CHAPTER 7 - EARTHWORKS

7.0 INTRODUCTION

This chapter outlines various road construction techniques and practices which will help the manager choose to the construction method best suited to the situation, and assist in calculating cost estimates.

Machinery types and combinations best suited to a roadline construction combined with productivity information have also been developed.

7.1 MARK CLEARING WIDTHS

7.1.1 Minimum Clearing Width

Clearing trees and topsoil from the roadway construction zone is the first step to be completed. Organic material is generally unsuitable for embankments and therefore must be disposed of. Removal of trees within 3 m either side of the proposed roadway should also be completed. Where the removal of additional trees is required for daylighting refer to section 7.1.2.

If the road to be constructed has not been designed and setout, then follow through both steps 1 and 2. If the road has already been designed and setout, then move directly to step 2.

7.1.1.1 Step One: Road has not been designed

Setting out cut and fill pegs will clearly identify the start of the cut and the end of the fill. The following procedure estimates the required clearing width. The alternative is to choose an arbitrary distance left and right of the gradeline for tree clearing. This will leave a corridor for the bull dozer or excavator operator to construct the road. An experienced bulldozer or excavator operator is needed for this construction technique.

7.1.1.1.1 Gradeline Location

Locate the formation centreline that is on grade. This may not be where the gradeline was marked as gradeline marks are placed at eye level on the nearest tree, (figure 46).

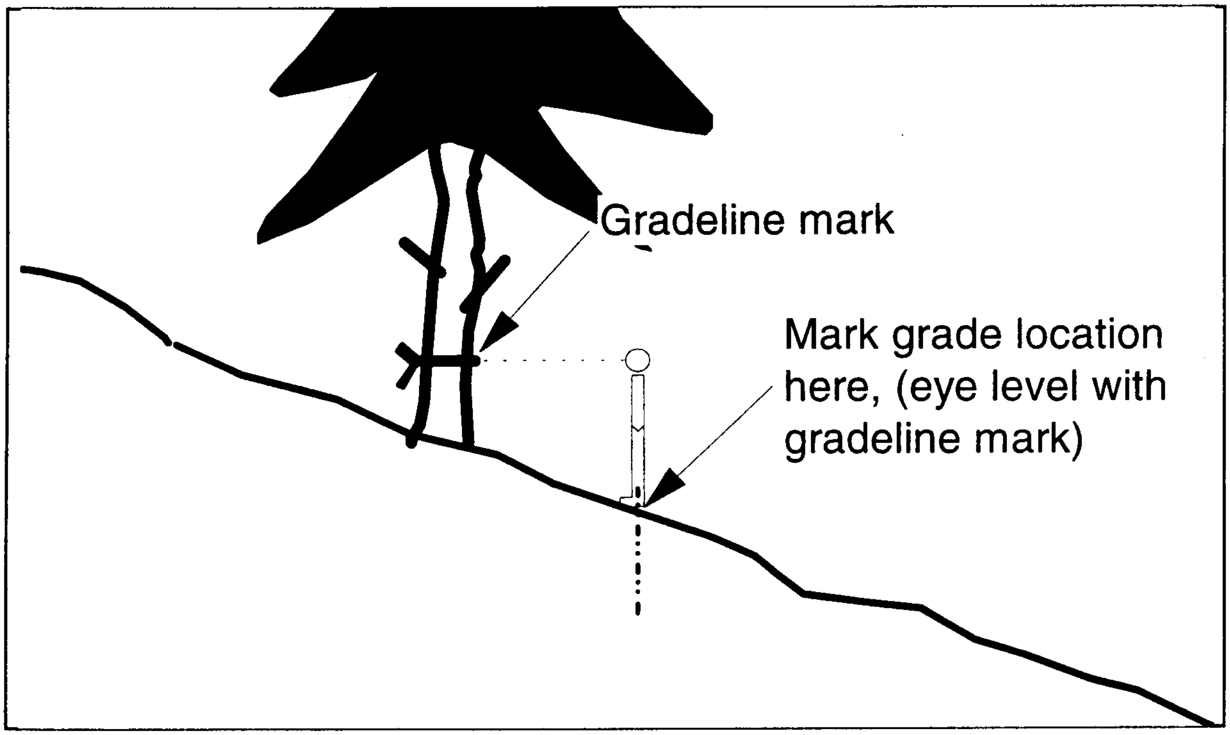


Figure 46 - Gradeline location

***Note:** this is the finished road level and is not the same as the road centreline*

7.1.1.1.2 Cross-sectional Layout

The cross-sectional design must be determined prior to beginning earthworks construction. This will enable the machinery operator to visualise the finished road and use the marker pegs effectively. Figures 47 and 48 show a typical cross sectional layout.

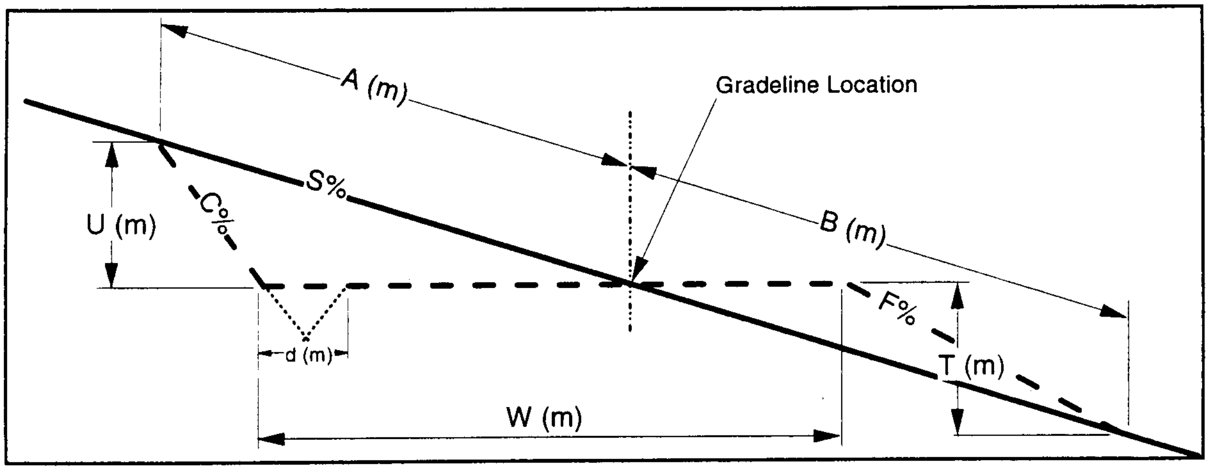


Figure 47 - Typical road cross-sectional layout

Where:

W = Full formation width in metres and includes the road, shoulder and ditch (d) widths.

S% = Side slope of natural ground in percent.

C% = Cut slope in percent.

F% = Fill slope in percent.

A = Offset distance along natural ground on uphill or cut side in metres.

B = Offset distance along natural ground on downhill or fill side in metres.

U = Depth of cut from the top of batter in metres.

T = Depth of fill from the toe of fill in metres.

To limit the quantity of earthworks required in steep country a steeper cut slope (C) can be made. The following table shows the advantages and disadvantages of a steep cut slope.

Advantages of steep cut bank	Disadvantages of steep cut bank
1. Less right-of-way	1. Difficult to revegetate
2. Less excavated material	2. Prone to ravel and ditch plugging
3. Less sidecast	3. Prone to tension cracks
4. Shorter slope exposed to erosion	4. Increased risk of rotational failure

Table 11 - Advantages and disadvantages of a steep cut slope.

The tables below have been produced to calculate the offsets and cut and fill depths for different side and cut slopes.

