reduced if there is not enough working space to allow a windrow of reasonable length to be formed. To crush in the pit it is necessary to have available an area of at least 150 m by 75 m.

The following procedure for treating oversize coralline materials in the borrow pit has been developed by a Contractor in Papua New Guinea.

- Form excavated material into a low stockpile about 2.5 m high and 100m long.
- A grader takes a windrow from the side of the stockpile and moves it as far away as it can in 2 passes.
- The crusher then passes over the windrow.
- After crushing the grader moves the processed material clear of the next crushing run, to where a loader then stockpiles it or loads to truck.
- While the crusher is running the grader will bring out the next windrow in I pass in readiness for the next crusher run.

The grader is a very important part of the whole operation, it is kept very busy and needs to have a skilled operator.

## 8.6. Crushing

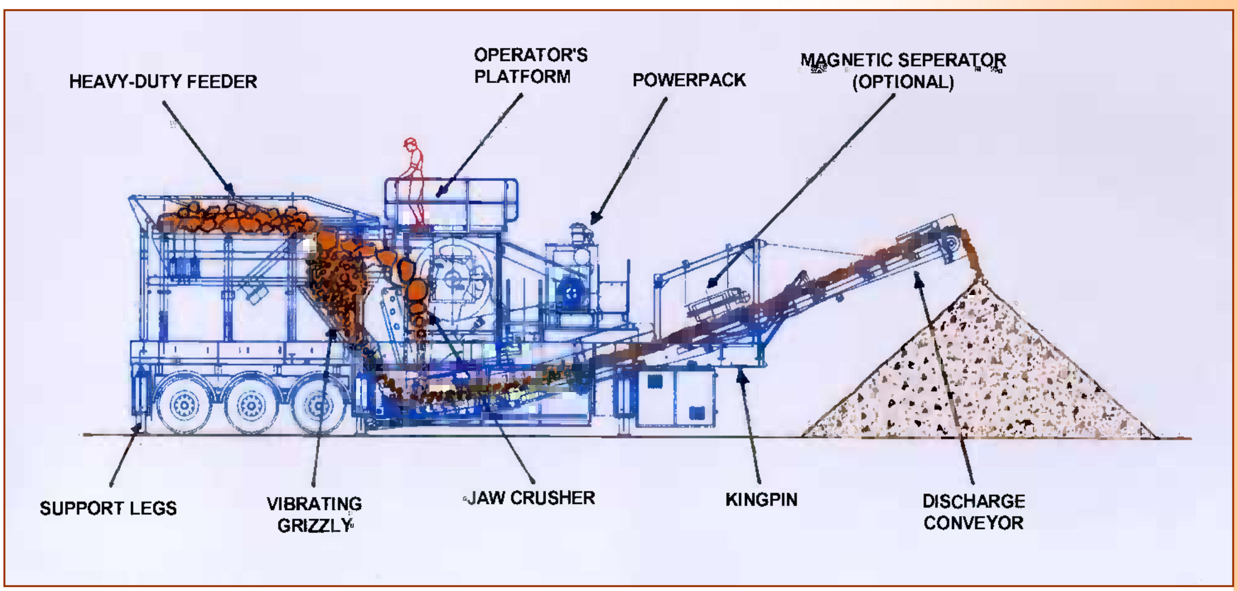
Occasionally situations will arise when it is necessary to consider using crushing plant to assist in the production of gravel road surfacing materials. Usually the quantities of processed material required from an individual pit or quarry will be relatively small and continuous processing will not be required therefore use of a small or medium sized mobile crusher is most likely to be appropriate.

Compact mobile crusher (Photo of Goliath 1206 courtesy of Svedala Industri)

Crushing involves large capital and running costs therefore it is essential that the most suitable equipment is selected for the job. A great variety of crushing plants exist that use a number of different crushing methods. It is therefore recommended that crusher suppliers are asked to assist in the selection of a suitable unit to service identified needs. The suppliers will need to know:

- Hardness and abrasive properties of the excavated material
- Input size (feed opening required)
- Method of feed input
- Whether the input material will typically be wet or dry and whether there will be plastic fines
- Output grading required
- Production volume required
- Ease of plant mobility required
- Location with respect to habitations (ie dust and noise control requirements)

Final crushing plant selection will require some understanding of the differences in plant available and their crusher products. Some plants have limitations as to the size and shape of their products. The characteristics of the usual types of crusher are introduced in the following sub-sections.




Source: Svedala Industri

**Figure 8-6 Section Through a Mobile Jaw Crushing Unit**

## Jaw Crushers

The jaw crusher compresses rock between a fixed jaw and a moving jaw to create breakage. The return motion of the moving jaw permits feed to enter the crushing cavity and sufficiently broken material to leave by gravity. The product size is mainly determined by the width of the discharge aperture when the moving jaw is fully open.

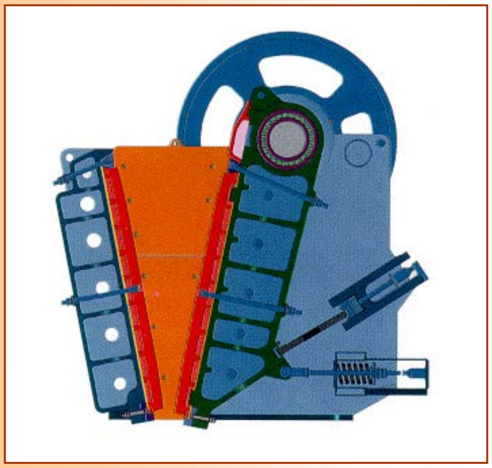
The moving jaw may be operated by one of two mechanisms, namely "single toggle" and "double toggle". There is vertical motion between the jaws with the single toggle mechanism that provides the advantage of greater out put for less abrasive rocks.

Vertical motion is eliminated with the double toggle crusher, which allows very powerful compressive forces by leverage in the upper zone of the crushing chamber and almost total absence of abrasive motion. This machine is therefore more applicable to the crushing of very strong and abrasive rocks. However, it is more complex, heavy and expensive than a single toggle crusher.

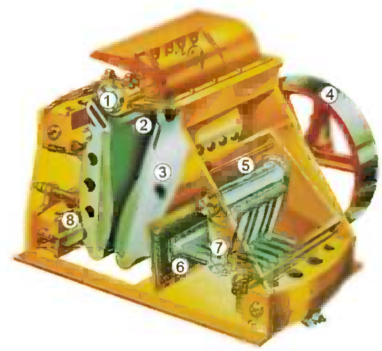
In both cases the jaws are protected by replaceable alloy liner plates which may be smooth or corrugated to reduce the production of slab shaped particles. The jaw crusher is generally suitable for all rock types.

## Gyratory and Cone Crushers

These crushers essentially consist of a bell inside a conical casing. The inner cone "gyrates" under the action of an eccentric mechanism. This equipment may be used for primary and secondary crushing. Gyratory and cone crushers are usually associated with the production of aggregate with good cubical particle shape. The high output of these crushers may justify their relatively high initial cost in some situations.

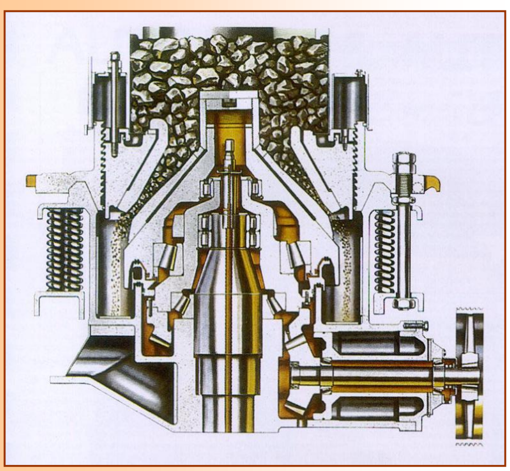


Section through a single toggle jaw Crusher
(Source: Svedala Industri)



1. Hinge Pin
2. Wide Entry Throat
3. Cast Steel Swing Jaw
4. Light Small Diameter Flywheel
5. Operating Mechanism
6. Double Toggles
7. Light Weight Pitman
8. All Adjustments

Section through a Double Toggle Jaw Crusher
(Source: BL Pegson)



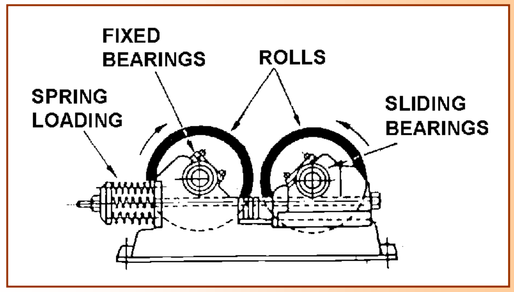
Section through a Gyracone Crusher
(Courtesy of BL Pegson)

**Photograph 8-1 Mobile Cone Crusher**
**(Photo courtesy of BL Pegson)**

## Rolls Crushers

A simple rolls crusher comprises two contra-rotating smooth crushing rolls. The size of the output material is determined by the spacing of the rollers. Before the development of cone crushers they were commonly used. They suffer two disadvantages: low capacity and rapid wear of the roller surface when crushing abrasive rock.

However, rolls crushers may still be useful for small capacity operations particularly where relatively weak rocks are to be processed (ie limestone). Also, rolls crushers may be relatively tolerant of wet sticky feed.

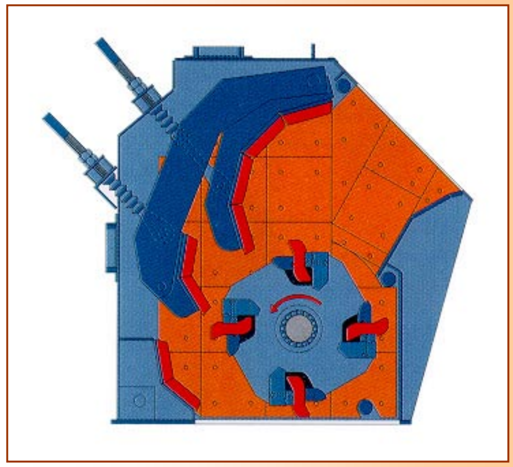



Section of a double rolls crusher
(Source Aggregates, 1993)

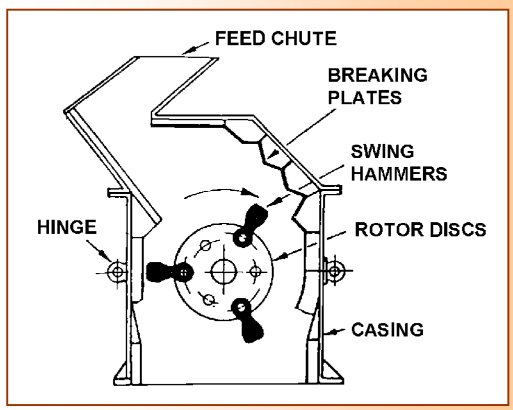
## Impactors

Impact breakers comprise a lined chamber within which a rotor revolves. The rotor is fitted with either swing hammers or blow bars. Impact with the rotor, the chamber liners (breaker plates) and collision between stones all contribute to the crushing. Impactors may combine low capital and operating cost with good particle shape. Product size can be varied within limits by changing rotor speed and the clearance between rotor and liners.

Impactors tend to be limited to crushing non-abrasive rocks because abrasive wear necessitates the costly replacement of hammers and blow-bars and results in loss of operating time.



Section through an Impact Breaker
(Source Svedala Indiustri - Impactmaster)




Swing hammer mill (impactor)
(Source Aggregates, 1993)

Disc harrow being used to prepare ground for treatment

## 8.7. Treatment to Modify or Stabilise Material

In certain circumstances there is justification for the treatment of low cost road materials with lime, cement, bitumen or synthetic chemicals in order to modify or stabilise natural materials that would otherwise lack durability or cohesion.

In all its forms stabilisation is expensive, due to the cost of the stabilising agent and the special techniques and plant required during construction. Stabilisation can result in pavement material costs (in place, on the road) that are comparable with materials that have been obtained by ripping and crushing.

Nevertheless, stabilisation may become a viable option worthy of consideration when:

- There are no available natural gravels or rippable rock deposits suitable for use (either "as dug", after screening treatment or after primary crushing);
- There are available resources of predominantly fine grained material (ie sands or clayey sands) occurring at regular intervals along the route that are suitable for stabilisation.
- Materials occurring in the subgrade (soil foundation) of the road can be effectively modified so that they are resistant to erosion under existing climatic conditions and expected traffic loads
- Existing surfacing materials in an unpaved road are performing poorly in-service due to lack of cohesion (ie lack of binder) or are susceptibility to seasonal changes in moisture content (ie excess plastic fines) and suitable natural materials for mechanical stabilisation are unavailable.

Stabilisation is most competitive with conventional unpaved road construction in instances when haulage of aggregates is eliminated or minimised. As is the case when existing subgrade materials can be modified to form the running surface or base course to a sealed road.

In depth consideration of stabilisation methods is beyond the scope of this manual. However, a brief review of stabilising agents and their possible application is presented below.

## Lime Stabilisation

Hydrated lime is preferred for fine grained clayey soils. As a guide, materials to be treated should have a Plasticity Index (PI) of between 10% and 30 % and a Plasticity Modulus (PM = PI x % passing 0.425 mm sieve) of not greater than 2,500.

Laboratory testing is required to determine appropriate lime content to be used, but is likely to be in the range 2 – 4%.

Materials treated with lime will become less plastic and more friable, they are therefore made more easy to compact.

Unpaved road materials are sometimes treated with lime. Experience in Australia has showed that stabilising the surface material with lime may reduce wear and dust, but may also render the material difficult to regrade during subsequent maintenance (ARRB Unsealed Roads Manual, 1993).

Base course material for bitumen sealed roads that have been treated with lime should at least conform with the property requirements of suitable untreated material. The Kenya Road Design Manual (1986) provides useful guidelines on use of stabilisation to improve low cost pavement materials.

When stabilisation is necessary consideration should be given to the economics of extending the life of the road surface by the application of a low cost bitumen seal, such as an "otta seal" (as shown above) or a sand seal. (Photograph courtesy of Botswana Roads Department).

## Cement Stabilisation

The addition of between 2 and 4% cement to poor quality materials can be very beneficial. Particularly if the materials are fine grained and lack good binder (ie gravelly and silty sands). Cement does have an effect on clay, but lime treatment is generally more effective and appropriate when the objective is primarily to counter the effect of excess clayey fines.

As a guide materials that are to be treated with cement should have a Plasticity Index (PI) of less than 25% and a Plasticity Modulus (PM = PI x % passing 0.425 mm sieve) of not greater than 2,000.

The aggregate and cement must be mixed before water is added and work must only be carried out during dry weather.

The ARRB Unsealed Roads Manual (1993) makes the following pertinent observations with respect to the use of cement in unpaved roads:

- Cement is usually not an appropriate stabilising agent for unsealed pavements especially wearing courses.
- The cementitious bonds are not strong enough to resist the the action of traffic without being protected by a bituminous seal.
- Also, because of the cementation, the surface is not amenable to being reworked with maintenance equipment like graders.
- Cement can however be used as a sub-base stabilising layer. Nevertheless, the economics of this application are seldom favourable for unsealed roads.

## Bitumen Stabilisation

Bitumen stabilisation of gravelly sands and silty sands may be an economical alternative to cement treatment in countries where bitumen is favourably priced with respect to cement. In this case, the materials should generally have a Plasticity Index (PI) of less than 15%, Liquid Limit (LL) of less than 40 and material passing the 0.075 mm sieve should be in the range 10-30% (Kenya Road Design Manual, 1987).

Cut-back (MC250 or MC 800) bitumen, bitumen emulsion and foamed bitumen emulsion are all suitable for bitumen stabilisation. Usually about 2 –4 % residual bitumen is used.

A simple "mix in place" treatment is contained in the New Zealand National Roads Board Sealing and Paving Manual, This involves spraying a slow breaking dilute emulsion (12 – 15 times its own volume of water) on loose windrowed aggregate. The material is then mixed, laid out and shaped with a grader before compaction. The emulsion is essentially used as a direct substitute for compaction water and brings the mix up to optimum moisture content for compaction. Depth of from 50 to 150 mm may be constructed in this way, but a maximum 100mm thickness should normally be applied.

The addition of a detergent or wetting agent assists in the thorough mixing of the emulsion with the water.

Appropriate application rates are likely to be between 1.2 and 3 litres of emulsion (20 to 40 litres diluted) per cubic meter for surface treatment (dust laying) and 5 to 12 litres of emulsion (70 to 100 litres as diluted) for full depth treatment. Detergent or wetting agent should be used at approximately 2 litres per 4,500 litres of water and emulsion.

Compaction will need to be delayed after mixing to allow the mix to aerate and excess water or volatiles to evaporate. The mixture is ready for compaction when the material does not rut or shove in front of the roller (Searle, 1976).

## Chemical (Synthetic) Stabilisation

A large number of synthetic chemical soil and aggregate stabilisers have become available during the last decade. These main types of chemicals available include:

- **Chloride Salts**. Calcium chloride may act as a dust suppressant and as a binder for unpaved road surfacing materials. The salt slows evaporation and attracts moisture from the air. An application rate of about 3 tonnes per km is likely to last about 12 months (depending on rainfall). Potassium chloride and magnesium chloride may also improve clayey gravel road materials. Salt treatment is not suitable for pavement materails that will be bitumen sealed.

- **Sulphonated Petroleum Products (SPP)**. Also called sulphonated hydrocarbons. This group are primarily compaction aids and dust suppressants, not binders. These chemicals are highly ionic. They work by expelling absorbed water from the soil which descreases air voids and increases compaction. SSPs react with clay, but are not effective with all plastic soils. Tolerances on application rates are often very critical and difficult to achieve in a "low technology" situation, too much can be as bad as too little
- **Lignin Sulphonates**. **Lignin Sulphonates**. Lignin sulphonates products are derived from the paper industry. Lignin is extracted from wood by treatment with sulphite chemicals, then treated with lime to produce cacium lignosulphonates, which are water soluble polymers. These chemicals can form strong bonds with soil particles and act primarily as binders. They can also act as a clay dispersant and compaction aid (NAASRA, 1986).
- **Polymer Stabilisers**. Polymer products may act as waterproofing agents and as binders. The chemistry of these products is little known, further research is required to define their value.
- **Enzyme and Microbiological Binders**. Few trials have been made to date with these products. Some products react with organic matter or clay in the soil to form cementitious compounds and some may be ionic and behave like an SSP.

When considering the use of synthetic stabilisers the following should be noted:

- Unlike traditional stabilisers such as lime, cement and bitumen **there are no standard specifications or test procedures** to effectively predict the performance of these stabilisers in the field. Some of these products have been aggressively promoted, but relatively few field trails have been considered successful.
- Most products may be quite **short lived in an unpaved road**.
- The **cost of the chemical is often so great** that other means of stabilisation (ie lime, cement or bitumen) are more economical.
- The effectiveness of some products is very sensitive to material type and uniformity
- **Construction tolerances,** particularly in relation to mixing and application rates, may be critical to success and therefore **introduce a high risk** factor not associated with traditional stabilisers.

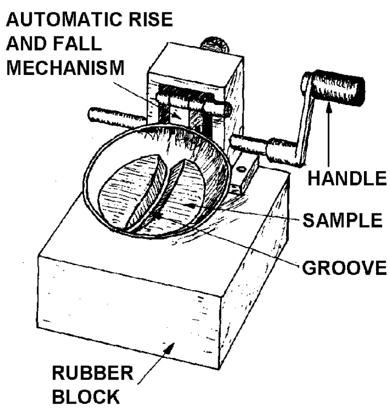
## 8.8. Quality Control

### Control of Excavation

Constant care and attention to the quality of work in the pit is required. The quality of materials produced and the road constructed is dependant to a large extent upon the following:

- Careful selection of suitable material and avoidance of contamination with overburden or underlying unsuitable deposits. Plant operators may require guidance initially.
- Continuous monitoring of any processing activities.
- Appropriate stockpiling methods.

Ideally, a pit supervisor should be appointed to control all extraction and processing operations. This is particularly important if the materials are variable or if plant operators may be changed frequently.




Laboratory quality control testing should be carried out before any pavement aggregates are approved for use.

### Frequency of Sampling and Testing

Prior to any regravelling operations laboratory testing should be carried out to determine:

- The characteristics of "as dug" materials in all borrow pits that may be required to supply the section of road to be regravelled
- Appropriate processing methods (if required)
- The characteristics and uniformity of the excavated or processed materials
- The characteristics of the existing road materials

| Tests | Frequency | Comments |
|---|---|---|
| Atterberg Limits (PL, LL, LS) | Every 2,000 $m^3$ | Increase frequency if variable or marginal suitability |
| Grading Analysis | Every 2,000 $m^3$ | Increase frequency if variable or marginal suitability |
| Compaction and CBR | Every 4,000 – 6,000 $m^3$ | Dependant on uniformity of material |
| Particle Strength AIV & ACV | Every 4,000 – 6,000 $m^3$ | Dependant on relative strength. |

Minimum sample size given in Table 3.2

**Table 8-3 Recommended Testing of Pit Materials**

| Tests | Frequency | Comments |
|---|---|---|
| Atterberg Limits (PL, LL, LS) | Every 3 km | Increase if variable or marginal suitability |
| Grading Analysis | Every 3 $km^3$ | Increase if variable or marginal suitability |
| Compaction and CBR | Every 6 km | Dependant on uniformity of material |
| Particle Strength AIV & ACV | Every 6 km | Dependant on relative strength. |

Minimum sample size given in Table 3.2

**Table 8-4 Recommended Testing of Road Materials before Regravelling**

# Section 9
# Material Supply Considerations

| Activity | Task Rate | |
|---|---|---|
| Excavation and loading onto Wheelbarrow | 2-4 $m^3$/worker day | |
| Hauling Soil by Wheelbarrow | Quantity | No of Trips/day |
| 0 – 40 m | 10.5 $m^3$/w.day | 210 |
| 40 – 60 m | 8.0 $m^3$/w.day | 160 |
| 60 – 80 m | 6.5$m^3$/w. day | 130 |
| 80 – 100 m | 5.5 $m^3$/w.day | 110 |

Notes:

1 Targets for hauling and tipping only: excludes loading and spreading

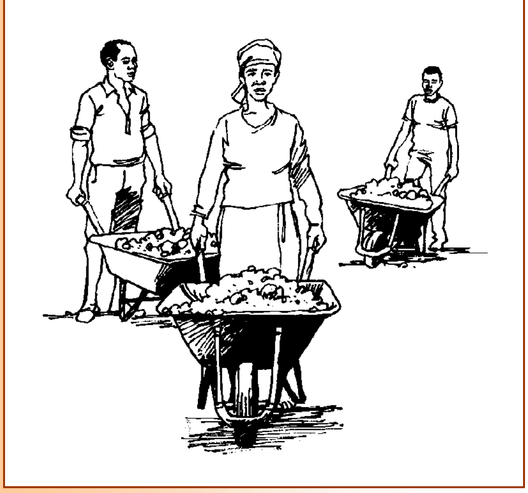
2 Assumes wheelbarrow volume equals 0.07 $m^3$ of loose material (0.5 $m^3$ compacted material)

3 2 wheelbarrows used by each hauling labourer

4 Good haul route (reduce targets for poor route)

Extract from PIARC Road Maintenance Handbook

Outputs for Haulage of Soil by Wheelbarrow



Labour intensive loading and haulage methods. Sketches from ILO/ASIST Bulletin No9 (1999)

# 9. MATERIAL SUPPLY CONSIDERATIONS

## 9.1. Loading and Haulage

### Labour Intensive Loading and Haulage

When specialist loading and hauling equipment is either unavailable or very expensive, maximum use may be made of labour based methods of material transport.

Usual methods that may be used of hauling materials for distances of less than 5 km are summarised on below:

| Haulage Equipment | Recommended Haulage Range (m) | Capacity ($m^3$) |
|---|---|---|
| Headbasket | 4 - 50 | 0.02 |
| Western Wheelbarrow | 25 -150 | 0.08 |
| Chinese Wheelbarrow | 50 - 400 | 0.16 |
| Animal Cart | 100 - 500 | 0.7 |
| Tractor and Trailor | 250 – 5,000 | 3 – 3.5 |
| Tipper Truck | >2,000 | 5 - 6 |

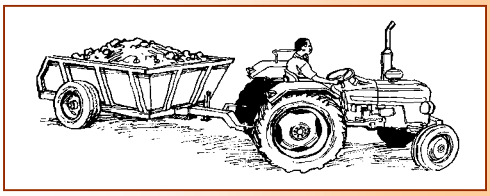
(Extract from ILO/ASIST Technical Brief No 2, 1998)

**Table 9-1 Selection of Haulage Equipment**

Over relatively short distances wheel barrows and animal carts may be used economically for haulage. Such short hauls are usually only associated with stripping of overburden or supply of embankment fill materials.

For distances of between about 2 and 10 km haulage may be economically carried out by a combination of agricultural tractors and gravel trailers. Rates at which gravel can be manually loaded onto a trailer, hauled and off loaded have been studied in some detail to obtain productivity norms. Table 9.2, extracted from the PIARC International Road Maintenance Handbook Volume II, summarises productivity information necessary for planning labour and tractor/trailer road regravelling. Table 9.2 assumes :

- Good haul routes.
- 45 –75 HP (34-56kW) tractors and 3 $m^3$ trailers.
- 8 to 10 $m^3$ of stockpiled gravel can be loaded by one labourer in a 9 hour day.
- 12-16 $m^3$ of material can be off loaded and spread by one labourer in a 9 hour day.
- Excavation rates will vary according to material hardness (refer Table 6.2). Labour force requirements in Table 9.1 conservatively assume that loose material is being excavated at 2-3 $m^3$/ worker day.



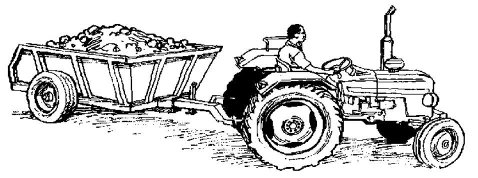
Gravel trailer for labour intensive material supply. Sketch from ILO/ASIST Bulletin No9 (1999)

| HAUL DISTANCE Km | NUMBER OF TRACTORS | QUANTITY OF GRAVEL HAULED m³/DAY (LOOSE) | EQUIVALENT LENGTH OF GRAVELLED ROAD METRES/DAY | | | APPROX. LABOUR FORCE REQUIRED (EXCAVATION, LOADING, UNLOADING AND SPREADING ONLY) |
|---|---|---|---|---|---|---|
| | | | $0.4m^3/m$ RUN COMPACTED * | $0.65m^3/m$ RUN COMPACTED ** | $0.9m^3/m$ RUN COMPACTED *** | |
| 0 - 1 | 2 | 126 | 252 | 156 | 112 | 63 - 90 |
| 1 - 2 | 2 | 108 | 216 | 133 | 96 | 54 - 77 |
| | 3 | 162 | 324 | 200 | 144 | 81 - 115 |
| 2 - 3 | 2 | 78 | 156 | 96 | 70 | 39 - 56 |
| | 3 | 117 | 234 | 144 | 104 | 59 - 83 |
| | 4 | 156 | 312 | 193 | 139 | 78 - 111 |
| 3 - 4 | 3 | 90 | 180 | 111 | 80 | 45 - 64 |
| | 4 | 120 | 240 | 148 | 107 | 60 - 85 |
| | 5 | 150 | 300 | 185 | 134 | 75 - 107 |
| 4 - 5 | 4 | 108 | 216 | 133 | 96 | 54 - 77 |
| | 5 | 135 | 270 | 167 | 120 | 67 - 96 |
| | 6 | 162 | 324 | 200 | 144 | 81 - 115 |
| 5 - 6 | 4 | 84 | 168 | 104 | 75 | 42 - 60 |
| | 5 | 105 | 210 | 130 | 94 | 53 - 75 |
| | 6 | 126 | 252 | 156 | 112 | 63 - 90 |
| | 7 | 147 | 294 | 181 | 131 | 73 - 105 |
| 6 - 7 | 4 | 72 | 144 | 89 | 64 | 36 - 51 |
| | 5 | 90 | 180 | 111 | 80 | 45 - 64 |
| | 6 | 108 | 216 | 133 | 96 | 54 - 77 |
| | 7 | 126 | 252 | 156 | 112 | 63 - 90 |
| 7 - 8 | 4 | 72 | 144 | 89 | 64 | 36 - 51 |
| | 5 | 90 | 180 | 111 | 80 | 45 - 64 |
| | 6 | 108 | 216 | 133 | 96 | 54 - 77 |
| | 7 | 126 | 252 | 156 | 112 | 63 - 90 |
| 8 - 9 | 4 | 60 | 120 | 74 | 54 | 30 - 43 |
| | 5 | 75 | 150 | 93 | 67 | 38 - 54 |
| | 6 | 90 | 180 | 111 | 80 | 45 - 64 |
| | 7 | 105 | 210 | 130 | 94 | 53 - 75 |
| 9 - 10 | 4 | 48 | 96 | 59 | 43 | 24 - 34 |
| | 5 | 60 | 120 | 74 | 54 | 30 - 43 |
| | 6 | 72 | 144 | 89 | 64 | 36 - 51 |
| | 7 | 84 | 168 | 104 | 75 | 42 - 60 |

* e.g. 4.0 metres wide and 10 cms thick
** 5.4 metres wide and 12 cms thick
*** 6.0 metres wide and 15 cms thick

Source PIARC International Road Maintenance Handbook (1994)

**Table 9-2 Outputs for Tractor and Trailer Haulage for Regravelling**



Tractor and gravel trailer (sketches from ILO/ASIST Bulletin No 9 1999).

