Topic 3 Section 2

Elements of an Estimate

Contents

Introduction to Estimating

As part of the job management team the job supervisor is responsible for the planning, organisation, direction and control of the available resources for the completion of the works to the standard set out in the scheme documents.

In contract schemes the work is carried out by contractors using their own resources. The contract documents usually consist of:

- Contract drawings (including construction tables)
- Specifications
- Quality Manual/Quality Plan
- General Conditions of Contract — detailing the general, legal and administrative requirements relating to the contract
- Schedule of rates and quantities
- Special provisions and other letters of contract
- Safety Manual

Contract Drawings

The drawings provided to the contractor must show accurately the extent of the work to ensure errors in construction are unlikely to occur. The drawings must be:

- clear and simple
- read in conjunction with the specifications
- drawn to show as much detail as possible
- drawn with as many dimensions as practicable.

Generally the drawings are completed before the specification is written. If there are differences between the two documents, the specifications usually take precedence.

Information for any particular part of the work should be on the one sheet, thus avoiding the necessity to cross reference other drawings. Suitable notes may be included on the drawings in order to reduce the volume of the specifications.

Specifications

The specification is the most important document produced for the contract. It sets out the actual work required, and in particular:

- identifies the materials required for the job
- class of workmanship
- method of construction
- classification of work for payment purposes

The specification is the direct explanation of the drawings. It is necessary to check the specification carefully in order to ensure:

- nothing is left out
- the requirements demanded are practicable
- proper safety precautions are included for dangerous work

Schedule of Rates/Schedule of Quantities

The schedule of rates and schedule of quantities are usually issued as appendices to the specifications. It is really a list of the various classes of work required for the project.

The appropriate quantities and rates payable are set out on the schedule. The schedule and the specification are complementary, and must not conflict with each other.

The schedule of rates is used for assessing the value of variations from the contract, and in this capacity it is of further use for computing progressive payments from time to time.

Construction Estimating

The degree of success which is achieved on any construction job depends upon the ability to predict as accurately as possible the various conditions and contingencies which may arise during the construction period. It is then possible to provide for these factors when selecting the methods to be adopted and the plant and equipment required to carry out the work in the most efficient way.

Evaluating Hazards and Risks

The majority of construction work involves hazards and risks which must be accurately evaluated before the project can be seen in its true perspective. Hazards that are experienced at the construction site include:

- risk of physical damage
- trenching hazards
- manual handling hazards
- working at height hazards
- working with plant and equipment
- materials handling
- weather
- fire
- floods.

Assessment of these contingencies is a matter of experience coupled with proper investigation of all available information. Supervisors must have the ability to analyse these hazards and risks in a sound and logical manner.

Local Factors

The actual procedure adopted for the execution of any particular project also requires proper investigation and logical analysis. Not only is it essential to study the plans and specifications, but also to examine the many local factors and physical conditions of the site, all of which have an important bearing on the best way to do the work.

Local factors and physical conditions that do have a marked influence on the plant and procedures to use for each job include:

- power supply
- fuel supply
- water supply
- access roads
- geology
- topography
- climatic conditions
- housing facilities
- cost of labour and materials
- specification requirements.

Job Dissection

The first step in devising the best procedure for carrying out the project is to list in detail the sequence of operations comprising the entire project. Each basic process is then studied, taking into account of:

- the demands of the specifications
- the quantities of work involved
- plant and materials needed
- labour force
- time required to complete the task

Co-ordination of these operations requires an intensive examination to determine how the job can best be done for the lowest cost. In order to do this we must determine the overall time required for the completion of the work and investigate alternative construction methods.

This phase is described as the preliminary planning stage and from it we will develop:

- the draft construction programme
- plant schedule

These in turn are followed by the detailed planning schedules.

These schedules apply equally to large and small jobs, for in the ultimate analysis a large project is simply a collection of smaller operations. A detailed picture of the project is obtained when the preliminary planning is carried out.

The costs of the project are also determined with greater confidence with the preliminary planning schedules. In addition construction can begin at short notice with a well defined plan already in place.

From the contractor's viewpoint the preliminary planning is the most important part of the tender process. The plan helps to determine construction methods, plant requirements and costs. From this the contractor can devise the tender price.

A successful tenderer then uses the preliminary plan for the contract and determines the construction procedure. Errors or major changes in the plan not only retard progress, but usually cost money.

Process Dissection

A detailed analysis of all the operations necessary to construct the works is prepared from the quantity schedule and the specifications.

The document, referred to as the 'Process Dissection' is drawn up and shows each specific operation comprising a schedule item of listed work. Computations are summarised and the basic costs are deduced.

Costs are reported separately as:

- labour
- materials
- plant

The total costs of these dissections are the direct cost of the item. The costs are then recorded in separate columns on the tender summary sheet. This provides the actual direct cost of each item, and the basic unit cost rate.

It is essential to list all operations for each part of the work. For instance the project may require:

- compressed air and water supply lines
- lighting
- dump trucks
- dozers
- sanitary arrangements.

The amount of detail in the process dissection varies with the size of the job and the experience of the construction planner.

When constructing a road, the plan and the shift programme is studied, so that the work is arranged for a specific task per shift. It is important to allow ample time for delays and the transport of personnel in and out of the project.

In all cases the project is broken down under itemised headings corresponding to the schedule of quantities and/or process that are submitted with the tender.

For example the cost of a task such as concreting includes:

- the cost of materials at the mixer
- batching and mixing
- transportation and placing
- formwork and curing

When computing the information on the process dissection the construction planner must draw from his/her own experience. It is also important to discuss the procedure with more experienced colleagues.

At this stage discuss alternative methods and examine existing plant. When two or more methods look equally effective, record details of each on the document for final decisions.

When the process dissection is completed the listed information includes:

- construction times for each operation
- plant and equipment required
- basic direct costs including:
  - labour
  - materials
  - plant
- quantities of materials and stores
- labour requirements.

The draft of the construction programme is drawn up using the construction times for each operation determined in the process dissection.

Likewise the plant schedule is also prepared. At times the construction programme will require rearranging in order to dovetail all the operations into a smoothly running programme.

Plant Schedule

The plant schedule is prepared from the process dissection and the work programme. The schedule shows the occupation of each item of plant during the construction period. This helps to avoid overlapping and excessive idle periods while the delivery date for all equipment is accurately predicted.

On the plant schedule, the delivery date for plant is the latest date for the arrival of the plant on the job.

Water supply and compressed air requirements for the project are computed from the information in the process dissection, and the capacities of the pumps, tanks, compressors and receivers are determined as well as the sizes and the quantities of pipelines, stop valves etc.

The completed plant schedule is a most valuable document for getting the job started at the earliest possible time.

Measurement

When performing estimates for road construction projects, the supervisor must make measurements to calculate the size of a project. If the amount, kind and location of cut, borrow and fill is not included in the specifications, it is often the supervisor's responsibility to calculate the amount of material that the construction crew is required to haul from one location to another. This is possible by using grade or route plans.

Basic Calculations— Lengths, Areas and Volumes

Lengths

Length is the basic measurement on which all construction calculations are based. In Australia, the unit of length is the metre (m). When one metre is divided into one thousand parts, each part is known as a millimeter (mm). Small measurements (e.g. dimensions of timber used as formwork) would normally be measured in millimeters. Longer distances, for example the distance by road between two towns, are measured in thousands of meters, or kilometers (km).

The prefixes milli — (one thousandth of) and kilo — (one thousand times) are also used with other units of measurement (see later, under Volumes).

Measurements of length, also known as lineal measurements, are made frequently during the course of a construction project.

Work such as ditching, installing pipe, tile and fencing is measured by the lineal metre. From both a time and cost viewpoint it is necessary to know:

- the width and depth of the ditch
- soil type
- special conditions
- size and type of pipe
- type and quality of fencing.

Drilling is usually measured in lineal metres, with the size of hole specified.

Areas

The three most common area calculations are for rectangle, square and circle.

Rectangle

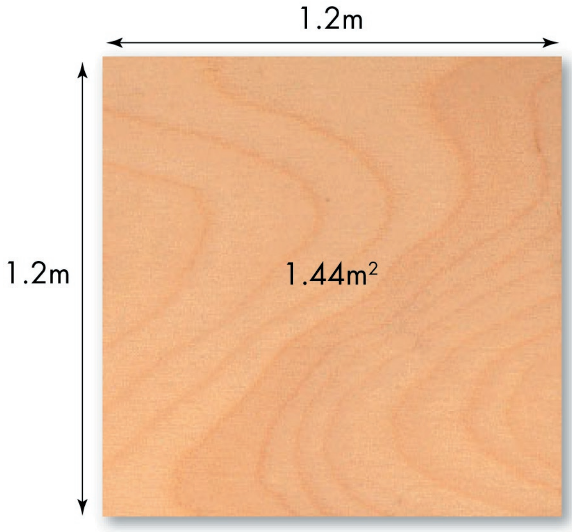
A rectangle is a flat surface where one side (the length) is longer than the other (the width). The area of a flat, rectangular surface is calculated as Length x Width. Both length and width must be expressed in the same units, usually millimetres or metres. Area is expressed in square millimetres (for very small areas) or (more commonly) in square metres.

For example, an area of road 1500 m long by 8 m wide is to be covered with a mixture of gravel, binder and water. The total area is:

1500 x 8 = 12000 square metres.

Square

A square is a special case of a rectangular area, in which the length and width are the same. The area of a square can therefore be calculated as Length x Length, or Length squared. For example, a square piece of plywood with a side of 1200mm (= 1.2m) has an area of:



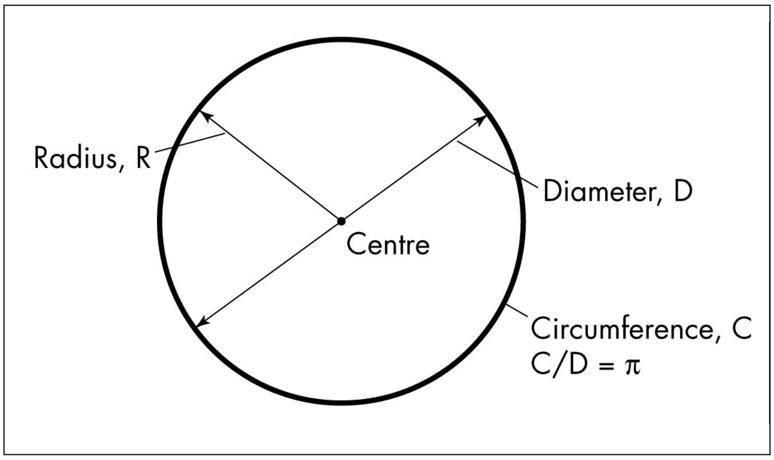
1.2 x 1.2m = 1.44 square metres.

Rather than write 'square metres' every time we want to state an area, we can use either of the following abbreviations:

- m^2
- sq m.

Circle

The area of a circle is frequently used in construction work.