Assumptions: Side slope up to 40% - 80% of the cut material is used as solid fill

Side slopes > 40% - End haul cut, no solid fill used

Multipliers of Formation Width, (W) Cut Slope = 200% Fill Slope = 70%				
Slope **S%**	**Offset Cut** **A**	**Depth Cut** **U**	**Offset Fill** **B**	**Depth Fill** **T**
10%	0.7	0.1	0.5	0.1
20%	0.7	0.1	0.7	0.1
30%	0.7	0.2	0.8	0.2
40%	0.8	0.3	1.0	0.4
50%	1.5	0.7	0.0	0.0
70%	1.7	0.9	0.0	0.0
70%	1.9	1.1	0.0	0.0
80%	2.1	1.3	0.0	0.0
90%	2.4	1.7	0.0	0.0
100%	2.8	2.0	0.0	0.0
110%	3.3	2.4	0.0	0.0
120%	3.9	3.0	0.0	0.0

Table 12 - Calculation of setout information for earthworks.

(For a 1m wide formation) Simply multiply the numbers provided by the actual formation width (W), to calculate your own setout information.

Figure 48 shows the setout for a standard cross-section. It may be easier to create your own table, prior to going out into the field, by multiplying table 12 by the formation width. Table 13 has been calculated for a formation width of 6.6 metres (figure 48).

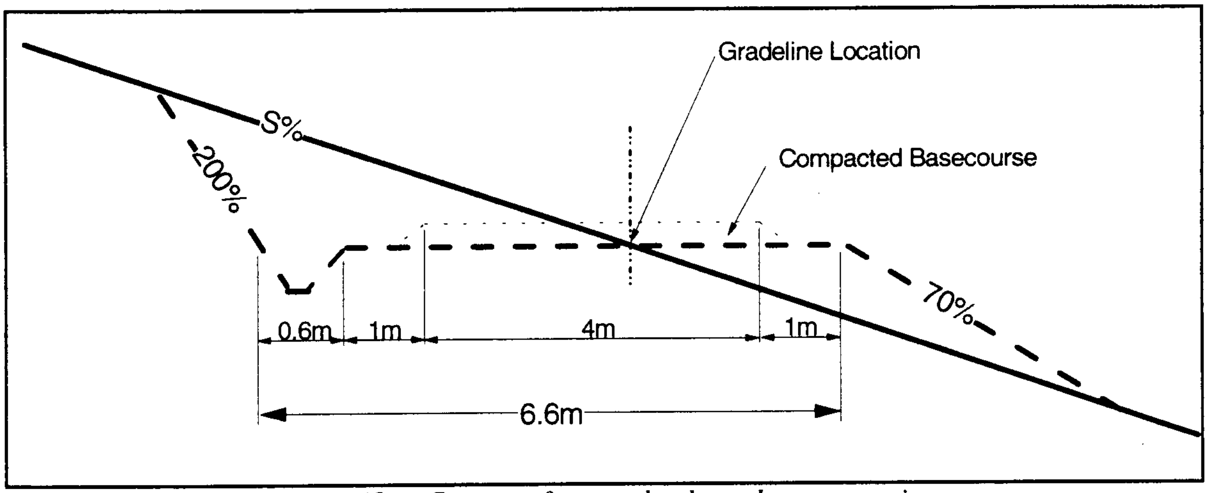


Figure 48 - Set out of a standard road cross-section.

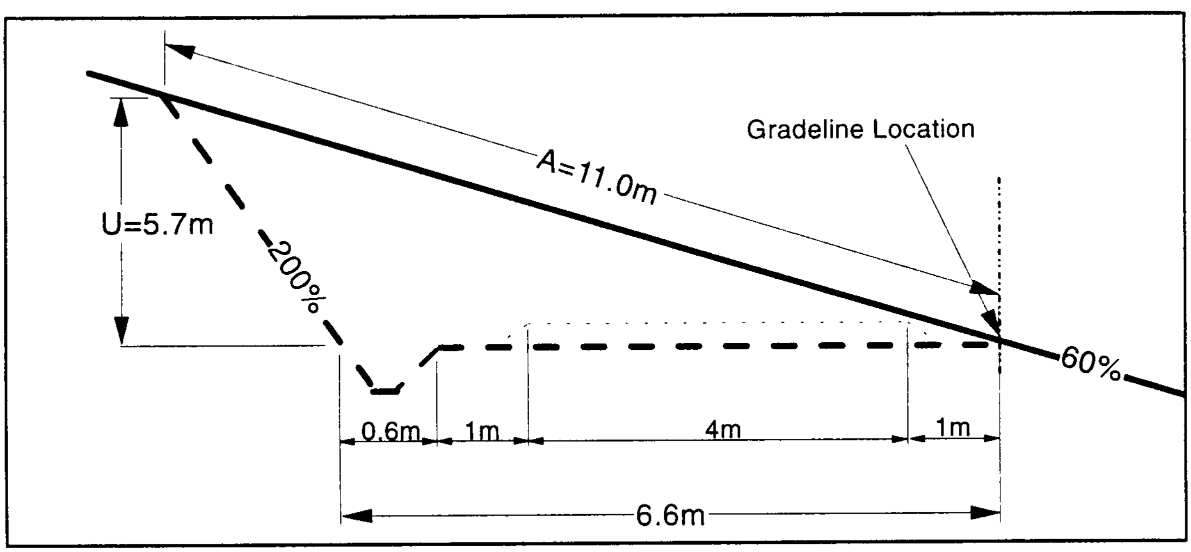


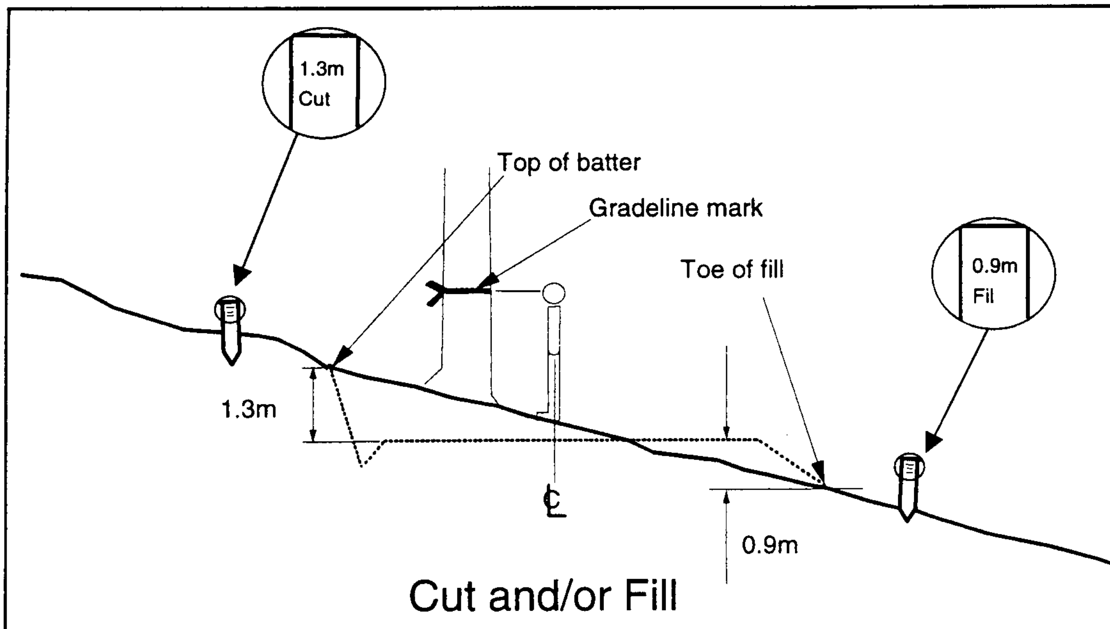
Figure 49 - Setout information for road cross-section with a side slope of 60%.

