Topic 2

Case Studies

Contents

Case Study 1

The following pages show part of the documentation for a road construction job involving widening of part of an existing road and some sections of new construction.

The upper part of the drawing on each page is called the plan. This shows the location of the job, including such details as:

- Starting and finishing points
- Chainages
- Existing signs, culverts, embankments and cuttings.

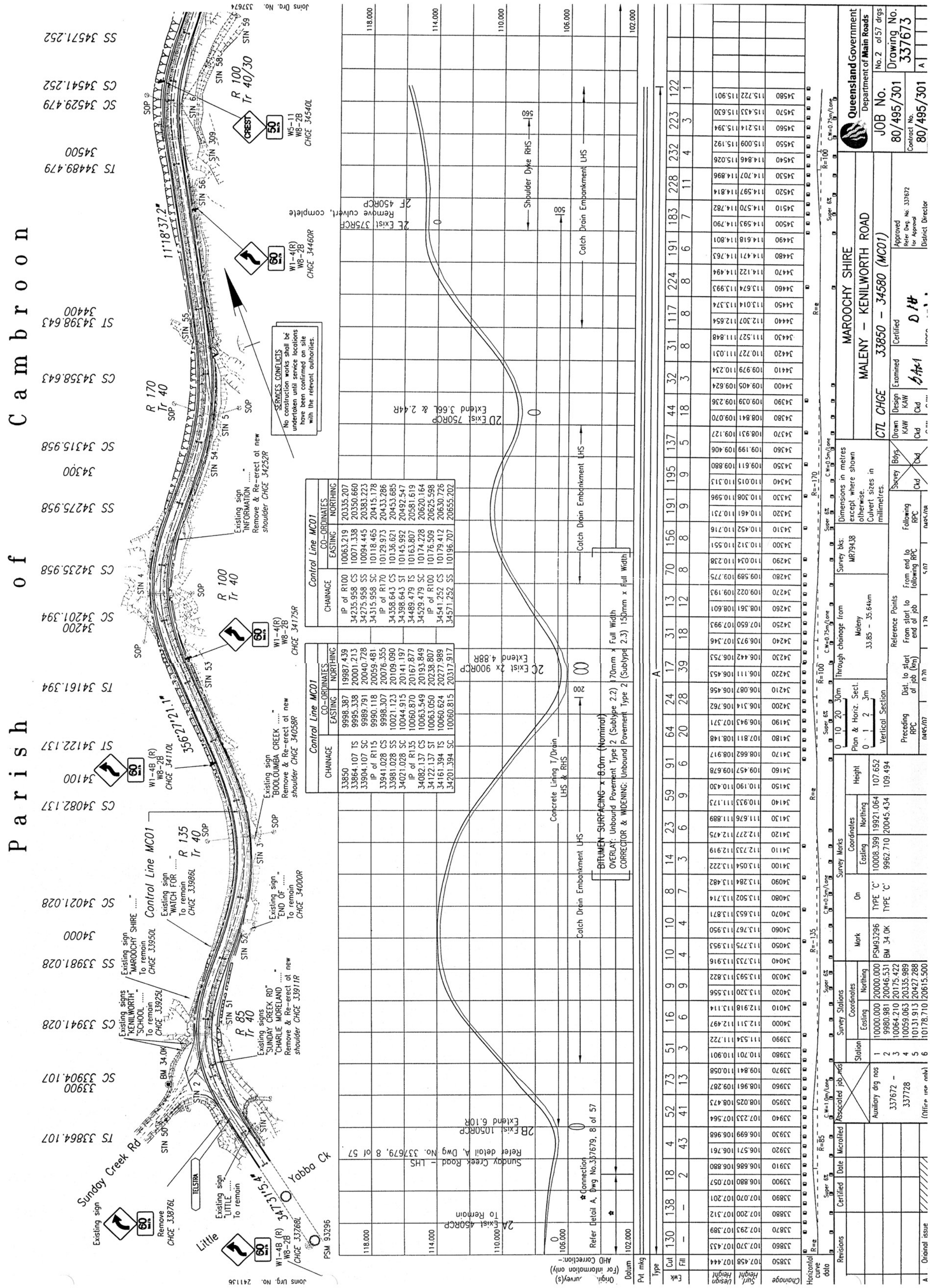
The lower part of the drawing on each page is called the section. This shows the rises and falls of the road as it climbs hills and crosses gullies. It also shows where cuts and fills will be required.

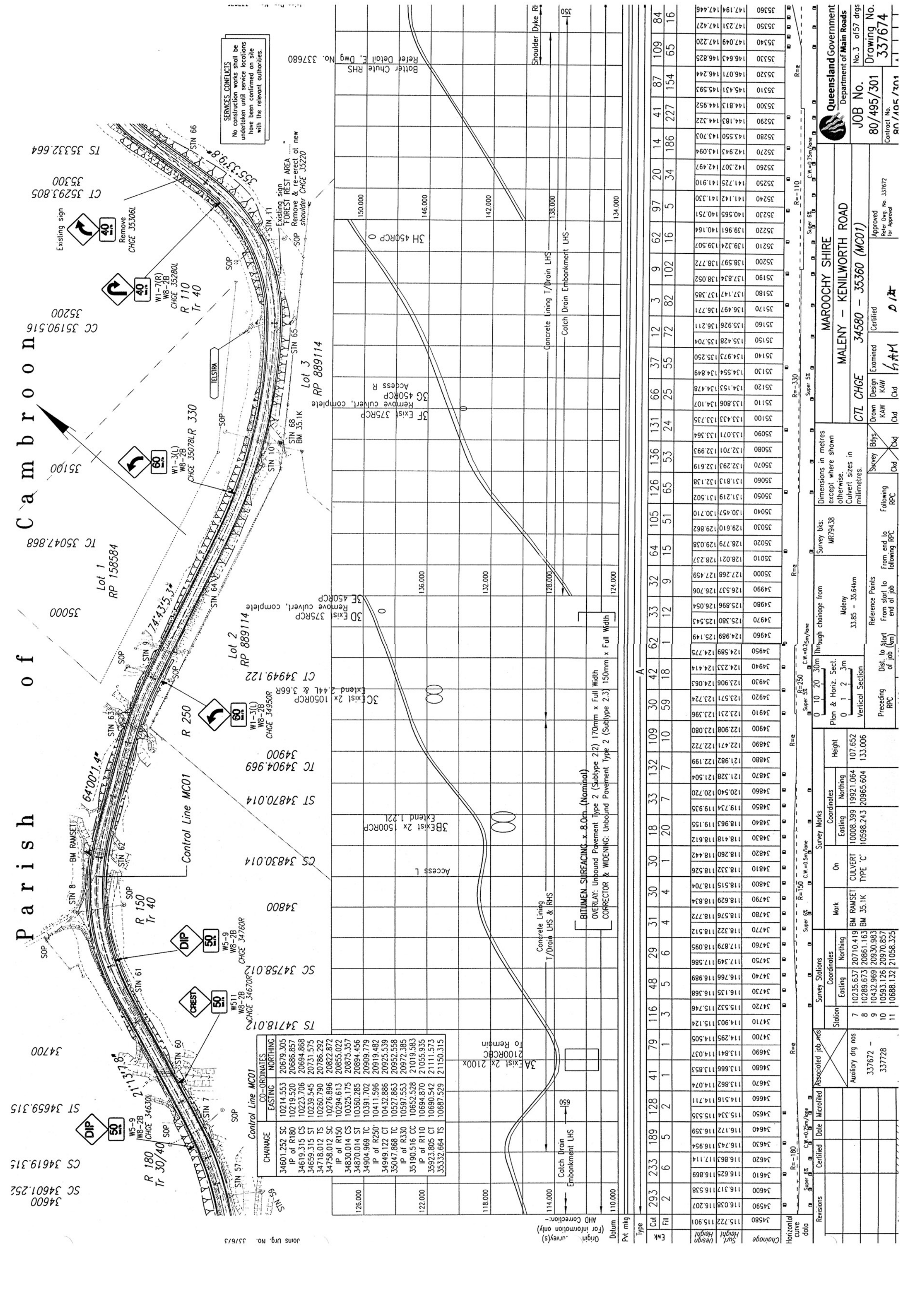
A table beneath the section shows:

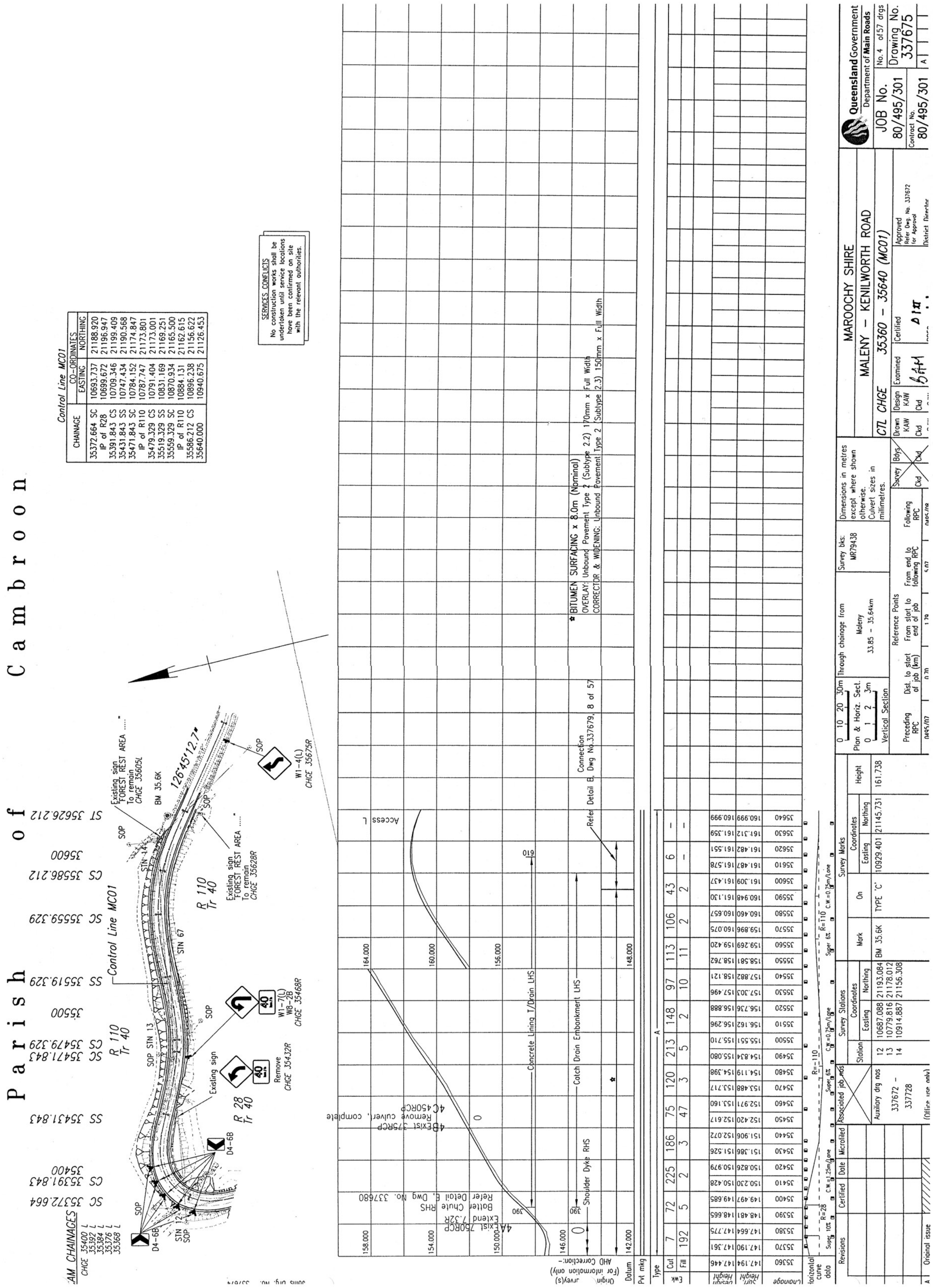
- the actual amounts, in cubic metres, of cut and fill required over each 10-metre length
- the existing and intended heights of the road at the centre point of each 10-metre length.