A circle is a regular shape in which all points on the outer edge (or perimeter) are the same distance from the centre. The distance across a circle is called the diameter; the distance from the centre to the perimeter is the radius. The circumference is the distance around the perimeter of the circle.

In all circles, the ratio of the circumference to the diameter is a unique number called Pi (Greek symbol π). Pi is approximately equal to 3.14 159 265 358 979…. For practical purposes, we use π = 3.1416.

To calculate the area of a circle, we use either of two formulas:

$$\text{Area} = \pi R^2$$

$$\text{Area} = \frac{\pi D^2}{4}$$

Examples of basic area calculations are given in the Case Studies section of Topic 2 in this learning resource.

The part of a construction job requiring a cover of top soil or turf, or to be seeded with grass, is normally expressed as an area in square metres.

Volumes

'Volume' means the amount of space occupied by a three-dimensional object. The space may be a solid object (such as a block of concrete) or an empty space (usually referred to as a void). Two main types of volume calculation are needed for construction work.

- rectangular and cubic spaces
- cylindrical spaces.

Volumes of Rectangular and Cubic Spaces

The volume of a rectangularly shaped space is calculated as Length x Width x Depth. Length, width and depth must be expressed in the same units, usually millimetres or metres. Volume may be expressed in cubic millimetres or cubic centimetres (for small spaces) or, more commonly, in cubic metres.

A cube is a special case of a rectangular space, in which the length, width and depth are the same. The volume of a cube can therefore be calculated as Length x Length x Length, or Length cubed. For example, a cubic block of wood with a side of 100mm (= 0.1m) has a volume of:

0.1 x 0.1 x 0.1 = 0.001 cubic metres.

Rather than write 'cubic metres' every time we want to express a volume, we can use either of the following abbreviations:

- m^3
- cu m.

Relationship between Fluid and Solid Cubic Measures

There are two types of cubic measure in the metric system, as used in Australia. 'Litres' (symbol L) are used for the volumes of fluids, while cubic metres (etc.) are generally used for solids. A litre is made up of 1000 mL (millilitres), and each millilitre is almost exactly the same as 1 cubic centimetre. As one centimetre is $1/100^{th}$ of a metre, a cubic metre is made up of:

100 x 100 x 100 = 1 000 000 cm^3 (cubic centimetres)

However, this is the same as 1 000 000 millilitres. One thousand millilitres make one litre. Therefore—

1 m^3 = 1 000 000/1000 = 1000 litres.

However, when we are dealing with large quantities of water or other fluids, we can use either type of measure, as convenient. For example:

- the volume of water delivered in a road-watering truck may be expressed in kilolitres (thousands of litres) or cubic metres (1kL = 1 m^3)
- the volume of water held in a dam may be expressed in megalitres (millions of litres), or in cubic metres (1ML = 1000 m^3).

Examples of basic volume calculations are given in the Case Studies section of Topic 2 in this learning resource.

In most cases, the earthmoving requirements on a job are expressed as a volume in cubic metres.

Although volumes are shown as a number of 'cubic metres' or m^3 on drawings, people may refer to them simply as 'metres' during discussions. However, if there is any possibility of confusion with lineal metres, it is better to use the term 'cubic metres'.

Measurements Used in Construction Work

The main purpose of the plans and drawings that form part of the contract is to ensure good communication. The people who designed the road will only see their design become reality if they clearly communicate their intentions to the people building the road.

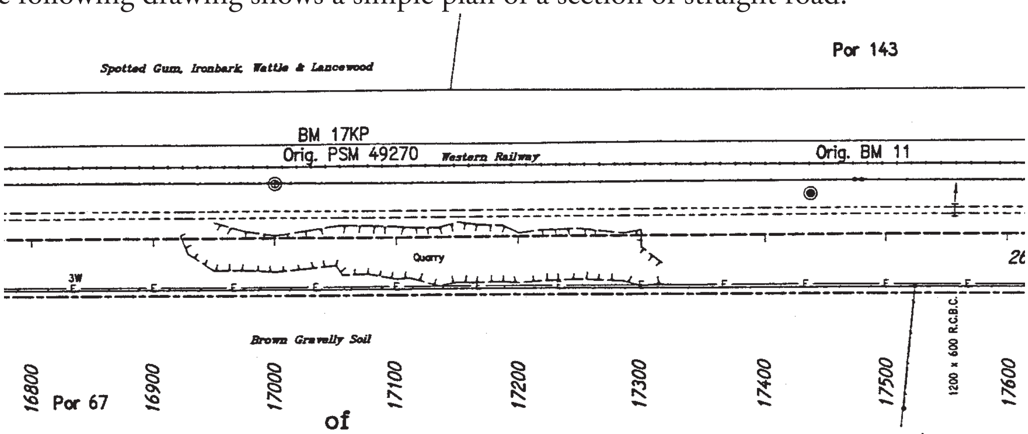
Therefore, the ability to read and understand plans is an essential part of the job of a leading hand, foreman or construction supervisor.

The main measurements that people refer to during a job are related to the horizontal alignment, vertical alignment and cross-section of the job.

Horizontal Alignment

A road is aligned both horizontally and vertically. At any point, it is either curved or straight (horizontal alignment); or level or heading uphill or downhill (vertical alignment). These basic details are shown on the plan and long section drawings of the road.

The following drawing shows a simple plan of a section of straight road.



Working Plan (drawing 2)

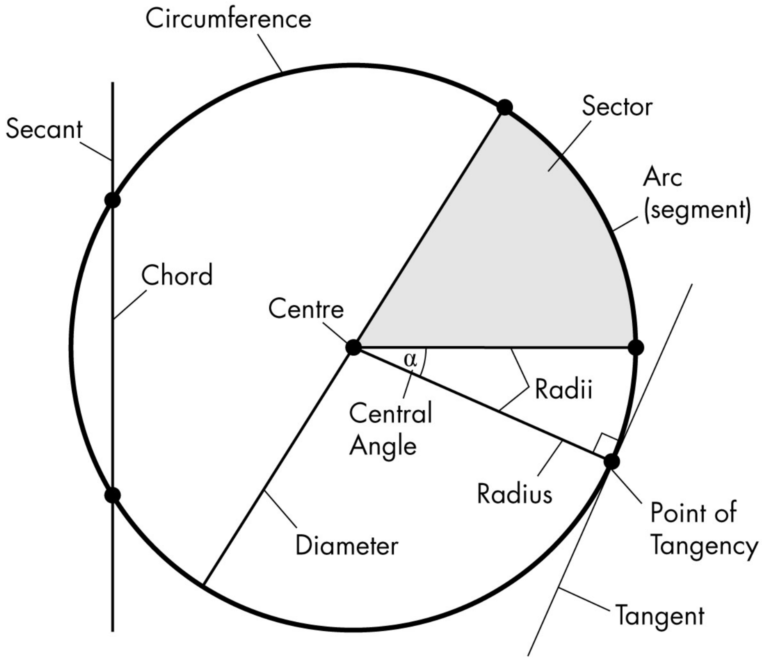
The plan shows distances along the road (in this case, from 16 800 to 17 600). These distances are known as chainages, and represent the distances from some known point. Although the reference is to chains (a unit in the Imperial system of measurement, equivalent to 66 feet), the distances are in metres.

The starting point from which the measurements are taken is a known, surveyed point; it is identified as such on a map. In the past, when surveys were carried out by a surveyor and a chainman, cairns of stones (constructed by the surveyor) or blazed trees (known as shield trees) were often used for this purpose.

Curves

In construction work, curves are laid out as arcs of a circle. An arc is simply a section of the curved perimeter of a circle. Each point on an arc is equally distant from the centre of the circle.

The drawing (below) shows the main parts of a circle. The terms identified in the drawing are defined in more detail in the Glossary.



Parts of a Circle

For construction purposes, a curve may be described in one of two ways:

- As the number of degrees of curve. This is equal to the central angle of a circle with an arc 30 m long. In this method of describing curves, an arc with a smaller radius has a larger number of degrees of curve.
- By the radius of the circle on which the curve lies.

In most construction work, the use of electronic measuring equipment (e.g. robotic total stations) has done away with most of the time-consuming work that was once required to survey and peg out a curved section of road. Because of this, most plans now describe a curve by using the radius of the circle.

The radius of a circle with one degree of curve is approximately 2000 metres. A 2° curve has a radius of 1000 metres.

It is possible to convert number of degrees of curve to radius by using one of the following formulas:

$$\text{Radius} = \frac{2000}{\text{degrees of curve}}$$

$$\text{Degrees of curve} = \frac{2000}{\text{radius}}$$

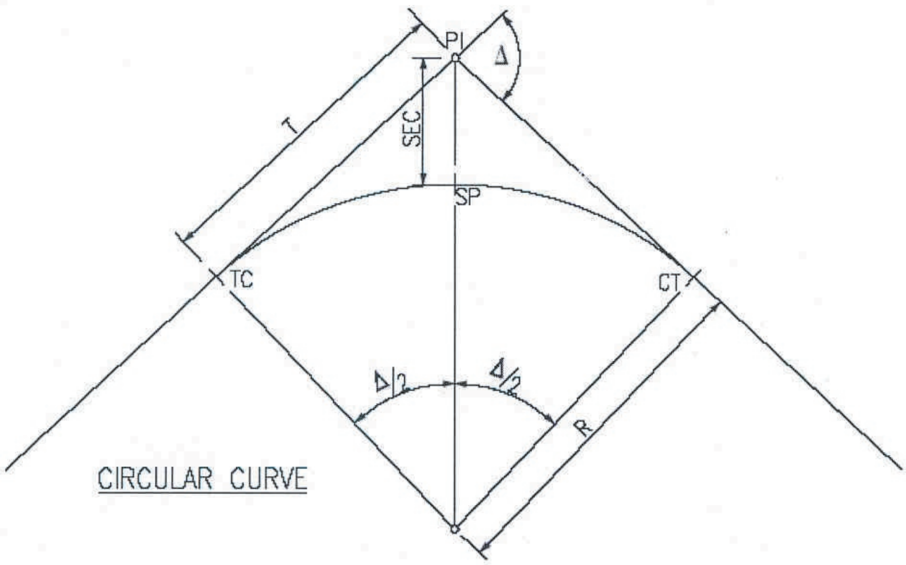
Horizontal Alignments

The horizontal alignment of a road, railway or similar project, is usually a series of straights (also known as tangents) and circular curves, which may or may not be connected by transition curves.

There are basically two types of curves. One is called an untransitioned curve or circular curve; the other is called a transitioned curve.

In this drawing, two straights intersect each other at PI (point of intersection). The angle formed at the intersection point, ? (triangle symbol), is called the intersection angle and it is usually shown in degrees. An untransitioned or circular curve of radius R smoothly joins these two straights. Where the circle touches the straights at the points TC (Tangent to Circle point) and CT (Circle to Tangent point), the circle is tangential. In the direction of chainage, TC comes before CT. The length of straight T between TC and PI (also PI and CT) is called the tangent length.