Figure 49 shows the setout of the example cross section for a side slope of 60%.

Multipliers of Formation Width Cut Slope = 200% Fill Slope = 70%				
Slope S%	**Offset Cut A**	**Depth Cut U**	**Offset Fill B**	**Depth Fill T**
10%	3.8	0.4	3.7	0.4
20%	4.2	0.8	4.2	0.8
30%	4.7	1.3	5.1	1.5
40%	5.4	2.0	7.7	2.4
50%	9.8	4.4	0.0	0.0
70%	**11.0**	**5.7**	**0.0**	**0.0**
70%	12.4	7.1	0.0	0.0
80%	14.1	8.8	0.0	0.0
90%	17.1	10.8	0.0	0.0
100%	18.7	13.2	0.0	0.0
110%	21.8	17.1	0.0	0.0
120%	25.8	19.8	0.0	0.0

Table 13 - Setout data for a formation width of 6.6 metres.

The top of the batter and the toe of fill can be located by measuring the ground slope in the field using a clinometer, and then referring to the appropriate table. Pegs are then located to mark these positions (figure 50).



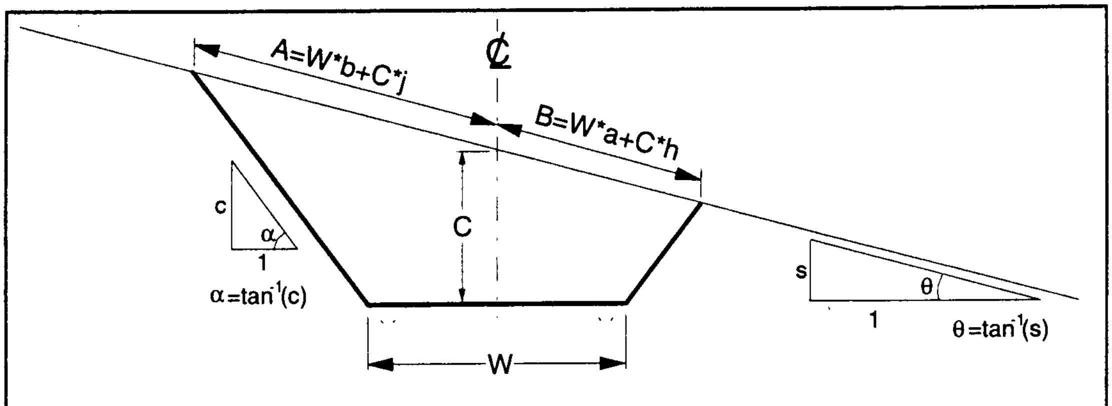
1. Offset pegs from the top of batter and/or toe of fill by using standard tables, road design cross sections or batter staking tables

2. After trees are cleared ensure offset pegs are still in place

Figure 50 - Setting out road using pegs.

The tables above are not appropriate for setting out box cut or all fill cross sections. Therefore, the following calculations should be made to determine the correct setout pegs locations.

7.1.1.1.2.1 All cut cross section



$$b = \frac{\sin(\alpha)}{2\sin(\alpha-\theta)} \qquad a = \frac{\sin(\alpha)}{2\sin(\alpha+\theta)}$$

$$j = \frac{\cos(\alpha)}{\sin(\alpha-\theta)} \qquad h = \frac{\cos(\alpha)}{\sin(\alpha+\theta)}$$

Figure 51 - Calculating the offsets for the top of a batter for an all cut cross-section

Offset cuts A and B can be calculated by the equations above, or by the following tables (table 14 and 15)

Example:

Formation width (W) = 6.6 m

Cut depth at centreline (C) = 1.5 m

Side slope (S) = 40%

Therefore offset distances:

A (uphill offset) = W x b + C x j = 7.7 x 0.77 + 1.5 x 0.77 = 5.4 m

B (downhill offset) = W x a + C x h = 7.7 x 0.45 + 1.5 x 0.45 = 3.7 m

	Calculating Batter Peg Offsets Constants, a & b Cut Slope = 200% Add the appropriate number below to offsets h and j.					
	Width, W =1.0 metres		Width, W =7.0 metres		Width, W =8.0 metres	
Slope (%)	a	b	W x a	W x b	W x a	W x b
10%	0.48	0.53	2.87	3.17	3.83	4.23
20%	0.47	0.57	2.78	3.40	3.71	4.53
30%	0.45	0.71	2.72	3.78	3.73	4.91
40%	**0.45**	**0.77**	2.79	4.04	3.59	5.39
50%	0.45	0.75	2.78	4.47	3.58	5.97
70%	0.45	0.83	2.79	5.00	3.59	7.77
70%	0.45	0.94	2.71	5.73	3.72	7.51
80%	0.47	1.07	2.74	7.40	3.77	8.54
90%	0.47	1.22	2.78	7.34	3.71	9.78
100%	0.47	1.41	2.83	8.49	3.77	11.31
110%	0.48	1.75	2.88	9.91	3.84	13.21
120%	0.49	1.95	2.93	11.72	3.91	15.72

Table 14 - Table to calculate offset constraints a and b for a cut slope (α) of 200%

	Calculating Batter Peg Offsets Constants, h & j Cut Slope = 200% Add the appropriate number below to offsets a and b.					
	Cut Depth, C=1.0 m		Cut Depth, C =2.0 m		Cut Depth , C=3.0 m	
Slope (%)	h	i	C x h	C x i	C x h	C x i
10%	0.48	0.53	0.97	1.07	1.44	1.59
20%	0.47	0.57	0.93	1.13	1.39	1.70
30%	0.45	0.71	0.91	1.23	1.37	1.84
40%	**0.45**	**0.77**	0.90	1.35	1.35	2.02
50%	0.45	0.75	0.89	1.49	1.34	2.24
70%	0.45	0.83	0.90	1.77	1.35	2.50
70%	0.45	0.94	0.90	1.88	1.37	2.82
80%	0.47	1.07	0.91	2.13	1.37	3.20
90%	0.47	1.22	0.93	2.45	1.39	3.77
100%	0.47	1.41	0.94	2.83	1.41	4.24
110%	0.48	1.75	0.97	3.30	1.44	4.97
120%	0.49	1.95	0.98	3.91	1.47	5.87

Table 15 - Table to calculate offset constraints h and j for a cut slope (α) of 200%

7.1.1.1.2.2 All fill cross section

Use the tables and diagram below for cross sections consisting of all fill.