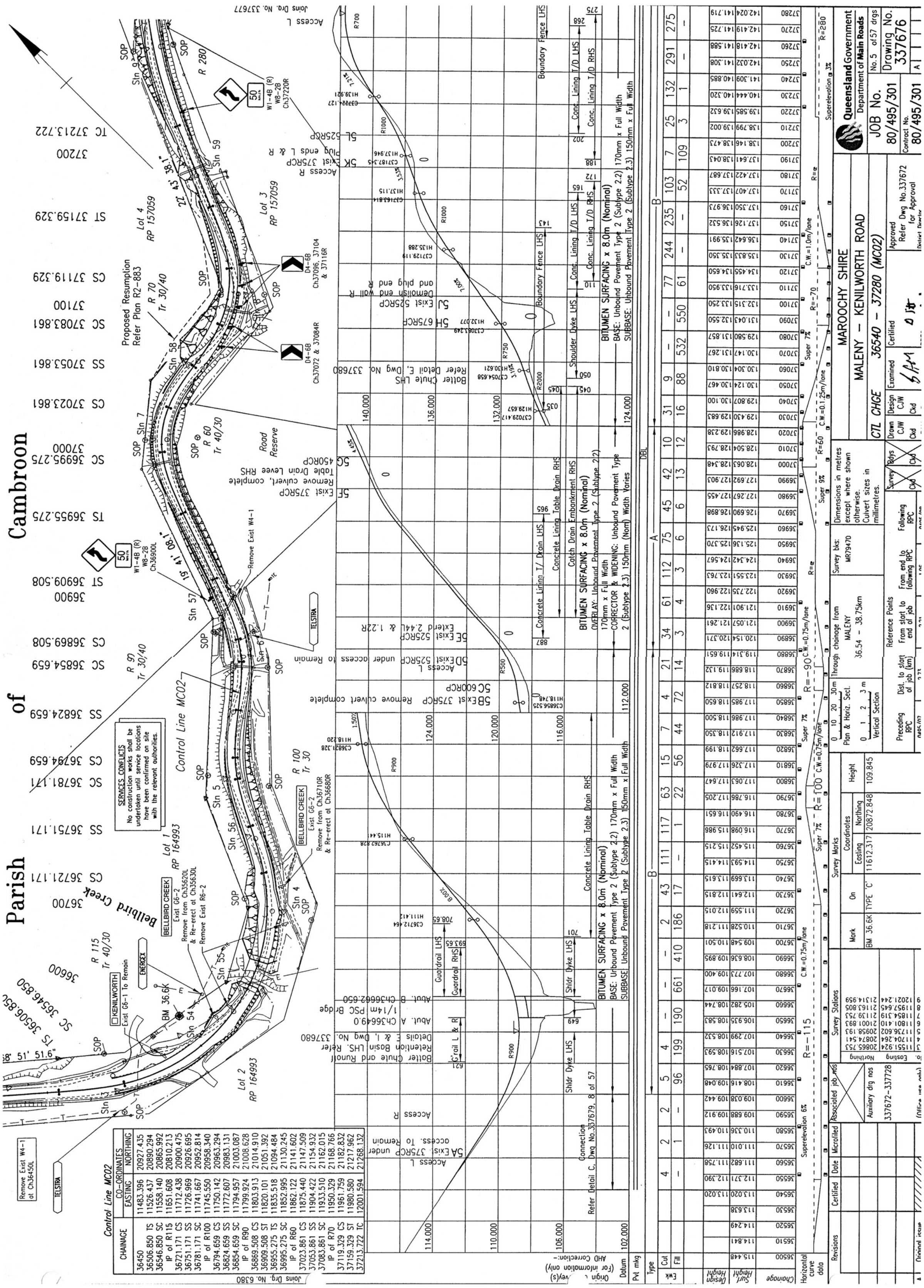
From the drawings provided, you should be able to identify:

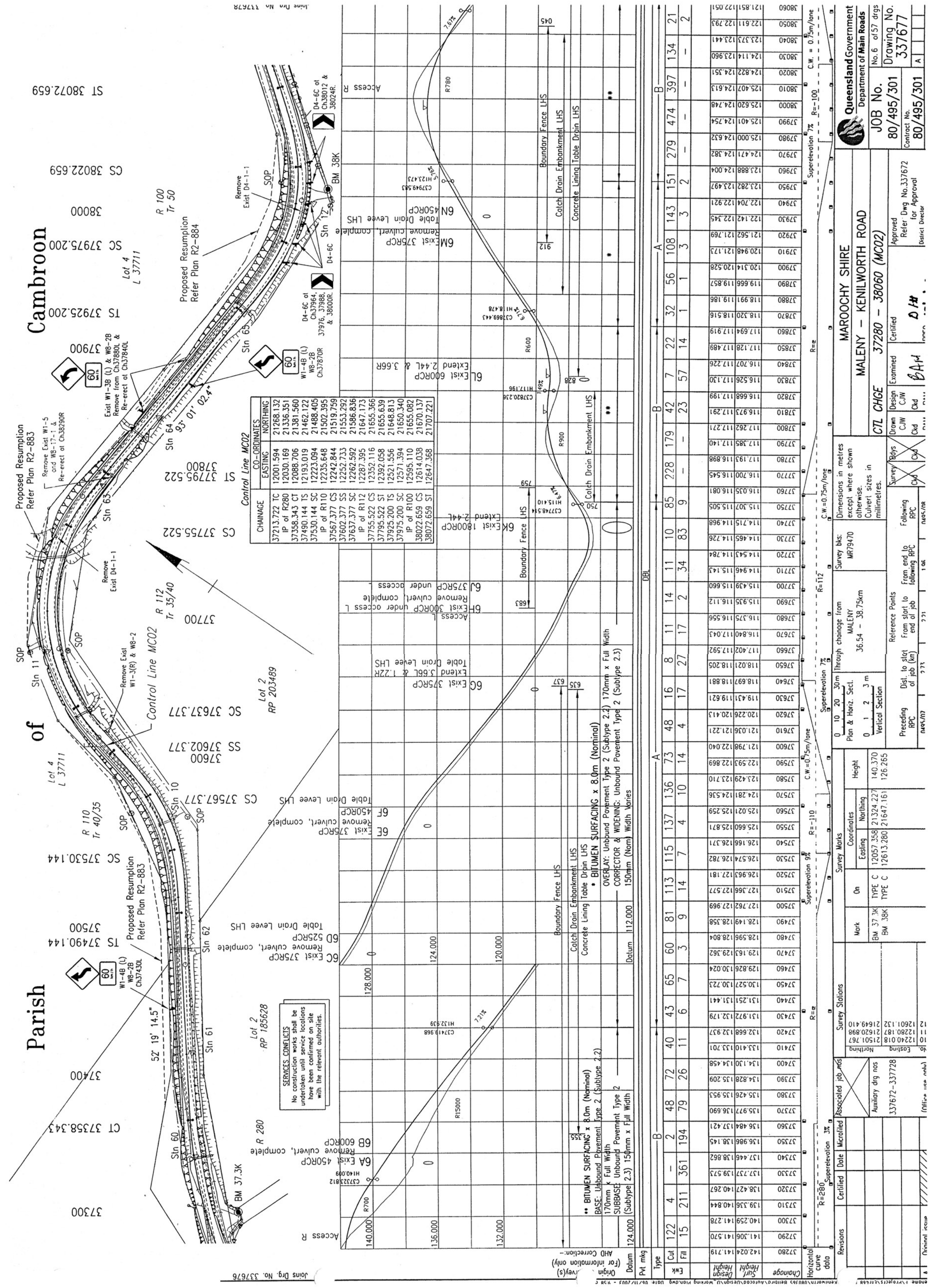
- The chainages at which the job starts and finishes
- The locations of major cuts and fills
- The location of bridge work
- The final locations of signs and guard rails.

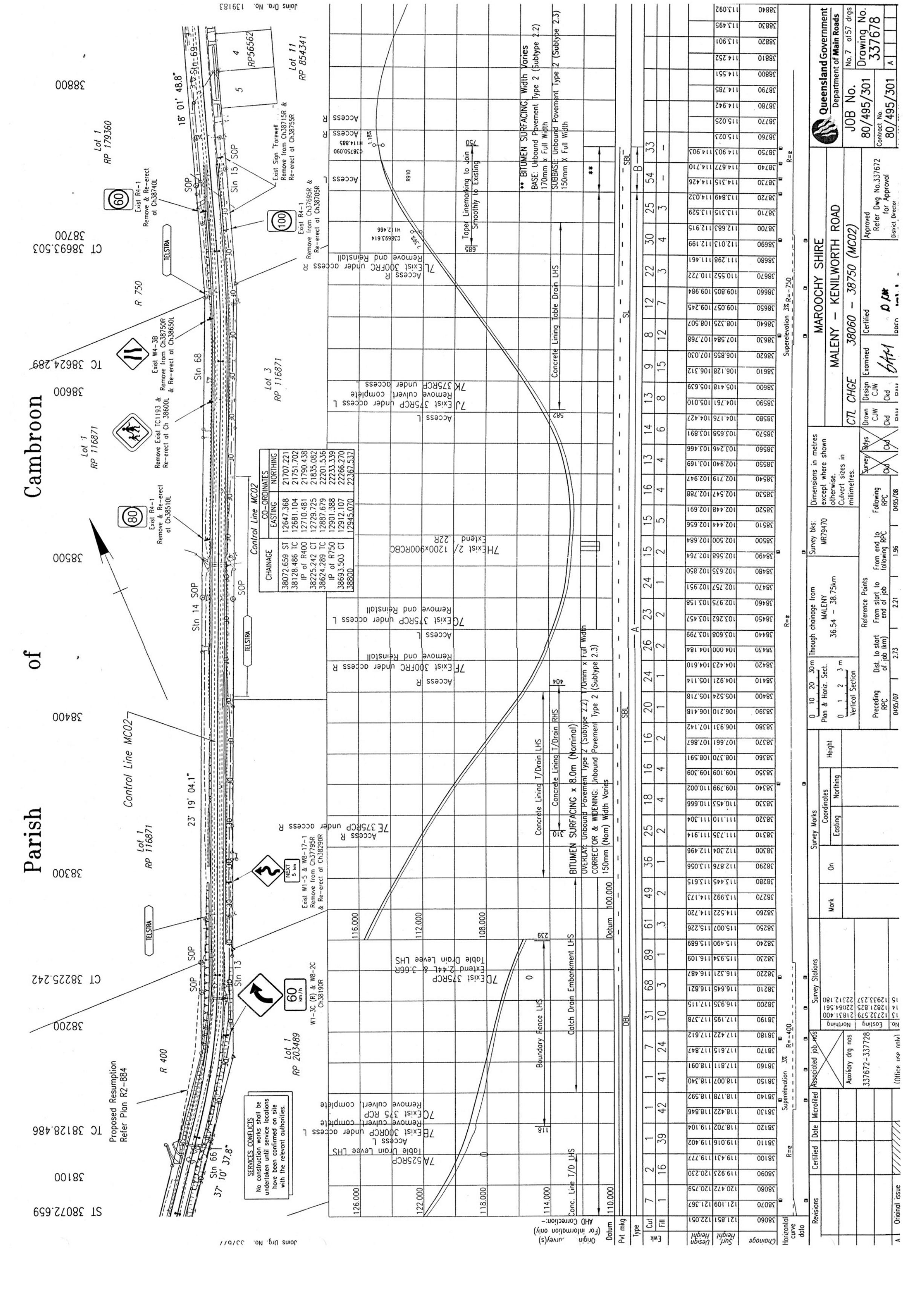

Parish of Cambroon
Control Line MC01
Sunday Creek Rd
Yabba Ck
SERVICES CONFLICTS
No construction works shall be undertaken until service locations have been confirmed on site with the relevant authorities.
Queensland Government
Department of Main Roads
MAROOCHY SHIRE
MALENY – KENILWORTH ROAD
CTL CHGE 33850 – 34580 (MC01)
JOB No. 80/495/301
Drawing No. 337673


Parish of Cambroon
Control Line MC01
Queensland Government
Department of Main Roads
MAROOCHY SHIRE
MALENY – KENILWORTH ROAD
CTL CHGE 34580 – 35360 (MC01)
JOB No. 80/495/301
Drawing No. 337674


Parish of Cambroon
MAROOCHY SHIRE
MALENY – KENILWORTH ROAD
Queensland Government
Department of Main Roads


Parish of Cambroon
MAROOCHY SHIRE
MALENY — KENILWORTH ROAD
36540 — 37280 (MC02)
Queensland Government
Department of Main Roads
JOB No. 80/495/301
Drawing No. 337676


Parish of Cambroon
Control Line MC02
MAROOCHY SHIRE
MALENY – KENILWORTH ROAD
37280 – 38060 (MC02)
Queensland Government
Department of Main Roads
JOB No. 80/495/301
Drawing No. 337677


Parish of Cambroon
MAROOCHY SHIRE
MALENY – KENILWORTH ROAD
Queensland Government
Department of Main Roads

Case Study 2

The table (below) shows how the rolling resistance of rubber-tyred vehicles changes according to the type of surface it is running on.

Type of Surface	Resistance per tonne wheel load	Per cent of gross vehicle weight
Hard, smooth gravel, loam or dry compacted soil. No flexing under load.	20 kg	2
Firm, smooth roadway with light revelling or light surfacing flexing when slightly under load.	33 kg	3.3
Uncompacted dirt roadway	50 kg	5
Rutted dirt roadway	75 kg	7.5
Moist sand	100 kg	10
Soft muddy roadway	100–200 kg	10–20
Dry sand	150 kg	15

If the all-up weight of a unit is 40 tonnes—

- On a hard, smooth loam surface, the rolling resistance would = 20 x 40 = 800 kg. This means that the machine has to supply 800 kg push to overcome the rolling resistance before it starts to do useful work.
- If the surface is a rutted, dirt roadway, the rolling resistance per tonne is 75 kg. Therefore the push required to overcome the rolling resistance, before any useful work can be performed,
  = 40 x 75 = 3000 kg.

