Implementing employment intensive road works

A cidb practice manual

Contributing to contractor development in job creation

MANUAL 1
The fundamentals of road construction

cidb
development through partnership

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

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Constructing shared growth

This set of practice manuals for employment intensive road construction, draws on the experience of the South African Construction Industry in the development of road building contractors, supervisors and designers, in implementing road works and creating jobs; and builds upon the labour-based best practice guidelines that have been published by the Construction Industry Development Board. (cidb) (see www.cidb.org.za):

"…..with the right construction technology, South Africa can successfully address infrastructural backlogs in a cost-efficient way and to acceptable engineering standards. We are saying we can do this while maximising job opportunities.…"
(Ms Thoko Didiza, Minister of Public Works. Vuk'uphile learners welcoming ceremony, Nkangala, Mpumalanga, 29 June 2006.)

In assembling this publication, the cidb has collaborated with the Council for Scientific and Industrial Research (CSIR), and the International Labour Organisation (ILO) in fulfilment of the cidb's mandate to promote *"national social and economic objectives, including the labour absorption in the construction industry"*. (CIDB Act 38 of 2000). The cidb is committed to further partnerships with industry and stakeholders, to promote the use of these manuals and the training of SME contractors within the framework of the National Contractor Development Programme and the Construction Charter.

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

CSIR
our future through science

ILO

Implementing employment intensive road works

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OVERVIEW of the practice manuals

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

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

This ci**d**b practice manual for *Implementing Employment Intensive Road Works* follows on from the ci**d**b's guide to best practice for *Labour-based Methods and Technologies for Employment-Intensive Construction Works*. The latter covers a broad spectrum of construction works. It establishes desirable and appropriate standards, processes, procedures and methods; relating to the design and implementation of labour-based construction technologies, methods for earthworks and for materials manufacture. This first set of guidelines provides sufficient technical information to enable those, responsible for the design of projects, to make confident and informed choices on their use in projects.

Implementing Employment Intensive Road Works aims to provide practical and technical guidance to small and medium sized (SME) contractors, supervisors and designers who are involved in the construction and upgrading of roads using labour and light plant. The need for these technical manuals was identified during the training of SME contractors, involved in the Gundo Lashu programme in Limpopo Province – a programme of labour-based upgrading of rural roads, promoted by the Department of Public Works, Roads and Transport in collaboration with the International Labour Organisation (ILO).

The development of this series of manuals is based on:

- experience gained in South Africa over the last ten years, including that of the Gundo Lashu project presently being implemented by the Road Agency Limpopo, with technical assistance from the ILO,
- best practices implemented by a number of Sub-Saharan countries,
- the relevant ci**d**b best practice guidelines, in its series of *Labour-based Methods and Technologies for Employment-Intensive Construction Works.*

These manuals support the objectives of South Africa's Expanded Public Works Programme (EPWP), and are aligned with the *Guidelines for the Implementation of Labour-intensive Infrastructure Projects under the Expanded Public Works Programme (EPWP)* of the Department of Public Works, obtainable on www.epwp.gov.za.

Acknowledgements

These manuals were compiled by the CSIR in collaboration with, and funding from, the ILO and cidb to promote the implementation of employment intensive road works.

A cidb Focus Group of industry specialists and stakeholders has further reviewed and refined these manuals.

The contribution of these individuals whose passion, commitment and knowledge has enabled the development of this publication as a common resource in the fight against poverty and joblessness, both in South Africa and globally, is acknowledged. Special thanks to:

- Adrian Bergh and Alex McKay of the CSIR.
- Jon Hongve of the ILO.
- Rob Little, Bryan Westcott, Ian van Wyk and Ron Watermeyer of the cidb Focus Group.
- Maikel Lieuw Song, Basotho Seetsa and Mpayo Kasure of the Department of Public Works, as members of the cidb Focus Group.
- The many organisations and individuals referred to in the references quoted in these manuals.

MANUAL 1: The fundamentals of road construction

Contents

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Introduction

1. Aim

The aim of this manual is to provide contractors, involved in the labour-based construction and upgrading of low volume roads, with an introduction to and basic understanding of mathematical concepts and calculations; survey concepts and calculations; materials and materials related concepts and typical road terms and components encountered in the construction of these roads.

2. Composition

The manual comprises the following modules:

Module 1: Basic mathematical concepts and calculations
Module 2: Survey concepts
Module 3: Material concepts
Module 4: Material-related concepts
Module 5: Typical road terms and components

3. Supplementary manuals

Manual 2: Planning and contract management
Manual 3: Gravel pavement layers
Manual 4: Bituminous seals
Manual 5: Concrete and masonry drainage works and structures

4. References

1. *Surfacing seals for rural and urban roads*. 1998. Pretoria: Department of Transport (Draft technical Recommendations for Highways; Draft TRH3).

2. *Guidelines for low-volume sealed roads*. July 2003: South African Transport and Communications Commission (SATCC).

3. *Labour Intensive Construction Techniques Volume 7: Upgrading techniques for low volume roads/streets*. August 1996: Pretoria: Department of Transport (LICT 7).

4. *Technical manual for labour-based road rehabilitation works*. March 1999: Lusaka: Republic of Zambia; Ministry of Works and Supply.

5. Course material. Civil Engineering Industry Training Scheme (CELTS) - For more information on available CELTS training courses contact 011 455 1700.

MODULE 1: Basic mathematical concepts and calculations

1. Introduction

This module is intended to refresh the contractor's memory and provide easy reference to some of the mathematical concepts and calculations encountered in the construction of roads and associated work. It is not intended as a text book in basic mathematics.

2. Units measurement

The units of measurement most often encountered in the construction of roads and associated work are the following:

Length

The total length of the road is usually given in kilometres (km) and the lengths of sections of a road in metres (m).

(1 km = 1 000 m)

Width

The width of a road, or the layers of a road, is normally given in metres (m).

Thickness

The thickness of a layer in a road, the thickness of the surface or the thickness of concrete work is given in millimetres (mm).

(1 000 mm = 1 m)

Radius

Straight sections of a road are joined with curves; the radius (R) of a curve on a road is given in metres (m).

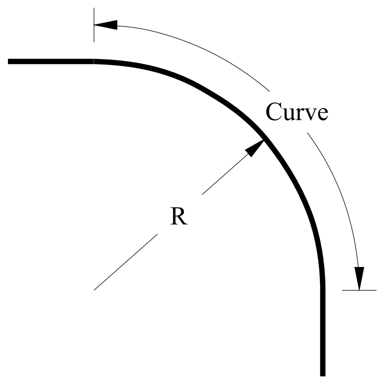

Figure 1.1

Area

The unit of measurement for an area is in square metre (m^2).
This term is mostly encountered in determining the area to be:

- Compacted
- Surfaced
- Grassed

Volume

- Volume of material

The most frequently used unit of measurement for volume is the cubic metre (m^3).

This term is mostly encountered in determining the amount of material to be:

  – Excavated
  – Used in the construction and compaction of a layer
  – Carted away

- Volume of liquids

The volume of liquid is normally measured in litres (*l*).
The term is encountered in determining the amount of:

  – Water
  – Emulsion
  – Bitumen

3. Typical shapes – areas and volumes

Area

- Rectangle

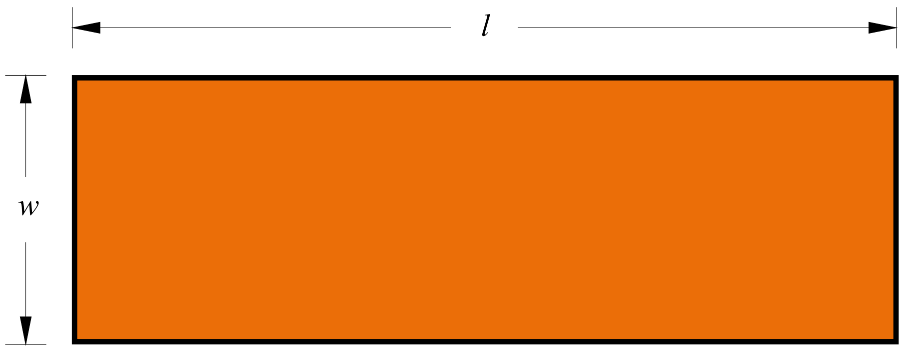

Figure 1.2

The area of a section of road is normally rectangular in shape and the area is obtained by multiplying the length of the road by the width of the road. The unit used for *l* and *w* must be the same (normally both are expressed in metres (m).

$$Area = l \times w$$

Example

If a road, that is 5 km long (l) by 7 m wide (w), is to be compacted, then the area to be compacted is:
5 km × 7 m or 5 000 m × 7 m = 35 000 m²

- Other common shapes
  - Triangle
  - Trapezium

$$Area = \frac{1}{2} b \times h$$

$$Area = \frac{1}{2}(l_1 + l_2) \times h$$

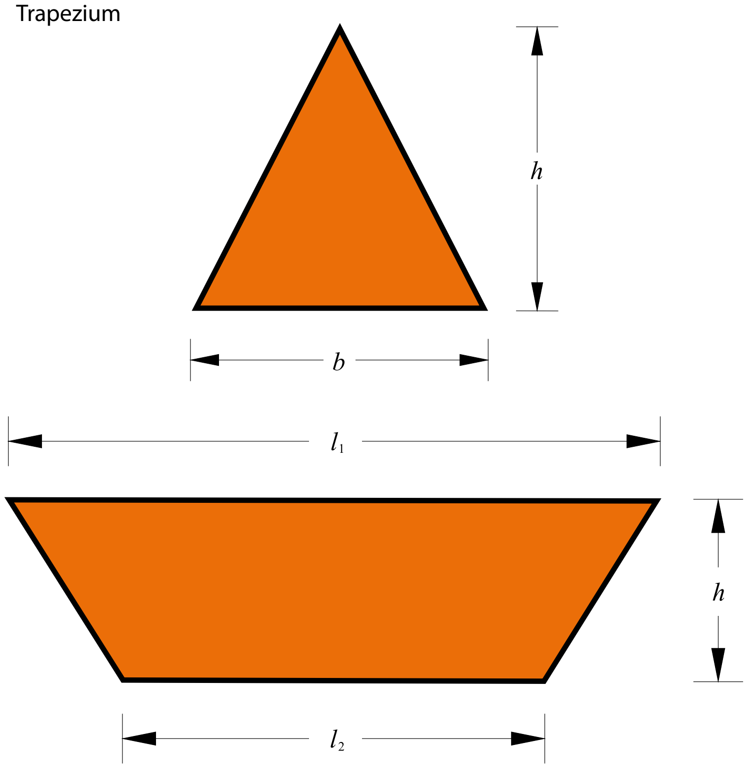

Figure 1.3

Volume

Volume of material is almost always measured in cubic metres (m³).