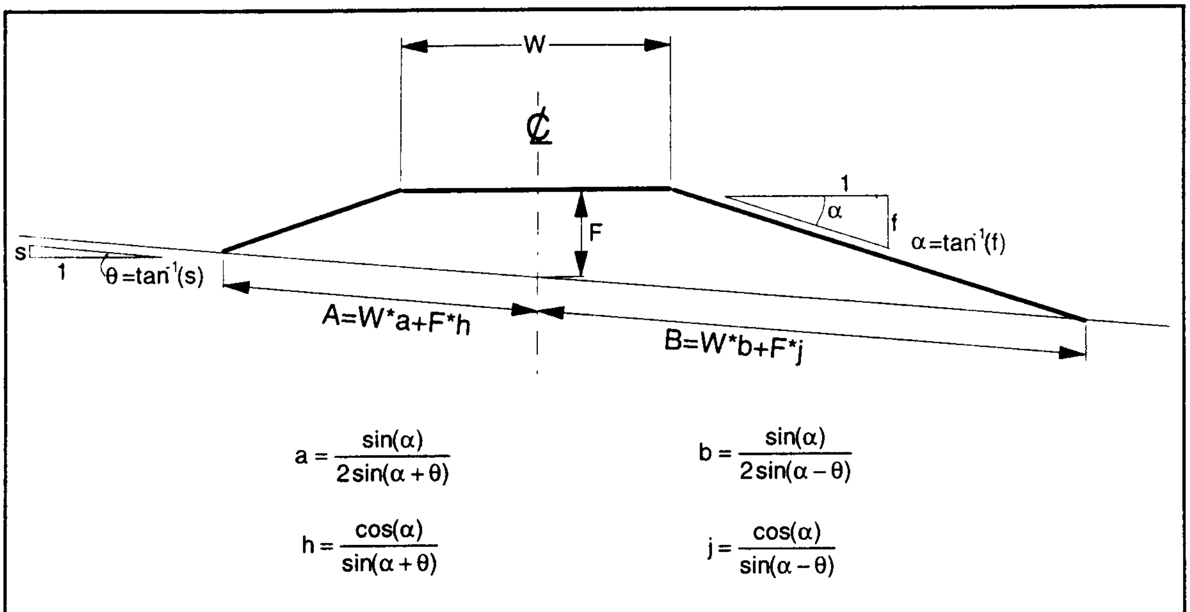


Figure 52 - Calculating the offsets for the bottom of a batter for an all fill cross-section.

	Calculating Batter Peg Offsets Constants, a & b **Fill Slope = 70%** **Add the appropriate number below to offsets h and j.**					
	Width, W =1.0 metres (Multiplier)		**Width, W =7.0 metres**		**Width, W =8.0 metres**	
Slope (%)	**a**	**b**	**a**	**b**	**a**	**b**
10%	0.59	0.44	3.52	2.74	4.79	3.52
20%	0.71	0.40	4.28	2.38	5.71	3.17
30%	0.91	0.37	5.48	2.19	7.31	2.92
40%	**1.27**	**0.34**	7.54	2.07	10.05	2.74

Table 16 - Table to calculate offset constraints a and b for a fill slope (α) of 70%

	Calculating Batter Peg Offsets Constants, h & j Fill Slope = 70% Add the appropriate number below to offsets a and b.					
	Cut Depth =1.0 metres (Multiplier)		**Cut Depth =2.0 metres**		**Cut Depth =3.0 metres**	
Slope (%)	h	j	h	j	h	j
10%	1.77	1.27	3.35	2.51	5.02	3.77
20%	2.04	1.13	4.08	2.27	7.12	3.40
30%	2.71	1.04	5.22	2.09	7.83	3.13
40%	**3.59**	**0.98**	7.18	1.97	10.77	2.94

Table 17 - Table to calculate offset constraints h and j for a fill slope (α) of 70%

Example:

Formation width, W = 7.7 m

Fill depth at centreline, F = 1.5 m

Side slope = 40%

Therefore offset distances:

A (uphill offset) = W x b + C x j = 7.7 x 0.34 + 1.5 x 0.98 = 3.7 m

B (downhill offset) = W x a + C x h = 7.7 x 1.27 + 1.5 x 3.59 = 13.7 m

Now that the road has been designed and setout, step 2 can proceed.

7.1.1.2 Road has been designed and setout with pegs.

The logging crew should be instructed to remove all the trees contained within the pegs (figure 53). After the trees have been removed the pegs should be checked to ensure they are still in place. The pegs determine the width for the bulldozer or excavator to clear all organic matter (figure 54).

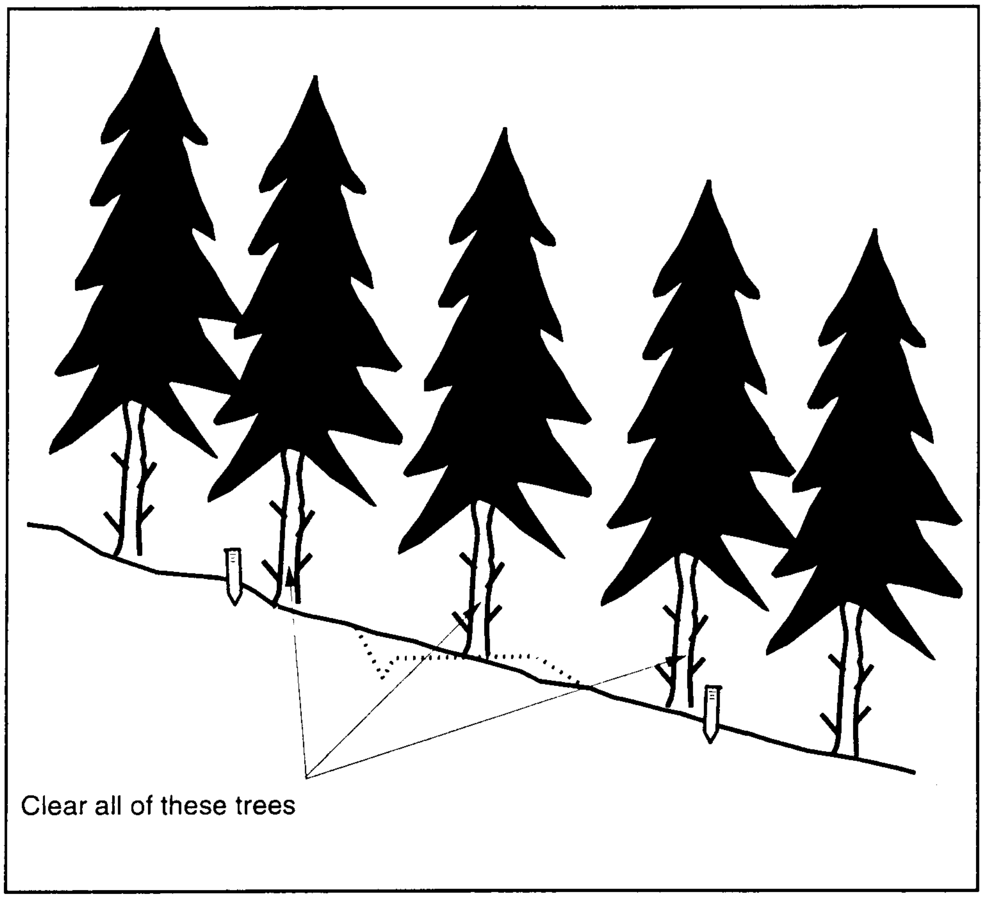


Figure 53 - Trees that are to be cleared for earthworks.

