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Topic 1 - Road terminology

Outcomes

Subject Outcome

1.1 Basic concepts and road-building terminology

Learning Outcome

2.1 Define Road building terminology.

Road-building concepts

Roads are essential for the economic and social well-being of a country. The majority of freight is moved by road and South Africa spends millions a year on construction and maintenance. The need for reliable, durable roads cannot be over-emphasized.

This section looks at the terminology used in road construction.

Cut and fill

These terms are used in earthworks where, for economic reasons, the excavated material in cuttings (cut) should, if possible, balance the amount needed to form embankments (fill). Disposing of surplus cut or importing fill usually involves extra work and expense.

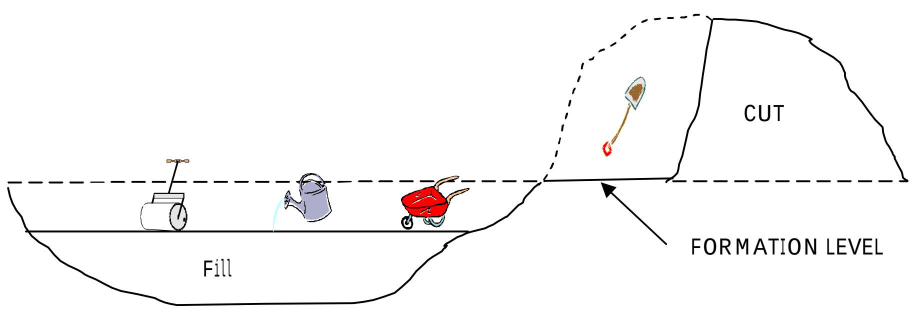


Figure 1.1

In a new road construction, “cut and fill” refers to the excavation in cuttings down to the formation level for the new road. This excavated material then being carted to adjacent areas where the formation level is to be above the natural ground level and where the “fill” is required to form an embankment up to the necessary formation level (Figure 1.1)

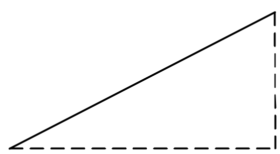
Ideal design uses all the excavated material from the cuttings to almost exactly form the embankments. Care must be taken to ensure that the excavated material from the cuttings is suitable for use in the fill areas. Topsoil should be stored on one side until the fill is virtually completed and can be used on the sides of both cuttings and embankments.

Cut is therefore the removal of surplus material to reach the formation level of the road.

Fill refers to using the excess material from the cut sections to raise the level of a low lying area to the formation level.

Where the quality of material obtained from the cut is not sufficient to be used as a fill, fill material is obtained from commercial sources. This material is spread in layers and compacted to avoid settlement at a later stage.

Cut and fill slopes are generally represented as 1 : X. For instance 1 : 2. This means 1 (vertical) to 2 (horizontal).



1

2

To keep a road straight and / or flat, and where the comparative cost or practicality of alternate solutions (such as diversion) is not possible, the land over which the road will travel is built up to form an **embankment**.

An embankment is therefore in some sense the opposite of a cutting, and embankments are often constructed using material obtained from a cutting.

Fill areas are often referred to as embankments.

Embankments should be constructed using suitable materials to provide adequate support to the formation and long-term stability.

Profiles – Road profiles are sight rails set out to control formation level and stages of road construction. By being set at fixed distances back from the edges of the road, the profiles define the edge of the formation, and the limits of placing pavement material.

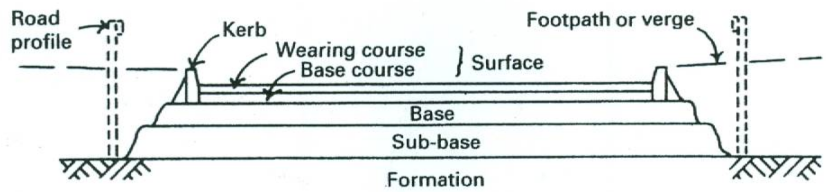


Figure 1.2

The road profiles can be used for boning in the sub-base and sometimes the base. They are commonly set 1m above the finished surface level, with the traveller length being adjusted at various stages. He engineer should supply the foreman with the traveller details and should frequently check that these are complied with. On the profile itself, it should be the chainage and the height of the cross head above the finished road level.

For dual carriageway, four profiles at each cross section are usually required, those between offside kerb-lines being set in the central reservation.

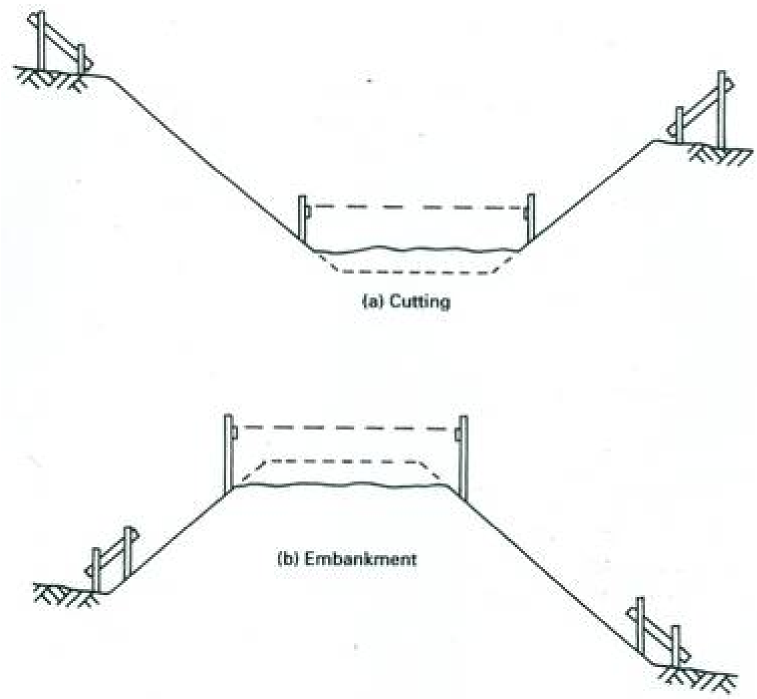


Figure 1.3

Batter boards – High speed roads run in cuttings or on embankments for considerable distances. The top of the cutting, or toe of an embankment, must be located, the angle of the slope indicated, and the bottom of the cutting, or top of the embankment, positioned.

The slope angle of the cutting or embankment is indicated by batter boards. These are the sloping boards on two stakes set both sides of the road every 10 or 20m or at a convenient distance. Batter boards are established outside the limit of excavation, and always in pairs.

For cuttings, the rails are set flush with the slope for boning in directly, whereas in embankments they are installed above the slope, with a traveller (boning rod) being used. This prevents disappearance of the batter boards when overfilling occurs. Figure 1.1 shows the section in cut, fill and part cut / part fill.

For cuttings, excavation can start as soon as the batter boards have been positioned. Frequently, however, before embankment filling commences, pegs are placed to indicate the limits of deposition. Only when a sufficient height of fill has been placed, compacted and ready for trimming to shape, is it worthwhile setting up batter boards; if set out earlier, they stand a risk of being disturbed.

The process of setting out batter boards is usually a trial and error affair, their exact position depending on the existing ground profile.

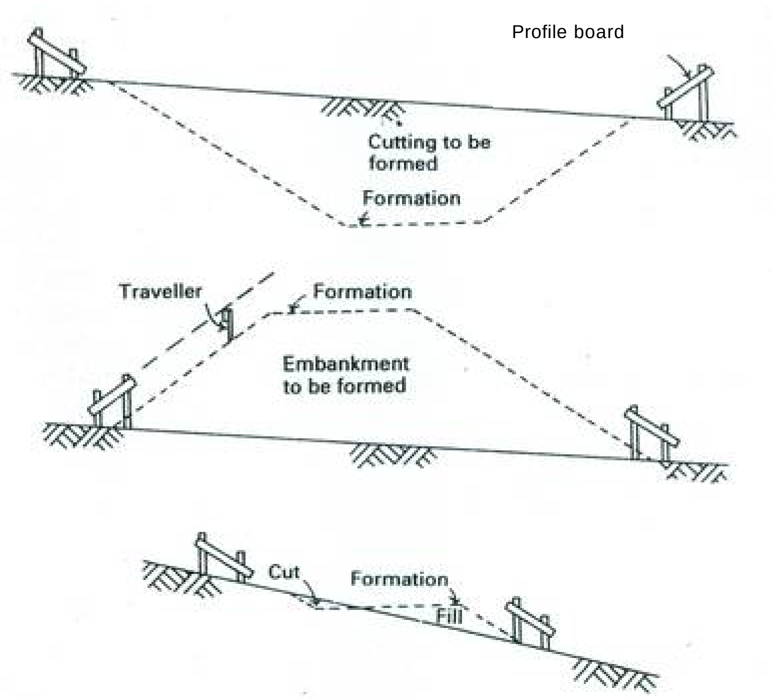


Figure 1.4

They are suitable marks placed for use as references or guides during the initial excavation.

Material classes

The selection of materials for a road pavement design is based on a combination of availability of suitable materials, environmental considerations, methods of construction, economics and previous experience. **Topic 3 and 6 cover road building materials in detail.**

G2 material

A G2 material is crushed stone material compacted to 100-102 % mod. AASHTO density or 85% of bulk relative density. G2 may be a blend of crushed stone and other fine aggregate used to adjust the grading.

G4 - G10 materials

G4 to G1 materials cover the range of relatively high quality gravels to relatively lower quality materials used in pavement layers. The durability of these materials should be checked against current specifications especially when using marginal materials on low volume roads.

C4 material

This is natural gravel or a mixture of natural gravel and boulders which may require crushing. It differs from G2 in that modification by the addition of small Quantities of lime or cement, or mechanical stabilization by the addition sand is required, to adjust its Atterberg limits.

Parts of roads

The cross-section of a road provides accommodation for moving and parked vehicles, drainage, public utilities and, to a lesser extent in the rural areas, pedestrians. For the safety and convenience of drivers, wide lanes and shoulders and gently sloping border areas are desirable, since they forgive minor errors of judgment and promote ease of operation.

Cross-sectional elements are discussed in this section. Alternatives to the elements suggested may be appropriate for particular conditions. Variations should be selected to suit these conditions, and careful consideration should be given to the function of the cross-sectional element. The elements selected for the road usually depend on the class of road being designed.

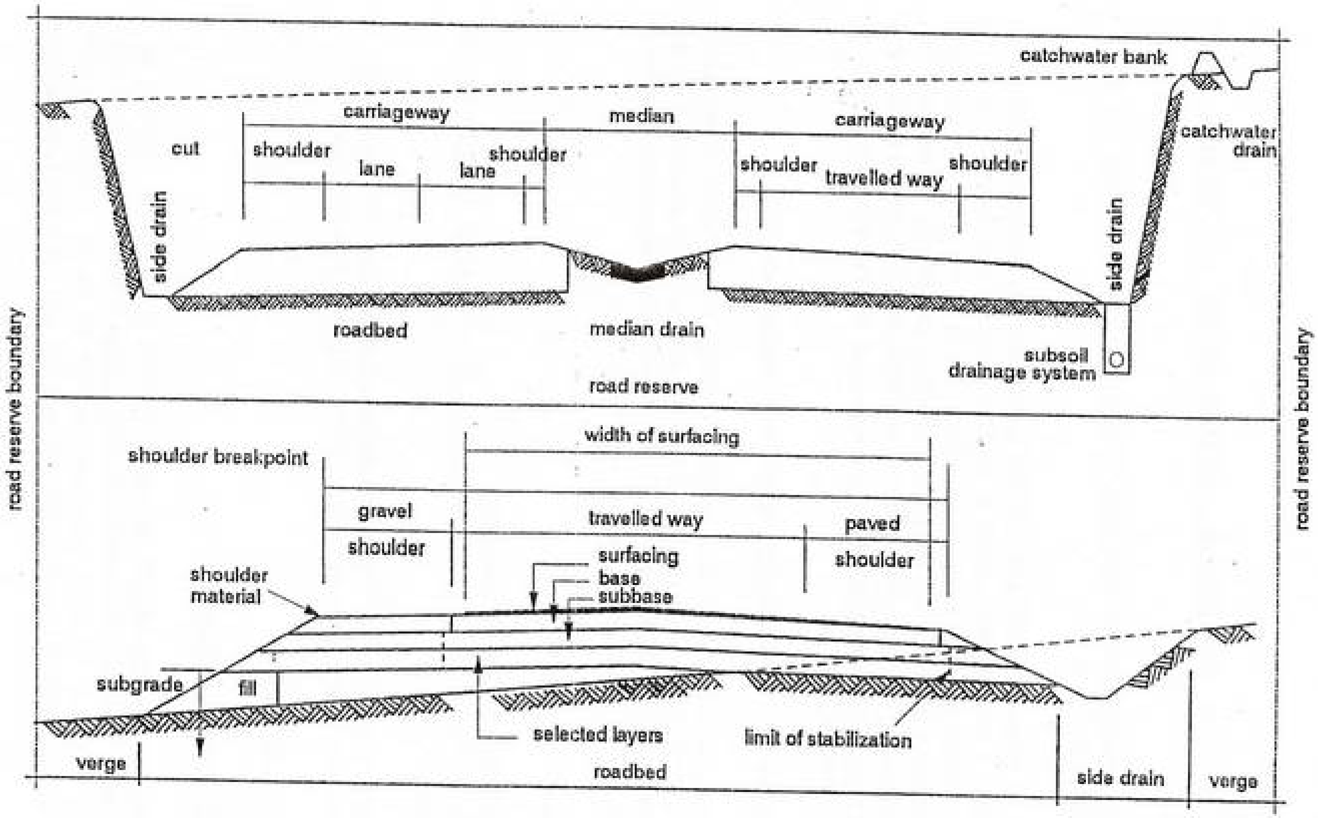


Figure 1.5: Road cross section

Lane

Undivided roads may have either one lane in each direction (two-lane two-way roads) or more than one lane in each direction (multi-lane roads). Dual-carriage-way roads have two or more lanes in each direction and are described in terms of the total number of lanes, e.g. as four-lane divided or six-lane divided roads. Customarily, there is symmetry of through lanes, and asymmetry on a particular section of road should arise only from the addition of an auxiliary lane that is clearly allocated to one direction of travel.

The selection of lane width is based on traffic volume and vehicle type and speed. Higher volumes and speeds require wider lanes, and the greatest lane width recommended is 3,7m. The narrowest width recommended is 3,1 m, giving a clear space of O,3m on either side of a vehicle that is 2,5m wide. This lane width is normally be employed only where speeds or traffic volumes are expected to be low. Intermediate conditions of volume and speed can adequately catered for by a lane width of 3,4m

Shoulder

A shoulder is the usable area alongside the travelled way, and the width allowed does not make provision for the mounting of guardrails, or for edge drains or shoulder rounding. The shoulder breakpoint is some distance beyond the edge of the usable shoulder, and this distance is usually about 0,5 to 1,0m

There are many possible uses for shoulders, including roadside vending, but in South Africa only emergency stopping is considered. A stopped vehicle can be adequately accommodated by a shoulder which is 3,0m wide, and there is no merit in adopting a shoulder width greater than this. The shoulder should not be so narrow that a stopped vehicle would not cause congestion by forcing vehicles travelling in both directions into a single lane.

Assuming the narrowest width of through lane, i.e. 3,1 m, it would be possible for two vehicles to pass each other next to a stopped vehicle if the shoulders were not less than 1,0m wide, giving a total cross-section width of 8,2m to accommodate three vehicles. It must be stressed that this width is an irreducible minimum and appropriate only to low lane volumes and low speeds, such as are encountered in climbing lanes. Hazards, including the edges of high fills, tend to cause a lateral shift of vehicles if located closer than 1,5m to the land edge, and for speeds higher than 60km/h a shoulder width of 1,5m should be regarded as the minimum.

Intermediate traffic volumes and higher operating speeds require a shoulder width greater than 1,0m, and three alternative shoulder widths are suggested, namely 1,5m, 2,0m and 2,5m. The 3,0m shoulder is appropriate for the highest operating speeds and heavy traffic volumes.

Where the traffic situation dictates a dual-carriageway cross-section, the highest standard of shoulder width is called for, namely 3,0m in the case of the outer shoulder. Only 1,0m is required for the inner shoulder, however, where it would be possible to move a broken-down vehicle onto the median and thus clear the lane,or where the vehicle would have to be moved across one lane only to reach the safety of the outer shoulder, as would occur on a four-lane divided road. As it is generally conceded that crossing two lanes with a defective vehicle would be very difficult, a six-lane divided road should have inner shoulders 3,0m wide. The alternative shoulder widths suggested above would not normally be used for the inner shoulders of a divided road.

The surfacing of shoulders is recommended:

- for freeways;
- in front of guardrails;

- where the materials of which the shoulders are constructed are readily erodible, or where the availability of materials for shoulder maintenance is restricted;
- where heavy vehicles would tend to use the shoulder as an auxiliary lane; in mist belts;
- wherever it is economically justified.

Median

The median is the total area between the inner edges of the inside traffic lanes of a divided road, and includes the inner shoulders and central island. The purpose of the median is to separate opposing streams of traffic and reduce the possibility of vehicles crossing into the path of opposing traffic. This is accomplished by the selection of the width of the median or by a physical barrier such as a guardrail.

Two different conditions dictate the steepness of the slope across the median: drainage and safety. As suggested earlier, the normal profile of a median would be a negative camber, i.e. sloping towards a central low point, to facilitate drainage. The flattest slope that is recommended is 1: 10. Slopes flatter than this may lead to ponding and water flowing from the median to the carriageway.

Slopes steeper than 1:4 would make control of an errant vehicle more difficult, leading to a greater possibility of cross-median accidents. If surface drainage requires a median slope steeper than 1:4 this aspect of road safety would serve as a warrant for replacing surface drainage by an underground drainage system.

Medians are also used to reduce the nuisance of headlight glare by the planting of shrubs on the central island. The shrubs should not grow so tall that sunlight could fall into the driver's eyes in bands - the stroboscopic effect encountered in avenues of trees in the early morning or late afternoon. In addition, the stems of the shrubs should not grow so thick as to become a further possible hazard to the motorist; a maximum stem thickness of 100mm is recommended. Medians should, as far as possible, be obstructed by kerbs, guardrails, lampposts, etc.

A median width of 9,2m would eliminate most cross-median accidents, and this width is recommended as a minimum where no barriers are provided between opposing traffic flows. Where a road is to be constructed in stages, the median will have to be wide enough to accommodate future lanes, without falling below the recommended width of 9,2m in the final stage.

The verge

The verge is defined as the area between the longitudinal works and the road reserve boundary. The boundary of the longitudinal works is often at the top of cut or toe of fill, but the longitudinal works may also include side drains or catchwater drains and hence be wider than the width of the road prism, for example. Any services not directly connected with the road, e.g. telephone or power lines, are normally located in the verge.

The verge should be at least 3,0m wide. The usual practice is to allow a minimum width of 3,0m from fill toe points and 6,0m from the top of cuttings.

Slopes

Camber and crossfall

Camber implies two slopes away from a central high point, as in a two-lane two-way road, where the cross-section slopes down from the centre line to the shoulders. Crossfall is a single slope from shoulder to shoulder. The slope, be it camber or crossfall, is provided to facilitate drainage of the road surface.

The steepness of the slope is almost invariably 2 per cent, although, in areas where heavy rainfall is common or where the most economical longitudinal gradient is 0 per cent, this can be increased to an absolute maximum of 3 per cent. Cambers steeper than 3 per cent introduce operational problems, both in driving and in increased wear of vehicle components. Where the shoulder is surfaced, the camber should be taken to the edge of the outer shoulder. Unsurfaced shoulders should have a crossfall of 4 per cent to ensure a rate of flow across this rougher surface that matches the flow across the surfaced area.

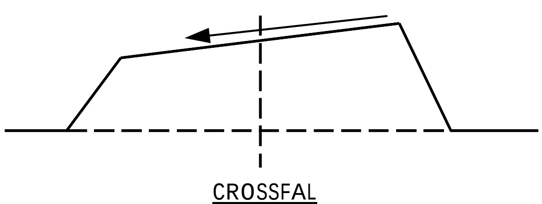


Figure 1.6(a)

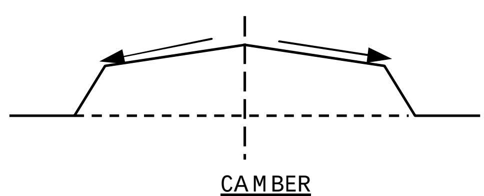


Figure 1.6(b)

Cut and fill slopes

The slopes of the side of the road prism are, like those of medians, dictated by two different conditions. Shallow slopes are required for safety, and a slope of 1:4 is the steepest acceptable for this purpose. The alternative is to accept a steeper slope and provide for safety by some other means, such as guardrails. In this case the steepest slope that can be used is dictated by the natural angle of repose and erodibility of the construction materials. Non-cohesive materials require a batter of 1:2, whereas cohesive soft materials can maintain a slope of 1:1,5. Cuts in firm cohesive materials such as the stiffer clays can be built to a slope of 1:1. Rock cuts can be unfissured and stable.

It is stressed that the batters suggested are only an indication of normally used values. The detailed design of a project should therefore include geotechnical analysis, which will indicate the steepest batters appropriate to the construction or in-situ material. Economic analysis shoul indicate the height of fill above which a slope of 1:4 should be replaced by a steeper slope and alternative provision made for safety.

Minor Structures

Agricultural underpass

An agricultural underpass provides access across a proclaimed road for mechanical farm implements. These underpasses offer the benefits of safety to the road user and convenience to the landowner but are expensive to provide. The provision of an underpass at a particular point is therefore a matter of economic evaluation and policy, rather than of design.

The height of the underpass depends on whether it is the only access to the farmhouse from the public road, in which case a height of 5,1 m is required. If it is not the only access, the height can be reduced to 4,0m. In both cases a width of 4,0m is generally adequate.

Underpasses for stock farming

Underpasses for stock farming purposes are generally 2,4m by 2,4m, but for small stock, such as sheep, this dimension can be reduced to 1 ,8m by 1 ,8m. Although sheep can pass through a structure smaller than 1,8m by 1,8m, they will not do so unless driven. Another option is to provide a 2,1 m x 2,1 m portal culvert or 2,4m x 2,4m cast in situ culvert. Naturally a suitable product can also be used depending on the circumstances. Before allowing for a stock underpass a warrant is normally done to determine if there is a need, and also to determine whether the adjoining landowner has to contribute to the cost or not.

Pedestrian underpasses have minimum dimensions of 2,4m by 2,4m. It is necessary for a pedestrian's sense of security to design the underpass so that the pedestrian can have a clear view through the underpass before entering it.

Exceptionally long underpasses may require special consideration, for example increasing the width to reduce the impressions of a tunnel.

Pedestrian footways

Another element of the road which is becoming more and more essential, especially in the densely populated rural areas, is the pedestrian footway. Where there is a lot of pedestrian movement along the road it is often necessary to provide footways as a safety measure.

The minimum width of the footway should be 1,5m. The footway can be constructed from either concrete or a form of bituminous surfacing but the choice of finish is normally dependent on economic constraints. The crossfall on the footway should be no greater than 3%. Where necessary a concrete lined "V" drain should be provided between the edge of the footway and the cut batter to prevent any soil which is eroded of the bank from spilling onto the footway.

The footway should preferably be raised above the level of the roadway and this is normally achieved by means of a kerb and if on the lower side of the superelevation by means of a kerb and channel drain.

Drainage elements

Drainage elements are discussed in detail in unit 4.

Road furniture

The term road furniture embraces all road fixtures or markings that have to be provided to assist the pedestrians and road users in the safe usage of the road.

Road furniture includes objects such as barriers, utility poles, bus shelters, bus stops, street lights, traffic signs, direction signs, road nameplates, safety fencing, benches, litter bins, sign support and other roadside support usually found on the road reserve. The following elements are discussed in this section.

Shy line

Single-vehicle collisions constitute more than 50 per cent of all collisions occurring on roads. To promote road safety an area clear of hazardous obstacles such as unyielding sign supports and utility poles, non-traversable drainage structures, and steep slopes should be provided. If an obstruction cannot be removed it should be placed as far away as practical from the roadway, shielded with a guardrail or delineated to make it readily visible.

The distance from the edge of the travelled way beyond which a roadside object will not be perceived as hazardous and cause a reduction in speed or change in position of the vehicle on the roadway is called the shy line offset. Roadside furniture should be placed beyond this offset.

Embankments and cut slopes

For adequate safety it is desirable to provide an unencumbered roadside recovery area that is as wide as practical. The recovery area or clear zone should be relatively smooth, traversable with shallow slopes. Slopes not steeper than 1:4 are recommended for safety. Embankments between 3:1 and 4:1 are considered non-recoverable. Slopes steeper than 3:1 are critical

Guardrails – Guardrails are steel rails with two corrugations at the shoulder edge of a highway, usually in front of roadside hazards. Guardrails prevent vehicles from veering off the roadway into oncoming traffic, crashing against solid objects or falling into a valley.

A secondary objective is to keep the vehicle upright while deflected along the guardrail. A guardrail is in itself a hazard and should be designed and installed to constitute a lesser hazard than that which it is intended to protect. It should absorb the impact with as little overall severity as possible.

Studies have shown that guardrails are struck more often than any other roadside object during single vehicle collisions. Guardrails should be placed sufficiently far from the edge of the roadway so as not to cause a hazard to vehicles on the roadway, nor reduce the effective width of the road.

Road signs

Road signs can be classified as either permanent or temporary. Temporary signs are used to warn users of obstructions on the highway caused by roadworks, warn the drivers of the hazards ahead, protect the personnel working, from vehicles passing by the site. These signs are removed when the roadworks are completed.

Permanent signs are used to control, warn and guide road users. They give the driver advanced warning. Signs should be visible at all times and should not be obscured. With increasing speed of transport, the tendency is for countries to adopt pictorial signs or otherwise simplify and standardize signs, to facilitate international travel where language differences can create barriers and in general to reduce the risks in driving.

Road markings

Road markings make a significant and contribution to the safe and efficient operation of the road network. They should be visible in all weather conditions and should be used in conjunction with road signs.

Speed humps

Speed humps are raised devices, parabolic in shape, placed across the road to slow traffic. They are often considered the most traditional traffic calming solution.

Speed humps can be used in the following situations:

- Junctions / Crossings
- Loading areas
- Office parks
- Shopping centres, etc

Pedestrian guard rails

Pedestrian Guard Rail is generally used along the edge of footways to provide guidance to pedestrians. It can also be erected at many different types of location including:

- along the kerb-line of high-density shopping streets
- at the entrances and / or exists to transport interchanges
- at road intersections
- at pedestrian crossings.

Guard railing has also been introduced at a number of sites as a way of keeping vehicles off the footway and to discourage parking where there is evidence of pedestrians being masked by parked cars.

Traffic lights

Traffic lights, also known as traffic signals, stop-and-go lights, robots, are signaling devices positioned at road intersections, pedestrian crossings, and other locations to control competing flows of traffic.

Traffic lights have been installed in most cities around the world to control the flow of traffic. They assign the right of way to road users by the use of lights in standard colors (Red - Amber - Green), using a universal colour code (and a precise sequence, for those who are color blind). They are used at busy intersections to more evenly apportion delay to the various users.

Street lighting

A street light, lamppost, street lamp is a raised source of light on the edge of a road, which is turned on or lit at a certain time every night. Modern lamps may also have light-sensitive photocells to turn them on at dusk, off at dawn, or activate automatically in dark weather

Materials used to build roads

(This section is covered in detail in topics 4 and 5)

Roads are designed to carry heavy traffic / loads. The road is made of several different layers, each of which has a definite purpose. From the top to the bottom, these layers consist of: the surface layer, the road base, and the subbase.

The specific composition of soil materials used in road construction makes a big difference in terms of performance and durability. Good road material should contain portions of the three basic types of soil that have specific properties that make it best for different aspects of road building: gravel, sand, and fines (silts and clays which are generally comprised of particles too small for the eye to see).

The Subgrade

The sub grade forms the formation level. In some cases, where the sub grade strength is poor (unable to safely bear the tensile stresses of the wheel loads), it is necessary to import more suitable material of a higher strength. This material is referred to as selected subgrade (SSG) material.

In cases where the sub grade is within certain strength parameters, the contractor usually rips and recompacts (R&R) the subgrade. To rip and recompact involves loosening the existing formation (subgrade), breaking up the material, watering, mixing and compacting it to a specified density so that the final compacted thickness of the prepared subgrade is not less than 150 mm.

The sub-base

In South Africa, there is a variety of base course material used, depending on the construction techniques, availability of material and performance. There are, three main categories of base course material:

- natural material base courses (crusher run, gravel);
- asphalt bases; and
- concrete bases.

Natural base courses

Gravel base course

Only approved gravel obtained from approved borrow-pits may be used. Coarse aggregate must have a dimension after compaction not exceeding two-thirds of the compacted layer thickness. If the layer is 150 mm thick, the coarse aggregate size should not be greater than 100 mm. Oversize material may be screened out before placing, broken down on the road or bladed off during placing.

Crusher run base course

Crusher run is a graded mix of coarse and fine aggregate (including crusher dust) passed through nine sieve sizes ranging from 53 mm to 0.075 mm.

Asphalt base course

An asphalt base course is a combination of fine and coarse aggregate and bitumen that is heated and mixed at a plant. The hot asphalt is transported to the site and placed on the road using a road paver. As soon as the asphalt is placed, it must be compacted using rollers.

Concrete bases

The concrete is either mass concrete or reinforced concrete. Usually the concrete base includes a surfacing, but in some cases a 'black top' may be laid over it.

Prime coat

The prime coat is a bituminous binder applied to a non-bituminous granular base to provide a bond between the base and the surfacing. It also provides an additional seal against the ingress of water and binds the upper layer of the base material.

The tack coat is also a bituminous binder sprayed onto an existing bituminous surface or asphalt base to ensure adhesion of the new surface to the old underlying surface.

Prime coats are generally low viscosity cut back bitumen, whereas tack coats are bitumen emulsions.

Surfacing

There are three main types of surface treatments:

- hot-mix asphalt (premix);
- chip and spray methods; and
- slurry methods.

Hot-mix asphalt

This is manufactured at a plant and despatched to site. Both the bitumen and the aggregates are heated to temperatures above 160°C and thoroughly mixed before being loaded into a truck for transportation to site. Once the hot-mix asphalt reaches the site, it is placed into a road paver and spread onto the surface. It is important that the premix remains hot during placing. Directly after placing, it is compacted using static rollers (a pneumatic-tyred roller and a steel-wheeled roller).

Chip and spray

The chip and spray process refers to the surface treatment application: The chip is the aggregate and the spray refers to the bitumen sprayed onto the surface. In this method bitumen is first applied either by hand spraying or using a large tank distributor, and the aggregates or chips are applied immediately afterwards followed by the rollers. Several applications use this method:

- Single seal is used for light trafficked roads. The process involves applying a tack coat, spreading the aggregate and rolling with care to ensure that the aggregate does not disintegrate.

- Double seal is similar to the single seal except that another layer of aggregate is added. Usually the first layer that is placed contains large aggregate and the second layer comprises smaller sized aggregate. A typical example of a double seal is using 19 mm aggregate for the first layer and following this with a 13 mm layer. The process therefore involves spraying a binder, spreading the larger aggregate and rolling, spraying a second binder, spreading the smaller aggregate and rolling.

- **Triple seal** is similar to the single and double seal except that now three layers of stone are placed. Once again, the aggregate sizes will decrease with each layer application. As an example, the aggregate sizes for a triple seal would be 19 mm, 9.5 mm and 6.7 mm. The process is as follows: spray a first coat of binder, spread the 19 mm aggregate and roll one pass of the steel wheeled roller; spray a second coat of binder, spread the 9.5 mm aggregate, and roll one pass of the steel wheeled roller; then spray a third coat of binder, spread the 6.7mm aggregate and roll.

Slurry seals

Surry is a mixture of fine aggregate (less than 4.75mm), water, cement and bitumen emulsion. Its prime function is to fill the surface voids. The slurry is prepared in a mixer on site and evenly spread using special brooms. It is then rolled.

Assessment tasks

1. By means of a neat labelled sketch, clearly show what each of the following cross-sectional elements are:
   a) Lanes
   b) Shoulders
   c) Median
   d) Verge
   e) Guardrail

2. Under what circumstances should the shoulder of a road be surfaced?
3. Describe the concept of “cut and fill” as used in road construction.
4. What is the difference between batter boards and profiles?
5. What is road furniture?
6. Discuss importance of the following as it applies to road furniture.
   a) Road signs
   b) Speed humps
   c) Traffic light

Topic 2 - Road surveying

Outcomes

Subject Outcome

2.1 **Road surveying**

Learning Outcome

2.2 Describe road surveying concepts.

2.3 Set out square corners and solve problems using Pythagoras' theorem and the 3-4-5-method.

2.4 Explain, correctly measure and quantify slopes and levels.

2.5 Describe and use a spirit level, water level and line level to set out roads.

2.6 Explain and set out a curve using a radius.

2.7 Describe and use profiles to excavate a drainage ditch.

2.8 Explain and demonstrate how to set out a road using centre lines, offsets and points of intersection.

Introduction

Once the road design is complete, the surveyor places and fixes the final location of the centreline and the left and right road edge positions with their associated finished road levels. This is the first step in preparing for the road construction.

Before carrying out any surveys or staking of road centre lines consultation should be made with the client regarding his requirements as most road authorities have specifications for survey work. Such requirements could be staking interval for centre line pegs, frequency of reference pegs, allowable closure errors on staking and levelling, etc.

Road Surveying Concepts

There are a number of appropriate methods for setting out the road alignment. The surveying equipment required is based on the setting out methods chosen. When choosing a specific method of surveying, it is important to bear in mind the required level of accuracy for the works. Obviously, the requirements of a rural road may not be the same as for major highways or city streets. Bearing this in mind, the following section describes the terminology used in road surveying and some methods used in setting out a road alignment.

Chainage

It is necessary to have some form of reference in relation to the cumulative distance along the centre line of the road. This distance, along the centre line of a road or railway is referred to as the "Chainage". The unit of measurement for road design is the metre. The chainage can be presented in multiples of 10, 20 or 50m

There are a number of alternative names used as an alternative to the word "Chainage" such as "meterage" if the distance is given in metres or "kilometrage" if given in kilometres. Another one is "stake value".

Reference pegs

Reference pegs are used to mark the alignment and road levels. They are invariably of wood, tree branches or stakes cut to length, ideally 40 cm long and 5 cm diameter or 5 cm x 5 cm square. It is advisable to paint them white or yellow for visibility and paint the chainage on a prepared face. To avoid loss or damage, the pegs should be offset from the road width, hammered deep into the ground to avoid pilferage and placed in a prominent location.