This is 3.75, or almost four, times the push required on the hard, smooth loam surface.

—

Case Study 3

For each 1% increase in grade, a machine must overcome an additional 10 kg of resistance for each tonne of total machine weight. This relationship has been determined from field experience.

Using these figures, we can determine a grade resistance or assistance factor which is expressed in kg per tonne.

For a 1% grade, grade resistance factor = 10 x 1 = 10 kg

For a 5% grade, grade resistance factor = 10 x 5 = 50 kg.

These figures are per tonne. Therefore if the machine weighs 10t, the total additional weight to be overcome is:

For a 1% grade, total grade resistance factor = 10 x 1 x 10 = 100 kg

For a 5% grade, total grade resistance factor = 10 x 5 x 10 = 500 kg.

Case Study 4

A machine has to overcome a combined rolling and grade resistance of 4500 kg on a specific job. If the kilograms pull–speed combinations for this particular machine are as listed below, what is the maximum reasonable speed of the unit?

Gear	km/h	Rated rimpull (kg)
1	4.16	17 400
2	8.00	9075
3	13.00	5530
4	22.00	3260
5	36.00	1985

The operator would select third gear, since the rated rimpull is 5530 kg. The machine speed will be 13 km/h. The best selection is always the one that is closest to, but delivers more than, the required rimpull.

If the total power required was more than 5530 kg, the operator should select 2nd gear. The rated kilograms pull should always be used for gear selection. The reserve rimpull of the maximum rating is always available (though at reduced speed) to pull the unit out of small holes or bad spots, and to help the machine accelerate.

Case Study 5

Consider two job sites with differing soils and underfoot conditions. Assuming a rubber tyred scraper has a load of 40 tonnes on its driving wheels, what usable pull is available to haul its pay load where the road condition is:

(1) a smooth, dry hard surface

(2) wet clay and loam.

For the smooth, dry, hard surface— from the table, the coefficient of traction is 0.90.

Therefore useable pull = 0.90 x 40 tonnes

= 36 tonnes.

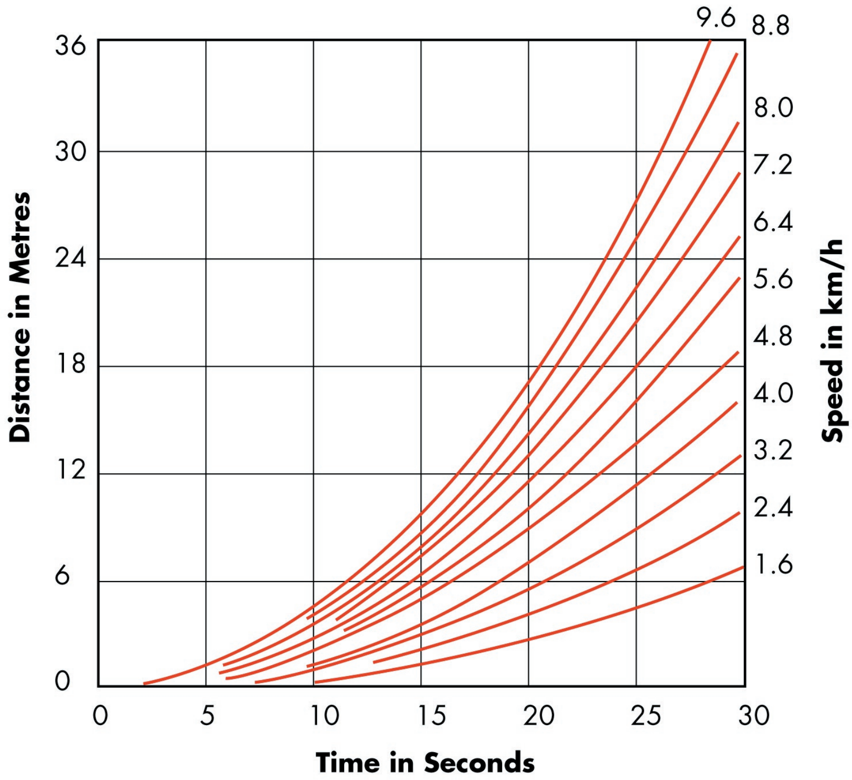
For wet clay and loam— from the table, the coefficient of traction is 0.45.

Therefore useable pull = 0.45 x 40 tonnes

= 18 tonnes.

This example clearly shows that the condition of the haul road, or poor site conditions, can greatly reduce the output of a machine.

Case Study 6



Distance Travelled in Fixed Time for Crawler Tractor Bulldozers

The graph shows the distance moved during the gear change and acceleration for a crawler tractor.

The graph includes a family of curves. Always read from the curve that represents the speed at which the dozer is travelling. For example, if a crawler tractor is travelling at 6.4 km/h (5th curve from the top), in a 20-second period it will travel approximately 11m.

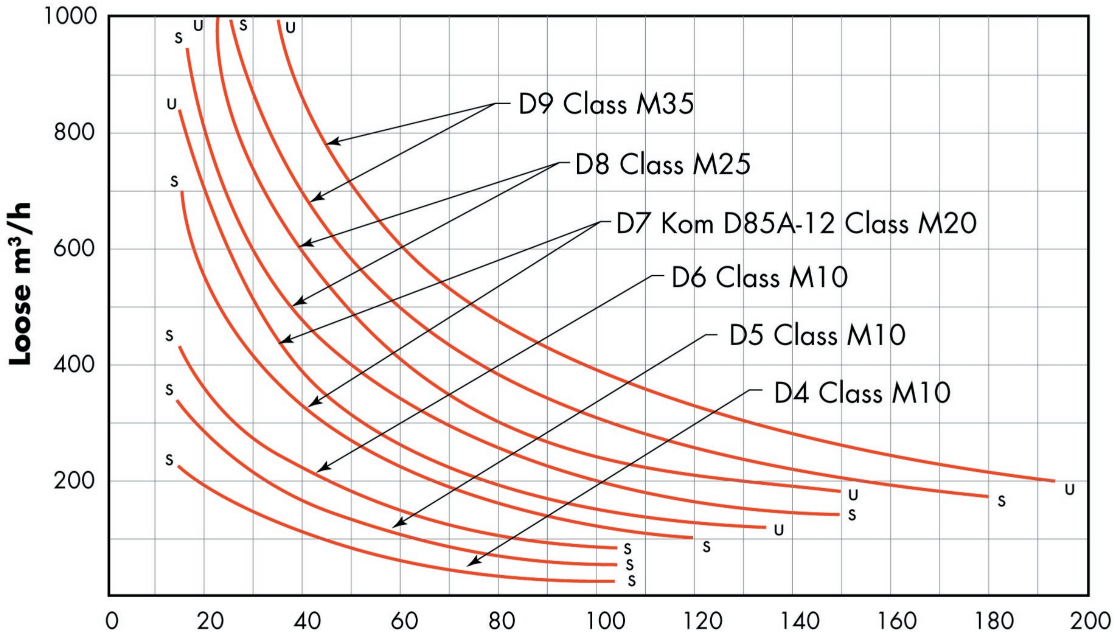
This figure is found by:

- following the 6.4 km/h curve down until it crosses the vertical line for 20 seconds
- reading across horizontally from the point where the two lines cross to the 'distance in metres' scale.

Case Study 7

Crawler tractor bulldozer production can be estimated using the production curves shown below and applicable correction factors. The following formula is used:

Production = Maximum production x Correction factors (loose m^3/h)



Estimated Crawler Tractor Dozing Production—
Universal (u) and Straight (s) Blades

For dozers of classes M35, M25 and M20, there are two curves— one for a straight blade (s) and one for a universal blade (u).

The bulldozer production curves above show only uncorrected production, and are based on the following operating conditions:

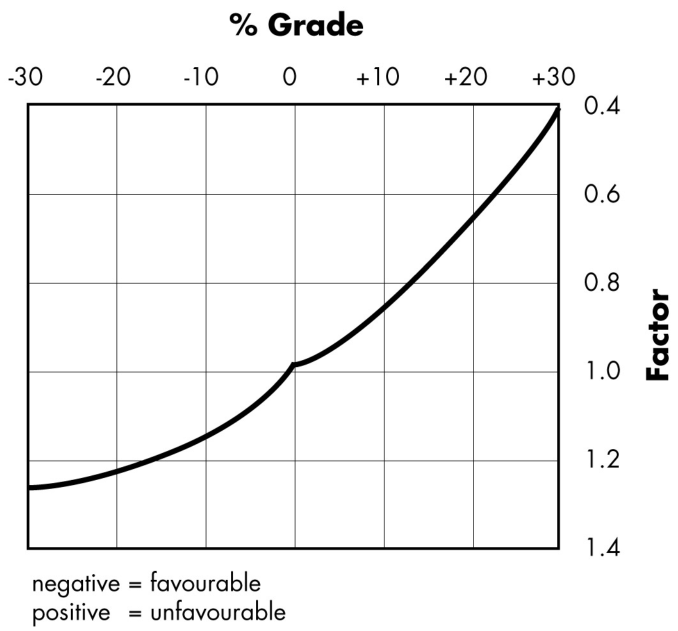
1. 100% efficiency
2. Power-shift machines with 0.05 min fixed times.
3. Machine cuts for 15m, then drifts blade load to dump over a wall.
4. Soil density is 1370 kg/loose m^3 (equivalent to 1790 kg/bank m^3), swell is 30%, and load factor is 0.77.
5. Coefficient of traction is 0.5 or better.
6. Blades are hydraulically controlled.

When you read a production figure from one of the production curves, you then need to multiply the uncorrected amount by a correction factor, as shown in the following table, to obtain corrected production in loose m^3/h.

Job condition corrections	Track-type tractor	Wheel-type tractor
Operator		
— excellent	1.00	1.00
— average	0.75	0.60
— poor	0.60	0.50
Type of material		
Loose stockpile	1.20	1.20
Hard to cut (i.e. hard dry clay)		
— with tilt cylinder	0.80	0.75
— without tilt cylinder	0.70	—
Hard to drift, 'dead' (dry, non-cohesive material or very sticky material)	0.80	0.80
Rock, ripped or blasted	0.60–0.80	—
Slot dozing	1.20	—
Visibility — dust, rain, fog or darkness	0.80	0.70
Job efficiency — 50 min/h	0.83	0.83
— 40 min/h	0.67	0.67
Grades — see following graph.		

Correction Factors for Dozer Production

As shown, correction factors for grade are read from a separate graph.



Grade Correction Factors

The corrected production figures are in loose m^3/h. To obtain estimated production in bank cubic metres, apply the appropriate load factor to allow for the decrease in the density of the material from its natural state to the loose state. This means multiplying the production in loose cubic metres per hour by the load factor—

Production (bank m^3/h) = Production (loose m^3/h) x Load factor

Case Study 8

A pavement is1500 m long. If it takes 6 passes of the grader to mix the gravel, binder and water, how long does it take to carry out this operation over the full 1500m length if the length of passes is 150m and 1500m?

Calculation for Passes of 150m

No. of 150m long passes required to mix 1500m of paving material $= 6 \times \frac{1500}{150} = 60$

From previous example, time taken for one pass 150m long = 2.30 min.

Total mixing time = Number of passes x cycle time

= 60 x 2.30 min

= 138 minutes

Calculation for Passes of 1500m

No. of 1500m passes to mix 1500 m of paving material $= 6 \times \frac{1500}{1500} = 6$

From previous example, time taken for one pass 1500 m long = 18.5 min.

Total time taken = Number of passes x cycle time

= 6 x 18.5 min

= 111 minutes

Time saved by mixing in 1500m length of pass = 138-111 min

= 27 minutes

$$\text{Percentage saving in time} = \frac{\text{time saved}}{\text{longest time}} \times 100$$

$$= \frac{27}{138} \times 100$$

$$= 19.6\%$$

Case Study 9

Decision to Turn or Reverse

If the time taken for a grader to turn is 0.5 min and it can reverse at a speed of 14 km/h, would it be quicker to turn or to reverse where the length of pass is 40 m?

$$\text{Travel time in reverse over 40m} = \left(\frac{L}{S} \times \frac{60}{1000}\right) \text{min}$$

$$= \left(\frac{40}{14} \times \frac{60}{1000}\right)$$

$$= \underline{0.17 \text{ minute}}$$

As the turning time is 0.50 min., there is a saving of 0.33 min (i.e. 20 sec) if the grader is reversed.

Case Study 10

Area Calculation

The job involves pouring a concrete slab for a shed 6.1m long x 2.75m wide. The slab must extend beyond the outer edge of the shed by 300mm all round. What is the overall area of the slab?