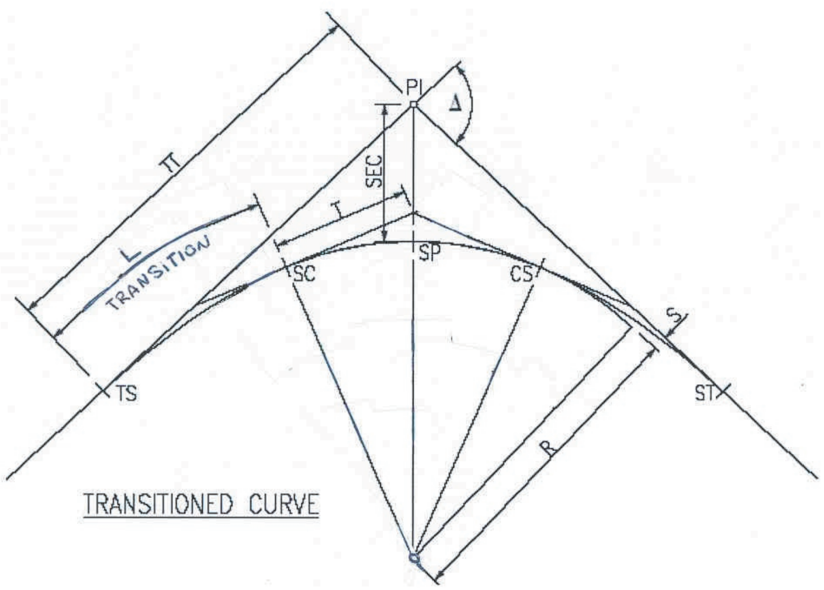
Also shown is SEC, which is the secant length of the curve, and SP which is the secant point.



A transitioned curve is shown in the following drawing.

This type of curve is similar to the circular curve shown above, except that it has a transition placed between the straights (tangents) and circular curve. This transition is a spiral which is simply a curve with an ever-increasing radius. This helps vehicles enter and exit tighter circular curves.

In this drawing, length L is the spiral or transition length. The offset or shift distance S is the distance the circular curve is away from the tangents. In the direction of chainage, the spiral leaves the straight or tangent at TS (tangent to spiral point) and joins the circular curve at SC (spiral to circle point). Between SC and CS (circle to spiral point), the curve is circular with a fixed radius of R. Another spiral then starts at CS and joins the following straight at ST (spiral to tangent point). The length of straight TT between TS and PI (also PI and ST) is called the total tangent length.



Centreline

On most jobs, the centreline (also known as a baseline or control line) is the basic location reference for the roadway. It may be the centre of the pavement in a single road, or the centre of the median strip in a dual highway whose two roadways are a fixed distance from each other.

Measurements are made along the centerline by using electronic instruments or with a steel tape and stakes are set at 30-metre intervals. This operation is often called chainage.

All distances are measured along the centreline, and structures and stakes are located in reference to the centreline— for example, profile pegs on batters. The centreline also provides the basis for grade calculations for single roadways.

Warning!
Never destroy, move or interfere with any of the stakes or markers on the job.

Example of Centreline Marking

There are a number of construction lines that run parallel to the centreline. These include:

- pavement
- shoulder
- drain
- slope edges.

They are usually measured off the centreline, at right angles to it on straight stretches, and from radial lines along curves.

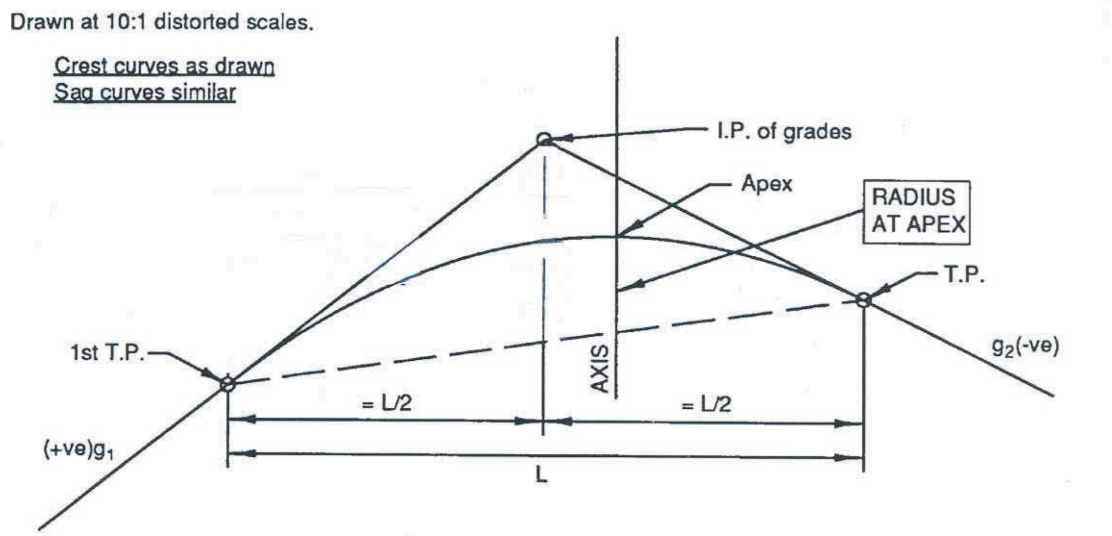
Vertical Alignment

The vertical alignment or long section of a road shows the rises and falls of the centerline; however, it does not indicate whether its route is straight or curved.

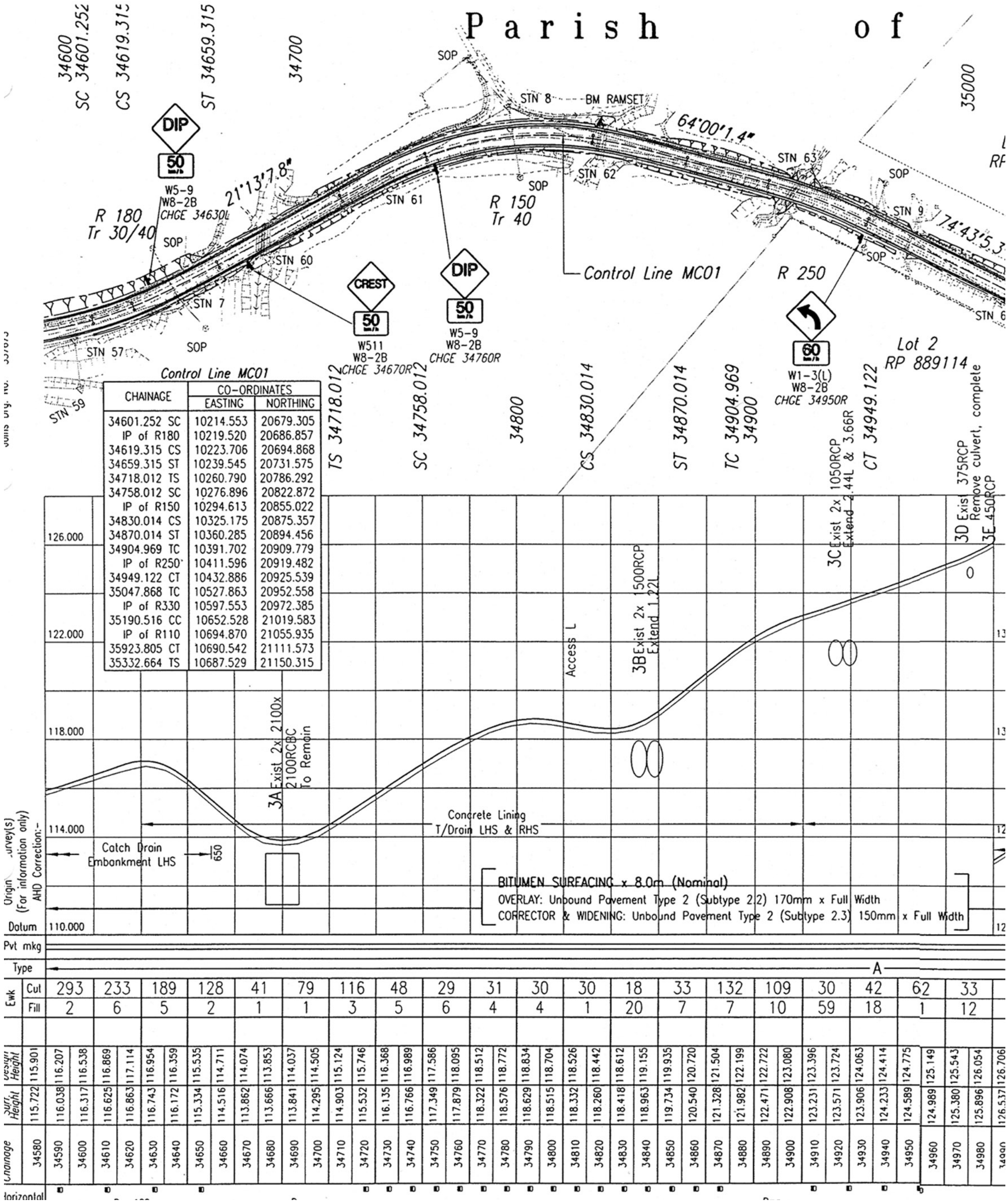
The vertical alignment of a road is a series of straights (tangents) and curves. Unlike the curves for horizontal alignments, vertical curves are not circular; they are parabolic and the straight sections are called grades.

In the drawing (below), the grades intersect each other at IP (intersection point). In the direction of chainage, rising grades are positive and falling grades are negative. Grades are shown in degrees. For example, 3% grade means the surface will rise 3m over 100m.

Curves which 'roll over the top' (as shown) are called crest curves. Sag curves are the opposite of crest curves. The radius shown in plans for a parabolic curve is radius measured at the apex of the curve, which is the highest (or lowest) point of the curve. The curve touches the grades at tangent points or TPs. Length L is the length of vertical curve and is measured horizontally between tangent points.



Two profiles are prepared, one of the existing ground surface, and the other of the proposed pavement surface. Both of these profiles are drawn on the one sheet or roll of cross-section paper, as shown in the example below.



Rough estimates of the cut and fill are made from the long section, although accurate determination usually requires cross-sections showing side slope of the ground, slopes proposed for highway cuts and fills and other details.

The long section is usually shown on the same sheet as (and below) the plan of the road, with the relevant chainages.