Survey pegs

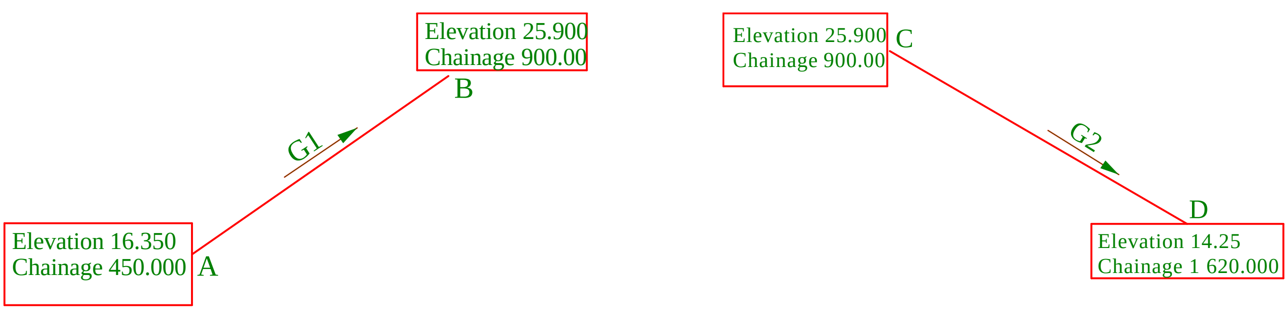
Survey pegs are usually set on the centre line, but unless there are no earthworks to be undertaken, they should be off-set from the road width. Multipurpose pegs may be needed to stake out cross-section, tasks, levels, etc. They are normally sharpened sticks 30 cm long used in conjunction with a string line to define horizontal or vertical alignment.

Slope / Gradient

A slope can be defined as an incline from the horizontal plane.

The steepness of slope can be described as a percentage (i.e 2%) or ratio (as 1 : X). For example, a gradient of 1:2 means that for every one metre vertical you need to measure two metres horizontal. This can also be represented in terms of slope as 0.5% (i.e 1÷2)

The gradient of a road is the slope of the road at a point relative to the horizontal usually expressed as a percentage.



To calculate the gradient of the road between points A-B and C-D in the diagram above, the difference between the elevations / heights is divided by the distance between them as shown below:

$$G_1 = \frac{25{,}900 - 16{,}350}{900 - 450} \times 100 = +2{,}12\%$$

$$G_2 = \frac{14{,}250 - 25{,}900}{1620 - 900} \times 100 = -1{,}61\%$$

Similarly, if you have a known gradient and distance between A and B, and elevation of point A , the elevation of point B can be calculated as follows:

Elevation at B = Elevation at A + (distance between A and B x gradient between A and B)

= 16.35 + (450 x 2.12%)

= 25.900

It is extremely important to observe the numerical sign of the grade.

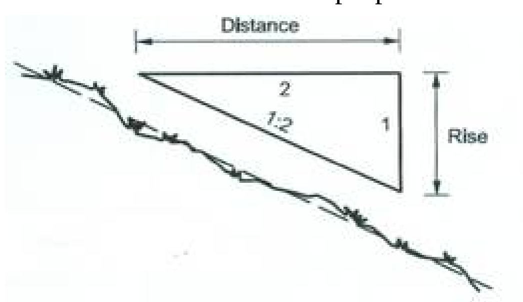
- A positive sign means the road is on an upgrade
- A negative sign means the road is on a down grade

From the vehicle operation viewpoint, gradients should be as flat as possible. Steep gradients present one of the greatest barriers to free-flowing conditions in mixed traffic.

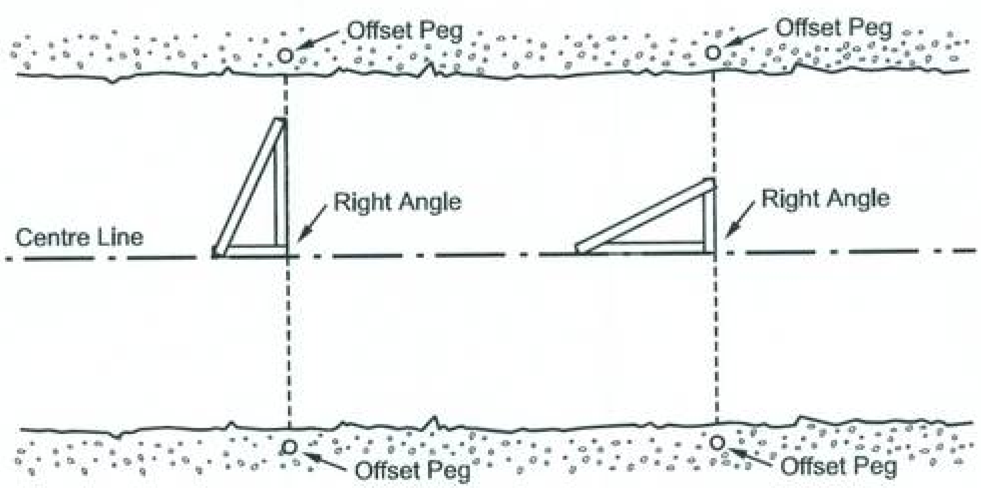
Right angles

Triangle sets can be manufactured by the site carpenter from laths and used for various purposes:

- to set out a right angle to the centre line (which has to be done when cross- sections are set out);
- to control or estimate the steepness of gradients - in this case a spirit level or plumb line is also required.



The triangle can also be useful in establishing a right angle to the road centre line as illustrated in the figure below.



Levels

Levels are used in conjunction with “levelling”. Levelling is used to describe the operation of finding the difference in height between points on the earth’s surface. Therefore a level is a height of a surface relative to a known point (datum).

Levelling is only accurate over relatively short distances as the line of sight is a tangent to the earth’s surface and longer sights would need to be corrected to take account of the earth’s curvature.
In roads levelling is used to:

- Find the difference in levels between two points
- To take the longitudinal section as well as the cross section of the ground along a given line
- To set out levels to control work in progress

Equipment

Although advanced levelling equipment such as the electronic levelling head is now used by specialist surveyors, most roads personnel employed in setting out still use the more basic equipment which is:

- A device which gives a truly horizontal line, such as a dumpy level or a tilting level.
- A suitably graduated staff for reading vertical heights

Horizontal Curves

The shortest distance between two points is a straight line. Because of topographical and other restraints it is not always practical to obtain straight lines. For this reason the straights are usually joined by a series of curves. This practice is known as horizontal alignment. Horizontal alignment should always be designed to the highest standard consistent with topography and economy. It should also be designed to be aesthetically pleasing.

Centre lines

The centreline of a road is generally a series of straight sections with curves introduced where the straights change direction. In most cases (i.e where the width of the road is symmetrical), the centre line is placed in middle of the road. The point of intersection of two tangents (straights) is usually called the PI. The horizontal alignment of a road is ususally based on the centre line of the road or the median in the case of a dual carriageway road.

Excavation

Excavation refers to the removal of material from its natural position. This is done in road construction either to reach the formation level or to replace the material with another material suitable for the purpose of construction. This material can be removed by using manual labour or excavating plant. If the material is good enough to be re-used, it is kept on site for use as a fill in other areas of the site. Excavation jobs require major details, since safety, hazards, dangers, and the like are top priority. Detailed excavation is covered in Unit 5, Earthworks.

Setting out

Setting out refers to the placement of pegs, profiles, etc that will indicate to the workforce the location of the works.

Before any construction, it is normal practice for the Surveyor to prepare a detailed centre line survey. This centre line survey should normally consist of stakes located every 20 metres on straights and every 5 to 10 metres along curves. A mark is placed on each of these stakes defining the distance (up or down) to the finished formation level of the road surface.

In order to relieve the surveyor from the onus of providing daily assistance to the site, it is essential that the basic survey skills are available on site. There are various methods used in setting out a new road. Some of the methods are explained below.

The 3-4-5 Method

The 3-4-5 method is used to set out a right angle from a certain point on the base line. To set out right angles, a measuring tape, two ranging poles, pegs and three persons are required.

By using properties of a particular right-angled triangle (Pythagorean) which has sides in the ratio of 3, 4 and 5, an offset line at 90º may be set out. Figure 2.1. shows a way in which a tape or line marked off at 3m, 4m and 5m may be used. One person holds the 12m mark to the end of the tape and places a pin at position C. The off-set is then at right angles from the position D on the original line AB.

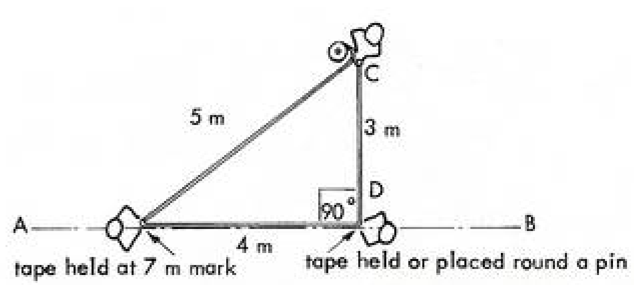


Figure 2.1

Alternatively, mark off equal distance each side of the point at which the off-set is required – say 3m, then securing or holding the tape at A and B, pull a length of tape or line out and place pin at the centre of this length (see figure 2.2). One person holds the tape at the 4m mark and places a pin at point C.

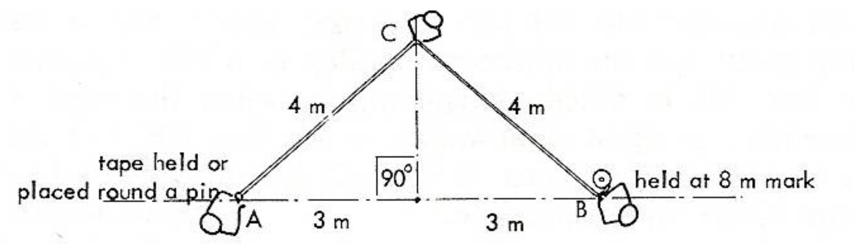


Figure 2.2

When an obstruction is in the line of sight the above method may be varied slightly (see figure 2.3). The operation is carried out twice to position pins C and D. The line through the pins will give an off-set at right angles to the original line.

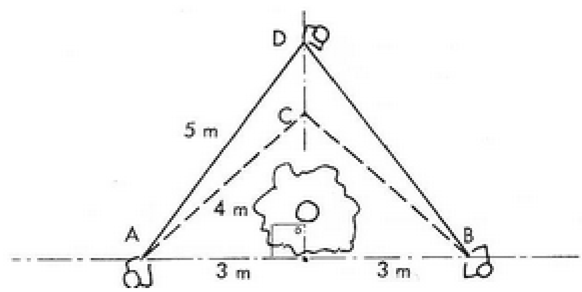


Figure 2.3

Right angle off-set from a point to the line

The method shown in figure 2.1 can also be used to establish a right angled off-set from a given point to the line AB.

Alternatively the tape is swung with its end at the given point and the minimum reading at which it crosses the line AB is noted. This happens when the tape is perpendicular or at right angles to the line AB, but the method can only be used on smooth ground where a free swing of the tape is possible.

Where the above method is not possible, with the end of the tape at point C (figure 2.4) strike an arc to cut the base line at the points A and B. The right angled off-set is then found by joining C to the point D, which is the middle point between A and B.

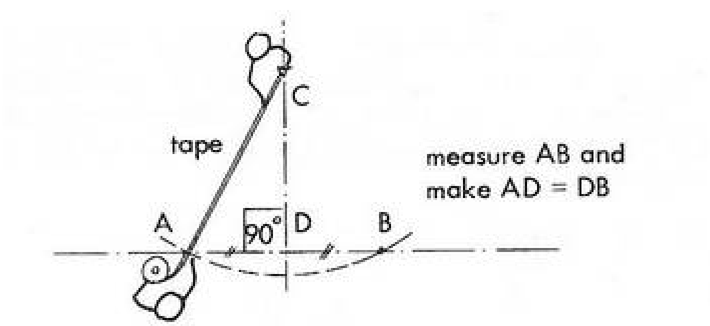


Figure 2.4

Another method is to swing the tape with the end at the given point C, to cut the base line at A (preferably measuring an even number of metres). See figure 2.5 (a). Then taking the mid-point at D of the line CA, swing an arc having a radius of $CA/2$ length as shown in figure 2.5(b).

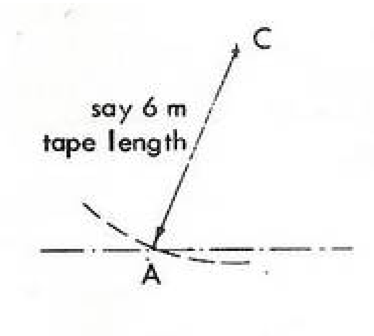


Figure 2.5(a)

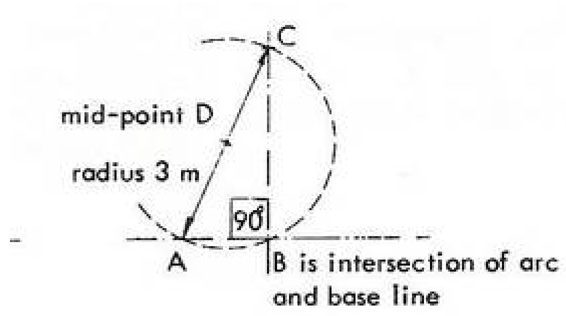


Figure 2.5(b)

The right angled off-set is then given by a line sighted between pins A and C (figure 2.5(b)).

The use of the Spirit level and Line level

The level of each of the profile boards can be controlled by using a line level. The line level is a short spirit level (about 100 mm long) with a hook at each end to hang it from a nylon string.

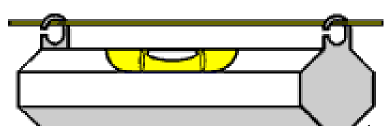


Figure 2.6

This instrument needs two persons to operate - one at the end of the line, and the second to watch the spirit level. The line operator moves the string up or down until the bubble is centred in the middle between the spirit level marks. The string line will then indicate the horizontal line. The line level can be used to:

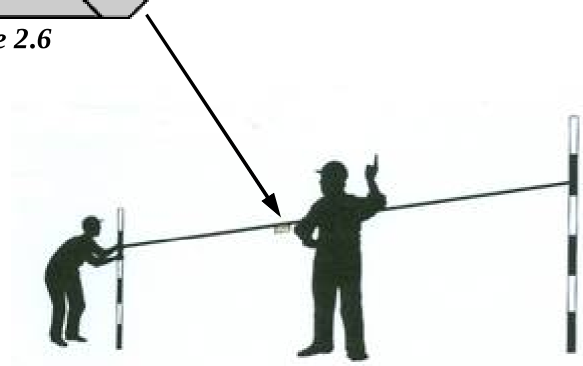


Figure 2.7

- transfer the exact level of one profile board to another profile, thereby ensuring that both are at the same level,
- measure up or down from a known horizontal level, and set a new level, and
- find the slope between two fixed profile boards, and determine which one is higher.

The line level has a range of up to about 50 metres. It is easy to carry around and with care can be used for setting out levels and slopes not less than 1 in 300.

Points to remember when using a line level:

- The string used should be a thin nylon fishing line, enabling the line level to easily slide along the string.
- The line level must be placed half-way between the two ranging rods. Use a measuring tape to find the exact middle point.
- Keep the string tight - do not let it sag.
- The line level is a delicate instrument, look after it - do not throw it around and treat it roughly.
- Check the accuracy of the line level regularly in the field.

Checking the Line Level

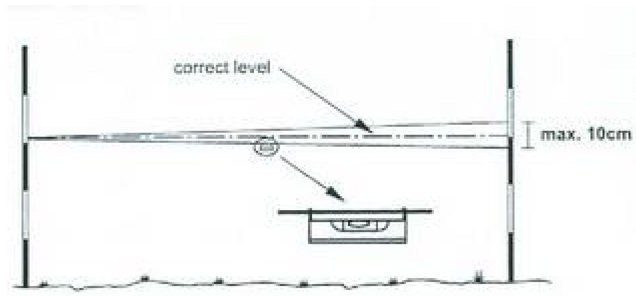


Figure 2.8

- Take two ranging rods across the road and transfer a level from one rod to the other. Mark the level on the second rod.
- Then keeping the string in the same position on the first rod, take the line level and turn it around on the string. Adjust the string on the second rod until the bubble is in the middle again and mark the new level.
- Check to see if the two marks are at the same place. If not, measure the difference between the two marks.
- If the difference between the two marks is less than 10 cm, you can get the right level by taking the point half way between the two marks.
- If the difference is greater than 10 cm, you should replace the line level for a new and more accurate one. It is always a good idea to turn the line level around every time you use it and take the middle of the two marks as the horizontal level.

Water Level

A very accurate and simple instrument for measuring the level differences of two points is the "tube water level".

This level, illustrated in figure 2.6, consists of a length of clear plastic pipe clipped at each end to a wooden levelling staff. The two levelling staffs should be of the same length, about 1.5 m long. A graduated tape is attached to each stave, with the zero level with the top end of the stave. The tube is filled with water until the level is about 1 m high from the ground. The ends of the tube are fitted with rubber stoppers to prevent loss of water. The total length of tube, which defines the range of the instrument, is variable, but is usually limited to about 15 m by the difficulty of moving the level around.

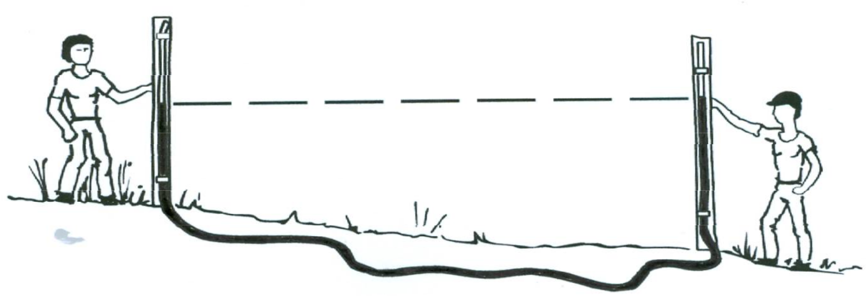


Figure 2.9

The two standpipes are brought together at the starting point, the stoppers removed and the readings taken level with the bottom of each meniscus. The readings should be the same (e.g. reading A = 50 cm, reading B = 50 cm). The surveyor takes his/her standpipe to the point being measured and takes another reading. The difference between the two readings is the difference in level (e.g. now reading A = 30 cm and reading B = 70 cm, the difference in level is now 70 - 30 = 40 cm).

Range is limited only by the convenience of being able to carry the tube. The two points whose difference in level is being measured do not need to be in sight of one another. The level gives accurate results and with care can be used for setting level lines or slopes not less than 1 in 1,000.

The use of Profiles to excavate a ditch

A commonly used setting out procedure is based on the use of a series of profile boards and a string line level giving control of levels during construction. The basic principle when using profile boards is that when they are set out, a series of level boards that show the level 1 metre above the completed construction levels, are placed.

For example:

Assume that a ditch is to be excavated from A to B to the level shown in by the dotted line:

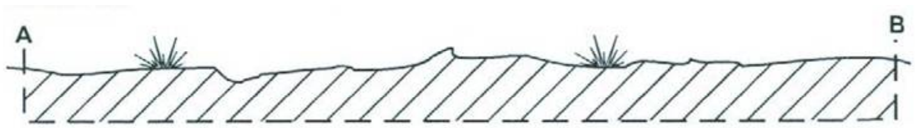


Figure 2.10

To ensure that the correct level is obtained in the ditch, profile boards are placed at positions A and B, 1 metre above the level of the planned ditch:

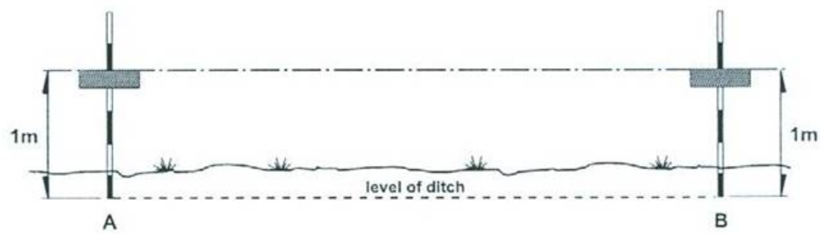


Figure 2.11

A travelling profile is used to obtain levels between two profile boards. A boning rod or a profile can be used as a traveller. Along the line from A to B, slots are excavated to the level of the ditch. By placing the traveller in a slot and sight from the profile board in position A to the profile board in position B, we can see if the traveller lines up with the two fixed profile boards. If the traveller is too low, the slot has been dug too deep. If the traveller sticks up above the sight line, the slot needs top be dug deeper.

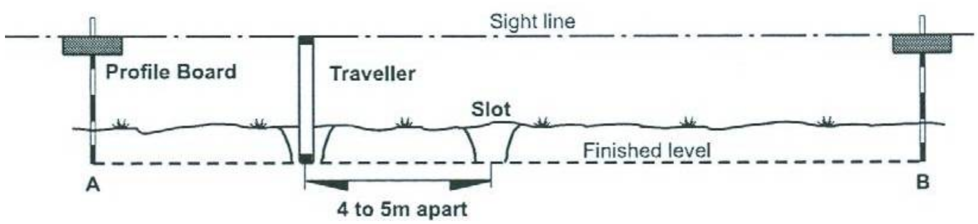


Figure 2.12

To provide good guidance, slots are dug at regular intervals, say at every 4 to 5 metres along the sight line. When sufficient slots have been dug, the workers can start excavating the ditch by joining up the slots. The traveller can then be used to check that the finished work is to the correct level and that there are no high or low spots.

Temporary travellers

It is also possible to take measurements below the line sighted between two profile boards by using a temporary traveller.

Temporary traveller

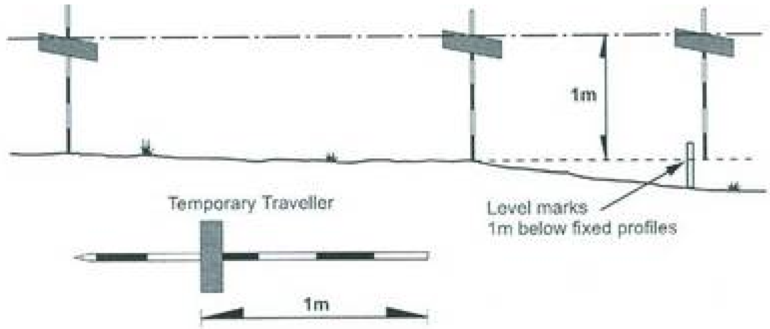


Figure 2.13

The temporary traveller is easily made on site by measuring the length needed from the blunt end of a ranging rod to the further edge of the profile, which is then clamped in position. The temporary traveller is then ready for use.

When used with fixed set out profiles, the traveller will give an indication of the finished construction levels anywhere along the sight line of the set out profiles. This is very useful for the site supervisor when setting out. The most frequent use the supervisor will make of temporary travellers is to mark earthwork levels on the edge of road pegs. But there are other uses for the traveller:

- to guide and check excavation below earthwork levels (eg. for excavation for drift base construction),
- to find out whether large boulders are above or below road levels before the road levels are finally decided upon,
- to estimate the amount of fill needed if the road is "lifted", or when the road crosses low areas - this will help estimate the work involved and help decide on the optimal road levels,
- to locate the end of drains and approaches, and
- to provide a quick check on work, levels, string lines etc.

However, for guiding drainage work the labourers and gang leaders should use the specially built travellers or a boning rod. This is because the profile on a temporary traveller can become loose and the supervisor may not be present to check and re-set the traveller length.

Setting out Curves

The centre line is normally described by means of a series of straight lines meeting at points of intersection. Eventually, these straights will be joined by curves that will be set out during the detailed setting out. The distance between the intersection points can easily be measured and used as a first estimate of the length of the road to be constructed.

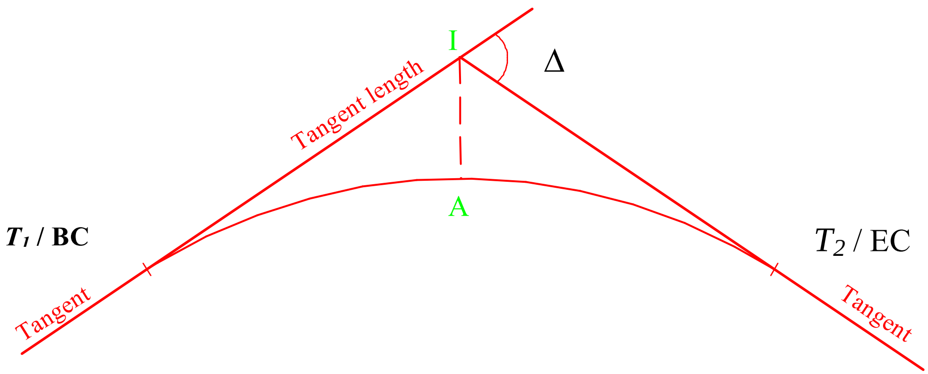


Figure 2.14: Circular curve geometry

In initial road design, the straights or tangents are located to suit the topography and function of the road; curves are then provided to accommodate the changes in direction and grade. ***Figure 2.14*** shows the layout of a circular curve.

Intersection point "I" – The point of intersection of consecutive straights.

Intersection angle "Δ" – the angle at the intersection point between the straights, measured between the first straight projected forward and the second straight; It is also called the deflection angle.

Tangent points "T_1 and T_2" – the start and finish of a curve, referred to as entry and exit tangent points. These points can also be referred to as the beginning of the curve (BC) and the end of the curve (EC)

Tangent length "IT_1 and IT_2" – the plan distance between the intersection and tangent points for a curve. Curve length "T_1T_2" – the length measured around the curve. For radius "R"

$$\mathrm{IT}_1 = R\tan\frac{\Delta}{2} \qquad \text{Tangent length}$$

$$T_1T_2(Curve) = \frac{\pi R\Delta}{180} \qquad \text{Curve length}$$

$$IA = R\left(\sec\frac{\Delta}{2} - 1\right) \qquad \text{Apex length}$$

$$T_1T_2 = 2R\sin\frac{\Delta}{2} \qquad \text{Long cord length}$$

A curve is defined if two of the following are known:

- Intersection angle
- Radius
- Tangent length
- Curve length
- Apex length

Design and site consideration determine the curve parameters.

There are various methods of setting out curves. With rural roads designed for low traffic volumes, it is usually sufficient to follow existing tracks and to improve existing curves where necessary. Two simple methods to set out circular and parabolic curves using only a tape measure, ranging rods, pegs and strings are described on the following pages.

Setting out using the centreline

Once the final route has been fixed, the co-ordinates of the points of intersection (PIs) of the straights have been established and the co-ordinates and chainages of the beginning of curves (BC), end of curves (EC) as well as further reference points (usually at 500 m intervals) on the centre line have been calculated, pegs marking these points can be set out on the ground in the field by the Engineer's surveyor.

Pegs are usually placed on the centre line of the road generally at 20 m intervals or sometimes at 50 m intervals according to the client's survey specification.

Before going out into the field to set out the centre line, a certain amount of calculation work is required.

- Joins must be taken out between successive traverse pegs in order to have a back sight (orientation) bearing.

- Joins must be taken out between the nearest traverse peg and the centreline peg to be established (set out) so as to have the setting out (forward) bearing and distance.

The general method of setting out is to use a theodolite and tape or electronic measuring device. Better still is to use a "total station" if this is available.

The following steps are used to set out a peg on the centre line:

- Set up the instrument over the traverse peg
- Back sight onto another traverse peg and set the instrument onto the correct back bearing
- Sight onto the next traverse peg and check that the bearing is correct.
- Set the instrument on the bearing to the peg you want to fix and set off the required distance and place the peg.

Figure 2.15 illustrates this sequence of events diagrammatically.

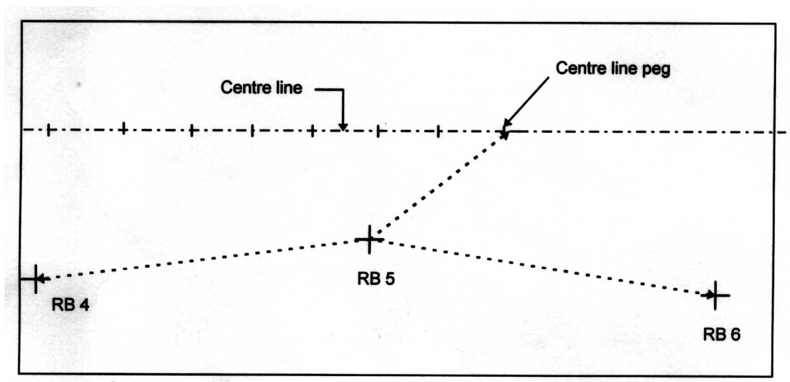


Figure 2.15

Although the intermediate 20 m (or 50 m) chainage pegs can be set out directly from the traverse pegs as illustrated above it is advisable to set up the instrument on the 500 m line pegs and to check that all the intermediate pegs are on a straight line and at the correct distance apart. The centre line pegs must be driven into the ground until only about 30 mm projects above the ground.

Because the centreline pegs will be removed as soon as earthworks construction begins reference pegs must be placed on either side of the centreline at all strategic points (BCs, ECs, MPs on curves and at the 500 m points on straights. These reference pegs are usually placed equidistant from the centre line, at right angles to it and just inside (approximately 1 m) the road reserve boundary.

The plan view (Figure 2.16) shows typically the relation of the reference pegs to the centre line and the road reserve.

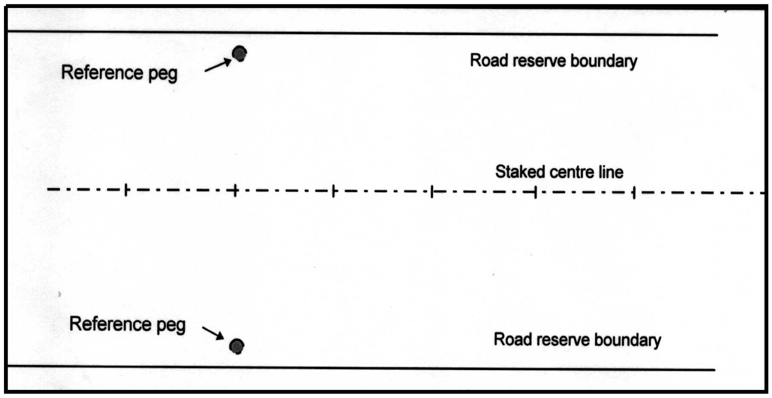


Figure 2.16

These levels taken along the centre line are used to draw up the longitudinal section plans for the road.

Figure 2.17 shows a typical reference peg.

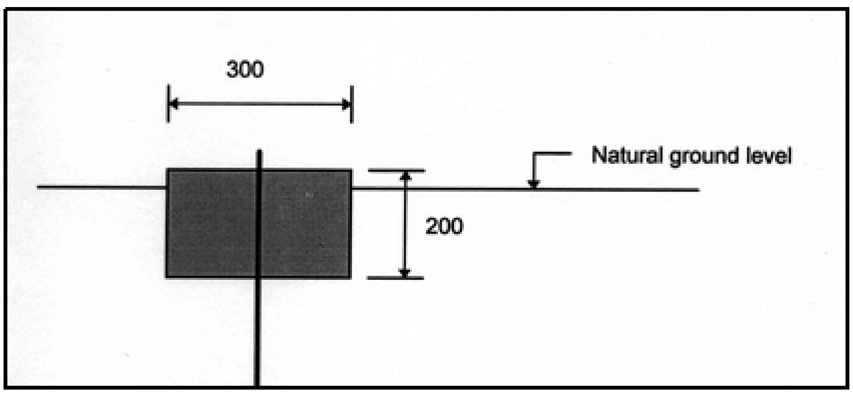


Figure 2.17: Typical reference peg

Centre line and reference peg levelling

In order to obtain accurate levels for detailed design and to establish bench mark levels on the reference pegs an accurate level traverse must be carried out along the centre line taking levels on all the centreline pegs and reference pegs along the route.

The reference datum for the level traverse is usually taken from the traverse peg near the start of the route and check closures made onto the traverse pegs at 1 to 2 km intervals along the route. If there is no traverse available, convenient trig beacons can be used to fix the start and end of the route, or else any other reliable co-ordinated survey pegs may be used.

During the staking and levelling operations notes and sketches should be made describing details, measurements and the chainages of existing features which occur within the road reserve such as buildings, fences, roads, footpaths, boreholes, windmills, pipelines, graves, streams, watercourses, springs etc.

Since the drainage of surface runoff of stormwater and also subsurface seepage is very important in the design of roads and railways it is essential that during the survey stage adequate details relating to these should be recorded in order that the designer in the office is fully aware of them.

Setting out curves with a large radius

This is the most common method of setting out large radius curves. It makes use of a theodolite set up a t a tangent point to swing the deflection angle from the forward tangent to each point to be set out, the distances being measured with a steel tape as successive short chords. This method is also known as the deflection angle or tangential angle method.

This method is usually carried out by setting up a theodolite on the PI and taping back along the tangents to place the BC and EC pegs. The theodolite is then moved to the centre line BC peg, sighting the PI and turning off the calculated offset angle to each centre line chainage peg.

First we need to calculate the offset angle to each centre line chainage peg.

From the geometry of circular curves as shown in figure 2.18 below the angle between the line BC - PI and the line BC - EC is Δ / 2. We now have to calculate the appropriate offset angle for each chord length as a ratio of the chord length to the curve length.

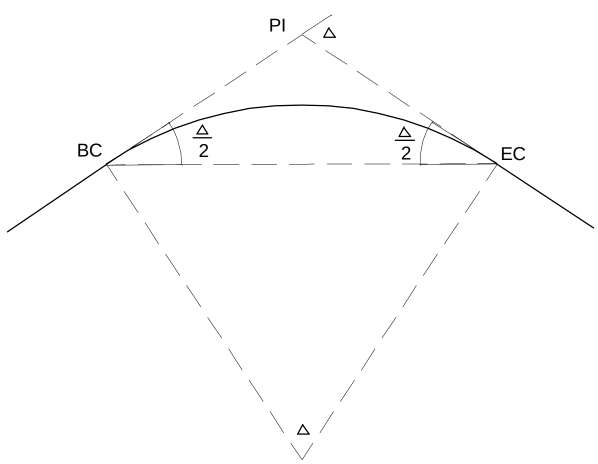


Figure 2.18

It should be noted that the chainage of the BC (or EC for that matter) almost never falls on a whole chainage. Consider the following curve details:

Δ = 67° 02' 10"   Tangent length = 264,935   Curve length = 468,000 m

BC Ch = 574,685   EC Ch 1 042,685

The deflection angle at each point is calculated from:

$$\text{Deflection angle} = \frac{\text{Chord length (l)}}{\text{Curve length (L)}} x \frac{\Delta}{2}$$

The chord length (l) is the distance between any consecutive pegs on the curve

The offset angle to each chainage peg is obtained by summing the deflection angles at the preceding chainage pegs.