- The following guidelines may help to improve the efficiency of tractor and trailer materials supply:
  - Each tractor should operate at least two trailers and maybe three so that the tractors can be fully utilised (ie a tractor may be returning an empty trailer to the borrow pit while one is being loaded and another is being unloaded).
  - Trailers should preferably have a hydraulic tipping capability and a capacity of 3 $m^3$ for 45 – 75 hp tractors
  - Trailers should be fitted with a rear tow bar so that one tractor is capable of moving more than one empty trailer at a time. For example, when moving between depot and borrow pits.
  - Ensure sufficient material is stockpiled and sufficient labour is available for loading
  - Where possible excavate loading bays in the borrow pit so that trailers can be backed in for loading (refer Figure 6.1). Ramps into loading bays should not be too steep
  - Sufficient room must be available in the pit for turning tractors and trailers.

Tractor and trailer haulage is typically suitable for providing gravel stockpiles (stacks) beside the road when labour intensive methods are to be used for routine maintenance activities (ie pothole repairs). Ideally one trailer load of gravel is placed at 100 to 200m intervals along the road (outside of the side drain).

Haulage of aggregates over distances of greater than 5km by tractor and trailer is usually not economic. Tipper trucks are normally the best option for hauls exceeding 5km. Manual loading of tipper trucks is difficult to carry out efficiently, therefore labour based loading is not usually employed. However, Table 9.3 provides a guide to the likely output from manually loaded tipper truck haulage.

| Haul Route Condition | Good | | | | | Average | | | | | Poor | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Haulage Distance (km | 2 | 4 | 6 | 8 | 10 | 2 | 4 | 6 | 8 | 10 | 2 | 4 | 6 | 8 | 10 |
| Trips per day per truck | 22 | 19 | 16 | 11 | 8 | 18 | 15 | 12 | 8 | 6 | 16 | 12 | 10 | 7 | 5 |

Source ILO/ASIST Bulletin No 9 (1999)

**Table 9-3 Tipper Truck Haulage Productivity with Labour Based Loading**

As indicated on Table 9.3 output is strongly influenced by the condition of the haul route (refer Section 9.3).

## 9.2. Plant Based Loading and Haulage

Mechanised loading in borrow pits is typically carried out by one of the following items of plant: excavator; tractor backhoe; wheel loader or crawler loader (refer Section 7).

Haulage output rates for plant based loading and transport can typically be accurately predicted from a knowledge of plant capacities (ie from manufacturers performance data), haul road condition and haulage distance.

The following factors should be considered in relation to aggregate loading:

- When possible select plant that can excavate and load the aggregate.
- If aggregates are likely to deteriorate in stockpile, try to combine excavation and supply activities.
- When necessary material should be moistened in the borrow pit before being hauled to the road (refer Section 7.3). This reduces segregation during haulage and assists with the compaction of the material. Construction in the wet season may permit rainfall to provide this moisture (CSRA TRH 20 1990).

The following guidelines should be applied when plant based haulage is employed:

- The direction of transportation of material should be such that the newly constructed road is not trafficked by the haulage trucks. If adequate compaction is carried out during gravel road construction, then trafficking by construction vehicles results in more damage to the road (ravelling and potholing) than the benefits gained from further compaction. If the compaction is minimal (not recommended) the passage of construction traffic may be beneficial (CSRA TRH 20 1990).
- Haul roads to the pit and stockpile areas should be kept in good shape. The condition of haul roads to borrow pits will have a significant affect on haulage costs (refer Section 9.3).

Try to use the same plant to excavate and load aggregate

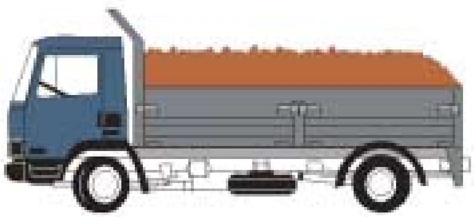
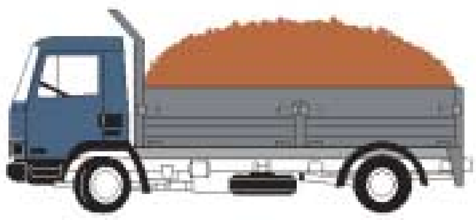
The pit stockpile areas should be maintained so as to allow easy movement of haulage vehicles

## Vehicle Overloading

Great care should be taken to avoid any overloading of haulage trucks. Any apparent saving in haulage time and cost will typically be offset by rapid deterioration in borrow pit access tracks and by rutting in both gravel roads and bitumen sealed pavements.

As a general rule, it has been shown that the relative damage to pavements varies as the fourth power of the applied load. Figure 9.1 (after RS Millard ,1993) indicates how the potential damaging effect of overloading escalates as represented in terms of the number of equivalent standard Axles (ESA). One ESA is equal to the passage of a standard axle load of 8.16 tonnes. The rear axle of the overloaded truck in the Figure is applying a load of 19 tonnes therefore one passage of this axle is equivalent to the passage of 44.9 axles applying a load of 8.16 tonnes

Haulage supervisors must determine a correct loading level for the vehicles in use and ensure that plant operators do not exceed this level.

| PROPERLY LADEN VEHICLE | OVERLADEN VEHICLE |
|---|---|
|  |  |
| ALL UP WEIGHT<br>16 tonnes | ALL UP WEIGHT<br>28 tonnes |
| AXLE WEIGHT<br>6 tonnes 10 tonnes | AXLE WEIGHT<br>9 tonnes 19 tonnes |
| EQUIVALENT STANDARD AXLES<br>0.25 2.50<br>Total ESA's = pavement damaging effect<br>2.75 | EQUIVALENT STANDARD AXLES<br>1.55 44.9<br>Total ESA's = pavement damaging effect<br>46.4 |
| PAYLOAD<br>10 tonnes | PAYLOAD<br>22 tonnes |

Source RS Millard (1993)

**Figure 9-1 Effect of Overloading Haulage Vehicles on Payload and Pavement Damage**

## 9.3. Access Roads

The condition and gradient of haul roads to borrow pits will have a significant affect on haulage costs. Efficiency of haulage may also be affected by the condition of the vehicle fleet. A simple classification of haulage conditions is given below:

| | |
|---|---|
| Good: | Undulating terrain, good road condition, trucks in good condition |
| Average: | Hilly terrain, average road condition, trucks in average condition |
| Poor: | Mountainous terrain, poor road condition and difficult pit/ quarry access |

Poor haul roads have a significant impact on material supply efficiency and costs.

The impact of haul road condition may be quantified in terms of the rolling resistance of the plant. When rolling resistance is converted into an equivalent gradient the importance of maintaining haul roads in good shape is easy to evaluate, as sh

| HAUL ROAD CONDITION | ROLLING RESISTANCE FACTOR | |
|---|---|---|
| | Kg/t | As Equivalent Gradient |
| Hard smooth gravel or stabilised surface, no penetration under load, well maintained | 20 | 2% |
| Firm smooth, rolling road with earth or light surfacing, some flexing under load, periodically | 32.5 | 3% |
| Earth road, rutted, flexing under load, little maintenance, 25 mm to 50 mm tyre penetration | 50 | 5% |
| Rutted earth road, soft under travel, no maintenance, 100 mm to 150 mm | 75 | 7.5% |
| Loose sand / gravel | 100 | 10% |
| Soft muddy rutted road no maintenance | 100 - 200 | 10 – 20% |

Source Caterpillar Overseas S.A

**Table 9-4 Haul Road Condition and Plant Operation**

## 9.4. Identifying Supply Strategy

Material supply strategies should be developed to ensure that **minimum costs** are incurred relating to the supply of suitable quality road building materials at the required destination on the road. In broad terms, comparing the material production and haulage costs that are associated with each potential source of supply will identify the optimum supply strategy.

Up to 70% of the construction cost of a typical low volume rural road may relate to pavement materials production and supply. Also, aggregate replacement costs are often as high as 60% of the maintenance costs of an unpaved road. Therefore very significant cost efficiencies can be achieved by implementing economic material supply strategies.

To develop a comprehensive material supply strategy the following factors need to be taken into consideration:

- **Material cost per cubic metre**. This is primarily determined by the following variables: Cost of land acquisition; extraction royalties; pit preparation and extraction costs (influenced mainly by need for haul road , site clearance and depth of overburden stripping); processing costs (if incurred); and reinstatement costs.
- **Cost of aggregate haulage**. This is essentially dependent on distance. When designing a supply strategy an adequate estimate of haulage costs can usually be obtained by calculating an average cost in terms of cost/$m^3$/km and by applying it to all the sources under consideration. This will not apply if short hauls can be carried out by a more economical method than long hauls.
- **Resource size**. This may influences the economics of supply, because if a relatively cheap material source is of limited size it may not be able to supply materials over the optimum length of road before becoming exhausted. The supply strategy must account for this, but will have identified the economic benefit of carrying out materials searches in the area to locate additional resources of similar material.
- **Material quality**. If all pit materials will not to be processed to produce a uniformly high quality aggregate, then some account should ideally be made for any likely variation in construction, maintenance and vehicle operating costs. A cost weighting may be devised to account for significant material quality variation. This will have the effect of promoting longer haulage of better quality materials. However, experience indicates that it is typically cost effective to avoid the use of any materials that have not been processed to a satisfactory standard.
- **Negative environmental impacts**. The costs associated with environmental impacts and their mitigation will generally be covered in the estimate for pit development and reinstatement costs and reflected in the material cost/$m^3$. However, if for example adequate reinstatement is impractical or impossible at a source then it may be appropriate to attach a cost to this adverse impact when assessing the optimum supply strategy.

Careful planning of material supply strategies will typically result in considerable cost efficiencies.

## Example of Material Supply Strategy Development

The analysis of pavement material supply strategies for low cost road construction and maintenance activities can be greatly aided by the preparation of economic haulage diagrams.

In the following paragraphs an example of the use of economic haul diagrams to identify the optimum material supply strategy for a gravel road is presented.

Supply strategies are best developed through the use of "line haulage diagrams" and "graphical haulage diagrams".

Figure 9.2 presents an example of line haulage diagrams prepared for a 100 km length of gravel road which has six potential sources of wearing course gravel (Pits A to F) located along its length. The characteristics of the pits are as summarised in Table 9.5.

In the example it is assumed that:

- cost of haulage will in all cases be $ 0.3/m$^3$/km,
- all pit materials will be processed to a high quality,
- no pit will cause significant long term adverse environmental impact.

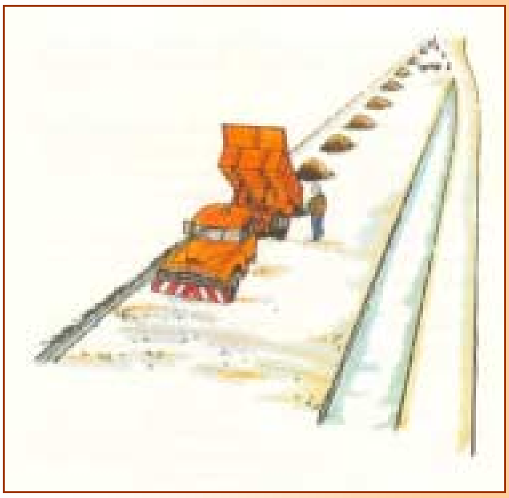
Optimum material usage will therefore be based on the relationship between three factors: pit location (haulage distance); cost/m$^3$ at the roadside; and material availability (resource size).

It is inappropriate to consider pit location in isolation from material cost/m$^3$ and material availability, but in order to demonstrate the interrelationship of these factors in determining a supply strategy Figure 9.2 illustrates "line haulage diagrams" that have been based upon the following:

A **Pit Location Only**. With supply strategy based solely on minimum haulage of processed material between sources (including pit offset distance from road in the haulage calculation).

B **Pit Location and Cost/m$^3$ at destination.** With supply strategy based on minimum cost of supply, regardless of material availability (with offset haulage included in roadside cost/m$^3$).

C **Pit Location, Cost/m$^3$ at the destination and Resource Size**. With supply strategy based on minimum cost of supply with account made for limitations imposed by the exploitable pit resource size.



Material supply for regravelling (Sketch from PIARC International Road Maintenance Handbook, 1994)

| PIT | CHAINAGE (OFFSET) KM | PIT STATUS | RESOURCE ESTIMATE ($m^3$) | "AS DUG" SUITABILITY RATING | RECOMMENDED PROCESSING | COST/M$^3$ PROCESSED AGGREGATE AT ROADSIDE |
|---|---|---|---|---|---|---|
| A | Km 5.0 (2.0 LHS) | Existing | Moderate (30,000 $m^3$) | 2 (Good) | Remove oversize by hand | $ 5 |
| B | Km 10.0 (0.5 RHS) | Existing | Moderate (20,000 $m^3$) | 1-2 (Very Good to Good) | Use "as dug" | $ 3 |
| C | Km 35.0 (0.5 LHS) | Potential | Limited (10,000 $m^3$) | 2 (Good) | Screen | $ 6 |
| D | Km 50.0 (4.0 RHS) | Potential | Extensive (100,000 $m^3$) | 4 (Poor) | Screen and blend | $ 7 |
| E | Km 55.0 (1.5 LHS) | Existing | Extensive (100,000 $m^3$) | 1-2 (Very Good to Good) | Use "as dug" | $ 4 |
| F | Km 90.0 (1.0 RHS) | Existing | Large (50,000 $m^3$) | 2-3 (Good to Moderate) | Blend with plastic binder | $ 5 |

Note: For definition of "As Dug " Suitability Rating refer to Section 4.1

**Table 9-5 Characteristics of Pits Used in the Example of Supply Stategy Development**

| PIT | CHAINAGE (OFFSET) KM | ECONOMIC HAULAGE Based on Pit Location Only | ECONOMIC HAULAGE Based on Pit Location and Cost/m$^3$) | ECONOMIC HAULAGE Based on Pit Location, Cost/m$^3$ and Size) |
|---|---|---|---|---|
| A | Km 5.0 (2.0 LHS) | Km 0.0 – 6.75 | Not Required | Km 0.0 – 10.0 |
| B | Km 10.0 (0.5 RHS) | Km 6.75 – 22.5 | Km 0.0 – 27.5 | Km 10.0 - 30.0 |
| C | Km 35.0 (0.5 LHS) | Km 22.5 – 44.25 | Km 27.5 – 42.0 | Km 30.0 – 40.0 |
| D | Km 50.0 (4.0 RHS) | Km 44.25 – 51.25 | Not Required | Not Required |
| E | Km 55.0 (1.5 LHS) | Km 51.25 – 72.25 | Km 42.0 – 74.0 | Km 40.0 – 74.0 |
| F | Km 90.0 (1.0 RHS) | Km 72.25 – 100.0 | Km 74.0 - 100 | Km 74.0 – 100.0 |

**Table 9-6 Review of Economic Haulage in Example**

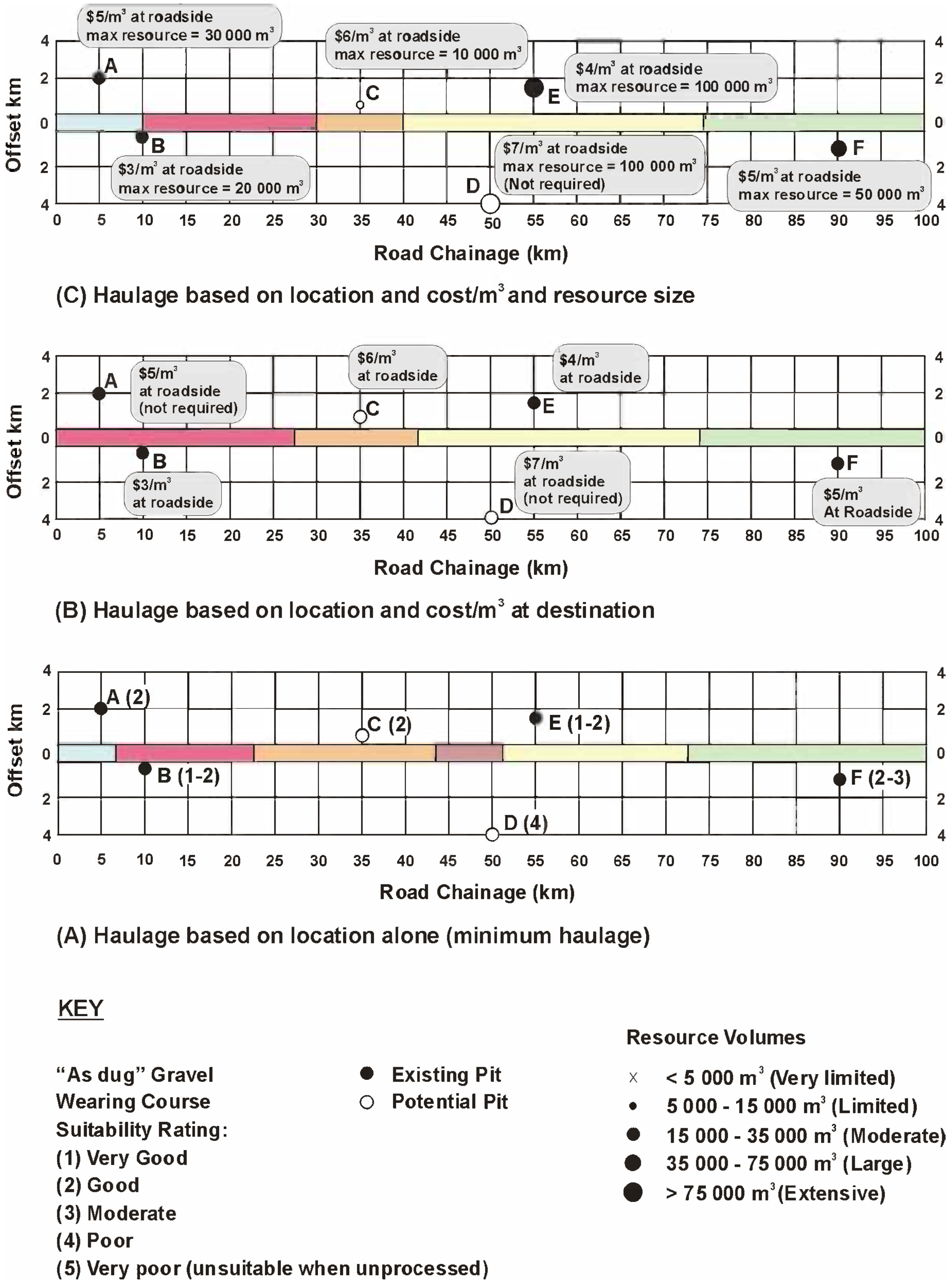



**Figure 9-2 Example of Line Haulage Diagrams for a Gravel Road**

Material supply (Sketch from PIARC International Road Maintenance Handbook, 1994)

In order to determine the two economic haulage strategies (B and C in Figure 9.2) that take into account the processed material cost/m$^3$ at its destination, "graphic haulage diagrams" are constructed as shown in Figure 9.3.

In a "graphic haulage diagram" aggregate cost/m$^3$ is plotted on the vertical axis and Road Chainage in km is plotted on the horizontal axis.

The cost/m$^3$ of a pit material at the roadside (including cost of offset haulage) is then represented on the graph by a vertical line that starts at the Pit Chainage.

Haulage cost from the roadside to the material's destination on the road is represented by the two inclined lines forming a Y shape. Haulage cost is estimated at \$ 0.3/m$^3$/km, this determines the angle of inclination of the limbs. The plot shows that 10 km of haulage along the road increases the supply cost by an addition \$ 3.0 (as represented by the inclined upper limbs of the Y).

The intersections of the inclined limbs from adjacent potential material sources identify the chainages where materials from each pit have the same on site delivery cost. In other words, the intersections mark the limit of optimum economic haulage.

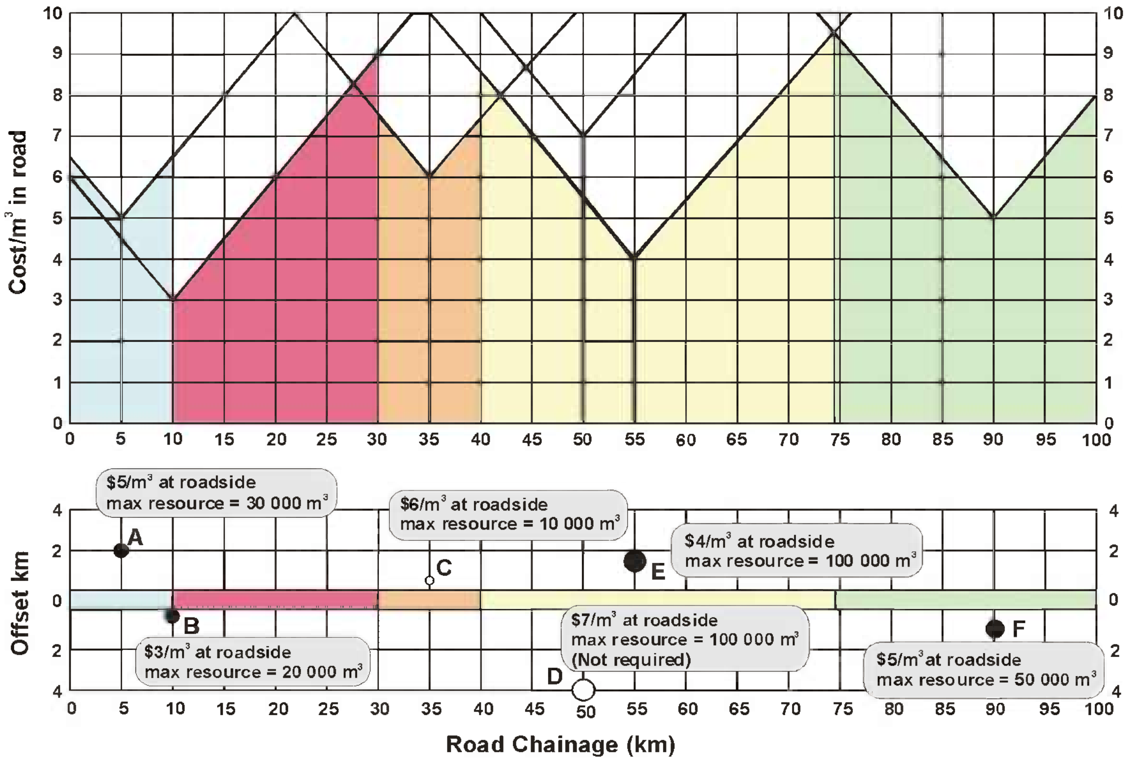
It should be noted that both Figures 9.3B and 9.3C indicate that Pit D should not be opened, because it is shown to be more economical to supply aggregates from Pit E.

Similarly Figure 9.3B indicates that supply of material from pit A is not economically justified. The graph indicates that hauling material from Pit A (at km 5) to km 0.0 will cost \$ 6.5/m$^3$, but hauling material from Pit B (at km 10) to km 0.0 will cost only \$6.0/m$^3$.

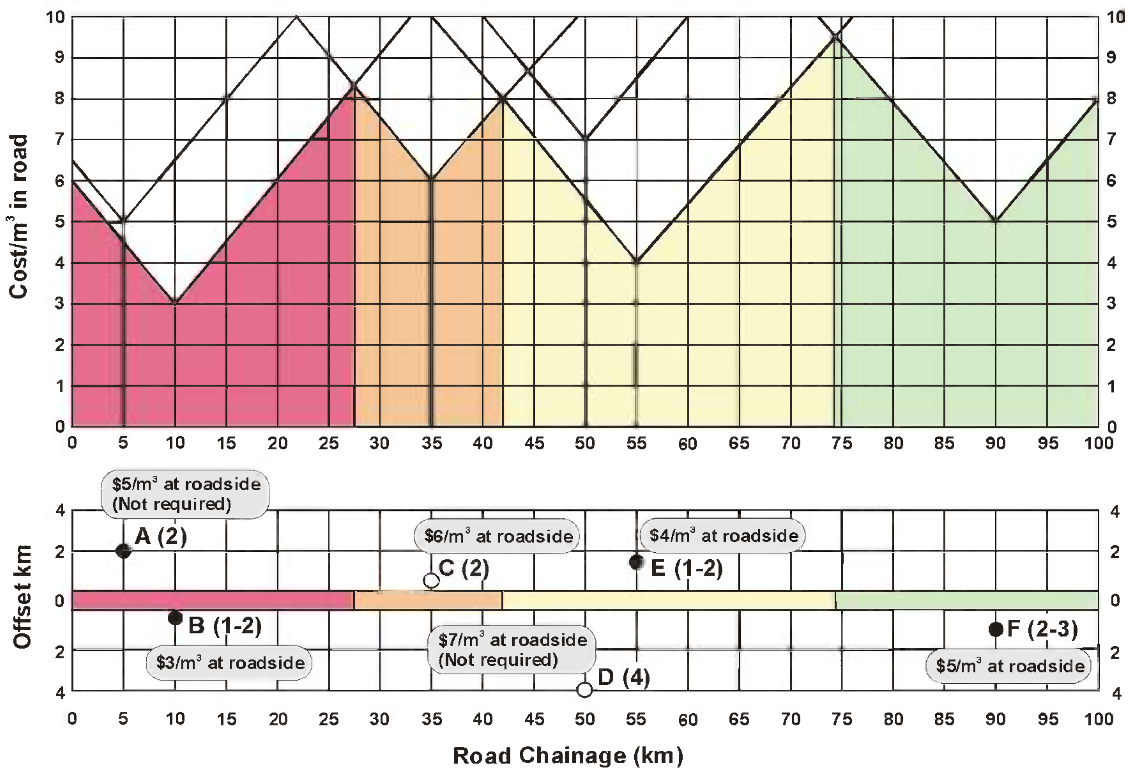
Figure 9.3C is different from Figure 9.3B because when resource size is taken into account it is found that there is insufficient material available in Pit C and Pit B to enable the optimum haulage strategy to be implemented.

Pit C has an estimated resource size of 10,000 m$^3$. The road is 6m wide and requires construction of a new 150 mm thick gravel wearing course (ie 900 m$^3$ of compacted gwc is required per km of road). There is therefore only sufficient material available in Pit C to regravel a maximum of 11.1 km of road, allowing for a small margin of error say 10 km. In which case Pit C should only be programmed to supply material between km 30 and km 40 (as shown in Figure 9.3C).

Pit B also contains a relatively small resource volume of 20,000 m$^3$. Which means this pit can supply a maximum of 22.2 km of road, say 20 km. Figure 9.3C indicates that the optimum use of Pit B materials is between km 10 and km 30 while Pit A should be used to supply surfacing aggregates from km 0.0 to km 10.