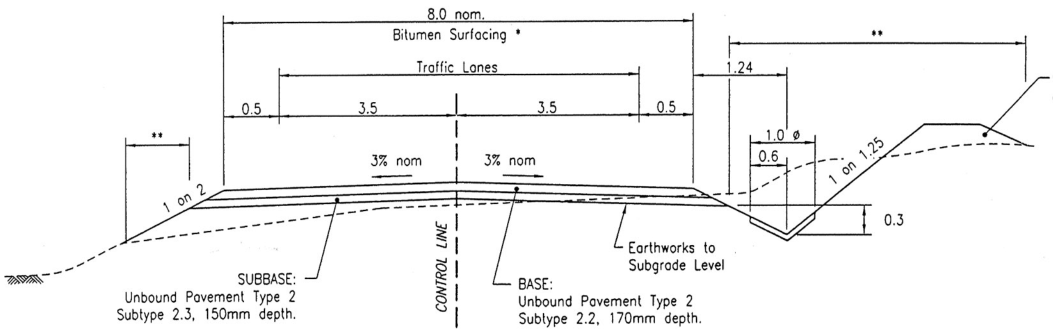
Cross-Sections

There are two types of highway cross-sections. The project plans usually include a set of typical road sections that shows the detail of pavement width and thickness, shoulder and gutter width, crown or side slope and other construction information. These typical sections serve as guides in staking out and building the road.

An ordinary cross-section is a profile taken at right angles to the centreline. It is at least long enough to include the full width to be graded.

The number of cross-sections taken depends on the irregularity of the ground. In hilly country, they are taken at each 30-metre station, and at additional stations where the ground surface changes. On perfectly flat land, only one or two cross-sections may be taken on an entire project.

The following example shows the cross-section of part of a construction job involving a new road alignment.



Methods of Measuring Distance

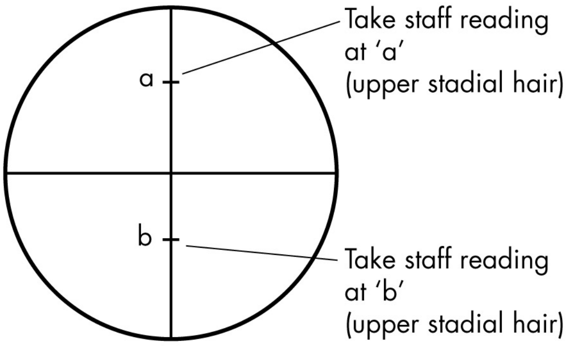
Distances may be measured as a rough estimate or as an accurate amount, depending on the requirements of the job and the technique used.

Rough Estimates

The following methods may be used for rough measurements of surface distances:

- Pacing
- Stadia
- Car speedometer.

The technique using stadia is well-known to surveyors. If a surveyor is using a dumpy level, the distance between the instrument and the staff (held by an assistant) can be easily estimated. The surveyor's view through the instrument is as shown below:



Stadial Hairs

The surveyor takes the staff reading at A and B (the stadial hairs) and multiplies the difference by 100 to get a rough estimate of the distance:

100 x {(Reading at A) – (Reading at B)} = Distance to staff

The distance estimate obtained in this way is usually accurate to ±100 mm.

Accurate Measurements

Methods used for more accurate measurements of surface distances include:

- Tape (chainage)
- Distance meters
- Measuring wheel.

Job plans and maps may assist in determining distances; however, it is important to be aware of the possibility of error when using these sources. For example, a distance shown on a map must be multiplied by a scale factor (e.g. 1: 50 000 or 50 metres to one centimetre) to convert it to an estimate of the actual distance. Use of the wrong scale factor, or failure to accurately read a distance from the map sheet, will lead to error. If possible, always use a distance measured on site in preference to one shown on a plan or map.

Measuring Wheel

The measuring wheel is a convenient way of measuring both short and long distances; it provides an acceptable degree of accuracy for most construction work. The correct methods are:

- Small wheel— hand roll along the ground
- Large wheel— hand roll, or tow slowly behind a vehicle.

A counter registers the distance covered in metres. Readings accurate to the nearest 50 mm are attained by using this method of measurement.

Calculating Volumes

The differences between bank, loose and compacted volumes of earth is explained in Topic 2 of this learning resource. The following discussion is about calculating the loose volume of a stockpile, and the bank volumes of cuts and fills.

Stockpile Volume

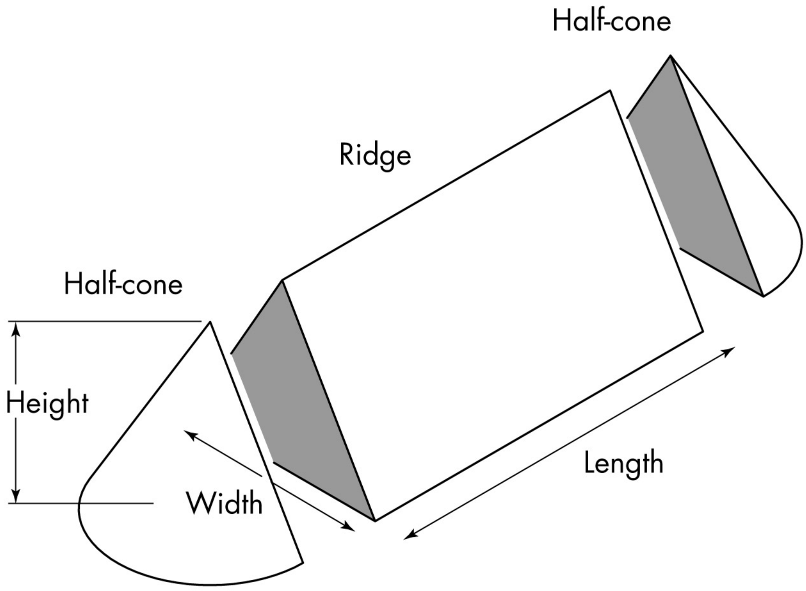
Calculating the volume of a stockpile is important, because this figure can be used to measure:

- An amount of material for payment purposes
- The quantity of material used on a job.

An experienced person can often estimate the volume of (loose) material in a stockpile by looking at it. However, for most purposes it is safer to use some form of measurement, even if only pacing out the pile's dimensions.

Modern electronic equipment makes it easy to take measurements and calculate volumes of stockpiles. However, knowledge of the underlying technique, as presented here, gives people on site the option of using direct, manual measurement and calculation if electronic equipment is not available at a particular time or place.

A typical shape of a stockpile is shown in the drawing. By visualising the stockpile as three regular shapes, in this case a triangular ridge and two half-cones, it is possible to estimate the volume.



Stockpile Measurement

The first step is to measure the length, width and height, as shown. The volume is then calculated in two parts:

Volume of End Half-Cones

The distance around the outside of a circle is known as the circumference. In this case, we have two half-cones, each of which has a circular base. If we measure the half-circumferences of the two end half-cones, the result is the circumference of one complete cone.

The formula for the area of the circular base of the complete cone is:

$$A_C = \frac{\text{circumference}^2}{12.6}$$

Alternatively, we could measure the width of the base of one half-cone; this is the radius of the circular base of one complete cone. The formula for area using radius (R) is:

$$A_R = 3.1416 \text{ x } R^2$$

To find the volume of one complete cone, multiply one-third of the area of the circular base by the height (H) of the cone:

$$V_C = \frac{A_C \text{ x } H}{3} \quad \text{(or alternatively, use } \frac{A_R \text{ x } H}{3}\text{)}$$

Volume of Triangular Ridge

The main part of the stockpile has a triangular cross-section. To calculate it volume, multiply half the width (W) by the height (H) by the length (L), as measured:

$$V_T = \frac{\text{Height x Width x Length}}{2}$$

Sum of Component Parts

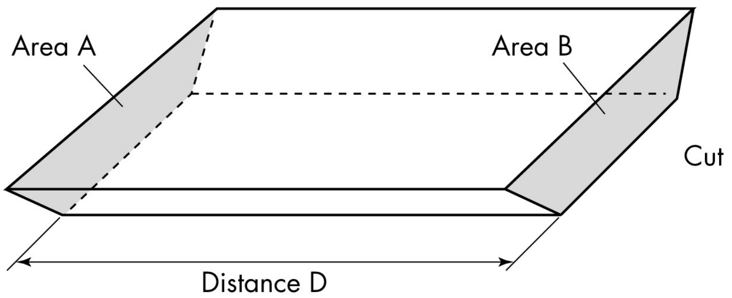
The volume of the stockpile (VS) is the sum of the volumes of the two components, as calculated above:

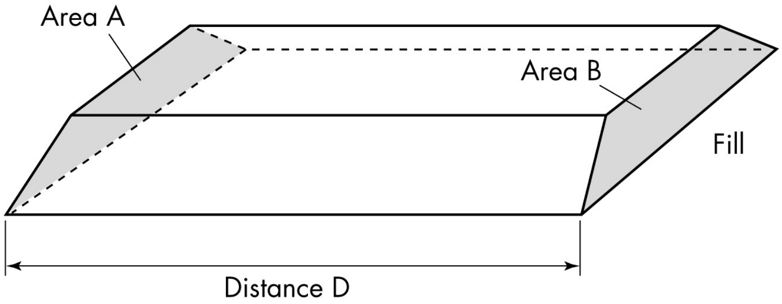
$$V_S = V_C + V_T$$

If the stockpile has been flattened or is irregular, measure the dimensions of cross-sections taken at points along the stockpile, and use the average end area method (as described previously).

Bank Volumes of Cuts and Fills

In calculating the volume of earthworks, we first calculate the area of a cross-section and then multiply by the distance between two cross-sections (i.e. the length).

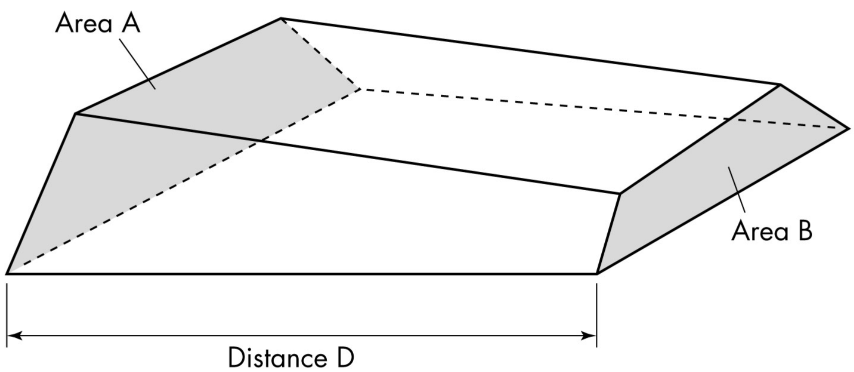




In the sketches above, if the end areas A and B of the cut (or fill) are equal, the correct volume would be obtained by multiplying either area by the distance D.

In practice however, the end areas are rarely equal, and so the Average End Area Method of calculating the volumes of cuts and fill is used.

In the following sketch showing a length of fill, area A and area B represent the areas of the two adjacent cross-sections in square metres, and D is the distance in metres between the two cross-sections.



The approximate volume of the length of fill (in cubic metres) is obtained by taking the average of areas A and B, and multiplying by the distance D, i.e.

$$\text{Volume} = \frac{\text{Area A} + \text{Area B}}{2} \times \text{Distance D}$$

This average end area method of calculating volumes may be used to determine the solid volume of cuts, fills and side cuts as follows:

- Calculate area A
- Calculate area B
- Add A and B then divide by 2 to find the average area
- Multiply the average area by the distance (D) between the cross-sections.