- Volume of material in a road layer

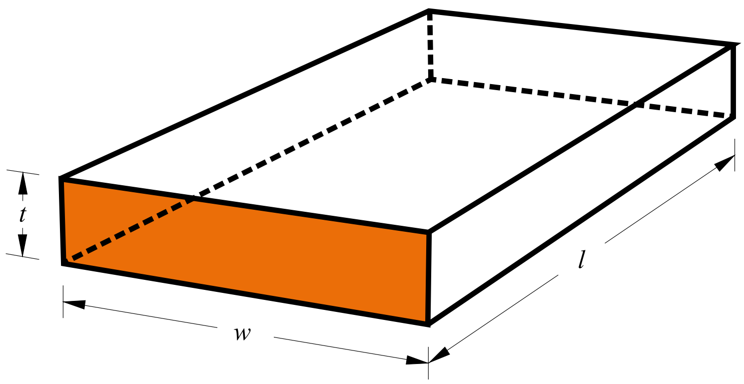

Figure 1.4

The volume of compacted material in a road layer is obtained by multiplying the thickness of the layer (t) by the width of the layer (w) by the length of the layer (l).

The problem here is that the length could be in km, the width in m, and the thickness in mm. They must all be brought to the same unit, normally metres to give a volume in m³ (cubic metres).

Example 1: Volume of material in short length of road

The volume of material in a layer 100 mm thick by 7 m wide by 500 m long is:

$$\begin{aligned} \text{Volume} &= t \times w \times l \\ &= 100\ mm \times 7\ m \times 500\ m \\ &= \frac{100}{1\ 000}\ m \times 7\ m \times 500\ m \\ &= 350\ m^3 \end{aligned}$$

Example 2: Volume of material in long length of road

The volume of material in a layer of 100 mm thick by 7 m wide by 5 km long is:

$$\begin{aligned} \text{Volume} &= t \times w \times l \\ &= 100\ mm \times 7\ m \times 5\ km \\ &= \frac{100}{1\ 000}\ m \times 7\ m \times (5 \times 1000)\ m \\ &= 3\ 500\ m^3 \end{aligned}$$

- Volume of material excavated from a trench or drain

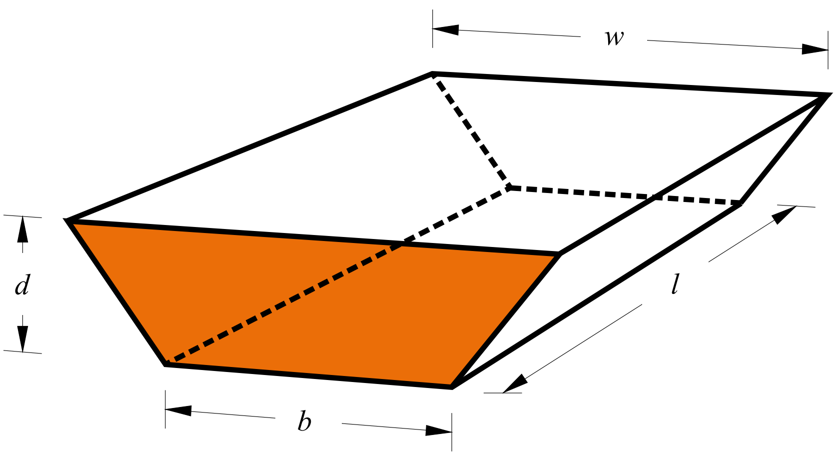

Figure 1.5

The amount of material to be excavated from a drain of the shape above is: $\frac{1}{2}(w + b) \times l \times d$

Again all the measurements must be brought to the same units, usually metres, giving a volume of material in m³ (cubic metres).

- Volume of material in a fill or embankment

A fill or embankment is, in effect, an upside down excavation; and the amount of fill material is calculated in the same way as the amount of excavated material.

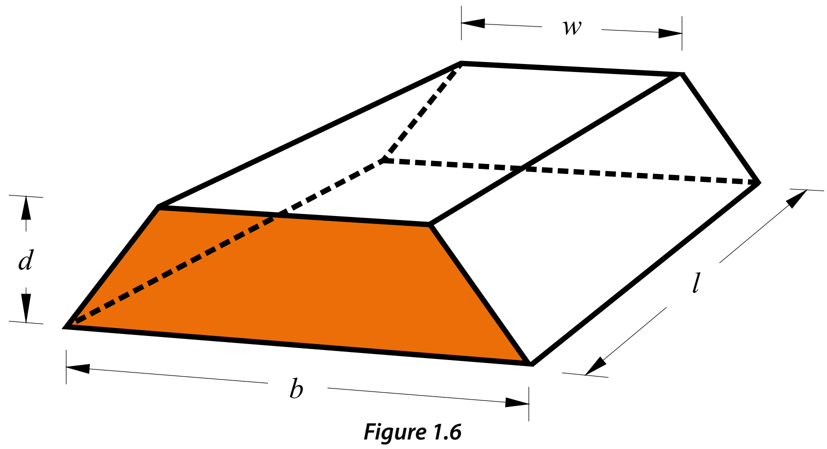

Figure 1.6

The amount of material in a fill or embankment of the shape above is:

$$\frac{1}{2}(w + b) \times l \times d$$

Again all the measurements must be brought to the same units, usually metres, giving a volume of material in m^3 (cubic metres).

4. Proportional calculations

Simple proportions and inverse proportions are particularly applicable in doing calculations related to production.

1. Examples of simple proportion

Example 1

If the production rate is 15 m^2 per day, how long will it take to spread 150 m^2?

From the above it is clear that it will take longer to spread 150 m^2.

15 m^2 = 1 day
150 m^2 = how many days?

$$\frac{150}{15} = 10 \text{ days}$$

Example 2

If you need to spread 150 m^2 of aggregate in one day and one worker can spread 15 m^2 in one day, how many workers are required to spread the 150 m^2 in one day?

Need to spread 150 m^2 in one day.
One worker can spread 15 m^2. How many workers (x) to spread 150 m^2?

1 worker can spread 15 m^2 in 1 day.
x workers can spread 150 m^2 in 1 day?

$$x \text{ workers} \times 15\ m^2/\text{day/worker} = 150\ m^2/\text{day}$$

$$x \text{ workers} = \frac{150}{15} = 10 \text{ workers}$$

2. Example of inverse proportion

If one worker takes one day (8 hours) to spread 15 m^2, how long (how many hours) will four workers take to complete the spreading?

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8 hours for 1 worker to spread 15 m²
x hours for 4 workers to spread 15 m²?

$x \text{ hours} = \frac{1}{4} \times 8 = 2 \text{ hours}$

5. Ratios

A ratio of one number to another number is the first number, divided by the second number e.g. the relation between the quantity of mixing water and the amount of cement in a concrete mix is known as the water:cement ratio.

$$\text{water:cement ratio} = \frac{\text{volume of water}}{\text{volume of cement}} \text{ or } \frac{\text{mass of water}}{\text{mass of cement}}$$

Note: A ratio has no units.

Example of ratios

Water:cement ratio (using the mass of water and the mass of cement)

If a concrete mixture contains 25 kg of cement and 15 litres of water, calculate the water: cement ratio based on mass.

As the mass of 1 litre of water is 1 kg the mass of 15 litres of water equals 15 kg.

The water:cement ratio is therefore: $\frac{\text{mass of water}}{\text{mass of cement}}$

$= \frac{15}{25} = 15{:}25$

The ratio is always expressed in the simplest form i.e.

3:5 or $\frac{3}{5}$ *or as a decimal 0,6*

(A decimal is obtained by dividing the lower number of a fraction into the upper number.)

6. Percentages (%)

The term percentage is made up of two words per and centage where per means for (part of) and centage means 100. A percentage (%) is therefore the name given to the mathematical expression, where the total of the parts/portions/ingredients is expressed as a 100 (100%), and the individual parts/portions/ingredients are expressed as a part of a 100.

Examples of percentages

Example 1

If a contract calls for 40% of the labour force to be made up of women, then of every 100 people employed, 40 must be women. (The remaining 60 will comprise the other groupings.)

Example 2

If the tender documents specify a 60% bituminous emulsion, the emulsion will comprise 60% bitumen and 40% water.

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7. Scale

When producing the drawings for the construction of a road (building or other structure), it is not possible to show the details on the drawings at the same size they are to be constructed, so use is made of a scale to provide the information on the drawings.

Scales often used in road construction are:

- Site plan – 1:50 000
  (This means that on the plan 1 cm = 50 000 cm on the ground = 50 000/100 = 500 metres on the ground {there are 100 cm in 1 metre}).
- Plan – 1:2 500
  (This means that on the plan 1 cm = 2 500 cm on the ground = 2 500/100 = 25 metres on the ground).

A scale is written as:

1:10; 1:100; 1:50 000, etc. A scale of 1:10 means that 1 unit, measured on the drawing, represents 10 units on the ground; while a scale of 1:100 means that 1 unit on the drawing represents 100 units on the ground.