(C) Haulage based on location and cost/m³ and resource size




(B) Haulage based on location and cost/m³ at destination

**Figure 9-3 Example of Graphical Haulage Diagram for a Gravel Road**

## 9.5. Record Keeping

Records keeping of materials usage is an essential element of efficient borrow pit management. The method of planning an economic haulage strategy has been described in the previous section. Records concerning the actual use of material need to be prepared following completion of any construction project or regravelling/rehabilitation operation. Also observations concerning in-service performance of the aggregate should be made and documented so that the quality rating of the material supplied may be assessed. The following data should be recorded:

- The actual source of materials used to supply each section of road.
- The characteristics of the materials used to supply each road section
- Actual cost/$m^3$ of material at the road side and actual haulage cost/km.
- An estimate of the exploitable resource remaining in each source after completion of construction.

Good record keeping is essential for efficient borrow pit management

This data can be used to form “as built” haulage diagrams. The information should also be incorporated in materials database and utilised in a maintenance management system (refer Section 10).

The benefits of good record keeping will include:

- Identification of resource deficiencies, enabling implementation of material searches and acquisition of pit extensions or new sources well in advance of material requirement.
- In-service performance monitoring will allow identification of materials that would benefit from improved processing or selection procedures.
- Improved economics of future material supply.

# Section 10
# Materials Data Management

# 10. MATERIALS DATA MANAGEMENT

## 10.1. Introduction

### Existing Situation

A review of record keeping practices and data management with respect to the supply of borrow pit materials has been carried out in a number of countries that have large networks of low cost rural roads.

This investigation revealed that in the majority of developing countries the records for existing material sources are inadequate and many pits have never been properly assessed for suitability or resource potential.

Material supply strategies, which are often determined by field supervisors from undocumented knowledge, are often exploiting a decreasing number of traditional natural gravel pits. In many places a significant number of existing material sources may become exhausted in the near future, and the need for material searches, adequate pit evaluations and material processing is not necessarily being recognised. As a result, the best road materials may not be being used and over-haulage is occurring due to material deficiencies.

The end result of poor record keeping tends to be poor materials management, which results in the inefficient use of the limited funds that are available for road maintenance.

A few countries have recognised the benefits of establishing some kind of national or regional borrow pit/quarry inventory that assembles and stores data concerning the location and engineering properties of low cost road building material resources.

Some of these countries are establishing simple spreadsheet based material resource inventories (ie Mozambique and Malawi), while other countries have progressed to more sophisticated computer databases for the management of borrow pit and pavement records (ie Zimbabwe and Indonesia).

One country (Papua New Guinea) commissioned, in 1990, a National Road Materials Resource Study that involved the preparation of a comprehensive database of pits and quarries required to maintain and upgrade its existing National Road Network (3865 km of gravel road and 1300 km of paved road).

This study took two years to complete. It involved materials engineers and technicians visiting, sampling and documenting about 1000 existing and potential borrow pits. Great emphasis was placed on the appraisal of material resources that supply the gravel roads, because the primary objective of the study was to enable more cost effective use of maintenance funds on gravel pavement maintenance.

Keeping up to date borrow pit records allows cost effective planning of material supply and ensures that the best sources are selected for use during maintenance and upgrading.

Much was learnt during this study (Bishop & Morey, 1992 and Engineering Geology Ltd *et al* 1992) in relation to the rapid assessment of low cost road material sources and subsequent data management. This experience has been drawn upon in the preparation of this manual.

This Section presents the following:

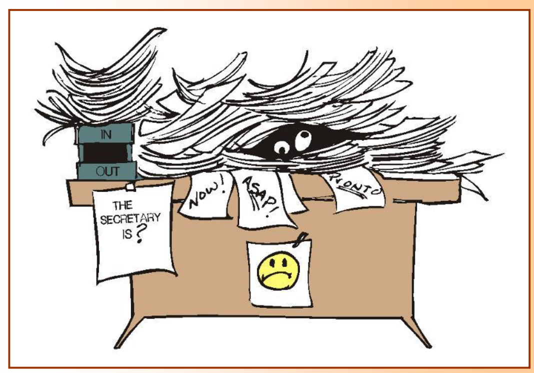
- Guidelines and recommendations on the design of an appropriate low cost road materials database, including an introduction to the principles of database operation.
- Recommendations relating to data collection and the establishment of a materials resource inventory.
- Consideration of the use of a materials database to improve maintenance cost efficiency.
- Review of the institutional establishment required for effective materials management.

Poor borrow pit record keeping tends to result in poor materials management and bad roads.

# 10.2. Design of an Appropriate Materials Management Database

## Introduction

In many developing countries most records relating to road material borrow pits exist only in paper form. Such records may occur in a variety of locations such as: Local Government Offices; National Works Department Laboratories; Consultant's Reports; Contractors records; Geological Institute Reports and Lands Department records. As a result, assembling information on material sources that may be used to supply a particular section of road is likely to be difficult and time consuming. Also, such records are often incomplete or confusing.




Paper records are bulky and are easily mis-filed, lost or destroyed

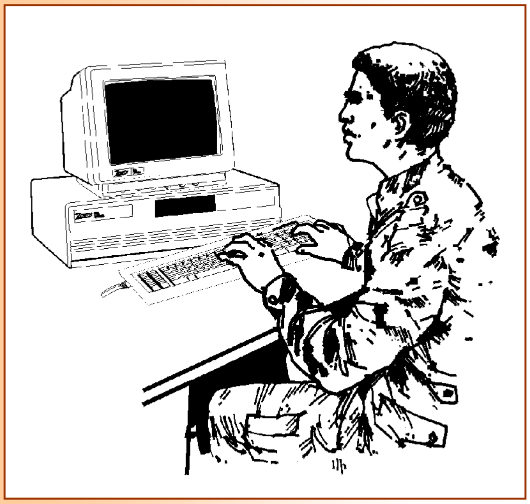
The purpose of a materials database is to assemble existing records and ensure that valuable data is preserved, centralised and made readily available to all interested parties. Paper records are bulky and are easily mis-filed, lost or destroyed. Throughout the developing world computers are increasingly being recognised as an essential and affordable means of storing and analysing all kinds of data.

The development of a computerised database is an ideal and cost effective solution to the problem of preserving existing borrow pit records and enabling all new information to be linked with historical data for analysis and evaluation. It will be cost effective because it will enable more efficient use of road maintenance budgets (in ways that are outlined in Section 10.4).

In its simplest form a computerised materials resource database can be established using a speadsheet programme such as "Excel" or "Lotus". This is encouraged as an intermediate measure, for gathering information on a road by road basis prior to the establishment of a more powerful and appropriate database management system.

A spreadsheet based inventory system will become restrictive and inappropriate when the aim is to centralise all records relating to a large network of roads and enable a variety of analysis functions to be performed and summary reports to be generated.

A Relational Database Management System (RDBMS) software package such as "Access" or "Oracle" is most suitable for handling large amounts of borrow pit information. Such a software package can provide almost complete flexibility in terms of data analysis and presentation. However the program will only carry out functions that it has been "programmed" to perform. As a result, successful development of an RDBMS material resource database will rely on careful planning and setting up (design) of the program functions.



A computerised database is an ideal solution to the problem of assembling old and new borrow pit data, and preparing "up to date" resource evaluations and cost effective material supply strategies.

Before considering the program design (database specification), an understanding of how a RDBMS operates is required.

## Principles of a Database Management System

### How Does a Database Work?

The following paragraphs provide an introduction to Relational Database Management Systems (RDBMS) in terms of explaining their function and operation with respect to the establishment of a road materials resource database and draws on information presented by Engineering Geology Ltd *et al* (1992).

A database system is a tool for organising, storing, calculating, linking and retrieving information (in this case an inventory of borrow pits and records associated with each). Essentially a database comprises a series of tables together with a series of views, queries (ie requested specific ranges of stored data) and reports (outputs) that are based on the tables.

A database system (RDBMS) can carry out a variety of tasks but its main purpose is to act as a connection (interface) between the storage and presentation of data. It provides a set of tools that handles information and performs three major tasks:

- **Database Management**. The storage and retrieval of data.
- **Data Access and Manipulation**. The linking of information and carrying out of calculations and analysis.
- **Programming**. The establishment of procedures to structure the database functions, including methods of analysis and presentation of data.

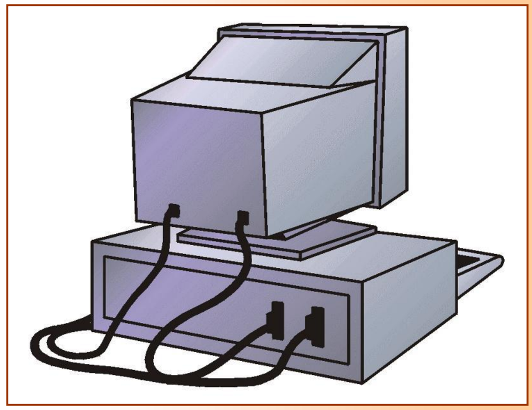
Not every user of a database should have access to use all the tools available, otherwise anyone could alter the structure of the database. Access to the database functions is therefore protected by a system of codes and passwords.

Apart from the Database Administrator, who is able to change the structure of the database other users of the system will typically be divided into two classes:

- **Record Maintenance Users**. People authorised to enter new data (ie input new laboratory test results or create new borrow pit sites); edit and delete data; query the database (implement analysis); and generate printed output.
- **Enquiry Only Users**. People who are only able to implement analysis and generate printed output.

**Menus and Forms**

Databases are menu driven systems that may contain a selection of menus, data entry forms, similar enquiry/ maintenance forms and some menu selected reports.



The selection menus allow the user to choose the appropriate form for his task. For instance, if laboratory test results are to be entered then a form with blank spaces (similar to a printed document) is called from the menu. This "fill-in-the-blanks" arrangement enables the user to interact with the database through forms (displayed on the monitor) that resemble printed forms/proformas (eg Data Entry Proforma- refer Figure 10.4. This allows the operator to type and edit the information on the form, as if he or she were filling out or correcting a paper form.

The electronic form displayed on the screen can provide "structured support" for data entry. For example the entry forms on a Road Materials Resource Database may include the following support tasks:

- Requirement that certain items of data be entered for each record (mandatory entries eg road number or road chainage).
- Validation of input data against a standard set of entries eg suitability ratings.
- The facility to set maximum or minimum values for certain field entries eg materials properties, such as PI values.
- Provision of on screen prompts.

The forms therefore perform a variety of functions that validate assist and enhance the operator's entries.

**Report Generation**

Database systems can be designed to generate various outputs (in the form of screen views and/ or paper print outs) by selecting certain stored data and presenting it in a required format. These are called "reports" and often take the form of summary tables of selected information or the results of data analysis carried out by the program (eg Tables 10.2 & 10.3).

## Design of a Materials Resource Database

A database program can only carry out functions that it has been programmed to perform. Considerable thought therefore must be given to identifying the following:

- Exactly what information will be required to be entered onto the database. For example, what range of sieve sizes are required on the form for entry of particle size distribution (PSD) grading data.
- What analysis functions should the program be able to carry out if required. For example, should the programme automatically calculate the Grading Modulus from a set of PSD results.
- What options are required in terms of presenting outputs (reports). For example, should the program be able to plot PSD curves and should it plot laterite gravel wearing course materials with a particular grading envelope.

The design of the materials resource database should be fully discussed with all potential users of the information and with the administrators of other databases with which it might be linked (ie bridge inventories, maintenance management systems etc).

Figure 10.1 presents a flow chart that identifies the main factors to be considered during the design of a materials resource database. This Figure identifies three possible sources of data to be entered on the database as follows:

- Existing Borrow Pit/ Quarry Data.
- Laboratory Test Results.
- New Field Data from Inventory Studies.

### a) Existing Borrow Pit/ Quarry Data

Existing pit information that needs to be incorporated in the database will relate to its location, the properties and characteristics of the material and any data on previous use of the source during road construction.

Each pit or quarry in the database will need to have a unique database reference (label), so that information related to that source can be readily retrieved. In the case of a road materials inventory it is logical and necessary for this label to be based on the pit's location on the road. A pit's unique database reference may therefore be created as shown in Table 10.1

| | Example | Comments |
|---|---|---|
| Road Number | NRO8 | Maximum number of letters must be determined |
| Road Chainage of Pit or pit access road | 38.3 | If no roads longer than 999km then this would require a three number entry with one decimal place ie 038.3 |
| Offset from road | 0 | More than one pit may occur along a feeder road, the pit closest to the road is labelled 0, the next 1 etc |
| A Reference Identifier | G | G for Gravel Pit. A complementary bridge inventory may use the "B" attachment |
| Unique Database Pit Reference: NR08038.30G | | |

**Table 10-1 Example of the Creation of a Unique Pit Reference**

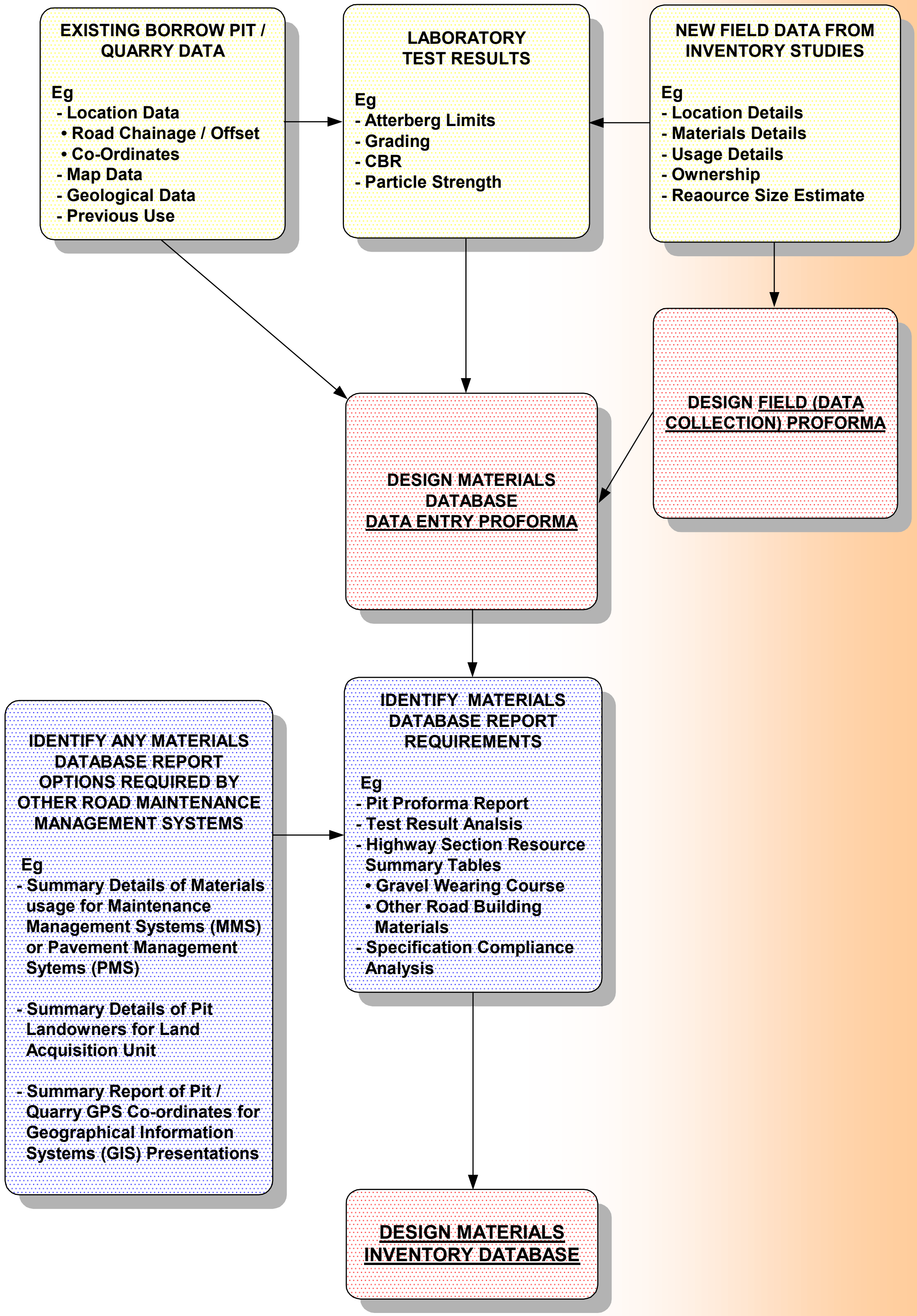
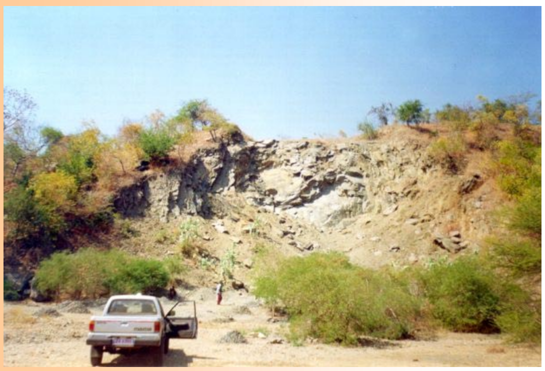



**Figure 10-1 Design of a Materials Resource Database**



A field survey to collect “up to date” borrow pit information and verify existing records should, if possible, accompany the establishment of a Materials Resource Database. This survey should involve completion of a specially designed “Field Proforma” that will ensure collection of all required field information in a format that will allow easy entry onto the database via a “Data Entry Proforma”.

**Laboratory Test Results**

Provision must be made during database design for the input of any existing test results and the entry of the results of any testing carried out in the future.

This simply involves creating a data entry proforma that has entry fields for all tests that may be carried out (refer Appendix C, Example of Data Entry Proforma).

**c) New Field Data from Inventory Studies**

When possible the establishment of a materials resource database should be accompanied by field studies that will collect “up to date” information on all existing borrow pits.

The value of a borrow pit inventory will be greatly diminished if it is based solely on historical data for several main reasons:

- Resource estimates, if they exist, will probably be out of date and unreliable.
- Some historical material sources may no longer exist, having been exhausted, back-filled or reinstated.
- Existing records may contain errors in terms of material description and even location.

In view of the above, historical data should be verified and should normally only supplement “up to date” information collected during borrow pit inventory studies that have been implemented specifically to create the materials resource database.

The information that is required for a borrow pit evaluation has been identified in Figure 2.3 (Borrow Pit Evaluation during Material Search Studies) and Figure 4.1 (Factors Influencing Pit/ Quarry Evaluation and Selection).

Figure 10.2 presents an example of a completed **“Field Proforma”** that was designed for use during Borrow Pit Inventory field studies to collect information for creation of the Papua New Guinea Materials Resource Database.

**d) Design of Database Data Entry Proforma**

The **Data Entry Proforma** is required to assemble all historical/ desk study data, laboratory test results and information collected during any field borrow pit surveys (refer Figure 10.4)

The data entry proforma will present all information that is to be included in the database in a format that can be easily entered onto the computer.

The paper data entry proforma should preferably have a similar appearance to the on screen data entry forms, which will require “fill-in-the blanks” data input.

**NATIONAL GRAVEL PIT INVENTORY**
**FIELD PROFORMA**

**PIT REFERENCE DETAILS**

| | |
|---|---|
| PIT LOCAL NAME: MINJIGINA PIT/QUARRY | PIT ALIAS NAME: — |

| | | |
|---|---|---|
| PIT REF. NM3901016·50G | PROVINCE Western Highlands | ROAD Baiyer Road NM3901 |

| CHAINAGE (km) | OFFSET (km) | DIRECTION | PIT STATUS | DATE INVESTIGATED | TOPOGRAPHIC SHEET |
|---|---|---|---|---|---|
| 016·50 | 02·10 | LHS | E | 30 JAN 92 | NAME Hagen<br>NUMBER 7786 |

LOCATION DESCRIPTION
Access from Baiyer Road 5.4km past Gumants Bridge. Pit offset 2.1km along Minjigina Estate Road. Pit in tea plantation.

| NATIONAL GRID REF. | GPS READING 1 (LEVEL 1950m) | GPS READING 2 (LEVEL ) |
|---|---|---|
| EASTING 883<br>NORTHING 647 | LATITUDE 5° 44.423<br>LONGITUDE 144° 11·151 | LATITUDE —<br>LONGITUDE |

| PIT PHOTOGRAPH REF. NO.'S | | SAMPLE DETAILS |
|---|---|---|
| 39/2/21 | 39/2/22 | GPS/92/39/17 (Pit-run bulk) |
| 39/2/23 | | |

**MATERIAL DETAILS**

| | |
|---|---|
| MATERIAL TYPE<br>WELDED TUFF | MATERIALS DESCRIPTION<br>Moderately graded, slightly silty, sandy, mainly medium and coarse angular GRAVEL with many cobbles (ML). |
| % OVERSIZE<br>>150mm 10-20%<br>>75mm 20-35% | GEOLOGICAL DESCRIPTION<br>Light grey weathering to reddish brown, medium grained, typically closely jointed, locally becoming very closely jointed, mainly moderately weathered, WELDED TUFF, moderately strong to strong (when slightly weathered). |
| % & TYPE WEAK, WEATHERED FRIABLE PARTICLES (%)<br>5-10% | |
| WEARING COURSE SUITABILITY<br>3-5 | |

**GRAVEL WEARING COURSE PROCESSING REQUIREMENTS**

| | |
|---|---|
| BLEND WITH Plastic binder | SCREEN OUT 760mm (Grizzly) |
| CRUSH Oversize as necessary | COMPACTION |

**OTHER GEOMATERIAL APPLICATIONS**

| SUB-BASE | BASE-COURSE | SEALING CHIP | GABION STONE | RIP-RAP | COARSE CONCRETING AGGREGATE | FINE CONCRETING AGGREGATE |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 2 | 3 | 2 | 2 |

**OWNERSHIP DETAILS**

Minjigina Plantation

**PERTINENT COMMENTS**

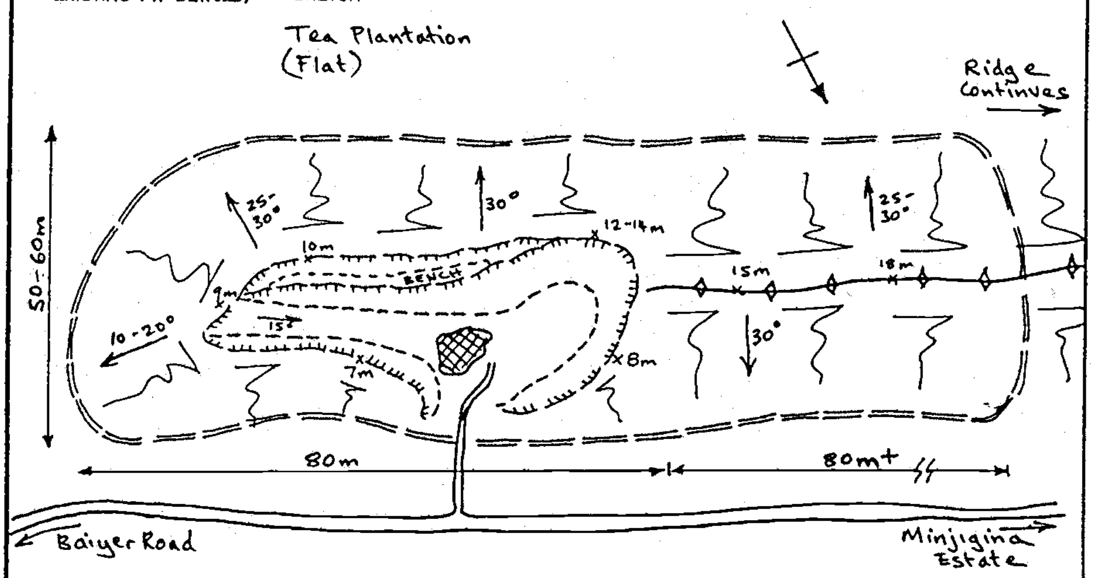
Large potential source of road-making material. Moderately to highly weathered deposits can be ripped for wearing course use. Less weathered deposits at depth (>10m) could be processed for sub-base and probably crushed for base course material.

**Figure 10-2 Example of a Completed National Gravel Pit Inventory Field Proforma (Sheet 1 of 2)**

NATIONAL GRAVEL PIT INVENTORY
FIELD PROFORMA

EXISTING & PROPOSED PIT DETAILS

EXISTING PIT DETAILS/PIT SKETCH




PROPOSED PIT DEVELOPMENT

Pit located in long ridge about 15-18 m high, running parallel to estate road. Extension of pit/quarry along ridge will provide a large resourse. Will become hard to rip and blocky at depths of greater than 8-10 m.

① Extension existing pit area
20 m wide x 6 m high x 80 m long ≏ 10,000 m³

② Extension along ridge
50 m wide x 10 m av. height x 80 m long ≏ 40,000 m³

| OVERBURDEN DEPTH (m) | RESOURCE VOLUME ESTIMATES (m3) | | |
|---|---|---|---|
| | TOTAL VOLUME | VOLUME EXCLUDING >150mm FRACTION | VOLUME EXCLUDING >75mm FRACTION |
| 2.0 to 3.0 m | 50,000 m³ | 42,000 m³ | 36,000 m³ |

MATERIAL EXTRACTION

MEANS OF ACCESS/ACCESS PROBLEMS
Good access road through Minjigina Estate.

PROPOSED METHOD OF EXTRACTION
Rip with light blasting if necessary at depth.

GEOTECHNICAL CONSEQUENCES OF EXTRACTION
None likely.

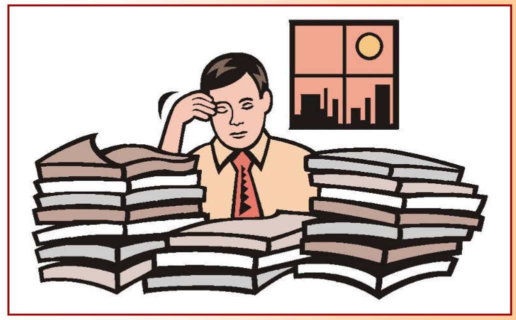
PREVIOUS USAGE

| ROAD NAME | ROAD No. | PAVEMENT APPLICATION | START CHAINAGE | START CHAINAGE | DATE COMPLETED | PERFORMANCE ASSESSMENT |
|---|---|---|---|---|---|---|
| Minjigina Estate Roads | — | Pit-run Wearing Course | Plantation Tracks only | | — | moderate (pit-run) |
| | | | | | | |

**Figure 10.2 Example of a Completed National Gravel Pit Inventory Field Proforma (Sheet 2 of 2)**

### e) Identification of Database Report Requirements

It has already be indicated that a Relational Database Management System (RDBMS) software package such as “Access” or “Oracle” can provide great flexibility in terms of data analysis and presentation. However the program will only carry out functions that it has been “programmed” to perform.



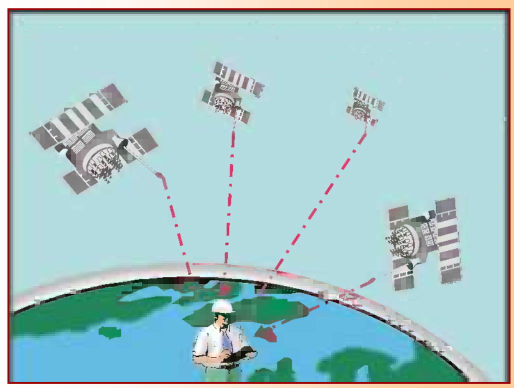
Careful consideration must be given during materials resource database design to the identification of all database report options that may be required.

It is therefore essential that the Materials Resource Database is set up to satisfy the requirements of all potential users. The functions of the database can be upgraded after the database is created, but every effort should be made during database design to evaluate all possible report requirements and build these into the system from the start.

A Materials Resource Database will almost certainly have links with other databases created for road maintenance management and presentation of road related data. The materials database must be compatible with such systems. A simple example would relate to road reference chainages, it is obviously necessary that all systems use the same road inventory chainages.

Database systems that may link with a Materials Resource Inventory database may include:

- Maintenance Management System (MMS). Such a system will include road and bridge inventories and will benefit from reports that provide information on materials usage (supply), material quality and cost.
- Pavement Management System (PMS). This system will require similar data on materials used for paved road construction.
- Geographical Information System (GIS). This system may require GPS co-ordinates of borrow pits in order to generate road asset maps.