When using the average end area method for volume calculations, it is desirable to use at least every cross-section given in the job documents for the section of roadway under consideration. The omission of any intermediate sections over a length of road can lead to noticeable errors in the calculated volumes.

Case Studies 1 and 2 show the calculations needed to obtain estimates of earthworks volumes using the average end area method.

An alternative method, using prisms, is shown in Case Study 3.

Casual Estimating

Where cuts and fills are shallow, and side slopes are moderate, grading is quite often estimated fairly accurately by inspecting the centreline stakes.

The exact metreage is not always of prime importance, as stripping topsoil and working over a piece of ground represent an amount of machine time. This time is only moderately increased by the cuts and fills.

Supervisors must watch for several errors. Cuts and fills on the stakes are figured from the top of the stake, from ground level or from a line on the stake. The grade indicated is either sub grade or finish grade.

If sub-grade is indicated it is taken at face value; on the other hand, if finish grade is indicated the depth of base courses and the depth of surfacing is added to the cuts and subtracted from the fills.

Calculating the width of the road includes:

- the road
- shoulders
- the drains
- the slopes

The depth of the topsoil to be stripped is subtracted from the cuts, added to the fills and considered separately as an important cost factor.

Under certain conditions it is the supervisor's responsibility to carefully calculate the meterage for the cut and fill areas. These conditions include:

- when cuts and fills are deep
- side slopes exist
- if it is not necessary to strip the topsoil
- when the job is large.

Calculating Distances

Long Section

The minimum staking for a road is the centreline. When this is done a profile is taken showing the elevation of the ground at each stake. These elevations are plotted on cross section paper, usually with the vertical scale 10 times the horizontal, and the points connected by a line.

A long section of the road is then sketched according to the standards of grade and vertical curve required, or from some previously formed plan. This line represents the sub grade before the addition of any imported material.

Distances measured from the road line to the ground line will indicate the depths of cut and fill required to establish the road grade. If topsoil is stripped, its depth should be added to the fills and subtracted from the cuts.

If the ground does not slope across the line of the road, the long section should provide a reasonably accurate picture of the relative volume of cuts and fills and the distances that they are to be moved. In other situations, e.g. side cuts, cross-sections must be calculated before the earthmoving task for the job can be estimated.

Side Profiles

If the road is laid out on the side of a hill, side stakes and slope stakes are set. The side stakes are placed at the edge of the pavement, at the outer edge of the shoulder, or on the far side of the drain. In general the shoulder or the drain locations are preferable.

Slope stakes are placed where the intended cut in the bank reaches its top, or at the outer, base edge of a proposed fill. These are not placed until cross sections are calculated.

If the side stake elevations are plotted in the same manner as the centreline, it is possible to draw two additional profiles. The left edge profile and the right edge profile provide additional information about the bulk of material to be moved.

Since these profiles do not provide cuts for drains, and cannot show the volume which must be dug or filled for side slopes outside the road lines, they are not an adequate basis for careful calculation.

Cross Section

A cross section is a profile taken at right angles to the centreline of the roadway. It is at least long enough to include the full graded width.

Cross sections are taken at each 30 metre station, and at points where the ground surface changes. The profiles are taken less frequently in smooth terrain.

The cross profile is also drawn on cross section paper and on the same vertical scale as the centre profile. The horizontal scale is either the same as the vertical scale or at a specified proportion of the vertical scale.

When ever the ground line is above the road line, a cut is taken and whenever the road line is higher than the ground line fill is required. It is always advantageous to lower the ground line by the depth of the top soil if it is necessary to strip and save top soil from the job. This saves confusion when determining if cut or fill is required.

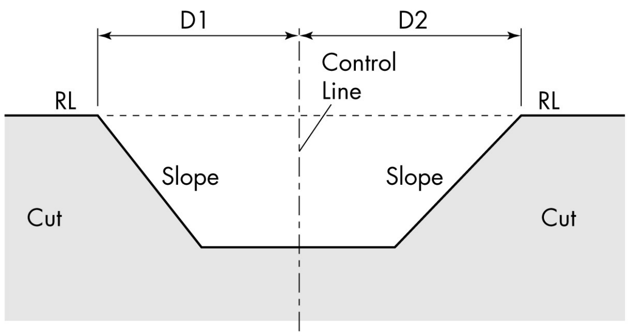
Cross-Sectional Areas of Cuts and Fills

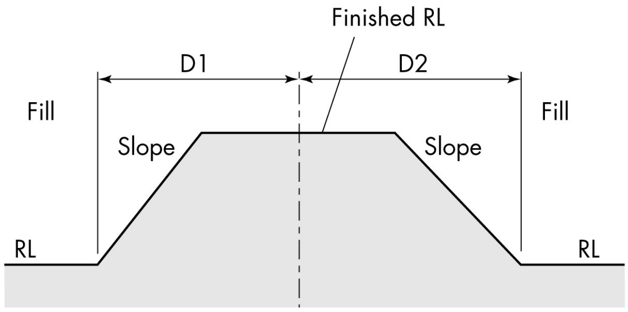
The most important component in the calculation of earthworks volumes is the cross-sectional area of a cut or fill.

It is normal practice to break down the cross-section into rectangles and triangles, to calculate the area of each separately, and then add them together to find the total area.

The following examples show how cross-sections are calculated in cuts, fills and side cuts.

The dimensions and levels normally given on cut and fill cross-sections are shown in the following drawing.





All other dimensions required to calculate the cross-section area are found by computation or scaling off the drawing, if it is drawn to scale.

The use of a planimeter to measure cross-sectional areas is described in detail in Topic 4 of this training series.

The following case studies (located in a separate section at the end of this manual) describe in more detail the various situations involving cross-sections:

Case Study No. 5— Calculating a simple cross-sectional area

Case Study No. 6— Calculating the area of cuts and fills of regular cross-section (ground level and control line in centre of cross-section)

Case Study No. 7— Calculating area of cross-section with ground level and control line not in centre of cross-section

Case Study No. 8— Calculating area of cross-section with fill on sloping ground, control line central

Case Study No. 9— Calculating area of cross-section with cut on sloping ground, control line central

Case Study No. 10— Calculating area of cross-section with side cut, control line central

Case Study No. 11— Calculating area of cross-section with fill on sloping ground, control line offset

Case Study No. 12— Calculating area of cross-section with cut on sloping ground, control line offset

Case Study No. 13— Calculating area of cross-section with side cut, control line offset

Case Study No. 14— Calculating cross-sectional areas of combination sections.

Estimating Labour

The cost of labour accounts for a large part of every construction dollar. No supervisor can afford to overlook the labour cost of a project.

Construction work is performed by the labour force in two ways. That is the job is done by either:

- labour alone; or
- labour with the aid of machines

Output per man-hour figures for both types of labour are available from:

- historical records of past work
- published costs of other work
- building up a composite list based on knowledge of a person's production output and the preparation of rates from first principles.

Once you determine the production output you can apply the appropriate labour and plant rates to the estimated hours. The simplest system for determining labour costs is to establish a rate per man-hour for the project.

In order to determine the rate per man-hour you must include direct wages as well as on-costs such as:

- workers compensation insurance
- sick pay
- holiday pay
- payroll tax
- living allowances
- overtime or shift work
- time lost in wet weather if applicable.

The man hour rate is then the real cost to the contractor for each hour worked.

Supervision Costs

Supervision at the project supervisor level is considered an overhead expense. Foremen may be charged to overhead also, but it is more usual to enter their pay as an operating expense. Therefore foremen and leading hand expenses are charged as an operating expense to the project.

Wages vs Costing Rate

The total cost to an employer of an employee's wages includes two components:

- The direct cost of wages
- Wages overheads.

Direct costs of labour can be attributed to labour as an activity, as part of the process of estimating the costs of the job. The direct costs of labour vary according to the numbers of hours people work, and usually include:

- Overtime penalties (e.g. overtime at 1.5 times, overtime at 2.0 times)
- Travel allowances in accordance with state or federal awards.
- Other allowances in accordance with awards (e.g. productivity, annual leave loading).

The cost of wages overheads is usually estimated as a separate exercise. Wages overheads depend on other factors in addition to hours worked; however, they must be paid in accordance with legislation or awards. These 'indirect' costs of employing a person may include:

- Superannuation
- Redundancy pay (e.g. at the rate of 1.75 hr/week, under BUSS(Q))
- Contributions to the Construction Industry Portable Long Service Leave fund
- State Government payroll tax
- Workcover (workers' compensation).

Skilled Labour Costs

Skilled labour on the construction site includes surveyors, materials testing personnel and tradesmen. Labour costs in this section of the work force are the most difficult to calculate because of inherent uncertainties.

Features making it difficult to determine the actual output cost per man-hour include:

- quality of labour
- varying working conditions
- varying site conditions in relation to the type of work being performed.

The best method is to adopt an ideal performance condition and then apply working condition factors to suit the anticipated site or quality of labour condition.

Performance Condition	Excellent	Average	Poor
Field Supervision	1.00	0.97	0.90
Physical Conditions Heat or cold Tools and Services Dust or Mud Access, Height and Depth	 1.00 1.00 1.00 1.00	 0.90 0.90 0.95 0.97	 0.70 0.75 0.85 0.85
Construction planning	1.00	0.95	0.80
Quality of Labour	1.00	0.90	0.70
Hours per Week per Employee	40 Hours	40/45 Hours	60 Hours
For Day Only	1.00	0.94	0.80
For 2 shifts	0.95	0.89	0.75
For 3 Shifts	0.93	0.87	

Working Week (Days) (Hours)	**Effective Work Time** (Percent)	**Hours of Work Factor**	**Actual Working Efficiency** (Percent)
5 X 8 5 X 9 5 X 10	91.6 92.5 93.3	1.00 0.97 0.94	91.6 89.7 87.7
6 X 8 6 X 9 6 X 10	91.6 92.5 93.3	0.94 0.89 0.80	86.1 82.3 74.6

These factors will vary with:

- quality of the field supervision
- nature of the site conditions
- efficiency of construction planning
- quality of labour.

Other time elements which are taken into consideration, for which employees are paid, but which cannot be considered productive are:

- meal and tea breaks
- starting up and stopping work
- time spent by labour getting to and from place of work
- plant and tool maintenance
- personal bodily requirements
- night work.

It is therefore important for an estimator to have a working knowledge of the provisions of the state and federal awards as well as other premiums pertaining to labour costs.

In the basic cost method of estimating all these elements of the total labour cost are included in the direct costs apportioned to work.

Subcontractors

Some parts of the job are programmed for completion by subcontractors; for example, supply of asphalt paving.

Sources of information for estimating subcontractors' costs may include:

- Previously submitted tenders for similar classes of work
- Quotes submitted by subcontractors for the relevant classes of work.