- Longitudinal section
  - Horizontal – 1: 2 500
  - Vertical – 1: 200

  (The different horizontal and vertical scales are used to be able to illustrate the differences in height along the route of the road – if the same scale is used for both, these would not be visible.)
- Cross section – 1: 50
  (This means that on the plan 1 cm = 50 cm on the ground = 50/100 = 0,5 metres on the ground.)

8. Understanding and using of graphs

A graph is, in effect, a visual representation of a number of results obtained by plotting the two factors used, to calculate the result along two lines at right angles to each other (called the x-axis and y-axis).

For example, the following simple information can be represented both in the form of a table and a graph as illustrated.

Example

Assuming trucks have a capacity of 6 m^3
Then:
One truck has a capacity of 6 m^3.
Two trucks will have a combined capacity of $2 \times 6 = 12$ m^3.
Three trucks will have a combined capacity of $3 \times 6 = 18$ m^3.
Six trucks will have a capacity of $6 \times 6 = 36$ m^3.

This can be represented in table form as follows:

Number of trucks	1	2	3	4	5	6
Combined volume (m³)	6	12	18	24	30	36

As a graph this would be shown as follows:

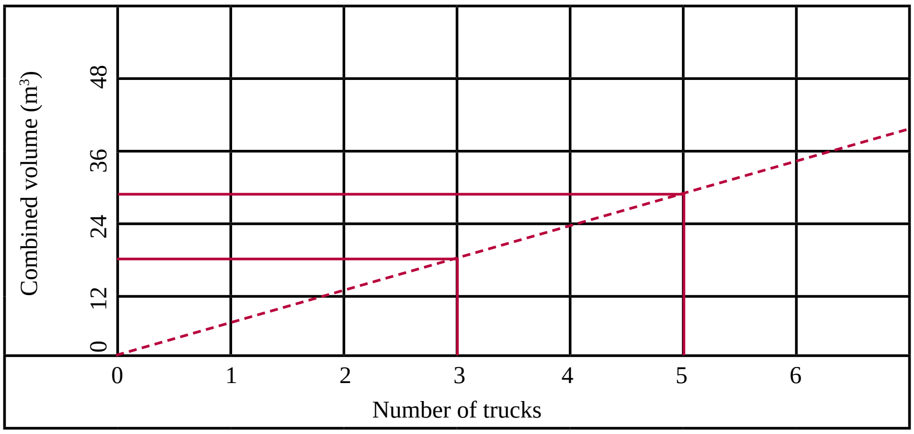

Figure 1.7

For example, reading off the graph, 3 trucks will have a combined capacity of 18 m^3 (half way between 12 m^3 and 24 m^3) and 5 trucks will have a combined capacity of 30 m^3 (halfway between 24 m^3 and 36 m^3).

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MODULE 2: Survey concepts

1. Horizontal alignment

The horizontal alignment of a road is the route that a road follows between two or more places of destination e.g. between two towns or villages, between the village and a school, clinic, etc.

It normally consists of a number of straight sections joined by a number of curves.

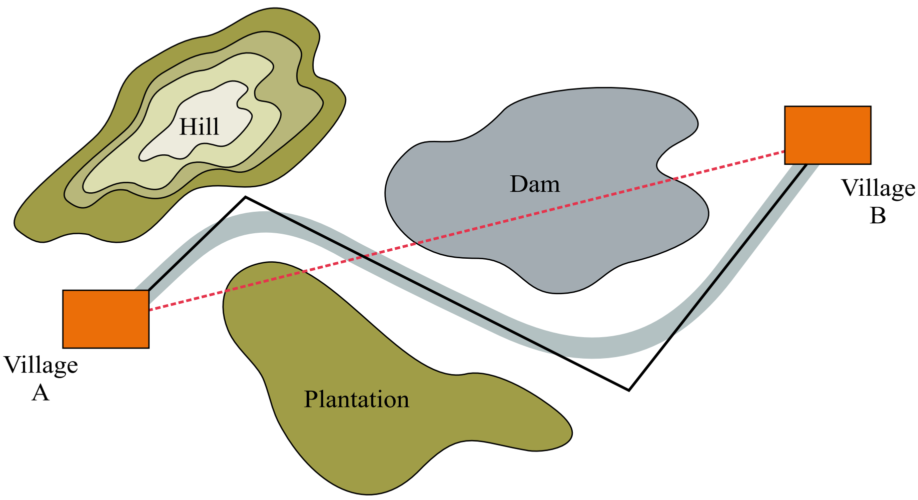

Figure 1.8: Alignment of road between villages A and B

It is seldom possible to join these destination places with a straight line, as there are often obstacles in the way e.g. rivers, hills, dams, farms, etc.

The sharpness of the curves that join these straight sections has a very large influence on the speed at which a person can safely drive on the road.

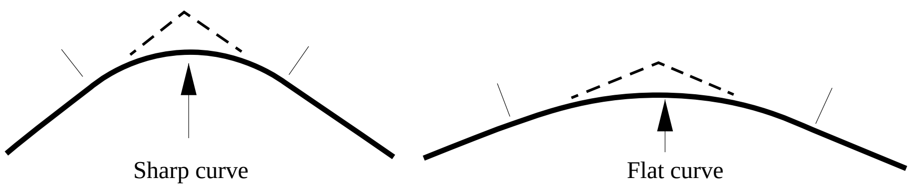

Figure 1.9: Horizontal curves

2. Vertical alignment

The vertical alignment is determined by the nature of the area in which the road is situated. For example, is the area hilly or flat? Are there rivers that have to be crossed, etc?

As with the horizontal alignment, it is seldom possible to join two places with a straight line from the lower place to the higher place. This would be too expensive, as lots of soil will have to be moved to construct the road, by either digging it out or filling it up (earthworks). It might even be necessary to construct tunnels.

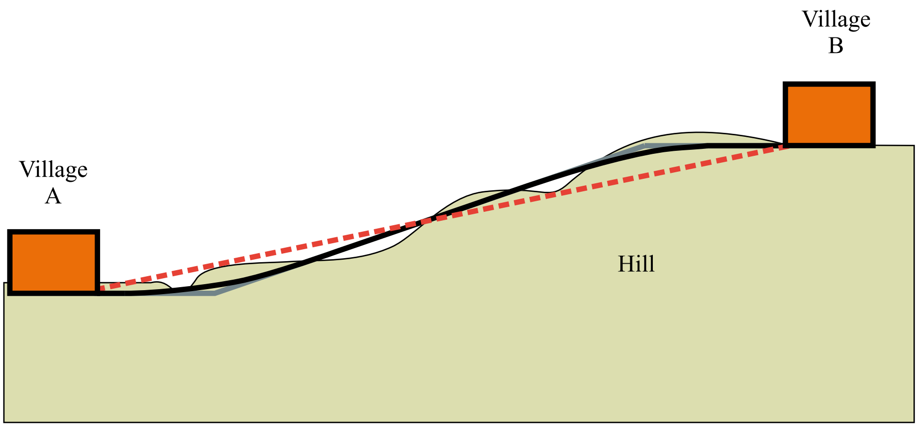

Figure 1.10: Vertical alignment of road between villages A and B

Therefore, a number of straight sections are used to follow the ground as closely as possible to reduce the cost of the earthworks. Again, as with the horizontal alignment, the sharpness of the curves that join these straight sections has a very large influence on the speed at which a person can safely drive on the road.

3. Longitudinal section

The longitudinal section of a road provides information regarding the height of the road above a certain point (datum) for various distances along the road from a fixed point.

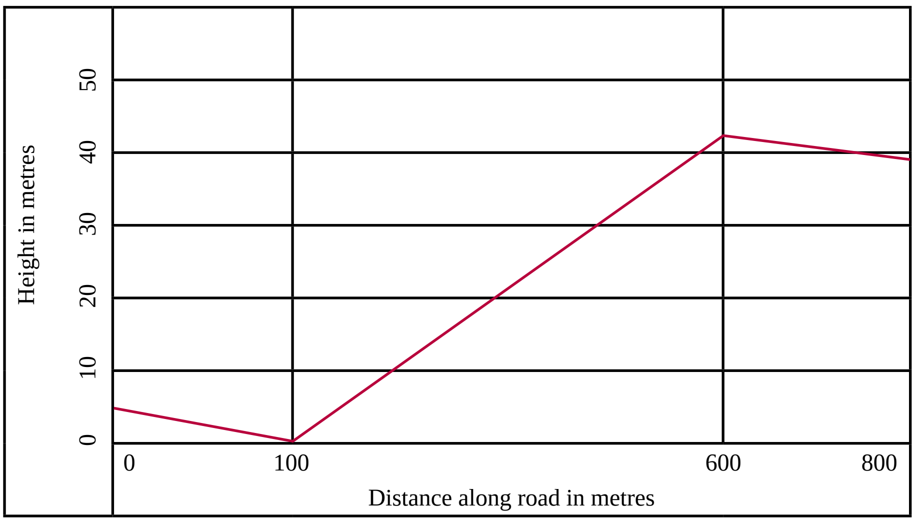

Figure 1.11: Longitudinal section of road between villages A & B

4. Cross-section

The cross-section of the road shows what you would see if you stood in the middle of the road and looked from left to right (Figure 1.12a), in the direction of increasing distance (chainage). It is also used to show what happens under the surface on which you are standing, and therefore, provides information on the various layers that go into building a road.