A database report summarising borrow pit GPS co-ordinates may be required by a GIS (Geographical Information System) program that will be used to produce maps of road assets.

Typical reports that would assist materials management and planning may include:

- Summary of the availability and characteristics of Gravel Wearing Course Sources along a specified length of road (refer Table 10.2).
- Summary of availability and suitability of paved road construction materials along a specified length of road (refer Table 10.3).
- Summary of test results for sealing chip sources along a length of road etc.

**PNG Department of Works**
**National Gravel Pit Inventory- Summary of Gravel Wearing Course Materials**

Date: **Nov 1992** Road Name: **Ramu H'way** Road No:**NR08** Road Section: **Km 0.0 - 130** Province: **Madang & Morobe**

| Pit Name | Pit Database Reference | Chainage | Off-set | Resource Estimate | Material Type | "As Dug" Wearing Course Rating | Recommended Processing | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | BL | SC | CR | CO |
| Warias Pit | NRO8027.50G | 27.5 | 0.0 | Extensive | Riverbed Gr. | 3 | | x | | x |
| Ramu/ Pompuquato | NRO8030.40G | 30.4 | 7.7 | Moderate | Riverbed Gr. | 2-3 | x | x | | x |
| Surinam Pit | NRO8038.30G | 38.3 | 0.2 | Extensive | River Terr Gr. | 2-3 | x | x | | x |
| Dumpu Pit | NRO8056.00G | 56.0 | 0.6 | Large | Coral Gravel | 1-2 | | | | |
| Bokia Pit | NRO8o64.70G | 64.7 | 0.0 | Moderate | Riverbed & Terr Gravel | 3 | x | x | | x |
| Tateng Nabia Pit | NRO8071.70G | 71.7 | 0.0 | V. Limited | Agglomerate | 2 | | | | |
| Omea Pit | NRO8077.30G | 77.3 | 0.0 | Limited | Riverbed & Terr Gravel | 3-4 | x | x | | x |
| Boku Pit | NRO8085.50G | 85.5 | 0.0 | Large | Riverbed & Terr Gravel | 3 | x | x | | x |
| Pitpit Pit | NRO8089.00G | 89.0 | 1.6 | N.S | N.S | N.S | * | * | * | * |
| Yakumu Pit | NRO8089.20 | 89.2 | 0.0 | Moderate | Riverbed Gr. | 3 | x | x | | x |
| Walium Pit | NRO8091.10G | 91.1 | 1.2 | Moderate | Limestone | 2 | | x | | |
| Erae Pit | NRO8095.40G | 95.4 | 0.0 | Extensive | River Terr Gr. | 3 | x | x | | x |
| Mea Pit | NRO8100.10G | 100.1 | 0.0 | Extensive | River Terr Gr. | 3 | x | x | | x |
| Usino Junction Pit | NRO8104.00G | 104.0 | 0.0 | Limited | Conglomerate | 5 | x | | | |
| Kove Ridge Pit | NRO8104.50G | 104.5 | 0.0 | Moderate | Conglomerate | 4-5 | x | | | |
| Simaburu Pit | NRO8107.50G | 107.5 | 0.0 | Limited | Siltstone | 4-5 | x | x | | |
| Metabolo Pit | NRO8108.90G | 108.9 | 0.0 | Limited | Greywacke | 3-4 | x | x | | x |
| Igure Pit | NRO8112.90G | 112.9 | 0.1 | Limited | Riverbed & Terr Gravel | 3 | x | x | | x |
| Tapopo Pit | NRO8115.70G | 115.7 | 0.0 | Moderate | Basalt | 3-4 | x | x | | x |
| Ono Pit | NRO8123.10G | 123.1 | 0.0 | Exhausted | Basalt Colluv. | 5 | x | x | x | x |
| Negri West Pit | NRO8125.70G | 125.7 | 0.0 | Exhausted | Basalt & Dolerite. | 5 | x | x | x | x |
| Negri Quarry Pit | NR08126.20G | 126.2 | 0.0 | Moderate | Basalt & Serp. | 4 | x | x | | |
| Nedgri East Quarry | NR08127.00G | 127.0 | 0.0 | Limited | Dolerite | 4 | | x | | x |
| Nuru Basalt Quarry | NR08128.60G | 128.6 | 0.0 | Moderate | Basalt & Doler | 5 | | x | x | |
| Nuru Mudstone Pit | NR08129.20G | 129.2 | 0.0 | Moderate | Mudstone | 5 | | | | |
| Nuru River Pit | NR08130.00G | 130.0 | 0.0 | Extensive | Riverbed Gr. | 3 | x | | | |

| KEY: | |
|---|---|
| Resource Volume Definitions | Very Limited < 5,000cu m; Limited 5,000 – 15,000 cu m; Moderate 15,000 – 35,000 cu m; Large 35,000 – 75,000 cu m; Extensive > 75,000 cu m; N.S - Not Studied |
| "As Dug" Gravel Wearing Course Suitability Rating | 1 – Very Good; 2 – Good; 3 - Moderate; 4 - Poor; 5 - Very Poor/ Unsuitable |
| Processing Recommendations | BL – Blending; SC – Screening; CR – Crushing; CO – Special Compaction (ie Grid Roller) |

**Table 10-2 Example of a Database Report - Summary of Gravel Wearing Course Material Resources**

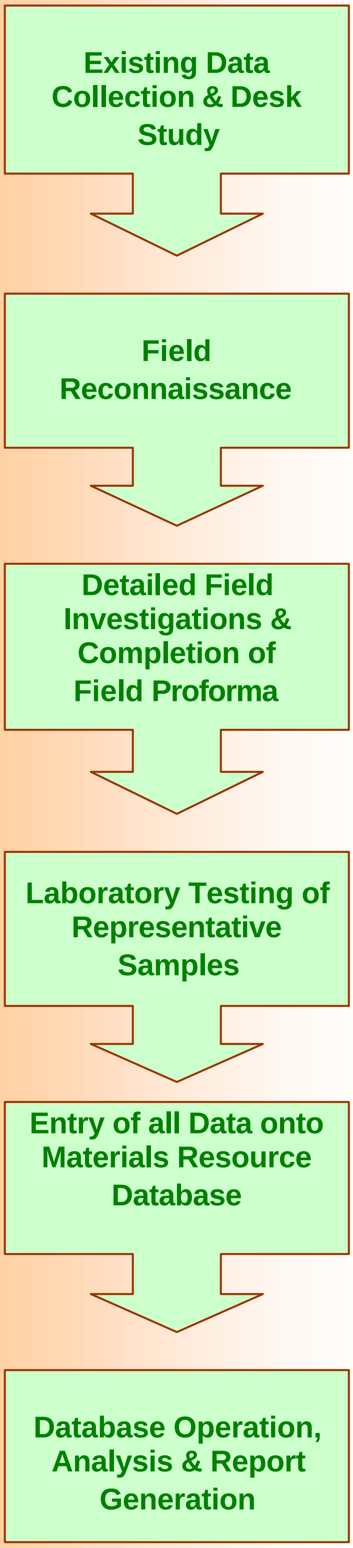
**PNG Department of Works**
**National Gravel Pit Inventory- Summary of Road Construction Resources**

Date: **Nov 1992** Road Name: **Ramu H'way** Road No: **NR08** Road Section: **Km 0.0 - 130** Province: **Madang & Morobe**

| Pit Name | Pit Database Reference | Chain. (Km) | Off-set | Resource Estimate | Material Type | Road Construction Applications | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | BC | SB | SC | GS | RR | CA | FA |
| Warias Pit | NRO8027.50G | 27.5 | 0.0 | Extensive | Riverbed Gr. | 3 | 2 | 3 | 4 | 4 | 3 | 3 |
| Ramu/ Pompuquato | NRO8030.40G | 30.4 | 7.7 | Moderate | Riverbed Gr. | 1 | 1 | 2 | 3 | 4 | 2 | 2 |
| Surinam Pit | NRO8038.30G | 38.3 | 0.2 | Extensive | River Terr Gr. | 2 | 1 | 3 | 2 | 4 | 3 | 3 |
| Dumpu Pit | NRO8056.00G | 56.0 | 0.6 | Large | Coral Gravel | 2 | 1 | 3 | 3 | 4 | 4 | 4 |
| Bokia Pit | NRO8o64.70G | 64.7 | 0.0 | Moderate | Riverbed & Terr Gravel | 2 | 1 | 2 | 2 | 4 | 2 | 2 |
| Tateng Nabia Pit | NRO8071.70G | 71.7 | 0.0 | V. Limited | Agglomerate | 2 | 2 | 3 | 3 | 3 | 3 | 4 |
| Omea Pit | NRO8077.30G | 77.3 | 0.0 | Limited | Riverbed & Terr Gravel | 1 | 2 | 2 | 1 | 4 | 2 | 2 |
| Boku Pit | NRO8085.50G | 85.5 | 0.0 | Large | Riverbed & Terr Gravel | 2 | 1 | 2 | 2 | 4 | 2 | 2 |
| Pitpit Pit | NRO8089.00G | 89.0 | 1.6 | N.S | N.S | * | * | * | * | * | * | * |
| Yakumu Pit | NRO8089.20 | 89.2 | 0.0 | Moderate | Riverbed Gr | 3 | 2 | 2 | 2 | 4 | 3 | 3 |
| Walium Pit | NRO8091.10G | 91.1 | 1.2 | Moderate | Limestone | 3 | 2 | 3 | 3 | 4 | 4 | 4 |
| Erae Pit | NRO8095.40G | 95.4 | 0.0 | Extensive | River Terr Gr | 2 | 1 | 3 | 2 | 4 | 3 | 3 |
| Mea Pit | NRO8100.10G | 100.1 | 0.0 | Extensive | River Terr Gr. | 2 | 1 | 2 | 2 | 4 | 2 | 2 |
| Usino Junction Pit | NRO8104.00G | 104.0 | 0.0 | Limited | Conglomerate | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Kove Ridge Pit | NRO8104.50G | 104.5 | 0.0 | Moderate | Conglomerate | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Simaburu Pit | NRO8107.50G | 107.5 | 0.0 | Limited | Siltstone | 4 | 3 | 4 | 4 | 4 | 4 | 4 |
| Metabolo Pit | NRO8108.90G | 108.9 | 0.0 | Limited | Greywacke | 2 | 2 | 3 | 2 | 3 | 3 | 4 |
| Igure Pit | NRO8112.90G | 112.9 | 0.1 | Limited | Riverbed & Terr Gravel | 2 | 1 | 2 | 2 | 4 | 2 | 2 |
| Tapopo Pit | NRO8115.70G | 115.7 | 0.0 | Moderate | Basalt | 2 | 2 | 3 | 2 | 3 | 2 | 4 |
| Ono Pit | NRO8123.10G | 123.1 | 0.0 | Exhausted | Basalt Colluv. | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Negri West Pit | NRO8125.70G | 125.7 | 0.0 | Exhausted | Basalt & Dolerite. | 3 | 2 | 4 | 3 | 2 | 4 | 4 |
| Negri Quarry Pit | NR08126.20G | 126.2 | 0.0 | Moderate | Basalt & Serp. | 3 | 2 | 3 | 2 | 1 | 3 | 4 |
| Nedgri East Quarry | NR08127.00G | 127.0 | 0.0 | Limited | Dolerite | 3 | 2 | 3 | 2 | 3 | 3 | 4 |
| Nuru Basalt Quarry | NR08128.60G | 128.6 | 0.0 | Moderate | Basalt & Doler | 2 | 2 | 2 | 2 | 2 | 2 | 4 |
| Nuru Mudstone Pit | NR08129.20G | 129.2 | 0.0 | Modertae | Mudstone | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nuru River Pit | NR08130.00G | 130.0 | 0.0 | Extensive | Riverbed Grav. | 2 | 2 | 2 | 3 | 4 | 2 | 2 |

| KEY | |
|---|---|
| Resource Volume Definitions | Very Limited < 5,000cu m; Limited 5,000 – 15,000 cu m; Moderate 15,000 – 35,000 cu m; Large 35,000 – 75,000 cu m; Extensive > 75,000 cu m; N.S - Not Studied |
| Construction Applications | BC – Base Course; SB – Subbase; SC – Sealing Chip; GS – Gabion Stone: RR – Rip Rap; CA - Coarse Concrete Aggregate; FA – Fine Concrete Aggregate |
| Construction Application Suitability Rating | 1 – Proven to be suitable; 2 – Likely to be suitable; 3 – Unlikely to be suitable; 4 - Unsuitable |

**Table 10-3 Example of Database Report – Summary of Paved Road Construction Material Resources**




## 10.3. Setting Up a Materials Resource Inventory

Recommendations and guidelines relating to data collection and the establishment of a road materials resource inventory are presented in this Sub Section. It has already been indicated that a field survey to collect "up to date" borrow pit information and verify existing records should, when possible, accompany the establishment of a Materials Resource Database.

The following guidelines particularly apply to the implementation of a regional material resources study leading to creation of an RDBMS based Materials Resource Database/Borrow Pit Inventory.

It is appreciated that in many cases, current work force and funding resources will not be immediately available to implement this level of investigation and data processing. However, Road Authorities are encouraged to start assembling and filing borrow pit data in the recommended form (road by road) so that this information may be used in the future as the basis for creating a computerised materials resource inventory. This could start life as a simple spreadsheet based inventory.

### Outline of Study Methodology

The stages of a materials resource study, whether for a road or a section of road network should normally comprise the Sequence shown on the left.

**a) Desk Study and Field Reconnaissance**

Desk study data collection and initial field investigations should be carried out essentially as described in Section 1.2 (Materials Searches). The aim of this work is to determine the location and resource potential of existing material sources and to verify the information obtained during the desk study.

The reconnaissance field visit along the study roads should be made with the Roads Works Supervisors responsible for maintenance of each section under study. The road supervisor's opinions on pit material quality, performance and usage should be noted at this time.

The reconnaissance visit will enable simple "line haulage diagrams" to be prepared (refer Section 9.4) that show estimated resource volumes and existing minimum haulage distances between pits. Resource deficiencies can then be identified.

**b) Detailed Pit/Quarry Investigation**

During the main field investigations along the study roads all existing pit and quarries should be revisited to carry out a full technical appraisal including a reassessment of potential resource size. The estimate of resource size should be influenced by expected demand. For example, there is little to be gained by using up time and resources to prove the existence of 80,000 $m^3$ of gravel wearing course material in a borrow area if it is only likely to be required to supply 25,000 $m^3$ over the next 20 years.

Materials searches should be undertaken in all areas identified as having resource deficiencies. Depending on the local circumstances, maximum haulage distances for gravel road surfacing material of greater than 7 to10 km (ie pits 14 to 20 km apart) may represent a significant resource deficiency that would justifies material searches to locate a new borrow source.

Searches for new borrow sites should be carried out where material deficiencies are identified.

**c) Field Proforma and Resource Evaluation**

Borrow pit inventory studies will inevitably require a great many material sources to be assessed in a relatively short period of time, it is therefore essential that field evaluations are concise but comprehensive. To satisfy these constraints a “clip board” approach is required. It is necessary to use a “Field Proforma” on which pit reference details, materials information and engineering geological data can be quickly recorded in such a way that standardised information recorded for each pit/ quarry can be readily input onto the computer database.

Figure 10.2 presents an example of a “Field Proforma” designed for use during pit inventory studies (Bishop & Morey, 1992). The entry of pit reference details, development proposals and some engineering geological data is self explanatory. In the following pages some guidance is given with respect to the collection of materials and geological data.

**Materials Description**

This is an engineering geological description of the “as dug” material written using the general guidelines and terminology for the description of the “material characteristics of soils” as outlined in BS 5930 (Code of Practice for Site Investigations) or contained a similar standard for engineering material description. The field materials description should be checked and if necessary corrected or improved, based on the findings of laboratory classification testing, before it is entered on the database.

The descriptions contained in the example Field Proforma (Figure 10.2) have been written directly on the proforma by an experienced materials engineer/geologist. It will be easier for a less well experienced technicians and engineers to use a separate tick box form to create a detailed description as shown on Figure 10.3. If used for data entry on the database such a form can be used to generate a standard technical description.

It is better to have a simple description and a less detailed pit inventory rather than no inventory, so do not be put off starting an inventory because it seems difficult and some incorrect field geological and materials descriptions may be used. A well designed database will make the updating and improving of inventory information an easy task.

**Geological Description**

The *in-situ* material characteristics should ideally be written using the guidelines in BS 5930 (or similar standard) for the description of the “material and mass characteristics of soils and rocks”. The geological description pays particular attention to the occurrence of natural fractures, the effects of weathering and the relative strength of the materials. These features will have a major role in determining excavation characteristics, construction material suitability and likely processing requirements.

## FIELD DESCRIPTION OF MATERIALS IN BORROW PITS

| Pit Name: | Road | | Sample Details: | | |
|---|---|---|---|---|---|
| **MINJIJINA PIT** | Baiyer Road, NM3901 | | Sample No: | Depth: | Trial Pit No & Sample Type |
| Pit Reference | Chainage | 16.5 | GPS/92/39/17 | 1.2 | TP 1, PIT RUN BULK |
| NM3901016.50G | Offset | 2.1 | | | |
| Logged By: | Date: | | | | |
| E.Sikam | 30-Jan-99 | | | | |

### *MATERIALS DESCRIPTION.*

| Layer No. | Layer No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| | Depth (m) | 1.5 - 4.0 | | | |

| *Colour:* | |
|---|---|
| Light | ✓ |
| Dark | |
| Mottled | |
| Speckled | |
| | |
| Red | |
| Pink | |
| Yellow | |
| Brown | |
| Olive | |
| Green | |
| Blue | |
| White | |
| Off-white | |
| Grey | ✓ |
| Black | |
| Purple | |
| Orange | |
| Silver | |
| Gold | |
| Bronze | |
| Beige | |
| Cream | |

| *Particle Shape:* | |
|---|---|
| Angular | ✓ |
| Sub-angular | |
| Sub-rounded | |
| Rounded | |
| Flat | |
| Elongate | |

| Secondary composition: | |
|---|---|
| Slightly | ✓✓ |
| very | |
| | |
| Clayey | |
| Silty | ✓✓ |
| sandy | ✓ |
| Gravelly | |
| Cobblely | ✓ |
| Bouldery | |
| | |
| Coarse | |
| Medium | |
| Fine | |

| *Main Soil Type/ Composition:* | |
|---|---|
| BOULDERS | |
| COBBLES | |
| GRAVEL | |
| Coarse | ✓ |
| Medium | ✓ |
| Fine | |
| SAND | |
| Coarse | |
| Medium | |
| Fine | |
| SILT | |
| Coarse | |
| Medium | |
| Fine | |
| CLAY | |
| PEAT | |
| TOPSOIL | |

| Particle Strength: | |
|---|---|
| More than one blow of hammer needed to break particles (Very Strong) | |
| Particles can be broken with a single hammer blow (Strong) | ✓ |
| 5 mm indentation with sharp end of geological pick (Moderately Strong) | |
| Too hard to cut by hand into a lab sample (Moderately Weak) | |
| Particles crumbles under firm blows with the sharp end of a geological pick (weak) | |

*% Oversize:*

| | | |
|---|---|---|
| *>150mm* | <2% | |
| | 2-5% | |
| | 5-10% | |
| | 10-20% | ✓ |
| | 20-35% | |
| | >35% | |
| *>75mm* | <2% | |
| | 2-5% | |
| | 5-10% | |
| | 10-20% | |
| | 20 - 35% | ✓ |
| | >35% | |

| *Grading:* | |
|---|---|
| Poorly Graded | |
| Uniformly Graded | |
| Gap Graded | |
| Moderately Graded | ✓ |
| Well Graded | |

**Generated Materials Description:**

**Light grey, moderately graded, angular, slightly silty, sandy, cobbly, medium and coarse, strong, GRAVEL.**

**Figure 10-3 Example of a Field Materials Description Proforma**

**Percentage Oversize**

A field estimate of the percentage of oversize particles present or likely to be present in the "as dug" material should be made on site, because it is effectively impossible to obtain a representative proportion of cobbles or boulders in a standard bulk sample bag.

**Estimate of Percentage of Weak Particles**

The presence of a high proportion of unsound or weak particles in a pit material will typically have an adverse effect upon the suitability of the material for use as gravel wearing course or for use in other pavement applications. In the field the percentage of unsound stone should be estimated by testing a large number of exposed particles (of various shapes and sizes) with a geological hammer. In a river gravel deposit it will sometimes possible to identify a particular rock type which is frequently present in a weak or weathered condition.

**Gravel Wearing Course Suitability**

Each deposit that might be used for gravel road surfacing should be assessed with respect to its "as dug" suitability rating (refer Section 4.1 and Table 4.3).

**Gravel Wearing Course Processing Recommendations**

The Field Proforma requires recommendations to be given concerning the type and nature of processing operations which it may be considered would be required to improve the suitability rating and performance of the material when used as wearing course aggregate. Options considered are shown on Table 10.3.

| | |
|---|---|
| **Blending** | Record the type of material (size fraction) which should be added to the "as dug" materials |
| **Screen Out** | Note the size fraction to be removed by grizzly and/or screening operations |
| **Crush** | Estimate the proportion of material that is considered to require crushing before usage to make the deposit viable as a source of wearing course. |
| **Compaction** | Record any special compaction recommendations (ie grid roller). Where no special compaction is recommended then 'normal' compaction may be assumed. |

**Table 10-4 Options for Gravel Wearing Course Processing**

### Other Road Construction (Geomaterials) Applications

Assess each deposit with respect to its expected suitability for other road construction applications (refer Table 4.9). This is an assessment of whether the deposit can be processed to meet the specifications currently applied to the materials.

### Pit Sketches

A schematic pit sketch should be produced at each existing and potential borrow site and should provides a diagrammatic representation of the pit and its surrounds. Figure 10.3 presents an example of standard symbols that may be when making field sketches. The main purpose of this sketch is to enable positive field identification of the site by others and to indicate clearly the location of any proposed future development. The pit sketch should also typically include:

- Lateral and vertical dimensions of any existing workings, with face heights reported relative to the base of the working.
- Major geological and topographical features such as: exposures, drainage features; slopes, ridges etc.
- Important man-made features such as: access roads; bridges; settlements; stockpiles etc.
- Locations of any site investigations such as: auger boreholes; trial pits etc.
- Orientation of the sketch with respect to north.

Pit sketches can be scanned and stored under their unique pit reference in the database.

The other sections of the example Field Proformas (Figure 10.2) need no further explanation and deal with: ownership details; pertinent comments (additional information considered important which is not recorded elsewhere on the proforma); proposed pit development; resource estimate; materials extraction; and previous usage.

Field sketches can form an invaluable record of the site and its potential for future development.

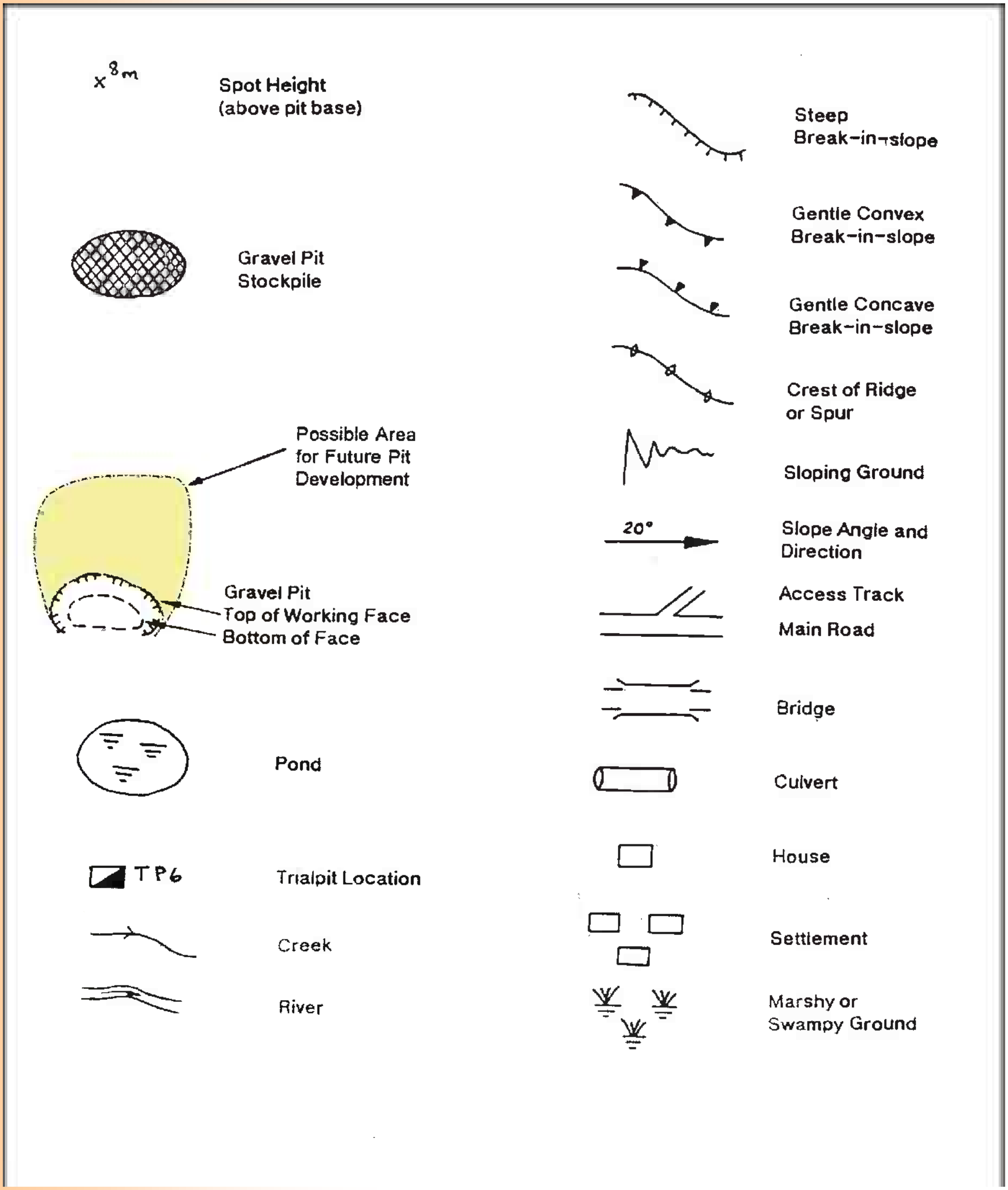



**Figure 10-4 Example of Standard Symbols for Use on Borrow Pit Sketches**

**d) Laboratory Testing for Pit Inventory Studies**

When possible pit inventory studies should include representative sampling to enable laboratory assessment of material suitability for use in road construction.

Inventory studies may create unusually large workloads for the testing laboratories unless sampling and testing is limited. Ideally, representative materials from every existing and potential source should be tested to determine Atterberg limits, particle size distribution and particle strength characteristics.

Generally it is sufficient to carry out one kind of particle strength test either Los Angeles Abrasion Value testing, Aggregate Crushing Value or 10% Fines Value testing. Results of each of these tests generally show good correlation with each other (Minty *et al*, 1980 and Toole, 1985).

**e) Materials Data Evaluation and Input to the Database**

The material suitability ratings allocated on the Field Proforma should be reviewed when the laboratory testing is completed. Also, the field descriptions should be reassessed following availability of test results and should be modified as necessary so that they conform with classifications contained in BS 5930 or a similar materials description standard.

All information is then assembled on Data Entry Proformas (refer Figure 10.4) and input onto the database.