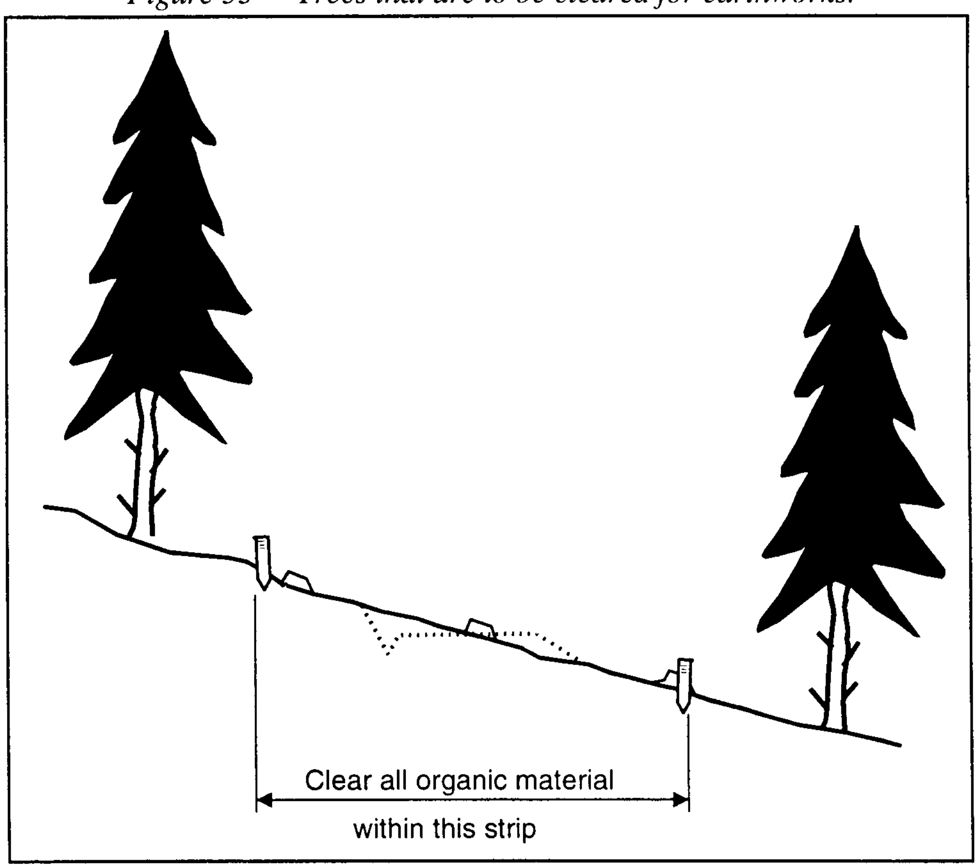


Figure 54 - Width to be cleared of all organic material for earthworks.

7.1.2 Daylighting

Daylighting is the process of removing trees on either side of the road to allow sunlight onto the road. This assists drying which will result in a firmer road, and reduce rutting. The clearing width is very dependent on the position or aspect of the road. There is little point in clearing a 40 m width of trees either side of the road if the sun will not reach the road in the middle of winter. It may be more beneficial to remove the north-facing trees, and leave the south-facing trees standing (figure 56). The mid-winter sun is then more likely to dry the road.

The daylighting width should be kept as small as possible, to ensure that the maximum productive area remains. Figure 55 can be used to estimate the amount of clearing width required, assuming that at least 1 hour of sunlight must hit the road on the shortest day of the year. A negative value denotes that the south-facing trees are to be cleared.

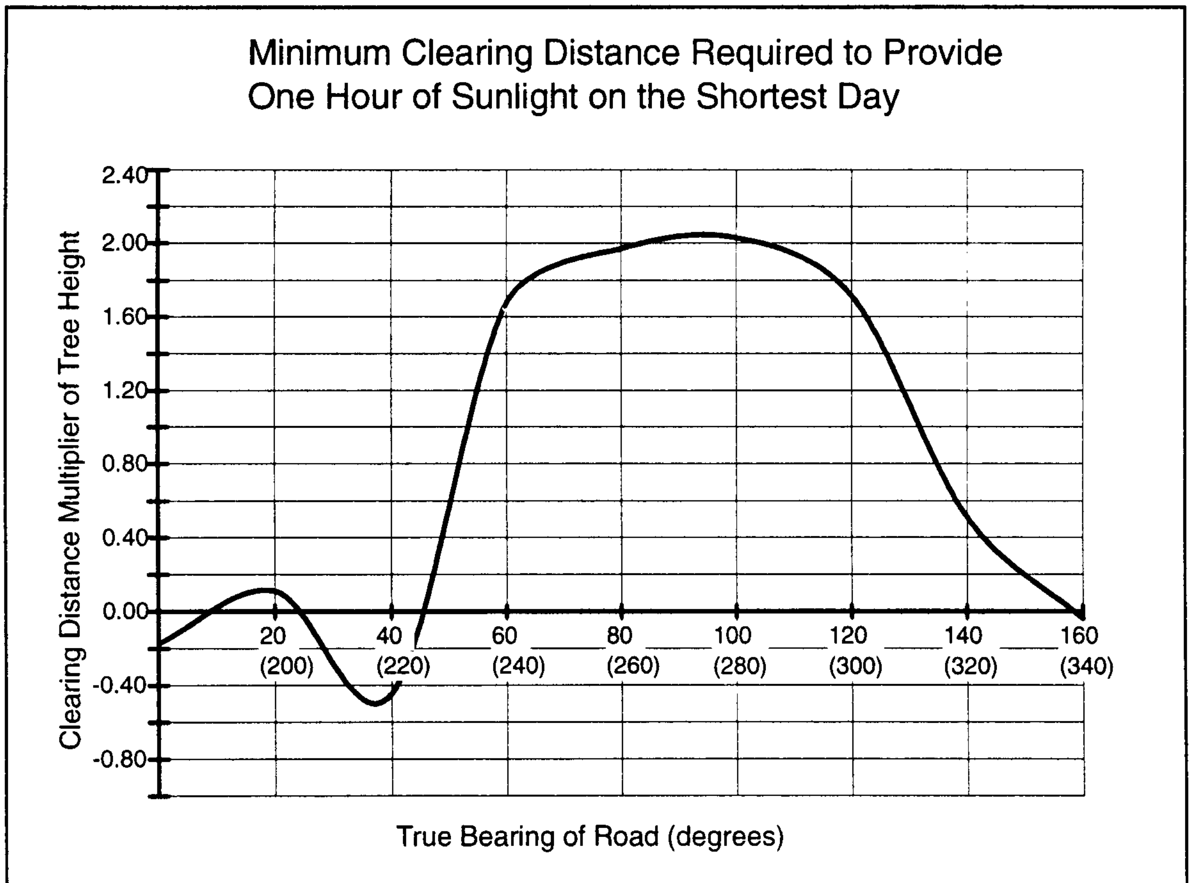


Figure 55 - The minimum clearing width required to provide at least one hour of sunlight on the road for the shortest day.