Estimating Construction Materials

Materials form part of the job and in the basic cost method they are estimated separately. The estimate of the materials element is normally broken down into two sections:

- Permanent Materials
- Temporary Materials.

Permanent Materials

Permanent materials are those which become a permanent part of the construction of the job. They are set down in the schedule of quantities or else extracted from the drawings.

Since permanent materials are scheduled or shown on the drawings, net quantities are accurately estimated, although allowance must be made for wastage.

In addition to wastage, some items include unmeasured quantities for which allowances should be made. For example in trench excavation or in any form of excavation over break will occur.

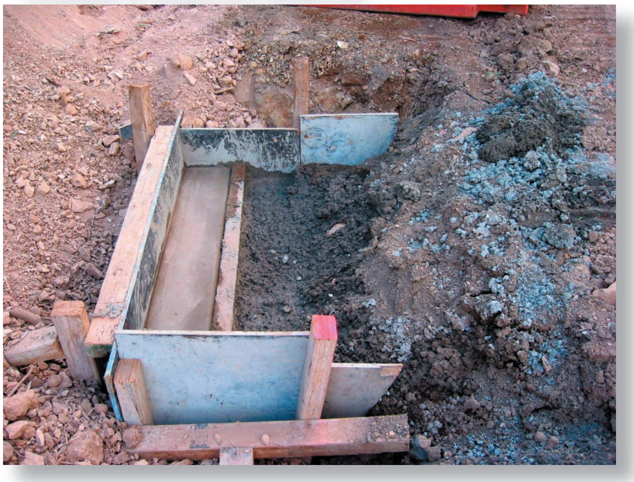
Road Materials

The main types of base and sub-base materials used for road construction include:

- soil aggregate
- crushed rock
- stabilised crushed rock, soil aggregate or soil
- bedding sands.

Temporary Materials

Example of Temporary Materials



Temporary items are used during the construction works, but do not permanently form part of the job. Examples include formwork, falsework, scaffolding and rock drills.

Often these items are obtained from the company's stores and are returned. However, they may be damaged or lost during the course of the job. Such occurrences are not usually accounted for in the schedule of quantities for the job; instead, a separate schedule is prepared.

Temporary materials are not so readily estimated and you will need to consider the following values:

- salvage value
- stores items and depreciation of equipment
- expendable items.

You must estimate the cost of all temporary materials and stores as accurately as practicable. Therefore the supervisor must have in place the following:

- Preliminary designs for form work and false work and temporary timbering.
- Preliminary planning to determine drilling and blasting patterns in the use of explosives.
- Preliminary planning of access, temporary tracks, bridges or culverts and the like which would require the use of materials.

Material Quantities

The amount of work spent on the preparation of temporary materials depends upon the amount of detail required to obtain essential quantities.

The details and hence the quantities are not as accurate as for permanent work. That is where past experience and costs of similar works carried out will short cut the preparation of extensive temporary works designs, if this type of information is used intelligently by a competent estimator.

When you have determined the quantities that are required for the job, you must make allowances for wastage and unmeasured items and deal with them in the same way as for permanent materials.

Factors Affecting Material Estimates

Factors that affect the process of material used in the construction project may include:

- bulking/compaction
- waste
- lapping
- unexplained discrepancies
- moisture
- density
- re-use
- coverage
- levels.

Bulking/Compaction

Supervisors are required to estimate cut and fill volumes. The actual haulage volumes are greater than the cut and fill volumes because the material is in a loose state during the haulage phase.

The density of a material, whether bank, loose or compacted is the weight of one cubic metre; it is stated as a number of kilograms (kg) per cubic metre (m^3). The density of water is 1000 kg/m^3.

The table on the next page shows:

- The densities of various materials in the bank state
- Densities of the same materials in the loose state
- Percentage swells, load factors and angles of repose of the materials (see later).

Table of Material Properties

Material	Density		Swell %	Load factor	Approx. angle of repose
	kg/bank m^3	kg/loose m^3			
Clay – dry	1310	1048	25	0.80	1:2 (27^0)
– light	1660	1278	30	0.77	1:2 (27^0)
– heavy/wet	1870	1402	33	0.75	1:1 (45^0)
Earth – dry loam	1600	1280	25	0.80	1:2 (27^0)
– moist	1735	1388	25	0.80	1:1 (45^0)
– wet	2030	1624	25	0.80	1:2 (27^0)
Earth, sand and gravel	1885	1602	18	0.85	1:2 (27^0)
Earth and rock	1565–2000	1205–1540	30	0.77	1:2 (27^0)
Gravel – dry/ loose	1885	1678	12	0.89	1:2 (27^0)
– wet/loose	2190	1927	14	0.88	1:2 (27^0)
Limestone	2590	1528	70	0.59	1:2 (27^0)
Rock – crushed	1920-2670	1420-1976	35	0.74	1:2 (27^0)
– massive	2605-3130	1745-2097	50	0.67	1:1 (45^0)
Sand— dry	1925	1713	12	0.89	1:3 (18^0)
– wet	2135	1857	15	0.87	1:2 (27^0)
Sand and gravel – dry	2000	1760	14	0.88	1:2(27^0)
– wet	2335	2008	16	0.86	1:2 (27^0)
Shale	1770	1327	33	0.75	1:1 (45^0)

Note!

Weights shown in the table are averages. Actual weights are affected by moisture content, grain size, and other factors. Tests must therefore be carried out to determine exact material characteristics.

The first two columns of the table show how much the densities of materials may vary. For example, at 3130 kg/m^3, the density of massive rock may be more than three times that of water.

The values in the table are given as a guide for estimating purposes. On the job, you can check the estimated amount against the actual amount of a material by:

- measuring up a cutting or excavation, and the fill to which the material is led
- measuring the capacity of the hauling vehicles
- tallying the number of loads required to shift the measured quantity.

Swell

Swell is the increase in volume of the material when it is removed from the natural state. It is expressed as a percentage of the bank volume. For example, if a material has a swell of 25%, it means that one cubic metre of the material in the bank state will occupy 1.25 m^3 in the loosened state.

Load Factor

Load factor is the percentage decrease in the density of a material from its natural state to the loose state.

$$\text{Load Factor} = \frac{\text{kg per m}^3\ \text{(loose)}}{\text{kg per m}^3\ \text{(bank)}}$$

$$\%\ \text{Swell} = \left[\left(\frac{1}{\text{Load Factor}}\right) - 1\right] 100$$

The table (below) gives the properties of materials commonly used in construction. Using dry clay as an example, we can calculate the load factor and swell as follows:

$$\text{Density in bank} = 1310\ \text{kg/m}^3$$

$$\text{Density loose} = 1048\ \text{kg/m}^3$$

From table, for dry clay

$$\therefore\ \text{Load factor} = \frac{1048}{1310}$$

$$= 0.80$$

$$\%\ \text{Swell} = \left[\frac{1}{0.80} - 1\right] 100$$

$$= 25\%$$

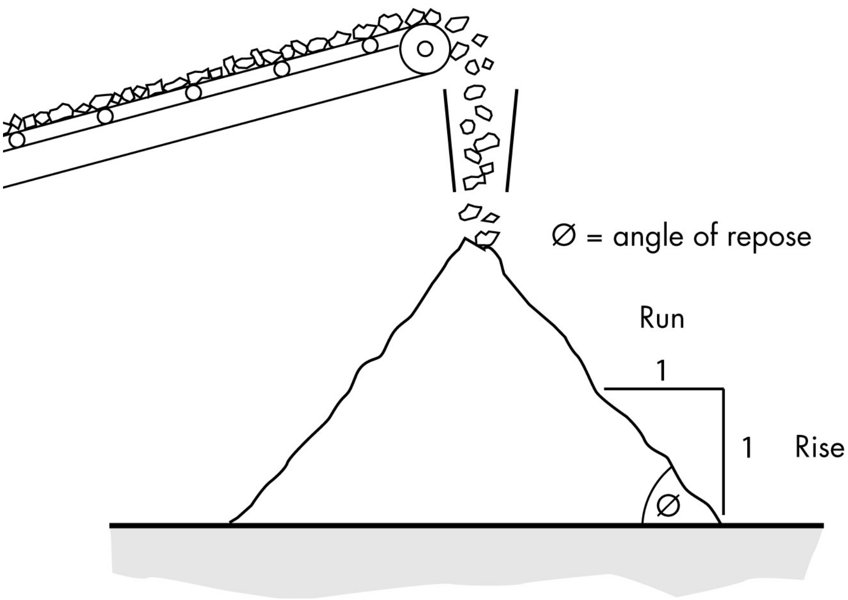
Angle of Repose

A stockpile is formed by tipping the material and allowing it to fall freely to the ground. The angle of repose of a material is measured as the angle that the side of the stockpile makes with the ground. It is the angle at which the material naturally tends to rest on a level surface, as shown below. The angles of repose of common construction materials vary between 20° and 45°.

The slope of material in a stockpile may be written in two ways:

- as an angle, in degrees
- as a fraction or a ratio.

To express an angle of repose as a fraction:



$$\text{Fraction} = \frac{\text{rise}}{\text{run}} = \frac{\text{vertical distance}}{\text{horizontal distance}}$$

In the example shown (a pile of shale), the fraction is $\frac{1}{1}$

To express an angle of repose as a ratio:

Ratio = 1 (Rise):1 (Run) = 1:1

Other common ratios of materials are 1:2 and 1:3.

The convention is that the Rise (vertical distance) is always divided by the Run (horizontal distance). This is the same as the convention used for expressing slopes and gradients.

Load Calculations involving Bank and Loose Volumes

The following calculations involve a self-loading scraper of 16.8 m^3 heaped capacity being used to move 200 bank m^3 of dry loam. The aims are to calculate:

- Weight of a heaped load (loose).
- Amount of loose material to be moved.
- Amount of swell (in m^3)

The table gives the following properties of dry loam:

Density	=	1600 kg/m^3 bank
Swell	=	25%
Load Factor	=	0.80

Calculating weight of a heaped load—

Each heaped cubic metre in the scraper bowl represents 0.8 of a bank cubic metre. Therefore:

16.8 m^3 loose x 0.8	=	13.4 m^3 of bank
Therefore weight of load (kg)	=	(13.4 m^3 x 1600 kg/m^3)
	=	(13.4 x 1.6) tonnes (1000 kg = 1 tonne)
	=	21.44 tonnes

Calculating amount of loose material to be moved—

Loose material to be moved	=	Bank volume divided by load factor
	=	(200/0.8) loose m^3
	=	250 loose m^3

Calculating amount of swell—

Swell	=	(250–200) loose m^3
	=	50 m^3

Calculations involving Loose and Compacted Volumes

When soil placed in a fill is thoroughly compacted by rolling, it will shrink. The amount of shrinkage that soil will experience depends upon:

- soil character
- structure in the bank
- thickness of fill layers
- weight and type of roller.

Measurement in the fill is described as compacted cubic metres or 'cubic metres after compaction'.