**NATIONAL BORROW PIT INVENTORY**

**DATA ENTRY PROFORMA**

| PIT LOCATION AND REFERENCE DETAILS | | | | | | |
|---|---|---|---|---|---|---|
| ROAD IDENTIFICATION No: | | | ROAD NAME: | | | |
| | | | | | | |
| CHAINAGE (KM): | | PROVINCE No: | | PROVINCE NAME: | | |
| | | | | | | |
| PIT LOCAL NAME: | | | | PIT ALIAS NAME: | | |
| | | | | | | |
| OFFSET (KM): | DIRECTION | PIT STATUS: | DATE INVESTIGATED: | TOPOGRAPHIC SHEET: | | |
| | | | | Name | | |
| | | | | Number: | | |
| LOCATION DESCRIPTION: | | | | | | |
| | | | | | | |
| NATIONAL GRID REFERENCE | | GLOBAL POSITIONING SYSTEM REF: | | | SKETCH MAP REFERENCE: | |
| Easting: | | Latitude: | | | | |
| Northing: | | Longitude: | | | | |

| MATERIAL AND GEOLOGICAL DETAILS | | | | | |
|---|---|---|---|---|---|
| MATERIAL TYPE: | | | MATERIAL CODE: | | |
| | | | | | |
| MATERIAL DESCRIPTION: | | | | | |
| | | | | | |
| ESTIMATE OF OVERSIZE PARTICLES | | | | ESTIMATE OF WEAK,WEATHERED OR FRIABLE PARTICLES %: | |
| > 150mm: | | >75mm: | | | |
| GEOLOGICAL SHEET | | GEOLOGICAL FORMATION NAME: | | STRATIGRAPHIC UNIT CODE: | |
| Name: | | | | | |
| Number: | | | | | |
| GEOLOGICAL DESCRIPTION: | | | | | |
| | | | | | |

| MATERIAL SUITABILITY | | |
|---|---|---|
| "AS DUG" GRAVEL WEARING COURSE SUITABILITY RATING: | GRAVEL WEARING COURSE PROCESSING REQUIREMWNTS | |
| | BLEND WITH: | SCREEN OUT: |
| | | |
| | CRUSH: | COMPACTION: |
| | | |

| OTHER GEOMATERIAL APPLICATIONS | | | | | | |
|---|---|---|---|---|---|---|
| SUBBASE | BASE COURSE | SEALING CHIP | GABION STONE | RIP RAP | COARSE CONCRETE AGGREGATE | FINE CONCRETE AGGREGATE |
| | | | | | | |

| PIT NAME: | | SHEET 1 OF 4 |
|---|---|---|

**Figure 10-5  Example Data Entry Proforma (Sheet 1 of 4)**

**NATIONAL BORROW PIT INVENTORY**
**DATA ENTRY PROFORMA**

| **LAND STATUS** | |
|---|---|
| LAND ACQUISITION UNIT REFERENCE: | LAND STATUS AND USE: |
| | |
| OWNERSHIP DETAILS: | |
| | |

| **PIT DEVELOPMENT DETAILS** |
|---|
| EXISTING PIT DETAILS (IF APPLICABLE): |
| |
| PROPOSED PIT DEVELOPMENT: |
| |

| OVERBURDEN DEPTH (m) | RESOURCE VOLUME ESTIMATES (m3) | | |
|---|---|---|---|
| | Total Volume | Volume Excluding >150 mm fraction: | Volume Excluding >50 mm fraction: |
| | | | |

| **MARERIAL EXTRACTION** |
|---|
| MEANS OF ACCESS / ACCESS PROBLEMS: |
| |
| PROPOSED METHOD OF EXTRACTION: |
| |
| GEOTECHNICAL/ENVIRONMENTAL CONSEQUENCES OF EXTRACTION: |
| |

| **PREVIOUS USAGE** | | | | | | |
|---|---|---|---|---|---|---|
| ROAD NAME: | ROAD No: | PAVEMENT APPLICATION: | START CHAINAGE: | END CHAINAGE: | DATE COMPLETED: | PERFORMANCE ASSESSMENT: |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| **PERTINENT COMMENTS** |
|---|
| FOR SUMMARY PROFORMA REPORT: |
| |
| FOR ADDENDUM PROFORMA REPORT: |
| |

| PIT NAME: | | SHEET 2 OF 4 |
|---|---|---|

**Figure 10.4 Example Data Entry Proforma (Sheet 2 of 4)**

## NATIONAL BORROW PIT INVENTORY - DATA ENTRY PROFORMA

### MATERIAL PROPERTIES

| SAMPLE DETAILS | | | | ATTERBERG LIMITS | | | | LOS ANGELES ABRASION | | | | COMPACTION | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | TEST 1 | | TEST 2 | | STANDARD | | MODIFIED | | |
| SAMPLE REFFERRENCE | DATA SOURCE | DATE | SAMPLE TYPE | NATURAL W% | LL % | PL % | LS % | LA | TEST PSD | LA | TEST PSD | MDD Mg/ m3 | Optimum w% | MDD Mg/ m3 | Optimum w% | |
| 1 | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | |

| SAMPLE DETAILS | | | | CALIFORNIA BEARING RATIO | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UNSTABILISED CBR | | | | | STABILISED CBR | | | | | | | |
| SAMPLE REFFERRENCE | DATA SOURCE | DATE | SAMPLE TYPE | CBR % | DD | W % | DAYS SOAKED | % COMP | CBR % | DD | W % | % Comp | DAYS SOAKED | AGE DAYS | STABILISER TYPE | STAB % |
| 1 | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | |

| SAMPLE DETAILS | | | | PARTICLE SIZE DISTRIBUTION | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | % PASSING TEST SIEVE APERTURE (MM) | | | | | | | | | | | | | | | | | | | | | | | | | |
| SAMPLE REFFERRENCE | DATA SOURCE | DATE | SAMPLE TYPE | 150 | 125 | 100 | 75 | 63 | 53 | 37.5 | 26.5 | 19 | 13.2 | 9.5 | 6.7 | 5 | 4.75 | 4 | 2.36 | 1.7 | 1.18 | 0.85 | 0.6 | 0.425 | 0.3 | 0.212 | 0.15 | 0.1 | 0.75 |
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| SAMPLE DETAILS | | | | OTHER MATERIALTERST PROPERTIES | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE REFFERRENCE | DATA SOURCE | DATE | SAMPLE TYPE | PS | FI | AN | ALD | BD Mg/ m3 | WA | ACV % | 10% FACT | 10% W/D | AIV | AAV | PSV | Na Sound | Mg Sound | UCS | |
| 1 | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | |

| SAMPLE DETAILS | | | | OTHER MATERIALTERST PROPERTIES |
|---|---|---|---|---|
| SAMPLE REFFERRENCE | DATA SOURCE | DATE | SAMPLE TYPE | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |

PIT NAME:

SHEET 3 OF 4

**Figure 10.4 Example Data Entry Proforma (Sheet 3 of 4)**

**NATIONAL BORROW PIT INVENTORY**
**DATA ENTRY PROFORMA**

| DATA SOURCES | | | |
|---|---|---|---|
| BORROW PIT INVENTORY REFERENCE | AUTHOR | DATE | TITLE |
| | | | |
| | | | |
| | | | |
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| | | | |
| PIT NAME: | | | SHEET 4 0F 4 |

**Figure 10.4 Example Data Entry Proforma (Sheet 4 of 4)**

## 10.4. Use of Materials Database to Improve Maintenance Cost Efficiency

Up to 60% of gravel road maintenance costs will typically relate to materials production and supply.

**Introduction**

Materials production and supply costs will often amount to more than 60% of total expenditure on unpaved road maintenance. Any savings that can be achieved through implementation of improved materials management are therefore likely to be significant.

A good regional knowledge of the availability and characteristics of potential borrow pits and quarries is essential to development of more cost effective use of road material resources. The creation of a Materials Resources Database will provide the tool required to:

- Identify of the best and most economical sources of material supply.
- Identify material resource deficiencies and highlight the need for effective materials searches in those areas.
- Identify appropriate (usually low cost) extraction and processing procedures, when required, to significantly improve the in-service performance of pavements.
- Identify improved economic haulage strategies for material supply.
- Identify situations when the introduction of special road and/or pavement designs would enable optimum use of available material resources

**Materials Location and Selection**

Existing materials search and borrow pit selection procedures frequently provide significant scope for improvement.

The "as dug" quality rating system proposed for potential gravel wearing course sources and the suitability rating system designed for other road construction applications provides the basis for summary database reports (refer Appendix D) that can greatly assist the initial identification of the most economic sources of road material supply.

Prior to use or reuse of a borrow pit, the database can supply all existing test results and pit records and enable assessment of the need and scope of new investigations. This "capture" of data ensures that potential problems are quickly identified and that field and laboratory investigations are not unnecessarily repeated.

Analysis functions in the database can be used to assist with the scientific selection of the best and most economic sources of material supply.

### Materials Processing Strategy

In the case of lightly trafficked rural roads, economic considerations dictate that readily available materials must be used with the minimum of processing. However, "as dug" road materials frequently contain a significant proportion of oversize particles and/or comprise too much or too little plastic fines.

There is an economic balance between the costs associated with material processing and costs that will be associated with utilising lower quality materials (ie increased maintenance costs and higher vehicle operating costs). The information contained in a materials resource database, when combined with traffic data and other cost considerations that may be stored in a Maintenance Management System (MMS) database, will enable economic material processing strategies to be analysed and defined.

As an example, various factors might influence what particle size is selected as being unacceptable oversize on a particular gravel road and how materials with an unacceptable oversize content might be most economically treated. These factors include:

- Road usage (traffic volume).
- Characteristics of available materials.
- Proportion of pit materials to be lost through screening.
- Proportion of oversize material that is likely to be broken down during normal compaction.
- Availability of processing plant (screening and crushing equipment) and/or special compaction plant (tamping foot and grid rollers).

Analysis of the regional situation with respect to material processing requirements, using information in the Materials Resource Database may provide economic justification for capital expenditure on items of plant such as grid rollers, mobile screens or mobile hammer mills ("rockbusters").

### Defining the Materials Supply Strategy

The development of materials supply strategies has been considered in detail in Section 9.4.

The planning of economic material supply strategies requires in depth knowledge of available material resources combined with an evaluation of costs associated with: material extraction; processing; haulage and in-service performance (maintenance costs).

Economic material supply strategies are best developed through analysis of information that should be stored on a Materials Resource Database and Maintenance Management System (MMS).

Analysis of information in a Materials Resource Database may provide economic justification for capital expenditure on processing plant, such as grid rollers or mobile hammer mills (photos courtesy of Broons Hire Pty Ltd)

**Road Design Improvements**

The information stored in a Materials Resource Database will assist the identification of situations when the introduction of special road designs would enable optimum use of available material resources. Design improvements may relate to:

- **Pavement Design**. For example: better use of available materials may be achieved through the use of strong coarsely graded selected subgrade (capping) layers and thin base course or wearing course layers.
- **Road Profile and Drainage**: For example: Increased pavement cross-fall may have advantages when gravel road surfacing materials are well bound. Improved side drainage may be beneficial if highly permeable base materials are used.
- **Gravel Road Versus Sealed Road Construction**. The Materials Database will aid identification of road sections that would benefit from bituminous surfacing because of high gravel wearing course supply or processing costs.

## 10.5. Institutional Establishment for Effective Materials Management

This Sub Section briefly reviews the institutional establishment or organisation that is required to implement effective material resources management for a low cost road network. The following are considered: staffing requirements; laboratory facilities; computer hardware and computer software requirements; and resources required to carry out a material inventory study

### Maintenance Field Staff, Materials Engineers and Technicians

Effective borrow pit management will ultimately rely on site supervision by experienced and conscientious pit/road supervisors.

The pit/road supervisor will be responsible for ensuring that only suitable deposits are extracted and that they are handled and processed in such a way that they produce satisfactory road construction aggregates. The site supervisor will need support from his engineering section and materials section in relation to:

- Suitable training and instruction (materials and engineering support).
- Assistance with the location and selection of borrow pits (materials support).
- Provision of laboratory testing facilities and quality evaluation reports (materials support).
- Provision of suitable plant to enable economic extraction and processing of materials (engineering support).
- Assistance with development of material supply strategies (engineering support).

In the case of large road networks, district or provincial engineering offices are typically required to implement road construction and maintenance work. Each office should ideally have its own soils testing laboratory and at least one experienced materials engineer and several experienced materials technicians to provide support services.

**Materials Laboratories**

Management of a low cost road network will usually require one or more district/provincial laboratories and a central materials laboratory. The minimum requirement of a district laboratory would typically be the capacity to carry out:

- Soil classification testing (Atterberg limit testing and particle size distribution analysis);
- CBR testing;
- At least one type of particle strength test.

A district laboratory will almost certainly require concrete testing facilities, therefore particle strength testing would usually involve Aggregate Crushing Value (ACV) determination or 10 % Fines testing.

Only the Central Materials Laboratory will need to be able to provide a full range of road material test procedures (ie chemical tests and soundness tests). The District Laboratories can forward samples to the Central Laboratory for the less routine quality control testing.

**Hardware and Software**

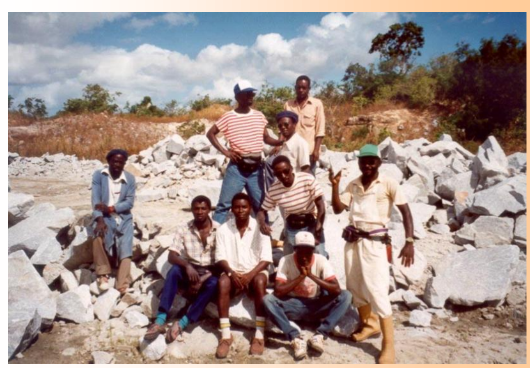
Ideally, both the Central Laboratory and District Laboratories should be equipped with computer hardware suitable for running an RDBMS (such as "access or "oracle") operated Materials Resource Database. Although it would be possible to have a single database computer located in the Central Laboratory and have new records forwarded from the districts/provinces for entry on the materials inventory.

Both Central and District Laboratories would ideally be equipped to input data onto the Materials Resource Database.

In the best circumstances there would be district database computers that would be networked with the central laboratory and with road maintenance engineering offices (this is the establishment in the Papua New Guinea Department of Works).

**Implementation of Materials Inventory Studies**

The carrying out of materials inventory studies, to establish a materials database, will typically require the temporary strengthening of a materials laboratory establishment. Otherwise the inventory investigations and testing may hinder the materials section's ability to keep up with its normal workload.



Temporary strengthening of the staff establishment will probably be required during materials inventory studies.

Borrow pit inventory studies will normally require special funding due to the need to employ additional materials engineers and technicians, to cover the cost of their field visits and to fund the laboratory testing. The establishment of additional or temporary laboratories would not be expected to be necessary.

# Section 11
# Review of Environmental & Social Considerations

# 11. REVIEW OF ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

Methods of limiting possible damaging effects to the environment must be determined during pit planning.

## 11.1. Introduction

The development of borrow pits and quarries to supply low cost road material requirements has the potential to create significant damaging effects (negative impacts) on the local environment and its inhabitants.

As a result of the general increased awareness of man's influence on the environment, the limitation of damaging environmental effects is becoming an increasingly important factor in the planning and development of all engineering work.

In relation to low cost road construction and maintenance, financial considerations must be a major factor in all engineering decisions. As a result, the costs associated with reducing environmental impact need to be in proportion to the funds available, the location of the development and the long term environmental consequences.

Fortunately, minimising the environmental impact of material resource developments can often be achieved by thoughtful planning or by adopting measures that do not have major cost consequences.

It is essential that methods of reducing possible negative impacts are fully evaluated, both during the planning of pit developments and throughout their operating life. This Section therefore presents a summary and review of key environmental and social issues associated with materials supply.

Severe soil erosion in a borrow pit that has exploited thin near surface gravel deposits and has been left open without any reinstatement.

## 11.2. Types of Material Source

There is a need to be aware of both the potential damaging (negative) impacts and positive aspects that may be associated with different types of borrow pit or quarry development. This is particularly relevant when there may be a choice of developing one or other type of resource.

This Section briefly considers the environmental impacts associated with the following main types of road building material source:

- River Bed Gravel Pits
- Beach Gravel Pits
- Near Surface Natural Gravel Pits (duricrusts, residual soil deposits, alluvial terrace deposits)
- Hill Slope Pits (weathered and/or closely fractured rocks)
- Hard Rock Quarries

## River Bed Gravel Pits

The development of river bed gravel sources is becoming a sensitive environmental issue in some countries. This is because uncontrolled extraction can have serious environmental impacts. Damaging effects are typically associated with over exploitation and careless extraction.

The intermittent extraction of small quantities of sand and gravel from a large dry river bed is probably the least damaging form of material supply. This is because no productive land is lost and the deposits will be replaced during future high water flows. Problems arise when the quantities of material extracted greatly exceed nature's ability to compensate for the loss. If there is any doubt about acceptable excavation volumes then expert advice should be obtained.

One serious consequence of over extraction close to bridges is loss of gravel around abutments and piers leading to scour damage. **Always extract gravels a minimum of 300 m downstream of bridges**.

If excavation is to be carried out in the river, then care must be taken to limit disturbance of the water quality by fine sediment or, for example, by fuel pollution. There will typically be people downstream who use the river water or perhaps obtain food from the river.

Sediment pollution can be controlled by constructing sediment traps / settling pools. Fuel and oil pollution can be prevented by servicing plant regularly and never refuelling or servicing in the river bed. When necessary temporary river crossings should be culverted.

Table 11.1 presents a summary of the positive and potential negative environmental impacts that may be associated with the winning of sand and gravel from river beds.

The effects of river bed extraction may need regular monitoring.

Simple sediment traps formed in a river downstream of the extraction point.

Rural communities often rely on undisturbed water downstream of a gravel pit.

| Positive Aspects | Possible Negative (Damaging) Environmental Impacts |
|---|---|
| • No loss of productive agricultural land or soil as a result of extraction from river bed.<br>• No noise, dust pollution or safety hazards resulting from drilling and blast operations.<br>• No safety hazards developed due to high working faces.<br>• Deposits will be self replenishing through replacement from upstream (provided extraction is not excessive).<br>• Permanent alteration to the visual appearance of the landscape negligible in the long term.<br>• Reinstatement essentially carried out by nature apart from minor reshaping by mechanical means. | • Uncontrolled extraction/excessive extraction may lead to changes in the position of the river channel and bank erosion, resulting in loss of productive agricultural land, damage to bridge abutments and increased sediment load in the river.<br>• Construction machinery working in the river channel should be avoided, but may be necessary during development and restoration works when there will be sediment and fuel pollution hazards. |

**Table 11-1 Environmental Impact of River Bed Extraction**

Extraction of gravel from a beach may result in loss of gravel further along the coast.

Extraction of thin near surface gravel involves disturbing a large area of land for a relatively small quantity of road material. Careful reinstatement should be carried out as an area of the pit is worked out.

## Beach Gravel Pits

Beach deposits within the tidal zone usually undergo rapid natural replacement (recharge). However, this may be associated with longshore drift (regional movement of deposits along a shoreline), in which case excessive extraction of these deposits may lead to serious depletion of beach materials at other locations along the shore.

As a rule, extraction from the tidal zone should be restricted to stockpiling of small quantities at intervals throughout the year with monitoring to ensure that this activity does not adversely affect other beachs. If larger scale extraction is required then expert advice should be sort, particularly if excessive extraction could have any adverse effects on local communities relying on tourism or other coastal activities.

Excavation of beach deposits from above the high water level may have a long term effect on the coastal environment, particularly if the pit becomes flooded and swampy. In which case it may become a health hazard for the local population (ie breeding ground for malarial mosquitos).

## Near Surface Natural Gravel Pits

In many developing countries low cost road construction relies heavily on winning construction materials from relatively thin and discontinuous near surface gravel deposits. These deposits include laterite, calcrete, silcrete, residual quartz gravels and alluvial gravels.

Easily extracted deposits close to existing unpaved roads are becoming exhausted along many road networks. This is now resulting in pressure to exploit marginal quality deposits in poor locations. The working of deposits less than 2m thick should be subject to an environmental impact review.

Working thin deposits involves a poor ratio between land take and resource size. This will become environmentally unacceptable in the following situations:

- Populated and cultivated areas, where pit development may result in permanent loss or down grading of productive land.
- Areas of natural beauty or habitats justifying a high level of conservation.
- Areas where topsoil is thin and cannot be salvaged to enable adequate pit reinstatement and prevention of soil erosion.

In such circumstances consideration must be given not only to initial economics of extraction, but also to long term economic and environmental consequences. Hauling material longer distances from pits with less adverse environmental impact will need to be considered

## Hill Slope Pits

The development of road material borrow pits in mountainous and hilly terrain can have significant damaging effects on the local environment, if they are not carefully located and operated in an environmentally sensitive way.

Most hillside pits exploit weathered and closely fractured rock materials. Topsoil is usually thin and stoney and as a result difficult to salvage and replace.

Excavation of natural gravel from steep slopes can cause serious slope stability hazards that may endanger the workforce, road users and people living downslope. Slope failures on valley sides can result in heavy sediment pollution of rivers. Carefully constructed benched excavations are often required.

On some hill roads there is a desire to open a large number of small pits (less than 3,000$m^3$) at regular intervals. This can be very destructive in the short and long term. It is better to identify a few well located borrow sites with relatively large potential resource sizes at wider intervals.

If pit development must be adjacent to the road, try to locate sites where extraction will improve the road bench stability or road alignment, for example: win material from a spur or blind spot in the road.

Short haulage should not be a factor that overrides environmental considerations in hilly terrain.

Great care should be taken when selecting hill slope pits for development.

Small hill slope pits can be extremely difficult to properly reinstate.

| Benefits | Possible Negative Damaging Environmental Impacts |
|---|---|
| • Well selected hill slope pits can typically provide large quantities of construction material over a long period<br>• Old pits may form environmentally acceptable locations for disposing of construction spoil and other waste materials (in terrain that provides few opportunities for safe disposal).<br>• Pit sites may create flat ground in areas where this is otherwise absent. Local communities may then be able to use this land for building or recreation facilities such as sports grounds. | • Site development may lead to loss of productive agricultural land<br>• Sites typically require topsoil and overburden stripping, which may lead to loss of some productive topsoil and generation of waste material for disposal<br>• Stripped areas may be subject to soil erosion prior to material extraction<br>• Material extraction may cause slope failures<br>• Side tipping of waste material down slope can also cause slope stabilise hazards<br>• Hill side pits are likely to be intrusive on natural landscapes<br>• Reinstatement of hill side pits to productive land is typically difficult and expensive and may require imported topsoil |

**Table 11-2 Environmental Impact of Hill Slope Pits**

Try to identify a few large sources rather than many small pits.

Layout of hard rock quarries and associated processing areas needs to be influenced by environmental considerations.

## Hard Rock Quarries

Environmental considerations are particularly important at the planning stage when construction materials need to be obtained from hard rock quarry sources. The following guidelines apply to quarry planning:

- Hard rock deposits rarely occur in isolation, therefore check the geology map and consider environmental effects when looking for the best site for development.
- **Quarry sites should be located as far away from settlements as possible**. Quarry operations will produce noise and dust that will impact on nearby inhabitants even if controls are imposed. Steep quarry faces are a hazard to people and livestock, therefore fencing and site security measures are essential.
- **The arrangement of the quarry working should be designed to cause least visual impact on the landscape and to allow for future reinstatement**. Natural vegetation (trees and bushes) should be preserved around the quarry site to screen the working.
- **Quarry site development costs are high and negative environmental impacts significant.** Therefore quarry sites should be selected that have the potential to supply very large quantities of material over a long period of time and sites should be relatively widely spaced apart. Haulage of aggregates, between hard rock quarries, for distances of greater than 20 km is usually economically and environmentally justified (when natural gravel deposits are not available).
- Crushing and screening plant and stockpile areas need not be located directly adjacent to the quarry working. **Visual intrusion may be significantly limited, at no great extra cost, by processing aggregates at a concealed location a short distance from the outcrop**.

| Benefits | Possible Negative Damaging Environmental Impacts |
|---|---|
| • Well selected quarries can supply high quality construction material over a long period<br>• Once developed quarries may form a local and national asset employing local people.<br>• It is usually possible to win large volumes of aggregate from a restricted area, since deposits should extend to considerable depths.<br>• Disused quarries may be used to dispose of large quantities of waste and spoil materials. However, contamination of groundwater must be prevented. | • Site development may lead to loss of productive agricultural land<br>• Sites typically require some overburden stripping, which may lead to loss of productive topsoil and generation of waste material for disposal<br>• Drilling and blasting causes noise pollution and is a hazard to local population<br>• Steep high quarry faces are a hazard to people and livestock<br>• Quarries are to a greater or lesser degree intrusive on natural landscapes<br>• Reinstatement of quarries (with steep high working faces) to productive land is typically difficult and expensive and may require imported topsoil |

**Table 11-3 Environmental Impact of Hard Rock Quarries**

# 11.3. Pit Planning

## Pit Location

Pits and quarries should be sited such that they cause the minimum of environmental damage and impact on local inhabitants. Typically the following guidelines apply:

- Pits should not be within 100m of a watercourse or of human habitation.
- If possible pits should be on land that is not used for cultivation and is not wooded.
- Areas of local historical or cultural interest should be avoided and pits should not be located within 25 m of grave sites.
- Wherever possible pits should be hidden from the road. Development should be designed to minimise visible scarring of the landscape.
- There should only be one agreed access to each site.
- Borrow areas should not be on steeply sloping ground if it can be avoided.

Pits should not be developed adjacent to the road when it can be avoided.

## Land Take

**Loss of land for borrow pit development may have serious consequences for the user/owner**. Land taken for material sources should always be minimised and fair compensation should be paid to the user. This applies equally to permanent and temporary land take. No land should ever be used without the correct authorisation.

It is important that compensation is paid promptly. This is fair and disputes with land owners can become very disruptive and expensive if access is denied to material sources when maintenance work is required.

Pit lay out and development should be planned not left to each plant operator.

## Pit Working Plan

Borrow pits should never be opened and operated in an uncontrolled manner. A working plan should be prepared before any excavation begins. Each plan should include:

- Arrangements for consultation with affected people.
- The extent of each pit/ quarry (or extension) should be clearly marked on the ground.
- A compensation agreement must be signed with the user/ owner and access arrangements must be agreed.
- An outline of the direction, timing and depth of working should be defined.
- Suitable locations for storing topsoil and overburden materials should be identified.
- Appropriate drainage and safety requirements should be determined.
- A reinstatement plan, giving details of final shape, method of achieving it, drainage and sediment control, resoiling and revegetation measures should be prepared.

Topsoil deposits must be carefully removed and stockpiled for replacing after material excavation.

Example of poor quarry practice. Benched rock quarrying makes excavation easier and safer and limits scarring of the landscape by allowing more effective reinstatement.

## 11.4. Pit Development

### Site Preparation

The first pit development activity is the clearing of vegetation and the stockpiling of topsoil. Topsoil is the organic soil typically occurring as a surface layer 150 to 200 mm thick**. It is essential that the topsoil is carefully removed and stockpiled for use during reinstatement of the excavation (refer Section 5.3)**.

The future productivity of the restored land is totally dependent on careful replacement of the topsoil layer. Failure to properly return topsoil materials will have a long term damaging affect on the environment and on the future ability of the land user/owner to earn a living from his land.

Any overburden soil (soil that rests on the gravel deposit and under the topsoil) should be stockpiled separately. Topsoil and overburden stockpiles should be located where they will not interfere with future pit extensions and should be shaped in order to best resist the erosive actions of rainfall.

### Pit Layout

Restoration of land used for borrow pits and quarries should be considered right from the start of excavation. The pit lay out should be designed to enable easy reinstatement. Unnecessarily high steep faces should be avoided both to avoid reinstatement problems and to reduce visual impact on the local landscape during pit operation.

Reduction in visibility of an excavation can often be achieved by identifying the best orientation of the working faces. However, despite the environmental desirability of a particular direction of working, the geological structure may determine the safest and most effective method of excavation and this will sometimes be the more important factor.

## Pit Operation

The actual extraction and processing of pit or quarry materials can have several adverse effects on the local environment. The most significant of these is the creation of noise, air borne dust and pollution of water courses.

**Noise** may be generated by the excavation process and is worst in the case of drilling and blasting for hard rock quarry operations. In this case, the timing of blasting should be discussed and agreed with any local inhabitants. It is important to limit noise as far as possible both for local residents and the workforce, who should be provided with ear protectors and dust filters.

Mobile processing equipment manufacturers will be able to supply information concerning the level of noise generated by their crushing and screening plants. This information should be taken into account during selection in some circumstances.