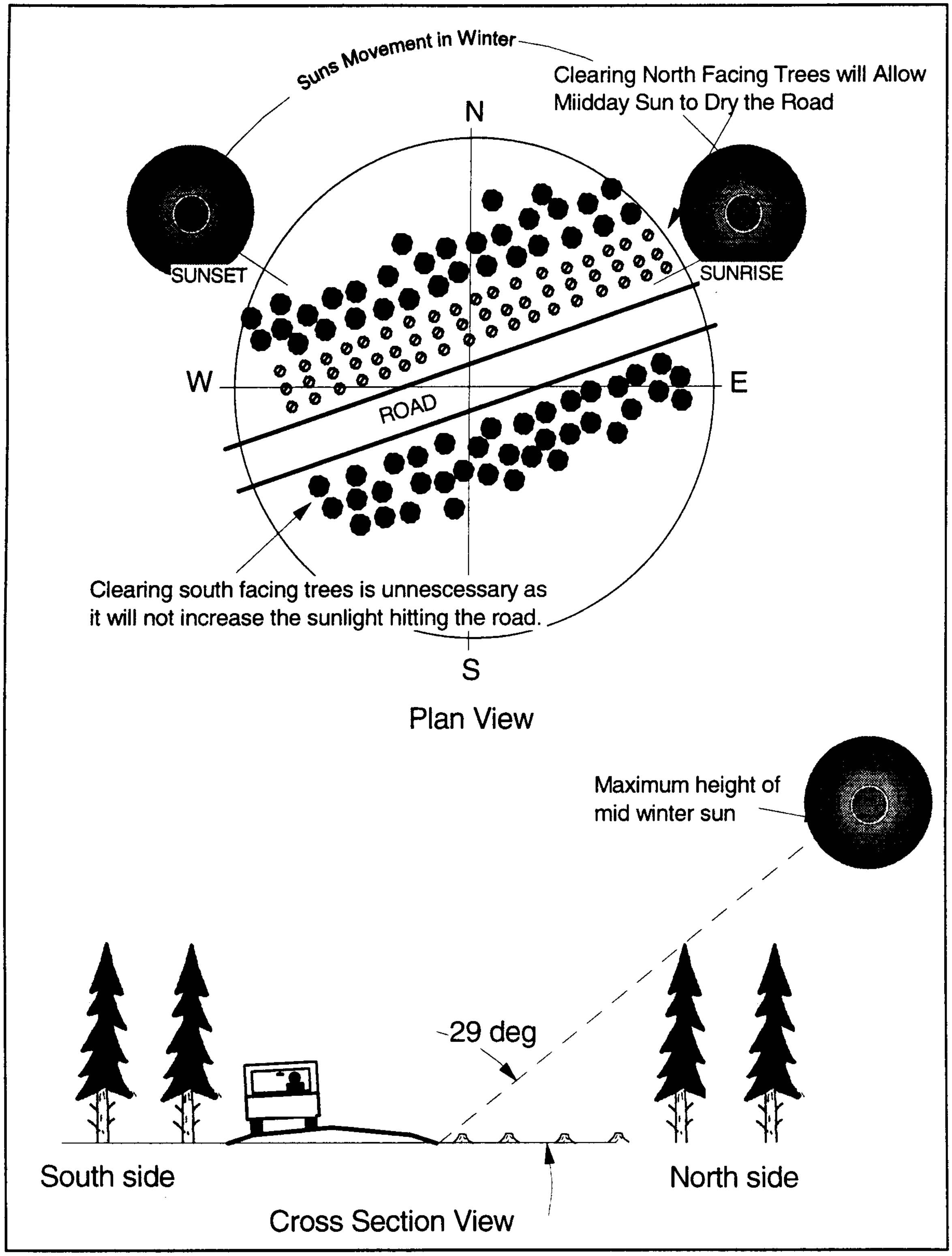


Figure 56 - Position of mid winter sun and the effect of cutting north-facing trees for daylighting.

7.2 TYPE OF EARTHWORKS

The following procedure will allow machine operators to correctly place cut slopes.

- Starting at the top of the cut slope, material is excavated and sidecast or removed until the desired road grade and width is obtained.
- Cut material can be pushed or "drifted" in front of the blade to areas where fill is needed, for example to cover culverts or build up flat areas.
- Fill needs to be spread and compacted in layers in order to improve strength.

While "cut and fill" road construction is common for gentle terrain, slopes over 40% usually require full-bench roads. Roads constructed in steep terrain can have an adverse impact on the environment, since steep, unconsolidated fill slopes are prone to surface erosion and mass movement during periods of intensive rainfall.

7.2.1 End-hauling

End-hauling road construction is one method used to minimise the adverse environmental effect of fill slopes. It should be used when the impact of sidecasting material is too great -on steep slopes, sidecast material may roll or slide down the slope, and into gullies and waterways, resulting in a negative environmental and visual impact. End-hauling actually removes the entire excavated material to a disposal area (figure 57).

End-hauling construction typically requires an excavator to form the road, and trucks to cart the excavated material to the dump site. Each bucket of excavated material is either stockpiled for later dumping, or loaded directly onto a truck. The loaded truck will then dump the fill material in a designated area, while a second truck prepares to be loaded.

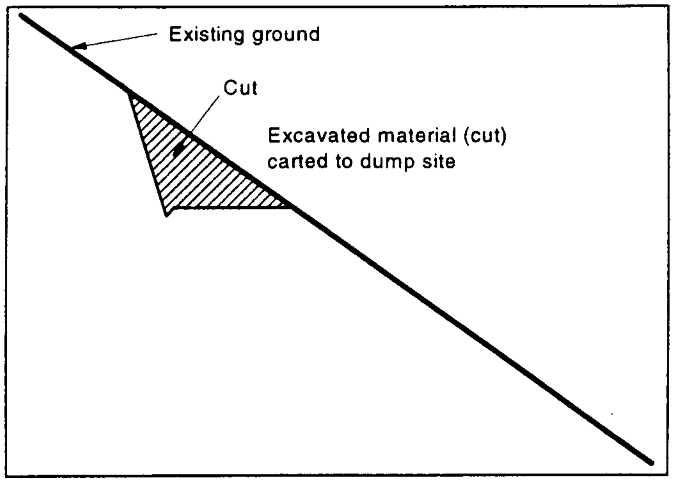


Figure 57 - End haul construction

The cost of end-hauling may be up to ten times greater than the cost of conventional sidecast construction. However, increased road stabilisation and reduced negative environmental and visual impacts can make end-hauling operations the best choice in some situations

To minimise the cost of construction it is important to optimise the number of trucks, and the size of excavator. The efficiency of an end-haul operation, including optimal dump site distance, turn out spacing, and machinery, is outlined below.

7.2.1.1 Reasons for End-hauling Construction

Regional requirements, topography, geology and proximity to water courses and public roads determine the need for end haul road construction. These five factors are summarised below:

7.2.1.1.1 Regional Requirements

Controlled, discretionary or non-complying activities may require the adequate disposal of waste and fill as a condition. On steep slopes an end-haul operation may be the only option which complies with this condition. However, the Territorial Authority may permit other options, such as fill compaction and hydroseeding.

7.2.1.1.2 Topography

On steep slopes > 70% (35 degrees), fill material cannot be supported on the slope. The result is a very long, unconsolidated, fill slopes which are prone to erode and move down the slope. In addition, the fill has insufficient strength to support vehicle weight.

7.2.1.1.3 Geology

In very erodible soil types such as granites, Territorial Authorities may restrict or prohibit road construction. End haul construction is unsuitable in some erodiable soil types (Chatwin *et al*, 1994):

- Unstable Rock, especially soft sedimentary with unfavourable bedding plains, may not be suitable for full-bench cuts.
- Deep Soft Clay Soils, such as lacustrine or marine soils, may also be unsuitable for end-hauling and may induce rotational failures.