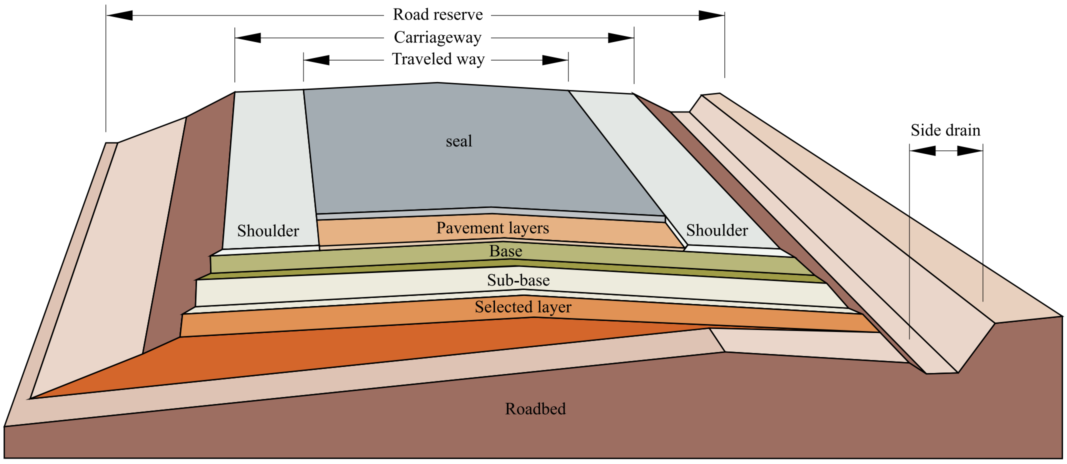

Figure 1.12a: Typical cross-section of a surfaced road

If you cut a slice (section) through the road you will see the layers shown in Figure 1.12.

5. Centre line

The centre line (C/L) of the road, is the line drawn down the centre of the road (see Figures 1.12 a and 1.12 b and Module 5 Section 2.2.1).

It is along this line that the horizontal and vertical alignment of the road, as well as the camber or cross-fall of the road, is set out.

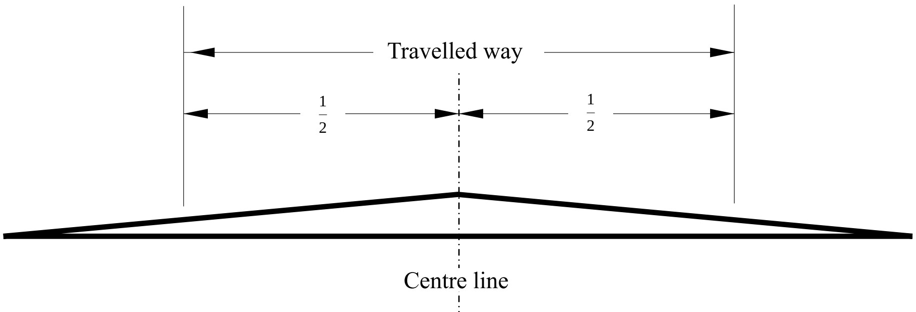

Figure 1.12 b: Centre line

6. Slope/gradient/grade

The slope/gradient/grade of a road or drain is the amount that the road or drain rises, or falls, over a certain distance. There are two main methods for expressing this:

Method 1

In Method 1, the slope or gradient is expressed as the distance over which the road falls or rises by one metre.

Example 1

If the slope gradient is given as 1 in 200, it means that the road rises 1 metre in 200 metres.

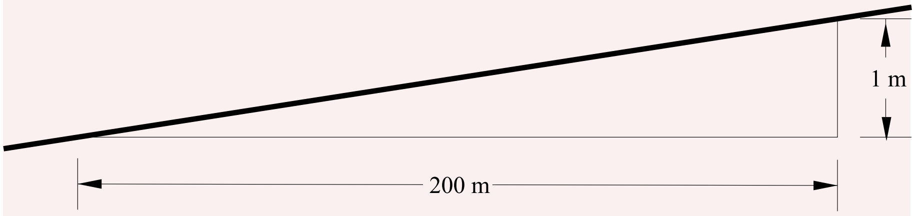

Figure 1.13: 1:200 gradient

Note: 1 in 200 is also shown as 1:200

Example 2

If the slope gradient is given as 1 in 20, it means that the road rises 1 metre in 20 metres and is therefore much steeper than the road in Example 1.

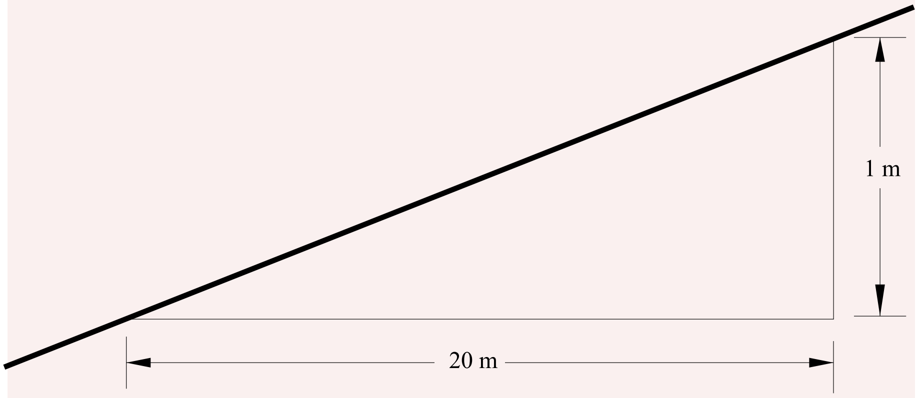

Figure 1.14: 1: 20 gradient

Note: 1 in 20 is also shown as 1:20

Method 2

In Method 2 the slope/gradient/grade is expressed as a percent i.e. the amount that the road rises or falls over a distance of 100 metres.

Example 3

If the slope of the road is given as 10% it means that the road rises 10 metres in 100 metres.

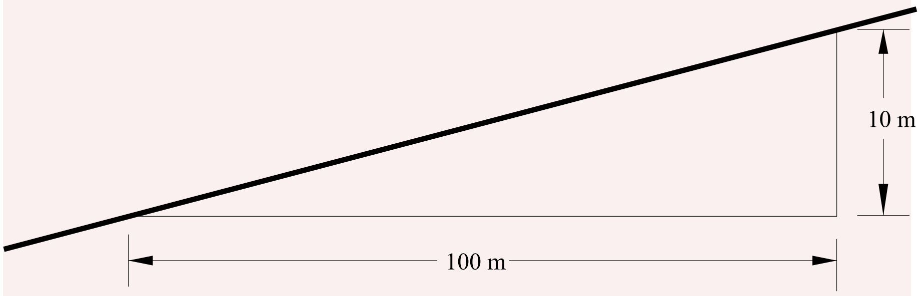

Figure 1.15: 10% slope

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Example 4

If the slope of the road is given as 1% it means that the road rises 1 metre in 100 metres horizontal distance. This slope/gradient/grade is much flatter than that in Example 3.

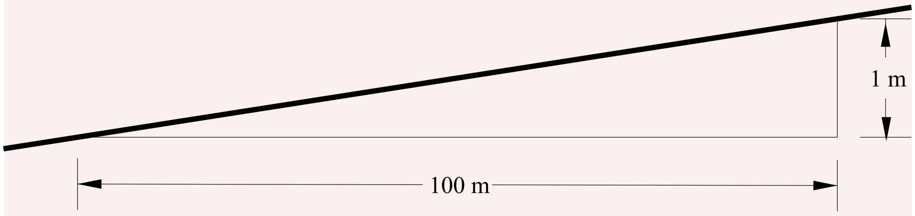


Figure 1.16: 1% slope

7. Simple survey tools

7.1 Metric tape

Most modern tapes are divided into metres (m), centimetres (cm), and millimetres (mm). Millimetres is the smallest unit of measure used in standard metric tapes. One centimetre is equal to ten (10) millimetres and one metre is equal to one thousand (1 000) millimetres. Generally, in construction, use is only made of mm and m. However, it makes a tape far easier to read if it is graduated in 10 mm sections. For higher accuracy, it may be desirable to turn the tape on its edge when taking short readings.

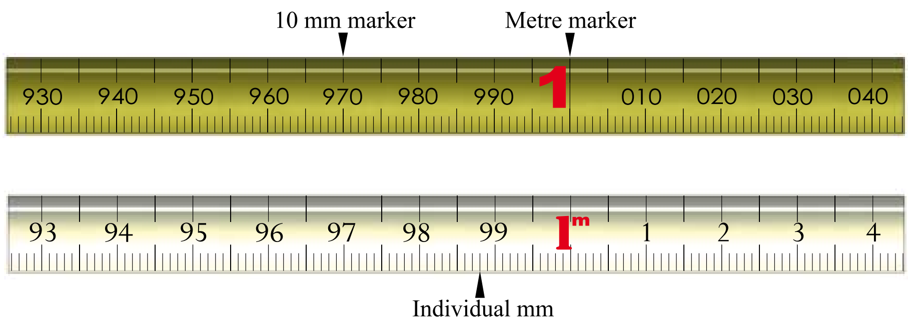


Figure 1.17: Metric tape

When using a tape, apart from ensuring that the zero of the tape is correctly identified, ensure that the tape is not twisted or kinked. Lift the tape up and pull it straight, then lower it slowly to the point at where measurement must be taken.

If the tape is not in a straight line it may be shaken gently, but care must be taken not to shake it too vigorously, as this could cause the tape to snap. If there are any obstructions in the way, they must be removed. The tape must lie straight and level.

7.2 Ranging rods

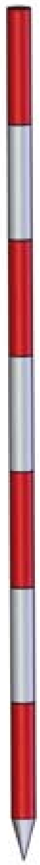
Ranging roads are used to make sure that measurements will be in a straight line.

A ranging rod is a straight rod with a sharpened point, to assist with placing it in the ground. Ranging rods are painted red and white to make them highly visible. Some ranging rods are extendable and have sections that screw into each other. Ranging rods must be held as vertical as possible and a spirit level can be used to ensure this.