**Dust** generated in material sources can be a health hazard causing respiratory diseases, it can cause of accidents in the pit and can inhibit the growth of plants. Care should therefore be taken to minimise dust emissions. The main sources of dust and appropriate methods of reducing emissions are listed below;

- Drilling. Dust suppressers can be fitted to drilling rigs;
- Movement of traffic. Dusty haul roads should be watered regularly with bowsers (water trucks) during dry weather;
- Dumping of dry aggregates in stockpiles. Material processing plants should be fitted with water sprays where stockpiling occurs, this will not only suppress dust but also inhibit aggregate segregation.

**Water course pollution** may be associated with sediment entering streams from the pit excavation. This can be prevented by constructing bunds to divert surface water away from the excavation and by ensuring that any water leaving the excavation passes through a settlement pond. Any refuelling or other plant maintenance activities carried out in the borrow pit should be controlled to avoid spills and water contamination. Any accidental spills should be cleared up and disposed of safely.

Constant exposure to apparently acceptable levels of noise and dust may affect workman, therefore protective equipment must be provided and used.


Use of poor materials may increase the number of road accidents, vehicle maintenance costs, journey times and discomfort for road users

**Safety**

Access to pits and quarries with steep potentially dangerous working faces must be restricted to prevent accidents involving local people and livestock. This may require construction of sound fences with warning notices and the posting of guards.

For the safety of the work force, dangerous loose faces should be made stable. Workmen and plant operators should receive suitable training that covers safe working practices in borrow pits and quarries. Appropriate safety clothing should be provided and may include hard hats, protective boots, ear guards and face masks.

Special care must be taken with blasting and the siting of quarries, which should not be close to settlements. Only suitably trained and qualified staff should handle explosives. Their storage must comply with internationally recognised standards of practice in terms of security and safety.

## 11.5. Material Supply and the Environment

The localised increase in traffic associated with aggregate haulage from pit to construction site may create hazards to road users that require appropriate action to limit negative effects.

- Warning signs should be placed before the pit access and at the construction site. Speed restrictions may need to be applied.
- The haul road should be kept in good condition. Watered if dusty and any surface damage repaired.
- Spillage of aggregate from haulage trucks must be prevented.
- An efficient construction and haulage programme should be prepared to limit the period of disruption to road users.

## 11.6. Material Characteristics and the Environment

The quailty of the aggregates used in an unpaved road construction may produce significant social and environmental impacts that should not be underestimated and may provide considerable justification for appropriate material processing.

Poor quality materials may produce slippery roads, bumpy roads and dusty surfaces. Such conditions will cause an increased occurrence of road accidents.

Also, poor quality materials quickly develop into rough roads that lead to significantly higher vehicle maintenance costs, journey times and discomfort for road users.

## 11.7. Pit Reinstatement

A recent study made by the UK Transport Research Laboratory (TRL 1999) in several Southern African Countries noted that:

- Historically, restoration of borrow pits has been the exception rather than the rule.
- The environmental damage caused by improper extraction and rehabilitation practices can extend over a wide area and may only become apparent after project completion. Examples include soil erosion causing siltation of natural water courses.
- Environmental damage caused by pits is often most severe in areas important for subsistence farming.

Successful pit reinstatement is largely dependant on:

- **Pit preparation work having been carried out carefully**. Topsoil should have been stockpiled separately from overburden soils and shaped to avoid loss and erosion by wind and rainwater (refer Section 5.3)
- **Due account being made for reinstatement during pit or quarry development.** As previously stated when considering the pit layout, the method of pit reinstatement and final shape of the working should be taken into account before any excavation starts.

### Future Land Use at Pit and Quarry Sites

The wishes of land owners and local communities (in the case of customary land) should be considered when planning the reinstatement of a pit or quarry. In most cases their wish will be for the land to be returned to a condition similar to that before extraction. On land used for agriculture the aim will probably be to reinstate the land to its original level of productivity. However, sometimes a different use is required.

For example, the owner or local community may want the pit site to hold water in order to create a watering place for livestock. This may or may not conflict with the road authority's wish to use the site for spoil disposal, but a solution which suits all can usually be achieved without incurring major additional earthworks costs.

In hilly terrain where flat land is not widely available a pit site may be designed to become a building site or playing field.

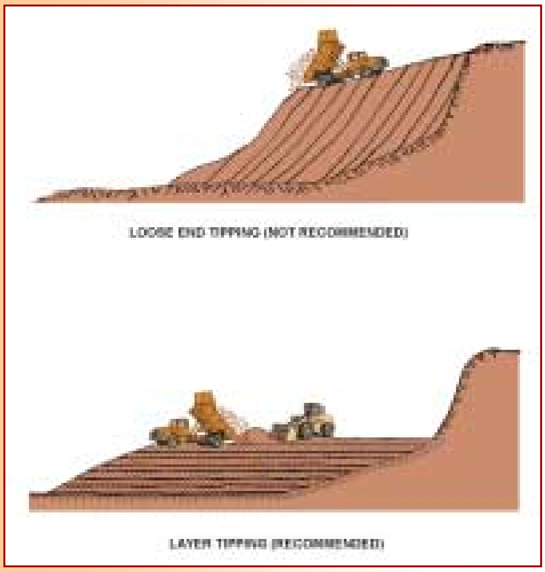
When considering the future use of a pit site the health and safety of the local inhabitants and livestock must be taken into account:

- No potentially dangerous slopes, pits, or toxic substances should remain at the site.
- Advise landusers that water holes may be a health risk (breeding ground for disease and disease carrying insects) and this factor may outweigh any positive benefits.

Do not forget the need to repair damage caused by excavation. In some cases associated costs will be significant.

Site of a shallow borrow pit after careful reinstatement (photo courtesy of TRL 1999).

Local residents and farmers may want water sources, but should be made aware of possible health and safety risks. This site should have been better landscaped.




Layer tipping is the preferred back-filling method

## Back-filling and Spoil Disposal

Ideally borrow pits should be reinstated as closely as possible to their original ground level. This avoids permanently changing the landscape and altering local drainage patterns.

Excavated gravel can be replaced with spoil materials derived from road construction or improvement works. Spoil materials may comprise cut materials not required for embankment construction or unsuitable subgrade materials provided that they do not contain large quantities of plant matter and are sufficiently dry to allow placement.

Layer tipping as opposed to loose end tipping is the preferred back-filling method. **Layer tipping produces stable fill that is resistant to erosion**.

Compaction of back fill material can typically be left to the action of the tyres or tracks of plant working in the pit (trucks, loaders and dozers). Over-compaction of the layer directly beneath the top-soil (sub-soil) should be avoided. It may be necessary to scarify this layer lightly before replacing the top-soil.

Backfill materials should not contain waste oils and toxic materials that might migrate and pollute ground water.

If no spoil material is available for back-filling then provision of drainage structures may be necessary to prevent the erosive action of surface water and/or ponding.

In the case of large borrow pits exploiting thin near surface gravels, areas that are worked out should be progressively back-filled, top-soiled and planted.

## Re-establishment of Top-soil and Vegetation

Replacing topsoil and planting of vegetation on shallow slopes (less than 20°) presents no difficulty, but needs to be carried out with care in an appropriate season of the year. Compaction of the top-soil should be avoided. Laying is best achieved with earth-scrapers, front-end loaders or back-actors and areas which have become compacted by tyres should be lightly ripped. Large stones should be removed manually and fertiliser added before planting commences.

Topsoil cannot normally be placed by machine on slopes greater than about 19 degrees (1V : 3H) and special measures may be required to fix topsoil on slopes that are formed at angles steeper than about 27 degrees (1V : 2H).

## Re-establishment of Top-soil and Vegetation on Steep Slopes

Material sources excavated in steep terrain, subject to active soil erosion processes are typically not well reinstated. This can result in significant degradation of the landscape and the environment . This section therefore considers, in some detail, appropriate methods for carrying out the reinstatement of borrow pits and quarries located in hill slopes.

In steep terrain it will often not be practical or economic to reinstate hillside pits and quarries to form slopes at angles of less than 19° (1:3), but it is important to prevent scarring of the landscape and soil erosion by the re-establishment of vegetation.

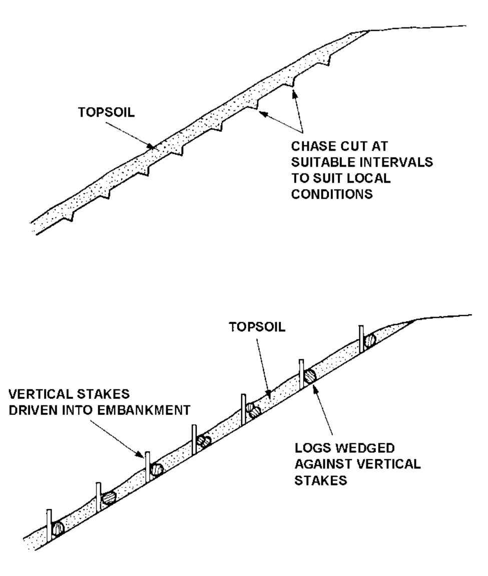
On slopes greater than 27° (1:2) top-soil should not be spread too thickly as loose material will easily erode or slip when wet. In general, maximum top-soil depth of 100 mm is appropriate for slopes exceeding 1:2. A moderately inclined smooth surface beneath the topsoil should be tilled to a depth of about 75mm or "chases" should be formed to provide keys for the top-soil. Chases may also act as water traps to encourage the establishment of vegetation. Alternatively, rows of stakes with log batters may be used (TRH 9 1989)

Steeply inclined hill slope pits may require special **bio-engineering techniques** coupled with slope **drainage and retaining structures** in order to stabilise soil movement and encourage plant growth.

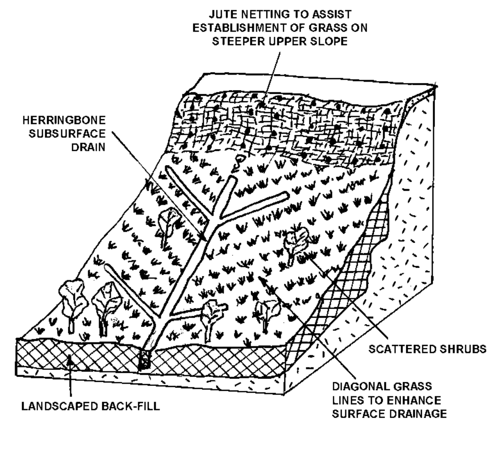
Bio-engineering is the use of living vegetation, either alone or in conjunction with civil engineering structures and non-living plant material, to reduce shallow seated instability and soil erosion on slopes. In the case of hill slope pits, **maximum use should typically be made of natural materials and bio-engineering methods so as to achieve greatest visual integration with the landscape**.

If quarry and pit waste, material has been side tipped down-slope then bio-engineering methods may also be required to stabilise and rehabilitate these slopes.

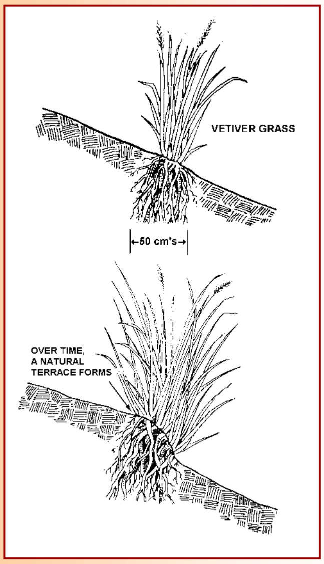
A summary of bio-engineering techniques that might be used for the rehabilitation of old pits with steep slopes is given in Table 11-4. Guidelines to assist with the selection of the most appropriate technique (for particular landform and climatic conditions) are given in Table 11.5.




Methods of retaining soil on moderately steep slopes (after TRH 9 1989)

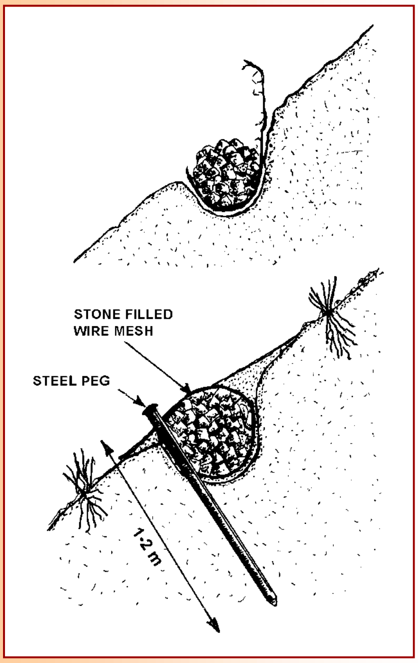



Material source reinstatement design involving landscaping, bio-engineering and slope drainage.




Vetiver grass may be a suitable plant to use where control of soil erosion is required.

Brush layering for improved slope stability and land scaping




Wire bolster construction

- **Grass Planting**

Grass is typically planted on steep slopes either by sprigging in young plants, by turfing or by hydroseeding. A mixture of suitable seed in a cellulose pulp is sprayed over the surface during hydroseeding. Local expert advice should be obtained in order to select a low growing grass that develops a strong spreading root system.

The planting of grass sprigs or slips in lines gives specific advantages in different situations. The lines will reinforce the soil, catch loose surface debris and may enhance drainage (see Table 11-4). The World Bank has sposored much research into the use of Vetiver grass to protect slopes from erosion. The attributes and widespread use of this plant is well documented (World Bank Technical Paper 273).

**Larger Plant Systems**

Shrubs and trees may be planted at intervals across the site. They grow to reinforce and anchor the slope as well as integrating the site with the surrounding landscape. The plants should therefore be grown from cuttings or the seeds of shrubs and trees that already colonise the area.

**Vegetation Structures**

A variety of live vegetation structures have been developed that assist in establishing plant growth on steep erodable slopes that may have very thin or stoney top-soil. These structures include palisades, brush layers, and fascines as described in Table 11-4 and shown in the sketches. These structures are planted in rows about 2m apart on slopes of 30 - 45° but may be 4m apart on slopes of less than 30°.

Live check dams might be used to reduce erosion along small drainage gullies in a borrow pit slope, but large gullies will require stronger measures such as a masonry structure.

The selection of appropriate cuttings to use in the construction of such vegetation structures may require expert advice or even trial and error. In this case, locally growing plants may not be suitable and so it may be necessary to obtain plant stocks from another source.

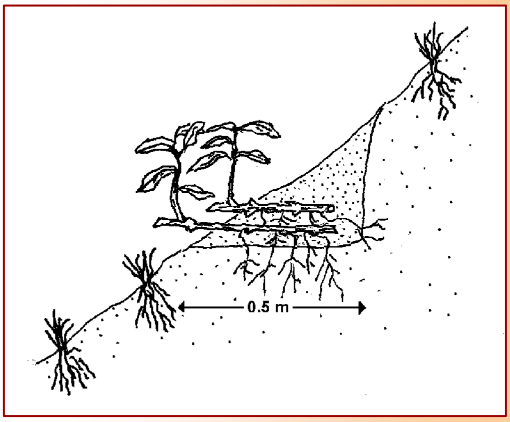
**Wire Bolster Cylinders**

Wire bolsters may be used to form a barrier to the development of soil erosion on steep slopes of 35° to 50° if the local environment does not allow use of live vegetation structures and in situations indicated in Table 11-5. The bolsters are typically constructed in the form of a 300 mm diameter tube of wire mesh held in place by a steel pin about 1 to 2 m long. If angled in a herringbone or chevron pattern they can serve a drainage function.

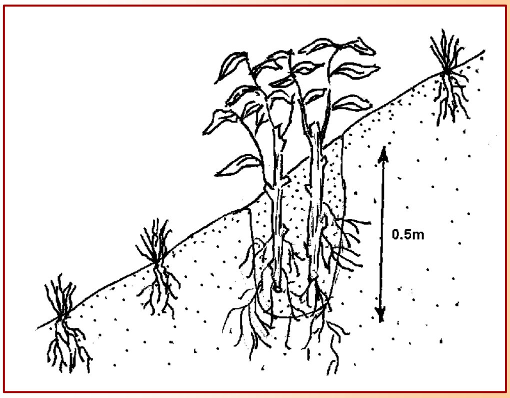
Wire bolsters are spaced at 2 to 4m intervals depending on the steepness of the slope. They are strong and long lasting but relatively expensive compared to bio-engineering measures.

| | |
|---|---|
| **Grass Planting Systems** | |
| Planted grass lines | Grass slips (or sprigs) are planted in lines on a slope. The lines can be either on the contour (horizontal), downslope (vertical) or diagonal: all three give specific advantages in different locations. Downslope and diagonal patterns enhance drainage. |
| Grass seeding | Grass seed is spread over a surface to give complete (but random rather than lined or structured) surface armouring. It is often covered in mulch or hydroseeded to aid establishment. |
| Turfing | A surface is covered with sods of turf brought from elsewhere. This gives complete and instant surface armouring. |
| **Larger Plant Systems** | |
| Shrub and tree planting | Seedlings of shrubs and trees are inserted into cracks on steep, rocky slopes. They can also be broadcast over a site. They grow to reinforce and anchor the slope. |
| Shrub and tree seeding | The seeds of shrubs and trees are inserted into cracks on steep, rocky slopes. They can also be broadcast over a site. They grow to reinforce and anchor the slope. |
| **Vegetation structures** | |
| Brush layering | Woody (or hardwood) cuttings are laid in trenches across a slope, usually following the contour. These form a strong barrier to prevent the development of rills and trap material moving down the slope. |
| Palisades | Woody (or hardwood) cuttings are planted in lines across a slope, usually following the contour. These form a barrier to slow the development of rills and trap material moving down the slope. |
| Live check dams | Woody (or hardwood) cuttings are built to form a live check dam. They armour and reinforce gullies, and trap material moving downwards. |
| Fascine constructions | Bundles of live branches are laid in trenches across a slope, usually following the contour. Once grown, these form a strong barrier to prevent the development of rills and trap material moving down the slope. |
| **Related small scale physical measures** | |
| Wire bolster cylinders | These usually take the form of a gabion tube 30 cm in diameter. They are laid into trenches in the slope and form a barrier to slow the development of rills and trap material moving down the slope. [1] |
| Jute netting | A geo-textile of woven jute netting is placed on the slope. It protects the surface, improves the slope surface for plants and acts as a mulch. |
| Notes 1 | If angled, these measures can also be used to serve a drainage function. |
| 2 | Table after Department of Roads, Nepal 1997 |

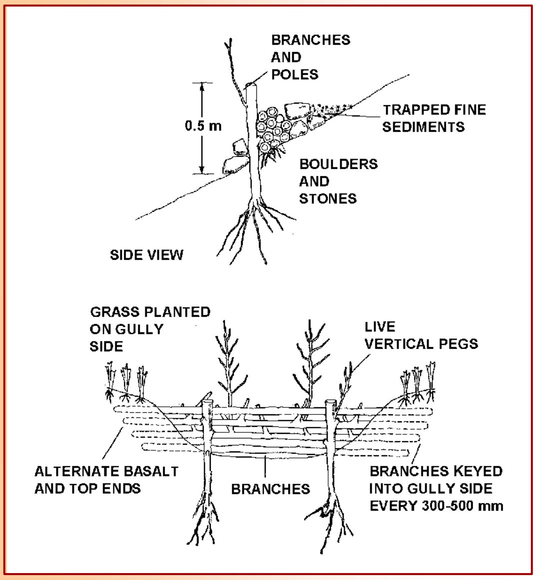
**Table 11-4 Bio-engineering Techniques for Rehabilitation of Steep Slopes**



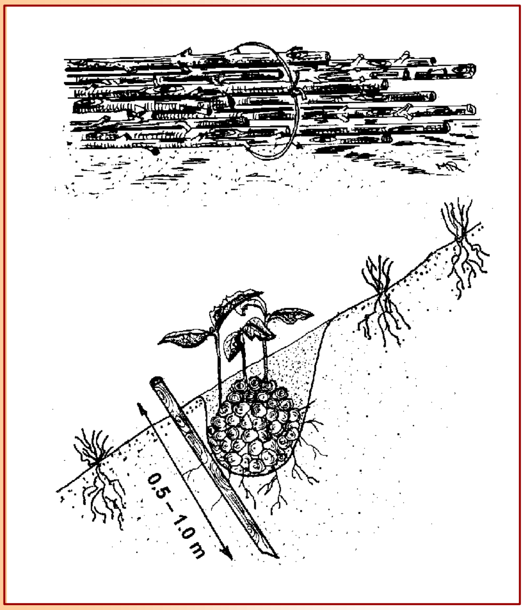

Brush layering




Palisade




Wire check dam construction




Facine construction

| Slope Angle | Slope Length | Material Drainage | Site Moisture | Best Technique |
|---|---|---|---|---|
| >50° | > 15 m | Good | Damp | 1 Diagonal grass lines |
| | | | Dry | 1 Contour grass lines |
| | | Poor | Damp | 1 Downslope grass lines and strengthened rills or<br>2 Chevron grass lines and strengthened rills |
| | | | Dry | 1 Diagonal grass lines |
| | <15 m | Good | Any | 1 Jute netting and planted grass |
| | | Poor | Damp | 1 Downslope grass lines<br>2 or Diagonal grass lines |
| | | | Dry | 1 Jute netting & planted grass or<br>2 Contour grass lines or<br>3 Diagonal grass lines |
| 35 – 50° | >15 m | Good | Any | 1 Horizontal bolster cylinders and shrub/tree planting or<br>2 Downslope grass lines and strengthened rills or<br>3 Grass seeding, mulch and wide jute mesh |
| | | Poor | Any | 1 Herringbone bolster cylinders and tree/shrub planting or<br>2 Another drainage system and shrub/tree planting |
| | <15 m | Good | Any | 1 Brush layers of woody cuttings<br>2 Contour grass lines or<br>3 Grass seeding, mulch and wide jute mesh. |
| | | Poor | Any | 1 Diagonal grass lines or<br>2 Herringbone fascines and shrub/tree planting or<br>3 Herringbone bolster cylinders and tree/shrub planting or<br>4 Another drainage system and shrub/tree planting |
| < 35° | Any | Good | Any | 1 Contour strips of grass and shrubs/trees or<br>2 Shrub/tree planting |
| | | Poor | Any | 1 Diagonal lines of grass and shrubs/ trees or<br>2 Shrub/tree planting |
| Any | | Any rocky material | | 1 Direct seeding of shrubs<br>2 or Shrub/ small tree planting |
| Notes: | 1 “Any rocky material” is defined as material into which rooted plants cannot be planted but seeds can be inserted in holes made with a steel bar<br>2 Chevron pattern: <<<<<<<br>3 Table after Department of Roads Nepal 1997 | | | |

**Table 11-5 Selection of Bio-engineering Techniques**

**Jute Netting**

Jute netting may be used as a temporary surface cover to help grass establish on very steep stony slopes of 50° to 80°. Standard netting comprises a 40mm square mesh of 5 – 8 mm yarn with anchoring pegs at 500 to 1000mm centres. On a steep dry slope the jute netting will have several functions:

- Protect the surface, allowing seeds or grass slips to hold or germinate, particularly in hot exposed conditions.
- Reduce the velocity of surface flow
- Retain small quantities of soil debris
- Hold moisture in the surface
- It will act as a mulch for the growing plants as it decays.

Jute netting is unsuitable where soils are wet or may undergo shallow failure (TRL Overseas Road Note 16, 1997)

Wide mesh jute netting (mesh 150 – 500 mm square) may be used to hold mulch on slopes of 35° to 50° that have been seeded.

**Maintenance of Vegetation**

In order to gain maximum benefit from vegetation in terms of site stabilisation and appearance it is essential that rehabilitated areas are monitored and maintained until the vegetation is well established.

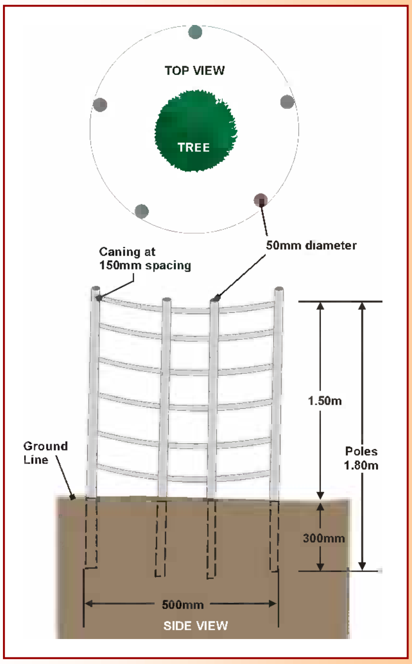
The frequency of vegetation maintenance activities and period over which they are required will depend on the local climate and conditions. During the first year after planting the following maintenance activities may be required:

- **Watering**. To sustain plants during dry times of year
- **Fertilising**. Spreading of nitrogen and phosphate fertiliser to enhance poor topsoil.
- **Mulching**. Leaves and unwanted cuttings are placed around seedlings to keep soil cool and moist
- **Grass Cutting**. May be required to encourage new growth
- **Weeding and Thinning**. To encourage vigorous growth of desired plants.
- **Replacement Planting.** Replanting to replace dead plants and fill gaps.
- **Protection**. Restriction of the use of the site by people and animals that might cause unacceptable damage to vegetation.

This work can programmed into the activities of routine maintenance gangs, but there are advantages in employing a local resident or landowner to take responsibility for the site.

Placing jute nets in preparation for grass planting

Spinning raw jute in Nepal. The spinners are twisting the fibres together into yarn for local net manufacture.




Tree protection cage

Regular pit inspections and environmental monitoring should be carried out.

## 11.8. Borrow Pit Environmental Monitoring

As a part of the record keeping for borrow pit development and operation it is recommended that an environmental monitoring form is completed for each active borrow pit or quarry (refer Figure 11.1 on following page).

At regular intervals the status and condition of borrow pits should be evaluated so that any problems or activities likely to result in damaging environmental impacts will be identified and reported. The possibility of disruptive disputes with land owners may also be identified during this monitoring.

Appropriate action should then be taken to correct or limit negative environmental impacts and to satisfy the requirements of landowners.

| ENVIRONMENTAL MONITORING FORM | | |
|---|---|---|
| **BORROW PIT / QUARRY DETAILS:**<br>**Name:……………………..…Road:………………………………km…………Offset………………**<br>**Reference…………………...Land Owners:…………………………………………………………**<br>**Date Assessed:……………Assessed By:……………………….** | | |
| **ACTIVITY** | **EVALUATION (1,2 or 3)** | **NOTES** |
| DEVELOPMENT PERMIT ISSUED | | |
| DEVELOPMENT PLAN APPROVED | | |
| LAND TAKE<br>Compensation Agreed<br>Compensation being Agreed<br>Compensation being Paid<br>Resettlement | | |
| SITE DEMARKATION | | |
| LAND CLEARANCE | | |
| TOPSOIL CONSERVATION | | |
| ACCESS ARRANGEMENTS | | |
| EXTERNAL APPEARANCE | | |
| POLLUTION<br>Noise (Blasting)<br>Dust<br>Contaminated Water<br>Machinery –fuel, lubricants, emissions | | |
| SAFETY<br>Slope Stability<br>Blasting<br>Machinery<br>Material Storage<br>Personnel Protection<br>Intrusion Protection (fences etc) | | |
| REINSTATEMENT | | |
| Other Environmental Issues: | | |

Environmental Monitoring Key to Evaluation:
1 = Satisfactory 2 = Unsatisfactory 3 = Not Carried Out

**Figure 11.1 Model Environmental Monitoring**

# References & Bibliography

## References
## Section 2 (Materials Searches)


Bishop EC & Morey A J. (1992). Road Materials Resource Study of Papua New Guinea. PNG Society of Professional Engineers Conference on Engineering to Sustain the Environment, Lae, PNG

Charman JH. (1988). Laterite in Road Pavements. CIRIA Special Publication 47. London UK Construction Industry Research and Information Association.

Leet LD, Judson S & Kaufmam ME. (1978). Physical Geology. 5th Edition. Prentice-Hill, New Jersey

Lawrance CJ, Byard RJ, & Beaven PJ. (1993). Terrain Evaluation Manual. Transport Research Laboratory State of the Art Review 7. HMSO Publication

Lawrance CJ & Toole T. (1984). The Location, Selection and Use of Calcrete for Bituminous Road Construction in Boswana. Transport Research Laboratory Report 1122

Netterberg F. (1978). Prospecting for Calcrete Road Materials in South and South West Africa. Civil Engineer in South Africa, 20, (6), 129 – 138.