7.2.1.1.4 Proximity to Water Courses

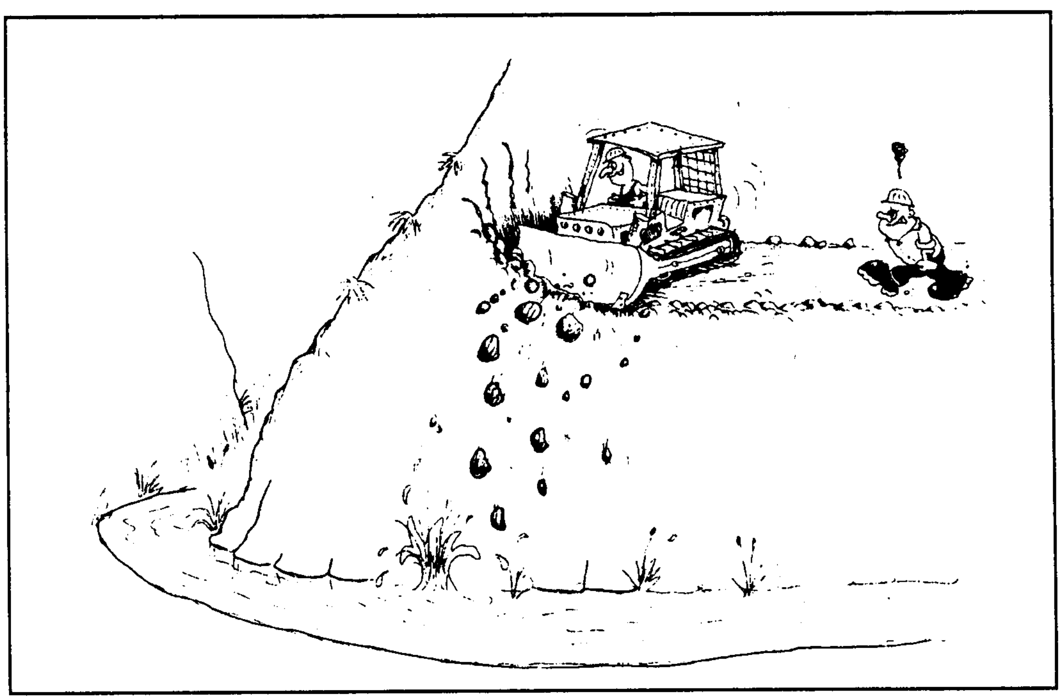


Figure 58 - Road construction near waterways on steep slopes - a sure method to produce large amounts of sedimentation

Road construction near waterways can potentially have a great impact on the environment, particularly on steep slopes (figure 58). In these situations, care must be taken to ensure that there is no sidecast material entering the waterway.

7.2.1.1.5 Proximity to Public Roads

Newly constructed roads which can be seen from public roads or townships have a high visual impact. They result in conspicuous lines on the landscape, through contrast between existing vegetation cover and the exposed underlying lighter coloured soil. Most people will accept a small amount of visual change in a plantation forest, but they are likely to resist the change if they observe careless, wasteful or unnecessarily destructive management practices. On steep slopes, mid-slope roads can look unattractive, due to the sidecast material carrying down the slope. End haul construction could be used to avoid this. Alternatively, the tree cover may hide the problem, and eventually vegetation will establish on the side cast material to reduce the contrast.

7.2.1.2 Types of End haul Construction

Two options for end haul construction are available:

7.2.1.2.1 One Pass

With one pass method, an excavator clears the trees and stumps, and forms the road in one pass. Every bucket load of material is loaded directly onto a truck for transportation to a disposal site. This method is suited to the construction of narrow one-lane roads in very steep country. An additional benefit is less risk of sediment entering streams than with other methods.

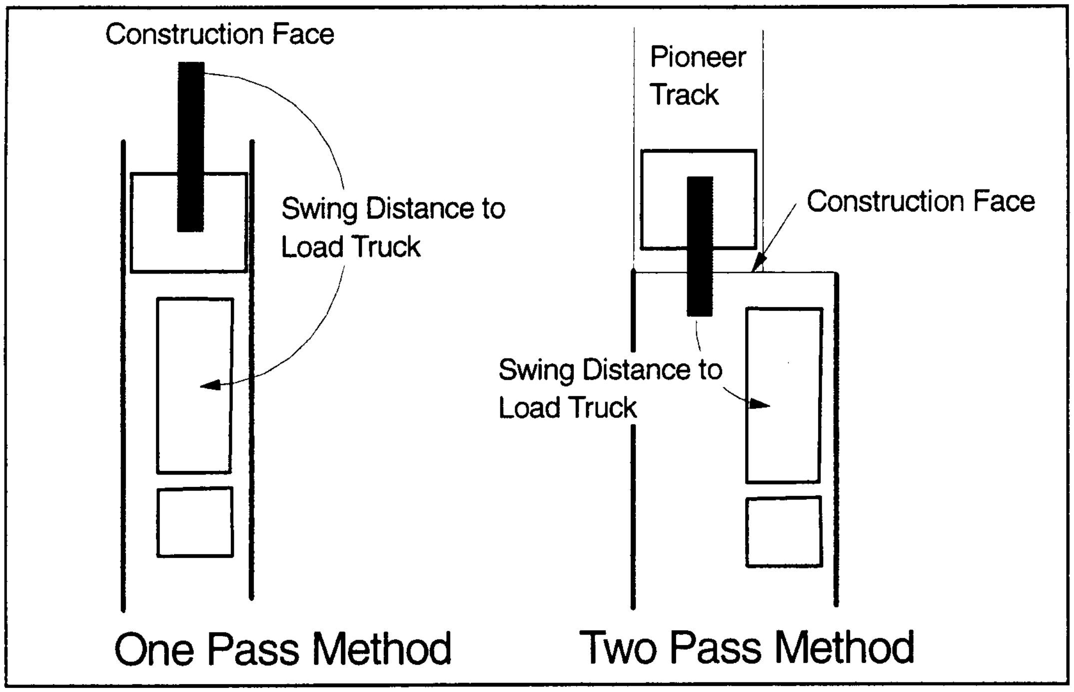


Figure 59 - One and two pass method of end-haul construction (swing time is reduced using the two pass method).

7.2.1.2.2 Two Pass

The two pass method is ideal for two lane roads. A small pilot track is initially constructed at approximately the $\frac{3}{4}$ mark (figure 60). The excavator then constructs the final road, loading both the side cast and excavated material into trucks, while backing along the pilot track. This method is cheaper than the one pass method since the swing time between excavation and loading is reduced. This method is only suitable if the excavated material will remain stable on the side of the hill while awaiting disposal.

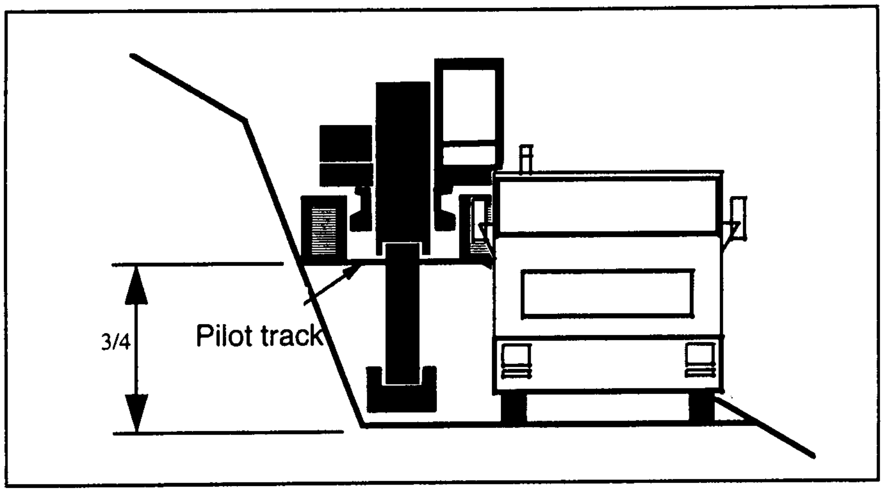


Figure 60 - The two pass method

7.2.1.3 End-haul calculations

7.2.1.3.1 Cycle Time

The procedure used to estimate one cycle time is outlined below. It should be noted that successive cycle times will be different, due to road construction length increasing linearly by ΔL after every truckload:

$$\Delta L = \frac{\text{Total End Haul Length} \times \text{Carrying Capacity}}{\text{Total Earthworks Volume}}$$

Total cycle time (T_{Total}) for a particular truck is equal to the maximum of either:

- the uninterrupted cycle time (T_{un})
- or the number of trucks (n), multiplied by the bottle neck time ($T_{Btlneck}$)

Therefore:

$$T_{Total} = \max(T_{Un}, n \times T_{Btlneck})$$

where:

T_{Un} = the total time for a truck to be loaded, dispose of the load, and return to the excavator for loading again (excludes waiting time).