To line up ranging rods, the following sequence is followed:

- Place a ranging rod at each known end point.
- Sight them on a straight line.
- Place intermediate ranging rods on the same line.

When placing ranging rods at the end points, it is important that the peg or mark is not damaged; so the ranging rod must be placed at a distance of ± 25 mm behind the pegs. The ranging rods must be positioned vertically and secured in the ground so that it will not move whilst you are busy sighting in the other rods.



Right: Figure 1.18: Ranging rod

7.3 Boning rods

Boning rods, in their simplest form, are T-shaped crossheads, of which the vertical legs are all of equal length.

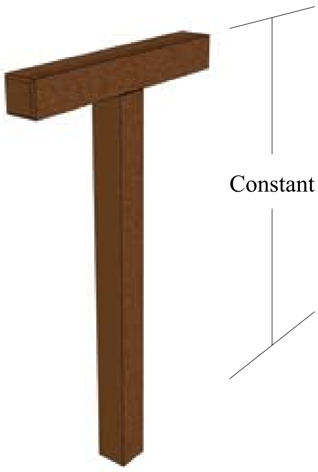


Figure 1.19: Boning rod

There are variations where the vertical leg is marked with a scale, or where the cross member can be adjusted up and down along the vertical leg.

7.4 Spirit level

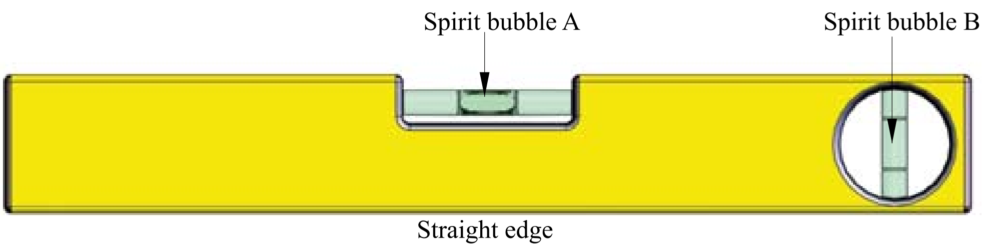


Figure 1.20: Spirit level

The spirit level consists of two spirit bubbles, set in a straight edge at right angles to each other.

The spirit bubble parallel with the long edge of the straight edge A, is used to determine a level plane. When bubble A is between the two marks on its casing, the surface on which the straight edge is placed, is level.

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Bubble B is used to determine a vertical plane. When bubble B is between the two marks on its casing, the surface on which the straight edge is placed, is vertical.

It is important to turn the spirit level around (through 180°) to check the accuracy. Inaccurate levels must be discarded.

7.5 Template and spirit level

The spirit level is used in conjunction with a template and is useful to set out cross-falls on roads, kerbs, channels, etc.

In Figure 1.21 the spirit level, together with a template, is used for establishing the level of the edge of a road for a given camber (3%) from the centre-line pegs.

Once the level of the centre-line peg (C) has been established, the edge of the road pegs can be determined with a template and spirit level as shown below.

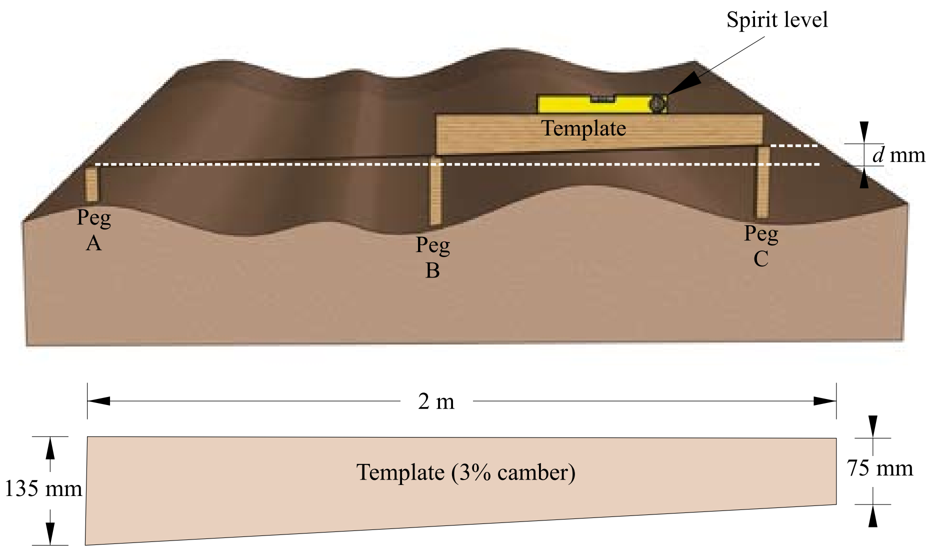

Figure 1.21: Setting out 3% cross-fall with template and spirit level

The intermediate peg at B can be removed once the peg at A has been established.

7.6 Line level and string

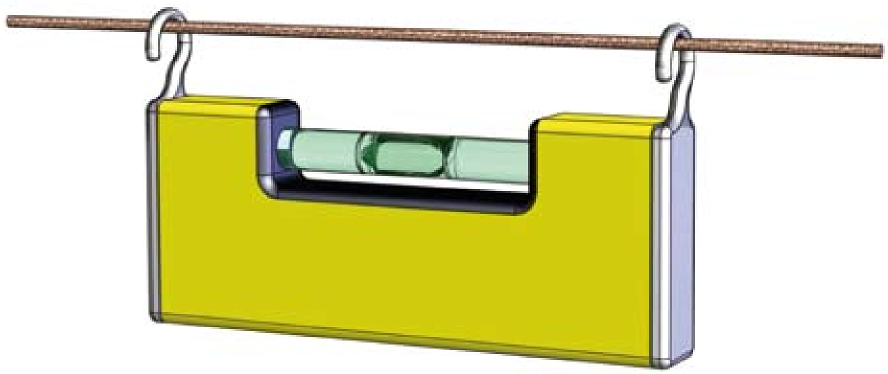

Figure 1.22: Line level

The spirit bubble, together with a string line, is handy for establishing the level of the edge of a road for a given camber from the centre-line pegs. As with the spirit level, the line level must be turned around (through 180°) to check accuracy. Grossly inaccurate line levels must be discarded.

Once the level of the centre-line-peg (C) has been established, the edge of the road pegs can be established with a string and spirit bubble, tape and boning rod (Figure 1.23 and Table 1.1). The boning rods must be marked with a scale or one rod must be adjustable.

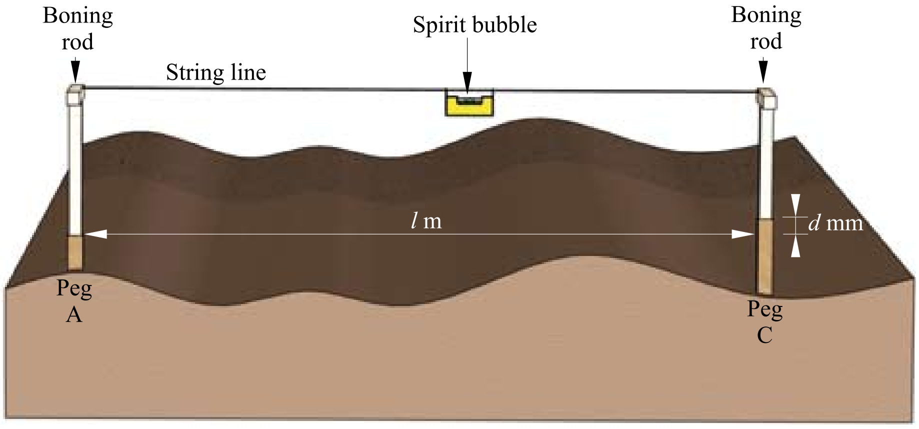

Figure 1.23: Setting out 3% cross-fall

Half width of road – l in (m)	Fall to edge of road – d in (mm)	
	2% cross-fall	3% cross-fall
2,0	40	60
2,5	50	75
3,0	60	90
3,5	70	105
4,0	80	120
4,5	90	135

Table 1.1: Fall to edge of road for 2% and 3% cross-falls

MODULE 3: Material concepts

1. Gravel

Gravel is normally regarded as material obtained from borrow pits or from excavations along the road, complying with certain laid-down requirements used in the construction of the pavement layers of the road or the construction of the gravel wearing course of the road.

2. Aggregate

As a rule, aggregates for concrete or bituminous seals consist of approved inert hard rock type material which has been crushed and/or screened to comply with certain specifications and requirements (coarse aggregate).

Washed selected and screened pebbles can also be regarded as an aggregate (e.g. Otta seal).

Crusher sand or washed natural sand is also classified as an aggregate (fine aggregate) e.g. in slurry seals, mortars and concrete.

3. Bitumen

Bitumen, a by-product of the petroleum industry, is the cementing (binding) agent in the binders for bituminous seals or asphalts. The viscosity (stiffness) of bitumen (resistance to flow at a certain temperature) is given in terms of a penetration.

The penetration value of a bitumen is the distance a standard needle will penetrate a sample of the bitumen at a certain standard temperature.

4. Bituminous emulsion

A bituminous emulsion is a liquid mixture of small droplets of bitumen suspended in water with the assistance of an emulsifier.

An emulsifier is an agent included in the bitumen water mixture, to distribute the bitumen droplets in the water and regulate its stability and breaking time.

There are a variety of bituminous emulsions e.g. anionic or cationic and spray grade or stable grade. The correct emulsion must be used for the correct application.

5. Cutback bitumen

A cutback bitumen is a penetration bitumen which has been softened with a lighter fluid e.g. dieseline.

There are three types of cutback bitumens e.g. :

SC = Slow curing
MC = Medium curing
RC = Rapid curing

6. Bituminous seal

A bituminous seal consists of aggregate of a specified size (or grading), held in place with a bituminous emulsion binder, penetration grade or cut back bitumen binder.