Transport Research Laboratory & Roughton International. (2000). Promoting the Use of Marginal Materials. TRL UK.


## Selected Bibliography
## Section 2 (Materials Searches)


Geological Society. (1993). Aggregates. Geological Society Engineering Geology Special Publication No 9 . Published by the Geological Society London.

Geological Society. (1982). Land Surface Evaluation for Engineering Practice *Q. J Eng Geol* , 15 265-316

Geological Society. (1997). Tropical Residual Soils. Geological Society Professional Handbooks. A Geological Society Engineering Group Working Party Revised Report. Published by the Geological Society London.

Goudie A. (1973). Duricrusts in Tropical and Subtropical Landscapes. Oxford, Clarendon Press.

Weinert HH. (1980). The Natural Road Construction Materials of Southern Africa, H & R Academica (Pty) Ltd.


## References
## Section 3 (Borrow Pit Site Investigation)


American Association of State Highway & Transportation Officials. (1997) AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing Eighteenth Edition Part II Tests.

Atkinson T. (1971). Selection of Open Pit Excavation and Loading Equipment *Trans. Min. Metall* 80 Section A Mining Industry, A101 – 129.

Bell FG (Editor). (1987). Ground Engineer's Reference Book. Butterworths.

British Standards Institution. (1981). Code of Practice for Site Investigations BS 5930.

British Standards Institution. (1990). British Standard Methods of Tests for Soils for Civil Engineering Purposes. BS 1377 Parts 1 to 4.

British Standards Institution. (1997). Testing Aggregates BS 812

Carter M. (1983). Geotechnical Engineering Handbook. Pentech Press.

Clayton CRI, Matthews MC & Simons NE. (1995). Site Investigation. 2nd Edition. Blackwell Science

CSIR. A Confidential Contractor Report to ASIST - Material Selection and Quality Assurance for Labour -based Unsealed Road Projects. Copy provided by ASIST.

Davis J & Lambert R. (1995). Engineering in Emergencies, A Prcatical Guide for Relief Workers. IT Publications on behalf of RedR.

Fiji Public Works Department. (1997). Road Works Design Construction and Administration, Road Maintenance Training Manual FRUP 2

Forssblad L .(1981). Vibratory Soil and Rock fill Compaction. Dynapac Maskin AB, Solna Sweden.

Franklin LA, Brock E and Walton G. (1971). Logging the Mechanical Character of Rock *Trans. Inst. Min. Metall.* 80 Section A – Mining Industry A1 – 9

Geological Society. (1970). The Logging of Rock Cores for Engineering Purposes. Engineering Group Working Party Report.

Geological Society. (1977). The Description of Rock Masses for Engineering Purposes. Engineering Group Working Party Report.

Henrich H. (1983). Aspects Of Flexible Road Design and Construction. Bomag –Menck.

Kenya Ministry of Transport & Communication, Roads Department. (1987). Road Design Manual. Part III Materials and Pavement Design for New Roads.

Kenya Ministry of Public Works, Roads Department. (1992) Technical Manual Volume 1 Minor Roads Programme.

MacGregor F, Fell R, Mostyn GR, Hocking G & McNally G. (1994). The Estimation of Rock Rippability. Quarterly Journal of Engineering Geology Vol 27 Part2. The Geological Society (UK).

Millard RS. (1993). Road Building in the Tropics. UK Transport Research Laboratory State of the Art Review 9. HMSO.

Netterberg F. (1978). Calcrete Wearing Courses for Unpaved Roads. Civil Engr in South Africa Vol 20 No 6 pp 129-138.

Pettifer GS & Fookes PG. (1994). A revision of the Graphical Method for Assessing the Excavatability of Rock. Quarterly Journal of Engineering Geology Vol 27 Part2. The Geological Society (UK).

Rico Rodriguez A, Del Castillo W & Sowers GF. (1988). Soil Mechanics in Highway engineering. Trans Tech Publications.

Technical Methods for Highways. (1979). TMH 1 Standard Methods of Testing Road Construction Materials. NITRR Pretoria.

Weltman AJ & Head JM. (1983). Site Investigation Manual. CIRIA Special Publication 25 London UK Construction Industry Research and Information Association.

## Selected Bibliography
## Section 3 (Borrow Pit Site Investigation)

Head KH. (1992). Manual of Soil Laboratory Testing Volume 1: Soil Classification and Compaction Tests. 2nd Edition . Pentech Press London.

Dumbleton MJ & West G .(1974). Guidance on Planning and Reporting Site Investigations. Transport and Research Laboratory (UK) Report LR625.

## References
## Section 4 (Pit/Quarry Evaluation & Selection)

Bishop EC & Morey A J. (1992). Road Materials Resource Study of Papua New Guinea. PNG Society of Professional Engineers Conference on Engineering to Sustain the Environment, Lae, PNG.

Botswana Ministry of Works Transport & Communications Roads Department. (1999). The Design Construction and Maintenance of Otta Seals. Guideline No 1.

**Committee Of State Road Authorities, TRH 20. (1990). The Structural Design, Construction and Maintenance of Unpaved Roads.**

**Committee Of State Road Authorities, TRH 14. (1985). Guidelines for Road Construction Materials. Reprinted 1989.**

**Kenya Ministry of Transport & Communication, Roads Department. (1987). Road Design Manual.Part III Materials and Pavement Design for New Roads.**

**Minty EJ, Pratt DN & Brett AJ. (1980). Aggregate Durability Tests Compared Australian Road Research Board (ARRB) Proceedings Volume 10 Part 3.**

**Netterburg F (1971) Calcrete in Road Construction NITRR Bulletin 10 CSIR Pretoria 77pp.**

**Netterberg F & Paige-Green P. (1988). Wearing Courses for Unpaved Roads in Southern Africa: a Review. Proc Annual Transportation Convention S 443 Vol 2D-5 Pretoria July 1988 36pp. Reprinted by CSIR.**

**Netterberg F & Paige-Green P. (1988). Pavement Materials for Low Volume Roads in Southern Africa : a Review. Proc Annual Transportation Convention S 443 Vol 2D-5 Pretoria July 1988 36pp. Reprinted by CSIR**

**Road Research Laboratory. (1952). Soil Mechanics for Rod Engineers. HMSO, London.**

**Transport Research Laboratory (UK) Overseas Road Note 2. (1985). Maintenance Techniques for District Engineers. 2nd Edition.**

**Transport Research Laboratory (UK) Overseas Road Note 3. (1982). A Guide to Surface Dressing in Tropical and Su-tropical Countries.**

**Transport Research Laboratory (UK), Overseas Road Note 31. (1993). A Guide to the Structural Design of Bitumen Surfaced Roads in Tropical and Sub-tropical Countries. 4th Edition.**

**Zimbabwe Ministry of Roads and Road Traffic (MRRT) (1975) Standardised Flexible Pavement design for Rural Roads with Light to Medium Traffic. Mitchell RL, Van der Merwe CP, & Geel HK. MRRT Special Report 1**

## Selected Bibliography
## Section 4 (Pit/Quarry Evaluation & Selection)

**Charman JH. (1988). Laterite in Road Pavements. CIRIA Special Publication 47. London UK Construction Industry Research and Information Association.**

Paige-Green P (1990). The Economic Optimisation of Unpaved Roads by Improved Material Selection and Construction Tehniques. Division of Roads and Transport Technology CSIR Pretoria . Low Volume Roads Research Report DPVT-106

Robinson P, Oppy T, Giummara G. (1999). Pavement Materials in Road Building, Guidelines for Making Better Use of Local Materials, Australian Road Research Board (arrb), 1999.

## References
## Section 5 (Pit Preparation)

Ferry AG. (1986). Unsealed Roads a Manual of Repair and Maintenance for Pavements. Road Research Unit (RRU) Technical Recommendation TR/8. National Roads Board New Zealand

Fookes PG. (1991). Geomaterials. *Q J Engng Geol* 24 pp3-15.

Hoek E & Bray JW. (1977). Rock Slope Engineering. The Institution of Mining and Mettallurgy.

Transport Research Laboratory. (1999) Environmental Reinstatement of Road Building Borrow Pits in Southern Africa,

ILO/ASIST (1999) Bulletin No 9

## References
## Section 6
## (Material Extraction - Labour Intensive)

ILO/ASIST Bulletins., (No5 1996, No. 6 1997, No 9 1999)

ILO/ASIST. (1998). Information Service, Technical Brief No.2, Productivity Norms for Labour-based Construction..

PIARC. (1994). International Road Maintenance Handbook Vol. 2 Maintenance of Unpaved Roads.

## Selected Bibliography
## Section 6
## (Material Extraction - Labour Intensive)

Anderson C-A., Beusch A., Miles D. (1996). Road Maintenance and Regravelling (ROMAR) Using Labour Based Methods, Handbook. ILO Romar Training Manual for Contractors. Intermediate Technology Publications.

Department Of State Roads, Zimbabwe. (1994) Field Manual for Labour Based Road Construction.

**Beusch A., Hartman P, Petts R, Winklemann P. (1997). Low Cost Road Construction in Indonesia. Labour-based road projects in Manggarai District. Volume 1 Documentation.**

**Larcher P. Labour-Based Road Construction. A state of the Art Review - Edited by P. Larcher.**

**ILO/ASIST. (1998). The Labour Based Technology Source Book – A Catalogue of Key Publications. 4th Edition. ILO Nairobi, Kenya.ILO/INTECH. (1997). Appropriate Technology - Labour Based Roadworks Technical Manual, Volume 1 Road Rehabilitation Works 1st Edition (4 volumes) The United Republic of Tanzania. Ministry of Works.**

**Stock, EA & de VEEN J.(1996). Expanding Labour-based Methods for Road Works in Africa. SSATP Working Paper No 22**

## References
## Section 7
## (Material Extraction - Mechanised)

**Ferry AG. (1986). Unsealed Roads a Manual of Repair and Maintenance for Pavements. Road Research Unit (RRU) Technical Recommendation TR/8. National Roads Board New Zealand.**

**Fiji Public Works Department. (1997). Road Works Design Construction and Administration, Road Maintenance Training Manual FRUP 2.**

**Geological Society. (1993). Aggregates. Geological Society Engineering Geology Special Publication No 9 . Published by the Geological Society London.**

**HORNER PC. (1981). Earthworks, ICE Works Construction Series, Thomas Telford**

## References
## Section 8
## (Material Processing and Control)

**Australian Road Research Board. (1993), Unsealed Roads Manual, Guidelines to Good Practice.**

**Botswana Ministry of Works Transport & Communications Roads Department. (1999). The Design Construction and Maintenance of Otta Seals. Guideline No 1.**

**Broons Hire. 1989). An Introduction to Road Pavement Materials and Pavement Design and the Use of the Broons Hire Rockbuster in Road Construction.**

**Caldwell GL. .(1985). Rockbuster Under Test, Municipal Engng Management Organisation and Town Planning Australia, Memo Number 59.**

**Ferry AG. (1986). Unsealed Roads a Manual of Repair and Maintenance for Pavements. Road Research Unit (RRU) Technical Recommendation TR/8. National Roads Board New Zealand.**

**Geological Society. (1993). Aggregates. Geological Society Engineering Geology Special Publication No 9 . Published by the Geological Society London.**

**Kenya Ministry of Transport & Communication, Roads Department. (1987). Road Design Manual. Part III Materials and Pavement Design for New Roads**

## Selected Bibliography
## Section 8
## (Material Processing and Control)

**Roughton International in Association with University of Birmingham and University of Nottingham. (2000). Appropriate and Efficient Maintenance of Low Cost Rural Roads in Developing Countries. Review of Soil Stabilisation Methods Report 5.**

## Manufacturers
## Section 8
## (Material Processing and Control)

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## References
## Section 9
## (Material Supply Considerations)

**PIARC. (1994). International Road Maintenance Handbook Vol. 2 Maintenance of Unpaved Roads.**

**ILO/ASSIST (1999). Bulletin No 9.**

**Committee Of State Road Authorities, TRH 20 (1990) The Structural Design, Construction and Maintenance of Unpaved Roads.**

**Millard R.S. (1993). Road Building in the Tropics. UK Transport Research Laboratory State of the Art Review 9. HMSO, London**

## References
## Section 10
## (Material Data Management)

**British Standards Institution. (1981). Code of Practice for Site Investigations BS 5930.**

**British Standards Institution. (1990) .British Standard Methods of Tests for Soils for Civil Engineering Purposes. BS 1377 Parts 1 to 4.**

**British Standards Institution. (1997). Testing Aggregates BS 812.**

**Bishop EC & Morey AJ. (1992). Road Materials Resource Study of Papua New Guinea. PNG Society of Professional Engineers Conference on Engineering to Sustain the Environment, Lae, PNG.**

**Engineering Geology Ltd, Roughton International & TI Kias. (1992). Road Materials Resource Study and Gravel Pit Inventory. Reports for the Department of Works. General Report.**

**Engineering Geology Ltd, Roughton International & TI Kias. (1992). Road Materials Resource Study and Gravel Pit Inventory. Report for the Papua New Guinea Department of Works. National Gravel Pit Inventory Database User's Manual.**

**Geological Society Engineering Group Working Party Report (1972). The Preparation of Maps and Plans in Terms of Engineering Geology. *G. J Engng Geol* 5 (4) pp293-382.**

**Minty EJ, Pratt DN & Brett AJ. (1980). Aggregate Durability Tests Compared. Australian Road Research Board (ARRB) Proceedings Volume 10, Part3, 1980.**

**Toole T. (1985). A Review of Specifications and Test Methods Used in the Selection of Unbound Road Bases and Surface Dressing Aggregates in the Tropics. Transport and Research Laboratory (UK).**

## Selected Bibliography Section 10 (Material Data Management)

Woodbridge ME, Cook JR & Moestofa B. (1999). Development and Implementation of a Construction Material Information sysytem. 7th International Conferrence on Low-Volume Roads, Baton Rouge, Louisiana USA..

Beaven PJ, Cook JR & Moestofa B. (1990). The Design and Use of a Road Materiala Inventory. Proceedings of the 6 th Conference of Road Engineering Association of Asia and Australasia (REAAA) Kuala Lumpur.

Clauss KA, Vail JW. (1975). A New Approach to Materials Data Banking for Road Construction. 6th Regional Conference for Africa on Soil Mechanics & Foundation Engineering Durban South Africa.

## References Section 11 (Review of Environmental and Social Considerations)

Transport Research Laboratory. (1999) Environmental Reinstatement of Road Building Borrow Pits in Southern Africa,

Transport Research Laboratory. (1997). Overseas Road Note 16, Principles of Low Cost Road Engineering in Mountainous Regions.

Nepal Ministry of Works and Transport, Department of Roads. (1997). Use of Bio-Engineering,

Nepal Ministry of Works and Transport, Department of Roads. (1991). Vegetation Structures for Stabilising Highway Slopes: A Manual for Nepal

Roughton International. (1999). Rehabilitation of the Managua-Rama Road, San Benito to San Lorenzo Bridge. Environmental Guide for the Execution of the Rehabilitation Works. Financed by DANIDA. (Source of Borrow Pit Environmental Monitoring Form).

World Bank. (1995). Vetiver Grass for Soil and Water Consewrvation, Land Rehabilitation, and Embankment Stabilisation. World Bank Technical Parer No 273.

## Selected Bibliography
## Section 11
## (Review of Environmental and Social Considerations)

**Asian Development Bank. (1993). Environmental Guidelines for Selected Infrastructure Projects ADB Office of the Environment.**

**World Bank.. (1997). Roads and the Environment, A Handbook. World Bank Technical Paper No 376.**

**World Bank. Environmental source Book Vol II Chapter 9 Transportation World Bank Technical report No 154.**

**World Bank Operational Manual. (1991) Operational Directives 4.01 (Environmental Assessment) 4.30 (Involuntary Resettlement).**

**Overseas Development Agency (now DFID) (1992). Manual of Environmental Appraisal.**

## References
## Appendix I
## (Gravel Wearing Course Materials)

**Bishop EC & Morey AJ. (1992). Road Materials Resource Study of Papua New Guinea. PNG Society of Professional Engineers Conference on Engineering to Sustain the Environment, Lae, PNG.**

**Engineering Geology Ltd, Roughton International & TI Kias. (1992). Road Materials Resource Study and Gravel Pit Inventory. Reports for the Department of Works. General Report.**

## References
## Appendix II
## (Paved Road Materials)

**Cardno & Davies PNG Pty Ltd. (1994) Research on Coronous Materials and Their Use in Road Construction. Report submitted to PNG Government.**

**Charman JH. (1988). Laterite in Road Pavements. CIRIA Special Publication 47. London UK Construction Industry Research and Information Association.**

**Engineering Geology Ltd, Roughton International & TI Kias. (1992). Road Materials Resource Study and Gravel Pit Inventory. Reports for the Department of Works. General Report.**

**Greening PAK & Rolt J. (1999). The Use of Marginal Materials for Road Bases in the Kalahari Region of Southern Africa. Intl Symposium on Thin Pavements. Surface treatments and Unbound Roads. University of New Brunswick, Canada.**

**Kenya Ministry of Transport & Communication, Roads Department. (1987). Road Design Manual. Part III Materials and Pavement Design for New Roads.**

**Transport Research Laboratory. (2000). Promoting the Use of Marginal Materials.**

**Woodbridge ME. (1997). Use of Soft Limestone for Roadbase in Belize. TRL PR/OSC/64/97.**

# Appendix I

## Review of Material Types for Use as Gravel Wearing Course

## TABLE A1 Review of Material Types for Use as Gravel Wearing Course (Sheet 1 of 7)
## Transported Sands and Gravels

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | WEARING COURSE SUITABILITY | | TYPICAL "AS DUG" SUITABILITY RATING (& RANGE) |
|---|---|---|---|---|---|
| | | | *ADVANTAGES* | *DISADVANTAGES* | |
| **River Bed Gravels, River Terrace Gravels & Alluvial Fan Gravels** | Typically well graded, slightly silty, very sandy rounded to subangular GRAVEL with a variable proportion of cobbles and boulders. | Associated with existing and ancient water courses | • River bed deposits will normally undergo natural self-replenishment.<br>• Alluvial deposits easily extracted with backhoe excavator or bulldozer and wheeled loader.<br>• If grading of material is favourable (similar to sub-base with additional plastic fines) the riding surface will be moderately resistant to natural erosion and traffic wear.<br>• Screening out of oversize through a grizzly is a simple operation and may produce useful strong pitching stone etc.<br>• Pavements containing the optimum proportion of plastic binder will not become excessively slippery in wet weather.<br>• Composition of pavement gravel may be improved during regrading (blading surface soil into road etc). | • Performance is strongly influenced by grading. "As dug" materials, particularly river bed deposits, often deficient in plastic fines. When this is the case blending with clayey weathered rock is recommended.<br>• Particles are typically rounded or sub-rounded resulting in poor interlock between particles, This results in loose and dangerous pavement surfaces particularly if the material is poorly graded.<br>• When an excess of silty/sandy low plasticity fines is present, the pavement will become soft in wet weather and dusty with corrugations in dry conditions.<br>• Oversize particles trend to be resistant to breakdown under compaction. They should therefore be removed by screening or crushed. The high strength of alluvial cobbles may cause high rates of hammer wear in mobile hammermills. | 3<br>(2 - 5) |
| **Beach Gravels** | Moderately to well graded, clean (non-plastic), very sandy to sandy, rounded to subangular GRAVEL with some cobbles. | May occur in any coastal area. May be an important material source on some of the smaller islands where alluvial deposits are scarce. | • Particles are almost always strong having been sorted and eroded by the sea.<br>• Easily extracted with backhoe excavator or bulldozer and wheeled loader. | • All deposits tend to be clean (lacking in any silty or clayey fines) and so suffer the disadvantages listed for river deposits, which are deficient in plastic fines.<br>• May contain salt which is corrosive to vehicles.<br>• Extraction from the tidal zone will normally need to be restricted to avoid adverse environmental effects. | 3<br>(3 - 4) |
| **Beach Sand Deposits** | Uniformly graded SAND. | May occur in any coastal area. | • Source of sand for blending purposes. | • Uniformly graded and lacking in plastic binder . Hence, unsuitable for use as wearing course without appropriate blending (mechanical stabilisation). | 5<br>(5) |
| **Colluvial Fan Deposits** | Natural gravel - variably graded clayey, sandy, silty, fine, medium and coarse angular GRAVEL with a variable cobble and boulder content. | Associated with steep hillslopes and valley sides in mountainous terrain. These deposits typically comprise weathered material transported primarily by gravity | • Generally reasonably graded with sufficient plastic binder.<br>• Angular particles produce good interlock on road surface.<br>• When not excessively weathered, particles will be durable and resistant to rapid degradation under traffic.<br>• Gives good smooth pavement surface.<br>• Even with a surplus of plastic binder the pavement may improve with time.<br>• Usually easily excavated with backhoe excavator or bulldozer and wheeled loader. | • Suitability of pit-run materials is strongly influenced by composition and nature of parent rock.<br>• Some deposits may contain a significant proportion of oversize particles. In which case crushing or 'special' compaction is recommended (grid roller).<br>• When the deposits contain an excessive proportion of binder, the resultant pavement surface may become slippery or greasy in the wet.<br>• Weathered particles may breakdown rapidly under traffic giving dusty surfaces when dry and soft surfaces when wet. | 3<br>(2 - 5) |
| **GRAVEL WEARING COURSE MATERIAL "AS DUG" SUITABILITY RATING: 1 - VERY GOOD, 2 - GOOD, 3 - MODERATE, 4 - POOR, 5 - VERY POOR (OR NOT SUITABLE WITHOUT SIGNIFICANT PROCESSING).** | | | | | |

## TABLE A1 Review of Material Types for Use as Gravel Wearing Course (Sheet 2 of 7)
## Pedogenic Gravels

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | WEARING COURSE SUITABILITY | | TYPICAL "AS DUG" SUITABILITY RATING (& RANGE) |
|---|---|---|---|---|---|
| | | | *ADVANTAGES* | *DISADVANTAGES* | |
| **Laterite Deposits** | "As dug" materials typically clayey to silty slightly sandy subangular relatively weak GRAVEL.<br>Various types of laterite identified with associated material properties documented | Product of rock weathering, ferrous chemical leaching and precipitation in existing and ancient tropical and subtropical environments. | • Most deposits tend to contain sufficient plastic binder.<br>• When well compacted these deposits typically form a dense relatively impervious pavement with good load bearing characteristics and fair resistance to natural erosion and traffic wear.<br>• Most deposits can be excavated by ripper.<br>• Oversize particle tend to break-down under "normal" compaction, hence screening is not usually required.<br>• Pavements containing the optimum proportion of plastic binder will not become excessively slippery in wet weather. | • These deposits may occur in exploitable beds only 1.0 to 2.5 m thick, hence the ratio of resource size to land take is typically poor.<br>• When an excess of silty/sandy low plasticity fines is present, the pavement may become soft in wet weather and dusty with corrugations in dry conditions. | 2<br>(1 - 3) |
| **Calcrete Deposits**<br>**(including calc tufa and caliche depsits)** | "As dug" materials are typically moderately graded, irregular to angular carbonate GRAVEL in a matrix of sandy carbonate silt and clay.<br>Various types of Calcrete identified with associated material properties documented. | Near surface soil deposits formed by precipitation of carbonates (primarily calcium carbonate - calc tufa) from solution in ground water. | • Most deposits tend to contain sufficient plastic binder in the form of carbonate clay and when well compacted form strong unpaved road surfaces.<br>• Typically easily extracted with a bulldozer and wheeled loader. | • These deposits may occur in beds less than 3m thick, hence the ratio of resource size to land take is typically poor.<br>• Some "hard pan" deposits will produce significant oversize material that may require crushing.<br>• .Some deposits are excessively silty (powder calcretes) and are then prone to formation of dust and pavement corrugations. | 2<br>(1 - 3) |
| **Silcrete Deposits** | Variably cemented SAND or SANDY GRAVEL – that produces weak to moderately strong aggregate | Natural granular materials that have become cemented through the deposition of silica from ground water. | • Weakly cemented deposits may be easy to excavate. | • Often poorly graded and lacking in plastic binder . Hence, unsuitable for use as wearing course without appropriate blending (mechanical stabilisation)<br>• May comprise hard oversize particles. | 3 - 5<br>(5) |
| **GRAVEL WEARING COURSE MATERIAL "AS DUG" SUITABILITY RATING: 1 - VERY GOOD, 2 - GOOD, 3 - MODERATE, 4 - POOR, 5 - VERY POOR (OR NOT SUITABLE WITHOUT SIGNIFICANT PROCESSING).** | | | | | |

## TABLE A1 Review of Material Types for Use as Gravel Wearing Course (Sheet 3 of 7)
## Residual Sands and Gravels

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | WEARING COURSE SUITABILITY | | TYPICAL "AS DUG" SUITABILITY RATING (& RANGE) |
|---|---|---|---|---|---|
| | | | *ADVANTAGES* | *DISADVANTAGES* | |
| **Residual Gravel Deposits**<br>• Quartz Gravels<br>• Weathered Granite/Gneiss gravels<br>• Other residual gravelly soils | Near surface soil typically comprising - Variably graded clayey sandy angular to subangular GRAVEL | These gravels are the product of *in situ* weathering and erosion and typically represent the end product of the decay of underlying sound rock. | • Most deposits tend to contain a considerable proportion of plastic binder and angular coarse particles.<br>• When well compacted the more gravelly deposits typically form a dense relatively impervious pavement with good load bearing characteristics and fair resistance to natural erosion and traffic wear.<br>• Most deposits can be excavated by ripper.<br>• Most oversize particle tend to break-down under "normal" compaction, hence screening is rarely required.<br>• Pavements containing the optimum proportion of plastic binder will not become excessively slippery in wet weather. | • These deposits may occur in exploitable beds only 1.0 to 2.5 m thick, hence the ratio of resource size to land take is typically poor.<br>• When an excess of plastic fines is present, the pavement may become soft in wet weather and dusty in dry conditions.<br>• Fine grained materials likely to be prone to erosion under the action of traffic and weather. | 3<br>(2 - 4) |
| **Residual Clayey Sand Deposits** | Near surface clayey silty SAND | Soils formed by complete (*in situ*) decomposition of rock. | • Easy to excavate and place.<br>• .Good source of material to blend with fines deficient natural gravels (such as river bed deposits). | • Prone to erosion by traffic and weather unless blended with coarse aggregate.<br>• .Excessively silty deposits will be prone to the formation of dust and pavement corrugations. | 4<br>(3 - 4) |
| **GRAVEL WEARING COURSE MATERIAL "AS DUG" SUITABILITY RATING: 1 - VERY GOOD, 2 - GOOD, 3 - MODERATE, 4 - POOR, 5 - VERY POOR (OR NOT SUITABLE WITHOUT SIGNIFICANT PROCESSING).** | | | | | |

## TABLE A1 Review of Material Types for Use as Gravel Wearing Course (Sheet 4 of 7)
## Weak or Poorly Consolidated (Rippable) Rocks