Three hundred millimetres is 0.3 of one metre (300/1000 = 0.3). The extra 0.3m forms a border right around the basic area of 6.1m x 2.75m and therefore applies to both sides of both the length and width of the slab. We therefore add the extra 0.3m twice to the length and twice to the width. The overall dimensions of the slab are:

Length = 6.1 + 0.3 + 0.3 = 6.7m

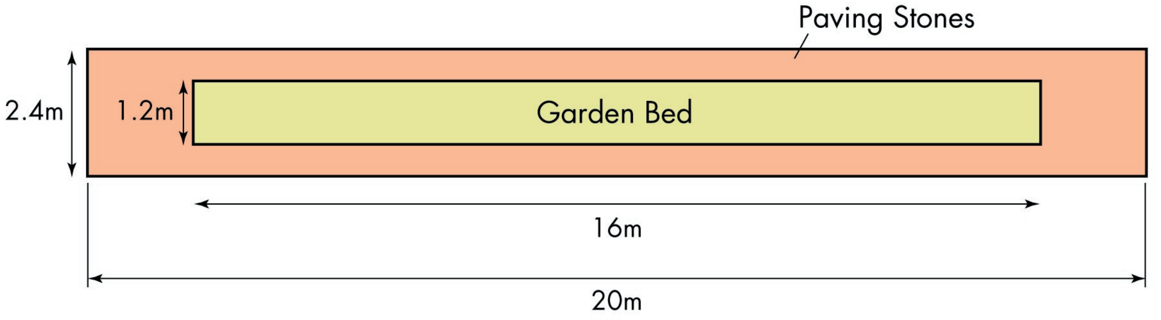
Width = 2.75 + 0.3 + 0.3 = 3.35m

Area = 6.7m x 3.35m = 22.445 square metres.

Case Study 11

Area Calculation

On a road job, there is a median strip 20m long by 2.4m wide. We need to cover the area with paving stones 200mm square, except that an inner area 16m x 1.2m will be garden bed. How many paving stones will be needed and what area will they cover?



The area of each paving stone is 0.2m x 0.2m = 0.04 m^2.

The overall length is 20m. This is equivalent to 20/0.2 = 100 paving stones long.

The overall width is 2.4m. This is equivalent to 2.4/0.2 = 12 paving stones wide.

If the whole area were to be covered with paving stones, we would need 100 x 12 = 1200 paving stones.

However, the length of the garden-bed area is 16m. This is equivalent to 16/0.2 = 80 paving stones long.

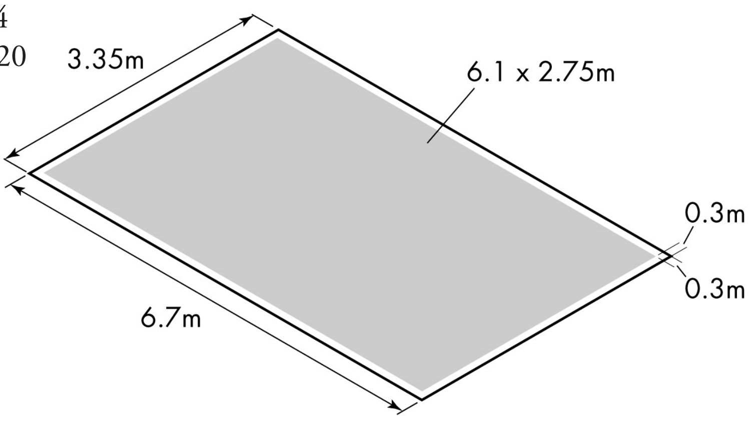
The width of the garden-bed area is 1.2m. This is equivalent to 1.2/0.2 = 6 paving stones wide.

The number of paving stones not laid because of the garden bed is 80 x 6 = 480.

The actual number laid is therefore: 1200–480 = 720.

As each paving stone covers 0.04 m^2, the area covered by pavers is 720 x 0.04 = 28.8 m^2.

If we know the cost per m^2, we can work out the total cost of the paving stones.



Case Study 12

Area Calculation

A roundabout is being constructed at a town-centre intersection. The roundabout has an outer concrete edging 100mm wide and an inner diameter of 3m. What is the total area of the circle?

The inner circle has a radius of 1.5m (i.e. half the diameter). When we add the extra 0.1m for the edging, the radius becomes 1.6m. Therefore:

Area = πR^2 = 3.1416 x 1.6 x 1.6 = 8.042496, or about 8.04 m^2.

Alternatively, we can work out the area by using the diameter. It will be 3.0m + 0.1m +0.1m or 3.2m. Therefore:

Area = $\pi D^2/4$ = 3.1416 x 3.2 x 3.2/4 = 8.042496, or about 8.04 m^2.

Case Study 13

Volume Calculation

In Case Study 12 there was an area 16m x 1.2m within a median strip that was to become a garden bed. We need to fill this space with loam to a depth of 0.6m, to enable establishment of shrubs as part of a town beautification project. The soil must be level with the top of the garden bed after settlement. The loam will be supplied dry. How much loose dirt do we need to deliver to the site?

The final volume of loam needed to fill the void for the garden bed is calculated as:

16m x 1.2m x 0.6m = 11.52 m^3

However, we need to actually place more than this amount of loam, to allow for settlement. The load factor for dry loam is 0.8. Therefore the loose volume needed is:

11.52/0.8 = 14.4 m^3

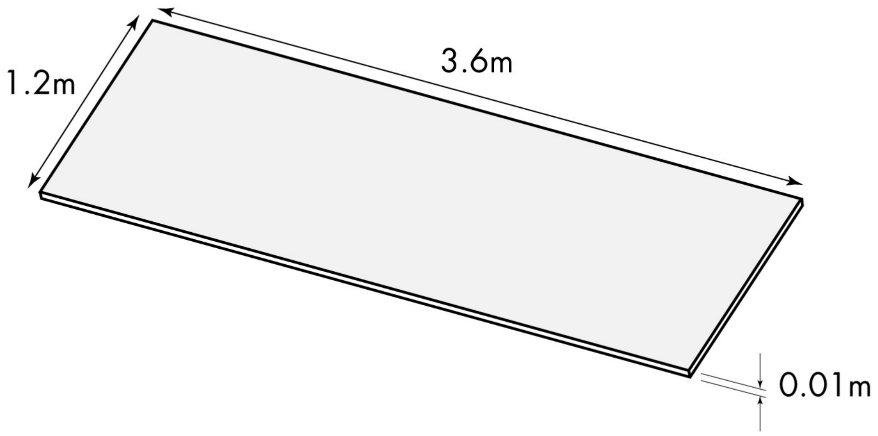
Case Study 14

Steel Plate

A steel plate is 3.6m long by 1.2m wide and 10mm thick. How much steel does it contain?

A steel plate is simply a solid, rectangular shape with a shallow depth. Ten millimetres is 10/1000 = 0.01m. Therefore the volume of steel is:

3.6m x 1.2m x 0.01m = 0.0432 m^3



Case Study 15

Concrete Pipe

A concrete pipe has an outer diameter of 500mm and the walls are made of concrete 25mm thick. Its length is 3.6m. What is the volume of concrete in the pipe?

A long, round shape with a constant thickness along its length is known as a cylinder.

To work out the volume of concrete, we need to subtract the volume of the cylindrical void from the volume of the overall cylinder shape.

We calculate the volume of the cylinder as the area of the circle at the ends of the cylinder, multiplied by the length of the cylinder. In this case, the overall volume is:

$V_1 = \pi D^2 L/4 = 3.1416 \times 0.5 \times 0.5 \times 3.6/4 = 0.70686\ m^3$

To find the volume of the void, we subtract twice the thickness of the wall from the cylinder's outer diameter. Therefore:

Inner diameter = 500–25–25mm = 450mm = 0.45m

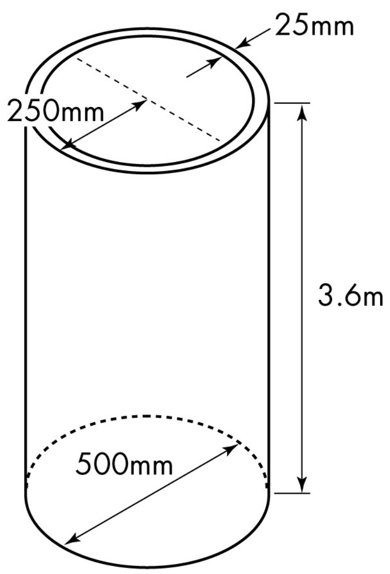
The volume of the void is:

$V_2 = \pi D^2 L/4 = 3.1416 \times 0.45 \times 0.45 \times 3.6/4 = 0.5725566\ m^3$

The difference between V_1 and V_2 is the volume of concrete contained in the pipe:

$V_1 – V_2 = 0.70686 – 0.5725566 = 0.1343034\ m^3$

The answer is about 0.13 of a cubic metre.



Alternatively, we may calculate the volumes of the cylindrical void and the overall cylinder shape by using half the diameter, or radius (plural: *radii*). The radii are:

Overall cylindrical shape: 500/2 = 250 mm = 0.25 m

Cylindrical void: 250–25 = 225 mm = 0.225 m

Volume of overall cylindrical shape—

$V_1 = \pi R^2 L = 3.1416 \text{ x } 0.25 \text{ x } 0.25 \text{ x } 3.6 = 0.70686 \text{ m}^3$

Volume of cylindrical void—

$V_2 = \pi R^2 L = 3.1416 \text{ x } 0.225 \text{ x } 0.225 \text{ x } 3.6 = 0.5725566 \text{ m}^3$

The difference between V_1 and V_2 is the volume of concrete contained in the pipe:

$V_1 - V_2 = 0.70686 - 0.5725566 \text{ m}^3 = 0.1343034 \text{ m}^3$.

This is the same (0.13 m^3) as the result obtained by using the diameter.

Case Study 16

Earthworks are an important and time-consuming activity on most projects. Often, good earthworks are the difference between making and breaking a project. This is why both the job supervisor and earthworks foreperson will usually work together to pool their knowledge and experience when planning this stage of the project.

Here are some of the main questions that should be considered when planning earthworks. We will deal with each within this example:

- What is the scope or extent of the work?
- What material is being dealt with (for example, soil type and rock locations)?
- What activities are required to complete this task?
- What other activities may affect this activity (for example, survey and drainage)?
- What plant is available?
- What plant and equipment is to be used?
- How long will the work take?

Scope / Project Review

Plans

The first step is to review the plans to gain an understanding of the work.

Drawings 1 and 2 (see section 3) show the extent of the earthworks. We can see that the scope of the works is a two-lane, two-way road on a new alignment— from chainage 16 350 to 17 850, a total of 1.5 kilometres.

The long section in Drawing 2 shows that the project is mainly downhill (from left to right). This is important, because working downhill is easier and quicker, and we can use this to advantage when planning the movement of earth. Brown, gravelly soil covers the whole area and there are no identified rocky outcrops. (On many jobs, rocky outcrops are a reminder to look for rock and to work out its effects on plant requirements for the job).

The highest fill is about 5 metres and occurs at chainage 16 750; the deepest cut is about 5.5 metres, at chainage 17 100. There is an old quarry site located roughly in the middle of the project. The quarry could be of use as a possible source of material or as a possible location for spoil; it could also show the sub-layers below the surface and the presence of rock.

It is also useful to be aware of culvert locations and the method of culvert installation (embankment or trench). For culverts constructed by either method, heavy earth-moving operations cannot proceed too close to these locations until the culvert construction and backfilling is complete. Some culverts, built at or about ground level, can also be built as per the trench method. This means that the earthworks are built up to a defined level and the culvert is trenched into the embankment. Culvert construction will affect progress of the earthworks and has to be considered in conjunction with the timing of earthwork activities.

Another point to consider is the location of private entrances, turnouts and intersections. Although this example does not include any of these, in other projects they may play a part and will therefore need to be considered in planning the earthworks. Where they occur, the issues private entrances, turnouts and intersections include earthworks and drainage requirements, increased difficultly to shape or form the turnout, traffic control and the need to allow and manage access.

Soil and Geotechnical Information

After reviewing the plans, it is worth checking with the job supervisor as to the availability of soil or geotechnical information. In many cases, results are available from soil testing; some areas have been subjected to a full geotechnical investigation.

The soil tests or results of the geotechnical investigation are valuable in that they can provide answers to questions, such as:

- What are the load and compaction factors (see later)?
- Are the soils to be excavated suitable to use as embankment material, or do we need to source, win and haul material from elsewhere?
- Is rock present? If so, where? Is it rippable or not?
- Where is the watertable?

The location of the watertable may not seem important, but if it is too close to the surface where embankment material is being placed, it can cause bogging of equipment, or may affect compaction operations. Seepage and slope failure may occur when the ground is cut close to the watertable. Most of these problems should have been dealt with as part of the design; however, it is important for the job foreman to be aware of and prepared for issues such as these.

Background Information

For the purposes of this example, the following assumptions are made:

- The whole site consists of brown gravelly soil, and is easily winnable.
- Soil testing results show that the soil is at 90% of Maximum Dry Density (MDD) in its bank (or natural, in-ground) state and 85% of MDD while in the loose state.
- The soil is suitable for use in embankments.
- Rock and acid sulphate soils are not present within the boundaries of the project.
- The watertable is well below proposed works and is unlikely to cause any issues.
- All clearing, grubbing and ground surface-treatment operations are now complete.
- Sufficient drainage activity will be completed to allow earthworks to commence.
- All required survey work to peg the batters, etc will be completed by the time the earthworks commence.

Note!