7. Concrete

Concrete is a mixture of predetermined quantities of dry materials (cement, stone and sand) and water. By varying the quantities of these constituents in a mix the characteristics (e.g. strength) of the concrete product is affected.

The quantities in a mix can be specified either by mass or volume (mass or volume batching).

The relationship between the dry materials is normally represented in the form of cement: sand:stone. A 1:2:4 mix would, therefore, mean in volume batching 1 volume of cement: 2 volumes of sand: 4 volumes of stone. For example, 1 pocket of cement (33 litres): 66 litres of sand (1 wheelbarrow): 132 litres of stone (2 wheelbarrows).

For mass batching, a scale is required to weigh the various constituents in the mix.

The water is the ingredient which reacts with the cement and causes the various dry ingredients to bind together to form the concrete. The amount of water added to the mix should never exceed that specified by the engineer.

8. Cement mortar

A cement mortar is a mixture of predetermined quantities of dry materials (cement and sand) and water. By varying the quantities of these constituents in a mix, the strength of the mortar is affected.

The stronger the mix, the more resistant it is to being eroded away by water or weather.

One of the main uses for cement mortar is to join together bricks or stones to form a structure, e.g. a wall or a lined channel.

9. Masonry work

Masonry work consists of work or structures constructed of bricks, blocks or selected stone, bonded together by means of a cement mortar.

Examples of masonry work/structures include:

- Drifts
- Arch culverts
- Small bridges
- Retaining walls
- Culvert inlet and outlet structures

MODULE 4: Material-related concepts

1. Grading

1.1 Soil/gravel

The grading of a soil (gravel, sand) is determined by passing the material through a number of sieves and is an indication of the percentage of coarse and fine material (particles) in the soil (gravel).

The physical volume of the different sizes of material making up the sample can be established if a sample of soil, gravel or sand is screened through a standard set of sieves. The percentage of whatever is retained on the various sieves is calculated by weight, for each size, making up 100% of the sample.

These percentages can be graphically plotted against the sieve sizes and a graph plotted. The shape of the graph will describe the material e.g. coarse material, fine material or different combinations of fine and coarse material.

Normally the higher the percentage of coarse material in the gravel, the more suitable it is for the construction of the pavement layers in road. Materials containing high percentages (over 50%) of fine material (-0,075 mm) are suspect and could cause problems.

1.2 Stone and sand for seals

The grading of the sand used in the manufacture of slurry will determine the texture of the slurry.

In seal work, the aggregate (stone) used for the construction of the seal is specified as a single size e.g. 9,5 mm, 13 mm, 19 mm, etc.

2. Atterberg limits

The tests making up the Atterberg limits were developed to determine the extent to which the specific soil (gravel) is affected by changes in moisture in the material i.e. its tendency to expand and contract under changes in moisture (clay material).

The tests are carried out on the material passing the – 0,425 mm sieve i.e. the material smaller than 0,425 mm contained in the gravel or soil.

The Atterberg limits are defined as:

2.1 Liquid limit (LL)

The liquid limit is the measurement of the amount of moisture in a soil (gravel) that will cause it to flow, if subjected to a certain standard test.

It therefore gives an indication of the amount of water (moisture content) that a soil can absorb before it becomes unstable and tends to flow.

2.2 Plastic limit (PL)

The plastic limit is the measurement of the amount of moisture in a soil (gravel) at which it acts like a piece of plasticine (i.e. plastic) and can be rolled into a worm.

It therefore gives an indication of the amount of water that a soil can absorb for it to be able to be moulded or is pliable without flowing, and is the lowest water content at which it is plastic.

2.3 Plasticity index (PI)

The plasticity index of a soil (gravel) is the difference between the liquid limit and the plastic limit.

$$PI = LL - PL$$

The PI is, in effect, the percentage of the moisture range beyond the plastic limit, indicating the potential instability of the material.

Soils (gravels) with a low PI can also cause problems as they have little or no cohesion (do not bind together) unless treated with a product like bitumen.

3. Optimum moisture content (OMC)

The optimum moisture content of a soil (gravel) is that amount of moisture required (expressed as a percentage of the compacted dry weight), to lubricate the material sufficiently to obtain maximum density of the material for a specific compaction effort.

Too much water will keep the particles of gravel apart and reduce density, while too little water will not lubricate the particles. This will increase the friction/roughness between the particles of gravel and reduce the density accordingly.

4. California bearing ratio (CBR)

The california bearing ratio (CBR) is a relationship between the bearing capacity of crushed stone aggregate and the natural gravel, both compacted in a standard mould with a standard compaction effort, soaked for four days in water, and then penetrated with a standard plunger at a specific rate.

The 'bearing' results of the stone is taken as 100% and the natural gravel 'bearing' result is compared with the stone as a percentage of 100%, giving the CBR of the gravel or soil.

The CBR of a material is an indication of the ability of the material to carry a certain design load transmitted through the wheels of a vehicle.

As the load decreases, the deeper it passes through the road layers. The CBR determines the depth below the surface of the road that a specific gravel material can be used or the amount of cover required over a specific soil.

5. CBR swell

While the compacted samples for the CBR test are being soaked in water for four days, the swell of the sample in the mould is measured and expressed as a percentage of the 150 mm deep mould.

This also gives a measure/indication of the stability of the material.

6. Average least dimension (ALD)

This expression is used as one of the characteristics for stone (aggregate) used in bituminous seals for surfacing e.g. single seal, Cape seal, etc., and is of importance when determining the rate at which the aggregate must be spread to prevent over or under application of the aggregate.

The ALD can be described as follows:

Any particle of aggregate that is not perfect in shape i.e. a 19 mm aggregate is not 19 mm in all directions, it has long and short sides.

If dropped on a surface it will always fall on the surface with its smallest dimension vertical to the plane of the surface.

It does not matter what the shape of the particle of aggregate is, it will always fall on the road with d_1 and d_2 (Figure 1.24 A & 1.24 B) i.e. the least or smallest dimension vertical to the road surface; e.g. a sample, if dropped in the road, will never come to rest on the road in this position where (d) the maximum dimension is vertical to the road surface. (Figure 1.24 C)

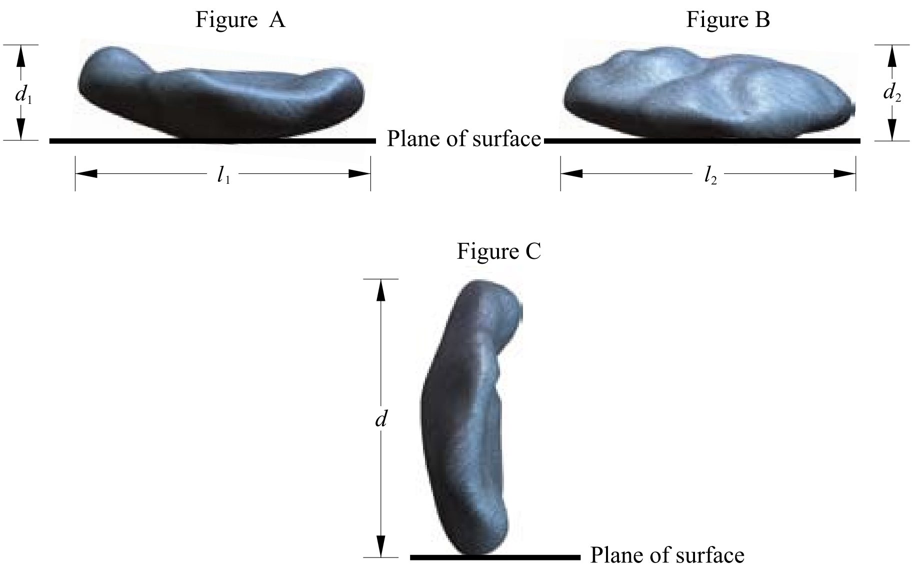

Figure 1.24: Average least dimension of aggregate (ALD)

7. Rate of application

The rate of application of a product or material is the amount of that material or product applied over a certain area.

Examples of rates of application are:

Activity	Unit
Spraying of Bituminous binder or emulsion	litres per square metre (l/m^2)
Spreading of aggregate for surfacing	cubic metres per square metre (m^3/m^2)

8. Compaction

Compaction in road construction terminology is essentially the densification or systematic packing closer together of the different sizes and shapes of the gravel or soil particles.

This process is assisted/advanced by using optimum water to lubricate the particles to slip/rearrange themselves into more stable positions, increasing the density and strength of the material.

Under controlled conditions of compactive force and moisture content, a specific soil can be densified to a state in which it has increased structural strength and stability and therefore the ability to withstand the forces imposed on it by the vehicles using the road.

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9. Dynamic cone penetrometer (DCP)

The dynamic cone penetrometer (DCP) is an instrument used to measure the resistance of a soil to penetration, by a standard cone under impact, by a standard weight (hammer) falling a standard distance onto an anvil by measuring the distance the cone penetrates into the soil. (Figure 1.25)

The penetration depth of the DCP cone has been correlated with standard parameters, such as density and CBR, and can therefore be used for applications such as:

- Centre-line testing to determine the CBR of the in-situ material.
- Control during construction to determine the density of compacted layers.