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | WEARING COURSE SUITABILITY | | TYPICAL SUITABILITY RATING (& RANGE) |
|---|---|---|---|---|---|
| | | | *ADVANTAGES* | *DISADVANTAGES* | |
| **Raised Coral Beach Deposits** | Natural gravel - typically well graded, slightly clayey, silty, carbonate SAND and irregular to angular GRAVEL with a variable cobble content. | Found beneath flat coastal plains or forming points in tropical and subtropical climates that support coral growth.<br>. | • Plastic binder material is typically present (although less than in raised reef deposits). This aids production of a good pavement running surface with 'normal' compaction. Significant break-down of oversize particles may occur under 'normal' compaction.<br>• There is good interlock between angular particles and a hard pavement 'crust' may develop.<br>• Pavements resist natural erosion and the formation of corrugations, and typically provide good skid resistance.<br>• With regular pot hole repairs, regravelling intervals may be extended.<br>• Typically easily excavated, but may require ripping if partially cemented. | • Rate of pavement wear/loss typically higher than for alluvial gravel pavements. This may become significant on more heavily trafficked roads.<br>• Material quality/performance deteriorates as sand content exceeds gravel content.<br>• Pot holes may form where pavement 'crust' is broken or softened.<br>• Material may contain salt which is corrosive to vehicles.<br>• High groundwater table frequently restricts pit excavation depth and may lead to water softening of particles. | 2<br>(1 - 3) |
| **Raised Coral Reef Deposits** | Poorly consolidated rippable rock producing - moderately to well graded, irregular to angular carbonate GRAVEL with some to many cobbles of sandy plastic 'putty' CLAY or sandy SILT. | Forms humocky, hilly or occasionally terraced terrain close to the coast in tropical and subtropical climates that support coral growth. | • Carbonate clay is an excellent binder, which produces a good pavement running surface with 'normal' compaction. Significant break-down of oversize particles may occur during compaction.<br>• When "as dug" material contains an excessive proportion of oversize particles, it can often be effectively treated with a mobile crusher of 'Rockbuster' type.<br>• There is good interlock between angular particles and a hard pavement 'crust' may develop. Providing advantages listed above for coral beach deposits.<br>• "As dug" pavement aggregate may be exploited to considerable depths by ripping. | • Disadvantages typically similar to coral beach deposits listed above.<br>• Material quality/performance deteriorates if carbonate clay (matrix) content becomes excessive.<br>• Pit materials with a high natural moisture content (damp/wet) are difficult to handle and compact, and tend to form a weak pavement when first laid.<br>. | 2<br>(1 - 4) |
| **Weak Marls and Limestones** | Inherently weak variably fractured rock producing soft gravels | Forms a component of sedimentary rock sequences | • Some deposits may be suitable for blending with gravels exhibiting a lack of plastic fines. | • Typically produce weak pavements subject to rutting and erosion. | 4<br>(4 - 5) |
| **Weak Conglomerates** | Weakly cemented rock producing - moderately graded, slightly silty, sandy to very sandy, fine, medium and coarse rounded to subangular GRAVEL with some to many cobbles and a variable boulder content. | Forms a component of sedimentary rock sequences comprising coarse alluvial gravels. | • Moderately weathered deposits can be easily extracted by ripping and some break-down of oversize material may occur during extraction and compaction.<br>• Oversize particles could be easily removed by passing the "as dug" material through a grizzly screen. | • Deposits typically contain a high percentage of oversize particles, may be gap graded and lack sufficient plastic binder.<br>• Highly weathered (near surface) deposits may contain an excess of weak particles, which break-down under traffic causing rutting and dust.<br>• Where a significant proportion of oversize particles are included in the extracted material crushing or 'special' compaction is recommended (grid roller).<br>• Deposits may become less weathered at depth, and more strongly cemented. As a result, the deposits may cease to be rippable. | 4<br>(3 - 4) |

**GRAVEL WEARING COURSE MATERIAL "AS DUG" SUITABILITY RATING: 1 - VERY GOOD, 2 - GOOD, 3 - MODERATE, 4 - POOR, 5 - VERY POOR (OR NOT SUITABLE WITHOUT SIGNIFICANT PROCESSING).**

## TABLE A1 Review of Material Types for Use as Gravel Wearing Course (Sheet 5 of 7)
## Weak or Poorly Consolidated (Rippable) Rocks

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | WEARING COURSE SUITABILITY | | TYPICAL SUITABILITY RATING (& RANGE) |
|---|---|---|---|---|---|
| | | | *ADVANTAGES* | *DISADVANTAGES* | |
| **Weak Sandstones** | Weakly cemented rock predominantly comprising sand size particles (usually dominated by quartz) | Geologically young sedimentary sequences.. | • Clayey sandstones may be useful as a source of fines to blend with coarse low plasticity gravels. | • Weak gravel fragments will tend to suffer excessive break-down during compaction and under the action of traffic and weather, to produce rutting ,dust and corrugation problems. | 4<br>(4 - 5) |
| **Weak Volcanic Tuffs** | Weakly cemented rock comprising silt and sand size particles sometimes with gravel size inclusions. "As dug" (ripped) materials tend to comprise blocky weak sandy angular GRAVEL and cobbles | Associated with existing and ancient centres of volcanic activity.<br>Tuffs are poorly consolidated accumulations of fine airborne volcanic ash. | • My provide a useful source of fines when blended with coarse gravels. Considerable particle break-down will typically occur during compaction. | • Will typically provide erodable pavement materials that rut and create dust and corrugations. | 4/5<br>(4-5) |
| **Shale and Poorly Consolidated Siltstones or Clayey Sandstones** | Weak (rippable) rock – producing angular or flaky weak GRAVEL in a matrix of slightly sandy, silty clay/clayey silt. | Forms a component of sedimentary rock sequences | • Weathered materials may represent a source of plastic fines for blending with binder deficient wearing course/shoulder materials (e.g. alluvial gravels). | • Weak material that would break-down under compaction and in service under traffic.<br>• Deposits often contain an excess of fines.<br>• Will give rise to dusty road surfaces in dry conditions.<br>• Will produce slippery and soft pavement surfaces that are liable to rutting in wet conditions.<br>• Some gravel particles may "slake" (disintegrate) on exposure to air. | 4/5<br>(4 - 5) |

**GRAVEL WEARING COURSE MATERIAL "AS DUG" SUITABILITY RATING: 1 - VERY GOOD, 2 - GOOD, 3 - MODERATE, 4 - POOR, 5 - VERY POOR (OR NOT SUITABLE WITHOUT SIGNIFICANT PROCESSING).**

## TABLE A1 Review of Material Types for Use as Gravel Wearing Course (Sheet 6 of 7) Weak or Unconsolidated Volcanic Deposits

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | WEARING COURSE SUITABILITY | | TYPICAL SUITABILITY RATING (& RANGE) |
|---|---|---|---|---|---|
| | | | *ADVANTAGES* | *DISADVANTAGES* | |
| **Volcanic Pumice / Ash Deposits** | Tpically loose silty sand and/or fine gravel deposit comprising weak vesicular particles | Associated with existing and ancient centres of volcanic activity involving acid (high silica content) rock types. | • Easy to excavate with a loader or excavator<br>• May be useful for blending with poorly graded coarse granular material. | • These deposits typically lacks plastic binder and comprises very weak particles.<br>• Produce very weak dusty pavements that are very prone to erosion and rutting. | 5<br>(5) |
| **Volcanic Scoria (Cinder) Gravels and Scoriaceous Gravels** | Loose natural gravel – typically comprising variably graded silty sandy to very sandy angular to subangular vesicular GRAVEL with some to many cobbles (volcanic bombs). | Associated with existing and ancient centres of volcanic activity involving basic (low silica content) rock types.<br>Scoria cones, comprising unconsolidated cinder gravels are formed when violent eruptions blow molten gaseous (frothy) lava of basaltic or andesitic composition into the atmosphere.<br>Scoriaceous gravels may be associated with the upper layers of basaltic lava flows that have been affected by release of dissolved gases. | • May occur in large relatively uniform exploitable deposits.<br>• Typically easily excavated by backhoe or wheeled loader.<br>• Angular gravel produces good interlock of particles when well graded.<br>• "As dug" materials may often be well graded.<br>• Larger particles tend to break-down under normal compaction and may improve the grading by creating sand and silt size particles, which reduce the percentage of voids. | • Completely weathered volcanic ash residual soils may form thick overburden deposits.<br>• Typically lack good plastic binder.<br>• Due to vesicular nature of these deposits, weaker materials may breakdown rapidly under compaction and in-service on the road to produce a dusty surface in dry conditions.<br>• Workable deposits may occur within a sequence, interbedded with tuff/clayey silt and hard basaltic lavas. Selective extraction at the pit is then necessary.<br>• If the "as dug" materials are uniformly graded and have a significant lack of fines adequate compaction will be difficult to achieve. | 3<br>(3 - 4) |
| **Weak and/ or Weathered Volcanic Agglomerate** | Weak or weathered rock producing - variably graded silty sandy to very sandy angular to subangular GRAVEL with some to many cobbles and occasional boulders (volcanic bombs), Typically becomes massive to widely fractured strong HARD ROCK at depth. | Associated with existing and ancient centres of volcanic activity.<br>Product of explosive volcanic eruptions. Agglomerate comprises consolidated ash and rock fragments (usually basaltic) derived from a volcanic cone. | • Easily excavated when moderately to highly weathered (deposits typically dense but poorly cemented).<br>• Angular gravel produces good interlock of particles when well graded.<br>• Upon extraction and appropriate processing (including crushing and screening), fresh to moderately weathered occurrences will normally produce strong durable angular aggregate. | • Completely weathered volcanic ash residual soils may form thick overburden deposits.<br>• Pit-run gravels typically lack good plastic binder.<br>• Workable deposits may occur within a sequence, interbedded with tuff/clayey silt and hard basaltic lavas.<br>• Moderately to highly weathered deposits typically contain a significant amount of weak material which will breakdown in service on the road.<br>• Most "as dug" wearing course materials will be prone to erosion and rutting, and will become dusty in dry weather.<br>• Slightly weathered to fresh deposits at depth may require use of hard rock quarrying operations for exploitation including drilling, blasting, crushing and screening. | 3/4<br>(3 - 6) |
| **GRAVEL WEARING COURSE MATERIAL "AS DUG" SUITABILITY RATING: 1 - VERY GOOD, 2 - GOOD, 3 - MODERATE, 4 - POOR, 5 - VERY POOR (OR NOT SUITABLE WITHOUT SIGNIFICANT PROCESSING).** | | | | | |

## TABLE A1 Review of Material Types for Use as Gravel Wearing Course (Sheet 7 of 7) Weathered or Highly Fractured (Rippable Rocks)

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | WEARING COURSE SUITABILITY | | TYPICAL SUITABILITY RATING (& RANGE) |
|---|---|---|---|---|---|
| | | | *ADVANTAGES* | *DISADVANTAGES* | |
| **Fractured /Weathered (Rippable) Limestones.** | Fractured and weathered rock forming - moderately to well graded clayey slightly sandy fine, medium and coarse angular GRAVEL with some to many cobbles. | Near surface (3-20 m depth) outcrops of limestone | • Carbonate clay is a good binder, which will harden with reduction of moisture content.<br>• Good interlock occurs between angular particles. Once compacted, well graded pavement materials are resistant to natural erosion and the formation of corrugations, and will also provide good skid resistance.<br>• Where material exhibits good natural fragmentation (i.e. closely fractured) ripped material may be well graded.<br>• Less weathered gravel particles may be strong and durable.<br>• Material may improve with time on the road, due to: loss of fines under dry conditions; degradation of weak particles; and a reduction in plasticity.<br>• When crushing is required, limestone is typically associated with low abrasive wear and good productivity. | • Suitability of pit-run aggregate strongly influenced by fracture spacing.<br>• Proportion of plastic binder is strongly related to degree of weathering and fracture spacing. Typically lacks sand fraction.<br>• May contain an excess of plastic fines making it difficult to work in wet conditions and initially produce a slippery surface.<br>• Clayey deposits may be difficult to screen. When the excavated material contains a high proportion of oversize particles 'special' compaction will be required (grid or tamping foot roller) or treatment with a mobile hammermill.<br>• Less weathered rock will occur at depth and will become blocky and increasingly difficult to extract without blasting. | 3<br>(1 - 4) |
| **Fractured /Weathered (Rippable) Foliated Metamorphic Rocks, eg**<br>• Slate<br>• Schist<br>• Phyllite | Rocks which when ripped may produce moderately to poorly graded, clayey, silty, sandy, often elongate, angular, flaky GRAVEL with variable cobble content. | Found in areas of past and present mountain building (areas of tectonic activity), where the forces of heat and pressure have produced altered rock types with preferred fracture planes. | • When the "as dug" material contains gravel size fragments that are angular and are not excessively flaky or elongate, good particle interlock in the pavement may be achieved.<br>• With sufficient plastic binder and strong gravel particles a reasonable pavement surface may be obtained.<br>• Oversize fraction will typically be reduced during compaction. | • Highly weathered particles are weak and liable to degrade rapidly in service under traffic.<br>• Frequently gives dusty surfaces in dry conditions.<br>• May produce slippery pavement surfaces in wet weather, which would also be liable to rutting.<br>• Particles are frequently very flaky or elongate with associated poor compaction characteristics.<br>• Deposits often require the addition of binder and application of heavy compaction to improve pavement performance. | 4<br>(3 - 5) |
| **Other Fractured /Weathered (Rippable) Rocks** | Many partially weathered rock types (whether sedimentary, igneous or metamorphic) may produce low cost sandy GRAVEL materials particularly if fracture spacing and or bedding planes facilitate extraction of well graded materials by dozer ripping. | Restricted in occurrence in the ground profile between completely weathered residual soils (often clayey and unsuitable foruse in pavement construction – overburden) and underlying unaltered hard rock (which requires use of costly extraction and processing procedures) | • Less weathered particles provide strong durable stone with good particle interlock.<br>• Highly weathered rock typically provide good plastic binder.<br>• With good compaction and an appropriate proportion of binder material a smooth and durable road surface will be produced.<br>• Heavy compaction will often improve material grading. | • Material is likely to become less well jointed and increasingly more blocky at depth, consequently the material becomes less easily exploited and an increased proportion of oversize particles will be produced.<br>• Careful blending of material at the pit may be required to achieve an acceptable grading.<br>• Where a significant proportion of oversize particles are included in the pavement crushing or 'special' compaction is recommended . | 3/4<br>(2-5) |
| **GRAVEL WEARING COURSE MATERIAL "AS DUG" SUITABILITY RATING: 1 - VERY GOOD, 2 - GOOD, 3 - MODERATE, 4 - POOR, 5 - VERY POOR (OR NOT SUITABLE WITHOUT SIGNIFICANT PROCESSING).** | | | | | |

# Appendix II

## Review of Material Types for Use in Low Cost Paved Roads

**TABLE A2 Review of Material Types for Use in Low Cost Paved Roads (Sheet 1 of 4)**

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | COMMENTS |
|---|---|---|---|
| **1 TRANSPORTED SANDS AND GRAVELS** | | | |
| **River Bed Gravels, River Terrace Gravels & Alluvial Fan Gravels** | Typically well graded, slightly silty, very sandy rounded to subangular GRAVEL with a variable proportion of cobbles and boulders. | Associated with existing and ancient water courses | • Many alluvial gravels, particularly river bed deposits, are suitable for use as subbase with appropriate screening and no crushing.<br>• Screened materials may be suitable for lower standard base (CBR 40 – 60%) on very lightly trafficked roads, but some crushing is required as traffic flows increase to improve particle interlock and load bearing characteristics.<br>• Suitability of alluvial gravels for crushed base will be influenced by unsound stone content and proportion of material with an undesirable particle shape (eg sheared or foliated rock particles).<br>• Determination of suitability for use as sealing chip requires individual assessment. River gravels comprise a variety of rock types resulting in variable engineering characteristics. Most deposits could be used for supply of “otta” (gravel) seal aggregate. |
| **Beach Gravels** | Moderately to well graded, clean (non-plastic), very sandy to sandy, rounded to subangular GRAVEL with some cobbles. | May occur in any coastal area. May be an important material source on some of the smaller islands where alluvial deposits are scarce. | • As pavement material sources these deposits when “as dug” typically lack fines.<br>• Gravels typically strong and suitable for production of sealing and concrete aggregates.<br>• Extraction from tidal zone will normally need tpo be restricted to avaoid adverse environmental effects. |
| **Beach Sand Deposits** | Uniformly graded SAND. | May occur in any coastal area. | • Sand deposits may be suitable for use as subbase material, if well graded.<br>• Suitably graded materials may be stabilised with lime, cement or bitumen for construction of base course layers. |
| **Colluvial Fan Deposits** | Natural gravel - variably graded clayey, sandy, silty, fine, medium and coarse angular GRAVEL with a variable cobble and boulder content. | Associated with steep hill slopes and valley sides in mountainous terrain. These deposits typically comprise weathered material transported primarily by gravity | • Suitability for pavement construction is largely dependant on the composition and nature of the source of the colluvial material.<br>• When the parent material is strong and not significantly weathered, the colluvial deposits may be suitable for a wide range of applications.<br>• Conversely when the parent deposits contains inherently weak material, the resulting colluvial deposits will typically be unsuitable for most construction applications.<br>• The amount of post depositional weathering is also an important factor. |
| **2 PEDOGENIC GRAVELS** | | | |
| **Laterite Deposits** | “As dug” materials typically clayey to silty slightly sandy subangular relatively weak GRAVEL.<br>Various types of laterite identified with associated material properties documented | Product of rock weathering, ferrous chemical leaching and precipitation in existing and ancient tropical and subtropical environments. | • Despite relatively high plasticity characteristics and low particle strength properties selected “as dug” materials have a good history of performance in paved road construction (Refer Charman 1988).<br>• Guidelines are published for use of laterite materials in base and subbase construction for low volume roads (refer TRL, 2000).<br>• When well compacted these deposits form a dense relatively impervious pavement with good load bearing characteristics.<br>• Higher plasticity materials will be subject to significant loss of strength on saturation and so their use must be restricted primarily according to climatic conditions, and predicted traffic loading.<br>• Lime and cement improvement/stabilisation of laterite deposits is widely applied in the construction of roads carrying low to medium traffic (refer Kenya Road Design Manual 1987). |

## TABLE A2 Review of Material Types for Use in Low Cost Paved Roads (Sheet 2 of 4)

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | COMMENTS |
|---|---|---|---|
| **Calcrete Deposits**<br>**(including calc tufa and caliche depsits)** | "As dug" materials are typically moderately graded, irregular to angular carbonate GRAVEL in a matrix of sandy carbonate silt and clay.<br>Various types of Calcrete identified with associated material properties documented. | Near surface soil deposits formed by precipitation of carbonates (primarily calcium carbonate - calc tufa) from solution in ground water. | • Selected "as dug" materials have a good history of performance in paved road construction despite relatively high plasticity characteristics and low particle strength properties.<br>• Guidelines are published for use of calcrete materials in base and subbase construction for low volume roads (refer Greening and Rolt, 1995; TRL, 2000).<br>• Caution needs to be applied with respect to cement and lime improvement of calcretes because cases of carbonation, resulting in loss of stabilisation, have been recorded. |
| **Silcrete Deposits** | Variably cemented SAND or SANDY GRAVEL – that produces weak to moderately strong aggregate | Natural granular materials that have become cemented through the deposition of silica from ground water. | • Suitability for use in paved road construction strongly influenced strength of cementation. Cement improvement may be required for base course construction.<br>• Some deposits may be suitable for supply of "as dug" subbase. |
| **3 RESIDUAL SANDS AND GRAVELS** | | | |
| **Residual Gravel Deposits**<br>• Quartz Gravels<br>• Weathered Granite/Gneiss gravels<br>• Other residual gravelly soils | Near surface soil typically comprising - Variably graded clayey sandy angular to subangular GRAVEL | These gravels are the product of *in situ* weathering and erosion and typically represent the end product of the decay of underlying sound rock. | • "As dug" residual soil deposits will rarely be suitable for use in base course construction, due to inherent variability in terms of grading , particle strength and plasticity.<br>• However, this group of deposits has been widely used as a source of aggregate for lime or cement improved/stabilised base material. Also used as subbase in lightly trafficked roads in dry regions.<br>. |
| **Residual Clayey Sand Deposits** | Near surface clayey silty SAND | Soils formed by complete (*in situ*) decomposition of rock. | |
| **4 WEAK OR POORLY CONSOLIDATED (RIPPABLE ROCKS)** | | | |
| **Raised Coral Beach Deposits** | Natural gravel - typically well graded, slightly clayey, silty, carbonate SAND and irregular to angular GRAVEL with a variable cobble content. | Found beneath flat coastal plains or forming points in tropical and subtropical climates that support coral growth.<br>. | • As dug and screened materials typically compact well to form a dense interlocking structure with some break-down of particles. High soaked CBR Values (80%) associated with low fines materials. Successfully used as roadbase in low volume roads.<br>• Almost all deposits suitable for "as dug" or screened subbase material.<br>• Guidelines are published for use of coralline materials in base and subbase construction for low volume roads (refer Cardno & Davies 1993; TRL, 2000). |
| **Raised Coral Reef Deposits** | Poorly consolidated rippable rock producing - moderately to well graded, irregular to angular carbonate GRAVEL with some to many cobbles of sandy plastic 'putty' CLAY or sandy SILT. | Forms humocky, hilly or occasionally terraced terrain close to the coast in tropical and subtropical climates that support coral growth. | • Despite apparent defects (high PI and fines content combined with moderately weak particle strength) wide variety of raised reef deposits produce "as dug" and screened aggregates with high soaked CBR characteristics. They have been successfully used as roadbase in low volume bitumen roads.<br>• Guidelines are published for use of calcrete materials in base and subbase construction for low volume roads (refer Cardno & Davies 1993; TRL 2000). |

## TABLE A2 Review of Material Types for Use in Low Cost Paved Roads (Sheet 3 of 4)

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | COMMENTS |
|---|---|---|---|
| **Weak Marls and Limestones** | Inherently weak variably fractured rock producing soft gravels | Forms a component of sedimentary rock sequences | • Selected low plasticity deposits may supply subbase materials and lower standard base materials (soaked CBR 40-60%) for very lightly trafficked bitumen surfaced roads.(<0.3 M esa). (Refer Woodbridge, 1997). |
| **Weak Conglomerates** | Weakly cemented rock producing - moderately graded, slightly silty, sandy to very sandy, fine, medium and coarse rounded to subangular GRAVEL with some to many cobbles and a variable boulder content. | Forms a component of sedimentary rock sequences comprising coarse alluvial gravels. | • Will have similar properties to alluvial gravels (from which conglomerates are formed).<br>• Conglomerate gravels will typically require crushing and screening in order to satisfy "standard" base course specification requirements. Lower standard base materials (CBR 40-60%) may be supplied from well graded or simply screened (ie grizzly) subrounded to subangular deposits.<br>• Crushed gravels for use in bituminous surfacing should be investigated to determine their unsound (weathered and inherently weak) stone content. |
| **Weak Sandstones** | Weakly cemented rock predominantly comprising sand size particles (usually dominated by quartz) | Geologically young sedimentary sequences.. | • Selected deposits may supply subbase quality materials and lower standard base materials exhibiting high unsoaked CBR values (60- - >100%) but poor soaked CBRs. Have been used for base construction for very lightly trafficked roads (<0.3 M esa) in low rainfall areas. |
| **Weak Volcanic Tuffs** | Weakly cemented rock comprising silt and sand size particles sometimes with gravel size inclusions. "As dug" (ripped) materials tend to comprise blocky weak sandy angular GRAVEL and cobbles | Associated with existing and ancient centres of volcanic activity.<br>Tuffs are poorly consolidated accumulations of fine airborne volcanic ash. | • May have characteristics similar to weak sandstones. Selected deposits may supply subbase and lower standard base materials. |
| **Shale and Poorly Consolidated Siltstones or Clayey Sandstones** | Weak (rippable) rock – producing angular or flaky weak GRAVEL in a matrix of slightly sandy, silty clay/clayey silt. | Forms a component of sedimentary rock sequences | • Some materials may be suitable for use as selected subgrade or subbase in roads upto medium traffic in well drained dry conditions. Will tend to soften rapidly in wet conditions. |
| **5 WEAK OR UNCONSOLIDATED VOLCANIC DEPOSITS** | | | |
| **Volcanic Pumice / Ash Deposits** | Tpically loose silty sand and/or fine gravel deposit comprising weak vesicular particles | Associated with existing and ancient centres of volcanic activity involving acid (high silica content) rock types. | • As dug" materials unlikely to be suitable for roadbase construction even on very low volume bitumenous roads due to very low particle strength and bearing capacity.<br>• Selected materials may be a useful source of well draining lower standard subbase and selected subgrade fill. |
| **Volcanic Scoria (Cinder) Gravels and Scoriaceous Gravels** | Loose natural gravel – typically comprising variably graded silty sandy to very sandy angular to subangular vesicular GRAVEL with some to many cobbles (volcanic bombs). | Associated with existing and ancient centres of volcanic activity involving basic (low silica content) rock types.<br>Scoria cones, comprising unconsolidated cinder gravels are formed when violent eruptions blow molten gaseous (frothy) lava of basaltic or andesitic composition into the atmosphere.<br>Scoriaceous gravels may be associated with the upper layers of basaltic lava flows that have been affected by release of dissolved gases. | • Despite relatively poor "as dug" grading and relatively low particle strength these materials may be successfully used for subbase and even base course in lightly trafficked bitumen sealed roads (TRL, 2000).<br>• The grading and particle strength properties of coarse deposits may be significantly improved by crushing.<br>• The more uniformly graded fine to medium gravel deposits are typically unsuitable for use in base construction but will represent useful sources of selected subgrade fill and lower quality subbase.<br>• Despite basaltic character problems with decay in service due to seconadary mineralisation not reported. |

**TABLE A2 Review of Material Types for Use in Low Cost Paved Roads (Sheet 4 of 4)**
**Weathered or Highly Fractured (Rippable Rocks)**

| MATERIAL TYPE | MATERIALS DESCRIPTION | OCCURRENCE | COMMENTS |
|---|---|---|---|
| **Weak and/ or Weathered Volcanic Agglomerate** | Weak or weathered rock producing - variably graded silty sandy to very sandy angular to subangular GRAVEL with some to many cobbles and occasional boulders (volcanic bombs), Typically becomes massive to widely fractured strong HARD ROCK at depth. | Associated with existing and ancient centres of volcanic activity.<br>Product of explosive volcanic eruptions. Agglomerate comprises consolidated ash and rock fragments (usually basaltic) derived from a volcanic cone. | • Rarely suitable for use in pavement construction without processing to reduce oversize content and improve grading. Cobble and boulder size fragments are typically strong basalt and may be difficult to treat with a grid roller or mobile hammer mill. Screening alone is likely to be wasteful hence use of quarry crushing and processing is likely to be required.<br>• Despite basaltic character problems with decay in service due to seconadary mineralisation not reported. |
| **6 WEATHERED OR HIGHLY FRACTURED (RIPPABLE ROCKS)** | | | |
| **Fractured /Weathered (Rippable) Limestones.** | Fractured and weathered rock forming - moderately to well graded clayey slightly sandy fine, medium and coarse angular GRAVEL with some to many cobbles. | Near surface (3-20 m depth) outcrops of limestone | • Well graded (suitably processed) clayey materials often provide high soaked CBR strengths of (60 – 80%). Selected materials can therefore be considered for supply of lower standard base course aggregates for lightly trafficked bitumen roads. Lime or cement improvement may allow use at higher traffic levels. |
| **Fractured /Weathered (Rippable) Foliated Metamorphic Rocks, eg**<br>• Slate<br>• Schist<br>• Phyllite | Rocks which when ripped may produce moderately to poorly graded, clayey, silty, sandy, often elongate, angular, flaky GRAVEL with variable cobble content. | Found in areas of past and present mountain building (areas of tectonic activity), where the forces of heat and pressure have produced altered rock types with preferred fracture planes. | • Materials with poor particle shape tend not to satisfy laboratory CBR 80% required for "standard" base course materials, but may be acceptable for use as subbase.<br>• May be satisfactory for lower standard base design such as CBR 50 or CBR 40% for lightly trafficked roads (less than 0.5 – 1.0 M esa).<br>• Can be improved by mechanical stabilisation – blending with well shaped angular materials designed to improve particle interlock, reduce voids and produce a smooth curve within the desired grading envelope. |
| **Other Fractured /Weathered (Rippable) Rocks** | Many partially weathered rock types (whether sedimentary, igneous or metamorphic) may produce low cost sandy GRAVEL materials particularly if fracture spacing and or bedding planes facilitate extraction of well graded materials by dozer ripping. | Restricted in occurrence in the ground profile between completely weathered residual soils (often clayey and unsuitable foruse in pavement construction – overburden) and underlying unaltered hard rock (which requires use of costly extraction and processing procedures) | • A wide range of weathered rock types will be suitable for supply of subbase and selected subgrade aggregates.<br>• Some rippable partially weathered and fractured rock types can supply base material for lightly trafficked roads. Aggregate quality will vary according to degree of alteration (ie depth below ground). Selection and mixing during extraction may be critical to obtaining a satisfactory aggregate. Some pit materials may require lime or cement treatment to improve their suitability. |