Calculations commonly carried out on compacted volumes include compaction factor and shrinkage ratio.

$$\text{Compaction factor} = \frac{\text{Volume in fill}}{\text{Volume in bank}}$$

Shrinkage ratio = 1 – Compaction factor.

An alternative approach is to use maximum dry density (MDD). This measure of compaction depends on the fact that soil materials can be compacted to varying degrees, depending on their moisture content. Generally, the degree of compaction (and therefore the density) of a dry soil increases with increasing moisture content; however, it only increases up to a certain point, beyond which it decreases as more moisture is added.

In short, MDD is a measure of the maximum mass per unit volume (density) that a given soil can achieve under optimal compaction conditions.

MDD is determined in the laboratory by testing the density of a soil over a range of moisture contents, to derive a moisture-to-density relationship. From this relationship, the maximum density achievable (for a standard compactive effort) and the corresponding moisture content can be identified. At this point, the soil is said to be at 100% MDD and the moisture content is known as the optimum moisture content. This is the moisture level construction crews try to achieve when compacting materials.

Materials in bank or loose states can be tested to determine respective densities and then related, as a percentage, back to MDD. These values can then be used to determine the changes in volume of materials between the different states (bank, loose, or compacted).

Waste

Waste is the act of digging, hauling and dumping of valueless material. It is necessary to clear waste materials to allow for production to continue.

Rated Capacities

Truck Bodies

Most truck bodies and equipment buckets are rated by the manufacturer to be able to carry a certain capacity in loose metres. Tip trucks and excavator or loader shovels are normally rated at water level. The body capacity of the vehicle is indicated by a printed plate on the side of the truck.

It is important to carry out regular checks to ensure the trucks are carrying their correct capacities. When carrying out a capacity check:

- trim and measure the bank prior to loading the truck
- fill the truck with a number of approximately equal loads
- count the number of loads that it takes to fill the truck
- once the truck is full it is necessary to trim and remeasure the bank
- the difference in the two measurements is then calculated in metres.

$$\text{Truck Load} = \frac{\text{Volume removed from bank}}{\text{Number of truck loads taken}}$$

In order to ensure the test is carried out accurately, run the test on the largest practical volume. For example approximately 180 metres is the minimum test capacity to use. Counting the number of buckets it takes to fill the truck during the test will supply container and output data for the excavator as well.

Machine Efficiency

A machine may go through many production cycles with less than its rated load. The ratio of the container's capacity to its actual load in loose metres is called its efficiency factor.

There are different reasons why containers of different machines carry less than their rated capacity. For example it is not always s possible to fill the bucket of an excavator because of difficult digging conditions. Other reasons may include:

- inadequate power
- improper design
- dull teeth
- traction
- heavy material
- operator's haste
- carelessness.

On the other hand it is often necessary to run a truck partly empty to enable it to

- climb steep grades
- reduce strain on rough ground
- cross soft ground
- increase haul speed
- poor mechanical state
- overcome poor tyre wear.

The container efficiency factor (CEF) formula is:

$$\text{CEF} = \frac{\text{Material in container}}{\text{Rated capacity of container}}$$

The amount of material in a container is determined by one or more of the following methods:

- careful measurement
- weighing a number of individual loads
- measuring either the bank or the fill to determine the amount of material moved in a certain number of cycles.

For example, during an excavation, a backhoe with a half-cubic-metre bucket digs a ditch 750mm wide, 1800mm deep and 3600mm long in 25 cycles, removing 5 m^3 bank volume during the operation. The following calculation shows the container efficiency in bank cubic metres:

Divide 5 by 25 = 0.2m^3 (to determine average bucket load)

Since the rated capacity of the bucket is 500mm we have:

$$\text{CEF (metres)} = \frac{200}{500} = 0.4$$

The efficiency factor in loose cubic metres is greater by the percentage of swell. In clay loam with 20% swell, the volume in loose cubic metres is determined by:

5 m^3 x 1.20 = 6

$$\text{Divide by } 25 = \frac{6}{25} \text{ (average bucket load)} = 0.24$$

$$\text{Then CEF (loose cubic metres)} = \frac{0.24}{0.5} = 0.48$$

Note!

It is important to specify whether the container efficiency factor is for loose or bank cubic metres.

Moisture

The critical factor when compacting soil on a job is the moisture content, since it can only be thoroughly compacted if it is at optimal moisture content. This is the percentage of moisture at which the grains of soil will slide against each other as they are pushed together, allowing them to be compacted at lowest cost. Excessive moisture forms an incompressible cushion that prevents the grains from moving together.

The solutions to inadequate or excessive moisture content are expensive; costs are incurred as a result of:

- carting, adding and mixing in the water, or
- the time required to reduce moisture content by drying.

In addition, material that contains too much moisture is likely to become too 'rubbery' under the roller. This causes it to push in waves ahead of and behind the roller. It will then spring back into its original position when the roller has passed. This is a very common condition in highway work.

Soil that is too dry will become loose or powdery under pressure; even if it is firm it is never as dense as it should be.

It is standard practice to add water to each layer by means of the water cart.

Material Density

The density of soil is measured in terms of its volume and weight. This ratio is expressed as kilograms of wet soil or dry soil per cubic metre. It is also expressed as porosity in percent of total volume. A high porosity indicates a low density.

The term compaction refers to the act of artificially increasing the density of soil. It involves pressing the soil particles together into closer contact, and expelling the air or water from the spaces between them.

The purpose of compaction is to stabilize soil so that it will show minimum change in volume or shape under influences of weather and time, and under the weight of structures, pavement and traffic.

Testing

Performing tests on the material at different stages of the project is an important part of the construction project. During the estimation of the project the cost of these tests must be taken into consideration.

The most effective way of reducing the cost of testing is to reduce the number of re-tests. This means maintaining good control of the job, so that tests are required less frequently and the total number of tests over the duration of the project, each of which costs money, is reduced.

The properties of a soil aggregate or crushed rock paving material which affect its performance in a road are:

- Durability
- Strength and Stability
- Permeability
- Workability — compactability.

Soil aggregate or crushed rock paving material must have sufficient strength and stability and be capable of being compacted to a dense mat and finished to the correct profile.

As well as this the stone particles must be hard enough not to break down excessively during compaction and must not contain minerals which decompose chemically during the life of the pavement.

Types of Testing

Two types of testing are commonly used in civil engineering work:

- Control testing
- Acceptance testing

Control testing is carried out by the contractor's staff during the progress of work, to ensure that the materials and/or processes will meet the required standards.

Acceptance testing is the testing carried out by the owner's representative or the resident engineer to ensure that the finished work complies with the specification and drawings, before it is approved.

The results of the acceptance tests provide an accurate picture of the quality of the work performed on the construction project.

The following guidelines are applicable to sampling and testing tasks:

- Only use specified testing methods.
- Ensure tests are carried out to the specified degree of accuracy.
- Carry out tests promptly and at the proper time.
- Carry out tests without obstructing the other work.

Samples that are taken for testing should clearly identify the:

- Specific project
- Location on the job
- Type of material
- Name of the person who took the sample
- Method used for taking the sample
- Date and time
- Any other details specified in the sampling procedure or recording form.

Frequency of Testing

The frequency of testing should be as specified in the specification or local government standard. Normally, the frequency of testing is higher at the commencement of operations. The higher rate of testing is maintained only until it is established that the material is of even quality. After that, the frequency of testing is reduced, as the purpose of testing is only to confirm that the operation is continuing without significant change.

One test alone tells us nothing regarding the variability of a process. Always consider and look at the results of tests in groups.

In control testing, control charts provide both a simple and a convenient means of assessing the variability of a process.

Cost of Testing

The tests used in road construction are significantly expensive. Therefore it is important to always plan and carry out tests in the most efficient manner.

When estimating the cost of a test we must take into account the following costs:

- soil testing staff
- laboratory equipment used to perform the test
- laboratory technician performing the test
- materials testing consultant
- frequency of tests.

Rework/Retest

Control over a process can only be maintained if tests are performed as soon as each section of the process is completed. If a process starts to get out of control, it is necessary to take immediate action to prevent a significant amount of material falling outside specification limits.

Should reprocessing become necessary, the whole of the material produced from the time the operations got out of control must be reprocessed.

Note!

On contract works the contractor is normally responsible for process control.

Rework and retesting operations are additional costs to the project.

Estimating Plant and Equipment

For many earthmoving operations there are alternative equipment selections to consider. The object is to select the piece of equipment, or the combination of equipment that will produce the lowest overall cost per cubic metre.

Selection of Plant and Equipment

It is necessary to understand the characteristics of the various types of plant available, their applications and limitations to properly select and use plant.

When selecting plant and equipment it is necessary to ensure the machinery is capable of carrying out all tasks on the job. Select plant and equipment and ensure:

- the fleet is balanced as far a s possible
- there is sufficient plant to achieve the desired progress
- the plant fleet is flexible enough to avoid a major hold-up if one item of plant breaks down
- the right type of machine is used for each task
- each machine is of sufficient capacity to carry out the work effectively and efficiently.

Understand the application and limitation of each type of machine. Closely supervise the work to ensure the standard set out in the plans and specifications are achieved and that the work is economically carried out.

The table identifies the main types of machinery used in construction work and the applications to which each item is best suited:

Operation	Dozer	Loader	Grader	Scraper	Haul truck	Excavator	Skid-steer loader	Backhoe
Clearing	M					M		
Removal of overburden	M	P		P	P	M	P	P
Ripping	M	P	P					
Pushing								
Earthmoving (short haul, to 50m)	M	P	P	P	P	P	M	P
Earthmoving (long haul)	P	M		M	M			
Trimming	P	P	M	P		M	P	P

M = main use; P = possible use.

Applications of Earthmoving Plant

Fleet Size

Regardless of whether plant is sourced from a hirer or the company's fleet, decisions about the number and size of equipment items required for the job are mainly based on cost. Factors that will affect the decision include:

- Hire costs per hour
- Suitability for the job
- Plant availability
- State of repair
- Hourly output
- Costs of getting machines to the job and of returning them on completion
- Comparative hire costs of alternative machines
- Effect of hiring a particular machine on degree of usage of other items.

Because there are so many variables involved in deciding the numbers of machines to use, supervisors and contractors need to spend time and effort on evaluating all relevant factors, including site conditions that may make one type of machine more cost-effective.

Experience is valuable in making decisions about the optimum plant fleet for the job. For example, a supervisor who has worked with articulated dump trucks would be aware that that, in conjunction with an excavator, they may be a lower-cost option than scrapers on sites with long hauls and minimal haul roads or muddy conditions.

Alternatively, computer software packages that enable selection of a number of 'best options' are now available. Specialised advice is required before using this method.

Total cost and cost-effectiveness are the key factors. The best choice is the plant item that produces a unit of work at the lowest unit rate (e.g. $ per cubic metre) and, in conjunction with secondary plant, the lowest cost overall.