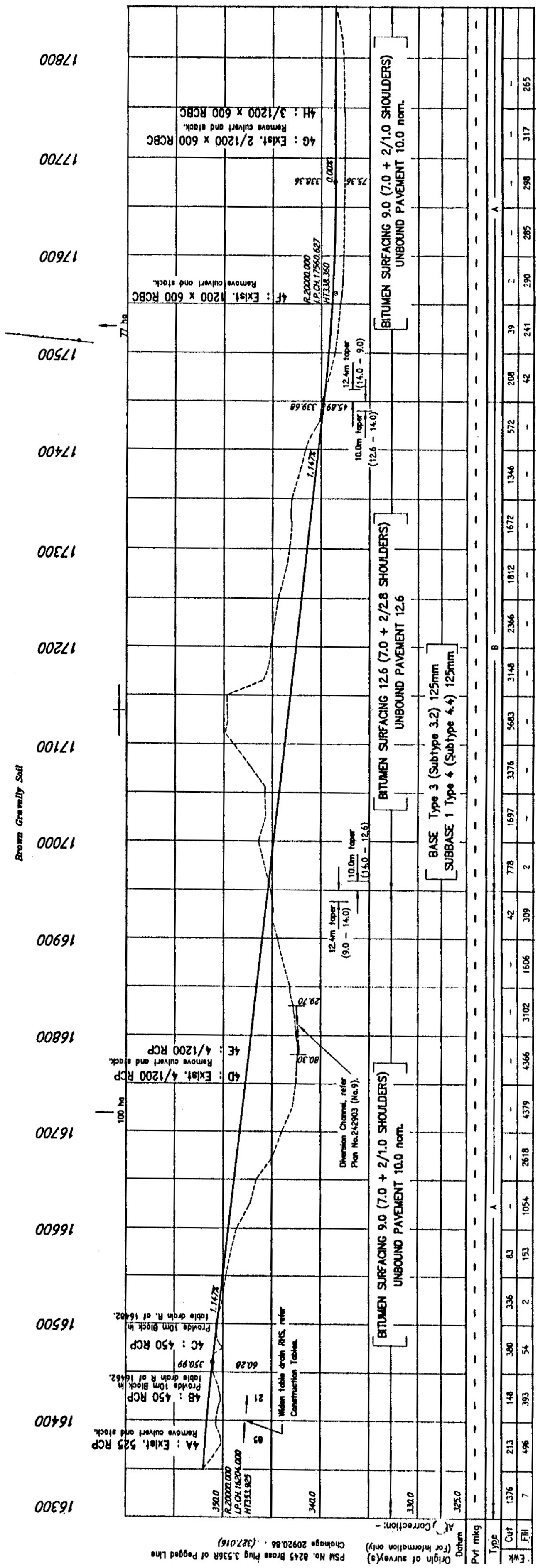
Maximum Dry Density is used in this example to determine bulking and compaction of material. This is slightly different to using straight swell and loading factors as discussed within the text of this topic (see Section 2).

Project Quantities— Earthworks

The following discussion shows how to calculate the overall quantities of earthworks required for the project.

The quantities of earthworks given in the project estimate usually cover all aspects of the project (total cut volumes and total fill volumes) and therefore may not be useful for planning the main earthworks activity.

In this example, the earthworks start at chainage 16 350 and extend through to chainage 17 850. Using the earthworks tables below the long section (see below), we can determine the amount of cut and fill that is required along the control line. By adding the quantities for the fifty-metre sections listed in the 'Cut' and 'Fill' rows of the table, we can estimate the total quantities for the project. These quantities relate to the material in its 'bank' state for cuts and 'compacted' state for fills. These volumes are the ones used in the estimate and are what payment is based on.


16300
16400
16500
16600
16700
16800
16900
17000
17100
17200
17300
17400
17500
17600
17700
17800
Brown Gravelly Soil
4A : Exist. 525 RCP
Remove culvert and stock.
4B : 450 RCP
4C : 450 RCP
4D : Exist. 4/1200 RCP
Remove culvert and stock.
4E : 4/1200 RCP
4F : Exist. 1200 x 600 RCBC
Remove culvert and stock.
4G : Exist. 2/1200 x 600 RCBC
Remove culvert and stock.
4H : 3/1200 x 600 RCBC
Widen table drain RHS, refer Construction Tables.
Diversion Channel, refer Plan No.242903 (No.9).
100 ha
77 ha
12.4m taper (9.0 - 14.0)
10.0m taper (14.0 - 12.6)
10.0m taper (12.6 - 14.0)
12.4m taper (14.0 - 9.0)
BITUMEN SURFACING 9.0 (7.0 + 2/1.0 SHOULDERS)
UNBOUND PAVEMENT 10.0 nom.
BITUMEN SURFACING 12.6 (7.0 + 2/2.8 SHOULDERS)
UNBOUND PAVEMENT 12.6
BASE Type 3 (Subtype 3.2) 125mm
SUBBASE 1 Type 4 (Subtype 4.4) 125mm
BITUMEN SURFACING 9.0 (7.0 + 2/1.0 SHOULDERS)
UNBOUND PAVEMENT 10.0 nom.
Datum
Pvt mkg
Type
Cut
Fill
Ewk

The results are:

Cut

Ch. 16 350 to 16 600	= 1 160m^3
Ch. 16 900 to 17 600	= 22 741m^3
Total Cut	= 23 901 bank m^3
	(Bank state = 90% MDD)

Fill

Ch. 16 350 to 17 000	= 18 534m^3
Ch. 17 450 to 17 850	= 1 888m^3
Total Fill	= 20 422 compacted m^3
	(Compacted state = 100% MDD)

To determine whether there will be enough material for the earthworks, we will need to convert the bank (natural ground) volume of material to the equivalent 'compacted' volume (i.e. 100% of MDD).

The brown gravelly material for this site is at 85% of MDD while in its loose state and at 90% of MDD in the bank state.

To obtain a more accurate idea of the quantity of loose material to be transported and stockpiled, we add another five per cent to the total bank volume (90 – 85% = 5%; this is a positive figure, so we add). We add the five per cent because the material swells when it is disturbed. It is now 105% of its original volume:

105% of 23 901m^3 (1.05 x 23 901) = 25 096 loose m^3

But do we have enough material to do the job? Firstly, we need to convert our 'loose state' volume to a 'compacted state' volume. To work this out we would take away ten per cent from the total bank volume (90 – 100% = –10%; this is negative so we reduce). When compacted properly, the material will only take up 90% of its original volume.

90% of 23 901 m^3 (0.9 x 23 901) = 21 511 compacted m^3

This is more than the total fill volume of 20 422 compacted m^3.

To determine whether there will be enough material to complete the earthworks without importing material, we deduct the total fill required from the total material available. (Both of these quantities are now compacted volumes).

21 511 m^3 – 20 422 m^3 = 1 089 m^3

This volume is positive; therefore we have more material than required. If the volume was negative, we would need to import material.

Since we have excess material or spoil, we will have to either stockpile this or remove it from the site. The volume stockpiled or transported will be in a loose state; we therefore need to convert the figure of 1 089 m^3 (100%MDD) to loose (85% MDD). This means adding another fifteen per cent (100 – 85% = 15%) to the compacted volume. (This increase is equivalent to a bulking factor of 1.15).

115% of 1 089 m^3 (1.15 x 1 089) = 1 252 loose m^3

This information helps us to understand the overall quantities for the earthworks activity. However, to calculate plant requirements and timings we need to look more closely at the project, to determine what earth needs to be moved and where it must end up.

Analysing Earthworks in Sections

By referring to the long section in Drawing 2, we can visually divide the project into four sections:

Section 1 / Ch. 16 350 – 16 550, looks like fill with a bit a cut

Section 2 / Ch. 16 550 – 16 950, appears to be mainly fill

Section 3 / Ch. 16 950 – 17 450, appears to be all cut

Section 4 / Ch. 17 450 – 17 850, appears to be mainly fill.

By using these sections and the quantities in the Cut and Fill rows of the drawing, and by calculating bulked up and compacted volumes, we can start to get a better understanding of the movement of earth that will be required.

Section 1

Section 1 includes the 200 m from Ch.16 350 to Ch. 16 550. The table shows the required cut and fill volumes, calculated by:

- Adding the individual volumes from the cut and fill rows along the bottom of plan
- Calculating loose volume (multiply cut volume by 1.05)
- Calculating compacted volume (multiply the cut volume by 0.9).

Cut volume 90% MDD	Loose volume 85% MDD	Compacted volume at 100% MDD	Required fill
1 077 m^3	1 131 m^3	969 m^3	945 m^3

The figure of 1 077 m^3 is the sum of 213 + 148 + 380 + 336, or the amounts of cut available from the 2nd, 3rd, 4th and 5th of the 50-m chainage sections in Drawing 2.

In the last two columns of the table, we can see that 969 compacted m^3 of material are available and that we only need 945 m^3. Therefore we have an excess of 24 compacted m^3 of material.

In practice, this means that all of the material excavated from this section will be used within the section. Very little haulage of material should be required from chainages 16 350 to16 550.

Section 2

Section 2 includes the 400 m from Ch.16 550 to Ch. 16 950. The table shows that we have 113 m^3 of compacted material available; however, we will need 17 587 m^3.

Cut volume 90% MDD	Loose volume 85% MDD	Compacted volume at 100% MDD	Required fill
125 m^3	131 m^3	113 m^3	17 587 m^3

This means that 113 m^3, plus the 24 m^3 hauled or pushed in from Section 1 (a total of 137 compacted m^3), will be available as fill and that we will need to haul in the remaining volume (17587 – 137 =17 450 compacted m^3) from another section.

Section 3

Section 3 includes the 500 m from Ch.16 950 to Ch. 17 450. The table shows that we have 20 205 m^3 of compacted material available and that we only need 2 m^3. Therefore we have an excess of 20 203 compacted m^3 of material.

Cut volume 90% MDD	Loose volume 85% MDD	Compacted volume 100% MDD	Required fill
22 450 m^3	23 573 m^3	20 205 m^3	2 m^3

As Section 2 requires 17 450 compacted m^3 of material, the equivalent in loose m^3 (i.e. 20 068) will be hauled from this section (3) back to section 2. Unfortunately, this means an uphill haul.

The remaining 2 753 compacted m^3 (20 203 – 17 450 m^3) will be available for another section.

As the volume of material produced in this section is being split and hauled to two different sections, it is important to determine roughly where this boundary occurs on the ground.

We know that 17 450 compacted m^3 is being hauled back to Section 2; therefore by simply adding compacted fill volumes from Ch.16 950 onwards until we get 17 450 m^3 of material, we can determine the approximate boundary location (chainage). This calculation is shown in the table below.

Chainage	Cut 90% MDD	Loose 85% MDD	Compacted 100% MDD	Cumulative volume of cut available
16950	0 m^3	0 m^3	0 m^3	0 m^3
17000	778	816.9	700.2	700.2
17050	1697	1781.9	1527.3	2227.5
17100	3376	3544.8	3038.4	5265.9
17150	5683	5967.2	5114.7	10380.6
17200	3148	3305.4	2833.2	13213.8
17250	2366	2484.3	2129.4	15343.2
17300	1812	1902.6	1630.8	16974.0
17350	1672	1755.6	1504.8	18478.8

From the results above, the boundary occurs between Ch.17300 and Ch.17350 (it would be closer to Ch.17300). Therefore all the material cut between Ch.16950 and Ch.17320 (approx.) is hauled back up to Section 2. The remaining material is hauled elsewhere.

Section 4

Section 4 includes the 400 m from Ch.17 450 to Ch. 17 850. The table shows that we have 224 m^3 of compacted material available, but require 1 888 m^3.

Cut 90% MDD	Loose 85% MDD	Compacted 100% MDD	Required Fill
249 m^3	261 m^3	224 m^3	1 888 m^3

This means that the 1 664 m^3 of compacted material required (1 888 – 224 m^3) will have to be hauled downhill from Section 3, which had 2 753 compacted m^3 left over.

To complete the calculation, we used 1 664 m^3 from the available 2 753 m^3 from Section 3, therefore we have 1 089 compacted m^3 (= 1 252 loose m^3) left over in Section 3 to spoil.

This figure of 1 089 compacted m^3 is the final amount of spoil left over on completion of the job. It relates back to the original calculation of the compacted volumes of cut and fill for the job as a whole:

$$21\ 511\ m^3 - 20\ 422\ m^3 = 1\ 089\ m^3$$

We now have a reasonable understanding of what quantities of earth have to be moved and where they are to be used.

Plant Requirements, Production and Time Frames

There are two generally adopted approaches to determining plant requirements and job timeframes for earthworks:

One approach is to determine how long the work will take, based on efficient use of available plant. This approach is used in the early planning stages or tendering process.

The other is that the timeframe is set and then determine what plant is required to achieve that deadline. This is the most common approach after the tender has been awarded. The earthworks foreman reads the initial works program (as used in the tendering process) to find the start and finish dates of the project.

For this example, we will adopt the second approach and calculate the plant requirements to complete the earthworks in a given timeframe. The planning and tendering for the project allowed 2 weeks or 10 working days (at 8 hours per day) for the earthworks.