CHAINAGE	CHORD LENGTH	DEFLECTION ANGLE	OFFSET ANGLE
BC 574,685			
	25,315	(25,315 / 468) × 33° 31' 05" = 1° 48' 47'	
600			1° 48' 47"
	100,000	(100 / 468) × 33° 31' 05" = 7° 09' 43"	
700			8° 58' 30"
	100,000	(100 / 468) × 33° 31' 05" = 7° 09' 43"	
800			16° 08' 13"
	100,000	(100 / 468) × 33° 31' 05" = 7° 09' 43"	
900			23° 17' 56"
	100,000	(100 / 468) × 33° 31' 05" = 7° 09' 43"	
1 000			30° 27' 39"
	42,685	(42,685 / 468) × 33° 31' 05" = 3° 03' 26"	
EC 1 042,685			33° 31' 05"

Note that the offset angle to the EC must equal Δ / 2.

The figure on the following page illustrates the above diagrammatically.

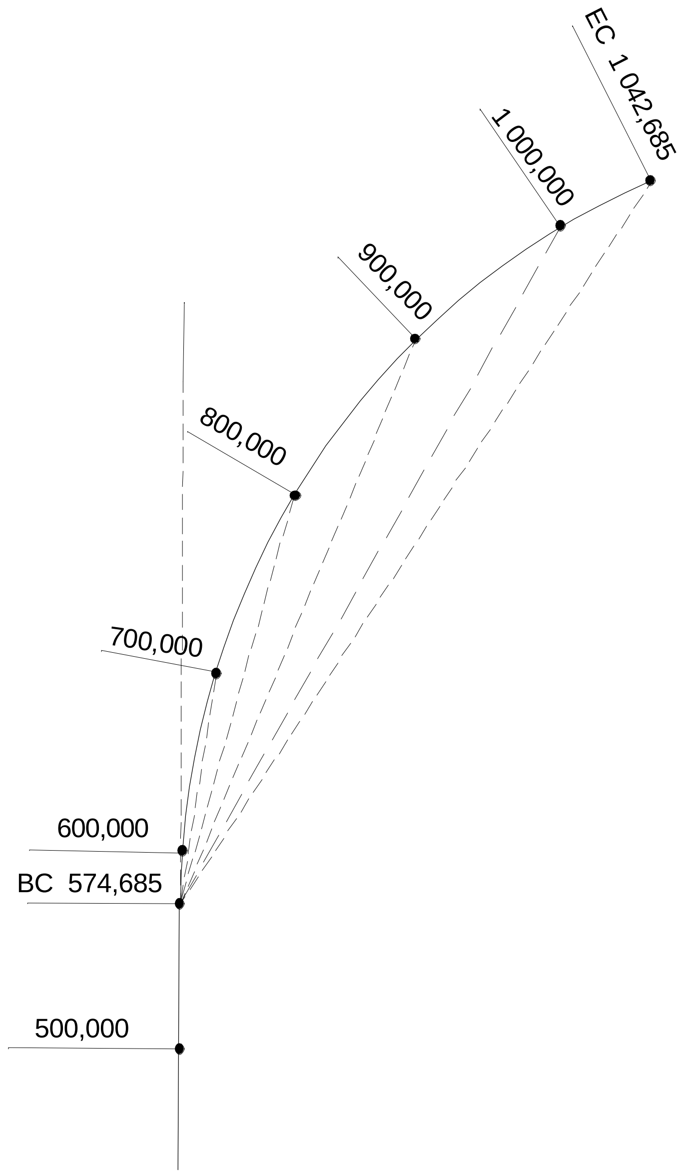


Figure 2.19

The method of setting out is as follows:

The surveyor sets up the theodolite over the BC peg, sights the PI and sets his horizontal angle reading on 0° 00' 00".

He then turns off the first offset angle i.e. 1° 48' 47" to Ch 600. The chain men measure off the distance from the BC to Ch 600 (i.e. 25,315 m) while the surveyor indicates that they should move to the left or right until they are on line. The chain men then place the peg.

The surveyor then sets the theodolite on the second offset angle (i.e. 8^o 58' 30"). The chain men then tape 100 m from Ch 600 while the surveyor shows them the line. When they are on line they place the peg for Ch 700.

This sequence of actions is repeated until all the curves are placed.

Setting out curves with a Small Radius

This method is usually used where the radius of the curve is less than 30m.

In Figure 2.20 kerbs have to be laid at the roadway junction. Consider the right hand curve. The deviation angle a is measured from the plan and the tangent length IT_1 and IT_2 (= R Tan a/2) calculated. The procedure for setting out the curve as follows:

- From I, measure back along the straights the distances IT_1 and IT_2
- Hammer in pegs at these points and mark the exact positions of T_1 and T_2 by nails.
- Hook a steel tape over each nail and mark the centre at O the point where the tapes intersect when reading R. Hammer in a peg and mark the centre exactly with a nail.
- Any point on the curve is established by hooking the tape over the peg O and swinging the radius.

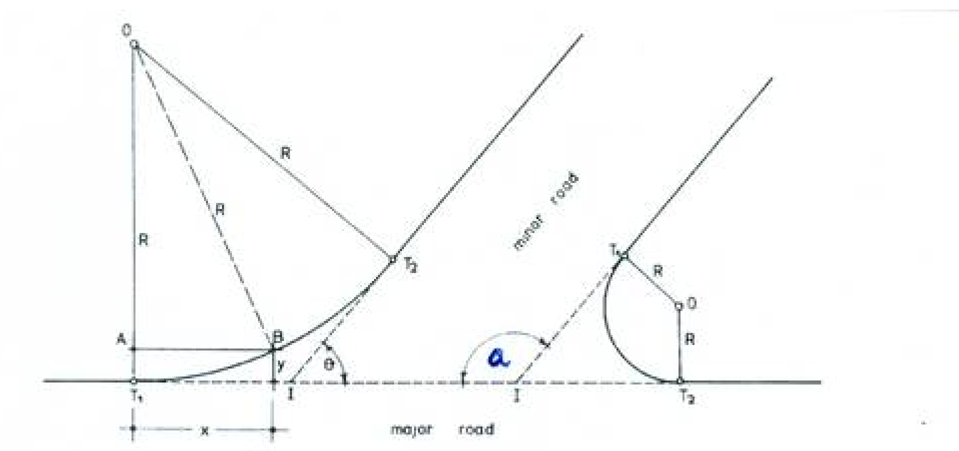


Figure 2.20

Setting out using offsets from the tangent

When the deviation angle is small (less than 50º), the length of the curve short and the centreline inaccessible, the curve can be set out from measuring offsets from the tangent. In the left hand curve of figure 2.20, y is an offset from the tangent at a distance x metres from Tangent point T1. In the figure, the line AB is drawn parallel to the tangent until it cuts the radius. The length AT1 = y and the length AO = (R – y).

In the triangle AOB,

$AO = \sqrt{OB^2 - AB^2}$ - by Pythagoras

i.e $(R - y) = \sqrt{R^2 - x^2}$

therefore $y = R - \sqrt{R^2 - x^2}$

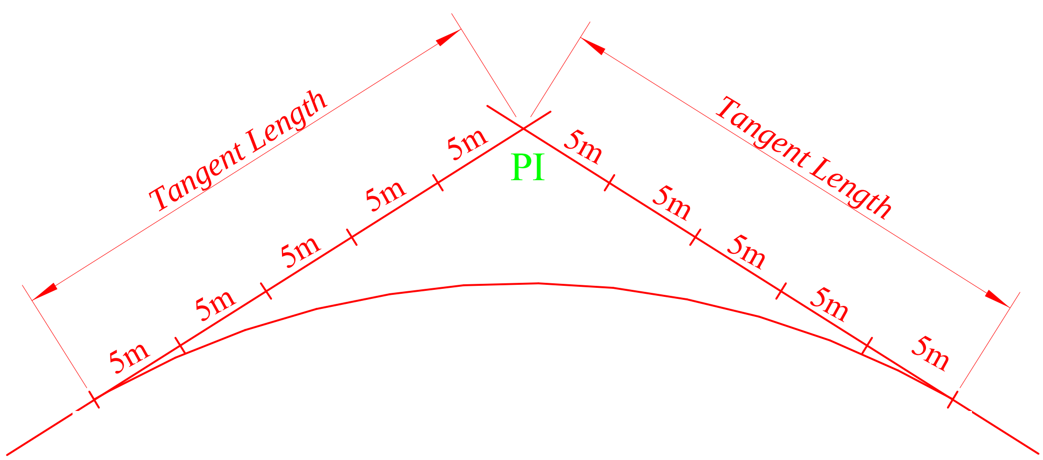
Thus the offset y can be calculated for any distance x along the tangent and can be set by eye or by optical square

Point of Intersection Method

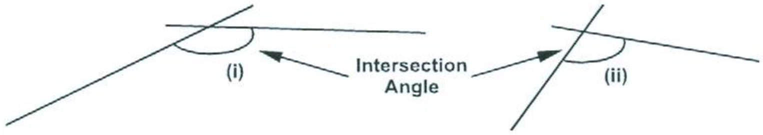
The intersection method is a simple and effective method to set out a parabolic curve. It requires simple equipment and can be easily understood.

Step 1:

First place a peg at the point where the two straight lines meet (intersection point PI). Then locate the tangent points, BC and EC. The first tangent point is where your curve begins, and the second is where it ends. Divide the tangent lines in equal lengths, by setting out a number of ranging rods along the tangent lines, at say 5m intervals



With longer tangents, you tend to achieve a longer curve with a larger radius. Deciding the length of the tangents is best done with experience. First look at the intersection angle between the two tangents:

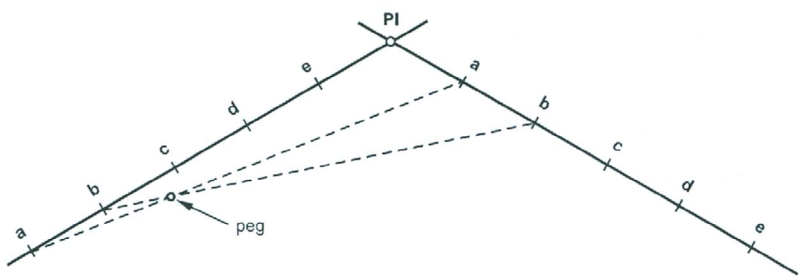


A large intersection angle (i) will produce an easy curve with a large radius. The tangent length can then be short (however, not shorter than 20m).

A smaller intersection angle will give a sharper curve with a short radius. In such situations, the tangent lines should be made longer (30, 40, 50 or 60m) to increase the radius of the curve. Sometimes, you will want to adjust the tangent length to control where the centre line of the curve goes (see below: Adjusting the Position of the Curve).

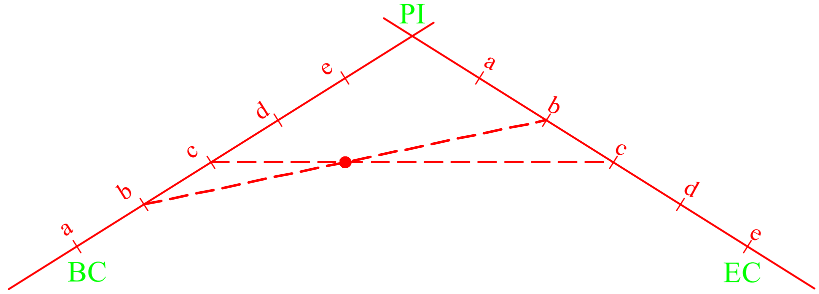
Step 2

Give each ranging rod a letter as shown in the figure below. Sight along line a – a with an assistant holding a ranging rod in your sight line. A second assistant stands at point b and sights along the line b - b. Move your assistant along line a - a until he also stands on line b - b. Mark this spot with a ranging rod and a peg. This is your first point defining the curve.



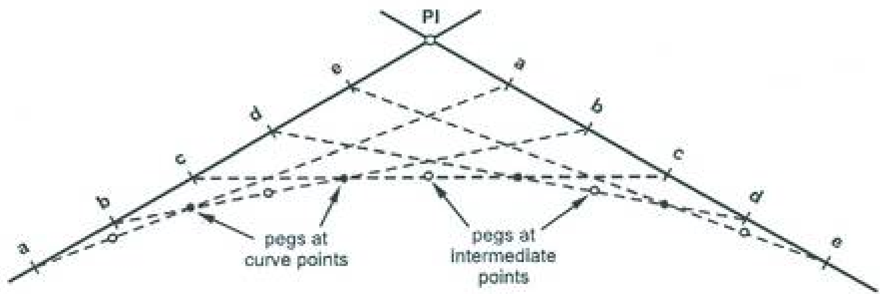
Step 3

Now repeat this exercise by sighting along b - b while an assistant is sighting along c - c to find your next curve point.



Step 4

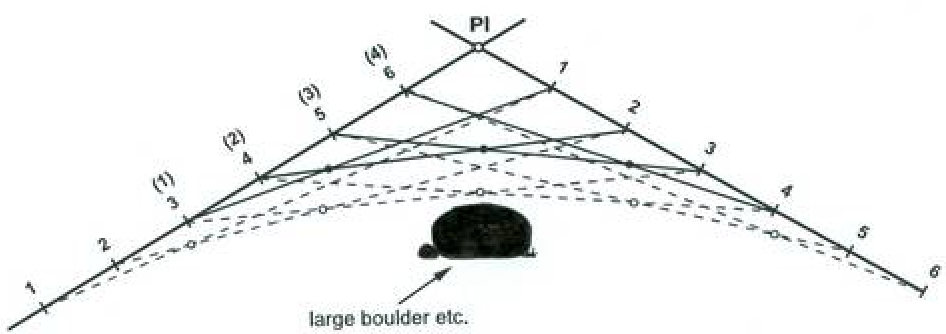
Complete the exercise for line c - c, d - d, etc. Finally, use these curve points to set out intermediate points along the curve at 5 m intervals. Inspect the curve and make sure that all the points provide a smooth curve.



Adjusting the Position of the Curve

You always get one curve point less than the number of ranging rods on the tangent length. For example, 5 ranging rods will give you 4 curve points (as above).

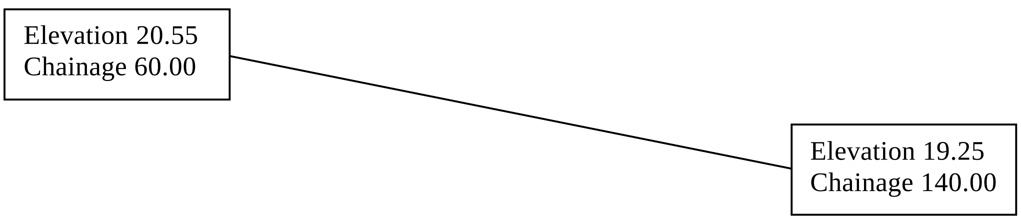
Even numbers of ranging rods gives uneven numbers of curve points, then the middle curve point will be opposite the intersection point, PI. Where the middle two lines intersect is the middle point of the curve (as below with 3-3 & 4-4 and 2-2 & 3-3).



If you increase the length of the tangent lines, the curve moves further away from PI. You can use this when you need to set out the centre line of the curve to avoid obstacles such as trees, buildings, boulders, etc.

Assessment tasks

1. What do you understand by the following terms as used in road surveying
   a. Slope
   b. Chainage
   c. Centrelines
2. Calculate the gradient of a curve given the following information:



3. Describe the process of setting out right angles using the 3-4-5 method
4. Describe the process of setting out using water level
5. How would you go about setting out curves under the following cases:
   a. The radius of a curve is 150m
   b. The radius of a curve is 25m
   c. Using off-set from the tangent

Topic 3 - Soils, gravels and road-building materials

Outcomes

Subject Outcome

3.1 Explain and use road-building materials.

Learning Outcome

3.1.1 Define different types of soils in road construction

3.1.2 Explain the differences between clay, silt, sand and gravel in terms of their particle sizes and physical properties.

3.1.3 Describe the mechanical properties of soils

3.1.4 Describe compaction of soil with reference to optimum moisture content

3.1.5 Using dry soil and water, demonstrate how you would achieve optimum moisture content by means of a simple hand-test.

3.1.6 Explain and demonstrate the purpose and test methods for a grading analysis, Atterburg limits and hydrometer test.

3.1.7 Explain the swell of soils during excavation.

Soils, gravels and road-building materials

Introduction

The structural Behaviour of a road pavement during its expected structural life is dependent on the Interaction between the strength of the various pavement layers and the repeated traffic stresses imposed on the pavement structure. Moreover, in a given environment the strength of the structural layers of the pavement is dependent on the properties of the materials used in their construction. To ensure that certain minimum strength criteria are satisfied It is therefore necessary to define these physical properties.

The structural design of road pavements is based on the knowledge of both the traffic which will use the pavement during the structural design period and the behaviour of the materials contained in the layered pavement structure.

Different types of soils used in road construction

Materials used in the structural layers of the pavement should be selected according to criteria of availability, economic factors and previous experience. These criteria must be evaluated during the design stage so that materials can be selected which are the most economical and best suited to the prevailing conditions.

Pavement materials are usually indicated by means of a code, e.g. AG, G1, G5, G10, etc, which refers to materials with certain defined properties. The following tables and descriptions give an overview of these materials.

Most of the material types currently used in South Africa have been included, e.g. natural soils and gravels, processed gravels and rock, bituminous and cementitious-treated materials. TRH 14 is the basic source document defining the selection criteria for materials.

Table 3.1

Material symbols and abbreviated specifications used in the Catalogue designs

SYMBOL	CODE	MATERIAL	ABBREVIATED SPECIFICATIONS
	G1	Graded crushed stone	Dense - graded unweathered crushed stone; Maximum size 37,5 mm; 86 - 88 % apparent relative density; Soil fines PI < 4
	G2	Graded crushed stone	Dense - graded crushed stone; Maximum size 37,5 mm;100 - 102 % Mod. AASHTO or 85 % bulk relative density; Soil fines PI < 6
	G3	Graded crushed stone	Dense - graded stone and soil binder; Maximum size 37,5 mm; 98 - 100 % Mod. AASHTO ; Soil fines PI < 6
	G4	Crushed or natural gravel	Minimum CBR = 80 % @ 98 % Mod. AASHTO; Maximum size 37,5 mm; 98 - 100 % Mod. AASHTO; PI < 6; Maximum Swell 0,2 % @ 100 % Mod. AASHTO. For calcrete PI ≤ 8
	G5	Natural gravel	Minimum CBR = 45 % @ 95 % Mod. AASHTO; Maximum size 63 mm or 2/3 of layer thickness; Density as per prescribed layer usage; PI < 10; Maximum swell 0,5 % @ 100 % Mod. AASHTO *
	G6	Natural gravel	Minimum CBR = 25 % @ 95 % Mod. AASHTO; Maximum size 63 mm or 2/3 of layer thickness; Density as per prescribed layer usage; PI < 12; Maximum swell 1,0 % @ 100 % Mod. AASHTO *
	G7	Gravel / Soil	Minimum CBR = 15 % @ 93 % Mod. AASHTO; Maximum size 2/3 of layer thickness; Density as per prescribed layer usage; PI < 12 or 3GM** + 10; Maximum swell 1,5 % @ 100 % Mod. AASHTO ***
	G8	Gravel / Soil	Minimum CBR = 10 % @ 93 % Mod. AASHTO; Maximum size 2/3 of layer thickness; Density as per prescribed layer usage; PI < 12 or 3GM** + 10; Maximum swell 1,5 % @ 100 % Mod. AASHTO ***
	G9	Gravel / Soil	Minimum CBR = 7 % @ 93 % Mod. AASHTO; Maximum size 2/3 of layer thickness; Density as per prescribed layer usage; PI < 12 or 3GM** + 10; Maximum swell 1,5 % @ 100 % Mod. AASHTO ***
	G10	Gravel / Soil	Minimum CBR = 3 % @ 93 % Mod. AASHTO; Maximum size 2/3 of layer thickness; Density as per prescribed layer usage; or 90% Mod. AASHTO

Table 3.2

Material symbols and abbreviated specifications used in the Catalogue designs

SYMBOL	CODE	MATERIAL	ABBREVIATED SPECIFICATIONS
	C1	Cemented crushed stone or gravel	UCS**** : 6,0 to 12,0 MPa at 100 % Mod. AASHTO; Specification at least G2 before treatment; Dense - graded ; Maximum aggregate 37,5 mm
	C2	Cemented crushed stone or gravel	UCS : 3,5 to 6,0 MPa at 100 % Mod. AASHTO; Minimum ITS ***** = 400 kPa at 95 - 97 % Mod. AASHTO compaction; Specification at least G2 or G4 before treatment; Dense - graded; Max. aggregate 37,5 mm; Max. fines loss = 5 %******
	C3	Cemented natural gravel	UCS : 1,5 to 3,5 MPa at 100 % Mod. AASHTO; Minimum ITS***** = 250 kPa at 95 - 97 % Mod. AASHTO compaction; Maximum aggregate 63 mm; 5 % Maximum PI = 6 after stabilization; Max. fines loss = 20 %
	C4	Cemented natural gravel	UCS : 0,75 to 1,5 MPa at 100 % Mod. AASHTO; Minimum ITS***** = 200 kPa at 95 - 97 % Mod. AASHTO compaction; Maximum aggregate 63 mm; 5 % Maximum PI = 6 after stabilization; Max. fines loss = 30 %
	BEM	Bitumen emulsion Modified gravel	Residual bitumen: 0,6 - 1,5 % (SABITA, manual 14, 1993); Minimum CBR = 45 and Minimum UCS = 500 kPa @ 95 % Mod. AASHTO. Compaction: 100 - 102 % Mod. AASHTO
	BES	Bitumen emulsion Stabilized gravel	Residual bitumen 1,5 - 5,0 % (SABITA, manual 14, 1993); Minimum ITS***** = 100 kPa; Minimum resilient modulus 1000 kPa. Compaction: 100 - 102% Mod. AASHTO
	BC1	Hot - mix asphalt	LAMBS; Max. size 53 mm (SABITA, manual 13, 1993)
	BC2	Hot - mix asphalt	Continuously graded; Max. size 37,5 mm
	BC3	Hot - mix asphalt	Continuously graded; Max. size 26,5 mm
	BS	Hot - mix asphalt	Semi - gap graded; Max. size 37,5 mm
	AG	Asphalt surfacing	Gap graded (TRH 8, 1987)
	AC	Asphalt surfacing	Continuously graded (TRH 8, 1987)
	AS	Asphalt surfacing	Semi - gap graded (TRH 8, 1987)
	AO	Asphalt surfacing	Open graded (TRH 8, 1987)
	AP	Asphalt surfacing	Porous (Drainage) asphalt (SABITA, manual 17, 1994)
	S1	Surface treatment	Single seal (TRH 3, 1996)
	S2	Surface treatment	Multiple seal (TRH 3, 1996)
	S3	Sand seal	See TRH 3, 1996
	S4	Cape seal	See TRH 3, 1996
	S5	Slurry	Fine grading
	S6	Slurry	Medium grading
	S7	Slurry	Coarse grading
	S8	Surface renewal	Rejuvenator
	S9	Surface renewal	Diluted emulsion
	WM1	Waterbound macadam	Max. size 75 mm; Max.PI of fines = 6; 88 - 90 % apparent relative density
	WM2	Waterbound macadam	Max. size 75 mm; Max.PI of fines = 6; 86 - 88 % apparent relative density
	PM	Penetration macadam	Coarse stone + keystone + bitumen
	DR	Dumprock	Upgraded waste rock, maximum size 2/3 layer thickness

**** UCS: Unconfined Compressive Strength (TMH 1, 1979, Method A14)

***** ITS: Indirect Tensile Strength (SABITA Manual 14, 1993)

****** Durability (TMH 1, 1979, Method A19)

Source: Draft TRH 4, Pretoria, South Africa, 1996

Table 3.3: Pavement layers where materials are often used

Layer	**Material codes (see table 1 and 2)**
Surfacing	AG, AC, AS, AO (In combination with AG, AC or AS)
Base	G1, G2, G3, G4, WM1, WM2 C1, C2, C3, C4 BC, BS, TC, TS, BT1, BT2, BT3, PM
Subbase	G5, G6 C1, C2, C3, C4 BT3
Selected layer	G6, G7, G8, G9
Subgrade	G8, G9, G10

Code	**Material**	**CBR**	**Field density**	**Max size**	**Plasticity Index**
G1	Dense graded unweathered crushed stone	-	86-88% solid density	37.5 mm	< 4
G2	Dense graded unweathered crushed stone	-	100-102% mod.	37.5 mm	< 6
G3	Dense graded stone + soil fines	-	> 98% mod.	37.5 mm	< 6
	Natural gravel base				
G4	Natural gravel subbase	> 80%	> 98% mod.	37.5 mm	< 6
G5	Natural gravel sub-base	> 45%	> 95% mod.	63 mm	< 10
G6	Gravel-soil selected sub-grade	> 25%	> 95% mod.	2/3 layer	< 10
G7	Gravel-soil sub-grade	> 15%	> 93% mod.	2/3 layer	< 3xGM + 10
G8	Soil lower sub-grade	>10%	> 93% mod.	-	< 3xGM + 10
G9	Soil fill	> 7%	> 90% mod.	-	-

G10		> 3%	> 90% mod.	-	-

Granular materials and soils (G1 to G10)

Generally, these materials show stress-dependent behaviour and, under repeated stresses, deformation can occur through shear and / or densification. However, by controlling the applied stresses (i.e. traffic loading), the rate of this deformation can be controlled.

A G1 is a dense-graded, unweathered, crushed stone material compacted to 86 to 88 % of apparent relative density. An unsuitable gradation may be adjusted only by the addition of crusher sand or other stone fractions obtained from crushing of parent rock.

G2 and G3 materials are crushed stone materials compacted to 100-102 % mod. AASHTO density or 85 % of bulk relative density. G2 and G3 may be a blend of crushed stone and other fine aggregate used to adjust the grading.

G4 to G10 materials cover the range of relatively high quality gravels to relatively lower quality materials used in pavement layers. The durability of these materials should be checked against current specifications especially when using marginal materials on low volume roads

Modified Materials

Natural gravels may be modified with relatively low quantities of cementitious or bituminous stabilizers (2 - 3 %). This practice improves material workability and moisture sensitivity, even though the quantity may be too low to prevent detrimental carbonation in the cemented materials.

Further compaction as well as quality control testing of this material is done approximately 24 hours after mixing.

Cemented Materials

Cemented materials, similar to concrete, are initially elastic and have limited tensile strength and usually crack under repeated flexure. These materials also crack because of shrinkage during drying.

A C2 material may be used when a non-pumping, erosion-resistant layer is required (as for a subbase of a concrete pavement).

Both C3 and C4 materials can be used in place of natural gravel layers in bases and subbases. They can be either cement treated or lime treated, depending on the properties of the natural materials. The longer term durability and resistance to erosion of these materials should, however, be carefully assessed.

Bitumen emulsion treated materials

Bitumen emulsion treated materials, also known as Granular Emulsion Mixes (GEMS) (SABITA, manual 14, 1993), are granular materials which have been modified with emulsion containing 0,6 % - 1,5 % residual bitumen, i.e. Bitumen Emulsion Modification (BEM) or stabilised with emulsion containing 1,5 % - 5,0 % residual bitumen, i.e. Bitumen Emulsion Stabilisation(BES)

Hot-mix asphalt materials

Hot-mix asphalt materials are visco-elastic and may be temperature dependent. Under repeated stresses the asphalt layer may either crack or deform or both. At low temperatures asphalt cracks and at high temperatures it deforms, usually by rutting. This behaviour, however, also depends on the type and quality of the supporting layers in the pavement structure.

The hot-mix asphalt material class has been divided into BC1, BC2, BC3 based on the maximum aggregate size and includes Large Aggregate Mixes for Bases (LAMBS).

Surfacing (AG to AP, S1 to S8)

Surfacing Seals (S1 – S8)

For a road to perform optimally (functionally and structurally), a durable, waterproof, skid resistant and all weather dust-free surfacing is required to provide the road user with an acceptable level of service and to protect the structural layers of the pavement from abrasive forces of traffic as well as from the effects of the environment.

In South Africa bituminous seals and slurries are commonly used for new construction and for resealing of existing bituminous roads because they are relatively inexpensive and have proved to be successful on highways, rural roads and urban streets, under traffic conditions varying from light to heavy. This section looks at some the surfacing seals using conventional and modified binders.

The main functions of a surfacing seal are to:

- Provide a waterproof to the underlying layers
- Provide a safe all-weather, dust free riding surface for traffic with adequate resistance
- Protect the underlying layer from the abrasive and destructive forces of traffic and the environment.

Since most seals are relatively thin, there have no load distribution properties. However, the seal itself should be able to accommodate the horizontal and vertical traffic-induced stresses.

A seal consists of a coat of bituminous binder sprayed onto a road surface which is then covered with a layer of aggreagate (stone or sand). The aggregate cover is applied immediately after the binder has been sprayed and then rolled to ensure close contact and thus good adhesion between the aggregate and the binder film. Rolling initiates the process of obtaining the particles into a mosaic pattern and working the binder into the voids between aggregate particles. The process is completed by the action of traffic, so that finally a dense and relatively impermeably pavement surfacing is obtained.

The most commonly used seals are single seal, double seal, Cape seal, slurry seal and sand seal. Different types of seals are illustrated in figure 3.1.

The cheapest and simplest seal is a sand seal, comprising a cutback bitumen tack coat sprayed across the base followed immediately by a heavy application of clean sand. The sand is rolled into the tack coat by pneumatic roller. More sand is added until the entire tack coat is blotted up by the sand. Sand seals are thin and are not robust and so are very dependant upon the strength and stiffness of the base for their performance.

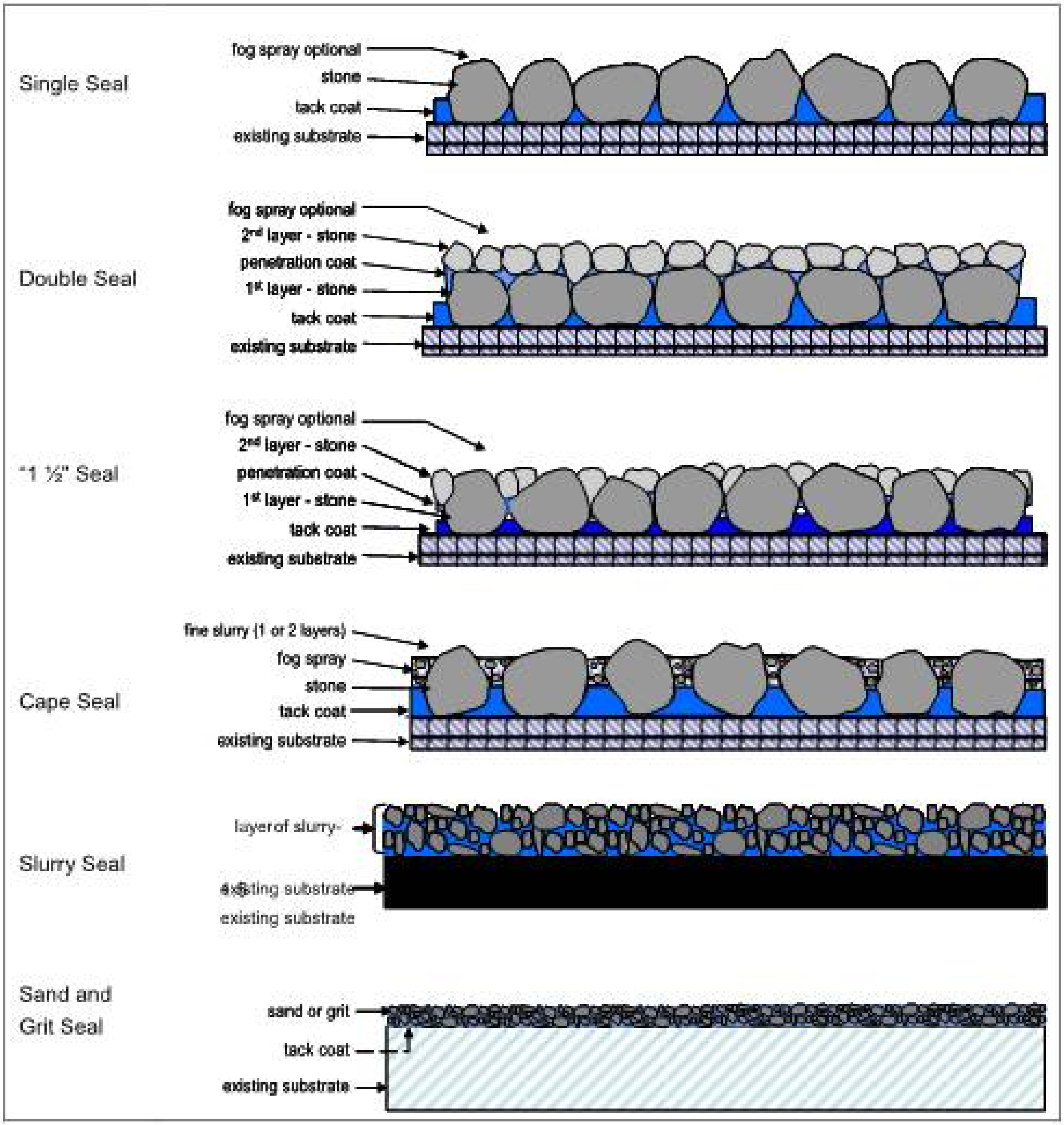


Figure 3.1: Surfacing seals

Single and multiple seals are constructed by spraying a binder or tack coat uniformly across the surface of the base and then spreading a single layer of selected single-sized stone across the binder. The aggregate is rolled into the binder with a steel-wheeled roller. Light drag brooming, after initial rolling, aids the uniform spread of aggregate into the binder. Further rolling completes the embedment of the aggregate into the tack coat. This comprises a single seal. A second tack coat, normally called a penetration coat, can then be sprayed, followed by a second layer of aggregate, rolled in, drag-broomed and rolled again, as before. This comprises a double seal.

A **Cape Seal** comprises a single seal that is covered with a generous layer of slurry. When the single seal comprises 13 mm aggregate or smaller, one layer of slurry is applied. However, when a 19 mm single seal is used, a double application of slurry is needed. The final product has the tips of the coarse aggregate showing above the slurry layer. The stone tips provide good skid resistance and the slurry provides considerable strength to the stone matrix. A Cape Seal is a robust seal, very resistant to water penetration and comfortable to walk on.

A **slurry seal** can be laid as the final seal, straight onto the base, but suffers from the same problems as a sand seal (thin, not robust, dependant on base strength). However, when used in maintenance or rehabilitation and applied onto existing bituminous surfacings, a slurry seal is excellent. Because it is rich in bitumen, it is weather resistant and waterproof and restores these qualities to the old surfacing, be it a seal or a premix. The use of crusher dust in the slurry gives good micro-texture to the slurry, enhancing skid resistance.