Productivity

Experienced supervisors are familiar with the output of the machines that they are in charge of on a construction project. However if this is not the case, it is possible to determine the out put of the machine from:

- field studies
- manufacturer's charts
- discussions with experienced operators.

There is a learning effect at the start of the construction operation that causes cycle times and costs to be higher than anticipated. Always take this time into account when performing estimation.

Always make allowances for special conditions that will affect the machine's performance. These are usually unfavourable and include:

- water
- mud
- cramped working conditions
- steep grades.

Favourable working conditions may include:

- expert operators
- light, easily dug soil
- rock with good fragmentation.

Production Measurements

There are three ways in which supervisors may determine production output. These include:

- job requirements
- machine production
- terms of cost.

Job Requirements

When measuring job requirements a supervisor may have to determine the amount of work to be completed on a per-day basis to complete the task.

For example, if a time schedule allows 200 working days to move 1 000 000 metres of earth the supervisor's earth-moving machines must move 5,000 metres each day on average.

Machine Production

The production of a certain machine is measured or estimated, to determine the number of such machines needed to meet the production required to complete the task.

In the previous example, if a scraper can move 1 000 metres of earth per-day under the conditions of the job, then the supervisor needs to keep five of the machines working each day to move the correct amount of earth for the job.

Cost of Production

The supervisor must also determine the cost of owning and operating the job equipment when estimating the price of a job. This allows conversion of total productivity figures into cost figures.

For example, if an excavator can load an average of 100 m^3 per hour after allowances for average delays, and all costs including operator costs are $500.00 per hour, then the loading cost is $5.00 per m^3.

To determine how long the machine is needed, divide the machine's total production into the volume of work. The same excavator above would take 1 000 hours to move 100 000 m^3 of dirt. This is equivalent to a years work, or $500 000 worth.

It is important to determine all 'hidden' expenses such as supervision, spotting, pit maintenance and incidental labour into each part of the job.

Machine Costs

When estimating the cost of the plant and equipment we must take into account of wear and tear on the machine as well as:

- tyre wear
- ground engaging tools
- fuel
- consumables
- down time
- maintenance.

Tyre Wear

Tyres represent an important part of the cost of construction equipment. They have several characteristics that make them difficult to fit into the same cost calculation as the rest of the machine.

The major operating expense of a tyre is its replacement. The actual cost divided by the number of hours it operates gives an hourly cost. However, many tyres reach an early and sudden end due to accidents or abuse. A realistic hourly cost for each tyre is calculated by adding up the life-time in hours of a large number of tyres, and dividing the total cost by the tyres by this figure.

Maintenance and repairs of tyres are assumed to cost approximately 15% of the replacement value of the tyre.

Fuel

Fuel costs vary with the power, type and condition of the engine, type and condition of equipment, type of work performed, and the grade of fuel.

Other factors that determine the price of fuel include:

- price of crude oil
- distance from the source
- quantities delivered
- seasonal demand
- imposed taxes.

Lubrication

There is considerable variation in lubricant prices and applications. In general the best quality and most suitable lubricant is the most economical regardless of its price per litre or kilogram. This is because the labour cost and the repair costs from wear and damage resulting from poor lubrication are vastly greater than the price difference.

Oil

Equipment manufacturers recommend that engine oil be changed at regular intervals. The intervals may vary from 75 hours to 200 hours in different makes and models.

The time between oil changes may be shortened due to dusty conditions or extreme temperatures. However, in some conditions, it is possible to lengthen the interval between changes; for example, if the work is light, the air is dust-free, or if heavy-duty filters are used.

In general, an allowance of three times the reservoir capacity per year will take care of two changes and losses by leakage or accident.

Grease

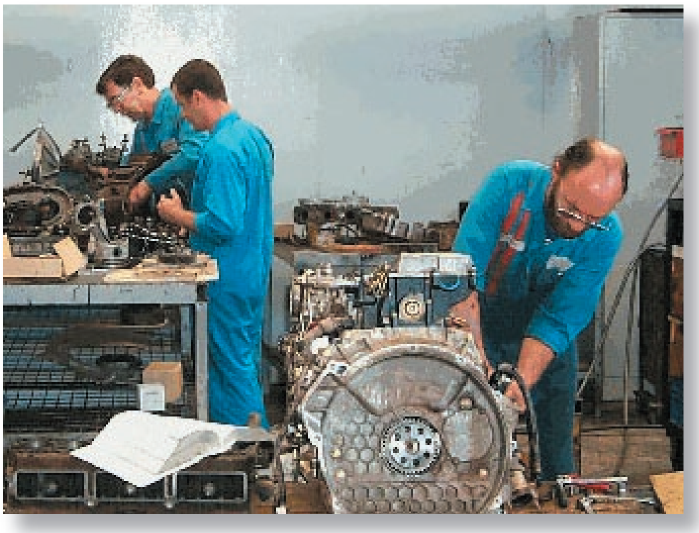
There are noticeable differences in the amounts of grease required for each machine. For example, an older model 20-tonne crawler tractor may use from one to five kilograms of grease every eight hours or less. A similar machine having positive seals may require lubricant in the rollers only at 1 000 hour intervals or when the rollers are rebuilt.

Records are the only indication of the amount of lubricant required for particular machines. Use the records to work out average requirements for the fleet.

Maintenance

Maintenance includes items such as:

- cleaning
- inspections
- adjustments
- routine replacements
- hard face
- welding.



Repair work involves replacement of defective or broken parts, together with adjustment or replacement of associated parts.

An overhaul involves thorough inspection and all necessary rebuilding of the entire unit.

Estimating Repairs

Supervisors must have a fairly accurate idea of the future cost of maintaining and repairing a machine. By keeping accurate records of past maintenance costs, supervisors are able to use them as a basis on which to allow for future expenses.

If there are no records, or if new equipment is so different that old records do not apply, cost estimates may be based on the manufacturer's recommendations for the particular operation and machine, or on records from other repairers, if available. (Such estimates may need to be adjusted to suit local conditions).

Down Time

Down time is the time during which a machine is unavailable for work on a specific job. Down time is often the result of bad weather, lack of work or the need of urgent repairs.

Equipment down time is often estimated to be between approximately 20% and 65% of working time. Age and condition of the machine and efficient fleet management are the most important factors in the variation of machine downtime.

Site Overheads

The costs of supervision, administration, and field set-up incurred during the course of construction are normally included as indirect costs. Typical indirect costs include:

- Foreman and other supervisors
- Clerical staff
- Engineering personnel
- Power
- Water
- Electrical services
- Site office
- Establishment costs.

There may be other charges that cannot easily be dissected and charged directly to the work item, but that are still part of the expenditure needed to construct the works. For example:

- Camp establishment
- Insurances, annual leave and payroll tax
- Floating plant and loose tools
- Wet weather and contingencies
- Transport of plant
- Off-site supervision
- Subcontractors.

Each company handles these costs in accordance with the relevant accounting principles for the item. In many cases, such items are included in the appropriate direct cost elements and are extracted from the relevant sections of the direct cost estimates. For example:

- Insurances, annual leave, payroll tax and wet weather are included in the labour cost estimate
- Floating plant and loose tools are included under the stores and temporary materials section.
- Transport of plant is a direct cost against the plant item and is included under the plant section.

- Subcontractor costs are included under the permanent materials section of the direct cost estimate.
- The element of supervision under foreman level, as well as field supervisor is included in the labour estimate.

Regardless of the type of work, it is important to manage costs associated with mobile equipment. The costs of leaving a machine idle are high and on-going. All supervisors must make decisions about plant: it should either be performing a productive role, or be en route to another job or activity.

The other important to realise about site overheads is that their nature changes with location. For example, a job near Innisfail in February or March is likely to include significant overheads from wet weather and annual leave costs; a job between Winton and Boulia at the same time will involve overheads arising from transport of plant and maintenance of the site compound.

General Overheads

Overheads include a wide variety of costs that may legitimately be added into the total costs of the job, even though they were not incurred on site. Items included in general overheads include fixed or portable plant that can be used elsewhere. General overheads will be added in accordance with the company's accounting procedures and must be allowed for when estimating overall costs of the job. Usually, the company will specify a percentage of the on-site costs. The following list of general overheads is not comprehensive.

- site compound
- photography
- accommodation
- water
- barricades and lights
- insurance
- fees
- petty cash
- site office
- office services
- protective clothing
- electricity
- telephone
- toilet
- small tool allowance
- plant transport
- building transport

- site vehicle
- site vehicle fuel
- engineer
- foreman
- labourer
- surveyor
- fuel (internal plant)
- fuel (external plant)
- concrete testing
- pavement testing
- WHS and PLS levy
- operations manager.

Section 2 – Assessment Activities

For information on how these assessment activities may be used as part of the learning process, see the section on 'Assessment' in the 'Topic Descriptor' section at the front of this topic.

Theory Questions

The following questions allow you to assess your progress in understanding the material presented in Section 2. The questions may be of any of the following types:

- multiple choice (identify correct answer or answers)
- multiple choice (identify incorrect answer or answers)
- fill in the gaps in a sentence or statement
- identify a sentence or statement as TRUE or FALSE
- write a few sentences or a short paragraph.

Answers to the question are shown in the separate 'Answer' section.

Question 1

Suppose that there is a big difference between the information given in a drawing and the relevant specifications. Which information should be used?

Question 2

List three hazards or risks and three local factors that may affect construction.

Question 3

What are the two stages of a job dissection? Discuss the purpose of each stage and anything that must be considered.

Question 4

What information is given in a process dissection?

Question 5

Describe how to calculate the area of a circle. How is this measurement used when calculating the volume of a cylinder?

Question 6

Answer the following information regarding curves:

What is the radius of a one-degree curve? The radius of a two-degree curve? How do you convert between degrees of curve and radius?

Question 7

Describe what is measured by vertical and horizontal alignment.

Question 8

What is the basic reference of location for a roadway? What construction lines are parallel to this feature?

Question 9

Calculate the volume of a stockpile (soil/gravel/sand/fill/etc) that is 3 metres long (along top of stockpile), 2 metres wide and 2 metres high.

Question 10

Describe what information is given by the long section, side profile and cross section of a road.

Question 11

The rate per man-hour is considered by contractors to be the actual cost of labour on a project. While it is easy to find out the man-hour cost of unskilled labour for a project, it is more difficult to estimate the man-hour cost of skilled labour. What factors makes this estimate more difficult to make? What factors affect the performance of skilled labour personnel?

Question 12

Define permanent materials and temporary materials.

Question 13

Define bulking and compaction. What factors affect how a material will bulk or compact? How is bulking and compaction expressed numerically?

Question 14

Answer the following questions relating to soil water content:

How does soil moisture affect calculations of soil volume?

Why is it expensive and difficult to adjust soil water content?

Why are soils that are too wet or dry difficult to manage?

Question 15

What are the two types of testing that need to be completed on-site? What is tested by each type of testing and who is responsible for conducting tests? When should each type of test be carried out?

Question 16

What should be considered when selecting plant for a project?