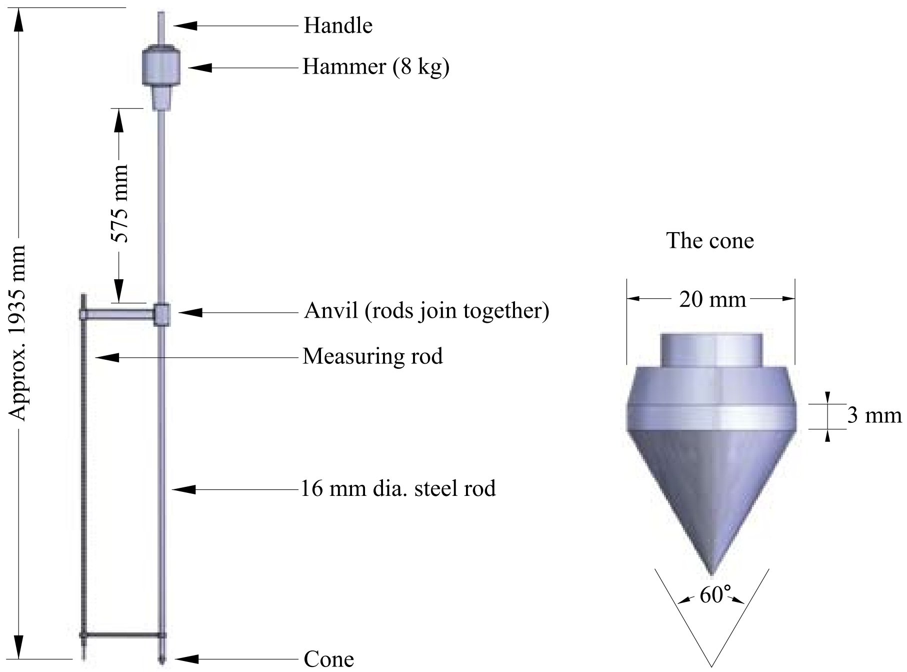

Figure 1.25: DCP instrument

MODULE 5: Typical road terms and components

1. Road terminology

1.1 Unsealed roads

1.1.1 Earth road

In many cases, an earth road is a track which has been formed as a result of frequent use of a certain route. It very seldom has any provision for drainage, is subject to erosion and, in most cases, is not suitable for use by traffic under adverse weather conditions e.g. when wet.

It can also be a road consisting of an in-situ material which is adequately drained and use by traffic under most conditions.

1.1.2 Gravel road

A gravel road is a road which is normally adequately drained and aligned; and has been provided with a wearing course of a selected gravel material, which meets certain requirements regarding grading and PI from a specified source to make it suitable for use by traffic under most weather conditions, if properly maintained.

1.2 Sealed roads

A sealed road is a road which has been provided with an all-weather riding surface of selected stone, held in place with a bituminous binder, constructed on layers of selected material compacted under controlled conditions. It is normally adequately drained and aligned.

1.2.1 Single seal

A single seal consists of a single-sized stone (normally 6,7; 9,7; 13,2 or 19 mm) held in position by a bituminous binder.

It is well suited for construction by labour using light plant because

- the binder, in the form of a bituminous emulsion, can be applied using a motorised hand spray;
- the stone aggregate can be distributed either with shovels or with the aid of a manual chip spreader; and
- the seal can be compacted with a pedestrian roller.

1.2.2 Cape seal

A Cape seal comprises a single seal (usually 13,2 or 19 mm stone) held in position with a bituminous binder, onto which a slurry of bitumen emulsion and fine aggregate of the specified grading is applied.

It is well suited for construction by labour using light plant because

- the binder, in the form of a bituminous emulsion, can be applied using a motorised hand spray;
- the stone aggregate for the single seal can be distributed either with shovels or with the aid of a manual chip spreader;
- the slurry can be mixed in suitably sized concrete mixers;

- the slurry can be distributed and spread by rubber squeegees and finished with a Hessian drag pulled by hand; and
- the seal can be compacted with a pedestrian roller.

1.2.3 Slurry seal

The slurry seal comprises a seal of a specified thickness of bitumen emulsion and fine aggregate of the specified grading.

It is well suited for construction by labour using light plant because

- the slurry can be mixed in suitably sized concrete mixers;
- the slurry can be distributed and spread by rubber squeegees between guide rails and finished with a straight edge resting on the guide rails by hand; and
- the seal can be compacted with a pedestrian roller.

1.2.4 Otta seal

The Otta seal originated in Norway and was developed by the Norwegian Public Roads Administration.

Basically it consists of the application of a bituminous binder, sprayed on a prepared/constructed base covered with a graded aggregate which is well rolled with a pneumatic roller, excess aggregate having been broomed off.

The road so treated is allowed to cure for 8 - 12 weeks before a sand cover seal or second Otta seal is applied.

The Otta seal has potential for the creation of employment in the screening, spreading and brooming of aggregate.

At present the potential of the Otta seal, as far as job creation is concerned, is affected by the following:

- The Otta seal requires the use of a hot penetration bitumen (generally 150/200) binder which has to be applied by a tanker.
- A pneumatic roller is required to effectively roll the aggregate (28/30 ton loaded).

2. Road cross-section: sealed (surfaced) road

2.1 Typical cross-section elements: sealed (surfaced) road

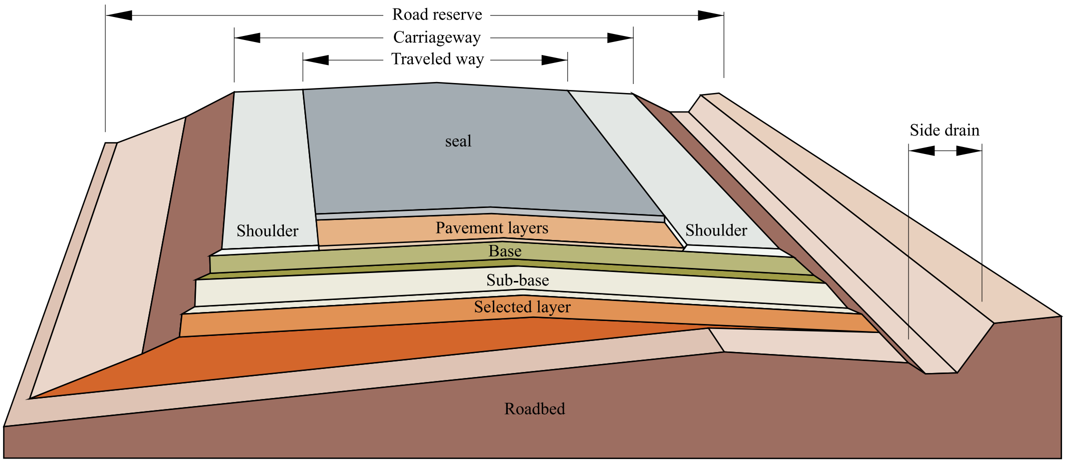

Figure 1.26 a: Typical cross-section: sealed road

2.1.1 Road reserve

The road reserve is defined as the entire area of land, included by the boundaries of the road, as proclaimed in the relevant Government Notice (usually the area of land between the boundary fences of the road).

2.1.2 Roadbed

The roadbed or sub grade is the in-situ material on which the layers making up the road are constructed.

2.1.3 Selected layers

The selected layers comprise those layers of natural gravel, selected to meet certain criteria, compacted to pre-determined densities between the top of the roadbed and the bottom of the sub-base described below.

2.1.4 Sub-base

The sub-base is the layer between the top of the selected layers and the bottom of the base described below.

The material (normally natural gravel) for the sub-base has to meet more stringent requirements than the material used in the selected layers and is compacted to a higher density.

2.1.5 Base

The base is the layer immediately below the surfacing and, as such, has to meet stringent requirements regarding material qualities and compaction.

It may comprise either a crushed stone or natural gravel and is, in many cases, treated (stabilised) with a bitumen emulsion, lime or cement to improve its road building qualities.

2.1.6 Travelled way

The travelled way of the road surface is that portion on which vehicles using the road normally travel.

2.1.7 Shoulders

The shoulder is that portion of the carriageway between the outer edge of the travelled way and the inner edge of the drain or side slope.

The shoulder may be surfaced (seal) or unsurfaced (gravel).

The shoulders provide a place for vehicles to stop for changing tyres or other emergencies.

2.1.8 Carriageway

The carriageway of the road includes the travelled way and the shoulders (which may by either surfaced or unsurfaced).

2.2 Cross-section terminology

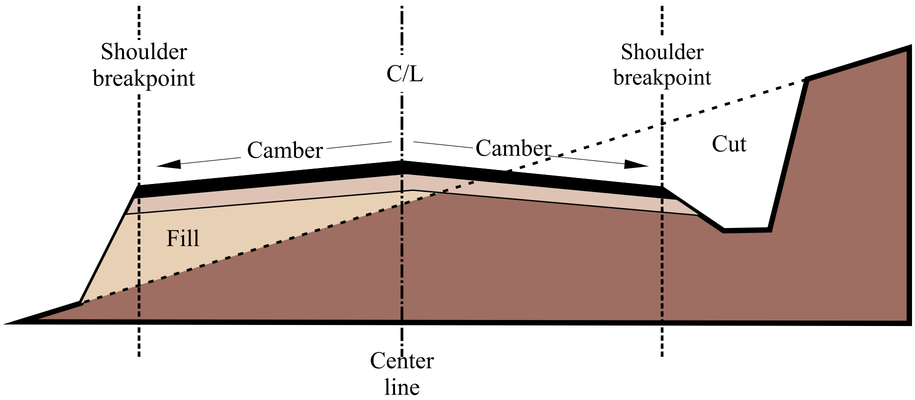

Figure 1.26 b: Cross-section terminology

2.2.1 Centre line (C/L)

The centre line (C/L) of the road is the imaginary line drawn down the centre of the travelled way of the road (See also Module 2 Section 5).

It is along this line that the horizontal and vertical alignment of the road, as well as the camber/cross-fall of the road, is set out.

2.2.2 Camber/cross-fall

The camber/cross-fall is the slope from the centre of the road to shoulder breakpoint. The camber on the surfaced portion is usually flatter than that on the shoulder. The camber sheds the water, from the road surface and shoulders, into the road reserve.

2.2.3 Shoulder breakpoint

The shoulder breakpoint is the point where the extended slope of the shoulder meets the slope of the fill or cut.

2.2.4 Cut

Cut consists of all excavations from the existing ground line to the roadbed and includes the side (table) drains.