Finally there are many combinations of the above seal types that have some advantage in particular circumstances.

The problems that must be overcome during the application of surfacing seals are:

- Binder must adhere to the base and hold the lower portion of every stone of the seal.
- Good adhesion between aggregate and binder is essential and depends both on the binder type and the aggregate type.
- The shape and size of the surfacing aggregate determines the voids available for the binder.
- The hardness of the base determines how far the aggregate will embed into the surface of the base under traffic, reducing the voids available for the binder.
- Traffic compaction and wear will further reduce the voids in the aggregate.
- Rate of application of both binder and aggregate.
- Good construction technique to produce a dense interlocking mosaic of stone.
- Climate and surface drainage conditions.
- Topography: steep slopes and sharp curves.
- Binder application must be sufficient to securely hold the aggregate and yet not too much that will fill the voids in the stone and spread across the surface (called flushing or bleeding of the

binder). Flushing produces a slick smooth surface that is particularly slippery when wet.

Table 3.4: Seal recommendation

Turning Actions	**Recommended Surfacing types for Initial Surfacing**								
	S3	S7	S1	S2(9)	S2(13)	S4(13)	S2(13/6)	S4(19)	S2(19/9) S2(19/6)	AC
Rural with occasional heavy vehicles	√	√a	√	√	√	√	√	√	√	√
Residential - developed	x	√a	√b	√	√	√	√	√	x	√
Residential - developing	x	√a	x	x	x	√	x	√	x	√
Urban with occasional heavy vehicles	x	√a	x	x	x	√	√b	√	x	√
Urban with many heavy vehicles	x	x	x	x	x	x	x	x	x	√

Notes:

a – Only thick slurries (>10mm)

b – Preferably blinded with coarse sand

x – Not recommended

Asphalt surfacing (AG, AC, AS and AO)

Hot-mix asphalt may be designed and produced from many different aggregate types, a wide range of aggregate size combinations and various binder types. Each mix has its own particular properties which make it suitable for specific conditions of use. Hot-mix asphalts are normally distinguished by aggregate grading; Some of the commonly used types are as follows: gap-graded, semi-gap-graded, continuously-graded, dense bitumen macadam (DBM), and open-graded mixes.

All these mixes can be produced using a blend of new and reclaimed materials. Such mixes are prefixed by the term 'recycled', e.g. recycled continuously-graded asphalt. Hot-mix asphalt is generally produced using a penetration grade bitumen or, at times, low-volatile tar. Modified binders that can be used include bitumen-rubber and polymer-modified binders. An asphalt mix is normally modified to

improve one or more of the engineering properties such as durability, fatigue resistance and resistance to plastic deformation.
The use of a modified binder is sometimes accompanied by a modification to the aggregate grading. This would, for example, allow these mixes to accommodate more binder, thereby improving their flexibility and crack resistance.

However, experience in the long-term performance of modified mixes is limited and mix design procedures and criteria are not well defined. Consequently, the use of modified mixes is often preceded by research and extensive laboratory testing, though the design criteria for conventional mixes are generally used as guidelines.

Modified mixes should not be used when conventional products provide adequate engineering properties. It is also evident from the uncertainties related to the long-term performance and design criteria of modified mixes that these mixes should be used with discretion.

Gap-graded

As the names imply, gap-graded and semi-gap-graded asphalts have a certain range of particle sizes missing from the total aggregate grading.

Gap-graded asphalt consists of coarse aggregate of a fairly uniform size blended with fine aggregate and filler, while semi-gap-graded asphalt consists of a more graded coarse aggregate blended with fine aggregate and filler. Both types of mix have been used with great success in South Africa as surfacings, bases and overlays.

Research studies have indicated that gap-graded and semi-gap-graded mixes are superior to more densely graded mixes as regards fatigue resistance. In practice, however, this will depend on the combination of layer thicknesses. For certain layer thickness combinations the strains in more continuously-graded mixes may be lower, owing to their increased stiffness. This can result in similar or higher fatigue lives for densely graded mixes than for gap-graded mixes.

Macadams

Waterbound Macadams

Waterbound Macadams (WM) consist of a coarse, single-sized aggregate together with fine material which is added during construction to fill the voids. A wet or dry method of construction can be used. WM 1 is compacted to 88 to 90 % of apparent relative density and WM2 to 86 to 88 % of apparent relative density.

These materials show stress-dependent behaviour similar to that of other granular materials. Under repeated stresses, deformation can occur through shear and / or densification. Waterbound macadams are highly resistant to the influence of water and are mostly used for pavements carrying heavy traffic in wet regions.

Recent research indicated that Waterbound Macadam base courses are capable of withstanding significantly higher shear stresses than crushed stone base courses (Phillips, 1994).

Penetration Macadam (PM) has a coarse single-sized aggregate and the voids are partially filled with hot bitumen.

Dense Bitumen Macadam

Dense Bitumen macadam is a very coarse and dense, continuously-graded asphalt mix intended for use as a base.

Nominal stone sizes of up to 40 mm are generally used, and this type of mix derives its high resistance to plastic deformation from the well-graded coarse aggregates. Dense bitumen macadam asphalt bases are used with great success under very heavy traffic conditions (up to 4 000 E80s per lane per day) in the UK. This mix type has not been used often in South Africa, but a few larger municipalities have reported very good performance.

Dense bitumen macadam asphalt bases may be a viable solution in areas where permanent deformation problems are encountered, such as those caused by the combined effect of slow-moving heavy traffic and high pavement temperatures. The relatively low binder content of this mix type, together with the coarseness of the aggregate, makes this mix unsuitable for use in surfacings.

Open-Graded Asphalt

Open-graded asphalt has an aggregate grading designed to give a high voids content in the aggregate structure, which results in a relatively coarse and open surface finish. It is normally used in a thin layer, e.g. 25 mm, to provide improved skid resistance, reduction in spray and splash from vehicles in wet weather, and reduced surface noise.

However, the high air voids content, essential to meet these requirements, may become partially filled with dust, reducing the effectiveness of this mix in the long term.

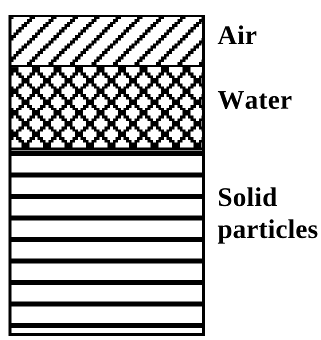
These surfacings are permeable to surface water. It is imperative, therefore, that they are laid over an impermeable asphalt layer, or seal, to ensure that the underlying pavement layers are protected. Durability may be a problem in the long term, and special care should be taken when selecting the binder type.

Open-graded asphalt does not distribute traffic stresses as well as the dense mixes, and should not be used as a strengthening course.

Differences between clay, silt, sand and gravel

Soil is a naturally occurring, unconsolidated or loose covering on the Earth's surface. It is composed of particles of broken rock that have been altered by through weathering and erosion. Soil has varying amounts of organic matter, minerals, and nutrients.

Soil is composed of solid particles, water and air voids.



Different-sized mineral particles, such as sand, silt, and clay, give soil its texture. Sand, silt, and clay are the basic types of soil. Most soils are made up of a combination of the three. The texture of the soil, how it looks and feels, depends upon the amount of each one in that particular soil. The type of soil varies from place to place and can even vary from one place to another in your own backyard.
The basic types of soils are indicated in the table below.

Soil	**Grain Size**	**Grain shape**	**Soil group**
Gravel	Over 2mm	Spherical or cubical	Granular
Sand	0.0625 to 2 mm	Spherical or cubical	Granular
Silt	Particles not visible to the eye	Spherical or cubical	Granular
Clay	Particles smaller than silt	Flat, plate shaped	Cohesive

Gravel

Gravel is rock that is of a specific particle size range. Specifically, it is any loose rock that is larger than two millimeters in its largest dimension and no more than 64 millimeters.

Gravel is an important commercial product, with a number of applications. Many roads are surfaced with gravel, especially in rural areas where there is little traffic. Globally, far more roads are surfaced with gravel than with concrete. Both sand and small gravel are also important for the manufacture of concrete.

Sand

Sand is a granular material consisting of rock and mineral particles that are very small. Therefore the texture is rough. Sand is a naturally occurring, finely divided rock, comprising particles or granules ranging in size from 0.0625 to 2 mm. An individual particle in this range size is termed a sand grain.

Silt

Silt consists of fine grains of soil minerals ranging between clay and sand in size. Silts are often laid down by rivers when the flood water is quiet. The diameter of silt particles ranges from 0.002 mm to 0.06 mm. Silt is easily transported in water and is fine enough to be carried long distances by air as “dust”.

Clay

A fine-grained, firm earthy material that is plastic when wet and hardens when heated, consisting primarily of hydrated silicates of aluminum. It occurs naturally and consists of very fine grained material with very less air spaces. Clay soil is formed after years of rock disintegration and weathering. It is also formed as sedimentary deposits after the rock is weathered, eroded and transported. The main differences between sand, silt and clay is the size of the particles. Sand has the largest, and is coarse. Silt has smaller particles, and feels slippery to the touch. Clay has the smallest particles, and feels like plastic. The amount of water that each allows to pass through decreases as the particles get smaller, which is why sand drains much better than clay.

Gravel and sand are coarse grained soils, while sand and silt are fine grained. Clays are cohesive soils, since the grains are bonded to each other. Gravels, sands and silts are usually found as individual grains. Most sands and silts may appear to have some cohesion when moist. But this cohesion is due to the moisture film around the grains, and disappears when the soil dries out.

Basic soil properties

To have an understanding of the soil action, the engineer must be familiar with certain basic properties of the soil. It must be remembered that the properties of any given soil depend not only on its general type but also on its condition at the time when it is being examined.

Strength bearing capacity

Bearing capacity is the capacity of soil to support the loads applied to the ground. The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil.

A pavement, like any other engineering structure, is designed to withstand certain loads. In this case the primary load that needs to be considered in the design is the traffic spectrum that will be carried by the road. The bearing capacity of a structurally well balanced pavement structure increases evenly with increasing depth (cover) over the subgrade material.

Permeability

The ability of water to flow through a soil (under action of gravity or applied force) is referred to as the soil's permeability. Different soil types have varying degrees of permeability.

It is generally the pore sizes and their connectivity that determines whether a soil has high or low permeability. Water will flow easily through soil with large pores with good connectivity between them. Small pores with the same degree of connectivity would have lower permeability, because water would flow through the soil more slowly. The permeability of gravel is higher than that of clay.

Compaction

Compaction is the process whereby the volume of air in the soil is reduced. The compaction is normally achieved through the use of compaction equipment. During this process solid particles become more closely spaced. This reduction of air volume in a mixture produces a corresponding increase in material unit weight, or density.

Compaction is the greatest determining factor in dense graded pavement performance. Inadequate compaction results in a pavement with decreased stiffness, reduced fatigue life, accelerated aging / decreased durability, rutting, and moisture damage.

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The extent of compaction depends on the moisture content of the soil and the compactive effort used.

Swell

A soil increases in volume when it is excavated because soil grains are loosened during excavation and air fills the void spaces created. As a result, a unit volume of soil in the bank condition will occupy more than one unit volume after excavation. This phenomenon is called Swell and may be calculated as follows:

$$\text{Swell}\,(\%) = \left(\frac{\text{Weight (bank volume)}}{\text{Weight (loose volume)}} - 1 \right) x100$$

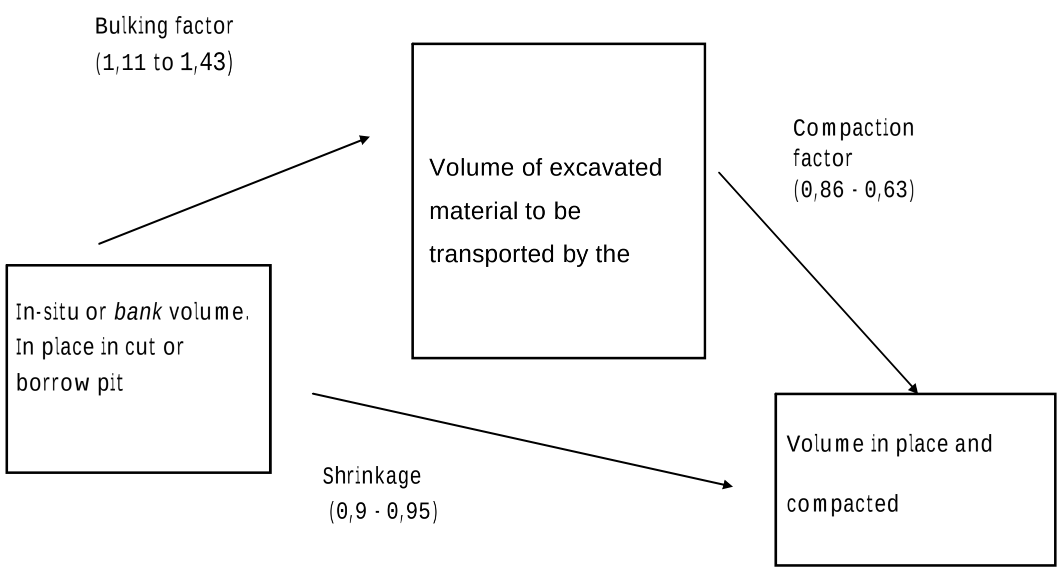
The swelling must be taken into account when assessing the amount of transport required, for costing and construction purposes.

Shrinkage

Shrinkage is the term used to describe reduction of the volume of a material that has been excavated when it is used as fill in an embankment. A small proportion of this loss may be attributed to spillage during transport from the cut to the fill, but the main loss occurs because the bank volume of the material is greater when in its natural state before being excavated than the compacted volume of the same material after it has been used to form an embankment.

This shrinkage factor must be determined for the material concerned and included in the calculations of the earthworks cost estimate and claims for payment. The factor is usually not applicable to rock but significant for most soils.

$$\text{Shrinkage}(\%) = \left(1 - \frac{\text{Weight (bank volume)}}{\text{Weight (compacted volume)}}\right) x100$$



Soil type	Condition Representing 1 m^3	Altered condition (m3)		
		Bank	Loose	Compacted
Sand	Natural state	1	1,11	0,95
	Loose	0,9	1	0,86
	Compacted	1,05	1,27	1
Average soil	Natural state	1	1,35	0,81
	Loose	0,8	1	0,72
	Compacted	1,22	1,29	1
Clay	Natural state	1	1,43	0,9
	Loose	0,7	1	0,63
	Compacted	1,11	1,59	1

Optimum Moisture content

The optimum moisture content (OMC) is an important characteristic of a soil, as it gives the amount of water that should be present in the soil during compaction, so that the maximum density can be obtained.

Compaction requirements are measured in terms of dry density of the soil. The expected value for dry density varies with the type of soil being compacted. For example clay soil may be rolled many times and not reach 2000 kg/m^3, whereas a granular soil may have a dry density above this value without any compactive effort. Therefore the value for the maximum dry density that can be expected must be established for each soil.

Under any compactive effort, the dry density of a soil varies with its water content. A soil compacted dry will reach a certain dry density. If compacted again with the same compactive effort – but this time with water in the soil, the dry density will be higher since the water lubricates the grains and allows them to slide into a denser structure. Air is forced out of the soil leaving more space for soil solids, as well as added water. With an even higher water content, a still greater dry density may be reached since more air is expelled. However, when most of the air in the mixture has been removed, adding more water to the mixture before compaction results in a lower dry density. The extra water takes the place of the solids.

Compaction Test

The objective of a compaction test is to determine the optimum moisture content and maximum dry density achievable with a given compactive effort. A plot of dry density versus moisture content (Figure 3.4) indicates that compaction becomes more efficient up to a certain moisture content, after which the efficiency decreases. The maximum dry density is obtained at this optimum moisture content.

If the compaction process were completely efficient, it would be possible (but not necessarily desirable) to expel all the air from the voids, in which case the dry density would correspond to a zero-air voids state (ie. the sample would be saturated with water). Since perfect compaction is not possible (except at high moisture contents and low dry density) the compaction curve will always fall below the ideal or zero-air voids curve (Figure 3.4).

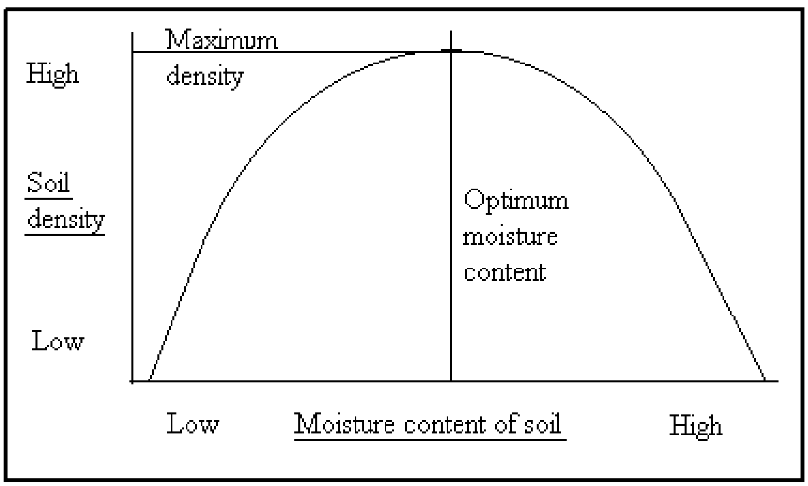


Figure 3.4

It should be noted that there are a number of standards for compaction tests, each differing in the amount of energy input into compaction. For a given soil the different tests will produce different maximum dry densities and optimum moisture contents (ie. these parameters are NOT soil properties). The maximum dry density and optimum moisture content are only relevant for a specified compaction procedure which should be stated when presenting the results.

In earthworks it is common to specify a dry density within a certain percentage of the maximum determined from a specified compaction test. For this to be a sensible procedure it is important that the compactive effort used in the laboratory is comparable to that supplied by the field equipment.

Laboratory procedure

About 2.5 kg of the soil is provided that it will pass through a 4.75mm sieve. The soil sample should be mixed with water and placed in the standard mould provided in 3 approximately equal layers. Each layer is to be compacted with 25 blows from a special compaction hammer. When the mould is full the weight of soil should be measured and then two moisture content samples should be taken for drying in the oven. The volume of the mould is approximately 944 cm^3 and should be checked by measurements of cylinder height and diameter. The remaining soil should be removed from the mould, broken down until it will again pass a 4.75mm sieve (determine visually), remixed with more water added, and then re-compacted into the mould.

The compaction test should be repeated five times with the assumed moisture content used in calculations to ensure that the dry density versus moisture content plot has points on both sides of the optimum moisture content. This assumed dry density and moisture content plot that must be produced during the session, will later be replaced in the report by a plot with the calculations based upon the average of the moisture contents measured with the sample tins.

The two groups performing the experiment should use different compaction hammer weights. To complete the report you will need to use the dry density versus moisture content data for both hammer weights.

Moisture Content

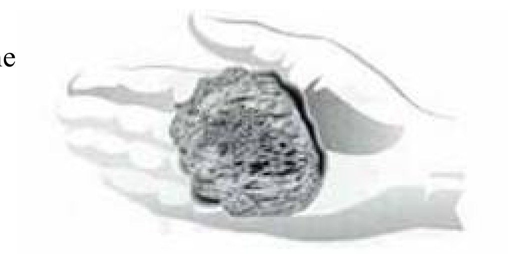
Determination No.	**1**	**2**	**3**	**4**	**5**
Container No.					
Container & Wet soil (g)					
Container & Dry soil (g)					
Container (g)					
Water Ww (g)					
Dry soil Ws (g)					
Moisture content (%)					

Dry Density

Determination No.	**1**	**2**	**3**	**4**	**5**
Mass mould & Compacted soil (g)					
Mass mould (g)					
Mass Compacted soil (g)					
Wet density ρt (g/cm3) or (t/m3)					
Dry Density ρd (g/cm3) or (t/m3)					

The hand test method

A quick method of determining moisture is known as the "Hand Test".



Procedure

Pick up a handful of soil.

Squeeze it in your hand.

Open your hand.

If the soil is powdery and will not retain the shape made by your hand, it is too dry. If it shatters when dropped, it is too dry. If the soil is moldable and breaks into only a couple of pieces when dropped, it has the right amount of moisture for proper compaction. If the soil is plastic in your hand, leaves traces of moisture on your fingers and stays in one piece when dropped, it has too much moisture for compaction.

Other test methods for materials

Every soil type behaves differently with respect to maximum density and optimum moisture. Therefore, each soil type has its own unique requirements and controls both in the field and for testing purposes. Soil types are commonly classified by grain size, determined by passing the soil through a series of sieves to screen or separate the different grain sizes.

Soil classification is categorized into various groups, a system set up by AASHTO (American Association of State Highway and Transportation Officials). Soils found in nature are almost always a combination of soil types. A well-graded soil consists of a wide range of particle sizes with the smaller particles filling voids between larger particles. The result is a dense structure that lends itself well to compaction. A soil's makeup determines the best compaction method to use. Grain sizes in soil samples are obtained by means of a two tests.

The sieve / grading analysis test is used for sand and gravels, and the hydrometer test for silts and clays.

Grading / Sieve analysis test

The type of soil is generally specified in terms of particle size present. The particles in the soil range from stones several centimetres in diameter to material that is too fine to be susceptible to direct measurement. The usual method of presenting the particles in a soil (sometimes called grading) is in terms of the percentages of particles by weight finer than specified sizes, as shown in figure 3.5 below.

The test procedure

Purpose:

To obtain the grain size distribution of a soil by sieve analysis

Theory

A sample of soil is dried out so that the weights obtained are of soil particles only and the grains are not bound together by the surface tension in water film. The sample size should be large enough to be representative of the soil being tested. The sample is placed in a nest of sieves that are arranged in order of size of opening (from large to small as shown in figure 3.5), then shaken by rotary and up-and-down motion until all the grains have passed through all sieves possible according to size.

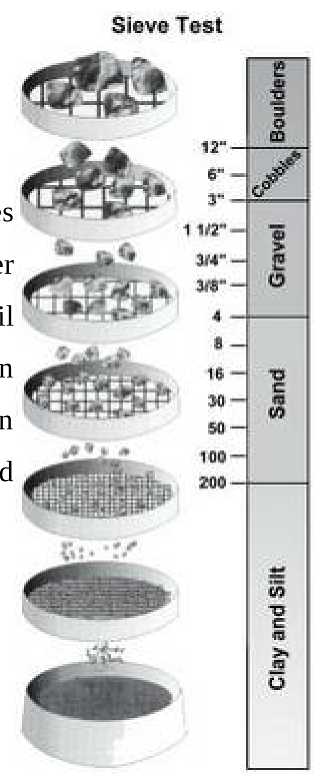


Figure 3.3

Apparatus

1. Sieves
2. Sieve shaker
3. Balances

Procedure

1. Oven dry the sample
2. Weigh the dried sample
3. Place the nest of sieves and shake for a few minutes
4. Weigh the amount of soil retained on each sieve and record the values in the table (as shown in table 3.5)
5. The amount of soil retained in each sieve is then converted to a percentage of the total mass of the dry material.
6. The percentage retained on each sieve is also converted to a percentage passing the sieve as indicated in the example below.
7. These percentages are then recorded and plotted to the nearest whole number on a suitable grading sheet (i.e figure 3.4)

Sieve Size (mm)	Mass of Soil Retained (g)	Percentage Retained	Percentage Passing
53.0	0	0	100
37.5	146	4.52	95.48
26.5	280	8.68	86.80
19.0	283	8.78	78.02
13.2	307	9.52	68.5
4.75	809	25.09	43.41
2.00	428	13.27	30.14
0.425	350	10.85	19.28
< 0.425	622	19.28	
Total	**3225**		

Table 3.5

The shape of the curve achieved says a lot about the distribution of particles. Certain broad terms are used to describe the shape of the particle distribution curve.

A **well-graded** soil is characterised by a wide range of particle sizes in proportions which give a smooth curve for the particle size distribution (Soil A).

In **gap graded** soils, although a wide range of sizes may be present, the soil is deficient in certain intermediate particle sizes. This results in a “stepped” distribution curve (Soil B).

A **uniformly graded** soil (sometimes referred to as single-sized soil) contains only a very narrow band of particle sizes (Soil C).

Examples of well-graded, gap graded and uniformly graded curves are indicated on figure 3.3.

The results of particle size distribution are of considerable value. Specifications for road bases and subbase construction use particle size analysis in the quality control of soil materials. Use is frequently made of particle size analysis for mix design or control purposes, when stabilising soils by mechanical or chemical means.

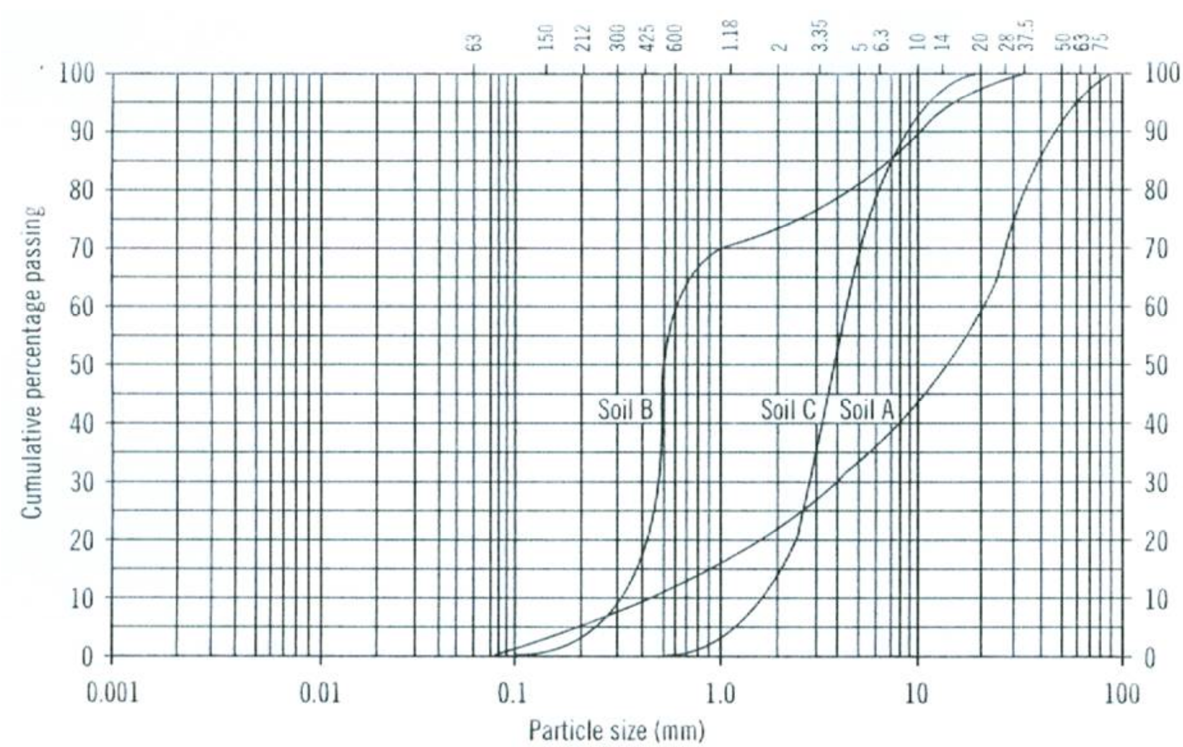


Figure 3.4

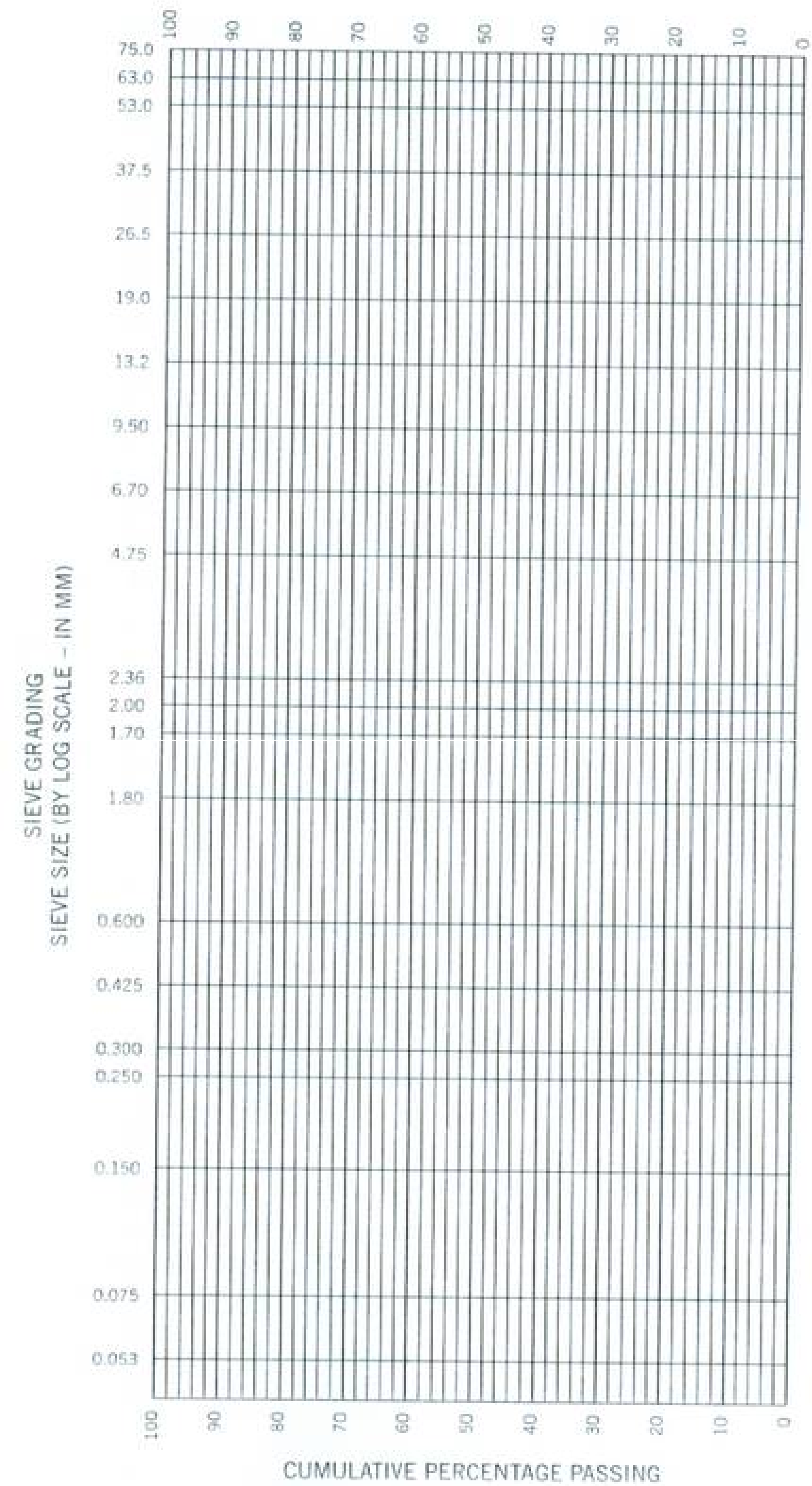


Figure 3.5: Grading sheet for sieve analysis

Hydrometer tests

This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 0,075 mm is determined by sieving while the distribution of particle sizes smaller than 0,075 mm is determined by a sedimentation process, based on Stokes's law as defined below, using a specially calibrated hydrometer. This method does not give absolute results, but gives data which are comparable and consistent if the method is followed in detail.

Apparatus

1. A balance to weigh up to 200g, accurate to 0.1g
2. A canning jar, wide mouth, about 1 000 ml capacity
3. A Bouyoucos cylinder, graduated at 1 130 and 1 205ml
4. A Bouyoucos hydrometer
5. A dispersing apparatus with paddle
6. A tablespoon
7. A stop watch
8. A water bath suitably lined or fitted with a thermostat unit to maintain a constant temperature of 20 ± 1ºC.
9. A wash bottle.
10. A dish or small basin ± 150mm in diameter.
11. A thermometer, measuring 0 to 50ºC, graduated in 0.2ºC.
12. A pipette, 10 ml in capacity.
13. Sodium silicate solution to be prepared as follows:
    Dissolve sodium silicate in distilled water until the solution gives a reading of 36 at 20ºC on the standard soil hydrometer. Filter the solution.
14. Sodium oxalate solution – this consists of a filtered saturated solution of sodium oxalate.

Method

Preparation of sample

Weigh out, accurately to 0,1g, 100g of the soil fines. If the material consists mainly of fine material with a relatively high percentage of silt and / or clay, weigh out 50g accurately to 0,1 g. The weighed sample is transferred to the canning jar, and about 400ml of distilled water and 5ml each of the sodium oxalate and sodium silicate solutions are added. The soil-water mixture is stirred well with a glass rod and left to stand for at least two hours but preferably overnight.

After the mixture has been allowed to stand, it is dispersed for 15 minutes with the standard dispersing paddle or five minutes with the egg whisk. The paddle is washed clean with distilled water, and the wash water is allowed to run into the container with the suspension.

The suspension is poured into the Bouyoucos cylinder and the canning jar is rinsed with distilled water from the wash bottle. All the suspension is tranferred quantitatively to the cylinder. The cylinder is then filled with distilled water to the 1 205ml mark (1 130ml for a 50g sample) with the hydrometer inside.

The hydrometer is removed and the cylinder inverted a few times with the palm of one hand held as a stopper over the mouth of the cylinder to ensure that the temperature is uniform throughout. It is then placed in the thermostat bath which is kept as near to 20ºC as possible. When the contents of the cylinder are approximately at 20ºC the cylinder is again shaken end over end until a homogeneous suspension is obtained. The cylinder is returned to the water bath and the time recorded. The water in the bath should come to almost the top of the contents of the cylinder but should not be too high as it will then not be possible to read the hydrometer.