Work Efficiency

It is important to establish, or at least estimate, the efficiency factors that will be used for this project. These efficiency factors are used to modify production rates and make allowance for unforeseen events or situations that will delay progress.

The job supervisor can advise the actual amounts of the factors used during the planning and tendering process for the job.

Job Efficiency

Job efficiency is an overall allowance for experience, attitude and judgement of operators and management, bad weather, machine failures and availability or delivery of parts, materials and services. This factor usually ranges between 0.65 and 0.85, and is applied to the overall project— the larger the project, the more impact this factor will have. As our example is small and we are only focusing on one activity, we will ignore the job efficiency factor.

Operator Efficiency

Operator efficiency is an allowance for the capability, skill and experience of plant operators, as well as for unscheduled machine adjustments and minor maintenance, operator fatigue, required breaks, and so on. This factor usually ranges between 0.67 and 0.83. It is possible to use different factors for different operations if the efficiency of operators is known.

Task Efficiency

Task efficiency is an allowance for down or idle time, additional manoeuvre time and unexpected delays due the nature of work. This factor generally only applies for plant items such as graders, rippers, scarifiers and towed rollers.

Initial Plant and Labour Considerations

Most earth-moving plant is heavy, large and slow. Most items are simply not designed to travel along the highway at 80km/hr or faster, nor are they designed to travel at their maximum speed for any great length of time. Therefore is it usually simpler and cheaper to hire local plant. Few construction contractors carry all their own plant to the job site. If they did, all the earthmoving plant would have to be floated to (and from) the job site by low loader. However, this depends on the location of the project.

Plant that cannot be hired locally or is specialised and simply not available locally, must be floated in (and then out) and the need to do this must be part of the planning for the job.

However, hiring local plant has a major disadvantage: you do not know its history, cannot assess wear and tear, and therefore cannot assess its reliability before hiring.

Moving plant to and from the site is costly; however, it is also expensive to have plant 'sitting there', doing nothing.

Another factor to be considered during the planning stage is the need to co-ordinate plant usage with other activities, like drainage and paving. For example, an excavator used for drainage construction may be used on earthworks when the drainage work is finished; a grader used to maintain haul roads while the earthworks were in progress may then be used for trimming during the paving activities. If this is possible (and it usually is), the best approach may be to select machines that will suit all activities that they can be used on.

Skilled and unskilled labour (including plant operators) are usually hired locally. Contractors will usually only bring experienced or specialist personnel to the job. The capability and efficiency of local labour is often an unknown quantity.

For this example we will use an Operator Efficiency factor of 75%. This amount is considered 'average', and will allow for the use of local labour and plant operators. If the operators prove to be better than average, the work can progress more quickly and will therefore finish before time. Progressing the work more quickly will also allow time if something beyond our control occurs and causes delays— for example, unexpected wet weather or machine breakdowns.

The following numbers and types of plant are available for use on the earthworks activity. It is assumed that all plant is in reasonable condition.

Primary Plant:

1 x D8 & 1 x D9 bulldozers

3 x Cat 621 & 2 x 631 Scrapers

3 x Cat 615 & 2 x 623 Elevating scrapers

2 x Cat 330 & 1 x 345 Excavators

2 x Cat 16H Graders

Secondary Plant

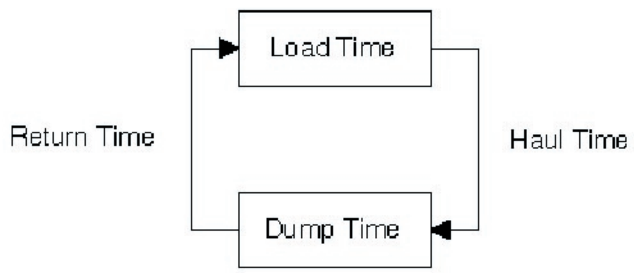
5 x Dump Trucks (all are 10m3 tippers)

1 x Cat 815 & 1 x 825 Soil compactors (these are also capable of spreading materials).

Note!
The use of a particular proprietary or brand name in this text does not imply endorsement or promotion of one product as being more or less suited to the job, as compared to other plant of similar power rating and capability.

Cycle Times— General

We know that the cycle time for a particular item of equipment, is the time it takes to complete a required activity and return, ready to commence again. An example is shown in the drawing.



Cycle time for a Dump Truck

Cycle Time = Load Time (Fixed) + Haul Time (Variable) +

Dump Time (Fixed) + Return Time (Variable)

To effectively plan our earthworks activity, we may need to combine the cycle times of several plant items; for example; a combined dozer / scraper / compactor operation, or an excavator / dump truck / spreader-compactor operation.

There are essentially two types of cycle times— theoretical and actual.

- Theoretical cycle times (TCT) are average cycle times calculated either by using a manufacturer's handbook or from experience. These are used during the planning phase to determine plant requirements and timeframes.
- Actual cycle times (ACT) are those observed directly on the job, by using a stop watch and timing on-site operations. These are taken and used to check or modify the works program and to check operator efficiency and consistency.

Theoretical cycle times are based on assumptions, such as those for efficiency factors, equipment capability, and material properties. It is most uncommon for the theoretical times to directly match the actual times. However, they should be reasonably close and this depends on the experience of the person who estimated or calculated the theoretical times.

Once we have determined the cycle times for various plant items, it is a simple matter to then calculate production rates and then estimate the time it will take to complete the activity.

The production rates and cycle times shown below are based on experience, and are supported by theoretical calculations. These will be used to estimate single and combined theoretical cycle times.

Methods of Construction

There are possible two ways of doing the work:

- Use scrapers to win and haul material
- Use excavators to win the material and dump trucks to haul the material.

The site layout includes an existing road for public vehicle usage and a wide road reserve along the northern side; therefore we can cut, win and haul along the control line and use the northern boundary as a return road. This gives us a 'haul loop' and allows free running of either scrapers or dump trucks.

The earthworks required in Section 1 consists of cutting and moving earth within the section. A bulldozer and a compactor / spreader can do this work. A grader will most likely be used for cutting and trimming side slopes and then shaping and trimming the subgrade.

Material cut and loaded in section 3 will be hauled to Section 2 for dumping and spreading there. Regardless of which method is used, a compactor / spreader will be required, as well as a grader for shaping and trimming. Similarly, material can be cut and loaded in Section 3 and hauled to Section 4 for dumping and spreading.

A water truck or trucks will be required. However, they usually can work in with other plant and therefore do not add to the time required to complete the earthworks.

The earthworks will not complete until 1 089 compacted m^3 of spoil has been removed form the site and disposed of.

We can now look at determining cycle times and production rates for individual items of plant, as well as combined cycle times.

Cycle Times and Production Rates

The planning and tendering process for the project allowed 2 weeks or 10 working days (at 8 hours per day) for completion of earthworks.

The steps required to calculate cycle times and production rates are:

- Look at each plant item that will be used for each method
- Calculate cycle times and production rates of individual items.
- Calculate the total time required for each method.
- At the end of the calculations for each method, combine various plant items that will work the sections to determine numbers required to complete the work within 10 days.

In the following calculations, we are assuming:

Operator efficiency factor is 0.75.

Task efficiency factor varies, and is addressed separately for each plant item.

Method 1— Using Scrapers to Haul and Win Material

In this method, the primary machines are bulldozers, scrapers, compactors and graders.

D8 and D9 Bulldozers

Production

Bulldozers are best used in short runs. They can usually cut the material and fill the blade in about 15m. They then drift the blade to push material where required; however, as they drift, material is lost and the effectiveness of the machine decreases. After pushing material for about 38 – 40m, a dozer will typically lose about 50% of the material. Therefore it is important to use bulldozers in short runs— such as moving material short distances along the control line (in small cuts and fills), or moving material from side to side (laterally). Task efficiency for this type of work is 1; the combined efficiency factor will be 0.75 x 1 = 0.75.

Production rates for D8 and D9 (or equivalent) dozers depend on the following assumptions about the conditions on site:

- Reasonably easy-to-work, rippable material
- Dozer using a universal blade
- Cut/push distances of 20–40m
- Reasonably flat grades (less than 2%)
- Some allowances are made for average operators, manoeuvre times, stalls, etc.

Under these conditions, the adjusted production rates in loose cubic metres per hour are:

D8 production: 493 x 0.75 = 370 loose m^3/hr

D9 production: 698 x 0.75 = 523 loose m^3/hr

Ripping

The material on this project is hard-packed, brown gravelly soil. Ripping and cutting should be fairly easy. Task efficiency for this type of work is 0.7; the combined efficiency factor will be 0.75 x 0.7 = 0.53.

Production rates for ripping by a D8 dozer are based on the following assumptions about conditions on site:

- Using a single shank with a penetration of about 600mm
- An average ripping speed of 1.4 km/hr
- About 910mm between passes
- 100m pass length for each rip.

D8 ripping: 720 x 0.53 = 380 bank m^3/hr

Production rates for ripping by a D9 dozer are based on the same assumptions as for the D8, except that the average ripping speed increases to1.5km/hr:

D9 ripping: 890 x 0.53 = 470 bank m^3/hr

Scrapers

Four types of scrapers are available for consideration:

- Cat 621 open-bowl scraper
- Cat 631 open-bowl scraper
- Cat 615 elevating scraper
- Cat 623 elevating scraper.

The scrapers will be used to move material from Section 3 to Sections 2 and 4. Cycle times will depend on the length of haul for both routes.

Hauling from Section 3 to Section 2

Material is cut between chainages 17320 and 16950, and filled from about Ch. 16 950 to Ch. 16 550 (see previous discussion, Analysing Earthworks in Sections). To determine the average haul length of haul, we find the average length of each section and add them together.

$$\frac{(16950 - 16550) / 2 + (17320 - 16950)}{2} = 385\text{m}$$

The slope of the haul route is about 1% on the up grade, giving a 1% down grade run for the return.

The usual allowances for loading and dumping are 50m each; half of each of these lengths is included in the average haul distance of 385m. We need to subtract this length before calculating travel times:

385 – (25 + 25) = 335m.

The table below shows the travel times for each of the four types of scrapers.

The Cat 621 and 631 will be push loaded by a D9. The Cat 615 and 623 are self loaders and therefore slower. Experience shows that all of the scrapers will dump their loads in about the same time. The haul and return times are estimates based on average speed, distance, effect of grade, weight of machine, and so on.

	Load	Haul	Dump	Return	Total
Length	50	335	50	335	
Grade	+1	+1	+1	-1	
Cat 621	0.4	1.17	0.7	0.7	2.97 min
Cat 631	0.6	1.37	0.7	0.75	3.42 min
Cat 615	0.9	1.33	0.7	0.72	3.65 min
Cat 623	0.9	1.17	0.7	0.7	3.47 min

The Cat 621 has the fastest cycle time— 2.97 min. However, we cannot say at this stage of calculation whether it will be the best for the job. We need to do more calculations, to combine scraper cycle times with those for bulldozers and compactors.

Hauling from Section 3 to Section 4

Material is cut from about Ch. 17320 back to Ch. 17450, and then filled from about Ch. 17450 to Ch. 17850. The average haul length is:

$$\frac{(17450 - 17320) / 2 + (17850 - 17450)}{2} = 265\text{m}$$

The slope of the haul route is about 1 % on the down grade, giving a 1% up grade run for the return. Grade assistance and resistance are opposite to those for the haul from Section 3 to Section 2.

The following table shows the calculations for the travel times for each of the four types of scrapers over the haul route from Section 3 to Section 4. Haul times are much quicker than those from Section 3 to Section 2; this is mainly due to the loaded downgrade run.

	Load	Haul	Dump	Return	Total
Length	50	240	50	240	
Grade	-1	-1	-1	1	
Cat 621	0.4	0.78	0.7	0.52	2.40 min
Cat 631	0.6	0.79	0.7	0.54	2.63 min
Cat 615	0.9	0.76	0.7	0.57	2.93 min
Cat 623	0.9	0.78	0.7	0.52	2.90 min

Cat 815 and 825 Soil Compactors

These machines are capable of spreading and shaping the material as well as compacting it. They can be used together with the bulldozer over Section 1, ensuring the bulldozer is put to its best use—cutting and pushing up the material, with minimal spreading or shaping work. Compactors can also work with the scrapers to spread and compact the embankment.

Production: Compaction

Embankments are built in layers. This allows ease of construction and ensures proper compaction of the material. Layers are usually about 150mm thick. In this case, four passes of the compactor are required to compact the material to specification. However, this number varies with material and moisture content; you will need to check this before assuming 4 passes is correct for other projects.

At an average speed of 10 km/h, the production rate for the compactors are:

Cat 815 production: 755 x 0.75 = 570 compacted m^3/hr

Cat 825 production: 869 x 0.75 = 650 compacted m^3/hr

Production: Spreading and Shaping

This rate is difficult to estimate, as this work is highly variable. The machines are primarily compacting material, but at the same time are able to spread and shape. It is reasonable to select a machine with a production rate much higher than the material delivery rate. This will allow time for the machine to spread and shape.