2.2.5 Fill

Fill consists of that imported material above the roadbed (see also Figure 1.26 a) on which the layer work (selected layers, sub-base and base) is constructed.

3. Road drainage

3.1 Drainage components

The drainage system of any road, be it a gravel road or a surfaced road, is an important factor affecting the life and serviceability of the road. Basically, the drainage system must function in such a manner that the road structure is protected from any ponding on, or next to, the structure, draining all storm water as rapidly as is practical from the road reserve, with little if any, erosion occurring. (Figure 1.27)

The main drainage system would be the box culverts and bridges but the minor drainage is equally important and can be classified as follows:

- Surface drainage
  - Actual riding surface of road
  - Shoulders
  - Side slopes
  - Cutting (excavation) faces

  The shape/condition of the surface must be such that it sheds the water readily, resulting in no ponding or erosion.

- Road reserve drainage
  - Table drains (side drains)
  - Catch-water drains
  - Mitre drains
  - Minor box culverts
  - Pipe culverts

  These structures receive the water draining from the surface. The structures referred to must be functional, in so far that they must remove the storm water without erosion, silting and ponding as soon as possible during and after a storm.

- Subsurface drains

  Subsurface drains are required to remove free water from the sub grade, i.e. below the foundation layers/sub-base and base, as well as wet areas adjacent to the road prism.

  Wet areas adjacent to the road can often be identified by the vegetation and/or grasses flourishing in the side drain.

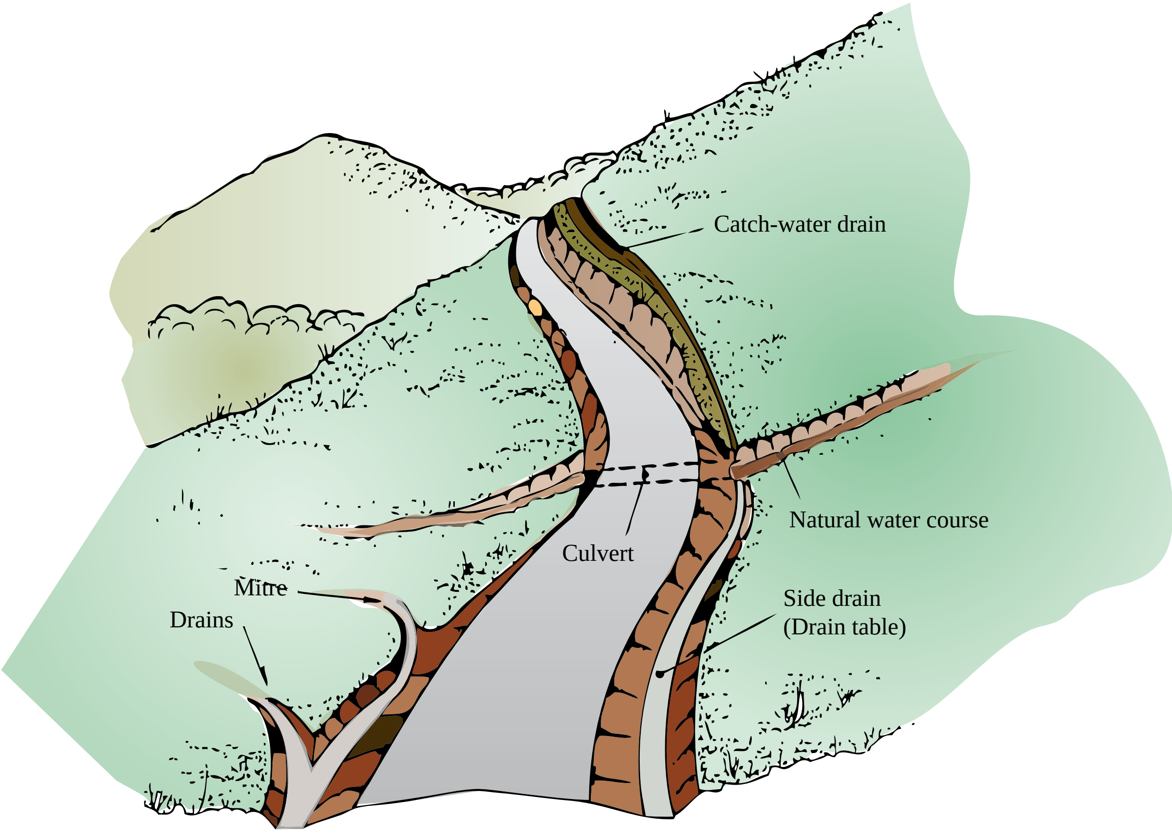

Figure 1.27: Components of drainage system

3.2 Drainage terminology

3.2.1 Road surface cross-fall (camber)

The cross-fall on the road surface sheds the water from the road surface onto the road reserve.

3.2.2 Table (side) drain

Table or side drains run parallel to the road, alongside the road on the upstream side. They are required to collect water from the carriageway and road reserve and transport the water to a convenient place of disposal (e.g. natural water course).

3.2.3 Catch-water drain

Catch-water drains intercept surface water flowing from adjacent land to the road reserve and lead it away. They are most often used at the top of cuttings, to protect the slope of the cutting against erosion.

3.2.4 Mitre drain

Mitre drains lead water out of the side drains and safely disperse it outside the road reserve onto adjoining land.

3.2.5 Culverts

Culverts convey water safely from the upper side of the road to the lower side.

3.2.6 Drifts

Drifts are low-cost structures that may be successfully installed as an alternative to a culvert. A drift allows water to cross the surface of the road rather than underneath. (Figure 28)

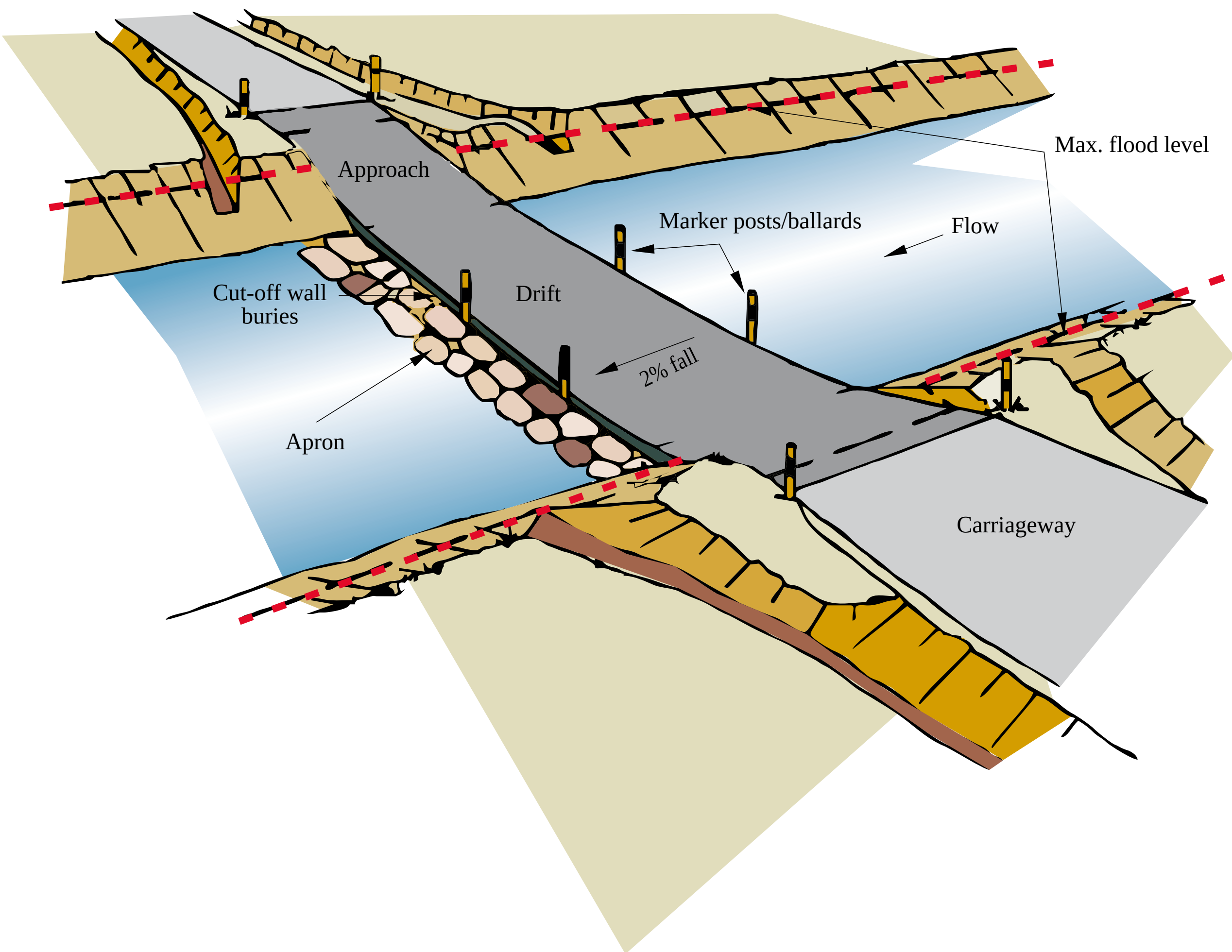

Figure 1.28: Drift features

3.2.7 Scour checks

Where longitudinal gradients in the table (side) drain are steeper than about 4%, the water flows at high speed. Therefore, if no protective measures are taken, scouring is likely to occur on erodable soils.

Erosion control checks (scour checks), can be constructed to reduce the velocity of water. They hold back the silt carried by the water-flow, and provide a series of stretches with gentle gradients interrupted by small waterfalls.

Scour checks are usually constructed of natural stones, wooden stakes and natural vegetation. For larger erosion areas, gabions or concrete weirs can be constructed.

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

President Thabo Mbeki