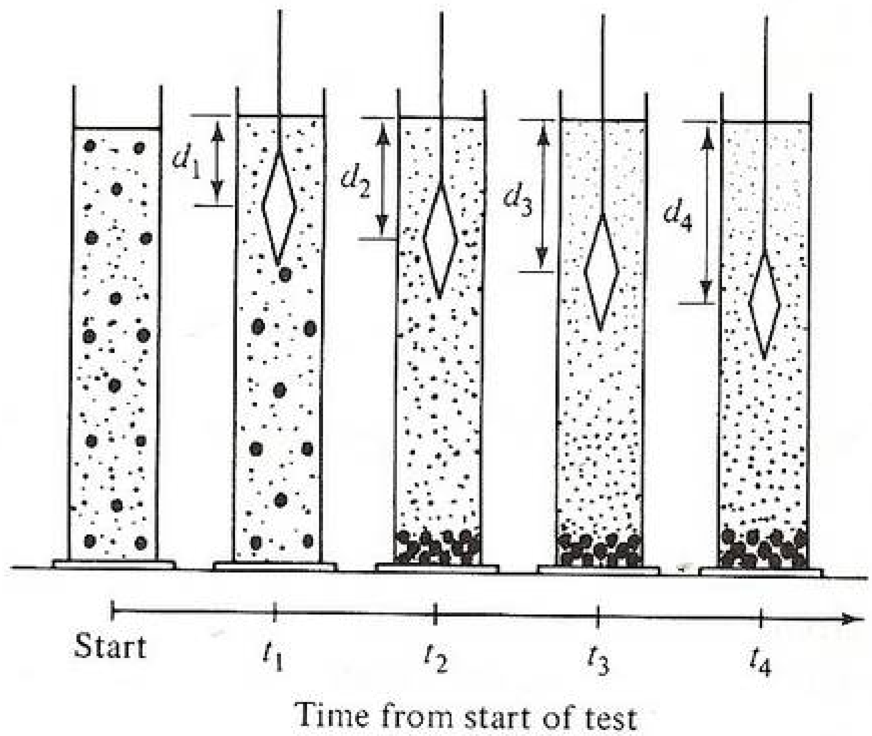
Hydrometer readings

Sixty minutes after the cylinder has been placed in the bath the hydrometer is inserted and a reading is taken to the nearest 0,5. The temperature of the contents is also determined. The hydrometer is removed and the cylinder is shaken again as described above. It is placed on a table and the stop-watch started. At about 20 seconds the hydrometer is inserted and a reading is taken at 40 seconds.

An 18-second reading, if required, can also be taken in the same way as the 40-second reading, except that the hydrometer is inserted at about 10 seconds. The temperature measured for the one hour reading is also taken as the temperature for the 40 and 18-second readings, provided the readings are taken immediately one after the other. The hydrometer readings, taken to the nearest 0.5, and the temperature should be recorded on any suitable data sheet.

The following table gives the maximum diameter of the particles as indicated by the hydrometer after different time intervals.

Hydrometer reading at	Maximum diameter Of particles in mm	Common terms
18 seconds	0.075	Material passing the 0.075mm sieve
40 seconds	0.05	Clay and silt
1 hr	0.005	Clay



Atterberg limits

The Atterberg limits are a basic measure of the nature of a fine-grained soil. They are used to distinguish between silt and clay, and they can distinguish between different types of silts and clays. They cover a range of soil tests relating to reactivity to moisture (water), better known as Plasticity.

The amount of water a soil sample can absorb before changing from a solid to semi-solid, a plastic and then to a liquid state is a very important indication of 1) whether the soil is mainly silt or clay, and 2) if it is clay, the characteristics of that particular clay minerals in the sample.

In each state the consistency and behavior of a soil is different and thus so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behavior.

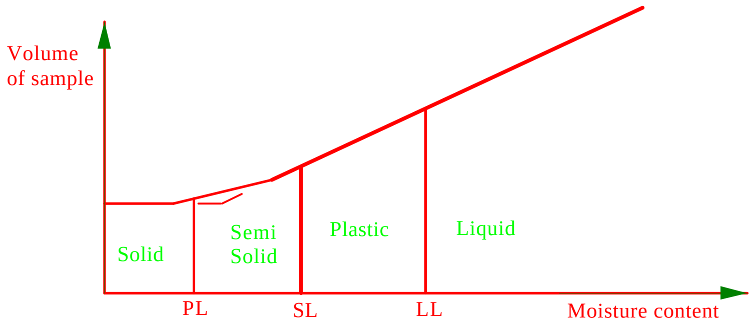


Figure 3.6

Shrinkage limit

The shrinkage limit (SL) is the water content, expressed as a percentage, where further loss of moisture will not result in any more volume reduction.

Plastic limit

The plastic limit (PL) is the water content, expressed as a percentage, at a boundary solid and semi solid state.

Liquid limit

The liquid limit (LL) is the water content, expressed as a percentage, where a soil changes from plastic to liquid behavior.

Plasticity index

The moisture range between the liquid and plastic limits is termed Plasticity Index. The plasticity index (PI) is a measure of the plasticity of a soil. The PI is the difference between the liquid limit and the plastic limit (PI = LL-PL). Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 tend to have little or no silt or clay

The test procedure

Purpose:

To determine the liquid limit of fine grained soil.

Apparatus

1. liquid limit device
2. Grooving tool
3. A drying oven
4. Calibrating plate with a thickness of 10.0mm ± 0.1mm
5. Porcelain evaporating dish with a diameter of about 10mm
6. A spatula with slightly flexible blade about 100mm long and 20mm wide
7. A burette with a capacity of 50ml or 100ml
8. A balance to weigh up to 100g, with 0.01g accuracy
9. Suitable containers such as weighing bottles with a capacity of 30 – 45ml, or matched watch glasses which will prevent the loss of moisture during weighing

Test procedure for plastic soils

48g of the thoroughly mixed soil fines (i.e material passing the 0.425mm sieve) is weighed and transferred to a porcelain dish.

Distilled water is added by means of a burette and the moist material is then thoroughly mixed for 10 minutes with a spatula. To facilitate mixing, water should be added in small quantities. When sufficient water has been mixed with the soil to form a stiff consistency, approximately three quarters of the wet soil is transferred to the brass bowl of the liquid limit device, mixed slightly and flattened out in the front portion of the bowl with the spatula.

The material is then divided into two equal portions with one cut of the grooving tool. The groove should fall along the centre line drawn through the cam-follower attached to the bowl. The device is then operated at a speed which results in two taps per second being applied to the soil, until the lower parts of the faces of the soil portions have flowed together and made contact across a distance of about 10mm. The number of taps required to close the groove across the distance is recorded and a sample of approximately 2 to 3g, representative of the total thickness of the layer, is transferred to a tarred weighing bottle for the determination of its moisture content.

The procedure is repeated for two additional determinations on the soil in the bowl of the liquid limit device. However, before each test the 2 to 3g of material from the porcelain dish is added to the material in the bowl, to ensure that the quantity of material in the bowl is approximately the same for all the determinations.

Sufficient water is added each time in order to obtain three samples of varying consistencies, so that at least one determination will be made in preferably each of the following ranges of taps: 28 to 35, 22 to 28, 15 to 22. The rest should preferably proceed from drier to wetter conditions of the soil.

The containers with the soil samples are weighed after which the samples are oven dried to constant mass at 105 to 110ºC overnight. When the containers are removed from the oven, the lids are replaced to prevent the absorption of hygroscopic moisture, and after being allowed to cool, the containers are weighed again. The loss in mass is the mass of moisture which is then expressed as a percentage of the oven dried mass of the soil.

Moisture content calculation

Procedure to find out how much moisture is in the sample is as follows:

Given: Mass of wet soil = 967 g

Mass of dry soil = 880 g

Mass of water = 87 g

Mass of moisture $= \frac{massofwater}{massofovendriedsoil} x100$

Moisture content $= \frac{Mass\ of\ water}{Mass\ of\ dry\ soil} \times 100$

$= \frac{87}{880} x100$

$= 9.89\%$

Liquid limit

A flow curve representing the relationship between moisture content and the corresponding number of taps is then drawn by plotting the moisture contents as ordinates on the natural scale and the number of taps as obscissae on a logarithmic scale. The flow curve should be a straight line drawn as near as possible through the three plotted points. The moisture content corresponding to 25 taps is then read off from the curve and is taken as the liquid limit of the soil and reported to the nearest whole number.

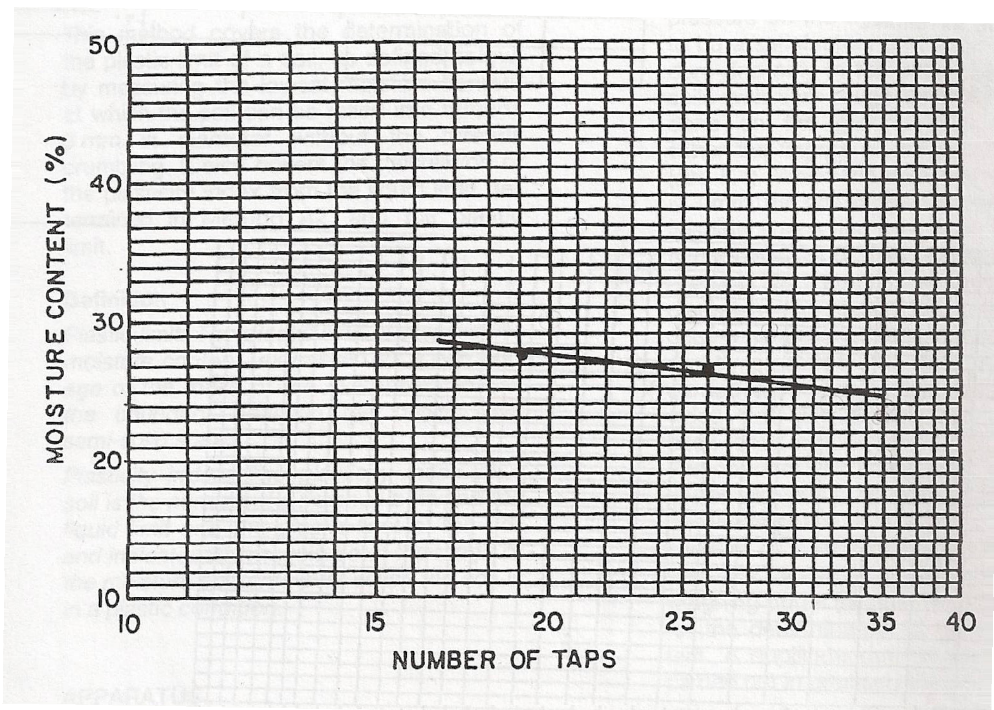


Figure 3.7 : Example of a flow curve

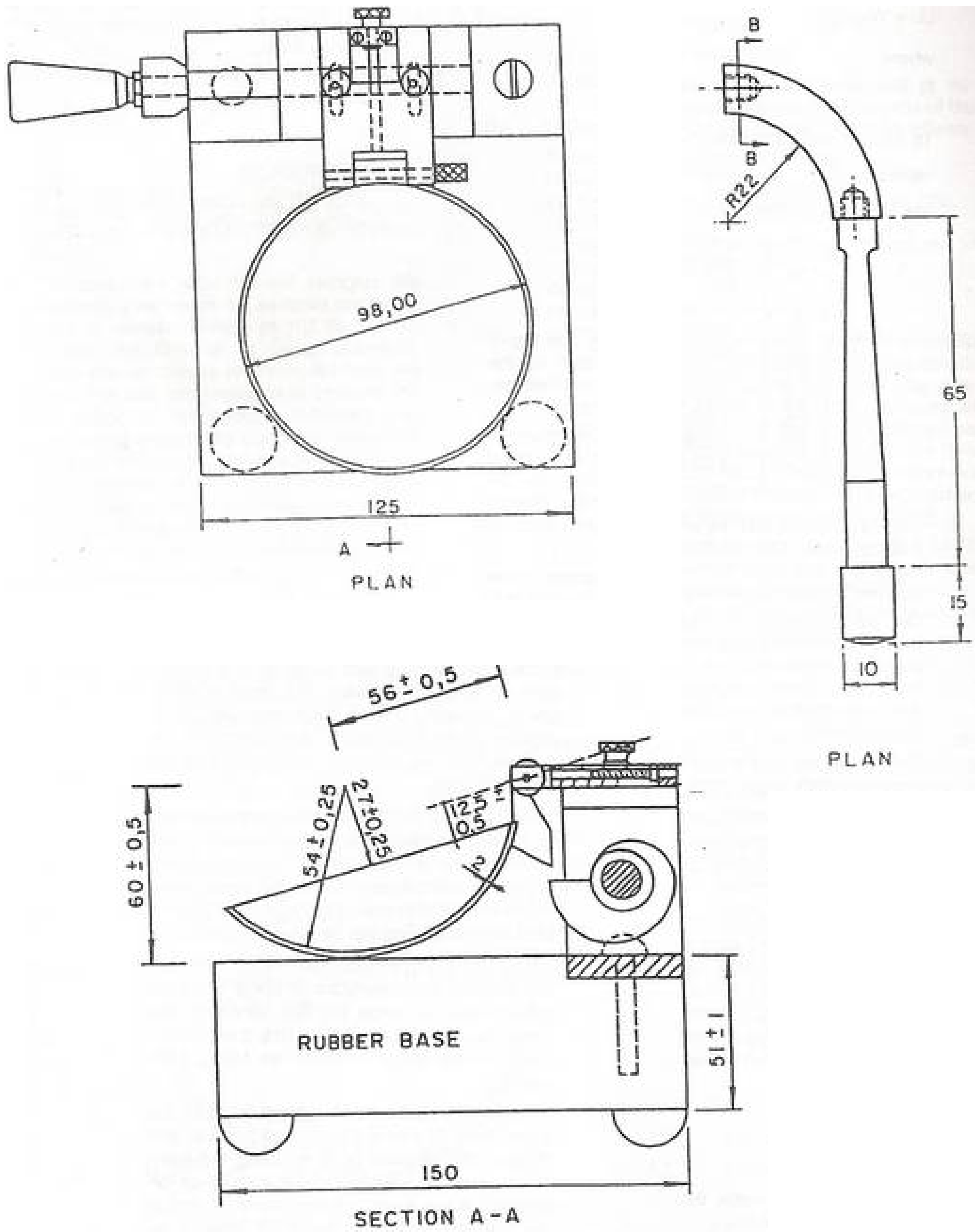


Figure 3.8 : Liquid limit device

Assessment tasks

1. What is the purpose of modifying materials?
2. Name three types of seals commonly used in road construction and give the difference between them.
3. What is a gap graded asphalt?
4. Differentiate between gravel, sand, silt and clay
5. What do you understand by the following terms:
   a. Permeability
   b. Compaction
   c. Strength bearing capacity
   d. Swell
   e. Shrinkage
6. Complete the sieve analysis for the data in the table below:
   a. Calculate the percentage passing for this soil
   b. Plot the particle size distribution curve using the semi-log graph paper
   c. From the graph give comment about the characteristics of the soil

Sieve Size (mm)	Mass of Soil Retained (g)	Percentage Retained	Percentage Passing
53.0	0		
37.5	248		
26.5	382		
19.0	385		
13.2	409		
4.75	901		
2.00	520		
0.425	452		
<0.425	1725		
Total			

7. Define the following terms:

   a. Liquid limit

   b. Plastic limit

   c. Shrinkage limit

   d. Plastic index

8. The results of a standard compaction test are as follows:

Trial No.1	Mass of soil + mould	5619g
	Mass of mould	3735g
	Water content	
	Mass of wet sample + container	288.28g
	Mass of dry sample + container	265.39g
	Mass of container	104.31g
Trial No.2	Dry density 1795kg/m^3	MC 14.9%
Trial No.3	Dry density 1828kg/m^3	MC 15.6%
Trial No.4	Dry density 1832kg/m^3	MC 16.5%
Trial No.5	Dry density 1796kg/m^3	MC 17.6%

Complete the calculation for trial no.1 and plot the moisture-density curve. Find the maximum dry density and the optimum moisture content.

MC = Moisture content

Topic 4 - Introduction to road drainage

Outcomes

Subject Outcome

3.1 Explain the functions and types of drainage for roads

Learning Outcome

3.1.1 Explain the need for road drainage in terms of safety, erosion control and durability requirements

3.1.2 List the differences between surface and sub-surface drainage.

The functions and types of drainage for roads

The purpose of drainage facilities is to remove stormwater from the road and allow stormwater to cross over or underneath the road in such a way that:

- Danger to vehicles and people is kept to a minimum
- Delays experienced by the public and associated inconvenience are minimised
- Damage to roads, services and property due to flooding is kept to a minimum

Another purpose of drainage facilities is to drain away sub-surface water which can severally damage pavement layers

Various types of drainage facilities are used to protect the road against damage by surface and subsurface water. Drainage facilities must be designed as simply as possible to convey the stormwater along or away from the road in the most economic, efficient and practical manner without causing unnecessary damage to the road and adjacent property.

It must be emphasised that drainage requirements vary significantly from one region to the other and also depend on the road type. While, for example, vegetation growth is encouraged in some areas to prevent erosion, it is a problem in other areas where excessive growth results in the obstruction of water flow. The resistance of in situ soils to erosion, rainfall characteristics, topography, maintenance methods, etc also vary from one region to the other. The designer must therefore give the necessary attention to the specific requirements of the region, local experience and the road authority's design guidelines.

The need for road drainage

During minor storms roads serve to carry stormwater runoff. During major storms the traffic function is interrupted and drainage function becomes more important. Good planning of road layout can substantially help reduce drainage problems. Road surfaces are usually given a rough finish to improve road holding and skid resistance without causing excessive tyre wear and road noise. The riding surface of the road should be kept clear of water.

The following considerations are important when road drainage facilities are planned:

- The basic cost of construction, incorporating the use of local materials wherever possible, and of labour intensive methods where appropriate.
- The useful life and cost of replacement or extension.
- The cost to the travelling public resulting from delays or extra travel distance due to road closures.
- The cost of repairs resulting from damage due to the overtopping of the road or from the concentration of water on adjacent properties.
- The cost of drainage infrastructure maintenance.

Erosion Control

Construction of road drainage infrastructure has the potential to cause environmental harm if not properly managed. One of the most common environmental impacts of drainage construction is the erosion of the soil and the subsequent sedimentation of watercourses or drainage infrastructure.

Deep cuttings and high embankments require special attention as far as drainage is concerned. The drainage of cuttings to enhance stability should generally be restricted to simple measures such as cut-off drains on slope and behind the cut face.

The erosion of the faces of slopes is common in South Africa, especially in the mountainous, wetter areas. Slopes should be made as steep as possible to minimise the exposure of cut and fill faces to rain and water. In some instances erosion can be prevented by establishing vegetation. If the slopes are too steep (more than 1:1.5) for the effective use of suitable vegetation, lined chutes at regular interval should be considered.

Vegetation establishment on slopes should only be done if absolutely necessary and arrangements should then be made to ensure that vegetation is watered during the initial phase to ensure proper establishment.

The presence of sand on the surface of the road after the rain could indicate a possible problem with the surface drain. Building up of material and grass on the edge of the shoulder also indicate possible drainage problems.

Erosion Control practices

Erosion control practices can protest exposed soil or reduce the duration of soil exposure. Knowledge of the soil types and the risk ratings is very important in the selection of erosion control measures. For example, some soils are highly erosive and will readily mobilise if not protected. Hence, the best practice requires that disturbance to these soils is minimised and high degree of protection be provided. This will reduce the potential for sediment mobilisation and deposition in watercourses and drainage lines.

Slope protection is required where the embankment slope surface may be damaged by either water or wind erosion; this applies to nearly all embankment slopes. Water erosion may be due to the runoff from the road and slope surface, or to water flowing along the toe of the embankment, or to scour on approaches to structures such as bridges or culverts.

Erosion by wind is more of a problem in light soils or sands. Such soils, due to their low moisture-holding capacity, dry rapidly and are easily blown away by high-velocity winds. The use of a parabolic embankment cross-section, and other methods such as soil cladding or admixtures of straw, may help.
Heavier soils may also suffer wind erosion, but not to the same extent as the lighter soils. The heavier or clayey soils are, however, prone to erosion by water. Soils of high clay content are relatively impervious, thus the runoff will increase and, if not controlled, may cause severe erosion on the embankment slope. Clayey soils which lose their cohesion on immersion in water (slake) are particularly susceptible to erosion. Similarly, fine-sandy silts which possess very little natural cohesion are highly erodible.

Methods of slope protection

The method of slope protection used on embankments depend on many factors, such as:

- the potential cause of damage necessitating slope protection;
- the climatic conditions such as regular high-velocity winds or high-intensity storms;
- the nature of the soil in the embankment, such as clayey soil, sandy soil or rock and gravel.

Some of the methods used to cope with the above conditions are outlined below.

Topsoil

Slope faces are often protected merely by spreading a layer of topsoil over the slope surface. Most topsoils contain sufficient grass roots, seeds or pioneer plants to establish eventually a growth of vegetation on the embankment slope.

Care should be taken, when spreading the topsoil, that it is not spread too thickly, as loose material is prone to sliding when wet. Conversely the layers should not be too thin, since they will not sustain plant growth for long periods. Topsoil in thin layers is also likely to erode more readily.
Common practice is to spread topsoil in layers varying from 75 mm to 100 mm, although thicknesses of up to 150 mm are sometimes specified.

Topsoil should be used as soon as possible after stripping, and the ideal would be to strip and spread it directly on the slope surfaces. This is, however, rarely convenient and stockpiling is usually necessary.
Where topsoil is spread on a rough surface, the necessary bond exists to prevent the topsoil from sliding down the slope. On smooth slope surfaces, however, measures such as tilling, to a depth of approximately 75 mm, or forming of chases may be necessary to prevent the topsoil from sliding. (See Figures 4.1)

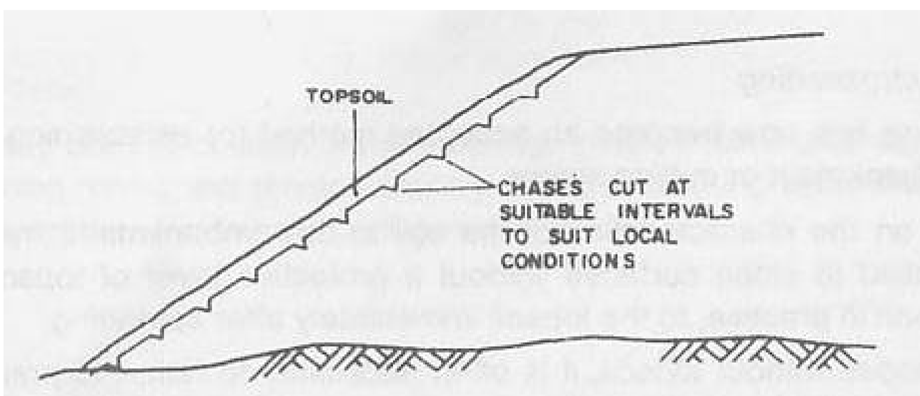


Figure 4.1: Protection of slopes: Chase method for topsoil

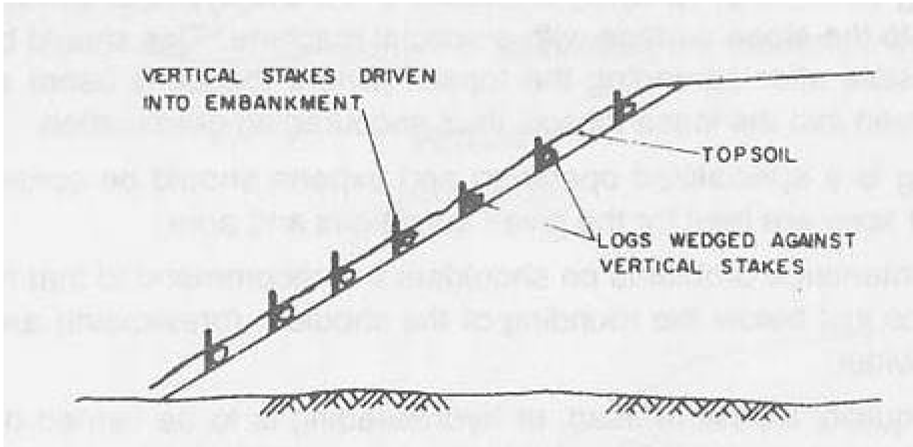


Figure 4.2: Protection of slopes: Stake and batter method

Other measures, such as a row of stakes with timber batters (Figure 4.2) or timber ledging, are sometimes used to anchor the topsoil to the slope surface. A recent substitute for logs is a bag made of open-weave artificial fibre, about one metre long and 100 to 150 mm in diameter, filled with a mixture of organic material, fertilizer and seed, and held in place by steel spikes and wire. There are numerous methods designed to overcome the problem of retaining topsoil. Unfortunately there is little firm evidence to support the claims of any of the proponents. It has frequently been found that the methods do not transplant readily from one area, soil type or weather pattern to another so the guiding principle must be to use the method that appears to be most successful in the relevant area. These measures are, however, seldom necessary on slopes flatter than 1:2, but are usually required on steeper slopes.

Mulch

This is normally used only where other covers, such as topsoil, are not available. Mulch covers offer immediate protection, and wheat, straw or hay, when properly anchored, provides effective protection since it protects the soil from direct rain, increases water infiltration and decreases runoff.

Even where permanent vegetation is to be established, mulch can be applied either before, or after, seeding or planting, since it promotes conditions favourable to the germination and establishment of permanent plants. Mulch is often anchored to the slopes, and methods such as a mulch-anchoring tool which pushes the mulch partly into the ground, mulch nets, application of asphalt emulsion to the mulch, or stakes, are often used, with mixed success.

Hydroseeding

Hydroseeding has now become an accepted method for establishing vegetation on road embankment or cutting slopes. Depending on the characteristics of the soil in the embankment, hydroseeding can be applied to slope surfaces without a protective layer of topsoil or, as is more common in practice, to the topsoil immediately after spreading.

On steep slopes without topsoil, it is often necessary to resort to practices such as the cutting of chases in the slope surface to prevent the seed from being washed down the slope during rain. Chases also act as water traps which encourage the establishment of the grass. Revegetation of slopes steeper than 1:1 is seldom successful without the use of specialized measures.

Hydroseeding consists of spraying a mixture of various types of seed, in a cellulose pulp, onto the slope surface with a special machine. This should be done as soon as possible after spreading the topsoil (where topsoil is used) so that the seeds are driven into the loose topsoil, thus encouraging germination. Hydroseeding is a specialized operation and experts should be consulted as to what types of seed are best for the given conditions and area.

To avoid maintenance problems on shoulders it is recommended that hydroseeding be done to just below the rounding of the shoulder (breakpoint) and not right up to the shoulder. Where poor quality topsoil is used, or hydroseeding is to be carried out over an area without topsoil, it may be advisable to add a suitable fertilizer to the soil prior to hydroseeding.

Planting

Under certain circumstances hydroseeding may not be possible or advisable. In such cases it may be necessary to protect the slope surface by planting grass or other ground-cover plants. Such cases may arise when for some specific reason tall grasses are not favoured, or a grass with a strong-spreading root system such as kikuyu or kweekgras is required. These two grasses require a fairly moist environment for successful propagation.

Ground-cover plants are used where deeper root systems are required, or sometimes for aesthetic reasons. If ground-cover plants are used for slope protection, it is advisable to select plants that will create the most debris.

Rock or gravel protection

Where road embankments are constructed under conditions such that water may wash against the embankment, or where wind erosion may occur, the slopes may be protected by various methods.

A common and effective method is to cover the slope surface with a layer of rock or gravel. This is merely dumped and spread on the surface and no compaction or other finishing operation is required.

Pitching

Pitching may consist of plain stone pitching, grouted stone pitching, plain wire stone pitching, wired and grouted stone pitching or pitching with precast concrete blocks. Two of these are shown in Figures 4.3 and 4.4.

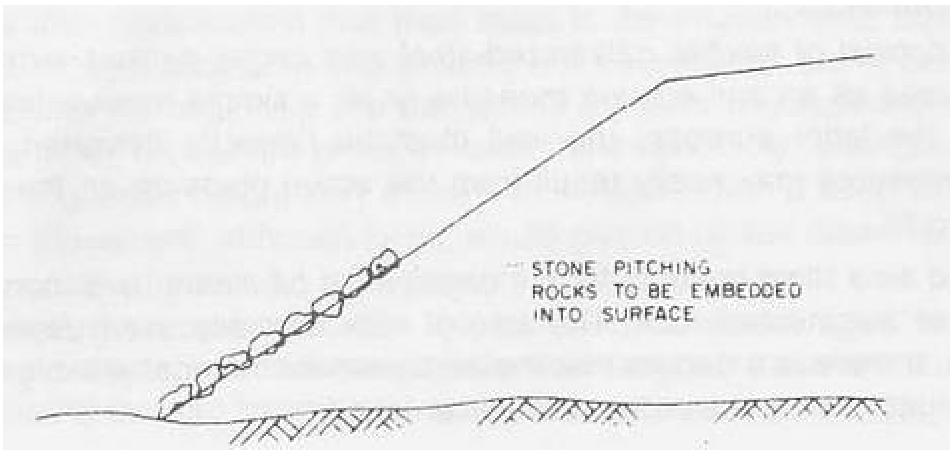


Figure 4.3: Protection of slopes: Stone pitching

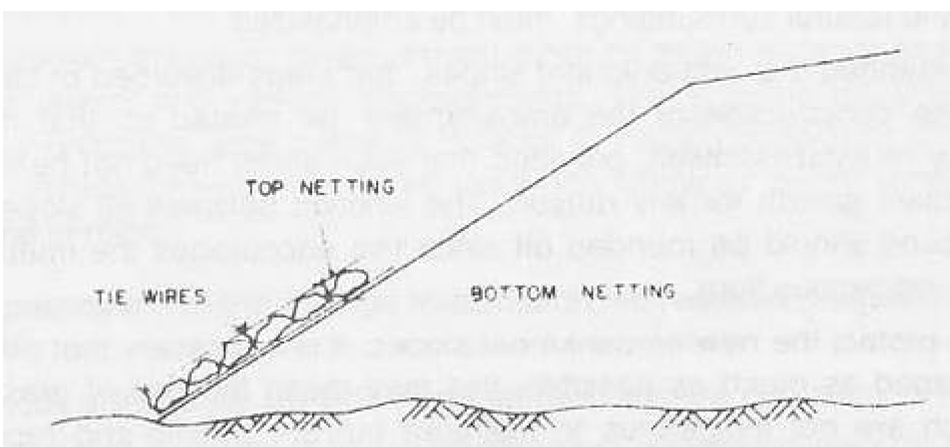


Figure 4.4: Protection of slopes: Wired Stone pitching

Pitching is normally used where there is a possibility of damage to embankments such as at culvert inlets and outlets, and at bridges. The type of pitching to be constructed is determined by the degree of damage expected. Stone for pitching must be sound and durable. The minimum size used in pitching is generally specified as about 200 to 225 mm. Smaller pieces, or spalls, however, may be used to fill the voids between the larger stones.

Before pitching commences, the slope surface must be compacted to ensure that no subsequent settlement occurs, and the stones used should be thoroughly embedded into the surface to be protected. It is recommended that a proper foundation should be laid along the toe of the embankment. There have been many cases where grouted pitching has concealed deformations in the slope beneath it by spanning across voids. It is therefore considered that this form of pitching should only be used if specifically justified. A further form of pitching is the use of precast concrete blocks. These are easier to lay and have a neat appearance, although generally they are more expensive. They are often used at open abutment bridges and on embankment slopes in urban areas.

Gabions

Gabions consist of flexible galvanized-steel wire cages packed with rock. They may be used as an anti-erosion measure or as a simple mass-retaining wall. If used for the latter purpose, the wall must be correctly designed, since high ground-pressures may easily result from the active pressure on the wall due to the sloping fill.

Rock used as a filling material for the cages must be clean, hard, non-weathered boulders or fragmented rock. The size of rock normally used depends on the cage size. If there is a danger that the embankment material will migrate into the voids, the gabions can be protected by filter fabrics.

Road drainage is divided into surface drainage and sub-surface drainage.

Surface drainage

Water flowing on the carriageway and shoulders of a road posses danger to the drivers. If the depth of the water on the road surface reaches an appreciable level, it can cause the vehicle tyres to lose contact with the road surface. It is therefore important to ensure rapid and efficient discharge of stormwater runoff from the road surface. Where roads are graded close to the ground level, stormwater runoff should be allowed to spill off the edge of the pavement.

Various elements of the drainage system commonly used are as follows:

Pavement and Shoulder cross slopes

In order to facilitate the removal of water from the wearing surface, roadway surfaces are normally crowned or sloped to the one side. The recommended crown or cross slope tends to be the compromise between the need of vehicular traffic and those for drainage. Pavement cross slopes should be steep enough to ensure proper drainage but not so steep to cause driver annoyance, discomfort or hazard. The amount of cross slopes varies with the type of surface, being generally small for relatively impervious surfaces such as concrete and large for pervious surfaces such as gravel or earth.

Gutters

Gutters are generally used in place of other type channels for urban roadway drainage and are sometimes used in rural areas, particularly on urban arterials, in mountainous regions, in sections with limited road prism, in areas of poor soil stability, and for special drainage problems such as traffic interchanges and underpasses.

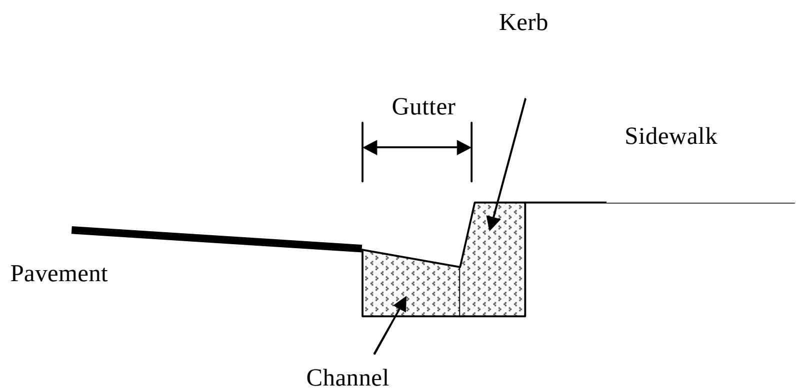


Figure 4.5

In areas where vegetative cover cannot be used to prevent erosion damage to high fills, shoulders are designed to serve as a gutter with a kerb constructed at the outer edge to confine the water to the shoulder. The water collected in the gutter is discharged down the slope through chutes. The kerb may be made of earth, bituminous material, Portland cement concrete, or cut stone.

Side Drains

Side drains are positioned outside the shoulder breakpoint and parallel to the road centreline. While usually employed in cuts, they may also be used to run water along the toe of a fill to a point where the water can conveniently be diverted, either away from the road prism or through it, by means of a culvert. Side drains are intended as collectors of water, and the area that they drain usually includes a cut face and the road surface.