Cat 16H Graders

Since the compactors are performing the initial spreading and shaping of embankments, the grader will be mainly used to maintain haul roads, cut side slopes and give the embankment its final shape and trim to subgrade level.

A grader can be used in two ways. One way is to use the machine to cut, spread and shape material. This work is estimated as a number of square metres per hour.

Typical or indicative production rates (for this example) can be read from the following table. The figures include efficiency factors.

Operation	Production (m^2/hr)
Heavy blading (avg speed 3km/h)	3 500
Ditch repair (avg speed 1.5km/h)	1 700
Haul road maintenance (avg speed 5km/h)	5 800
Side slope work (avg speed 2km/h)	2 300

The other way of using a grader (and this is its most important role) is for final trimming and grading. This work is typically done in long lengths or runs. This usage is estimated as a cycle time in hours (or mins).

The following table shows indicative cycle times based on a single pass and an average speed of 2 km/h. The figures include efficiency factors.

Length	Time
200m	8min
300m	12min
400m	16min
500m	20min
600m	24min

A single pass gives a bladed width of approximately 3.7m. This 'effective width' varies according to machine size and mouldboard size, and represents the width of the mouldboard square to the direction of travel. To grade across the formation, several side-by-side passes would be required, with an overlap of 0.6m. Therefore if we are required to grade a haul road 6.2m wide by 400m long and it needed two passes, then the estimated time would be:

Show as equation

$$\frac{2 \text{ passes x } 20\text{min x } 6.2\text{m}}{(3.7 - 0.6)} = 1\text{hr } 20\text{min}$$

Combined Cycle Times and Production Rates

Now that we have calculated individual machine cycle times and production rates, the next step is to combine these factors and determine the timeframes for Method 1.

We do this by calculating and comparing the cycle times for all combinations of available plant for this method. The combination which gives the shortest timeframe is generally the best solution; costings can change this outcome, but are not considered here. To reduce the amount of detail shown, some calculations have been left out.

Working Section 1

Because this section is short (i.e. about 200m), we should limit the numbers of machines working the section, to avoid clashes and delays.

A bulldozer rips, cuts and pushes the material. Distance of push is kept short to maintain the machine's efficiency. We also use a spreader–compactor to assist the bulldozer in spreading and shaping, as well as to compact the material. The grader cuts and shapes the side slopes and then trims the formation to subgrade level.

In previous calculations, the timings for scrapers being pushed by a bulldozer were based on a D9 bulldozer. We therefore assume that a D9 to be used throughout the project.

As previously calculated, a D9 can rip 467 bank m^3/hr. For this section, we have 1 077 bank m^3 (= 1 131 loose m^3) of cut to be ripped, therefore:

$$\frac{1\ 077\ \text{m}^3}{467\ \text{m}^3/\text{hr}} = 2.31\text{hrs} \quad \text{allow 2hrs 30min}$$

We previously calculated a production rate of 523 loose m^3/hr when using the D9 to cut and push material; therefore:

$$\frac{1\ 131\ \text{m}^3}{523\ \text{m}^3/\text{hr}} = 2.16\text{hrs} \quad \text{allow 2hrs 30min}$$

While the bulldozer is cutting and pushing material, a compactor can start work. For this section, we have 945 compacted m^3 of material (see figure for 'Required fill' in table for Section 1). Remember that a Cat815 compactor has a production rate of 570 compacted m^3/hr, while a Cat 825 has a production rate of 650 compacted m^3/hr (see previous section, Production: Compaction).

Both machines should be able to keep up with the bulldozer, but these production rates are for compacting only. We need to allow time for the machine to spread and shape, therefore it would be more productive to use the Cat 825.

$$\frac{945\ \text{m}^3}{650\ \text{m}^3/\text{hr}} = 1.45\text{hrs} \quad \text{allow 1hr 30mins}$$

A 16H grader will be used to cut and shape the side slopes. In the previous section 'Cat 16H Graders', we saw that the production rate is 2 300 m^2/hr for a grader doing side slope work. Using the estimated area of 3 200m^2 on this section, we can calculate the time required to complete cutting and shaping of the side slopes:

$$\frac{3\,200 \text{ m}^2}{2\,300 \text{ m}^2/\text{hr}} = 1.39\text{hrs} \quad \text{allow 1hr 30mir}$$

When the formation is built up above required subgrade level, a multi-tyre roller and grader will prepare the subgrade, ready for final trimming.

For grading, the area of subgrade is approximately 1 900 m^2; therefore, with a production rate of 3 500 m^2/hr, the required time is:

$$\frac{1\,900 \text{ m}^2}{3\,500 \text{ m}^2/\text{hr}} = 0.54\text{hrs} \quad \text{allow 45mins}$$

A multi-tyre roller (4 passes @10km/h) has a production rate of about 723 compacted m^3/hr. The subgrade to be compacted is 9.5m wide, 150mm thick and the section is 200m long, therefore the compacted volume equals 285 m^3. The time required for the multi-tyre roller is:

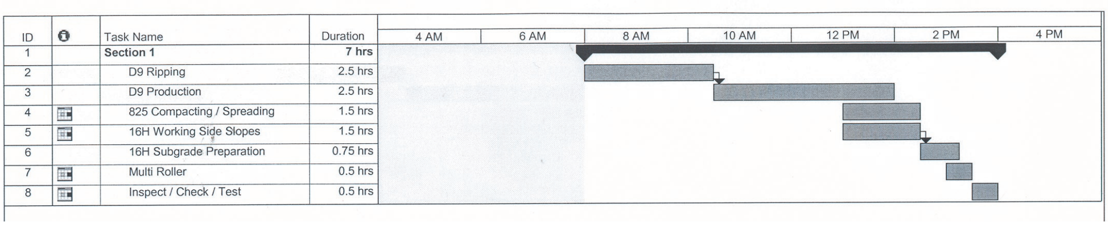
$$\frac{285 \text{ m}^3}{723 \text{ m}^3/\text{hr}} = 0.39\text{hr} \quad \text{allow 30mins}$$

We have now estimated the time for all the main plant items to construct the formation in Section 1. Water trucks will be needed, but they can generally fit in with the other machines and therefore do not add any more time to the work.

Testing, inspection and survey work need to be allowed for, as this work can interrupt machine operations. Allowance for this work is small.

Chart 1 shows how long the work on Section 1 will take. Here we have used Microsoft Project to draw the chart; however, you can draw a similar chart using graph paper.

Chart 1



Some work has to be done sequentially, especially when the same machine is used for different operations. For example, the D9 can either rip or cut and push; therefore we add the two times together. Other work (using other machines) can sometimes be done in parallel. For example, after the D9 has worked for a while and has pushed up and roughly spread the material, the compactor can start shaping the formation as well as commencing compaction.

As shown in the chart, the estimated time for the work to complete Section 1 is about 7 hours. This would allow about 1 hour to tidy up before finishing the 8 hour day. However, we still need to consider the other sections and to allow time for the grader to work and maintain haul roads.

Working Sections 2 and 3

While the bulk of work in this section will be done by scrapers, dozers are still needed to rip the surface. This will assist the initial loading of scrapers. The length of cut is about 370m (17 320 – 16 950). If the depth of rip is 0.6m, we have a total of 3 330 bank m^3 to be ripped, therefore:

$$\frac{3\ 330\ m^3}{467\ m^3/hr} = 7.13hrs \quad \text{allow } 7.5hrs$$

The Cat 621 Scraper as it is the quickest scraper for the job (refer table in previous section Hauling from Section 3 to Section 2); three of them are available (see previous section Initial Plant and Labour Considerations).

If we use a D9 dozer to push-load the Cat 621s, we need to determine the production rate when using these two machines in combination.

The cycle time for a D9 push-loading a scraper includes pushing the scraper, manoeuvring and returning in readiness for the next scraper. A D9 can do this in about 0.95min. We can therefore calculate a scraper / dozer ratio. This ratio tells us how many scrapers can be continually serviced by one bulldozer.

D9 TCT = 0.95min

621 TCT = 2.97min

$$\frac{\text{Cat 621 scraper}}{\text{D9 dozer ratio}} :$$

$$\frac{2.97}{0.95} = 3.13$$

(round this down to 3 for practical purposes)

The ratio indicates that 3 scrapers can be in a continual cycle of loading, hauling, dumping and returning to the one dozer.

The heaped capacity of a Cat 621 is 15.3 loose m^3. To calculate the production rate:

Cat 621 scraper production rate:

$$3 \text{ machines x } 15.3 \text{ m}^3 \text{ x } \left(\frac{60\text{min}}{2.97\text{min scraper cycle time}}\right) \text{ x } 0.75 \text{ efficiency} = 695.45 \text{ loose m}^3\text{ /hr}$$

The time required to haul the material from Section 3 back to Section is calculated from the volume to be shifted (20 068 loose m^3) and the scraper production rate:

$$\frac{20\ 068 \text{ m}^3}{695.45 \text{ m}^3\text{/hr}} = 28.86\text{hrs} \quad \text{allow 29hrs}$$

In the initial calculations for Section 1, we found an excess of 24 compacted m^3 was to be pushed in from Section 1 to the beginning of Section 2. The time for this should not adversely affect the overall programme and can therefore be ignored.

Since we will be using a Cat 825 Compactor in Section 1, we need to check that this machine can compact the material faster than the rate it is delivered in this section.

We know that 695.45 loose m^3/hr (i.e. the Cat 621 scraper production rate) = 594.61 compacted m^3/hr.

This is less than the 650 m^3/hr production rate of the Cat 825 compactor. The compactor should therefore have time to spread and shape as well as compact.

For section 2, we need a total of 17 587 compacted m^3 of material. We can estimate the time required to compact the material using the Cat 825:

$$\frac{17\ 587 \text{ m}^3}{650 \text{ m}^3\text{/hr}} = 27.06\text{hrs} \quad \text{allow 27hrs}$$

The 16H grader will be used to cut and shape the side slopes. The estimated area for this section is 12 320m2. With a production rate of 2 300 m^2/hr for side slope work, the estimated time required to complete this part:

$$\frac{12\ 320 \text{ m}^2}{2\ 300 \text{ m}^2\text{/hr}} = 5.36\text{hrs} \quad \text{allow 5hrs 30mins}$$

We now need to estimate the time required to prepare the subgrade using a grader and multi-tyred roller.

For grading, the area of subgrade is approximately 7 315 m^2, therefore with a production rate of 3 500 m^2/hr:

$$\frac{7\ 315 \text{ m}^2}{3\ 500 \text{ m}^2\text{/hr}} = 2.09\text{hrs} \quad \text{allow 2hrs}$$

The top layer of subgrade to be compacted is:

9.5m (width) x 150mm (thickness) x 770m (length of section) = 1 098 compacted m^3 (volume)

Therefore the time required for the multi-tyred roller is:

$$\frac{1\ 098\ m^3}{723\ m^3/hr} = 1.51 hrs \quad \text{allow 2hrs}$$

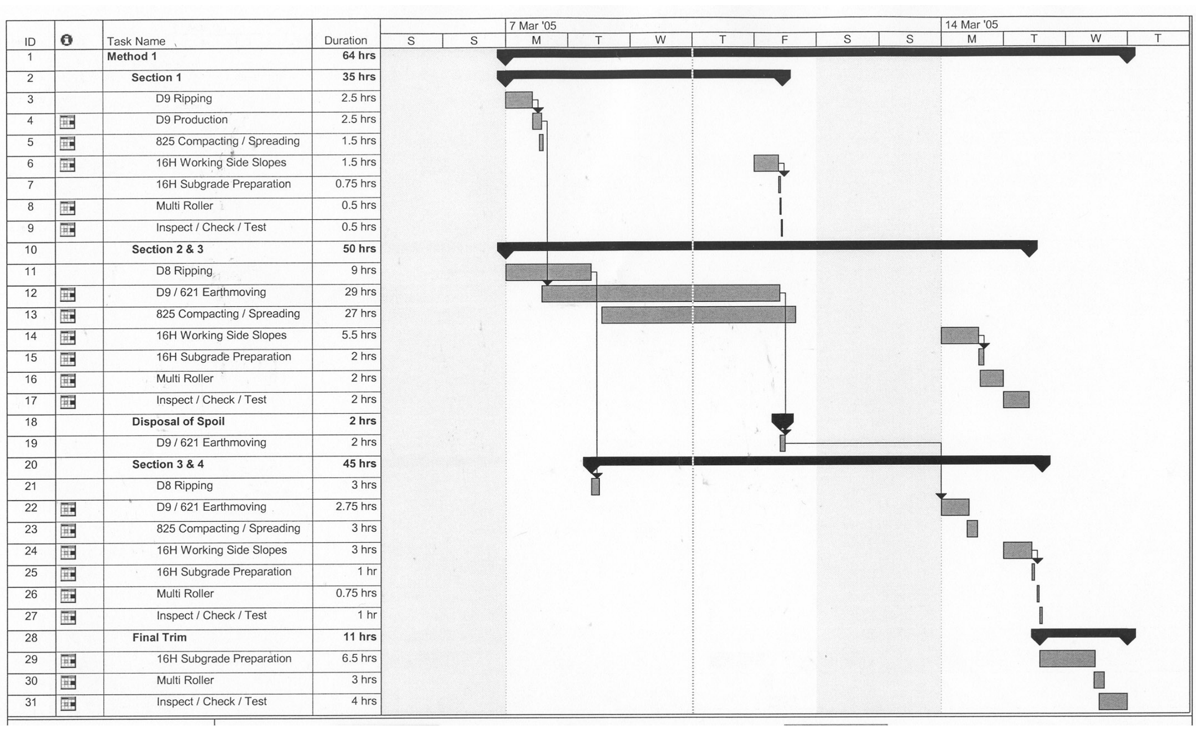
We have now estimated the time for all main plant items to construct the formation in Section 2. Water trucks will be needed, but they will fit in with the other machines and do not add time to the work.