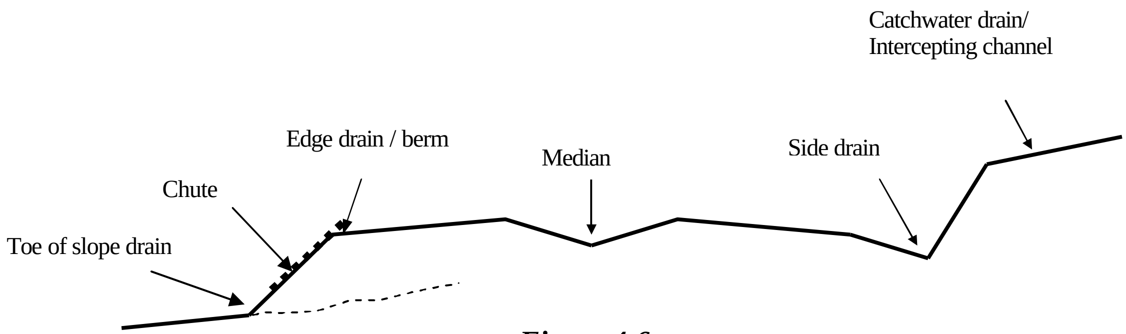


Figure 4.6

Edge Drain

Edge drains are intended to divert water from fill slopes that may otherwise erode either because of the erodability of the material or because they are subjected to concentration of water and high flow. Guardrail posts tend to serve as a point of concentration of water. As a general rule, edge drains are warranted when fill material is erodible or when guard rails are to be installed. Edge drains are constructed of either concrete or premixed bitumen.

Catchwater drains

Catchwater drains and banks are situated on the top edge of cuttings and are constructed to prevent water from flowing down the face of the cutting. Even if the cut is through material which is not likely to scour, the catchwater drain serves to reduce the volume of water that would otherwise have to be removed by the side drain.

Kerbs and Channels

Most urban roads are constructed with kerbs at the road edges. The kerbs and channels assist in containing the stormwater runoff and prevent scouring. A kerb serves as a stormwater channel with a capacity greater than that of a concrete or asphalt berm. Kerbs also provide some structural support during pavement laying operations and protect footpaths and verges from vehicular overturn.

Kerb Inlets

Kerb inlets are located at or above the points at which the gutter is calculated to be flowing at full capacity.

Figure 4.7: Kerb Inlet

Discharge from drains

The main problem of median drainage is the removal of water form the median. Water concentrated by the edge drain must be removed from the shoulder before it encroaches the travelled way. Generally, discharge from drains must be considered as carefully as drainage itself, if this discharge is not to cause either a hazard to the road user and damage to the permanent works, or a nuisance to adjacent land-owners.

Underground systems

These must be efficient and correctly located to ensure that water does not back up onto the road surface or saturate the road layers. To restrict hazards to the road user, inlets that are flush with the surface drain invert are preferable to raised structures.

Underground reticulation is costly both to provide and maintain. The designer should therefore, without violating the principles discussed above, attempt to reduce the use of underground drainage as far as possible by discerning use of surface drainage.

Mitre drains

These banks are constructed at an angle from the road centreline. They are intended to remove water from a drain next to the toe of a fill, and to discharge it beyond the road reserve boundary. Several mitre banks can be constructed along the length of a drain, as the concentration of water in the drain 6

The upstream of a mitre bank is usually protected by stone pitching, since the volume of flow of water it deflects may cause scour and ultimately lead to breaching of the mitre bank.

Chutes

Chutes are intended to convey a concentration of water down a slope which, without such protection, would be subject to scour. They may vary in size from a large structure to a half round precast concrete product, but they are all open channels.

An example of the application of shutes is the discharge of water down a fill slope from an edge drain. Chutes should be as shallow as is compatible with their function, and depths in excess of 150mm should be viewed with caution.

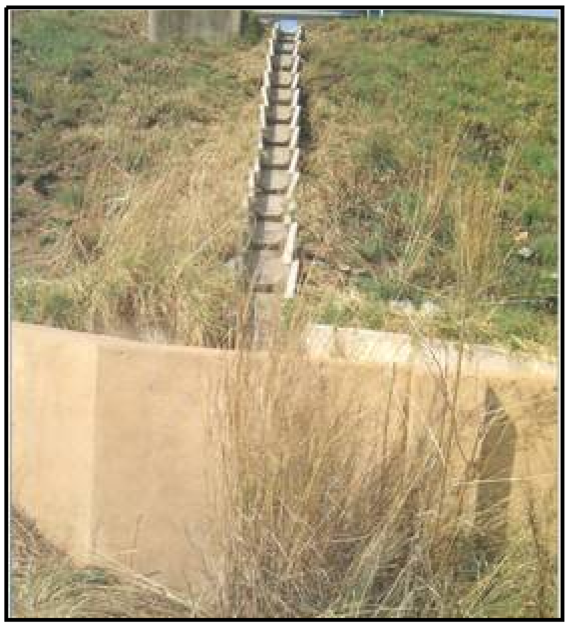


Figure 4.8: Discharge chutes

Culverts

A culvert is used to convey water from the upstream to the downstream side of the road. This water may either flow in a channel that crosses the road, or it may come from the side drains. In the latter case the culvert is referred to as a relief culvert.

Hydraulic performance is one of several factors which influence the selection of the type of culvert for a particular location. The shape and type of culvert to be used should, however, not be determined by the hydraulic performance alone, as the economics and availability of different culvert types should also be considered.

In the selection of the appropriate culvert type cognizance should be taken of the in-situ soil conditions. In flat poorly drained or expansive soil conditions culverts must be watertight. If not, the in-situ soils will expand, resulting in poor riding quality on the road surface.

Sub-Surface drainage

Water in the structural layers of a pavement is the main cause of road failures. This water weakens the pavement layers and under traffic loading pumping occurs with eventual collapse of the pavement structure. During the design phase of a road, subsurface drainage should be considered. Whenever possible, the route should avoid obvious problem drainage areas such as swampy grounds, high water tables or seepage zones.

The purpose of sub-surface drainage is to remove any infiltrated water from the road structure as quickly as possible. Important sources of ground water are:

- The natural water table
- Irrigation canals and dams
- Rainfall infiltration

Such water may enter the pavement layers either by infiltration, sideways or through the road surface.

The following underground drainage systems are normally used:

- Trench drains (Interception drains)
- Herringbone drainage
- Layer drainage
- Structural drainage

Trench drains (Interception drains)

This type of drain intercepts mainly ground water moving horizontally, and lowers the water table. It is used in the following cases:

- At the toe of a cut where the side slope is stable
- At the toe of a fill to prevent or limit groundwater inflow into the road prism; and
- Across the road on a downhill side of a cut

Trench drains consist of conventional drains incorporating granular material. This material could act as a natural filler, a permeable collector or a geocomposite incorporating a synthetic collector.

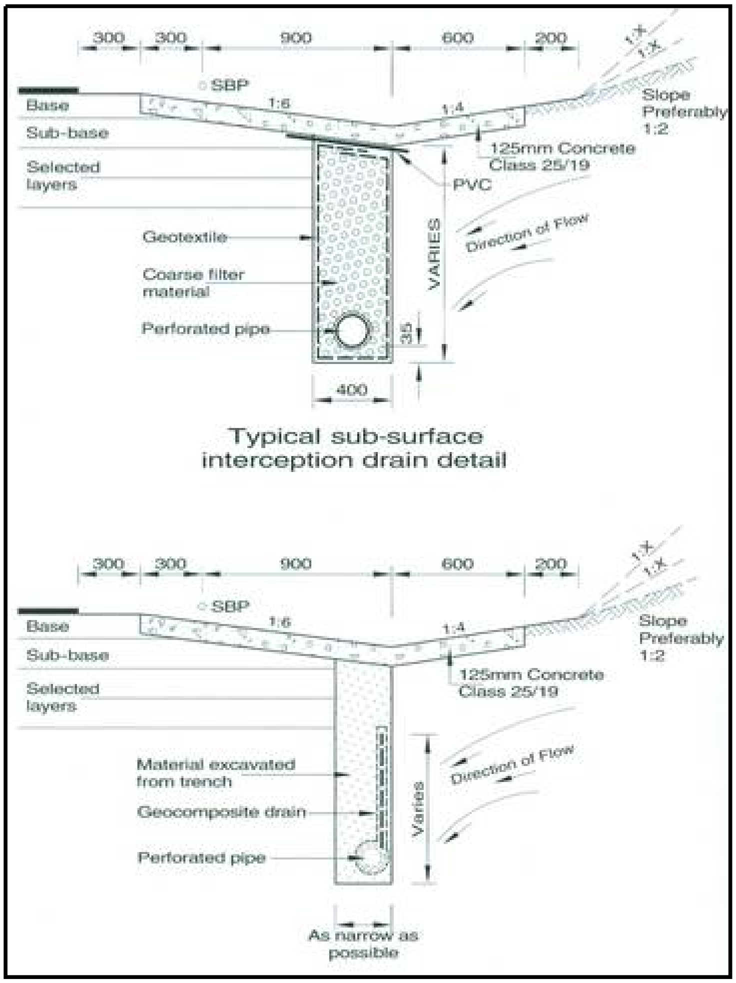


Figure 4.9: Typical sub-surface interception drain detail

Herringbone drainage

This type of sub-surface drainage reduces a generally high groundwater table to an acceptable level. It is used in the following cases:

- In areas, cut or fill, where there is a high groundwater table that is undesirable; or
- To stabilize areas where a high water table interferes with construction

The herringbone drainage system may be installed below the road prism or within the pavement layers

Layer drainage

Layer sub-surface drainage removes, in particular, water that seeps through the road surface. In many cases an attempt is made to make the road surface impermeable, which from the point of view of drainage, makes the construction of an open-graded layer unnecessary.

Blanket drains could consist of either natural filters or permeable collectors. A geosynthetic filter material is placed at the interface between the permeable collector (sand, gravel or aggregate) and the subgrade, and functions as a filter and a separator to prevent two dissimilar materials from intermixing. These drains may consist of a thick geosynthetic material where the flow may occur both perpendicular to and transversely in the plane of the geotextile.

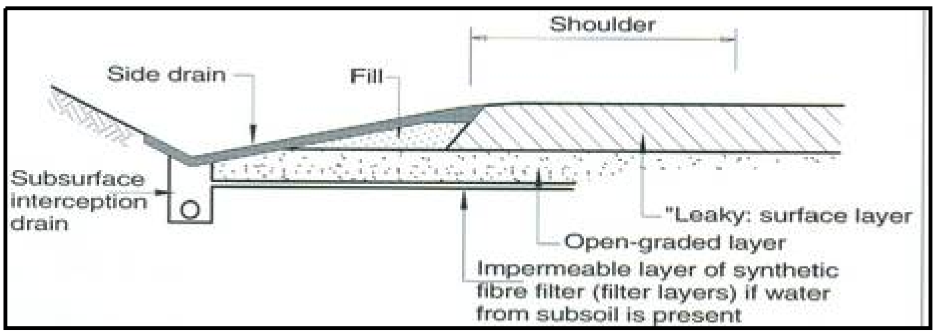


Figure 4.10: Typical section through a layer drainage

Structural drainage

Structural sub-surface drains are used for structures such as bridge abutments and retaining walls. Geocomposite drains or thick non-woven geotextiles tied into a collector pipe are especially useful in these applications because of the speed and ease of installation, pre-assembly benefits and narrower dimensions.

Culverts

When a new road is being designed, it is sometimes found that it crosses many small natural water courses, and that culverts are needed to safely convey the stream water under the pavement. A culvert is simply an enclosed channel that is open at both ends and used to convey the water through an embankment.

Pipe and arch culverts are formed from both rigid and flexible materials, whereas box culverts - these have rectangular cross sections - are always made rigid. Flexible culverts are either thin-walled steel pipes or galvanised corrugated metal pipes that are designed to deflect under load; when deflection takes place the horizontal diameter of the culvert increases and compresses the soil laterally so that the passive resistance of the soil is mobilised to support the applied loads.

Rigid culverts are composed of reinforced concrete, cast iron or vitrified clay and their load-carrying ability is primarily a function of the stiffness of the culvert wall(s).

To operate most effectively a culvert is placed in the natural stream-bed so that its alignment conforms with the original situation, even though this may result in the culvert being skewed rather than at a right angle to the road’s centreline. If the stream meanders or if using the natural channel requires an inordinately long culvert, the stream is often diverted into a new channel prior to the culvert; however, the flow is then returned to its natural channel as soon as possible after passing through the culvert. The slope of a culvert should also conform closely to that of the natural stream bed. If the culvert slope is greater than that of the natural watercourse, the higher water velocity may cause scouring of the sides and bottom of the stream channel at the culvert outlet.

Assessment tasks

1. Why should water not be allowed to collect on the surface of a road?
2. By means of a neat labelled sketch, clearly show what each of the following cross-sectional elements are:
   f) Median drain
   g) Catchwater drain
   h) Edge drain
   i) Side drain
   j) Chute
3. What is the purpose of a kerb inlet
4. What are the main sources of sub surface water?
5. Describe any two types of drains used to control sub-surface water.
6. Describe some of the methods used to control erosion of the soil embankment.
7. What is a culvert, and what is it used for?

Topic 5 - Earthworks

Outcomes

Subject Outcome

5.1 Select and use equipment safely during earthworks

Learning Outcome

5.1.1 Identify safety hazards of earthworks.

5.1.2 Explain the importance of safety and the need for lateral support in surface excavations.

5.1.3 Explain practical measures to mitigate hazards in the workplace.

5.1.4 Suitable techniques and equipment for excavating, hauling, spreading and compacting soils are identified and correctly used.

5.1.5 Identify and correctly use suitable techniques and equipment for excavating, hauling, spreading and compacting soils.

Earthworks

Earthworks refers to the process of moving soil from one location to another and processing it so that it meets construction requirements of location, elevation, density, moisture content, etc. Activities involved in this process include excavating, loading, hauling, placing (dumping and spreading), compacting, grading and finishing.

The earthworks on a road construction project form a major part of the contract and require careful planning so that it can be carried out swiftly in order that the subsequent layer works can follow on as soon as possible with continuity of work.

Earthworks may be divided into two main categories, namely, that below the formation level and that above the formation level. Generally the formation level is taken as the underside of the structural pavement layers (i.e. bottom of selected sub-grade).

The earthworks required to reach the formation level, which forms the platform on which the pavement is constructed, may consist of excavation (cut) or embankment (fill). Figure 5.1 gives an illustration of a typical longitudinal section along the centre line of a road.

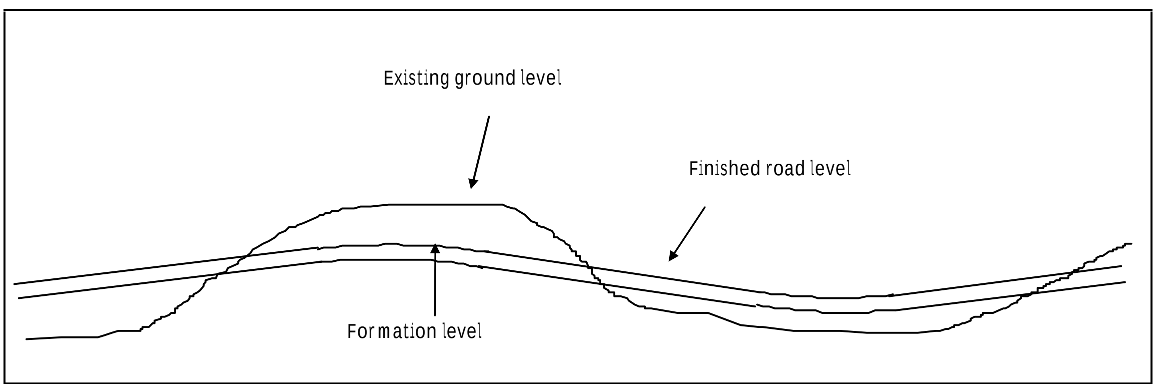


Figure 5.1

Earthworks range from a few thousand cubic meters for a road across a flat terrain to several million cubic meters of rock through mountains.

Safety hazards

Construction is inherently a dangerous process. Historically, the construction industry has had one of the highest accident rates among all industries. Most serious construction accidents involve construction equipment operations, trench and embankment failure, falls from elevated positions, collapse of temporary structures and formwork, or the failure of structures under construction.

Some of the main aspects of safety on a road construction site:

a) the safety of the travelling public;
b) the protection of roadmen from the travelling public;
c) the safety of roadmen from potential hazards on a particular site;
d) the safety of roadmen from one another's actions;
e) the protection of an individual from the consequences of his own actions.

Aspects (a) and (b) require a system of temporary roadwork signing to be established at and on the approaches to the site.

The Safety of Roadmen from Potential Hazards

Falls

Almost half the accidents in construction work are due to the falls of men or materials. Men not only fall from working places, they slip and fall when making their way from one part of the site to another and can also be injured when badly stacked materials fall on to them.

To prevent persons from Falling:

1. Keep the site tidy and get rid of rubbish. Store materials methodically and establish clear routes through the site.
2. Provide hand rails for stairs and gangways over trenches.
3. Fence or cover all openings in floors, holes in ground and similar hazards.
4. Provide good lighting on stairs, passages and other access routes.
5. Use only well-constructed ladders properly secured, and where necessary, suitable scaffolding for all work that cannot be done safely from the ground or from a building.
6. Check that any safeguards, such as guardrails, hand rails and covers over openings in floors, which have been provided are kept in place.

To prevent materials from falling:

1. Ensure that materials are properly stacked and that they are not likely to be blown or knocked over.
2. If persons are working regularly in places where they are liable to be struck by falling materials, provide a strong protective cover. Similar protection is advisable over passageways in common use. Provide safety helmets.

3. Materials should not be thrown down haphazardly from a height. Lower them or provide a chute or, if the materials are to be thrown down, barrier off the area into which they will fall.
4. Pipes should be placed at an angle of 45° to the run the trench and sufficiently far back to prevent them from being accidentally knocked into the excavation.

To prevent head injuries:

On many sites there is an obvious risk of head injury from falling or swinging objects or from striking the head against something. For this reason the wearing of hard hats is compulsory on construction sites where there is foreseeable risk of head injury. Employers must ensure that employees wear hard hats when engaged in operations involving work in excavations, partly completed structures, near machinery / plant with swinging booms and work scaffolding.

Excavations

Dangerous excavations need to be closed or fenced off in such a way that people cannot fall into the excavation at night. This implies that the wire used for the fence must be strong enough to catch a person walking into the fence and must prevent them falling through. “Safety tape”, which a thin plastic tape, is only good for showing where the danger lies. It is not strong enough to stop people walking through.

Any work near a roadway carrying traffic must be barricaded in such a way that drivers can see clearly where they should go. Road signs must be posted at least 100 m away to warn drivers that work is being done in or near the road. Red danger flags may be necessary if traffic has to be directed. All workers exposed to the traffic must wear safety vests with bright colours so that they are easily seen. The Supervisor must arrange for the supply of all traffic signs and flags as well as any other materials required to provide for safety on the site.

The sides of excavations must be made safe so that they do not fall onto workers in the excavation. Trenches for pipelines and cables are especially dangerous as they are narrow and may be very deep.

By law precautions must be taken for every excavation over 1.6 m deep. The sides must be sloped or must be supported with planks and struts. In road and drainage works we seldom need to dig trenches so deep that they need to be supported. However, all Supervisors must be aware of the danger of earth slips or earth movements that could endanger lives.

Noise

Personnel can easily be exposed to the risk of damage to their hearing when operating machinery on a construction site. The Noise Regulations put legal obligations on employers to prevent damage to the hearing of workers from excessive noise at work. The employer is required to carry out a noise assessment where excessive exposure is likely, a rough guide being where people have to shout or have difficulty in being heard clearly by someone about 2 metres away. Action must then be taken to reduce the risks present.

Noise is usually measured in decibels (dB), shown on a meter filtered to reduce very low and very high frequencies as a dB(A) reading. Note that, as the decibel scale is logarithmic, an increase of 3 dB is actually a doubling of the noise intensity. A decibel scale of typical noise levels gives the following values:

0	The threshold of hearing
10	A quiet whisper
30	The tick of a watch
50	A normal conversation
70	A smooth-running machine
80	A noisy street - hearing damage starts
85	The first action level - an employer must provide hearing protection and attempt to reduce the intensity
90	The second action level - an employer must ensure that hearing protection is worn and ear protection zones are signed
100	A pneumatic drill
120	A rivet gun
130	The pain threshold

Clearly, the dangers of increasing deafness require all personnel to use methods of reducing the risks of excessive noise exposure. In addition to using hearing protectors, measures for quietening or muffling noisy equipment / tools or even of replacing them with quieter types need to be considered for most sites.

Use of hazardous substances

Many hazardous substances are used in or generated from work activities on construction sites. In roadwork, construction workers may be exposed to considerable health risks when using tar binders, bridge deck sealants, epoxy resins etc.,

An assessment must be made of the risks present when any hazardous substance is used or produced. A sealant with a low risk level when used in the open air may present a serious hazard in a confined space, so the method of use must be considered when assessing the level of risk. Protective equipment may need to be used when applying such substances and its use must then be monitored to ensure that safe working practices are adhered to.

The results of assessments must be passed on to the workforce through briefings / training and management must periodically review the efficiency of the measures taken.

The safety of a roadman from another's actions

Many dangers arise from the thoughtless actions of workers unconcerned with the safety of their workmates. Some of the more common and those resulting in a high incidence of accidents are listed below:

- Treading on nails projecting from loose timber is a very common place site accident. When timber framing or shuttering is dismantled, nails should be removed or knocked flat or the timber should be stacked where it cannot be trodden on.
- Failure to replace guarding equipment after carrying out work which necessitates its removal.
- Careless operation of machinery without ensuring proper safeguards such as help in reversing, or use of a banks man with cranes or earthmoving machinery.
- Failure to report defects in machinery and equipment, resulting in unsafe plant being used by others.
- Creating makeshift and unsafe situations such as sub-standard electrical connections and trailing cables, etc.

The protection of an individual from the consequences of his own actions

When a man injures himself through his own actions the cause is usually either ignorance of the work process involved or just carelessness. It follows that a man must be trained or made familiar with any techniques before being allowed to begin work. Many accidents could be prevented with the use of protective equipment, such as:

- High visibility and reflective jackets for workers on the highway.

- Protective spectacles, goggles or visors when working with hammers and chisels or cutting machinery on concrete or stone.
- Face masks when cutting concrete or stone with disc cutters.
- Helmets when working below other workmen or in situations where objects are liable to fall from above.
- Ear muffs or plugs when using compressed air tools such as breakers and drills. Also when working with piling equipment.
- Gloves in manual activities such as kerbing, etc.
- Protective boots with steel caps and soles to prevent injuries through crushing and from treading on nails.

If plant and equipment is not used sensibly then a considerable risk is involved. For example, ladders should be set at the correct angle (one out for every four up) and always secured.

Many highway workers are injured by unthinkingly reaching or stepping out from a protected work area into the path of an oncoming vehicle.

The need for lateral support in surface excavations

There are many potential hazards when working in excavations and trenches. Probably the most common hazard at any work site is the threat of **cave-in**. A cave-in occurs when walls of an excavation collapse.

Cave-ins can be deadly. Wall failures often occur suddenly, with little or no time for the worker to react. The weight of the soil crushes and twists the body, causing death or serious injury in a matter of minutes. Excavations need not be deep or large to create a life threatening hazard, so **every** excavation must be taken seriously.

Why do cave-ins occur?
Undisturbed soil is kept in place by natural horizontal and vertical forces of the nearby soil. When the earth is dug, these natural forces are no longer able to hold back the soil left behind. With no support, eventually the laws of gravity take over, and the soil from the excavation walls move downward and inward into the excavation. The result is a cave-in.

Cave-ins are more likely to occur in unprotected excavations where:

- The excavation is dug in unstable soil, or in soil that has been dug in before;
- There is excessive vibration from construction equipment or vehicle traffic around the excavation ;
- Too much weight near the sides of an excavation, most frequently from equipment or the excavated material (spoil pile) too near to the edge;
- Water has collected in the excavation;
- Changes in weather conditions (freezing, melting, sudden heavy rain, etc.)

  Although there isn't much that can be done about the weather, there are ways to help control these conditions. In order to safely and efficiently work around excavations and prevent cave-ins from occurring, always follow the points below:

Re-route traffic whenever possible, and keeping only the heavy construction equipment needed near the excavation;

- Keeping the spoil pile at least away from the edge of the excavation;
- Pumping water out of the excavation before anyone enters it;
- Using protective systems when required.

The threat of a cave-in is not the only safety concern when working around excavations and trenches. Other hazards to be considered include **accidental contact with utility lines**, crushing and striking hazards posed by **mechanized equipment**, and **hazardous atmospheres**. All of these hazards, however, can be kept to a minimum with thorough planning.

Because of the frequency and severity of cave-in accidents, a number of safety regulations affecting excavation operations have been established. These regulations require, among other things, that workers in an excavation be protected from cave-ins by one of the following methods:

- Sloping or benching of the sides of the excavation
- Supporting the sides of the excavation by shoring
- Placing a shield between workers and the sides of the excavation.

The only exception to these requirements are when excavation is made entirely in stable rock, or the excavation is less than 1.2m in depth and examination of the ground by a competent person provides no indication of a potential cave-in.

Protective systems

Protective systems are methods of protecting workers from cave-ins of material that can fall or roll into an excavation, or from the collapse of nearby structures. As mentioned in earlier chapters, if an excavation is less than 1.2m deep, OSHA does not require a protective systems unless the competent person sees signs of a potential cave-in. For trenches greater between 1.2 and 6m deep, shoring and sheeting, shielding, sloping and benching are all acceptable protective measures. It is up to the planners of the construction project and the competent person on site to determine which systems will work best. If an excavation is greater than 6m deep, a registered professional engineer must design the protective system.

Shoring systems

Shoring systems are structures of timber, mechanical, or hydraulic systems that support the sides of an excavation and which are designed to prevent cave-ins. Sheeting is a type of shoring system that keeps the earth in position. It can be driven into the ground or work in conjunction with a shoring system. Driven sheeting is most frequently used for excavations open for long periods of time. These strutted systems are also referred to as active systems. The most frequently used strutted system involves aluminium hydraulic shores which are lightweight, re-usable and installed and removed completely from above ground.

Sloping or benching

According to the Occupation Safety Health Act (OHSA) rules, when workers are required to be in an excavation, the maximum allowable steepness of the sides of excavations less than 6m deep when employing a simple uniform slope is given in table 5.1.

Sloping or benching for excavations greater than 6m deep must be designed by a registered professional engineer. The major disadvantage of benching or sloping of excavation sides is the space required for the excavation plus the side slopes.

Soil type	Maximum allowable slope for Excavations less than 6m deep
Solid rock	1.5 : 1 to vertical
Well jointed / bedded rock	1:1
Gravel	1:2 to 1 : 3
Sand	1:2 to 1 : 3
Clay	1:2 to 2 : 1

Table 5.1 : Maximum allowable slopes for temporary excavations

Shoring and Shielding

Lateral support for the sides of an excavation is usually provided by shoring. A shoring system that completely encloses an excavation is essentially a cofferdam, which is a structure designed to keep water and / or soil out of an excavation area.

Common types of shoring systems include timber shoring, aluminium hydraulic shoring, lagging, and steel piling. Shoring and steel shielding systems must be installed in compliance with OHSA tables, manufacture's tabulated data, or as designed by a registered professional engineer.

Timber shoring

Timber shoring (Figure 5.2) employs vertical timber uprights placed against the sides of the excavation, either in a continuous fashion or at intervals. Upright are supported by a horizontal beam called wales or stringers. Wales, in turn are supported by horizontal timber cross-braces or trench jacks.

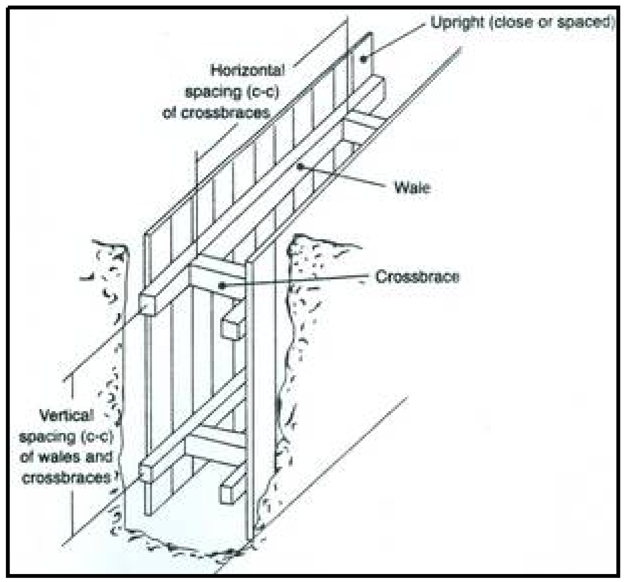


Figure 5.2: Timber shoring system

Trench shields

Trench shields or trench boxes are used in place of shoring to protect workers during trenching operations. Figure 5.3 illustrates such a movable shield. The top of the shield should be extended above the sides of the trench to provide protection for workers against objects falling from the sides of the trench. The trench shield is pulled ahead by the excavator as work progresses.

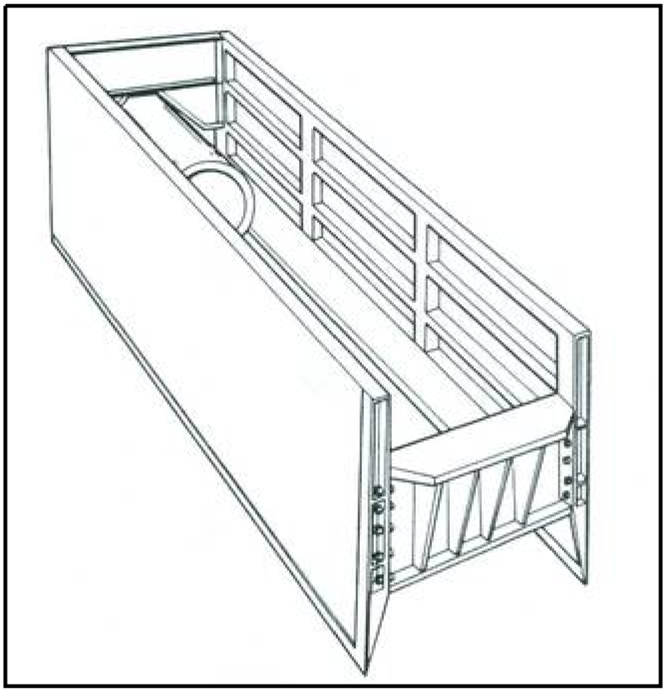


Figure 5.3: Trench shield

Practical measures to mitigate hazards in the workplace

Concern over the frequency and extent of industrial accidents and health hazards led to the passage of the Occupational Safety and Health Act (OHSA), which established specific health and safety requirements for virtually all industries, including construction.

The following list of major safety precautions should be helpful as a general guide. Good housekeeping on a project site is both a safety measure and an indicator of good project supervision.

Safety programs

All construction firms need a carefully planned and directed safety program to minimise accidents and ensure compliance with OHSA and other safety regulations. However, no safety program will be effective without the active support of top management. Although there are many components of a comprehensive safety program, some of the major safety elements are:

- A formal safety program for all new employees
- Periodic refresher training for each worker
- A formal supervisory safety training program for all supervisors

- A program of regular site visits by safety personnel to review and control job hazards
- An established procedure for the emergency evacuation of injured workers
- Provisions for maintaining safety records and reporting accidents in compliance with the OHSA requirements.

Equipment Operation

- Require operators and mechanics to use steps and handholds when mounting equipment.
- Exercise extreme caution and comply with safety regulations when operating near high-voltage lines. In case of accidental contact with a high-voltage line, the operator should attempt to move the equipment enough to break contact.
- Make sure that machines are equipped with required safety features and that operators use seat belts when provided.
- Use care when operating equipment on side slopes to prevent overturning.
- When operating cranes, be extremely careful not to exceed safe load limits for the operating radius and boom position. Electronic load indicators are available.
- Do not allow workers to ride on equipment unless proper seating is provided.
- Haul roads must be properly maintained. Items to check include condition of the road surface (holes, slippery surface, excess dust), visibility (curves, obstacles, intersections, and dust), and adequate width for vehicles to pass (unless one-way).
- Park equipment with the brake set, blade or bowl grounded, and ignition key removed at the end of work.
- Take positive action to ensure that equipment under repair cannot be accidentally operated.
- Ensure that any guards or safety devices removed during equipment repair are promptly replaced.
- Shut down engines and do not allow smoking during refueling.

Construction plant

- Set equipment containing hot or flammable fluids on firm foundations to prevent overturning. Clearly mark high-temperature lines and containers to prevent bums. Be especially careful of live steam. Provide fire extinguishers and other required safety equipment.
- Aggregate bins and batching plants should be emptied before performing major repairs.
- When electrical equipment is being repaired, shut off and tag electrical circuits.
- Ensure that wire rope and cable is of the proper size and strength, well maintained and inspected at least weekly.

Excavations

- The location of underground utilities and other hazards must be determined before starting an excavation. Contact utility companies and property owners to request that they establish the location of such installations.
- The sides of excavations must be properly shored or sloped to the angle of repose to prevent cave-ins. OSHA regulations require that banks over 1.2 m must be shored, cut back to a stable slope or otherwise protected. Regulations also require that protective systems (sloping, benching, shoring, or shielding) for excavation over 6.1 m deep must be designed by a registered professional engineer.
- Avoid the operation of equipment near the top edge of an excavation because this increases the chance of slope failure. The storage of materials near the top edge of the excavation, vibration, and the presence of water also increase the chance of slope failure.

  When these conditions cannot be avoided, additional measures must be taken to increase slope stability.
- Ensure that workers are not allowed under loads being handled by excavators or hoists.
- Watch out for buried lines and containers when excavating. Possible hazards include toxic and flammable gases, electricity and collapse of side slopes caused by sudden release of liquids

Suitable Techniques and Equipment used in Earthworks

Earthwork operations are highly mechanized and carried out most economically with the aid of very efficient machines, some of which have been developed for specific tasks whilst others have a multiplicity of uses.

The choice of equipment to be used on a construction project has a major influence on the efficiency and profitability of the construction operation. Although there are a number of factors that should be considered before selecting equipment for a project, the most important criterion is the ability of the equipment to perform the required work. Then the next criterion amongst the selected equipments becomes maximising profit or return on investment produced by the machine.

This section looks at different equipment used for excavation, hauling, spreading and compacting soils.

Excavating, lifting and earthmoving equipment

Excavator

An excavator is a power driven digging machine. Many types of excavators used in earth moving operations include hydraulic excavators and members of the cable operated crane-shovel (shovel, draglines, hoes, and clamshells). Dozers, loaders and scrapers can also serve as excavators.

An excavator designed primarily for excavation below grade. As the name implies, it digs by pulling the dipper back toward the machine.

Backacter

A backacter, also known as a backhoe, has a heavy bucket that is connected to the machine's arm by means of a knuckle joint which simulates the action of a human wrist and allows excavation to take place to depths of 5 m or more, digging towards the machine, below ground level. The hydraulically-operated machines can dig deeper ditches and work in harder soils.

Figure 5.4: Backactor loading tip truck

The backhoe is widely utilized for trenching work. In addition to excavating the trench it can perform many other trenching functions such as laying pipe bedding, placing pipe, pulling trench shields and backfilling the trench. Other suitable backhoe applications include excavating basements, cleaning roadside ditches, and grading embankments.

A bulldozer

A bulldozer is essentially a track-mounted (crawler) or rubber-tyred tractor that is normally fitted at its front with a straight or angled dozer blade to push earth. Crawler machines are slower than rubber-tyred units, but can handle much rougher terrain.

The cross-sections of most straight blades are actually curved so that, as the machine advances, the hardened steel edge digs into the soil and the loose material is pushed upward and forward. Whilst the straight blade is used for general purpose earthmoving, the angled blade is used to push material sideways. A "universal" blade has large wings for moving large loads over longer distances.

The bulldozer is also used to push scrapers, using a reinforced blade that is fitted with a stiffened push plate and shock absorbers. When the ground is very hard a hardened steel ripping tool (usually with up to three teeth) is often attached to the rear of a bulldozer and used to 'plough' the ground to depths up to 1 m deep; the most effective results are obtained if ripping is carried out downhill in the direction of the slope and, in the case of rocks, in the direction of the dip of bedding planes.

Figure 5.5: Bulldozer

Dragline

The most common dragline crane is essentially a crawler-mounted crane that has a revolving superstructure and is fitted with a rope-operated excavation bucket that can be cast out from a long boom.

The bucket, which may be perforated for underwater use, has hardened cutting teeth and is filled by dragging it along / in the ground towards the machine. The dragline is able to dig to a depth below its tracks of roughly from one-third to one-half the length of the boom whilst the throw of the bucket beyond the radius of the boom may be of a similar length, depending on the skill of the operator. The dragline bucket may be replaced with a grab bucket, which has two half-shells hinged at the centre and fitted with interlocking teeth, or a clamshell bucket which is similar to the grab but has no teeth. The grab crane is used to 'spot' excavate, for example, deep shafts, whilst the crane with clamshell is used to stockpile loose materials such as sand.

Figure 5.6: Dragline

Clamshells

A clamshell is capable of excavating to great depths but lacks the positive digging action and precise lateral control of the shovel and backhoe. Clamshells are commonly used for excavating vertical shafts and footings, unloading bulk materials from rail cars and ships, and moving bulk material from stockpiles to bins, hoppers, or haul units.

A clamshell bucket is illustrated in Figure 5.7. Notice that the bucket halves are forced together by the action of the closing line against the sheaves. When the closing line is released, the counterweights cause the bucket halves to open as the bucket is held by the holding line. Bucket penetration depends on bucket weight assisted by the bucket teeth. Therefore buckets are available in light, medium and heavy weights, with and without teeth.

Figure 5.7: Clamshell bucket

Heavy buckets are suitable for digging medium soils. Medium buckets are used for general-purpose work including the excavation of loose soils. Light buckets are used for handling bulk materials such as sand and gravel.

The face shovel

The face shovel also has a rotating superstructure mounted on a crawler- or wheeled-tractor, and has a bucket attached to the boom that is either rope-operated or hydraulically-operated. When in use the bucket is positioned at the bottom of the face being excavated, pressed into it, and pulled upward so that it fills with soil as it rises; the bucket is fitted with hardened teeth to assist in the penetration of the face.

Figure 5.8: Face shovel

The front-end loader

The front-end loader, also commonly known as the loader shovel, can do work normally associated with both the face shovel and a smaller bulldozer. In fact, the tracked loader looks very much like a bulldozer and its pushed bucket is a very effective excavator; however, the wheeled loader does not have good traction and is therefore more effectively used to dig in loose soils and/or for stockpiling work.

Figure 5.9: Front-end loader

The motor grader

The motor grader is composed of a 2- or 3-axle frame with a centrally-mounted 3-5 m blade that is carried by four or six wheels. When the bottom of the blade is operated in the horizontal position the grader can, very effectively, trim surfaces and / or push spread excavated earth over short distances:

- to slice off a layer of cohesive soil (e.g. to trim a subgrade) the blade is set with its top tilting backwards;
- to trim a compacted granular material the blade top is tilted forward;
- to grade loose soils the blade is set vertically or with its top slightly forward.

Figure 5.10: motor grader

If the blade is tilted to the side, or rotated at the side through variable positions to the near-vertical, it can be used to form ditches and to shape the sides of embankments and cuttings.

The scraper

Scrapers are capable of excavating, hauling, and dumping materials over a medium to long haul distances. The scraper is essentially a metal box on wheels that has a bottom that can be lowered so that one end digs into the ground when excavating. As the scraper moves forward, a layer of earth (typically 150-300mm deep, depending upon the setting of the cutting edge) “boils” upward over the edge into the bowl of the box; when the bowl is full the bottom is raised and the scraper then transports the soil to wherever it is to be spread.

Figure 5.11: The scraper

Loading is most efficiently carried out downhill, in the direction of travel. At the spreading site, e.g. an embankment, the edge of the bowl is again lowered to an above-ground height that will ensure that the desired layer thickness of soil is deposited as an ejector plate pushes from the back of the bowl as the scraper continues to move forward. Scrapers used on large projects are usually motorized and capable of achieving high speeds on haul roads; these may / may not be assisted by pusher-dozers during the digging process.

Scrapers used on smaller projects, with short haul-distances, are often non-motorized and not self-loading, i.e. each is towed by a separate tractor, usually a bulldozer, during the digging, transporting and spreading process.

Cranes

Cranes are primarily used for lifting, lowering, and transporting loads. They move loads horizontally by swinging or traveling. Most mobile cranes consist of a carrier and superstructure equipped with a boom and hook as illustrated in Figure 5.12:

The major factor controlling the load that may be safely lifted by a crane is its operating radius (horizontal distance from the center of rotation to the hook). Some of the other factors influencing a crane's safe lifting capacity include the position of the boom in relation to the carrier, whether or not outriggers (beams that widen the effective base of a crane) are used, the amount of counterweight, and the condition of the supporting surface. Safety regulations limit maximum crane load to a percentage of the tipping load (load that will cause the crane to actually begin to tip). Crane manufacturers provide charts giving the safe load capacity of the machine under various conditions.
Notice that hook blocks, slings, spreader bars, and other load-handling devices are considered part of the load and their weight must be included in the maximum safe load capacity calculation. Electronic load indicators are available that measure the actual load on the crane and provide a warning if the safe capacity is being exceeded.

Figure 5.12: mobile crane

Trucks

Trucks are still the most common form of construction hauling equipment. The heavy-duty rear-dump truck is most widely used because of its flexibility of use and the ability of highway models to move rapidly between job sites. There are a wide variety of types and sizes of dump truck available. Trucks used for hauling on public highways are limited by transportation regulations in their maximum width, gross weight, and axle load.

Trucks must be loaded when they arrive at the borrow pit. Arrange the loading area so that the truck is lower than the loaders. Note the difference in height of the types of trucks available. Tipper trucks are very high and will need a lower loading position than flatbed trucks. If the trucks are mixed, then two loading areas may be necessary to suit the different loading heights.

To speed up the loading, arrange a large stockpile of gravel always ready for loading and take workers away from other teams when the truck arrives, so that enough loaders, arranged around the truck, can load the truck in a few minutes.

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

Figure 5.13: tipper truck

Spreading and Compacting equipment

Many factors influence the dry densities achievable in the course of earthworks compaction, including the soil type and moisture content, the type of compaction equipment used and the number of passes made by each machine, and the layer depth of soil being compacted.

Compaction equipment should be chosen on the basis of the soil to be densified; in practice, however, that decision is often influenced by the equipment available at the time. Whatever the equipment used the overall compaction objective is to obtain a uniform densely-compacted platform upon which the pavement layers can be placed.

Soils with hazardous chemicals, peats, highly organic soils, and (especially in wet climates) clays with high liquid limits, should never be used in embankments.

The following are the four main ways in which earthworks materials are compacted by various types of equipment:

- Using heavy static weights to press the particles together, e.g. smooth-wheeled rollers. Grid rollers act similarly to smooth-wheeled rollers when compacting coarse materials; however, with fine-grained soils they compact partly by direct contact pressure and partly by a kneading action. Rubber-tyred rollers have an action that is a cross between the static pressure of a smooth-wheeled roller and the kneading action of a tamping roller.

- Kneading the particles whilst at the same time applying pressure, e.g. tamping rollers.
- Vibrating the materials so that the particles are shaken together into compact mass, e.g. vibrating rollers.
- Pounding the soil so that the particles are forced together, e.g. impact rollers or tampers.

Smooth-wheeled rollers

Current smooth-wheeled rollers are either single-axle rollers that are towed by tractors, or tandem or three-wheeled rollers that are self-propelled. These rollers apply static compaction, and their mass can be increased by adding damp sand or water ballast to the hollow steel drum roll, or by placing ballast weights on the roller frame. With articulated-steering types of three-wheeled roller the three drums have about the same static linear load, and the rear rolls overlap the front one; this enables a uniform compaction to be obtained across the entire roller width and ridges are not formed during the compaction process.

Figure 5.14: Smooth-wheeled rollers

The main factors affecting the compacting performance of smooth-wheeled rollers are the mass per unit width under the compaction rolls and the width and diameter of each roll. The mass per unit width and the roll diameter control the pressure near the surface of the material being compacted whilst the gross mass of each roll affects the rate at which this pressure decreases with depth. Also, the greater the roller mass and the smaller its diameter the greater the wave of material pushed ahead of the roller as it moves forward, and the less even the compacted surface that is left behind.

Smooth-wheeled rollers are most effectively used to compact gravels, sands and materials that need a crushing action; however, they are of no value on rock fill. They have difficulty in maintaining traction on moist plastic soils, and they often cause a “crust” to be formed on the surface of these soils which can prevent proper compaction of the material beneath.

Tamping foot rollers

Tamping foot rollers utilize a compaction drum equipped with a number of protruding feet. Tamping foot rollers are available in a variety of foot sizes and shapes, including the sheepsfoot roller. During initial compaction, roller feet penetrate the loose material and sink to the lower portion of the lifts. As compaction proceeds, the roller rises to the surface or "walks out" of the soil. All tamping foot rollers utilize static weight and manipulation to achieve compaction. Therefore, they are most effective on cohesive soils.

While the sheepsfoot roller produces some impact force, it tends to displace and tear the soil as the feet enter and leave the soil. Newer types of tamping foot rollers utilize a foot designed to minimize displacement of soil during entry and withdrawal. These types of rollers more effectively utilize impact forces.

Figure 5.15: Tamping foot rollers

Grid or mesh rollers

This roller typically consists of a box-girder framework within which two rolls are mounted end-to-end. The surface of each roll is composed of a heavy square patterned steel mesh, whilst the core of the roll is a conical container with its minimum diameter to the outside of the roller.

Grid or mesh rollers utilize a compactor drum made up of a heavy steel mesh. Because of their design, they can operate at high speed without scattering the material being compacted. Compaction is due to static weight and impact plus limited manipulation. Grid rollers are most effective in compacting clean gravels and sands. They can also be used to break up lumps of cohesive soil. They are capable of both crushing and compacting soft rock.

Figure 5.16: Grid rollers

When used with fine-grained soils the grid roller's compaction action partly involves direct contact pressure and partly a kneading action.

Vibratory compactors

Vibratory compactors are available in a wide range of sizes and types. In size they range from small hand-operated compactors through towed rollers to large self-propelled rollers. By type they include plate compactors, smooth drum rollers, and tamping foot rollers. Small walk-behind vibratory plate compactors and vibratory rollers are used primarily for compacting around structures and in other confined areas.

Figure 5.17: Vibratory compactors

Vibratory plate compactors are also available as attachments for hydraulic excavators. The towed and self-propelled units are utilized in general earthwork. Large self-propelled smooth drum vibratory rollers are often used for compacting bituminous bases and pavements. While vibratory compactors are most effective in compacting non-cohesive soils, they may also be effective in compacting cohesive soils when operated at low frequency and high amplitude. Many vibratory compactors can be adjusted to vary both the frequency and amplitude of vibration.

Rubber-tired or pneumatic rollers

Rubber-tired or pneumatic rollers are available as light to medium-weight multi-tired rollers and heavy pneumatic rollers. Wobble-wheel rollers are multi-tired rollers with wheel mounted at an angle so that they appear to wobble as they travel. This imparts a kneading action to the soil. Heavy pneumatic rollers are used for dam construction, compaction of thick lifts, and proof rolling. Pneumatic rollers are effective on almost all types of soils but are least effective on clean sands and gravels.

Figure 5.18: Rubber-tired rollers

Compacting in Confined areas

The equipment available for compaction in confined areas such as trenches and around foundations includes small vibratory plate compactors, tampers or rammers, walk-behind static and vibratory rollers, and attachments for backhoes and hydraulic excavators.

The proper selection of compaction equipment is an important factor in obtaining the required soil density with a minimum expenditure of time and effort. The chart in table 5.2 provides a rough guide to the selection of compaction equipment based on soil type.

Table 5.2: Roller recommendations

ROLLER	Rock -fill	Sand and gravel		Silty and clayey		Clay	
		Well-graded	Poorly graded	Silty sand / gravel	Clayey sand or gravel	Low to medium plasticity	High plasticity
Non-vibrating smooth steel wheel		C	C	C	C	C	C
Sheeps-foot					R	R	R
Grid	C	R	R	C			
Pneumatic		C	C	C	C	C	
Light vibrating smooth wheeled	C	R	R	R	C	C	
Heavy vibrating smooth wheeled	R	R	R	R	C	C	
Vibrating tamping-foot	C	R	C	R	R	R	R
Impact	C	R	R	R	C	C	C

Key: **C = Can be used**

R = Recommended

Table 5.3: Equipment recommendations

Equipment Type	Examples	Typical uses / application
Excavators	Backactor	For trenching
	Dragline	For bulk excavation or excavation in bad ground where the excavator can stand clear of the area being dug out.
	Face Shovel	For digging at a vertical face in front of the machine
	Skimmer	For grading and levelling
Earthmoving	Bulldozer	Ripping and loosening of rocky earth in preparation for excavation; earthmoving operations for short distances, especially in rough, rocky ground and on steep slopes; tree removal
	Tractor with front end loader	Miscellaneous operations associated with earthwork, such as filling trenches, excavation in limited areas, and cleaning up along aggregate stockpiles
Paving machines	Floating sreed pavers	To receive hot or cold materials from a wide variety of trucks without spillage and spread this material to a variety of widths and depths without segregation.
Road rollers	Tandem roller	For compaction of soil and road material
	Pneumatic-tired roller	Compaction of wide range of soils of low to moderate plasticity including silty gravels, sands, silty sands, and clayey sands
	Sheep's-foot roller	Compaction of soils of moderate to high plasticity including silts, clays, clayey sands, silt-clay mixtures, clayey gravels, and silty gravels.
Other	Motor grader	Shaping of subgrades, shoulders, ditches and slopes; maintenance of construction roads
	Trucks	Various hauling operations
	Crawler tractor	Various pushing/pulling operations such as push-loading scrapers

Assessment tasks

1. What do you understand by the term “earthworks”?
2. Which construction activities are responsible for the majority of serious construction accidents?
3. What are some of the precautions that can be taken on site to prevent the following accidents:
    a. To keep persons from falling
    b. To prevent head injuries
    c. To prevent materials from falling
4. Cave-ins is the most potential hazard when working with excavations. What are some of the commonly used methods to prevent cave-ins?
5. Discuss the practical measures to mitigate hazards in the workplace under the following headings:
    a. Safety programs
    b. Equipment operation
    c. Excavation
6. Briefly describe the basic functions of the following construction plant?
    a. Excavation
    b. Backactor
    c. Dragline
    d. Trencher
    e. Bulldozer
    f. Grader
    g. Front-end loader
    h. Compaction
    i. Vibratory roller
    j. Vibrating plate

Topic 6 - Layerworks

Outcomes

Subject Outcome

6.1 Describe and use suitable road foundation

Learning Outcome

6.1.1 Distinguish between a base coarse, a sub-base, a sub-grade and fill.

6.1.2. Describe the requirements and desirable properties of layers.

6.1.2 Explain and demonstrate stabilising of layers.

6.1.3 Explain and demonstrate stabilising of soils using various materials.

6.1.4 Explain the design and placement of gravel wearing courses.

Introduction

The pavement is a structure which separates the tyres of vehicles from the underlying foundation material. The latter is generally the soil but it may be structural concrete or a steel bridge deck. Pavements over soil are normally of multilayer construction with relatively weak materials below and progressively stronger ones above. Such an arrangement leads to the economic use of available materials.

Layerworks comprises the construction of the selected sub-grade, sub-base and base. Most of the materials for these layers come from borrow pits. Material for the base may come from borrow pits (natural gravel base) or may comprise processed material from a rock crusher (crusher run base).

The quantity of material for each layer must be calculated, correctly ordered, transported, dumped, spread, watered, mixed and compacted. Using known productivities the duration, resources required and hence the cost, of every activity can be calculated.

Pavements are usually classified as “flexible” or “rigid”, depending on how they distribute their loads. Rigid pavements usually consist of two layers only, the concrete slab and the sub-base. The slab may be laid in composite form using different aggregates in the upper and lower layers.

Flexible pavements consist of three main layers, bituminous surfacing, the base (road base) and the sub-base. The surfacing is generally divided into the wearing course and the basecourse (or binder course), laid separately. The base and the sub-base may also be laid in composite form using different materials designated the upper and lower base or sub-base material.

Roadbed and formation

The roadbed comprises in situ material, often with some extra soil or gravel added to make up the level. The roadbed is unlikely to be at the level or be to the shape required. Note that in most cases the roadbed has to be dug loose and re-compacted. This is done to ensure that the earth on which the road is to be constructed is uniform in both shape and density.

Impact rollers can be very effective in compacting problem roadbeds, as the compaction can reach the considerable depths. Collapsing sands are best compacted with impact rollers, as achieving the moisture content required for efficient compaction with other rollers can be difficult. Collapsing sands are often quite thick, from half a metre to two or three metres. High-energy impact rollers can be effective to depths of this magnitude.

By definition, the formation is the surface of the ground in its final shape after completion of the earthworks and of consolidation, compaction, or stabilisation The formation fills are sourced from cuttings where possible, to limit costs.

Pavement layers

The road usually consists of four layers. These being built up on the formation as shown in figure 6 .1 below.

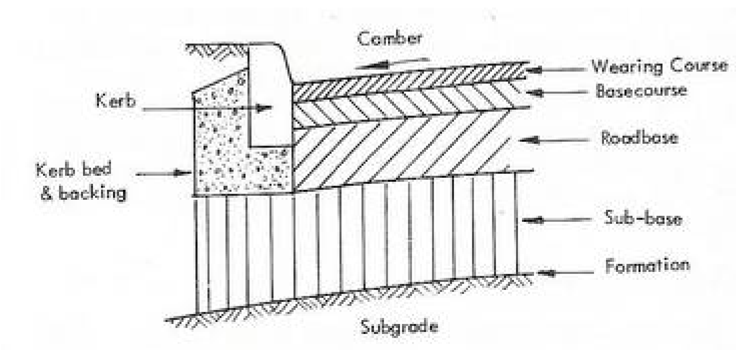


Figure 6.1: Road cross section

The four layers of the road structure are:

The sub-base

The sub-base is below the base and serves to transmit traffic loads to the Sub-grade while providing drainage protection. Both the base and sub-base layers are formed by spreading the aggregate in thin layers and then compacting with heavy equipment until the material forms a dense layer of interlocking aggregate.

A sub-base is not always needed or used in pavement design. However, a pavement constructed over a low quality soil such as swelling clay may require additional load distribution characteristics that a sub-base course can offer. In this case the sub-base course may consist of a high quality fill used to replace poor quality Sub-grade.

The functions of the sub-base are to:

- Assist in load spreading as part of the structural design
- Provide some protection to the sub-grade as soon as it is exposed

- Provide a platform on which to lay the base

The sub-base should be laid as soon as possible after final stripping to formation level. This is done in order to prevent deterioration of the formation due to:

- Rain, which causes the exposed ground to become soggy and may even cause erosion
- Sunshine, which can dry out the surface and cause cracking in the Sub-grade

The road base

The road base is the layer immediately beneath the surfacing. The base in pavement structure is composed of either solely granular materials (aggregate), or soil or granular materials stabilized by an additive. Properties required in materials used for base courses vary with the type of pavement and the depth of the material in the structure.

Road base in flexible pavement must help distribute the load to underlying layers. While distributing the load, the base course itself must not be the cause for failure. Thus it must be strong enough to carry the load without shear failure and resultant rutting.

The base course

This layer can sometimes be referred to as the binder course. This is the layer of material below the wearing course and above the road base. layer supports the wearing course and also assist in protecting the road

Surfacing

The upper most layer of the pavement is the surfacing. This is the layer that is in direct contact with the traffic loads and normally contains the highest quality material. It provides characteristics such as friction, smoothness, noise control drainage, etc.

The functions of the surfacing are to:

- Carry the direct load from traffic and spread it to reduce the stress on the lower parts of the road structure
- Provide a safe, skid-resistant surface
- Prevent the ingress of excessive quantities of surface water into the underlying layers

Stabilisation of layers

Stabilisation is a term used to describe methods of improving the quality of soils and gravels used in the construction of pavements for roads and airports. The objective of stabilisation is to improve the physical properties such as strength, durability and grain structure as well as some chemical and physical properties in order that the stabilised materials can carry imposed loads over the design life of road or airport pavement structure concerned.

In areas containing few gravels of road quality, engineers are forced to look at the alternatives of treating the available soils so that roads may be built of them. The increasing difficulty of finding good quality gravels for gravel surfacing and layerworks and the growing need to conserve these materials, has led to increased focus on the greater use of marginal materials.

Stabilisation of materials is not restricted to roads but can be used anywhere where improved properties are required.

The choice of whether to stabilise or not is based largely on cost. The cost of stabilisation is compared to the cost of transporting good material to the road. If suitable material can be found nearby, it is clearly not worth the additional cost of stabilisation. The choice of stabiliser depends on several characteristics, particularly the properties of the soil that is to be stabilised.

The most commonly used methods of stabilising soils are:

1. Mechanical stabilisation
2. Lime
3. Cement
4. Bitumen

Before any decisions can be made on stabilisation, the soils must be tested and their basic properties measured. From the soil properties and the specified requirements for the layerworks, a suitable stabiliser can usually be chosen. Further testing is then essential to confirm the choice of stabiliser and to find the dosage rates needed to provide the required strength or other property desired.

Mechanical Stabilisation

Mechanical stabilisation is achieved by mixing two or more soils together so that the properties of the mixture are within the specification of the road structural layer concerned. For example, silty clay can be improved by the addition of coarse river sand to make an acceptable selected sub-grade material. Another example would be the correction of the grading of a crusher run by the addition of soil fines.

Grading correction

Correction of poor grading can be done by proportioning the sieve sizes of two or three materials in the ratio of the mixture. This can most easily be done graphically for a two material mix (see graph below).

Example of graphical solution

Gradings of Soil 1 (binder) and Soil 2 (crushed stone) are as follows: % passing is given

Sieve size	**Soil 1 (binder)**	**Soil 2 (crushed stone)**
37 mm	100	92
19,0 mm	100	75
4,75 mm	90	50
1,18 mm	49	36
0,30 mm	29	25
0,075 mm	13	4

Table 6.1: Soil grading example

A graph is drawn up showing percentage passing from 100 % at the top to 0 % at the bottom. The horizontal scale is divided into 100 divisions and the top scale is marked 100% of Soil 1 on the left and 0% on the right. Similarly, the bottom scale is marked 100% of Soil 2 on the right and 0% on the left.

Soil 1 is plotted vertically on the left: the percentage passing is marked on the % scale and the sieve size is written in. Soil 2 is plotted vertically on the right with the percentage passing marked on the % scale and the sieve size written in.

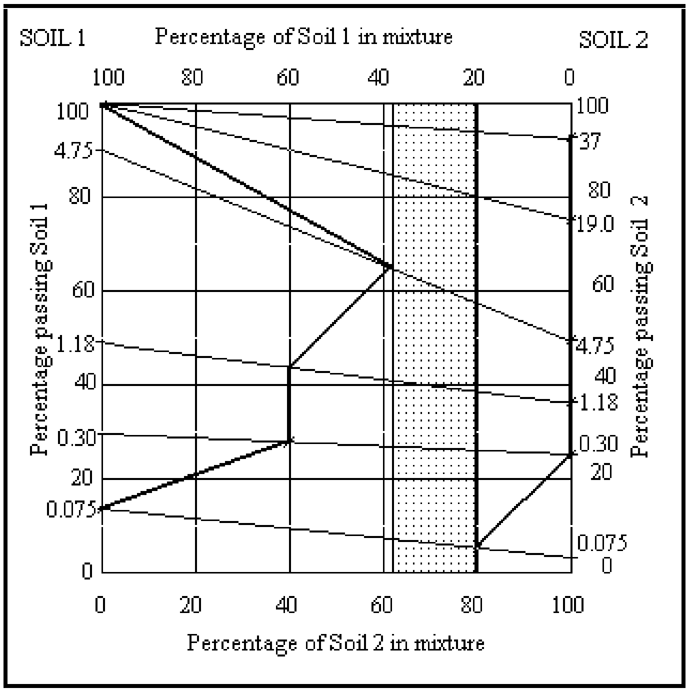


Figure 6.1: Graphical method of mixtures

Now straight lines are drawn, joining like sieve sizes, from the left vertical scale to the right vertical scale. Where Soil 1 has 100 % passing a particular sieve size, the 100% mark is joined to the same sieve size on the right hand scale.

The grading limits are obtained, in this case from SABS 1200 MF: Base. They are tabulated below.

Sieve Size mm	Percentage passing by mass
37	85 – 100
19,0	60 – 100
4,75	30 – 65
1,18	16 – 43
0,30	9 – 27
0,075	5 - 15

Table 6.2: Grading limits of natural gravels

These grading limits are transferred to the graph, marking where each line joining sieves of the same size cut the limiting percentage (marked on the example with a small diagonal line). The limits are then joined with straight lines, starting with either the largest or the smallest and joining the limits in strict sequence (thick lines in the example). The shaded vertical band shows the possible range of mixes of soils 1 and 2 that will satisfy the specified grading limits. As can be seen, any mixture of Soil 1 between 21% and 38% and the corresponding amount of Soil 2 between 79% and 62%, respectively, will satisfy the specification. The grading of the mixture can be read off the graph. For example, if a 30% / 70% mix were to be chosen, the grading would be:

Sieve Size mm	**Percentage passing by mass**
37	95
19,0	83
4,75	62
1,18	40
0,30	27
0,075	7

Table 6.3: Grading of mixture

Reduction of plasticity

Bringing the plasticity index (PI) of the mixtures within specification is easy, as high PI is usually indicative of active clay. When mixing sand into active clay, it seems to require more than the expected amount of sand to cut the PI, probably due to the higher activity of the clay. Note that the PI is always measured on the fraction of soil passing the 0,425 mm sieve. The recommended procedure is to proportion the fines passing 0,425 mm in the ratio needed to bring the PI within the desired range, and then to back calculate these proportions to the whole sample of each soil. Small specimens should be made up and tested in a soils laboratory to confirm the changes in plasticity index. It saves time if several mixtures are made up, starting at the theoretical mix and increasing the sand content in steps above this, in an attempt to bracket the desired value of PI.

Lime Stabilisation

Lime stabilisation is the most common type of subgrade stabilising. It involves the spreading of lime oxided (CaO) which is then watered (slaked) to form lime hydroxide (Ca(OH)2) and mixed into the subgrade soil. The lime hydroxide reacts with the aluminate and silicate minerals found in almost all clayey soils. The resulting calcium silicate and calcium aluminate hydrates are very similar to those produced by the hydration of Portland cement and produce often significant increases in soil strength over a relatively short time period.

Subgrades are generally stabilised with lime or cement or a combination of the two. Generally cohesive, silty, clayey soils will react well with lime and sandy soils will react well with cement. Some soils will be a combination of silt, sand and clay and could require stabilising with both lime and cement.

Depending on the reactiveness of the soil, strength gains of up to 20 times is often achievable. This strength increase is one of a number of benefits subgrade stabilisation offers and enables a pavement to be designed with reduced depths of subbase and basecourse aggregates.

Process

The subgrade stabilisation process involves the following:

- Spreading a specified application of either lime and /or cement on the prepared subgrade via purpose built precision spreader trucks.
- Applying sufficient water to the binder for slaking / hydrating via purpose built pressurised water carts, preferably with side mounted spray bars.
- Mixing the binder with a purpose built stabilising hoe to a specified depth and to achieve a specified degree of mixing and soil particle size.
- Compacting the mix with a heavy, vibrating padfoot roller.
- Trimming to final design levels using a grader and smooth drum roller.

Manufacture

Road limes are prepared from limestone ($CaCO3$) or dolomite ($CaCo3.MgCO3$) by heating to drive off $CO2$. The resultant quicklimes (CaO and $CaO.MgO$) can be used directly for treating soils but for ease of handling and transportation the quicklimes are normally slaked by the addition of water and sold in the hydrated form ($Ca(OH)2.Mg (OH)2$).

Lime / soil reactions

Calcium hydroxide (slaked lime) is not a hydraulic cement. Its stabilising action arises in two ways: a rapid ion exchange reaction (termed modification) and a long-term pozzolanic reaction leading to strength gain (termed cementation). The presence of excess calcium ions has the effect of altering the base-exchange status of clay minerals and this changes the state of aggregation of the clay particles to a more flocculated form, thus modifying the physical properties of the material. These reactions take place rapidly. In addition, over long periods of time, from the clay minerals the lime forms hydrated calcium silicates and aluminates of the same type as are formed in the hydration of ordinary cement. Lime can, therefore, have a cementing action provided there is finely divided reactive material present. Lime treated clays will, in time, develop mechanical properties similar to those of cement-treated soils and the resultant material will be equally durable.

Factors affecting the clay / lime reaction are:

The presence of clay is essential - a useful working rule is that the soil should contain at least 15 percent of material passing 0,425 mm and have a plasticity index (PI) greater than 10. The rate of clay lime reactions is markedly affected by temperature and is very slow below about 15°C.

Lime can react very rapidly with some types of organic matter and with certain amorphous materials, like silica, in soils. These rapid reactions may or may not contribute to modification and cementation. It is important to ensure that these very early reactions are satisfied and that sufficient lime has been added to ensure full modification.

The “Initial Lime Consumption Test” provides a rapid and simple means of determining the amount of lime required for full modification, and involves only the measurement of pH. In effect it ensures that sufficient lime is added to allow some free lime remaining at the end of 1 hour of reaction. The test measures the “lime demand” of the soil.

In certain intermediate materials, lime can be used as stabiliser if it is combined with enough slagment to provide the reactive silica and alumina that may be missing from the soil.

Shrinkage

All cement and lime stabilised soils shrink upon drying. The greater strength of cement leads to larger intact blocks and wider cracks, whereas lime gives smaller and more frequent cracking. Shrinkage cracks eventually initiate failure of the road layers under traffic.

Cement Stabilisation

Stabilisation with portland cement, portland blast furnace cement and slagment is used for soils with low cohesion, largely to improve borderline gravels to perform acceptably as sub-bases and lightly trafficked base-courses. Cement works by binding the particles with crystal growths of dicalcium and tricalcium silicates, rather like weak concrete. Cement may sometimes be the only stabiliser that can be effectively used to bind a particular soil, for example, sand. One frequent use of cement stabilisation is to produce a sub-base that is not water sensitive below a crusher run base that is to be slushed.

There may be some chemical activity due to the lime content of the cement, but most of the strength comes from the cementing action of the soil particles and cement. The hydration of cement proceeds independently of the aggregate and does not rely on a chemical interaction between the cement and aggregate for the development of strength (see lime treatment).

Strength

The factors affecting strength development in cement treated soils are:

- cement content
- type of cement
- curing period and method
- curing temperature
- soil type (grading and composition)
- density of mix
- moisture content of mix
- ease of mixing.

Physical composition

The physical composition of the material affects the degree of compaction, the moisture content and the ease of mixing. The clay content of a material is a major factor influencing its physical properties and has a direct bearing on the strength that can be achieved with cement stabilisation. The higher the density that is achieved, the higher is the strength gain in any soil. A sandy or gravelly soil will usually have a higher strength than a clayey soil, for a given cement content. A reduction in moisture content reduces water/cement ratio and this increases the strength. The optimum moisture content of gravel is lower than that of clay. For maximum effect the cement must be uniformly distributed throughout the material. Mixing efficiency is greater for sandy soils and lower for clay soils.

Cement content

The cement content affects the strength as follows. Provided the material is reasonably well graded the strength of cement-treated materials increases linearly with cement content for materials having a wide range of mean particle size. The chief exception is the case of uniformly graded materials.

Compaction delays

A delay in compaction after mixing can seriously effect strength development in cement-treated materials. Initial set of cement usually takes place within two hours and final set within 6 to 8 hours. It is essential that compaction is complete before final set. In the case of lime-treated materials, delay is not very important.

Curing

Curing is critical for cement-treated layers and they should be protected against drying for 7 days, the protection to be applied before the end of the day on which the layer was constructed. Curing is much less critical with lime-treated soils but excessive drying out should be avoided. Curing is an aspect that is very often neglected in South Africa.

Shrinkage cracking

Cracks are not desirable and should be avoided if possible, because they can let water penetrate into the lower layers. A relatively strong material will produce a few wide (1 mm) cracks at large (4 to 6 m) spacing, but weaker materials will result in numerous narrow cracks at shorter spacing. Cement stabilisation at the higher end of strength will produce large cracks, while lime treatment will produce much smaller cracks, partly due to the slower gain in strength. Overall shrinkage can be reduced by working the material at lower moisture content, provided that the required density can still be achieved.

Figure 6.2: Typical block cracking due to shrinkage

Construction

The material in the layer should be wetted and the water thoroughly mixed in the afternoon before stabilisation is to commence. In the morning the layer should be lightly rolled with at least one pass of a flat wheel roller to provide a firm surface.

The stabiliser should be spread carefully and uniformly over the area to be treated. The minimum of cement that can be mixed efficiently is about 2% by mass and the minimum of lime is about 1% by mass. Spreading may be by hand or by mechanical means.

Mechanical application

Spreading mechanically is done with a distributor attached to the rear of a tanker. The spreader width should be adjusted that the entire road width can be covered with two or three runs of the tanker truck. The powdered stabiliser is fluidised by means of compressed air and sprayed onto the road.

Figure 6.3: Mechanical application

Bag application

If by hand, the sacks of stabiliser should be spotted in rows, measured from the centre-line of the road and spaced evenly along each row. The sacks are then chopped open with spades and the contents spread evenly around the sack. A labourer with a broom may be needed to even out the stabiliser if obvious gaps are to be seen.