Testing, inspection and survey work has to be allowed for, as this work can interrupt machine operations. Allowance for this work will be small.

Working Section 3 and 4

Calculations for this section are similar to those for Sections 2 and 3. Timings have been calculated and included in Chart 2.

Chart 2



Final Trimming of Whole Subgrade

Now that the formation is complete and the subgrade has been roughly graded to correct levels, we need to allow for finally trimming and rolling, as well as level checks.

The final trim will be by grader. The area of subgrade is approximately 14 250 m^2. Allowing for 4 passes @ 1.5 km/h, it is estimated that 6hrs 30min will be required to trim the subgrade.

A multi-tyre roller (4 passes @ 10km/h) has a production rate of about 723 compacted m^3/hr. The subgrade to be compacted is 9.5m wide, 150mm thick and the whole section is 1500m long, therefore the compacted volume equals 2 138 m^3. The time required for the multi-tyre roller is:

$$\frac{2\ 138\ m^3}{723\ m^3/hr} = 2.96hrs \quad \text{allow 3hrs}$$

To check levels, we should allow 4hrs for survey.

Disposal of Spoil

On this job, the spoil can be placed along the edge of the embankment of Section 2; this work can be completed while or after we complete that embankment. The spoil material is 1 089 compacted m^3, equivalent to 1 252 loose m^3.

We know that the scrapers have a production rate of 695.45 m^3/hr for this section, therefore the time to remove this material is:

$$\frac{1\ 252\ m^3}{695.45\ m^3/hr} = 1.8hrs \quad \text{allow 2hrs}$$

Spreading the material to allow for drainage and compaction can be done by the 825 compactor without adding any time to the project.

Bar Chart / Programme for Method 1

To estimate the overall timing to complete the earthworks, we now combine all of the timings calculated for the three sections. This means programming the plant to ensure that high cost items are continually used. For example, once the bulldozer is finished in section 1, it can move on to section 2/3 and commence ripping operations while other machines are finishing off section 1.

Chart 2 shows that the D8 has been brought in for two days, to rip Sections 2 and 3 and 3 and 4. This additional plant allows the D9 operator to concentrate on loading the scrapers. The grader and multi-roller could start work on Monday as per Chart 1, but they are not required on the next section until the following Monday. As a result, they could spend up to 4 days with very little to do— a waste of money. Instead, if they are programmed to start on Friday, their work will flow from one section to the next and still allow some time for other tasks like haul road maintenance.

In Method 1, work starts on a Monday and finishes on the following Wednesday, for a total of 8 working days or 64 hours. The original estimate was for 10 days; therefore, we have 2 whole days extra to allow for machine breakdown or some other delay.

However, we have to allow for close down procedures each working day. These include parking and securing of plant and a quick grading of the earthworks, to ensure a smooth surface that will freely drain— in case it rains overnight. This may take 1 hour of time each day, leaving only 7 effective working hours per day. If we allow for requirement each day over the 8 days of work, there will be an extra 8 hours or one day in the programme. Effectively, the work will be completed in 9 working days. On larger projects, you may need to actually include close-down time in the programme calculations.

Method 2

In this method, the primary machines are bulldozers, excavators, dump trucks, compactors and graders.

D8 and D9 Bulldozers

Bulldozers will perform the same work for both methods; the same calculations as for Method 1 apply here.

Cat 330 and 345 Excavators

Typically, these machines use a 1.52m general-purpose bucket for earthmoving operations. To ensure good production rates and efficient operations, the following conditions must be achieved and maintained:

- No obstructions
- Proper placement and operation of the machine
- 600 to 900 swing.

The cycle time (TCT) for any excavator is the total time it takes to load the bucket, swing with the load, dump the bucket and swing back empty ready to reload.

The cycle time (TCT), based on the above factors, for a Cat 330 excavator is 0.33min (about 20 seconds) and it can produce about 378 loose m^3/hr. A Cat 345 has a cycle time (TCT) of 0.3min (about 18 seconds) and can produce about 500 loose m^3/hr.

Allowing for an efficiency factor of 0.75, a Cat 330 excavator can produce about 285 loose m^3/hr. A Cat 345 can produce about 375 loose m^3/hr.

We can now estimate the time it takes each excavator to load a 10 m^3 tip truck.

For a Cat 330 (bucket capacity of 2.2 loose m^3) it takes:

10 / 2.2 = 4.6 machine cycles to fill the truck, allow 5

The time taken to fill a truck body is therefore:

5 x 0.33min = 1.65min

For a Cat 345 (bucket capacity of 2.6 loose m^3) it takes:

10 / 2.6 = 3.85 machine cycles, allow 4

The time taken to fill a truck body is therefore:

4 x 0.30min = 1.2min

Tip Trucks

The following calculations assume a truck capacity of 10 m^3. The haul distances on this job are short, therefore the haul and return travel times are similar to those of the scrapers. Loading time is based on the capabilities of the excavators, while dumping time will take about 0.7min.

Based on these facts, and using a Cat 345 (the larger excavator) to load, the cycle times for trucks are:

For Section 2/3—

1.2min (load) + 1.17min (haul) + 0.7min (dump) + 0.7min (return) = 3.77min

For Section 3/4—

1.2min (load) + 0.78min (haul) + 0.7min (dump) + 0.52min (return) = 3.20min

Cat 815 and 825 Soil Compactors

Soil compactors will perform the same operations for both methods; the calculations used in Method 1 apply here.

Cat 16H Graders

The graders will perform the same operations for both methods; the calculations used in Method 1 apply here.

Combined Cycle Times and Production Rates

Working Section 1

Work for this section is the same as for Method 1, therefore the timeframe will be the same.

Working Sections 2 and 3

Previously we used a bulldozer to rip the surface and assist the initial loading of the scrapers. Excavators don't need this type of assistance unless the ground is really hard. The material for this example is easily winnable, therefore no ripping is expected.

The Cat 345 Excavator loads quicker than the 330.

As above, we need to calculate a truck / excavator ratio. This ratio will tell us how many trucks can be continually loaded by one excavator.

- Cat 345 TCT = 1.2min
- Truck TCT = 3.77min

Cat 345 excavator / 10 m^3 tip truck ratio:

3.77 / 1.2 = 3.14 (round this down to 3 for practical purposes)

The ratio indicates that 3 trucks can be in a continual cycle of loading, hauling, dumping and returning.

The capacity of a tipper is 10 loose m^3. The production rate can be calculated:

$$3 \text{ trucks x } 10 \text{ m}^3 \text{ x} \left(\frac{60\text{min}}{3.77\text{min truck cycle time}}\right) \text{x } 0.75 \text{ efficiency} = 358.09 \text{ loose m}^3\text{/hr.}$$

We need to estimate the time required to haul the material. For this section, we are hauling 20 155 loose m^3 of material.

$$\frac{20\ 155 \text{ m}^3}{358.09 \text{ m}^3\text{/hr}} = 56.28\text{hrs} \quad \text{allow } 57\text{hrs}$$

This rate is much slower than Method 1 (it will take 29 hours to haul the same volume using scrapers). To increase production, it may be necessary to add a Cat 330 and two more trucks; however, only 5 trucks are available. If we did this, it would give us a production rate of approximately 600 loose m^3 /hr, for a total of about 34hrs of work.

As calculated previously, an 825 Compactor (650m^3/hr) will be able to compact the material faster than the rate it is delivered. It was estimated to take 27hr to compact this section.

For the reminder of the work (grading, trimming, rolling, etc), the calculations and timings are as for Method 1. Similarly, testing, inspection and survey work has to be allowed for as this work can interrupt machine operations. Allowance for this work will be small.

Working Section 3 and 4

The graders will perform the same operations for both methods; the calculations used in Method 1 apply here.

Calculations for this section are similar to those for Method 1; therefore the timings have been calculated and included in Chart 3.

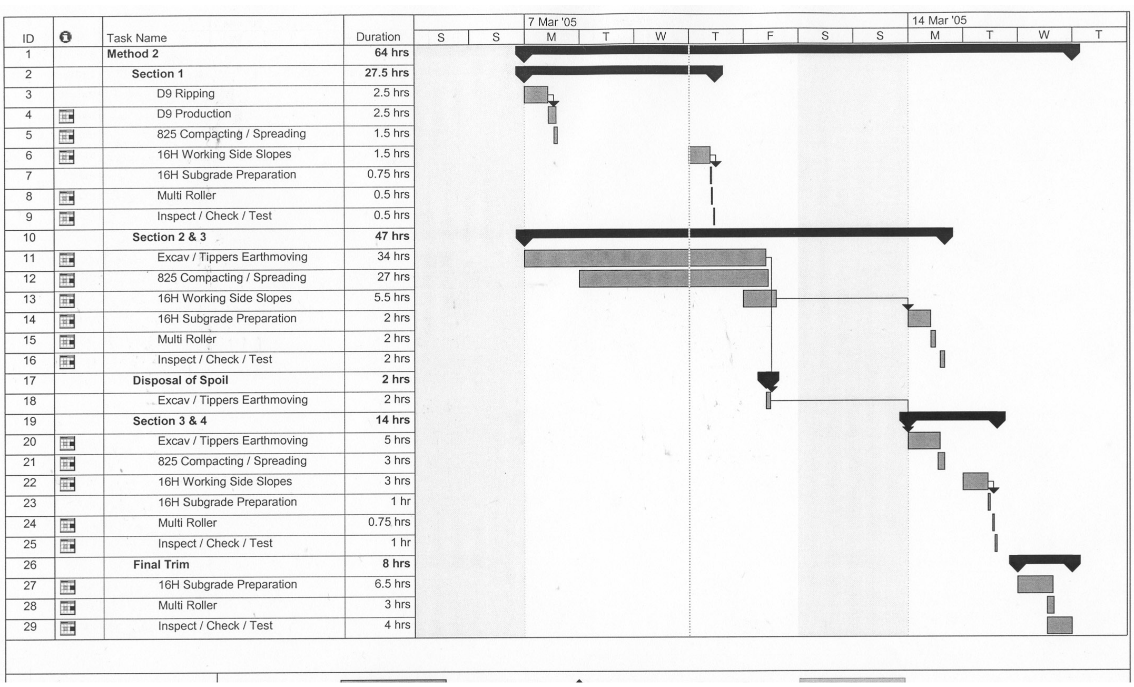
Bar Chart / Programme for Method 2

As for Method 1, we can now combine all of the timings calculated for the three sections.

Other calculations (not shown here) have demonstrated that using only the Cat 345 and 3 dump trucks would result in the project exceeding the set period of two weeks. In effect, this means we need to bring in the Cat 330 and two more dump trucks.

Refer to Chart 3 (see following page) shows the timings of the work required under Method 2. As in Method 1, the grader and multi-roller have been programmed to start work on Thursday. They then move on to Sections 2 and 3 on Friday. There is sufficient time to allow these machines to perform haul road maintenance, etc.

Chart 3



The overall result from Method 2 is the same as for Method 1; 64 hours of work over 8 days. However, this has happened more by chance than by careful planning.

We would still need to close down each day, extending the programme to 9 days.

Comparison of Methods

Both methods will result in completion of the earthworks within the allowed 10 working days. Either method would be therefore be suitable.

However, the choice of a method will depend on costings. The method that has the lowest overall cost will be the more efficient. For the purposes of this case study, we can use the plant requirements for each method, as programmed, as a means of choosing between them.

Plant Requirement for Method 1

Number	Plant item
1	D8 bulldozer
1	D9 bulldozer
3	Cat 621 scrapers
1	16H grader
1	Cat 825 compactor
1	Multi-tyred roller
8	Total plant items

Plant Requirement for Method 2

Number	Plant item
1	D9 bulldozer
1	Cat 345 excavator
1	Cat 330 excavator
5	10m3 dump trucks
1	16H grader
1	Cat 825 compactor
1	Multi-tyred roller
11	Total plant items

Method 1 requires fewer machines and may therefore be the better option, as there are fewer chances of breakdown. Also, the haul roads for the project are short, and Method 1 will result in fewer machines and therefore less congestion than Method 2. Method 2 would also require more supervision, to ensure that the two excavators work clear of each other, and that the dump trucks worked efficiently with these machines.

Other Considerations in Programming

Safety is of paramount importance. When programming activities, you must think about the relative safety of the operations proposed under each method.

Public holidays are something else you need to be aware of. They need to be included in the programme as non-working days, unless the project supervisor decides that work will continue through these days.