Figure 6.4: Mechanical application

Application rates, by hand or by machine, should be checked by means of canvas squares of 1 m2 area that are laid randomly on the layer before stabilisation commences. The mass of stabiliser on the canvas is weighed with a spring balance or scale and is recorded against the chainage and lateral position. The final check of spread rate is the computation from the known mass of stabiliser spread and the measured area covered.

Mixing of the previously dampened material should commence as soon as the stabiliser has been spread. Effective mixing can be achieved by scarifying and then harrowing with a disc harrow. Additional blading with a grader should be done to ensure that the stabiliser has reached to the full depth of the loose material. Watering should commence after the material has been fairly well mixed. There should be several uniform applications of water while the material is being turned.

Mixing quality can be checked by digging trenches in the loose material: some transversely and some longitudinally. The material in each trench should be carefully inspected for uniformity of colour and texture. Poor mixing shows up clearly.

Compaction should commence as soon as mixing is complete. Compaction should be completed within 6 hours if cement is used and 8 hours with lime (cementation) or 48 hours (modification).

Figure 6.5: Mixing material

After each day's construction and when construction operations are delayed a transverse construction joint should be formed by cutting back into the completed layer.

After the treated layer has been finished it should be protected against drying for seven days and traffic should not be allowed on the layer during this period. One of the following curing methods should be used:

a) Frequent light layer water spraying to ensure that the layer and the surface remain continuously damp.
b) Watering and covering with plastic sheeting.
c) Application of a curing membrane consisting of spray grade emulsion.
d) Covering the treated material while it is still damp with material that may be required for the next layer (the treated layer must not be damaged).

The amount of stabiliser required is normally given as a percentage of the mass of the compacted gravel or soil. This percentage is converted to kilogram per cubic metre by multiplying by the required layer density and can be converted to kg/m^2 if the result is multiplied by the layer thickness. Mechanical spreading is controlled by the spread rate in kg/m^2, by adjusting the stabiliser flow rate through the spreader nozzles and truck speed. Hand spreading is controlled by placing the sacks of stabiliser at a spacing that will give the correct rate.

Bitumen Stabilisation

Bitumen has been used to improve gravel properties for roads since the advent of rubber-tyred vehicles. It has more recently also been used as soil improver. Bitumen stabilisation of base course, sub-base and selected sub-grade layers improves the load bearing capacity and resists the ingress of water.

Examples of the use of bitumen as stabiliser or modifier are:
Base course comprising a crusher run or large aggregate mix bound with high viscosity bitumen is used where very heavy traffic has to be carried. Bitumen emulsions can be used to stabilise and waterproof low plasticity base and sub-base materials. Cutback bitumens have been used to stabilise sands, often being mixed in place. Foamed bitumen has been used to stabilise sand and other sub-standard base materials.

Stabilisation with bituminous products is generally more expensive than with lime and cement.

Bitumen stabilised base courses

Bitumen treated base (BTB) and LAMBS

BTB (bitumen treated base) is simply a low fines crusher run bound with a hard bitumen, hot mixed and placed in substantial layers of 100 to 150 mm thick, as opposed to asphalt that is normally (in South Africa) not laid any thicker than 60 mm. The bitumen content is also lower than typical asphalt.

LAMBS (large aggregate mixes for bases) is a newer development of BTB technology, incorporating large maximum sizes of aggregates (37 to 53 mm) with a low viscosity binder. The bitumen content is lower than typical asphalt.

These materials are used only where heavy traffic loads and volumes are expected. For example, the materials are suitable for highways with design traffic volumes of 50 million E80s or more, runways of high-volume airports and certain loading facilities. The material obtains its strength and resistance to deformation primarily from aggregate interlock. As the material is not suitable as a wearing course, factors such as skid resistance, ravelling and bleeding do not have to be considered.

Emulsion treated bases (ETB)

The product most commonly used is bitumen emulsion because it can be applied and mixed into the material without heating. Because emulsions contain 30 – 50% water in which the bitumen is dispersed in finely divided droplets, it is easily mixed into a soil or gravel. When the emulsion "breaks" the water evaporates leaving the bitumen as a binder. Bitumen increases cohesion between the soil particles and improves the strength. It also acts as a waterproofing agent. The treatment produces a tough strong base that is resistant to potholing.

A stable grade anionic emulsion is used as it provides sufficient time for mixing, shaping and compaction of the mixed material before break. When calculating the amount of water to be added to the material to obtain the required degree of compaction it is important to take into account the water content of the emulsion. The emulsion acts as a compaction aid if the process is quick enough to complete compaction before breaking of the emulsion starts. A small amount of cement, about 1% by mass of the soil, is added to ensure that the emulsion breaks throughout the full depth of the layer.
The material for stabilisation is spread and emulsion is applied from a bitumen distributor or water tanker in neat or dilute form according to the moisture present in the material and the optimum moisture content necessary to ensure good compaction. Mixing may be done by a variety of methods

such as grader, disc harrow, rotavator or pulvimixer. Compaction is usually carried out using pneumatic rollers, interspersed by trimming and shaping with a grader. Steel-wheeled (flat) rollers may also be used, but there is a tendency to layer, so their use is preferably confined to the rolling of the surface. Traffic should be kept off the layer for several days, to allow the material to stiffen. Premature trafficking can result in rutting.

Bitumen emulsion treatment can be used for any structural layer, but is usually reserved for bases as the properties of the treated material are so high.

Foamed bitumen

Foamed bitumen produces a material very like that of an emulsion treated material: tough and strong, and so is usually reserved for bases.

Foamed bitumen treated material is usually produced in a batch mixer like a pugmill. The pugmill is filled with gravel or soil and during mixing, hot bitumen and steam or water are sprayed in under high pressure. The interaction of the hot bitumen and steam or water produces bituminous foam that readily coats the soil particles. Once properly mixed, the material is emptied from the pugmill and stockpiled. The stockpiled material can then be transported to the road where its moisture content is brought to optimum and it is compacted. Research has shown that foamed bitumen treated gravels can be stockpiled up to 4 months without appreciable loss of properties.

In situ applications have been successfully carried out using a modified pulvimixer with suitable sprayers for hot bitumen and water. Being a continuous process, some research was needed with regard to spray rates and the forward speed of the machine while stabilising a particular material.

Foamed bitumen has been used successfully on sands with minimum bitumen content of 3 to 4 %.

Advantages of foamed bitumen treatment are:

- It requires a low bitumen content, resulting in cost savings.
- It upgrades poor materials; therefore cheap local aggregates can be used.
- No aggregate heating is necessary.
- It often means the thickness of pavement structure can be reduced, again saving costs.
- It speeds up construction (up to 5 km of 7 m-wide road base per day for in situ mixing).
- In the use of foamed bitumen no curing is needed before compaction.
- Unsurfaced roads can be upgraded without base removal.
- It can be stockpiled and can then be reworked at a later stage.

Disadvantages are:

- Specialised machinery is essential
- Cost can be very high for small quantities

Benefits of a Stabilised Subgrade

Subgrade Stability:

A stabilised subgrade is a much more stable and durable subgrade that is resistant to volume and strength changes caused by moisture and temperature variations.

Compaction Anvil:

Stabilising will produce a subgrade layer with increased strength that will act as an anvil when compacting subsequent aggregate layers thereby enabling higher densities to be achieved in the aggregate layers, realising the aggregates full potential.

Reduced Pavement Depth:

By stabilising a subgrade an increased design CBR strength can be used with resulting reductions in overlying aggregate layer depths for an equivalent pavement design life and traffic loading. Reduced aggregate layer depths result in reduced aggregate volumes, thereby saving costs.

Strength and Stiffness:

Aside from the previous items, increasing the strength and stiffness of a subgrade will provide a much more stable platform that is resistant to deformation and failure caused by construction traffic and requires less effort to trim to final levels.

Reduced Plasticity:

Clayey soils have a high plasticity index which is the range of water content that the soil maintains a plastic state. Lime stabilising reduces the plasticity index and increases the workability of the soil and its ability to maintain its desired profile under loading.

Moisture Barrier:

A stabilised subgrade will form a moisture barrier that will protect the overlying aggregate layers from capillary action and the underlying soils from gravity action. Subsoil and water table drains provide an important component in all types of pavements and are critical in removing water trapped by the stabilised layer.

Particle Migration:

A stabilised subgrade reduces or eliminates the migration of soil particles into the overlying aggregate which causes aggregate contamination and can act as a lubricant between the aggregate particles. Also aggregate particles will not punch into the subgrade and effectively become lost to the integrity of the pavement

Design and placement of gravel wearing courses

Introduction

The economic well-being of a country is closely related to the state of its road network. The agricultural, mining, forestry and tourist industries of all countries rely heavily on an adequate network of all-weather roads for their economic viability. The future development of most third-world countries is fundamentally dependent on the existence of adequate road networks.

Unpaved roads are the major component of the road network in most developing countries and comprise a significant portion of the network even in highly developed countries such as the United States. It is unlikely that the overall percentage of unpaved roads will decrease significantly in the foreseeable future and techniques for improving the unpaved road networks are thus becoming increasingly important. Many unpaved roads are presently designed with very little scientific input and are constructed from the nearest available material. Minimal attention is directed towards providing an adequate formation or effective drainage, or towards selecting suitable material for the prevailing conditions. Minimal maintenance is the norm in most developing areas. It is generally acknowledged, however, that worthwhile benefits can be obtained from an appropriate level of engineering input.

Unpaved roads may be divided into earth tracks, earth roads or gravel roads. This section covers the design and placement of gravel wearing courses.

Gravel roads

Gravel roads have a designed layer of imported material which is typically constructed to a specified standard and width and provides an all-weather surface. The vertical and horizontal alignment is generally upgraded to appropriate standards. Maintenance of gravel roads is carried out on a more regular and systematic basis and a higher level of service is obtained, although the roughness varies considerably with time and depends significantly on the maintenance activity.

Traffic

Gravel roads are nearly always lightly trafficked. Should the traffic exceed about 300 vehicles per day, it is often economically viable to surface them with a bituminous seal, although in developing areas a figure of 400 vehicles per day is probably more appropriate.

Typical unpaved road defects

Typical defects which may affect gravel roads are dustiness, potholes, stoniness, corrugations, ruts, cracks, ravelling (formation of loose material), erosion, slipperiness, impassability and loss of surfacing or wearing course. Many of these have a direct effect on the road roughness and safety.
The causes of each of these modes of distress and possible remedial actions are discussed in turn.

Dustiness

Dust is the fine material released from the road surface under the wheels of moving vehicles and the turbulence caused by vehicles. Silt-sized particles (2 – 75 µm) are the predominant elements in dust and the quantity of dust generated by a vehicle is a function of its aerodynamic shape, speed of travel and the surfacing material properties.

Dust is undesirable from a number of points of view:

- Safety – Dust affects visibility significantly and can result in highly unsafe following and passing conditions (especially during peak traffic periods).
- Comfort – Excessive dust can result in significant discomfort to drivers and passengers, especially in the hotter areas of southern Africa where it is impractical to keep all windows closed.
- Health – Although no positive evidence of the detrimental effects of dust on the health of road users has been produced locally, the problem has been investigated in the United States. Certain materials such as asbestos and silica dust, which may occur in some wearing course gravels, can certainly be considered undesirable from a health aspect.
- Vehicle damage – Dust can significantly increase the rate of wear of moving parts of vehicles, under both dry and wet conditions, when it acts as a grinding paste.

- Vegetation – The effects of dust on roadside vegetation and crops is difficult to estimate, but may be significant in certain areas, especially where intensive agriculture or stock and game farms are found.
- Environmental – Excessive dust generation often results in air pollution, this being particularly prevalent in deep valleys during winter. Temperature inversions result in thick blankets of dust being suspended in the air.
- Economic – The loss of wearing course material in the form of dust results in a change in the properties of the wearing course gravel. Materials which initially had adequate plasticity have been observed to form corrugations as the fines are lost. This should be borne in mind during regular grader maintenance.

Dust is generally considered by the travelling public to be unacceptable when it totally obscures vehicles behind a moving vehicle, either following vehicles or those passing from the opposite direction, especially near road junctions.

The potential dustiness of a material is very difficult to predict. Although material composition is the major characteristic affecting dustiness, aspects such as the vehicle volume, mix and speeds of vehicles, moisture content of the road, looseness of the material, maintenance frequency and wind all affect the apparent dustiness.

In many cases it may be necessary to apply dust palliatives in order to bind the dust particles. A number of dust palliatives are commercially available but each one has to be tested individually in order to identify its suitability and cost-effectiveness for the material under consideration.
Common dust palliatives may be bitumen- or tar-based, inorganic compounds (magnesium and calcium chlorides being the most popular), ligno-sulphonate (a product of the sulphate timber pulping process) and various commercial products of variable effectiveness.

Potholes

Potholes play a significant role in the development of roughness on gravel roads and may cause substantial damage to vehicles if they are allowed to develop and increase in size. The effect of potholes on vehicles depends both on the depth and diameter of the pothole. The potholes which affect vehicles most are those between 250 mm and 1 500 mm in diameter with a depth of more than 50 to 75 mm.

Potholes may arise from the following processes:

- poor road shape and drainage;
- poor grader operation practice, e.g. plucking of oversize material and destruction of the crown;
- compaction of material behind oversize stones under wheel loads;
- enlargement of corrugation troughs;
- deformation of weak Sub-grades and wearing courses;
- subsidence of animal and insect burrows;
- disintegration of highly cracked roads (i.e. excessive plasticity);
- disintegration of soft oversize material;
- dispersive soils;
- poor compaction;
- material and moisture variability.

Once pothole formation has been initiated (irrespective of the cause), the drainage deteriorates, water ponds in the depressions and the potholes are enlarged by traffic. Particular attention should be given to maintaining adequate cross-fall on such sections. The enlargement occurs through compaction and remoulding of the weakened material (in the wet state) and removal of the material from the hole by wheels and splashing. Materials with a low soaked strength are thus likely to develop larger and deeper potholes in shorter periods. The influence of drainage on pothole formation is clearly manifested by the general absence of potholes on grades. Potholes are usually worst at the bottom of sag vertical curves in the alignment, on level road sections with poor shape, and near bridges.

Potholes are difficult to repair, very few being successfully repaired by routine grader maintenance or by manual filling behind the grader. The only successful way to repair them is by enlarging the hole, overfilling it with moist gravel and compacting it (in layers, if necessary). Many potholes have been recorded in the same place for over two years, gradually becoming wider and deeper despite routine grader maintenance. It may be necessary in certain areas where a particularly pothole-susceptible material is common to have a team specifically for patching potholes.

Stoniness

Stoniness is the relative percentage of material in the road which is larger than a recommended maximum size (usually 37.5 mm). This is one of the few defects of unpaved roads which can usually be controlled.

Excessively stony roads result in the following problems:

- unnecessarily rough roads;
- difficulty with grader maintenance;
- poor compaction of areas adjacent to stones (leading to potholes and ravelling);
- the development of corrugations;
- thick loose material is necessary to cover the stones.

Ruts

Ruts are parallel depressions of the surface in the wheel tracks. They may form as a result of deformation (compaction) of the Sub-grade, compaction of the wearing course or loss of gravel from the wearing course.

Under local conditions rutting is usually insignificant in terms of the overall unpaved road performance. The probable reason for this is the typically strong, free-draining, sandy Sub-grade prevalent over much of southern Africa, as well as the deep water tables.

Ruts pose potential problems as they tend to retain rain water which softens the wearing course and allows deformation under traffic. Routine blading of unpaved roads replaces gravel in the ruts and simultaneously compensates for any Sub-grade deformation which may have occurred. The material graded into the ruts is generally compacted only in a moist condition. However, after grading, no definite wheel tracks are visible and ruts often begin to form at a slight distance from the previous ones. This allows time for rehabilitation. The main cause of rutting in southern Africa is the ravelling of low-cohesion material under traffic movement.

A secondary cause is the deformation of highly cohesive wearing course materials under traffic. Both of these require a different gravel if the rut formation is such that maintenance becomes excessively costly.

Cracks

Cracks are not a major problem on unpaved roads but bad cracking may lead to the formation of potholes. Cracking of the wearing course (which usually occurs only during the dry season) is the result of the plasticity being too high or the material being very fine-grained (e.g. dolomitic wad). The materials which crack badly also tend to become slippery when wet.

Ravelling

The generation of loose gravel under traffic, termed ravelling, is a significant economic and safety problem.

Loose gravel may be distributed over the full width of the road but more frequently is concentrated in windrows between the wheel tracks or alongside the travelled portion of the road. The major problems with roads susceptible to ravelling are:

- the windrows are a safety hazard;
- stones from the loose gravel may damage vehicles or windscreens;
- the rolling resistance of the vehicle is increased by loose material with concomitant increases in fuel
- consumption and vehicle operating costs;
- problems with lateral drainage of the road may be caused by windrows of loose material

Ravelling is mainly caused by a deficiency of fine material (and hence cohesion), a poor particle size distribution (e.g. skip grading) in the wearing course gravel and inadequate compaction. Ravelling is generally worse in the dry season than in the wet season when capillary suction results in some "cohesion".

Fine material can often be blended with the gravel to increase cohesion. A good degree of moist compaction can also be used to cut down ravelling.

Erosion

Erosion (or scour) is the loss of surfacing material caused by the flow of water over the road. The ability of a material to resist erosion depends on the shear strength (equal to the cohesion, as the normal stress is zero) under the conditions at which the water flow occurs. If the shear strength of the material is less than the tractive forces induced by the water flowing over the material, grains will become detached and erosion will occur. Finer grained materials with minimal coarse aggregate are particularly susceptible to erosion. However, those with a relatively high plasticity (which will usually become slippery when wet) may resist erosion.

Erosion can be prevented by:

- Increasing the shear strength of the wearing course material by improving the grading of the material and ensuring a well-graded, cohesive mixture with adequate gravel up to 26,5 mm in size. Good compaction also increases the shear strength by improving the granular interlock and decreasing the permeability of the material.

- Decreasing the shear stresses induced by the flow of water by retarding the rate of flow. This is best done by decreasing the grade and the cross-fall and ensuring that the length of the flow path of the water is minimised.

Erosion of the weathering course results in a change in the properties of the material as various fractions of the material are selectively removed during erosion.

Shape

Poor cross-sectional shape of the road usually results in bad drainage which accelerates the formation of potholes and ruts as well as erosion. Routine maintenance of unpaved roads should be carried out timeously to retain the crown of the road and to ensure adequate cross-fall. Excessive deterioration of the road prior to maintenance results in difficulty in achieving the required shape.

On vertical grades the development of ruts can be a major problem as they form drainage channels during storms and erode rapidly. Special attention should thus be paid to the elimination of ruts on grades during maintenance.

Slipperiness

Slipperiness of the surface of an unpaved road is a significant safety problem. In wet weather, slipperiness is caused by excessively fine or plastic material in the wearing course. Even materials with adequate coarse aggregate may become slippery if the fine silt and clay fraction becomes concentrated near the surface.

Special care should be taken with the use of certain mud-rocks which are susceptible to slaking on exposure to the atmosphere. An initially granular material can soon become a fine clayey mud.

The only cure for roads which are slippery when wet is to regravel with a better gravel (i.e. having a lower shrinkage product), and for those which are slippery when dry to improve the blading operation. Warning signs should be prominently displayed on slippery roads. The practice of adding a gravel or sand to the existing material is recommended in some manuals but this does not avoid the possibility of the fine material migrating to the surface.

Gravel loss

Although the loss of the wearing course material from the road surface under traffic and climatic conditions (rain and wind) is inevitable, the replacement of this lost material is the most costly maintenance operation.

Material which ravels is most likely to result in a high gravel loss. Although the major contributor to the gravel loss is the traffic (Section 3.2.3), significant reductions in gravel loss can be obtained by selecting material with a suitably high plastic factor (PF greater than 500) and percentages passing the 26,5 mm sieve (Section 3.2.3). Well-graded and well-compacted gravels resist gravel loss better than materials deficient in either fine or coarse fractions.

Erosion should be reduced as far as possible to avoid excessive gravel loss on longitudinal grades.

Design of Unpaved Roads

Geometric design

The road alignment should be adapted to the prevailing conditions. A different philosophy should be applied to roads opening up areas and those which are likely to be forerunners of paved roads. It is not usually economically feasible to construct deep cuts, high fills or large radius horizontal curves in mountainous areas in order to accommodate the recommended geometric standards. Economic constraints usually dictate that the geometric standards have to be compromised (with speed restrictions or warning signs where necessary). Where possible, construction along watersheds is recommended.

A significant problem in southern Africa is the occasional construction of unnecessarily wide unpaved roads (roads with travelled ways of up to 10 m and up to 14 m between shoulder breakpoints have been recorded).

This results in unnecessarily excessive surfacing gravel and grader maintenance being required and a rapid loss of shape of the road. On the other hand, excessively narrow roads result in deep rutting, poor safety standards and high gravel losses.

The total gravelled width of the road should be about eight metres for most unpaved roads carrying between 50 and 200 vehicles per day. This can be reduced for roads carrying less than 50 vehicles per day and in mountainous terrain and should be increased to 9 m for roads carrying more than 200 vehicles per day or those carrying large vehicles such as coal or sugarcane trucks.

The width and alignment of unpaved roads should generally be appropriate to the prevailing traffic, climate and topography and geometric standards for unpaved roads should be flexible enough to provide for this. Care should, however, be taken to create a speed environment with matching geometric elements to eliminate the element of surprise and avoid unsafe conditions to which driver awareness is not sensitive.

Thickness design

The structural design of paved roads has, in the last two or three decades developed into a highly sophisticated branch of engineering. The design of unpaved roads, on the other hand, has received minimal attention. Unpaved roads may form an initial stage towards paved roads and designs should take this into consideration.

Traffic induced compaction

Wearing courses which have been compacted with a nominal number of passes of a grid-roller can lose up to 30 per cent of the constructed thickness within a short period due to traffic compaction. It is therefore important to ensure adequate compaction or allow for the loss in pavement thickness caused by traffic compaction in the thickness design. This is especially relevant when the materials are relatively dry of optimum moisture content during grid-rolling, as the air voids are high and traffic compaction will occur rapidly.

The following can be used as approximate estimates of the potential traffic compaction:

Compaction during construction	**Moisture content during construction**	**Potential loss of gravel thickness**
3 passes of a grid roller	about OMC	10%
3 passes of a grid roller	dry of OMC	20%
3 passes of a pneumatic tyred roller	About OMC	5%

Local experience and field trials may be necessary to quantify these estimates more accurately.

The compaction which occurs during normal construction should not be neglected and up to about 30 per cent more bulk material is required to allow for this and still produce the required thickness.

Material selection

Numerous specifications are currently available for the selection of materials for unpaved road wearing courses in southern Africa. These have been compared with the properties of a number of in-service roads in southern Africa and found to be generally lacking in their ability to predict the performance of roads. Many satisfactory materials are rejected while many materials which perform poorly are deemed acceptable.

Construction

Sub-grade preparation

Many unpaved roads, however lightly trafficked at the time of construction, will with the passage of time capture more traffic and increase in use (and importance) as the local population increases. They may eventually be upgraded to higher standard unpaved roads or even relatively lightly trafficked paved roads. Good preparation of the Sub-grade for a new unpaved road is therefore extremely important as this will often be the Sub-grade for a large part of the future improved road.

Initially the Sub-grade should be cleared of bush and trees over the full width of the road prism. All vegetable matter and organic soil should be removed by grader or bulldozer from the road prism. The road bed should be ripped and mixed, sprayed with water to about Optimum Moisture Content (OMC) and then be compacted to a density of at least 90% Mod AASHO (about 95% Proctor) maximum dry density.

Adequate Sub-grade compaction reduces the possibility of Sub-grade deformation and reduces the permeability and strengthens the Sub-grade. The Sub-grade should then be smoothed and shaped with a suitable cross-fall (about 2 per cent). Material of at least Sub-grade quality (CBR = 5%) should be used to build up the formation to a height of not less than 300 mm above the natural ground level in flat terrain. This material can usually be obtained during the construction of side drains parallel and on each side of the road and mitre drains to remove water from the side drains. The drains should be deep and wide enough to remove all the expected surface water during wet periods from the road and its adjacent areas without ponding or excessive erosion. In flat areas, the formation should be high enough to allow the placement of drainage structures (usually pipes) at adequate depths beneath the wearing course. It is important that the construction of the formation does not interfere with the natural drainage of the surrounding area and cause ponding.

The material used for the formation should be slightly plastic with a plasticity index of about 4 in order to provide a stable platform for construction of the wearing course.

Other material from a borrow pit may be required to build up the formation. Once adequate material has been dumped on the Sub-grade, the formation should be compacted at about OMC to a density of 90% Mod AASHO and smoothed and shaped as for the Sub-grade. It is important that the formation level is smooth and has an adequate cross-fall to ensure that any water that soaks through the wearing course does not pond at formation level, should a permeability differential exist.
The wearing course is placed directly on the formation in most unpaved roads, although “sub-bases” may be used if the Sub-grade is poor or large numbers of heavy vehicles are likely to use the road.

Gravel operations

The location, winning and transportation of wearing course gravels is one of the most expensive operations associated with the development of unpaved roads. It is therefore important that the optimum material be located nearby and used to maximum advantage.

Wearing course construction

Good construction practices for wearing courses will:

- provide the correct thickness of material;
- provide adequate compaction;
- provide a smooth finish with a good cross-sectional shape.

Thickness

It is important that the material be dumped on the road at the correct spacing to provide for the expected thickness of gravel after spreading and compaction. If the constructed thickness is incorrect, the management of the maintenance of the road network will be disrupted as premature regravelling may be necessary or the road may need a thinner layer of gravel when being regravelled. Both of these variations affect the budgeting requirements. The thickness must be as consistent as possible over the length of the link to avoid total loss of gravel over portions of the link only.

Compaction

Good compaction produces a tightly bound gravel with optimum particle interlock, minimum permeability and porosity and significantly increased strength.

High degree of moist compaction results in a road with a lower roughness than similar materials which are poorly compacted in a dry condition. The roughness deterioration can be much slower and gravel loss and dust emission can be significantly reduced.

A poor degree of compaction results in a low density, permeable material which ravels easily and is highly moisture sensitive. Deep rutting, compaction under traffic, potholing, corrugations and passability problems under soaked conditions are common problems with poorly compacted material. The initial traffic-induced compaction and increased gravel loss again interfere with the maintenance management strategy for the road.

In order to take advantage of the moisture added to the material before hauling, the material should be dumped, spread and compacted before a significant quantity of the water has evaporated. This requires careful project planning and management. Construction during the wet season results in additional moisture being available (from rain) and often lower evaporation.

Finish and shape

The roughness of a road is one of the most important factors influencing vehicle operating cost, affecting every contributor except depreciation. It is important therefore to make use of competent grader operators who can provide a smooth, well-finished riding surface. A good surface after construction can be maintained to a much better standard than a poorly finished surface.

The cross-section and shape of the road should ensure a definite crown with a cross-fall of about 4 per cent (not more than 5 per cent). Large stones (greater than 50 or 75 mm), which have found their way into the gravel, should be removed (manually if necessary) and discarded at a distance from the road to ensure that they are not bladed onto the road during routine blading or drain clearing.

Drainage

Unpaved roads are totally exposed to the elements and rainfall can result in significant maintenance problems. The importance of good drainage cannot be overemphasised. The moisture content of an unpaved road is one of the few causes of problems which can be controlled by the road maintenance team.

The water in an unpaved road can only come from two sources:

- surface water from precipitation (including flooding);
- subsurface water from high water tables, seepage, springs and capillary suction.

Surface water

Surface water is predominantly in the form of rain (not necessarily in the specific area in the case of flooding) but may arise from snow and hail to a lesser extent. Infiltration of this water into the wearing courses can be limited by ensuring a compact, tightly bound wearing course with an adequate cross-fall which removes the water rapidly from the road surface into the side drains without causing scouring. Side drains should only be used where natural dispersion of surface water is disrupted, as concentration of water is the root cause of erosion.

The side drains should run parallel to the road, collecting the surface water from the pavement and shoulders and removing it through mitre drains (or turnouts) as far from the road as practically possible, where it can soak into the ground or flow into a natural drainage course without influencing the road structure. The distance between mitre drains (which need not necessarily always be associated with side drains) depends on their grade with a smaller spacing on flat grades and greater spacing (not far enough to cause excessive flow velocities) between them on steeper grades (Figure 4).

The principle is to place the mitre drains at intervals which avoid ponding adjacent to the road but not far apart enough to allow the build-up of high concentrations and flow velocities which lead to scouring. Flow velocities can also be decreased by using mitre drains constructed with a grader. (The 0,6 m drains illustrated in Figure 4 are only recommended for urban areas.) The width of mitre banks should generally be 1 to 1,5 metres.

The importance of the road surface being raised above the surrounding area is obvious. When the surrounding area is higher than the road surface, the road becomes the drain during periods of heavy rainfall and rapidly becomes deformed or even impassable if the water soaks in.

The drains should be deep and wide enough to contain the expected water volumes and avoid flooding of the carriageway. Their dimensions should be such that the velocity of flow is not excessive (which results in scouring and erosion) and the intended maintenance is practical (i.e. wide enough for graders if grader clearing is anticipated). Flat-bottomed drains are less susceptible to erosion than V-shaped ones and where graders are to be used for maintenance it should be ensured that they are wide enough to accommodate the graders. On steeper grades some form of erosion protection of the drains is usually necessary. A number of idealised drain and ditch designs are shown in Figure 4.

If the natural topography is such that water will disperse by itself and drains can be avoided, significant cost savings can be effected and potential problems avoided. It is important that the road structures do not interfere with the cross drainage of the area. Adequate means of cross drainage such as culverts are necessary with careful attention being paid to their size and inlet and outlet control.

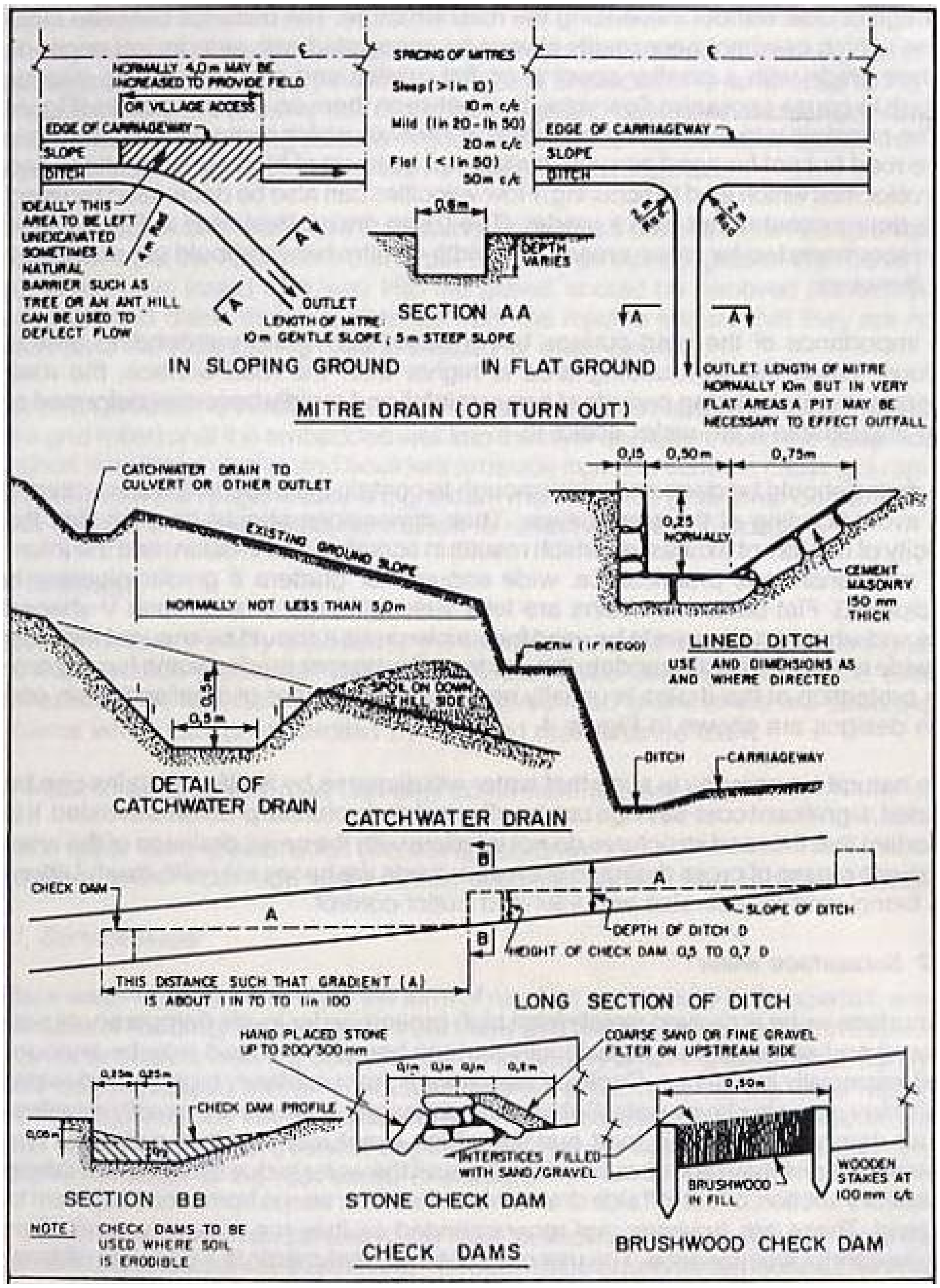


Figure 6.3: Ditches and drains

Subsurface water

Subsurface water is derived mainly from high ground-water levels (temporary or permanent) and seepage, but occasionally springs beneath the road may be encountered, especially in cuttings. Capillary rise of water from relatively high ground-water levels may occur in clayey soils. Subsurface drainage problems are usually manifested as damp areas on the road surface which eventually result in potholes. The remedial actions may require subsurface drains if the water is due to high water tables or capillary suction, or cut-off side drains when the water seeps from areas adjacent to the road. These are, however, not recommended as they are expensive and often require careful maintenance. The use of rock-fill embankments is a possible alternative, but geotechnical assistance should be obtained to identify the source of the water and propose remedial measures in these cases.

Assessment tasks

7. What are the functions of the following pavement layers?
   a. Surfacing
   b. The base
   c. The subbase
   d. The road bed
8. What are the objectives of stabilisation?
9. What is “mechanical stabilisation or modification”?
10. What soils can be stabilised with lime?
11. Describe how lime stabilisation works.
12. Explain why mixtures of lime and slagment can be successfully used to stabilise intermediate soils (soils without sufficient clay).
13. List four of the factors that affect the strength of cement treated soils.
14. What are the advantages of a bitumen treated base?
15. Describe the process of stabilising a soil with foamed bitumen.
16. What are the benefits of a Stabilised subgrade?
17. Describe some of the defects which might affect gravel roads

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