$T_{Btlneck}$ = the total time from a truck entering the newly constructed one lane road, to leaving it after being loaded. No other truck can enter the newly constructed road during this time until the truck being loaded has departed.

The bottleneck time and uninterrupted time can be calculated using the following formula (Numbers refer to the positions labelled in figure 61):

$$T_{Btlneck} = T_{2-1} + T_{Load} + T_{1-2}$$
$$T_{un} = T_{load} + T_{1-3} + T_{Dump} + T_{3-2} + T_{turn} + T_{2-1}$$

where:

T_{1-3} = travel time from position 1 to 3

T_{3-2} = travel time from position 3 to 2

T_{2-1} = travel time from position 2 to 1 (Reversing)

T_{Load} = the total time a truck is required to wait at position 1 to be fully loaded

T_{Turn} = the time required for the truck to turn around at position 2 ready for reversing to the excavator (position 1)

T_{Dump} = the total time, from when the truck arrives at the dump site (position 3), to turn around, dump the spoil and be ready to leave

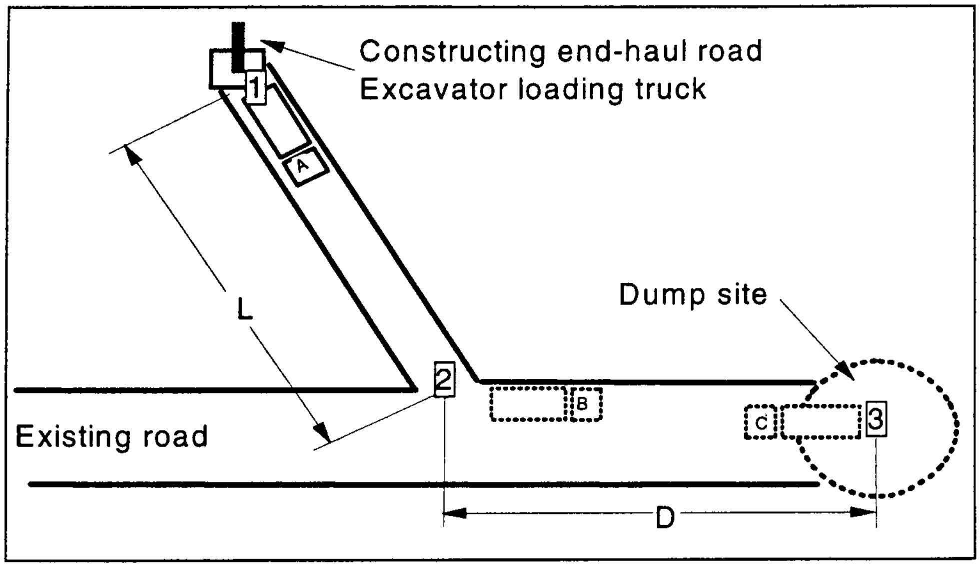


Figure 61 - Typical end-haul scenario

7.2.1.3.2 Factors to Consider

- ***Accurate Inputs***

Accurate results are only obtained from accurate inputs while it is common to use a 30-tonne excavator in combination with two 15 m^3 all-wheel drive dump trucks, the performance of these machines will be different to a 20-tonne excavator and eight-wheeler gravel trucks. Therefore, model inputs should be altered to suit values applicable to the machinery used and the conditions encountered.

- ***Passing Bays on a one-lane road construction***

Installing passing bays at regular intervals along a one-lane road construction (figure 62) will increase production, since the excavator has less time to wait for the next truck to load, i.e. the bottleneck time ($T_{btlneck}$) is reduced.

A new value for $T_{Btlneck}$ can be approximated by calculating the time the truck takes to travel between the passing bays.

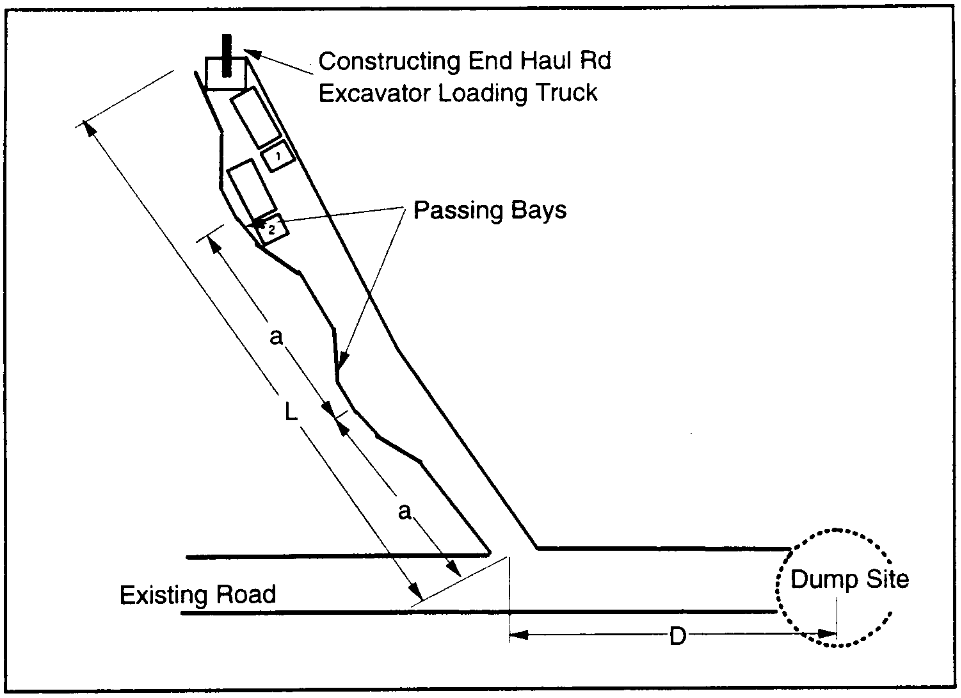


Figure 62 - Typical end-haul road construction with passing bays.

- ***Truck Speeds and Excavator Loading Times***

Excavator production can be considerably slowed by hard rock. Also, a change in the dump sites could result in different truck speeds. Where inputs are expected to change, the road should be divided into segments with similar characteristics, and costed separately.

- ***Additional Costs***

The above model does not take into account any additional costs, such as the optional use of a bulldozer to level and compact the fill on the dump site, metalling, blasting or logging. These costs will need to be calculated separately, and added to the total cost.

7.2.1.3.3 Example

End haul Road Construction Inputs	
Road Description	
Total end-haul length	1000 m
Average dump distance	500 m
Average turnout spacing	200 m
Formation width	4 m
Average side slope	80 %
Total earthworks volume	*11267 m^3
Sidecast material (i.e: rock suitable for sidecast)	*1127 m^3
End-haul volume	*10140 m^3
Dump Truck	
Carrying capacity	8 m^3
Number	3
Truck loaded speed	2.74 m/s
Loading time	122 s
Dumping time	104 s
Turn in preparation for reversing	36 s
Truck empty speed	2.57 m/s
Truck reverse speed	1.36 m/s
Hours paid per day	9.5 hrs
Productive hours per day	8 hrs
Hourly rate	66 $/hr
Excavator	
Bucket capacity	1.14 m^3
Loading time per bucket	17.47 s
Hours paid per day	9 hrs
Productive hours per day	8 hrs
Hourly rate	100 $/hr

Table 18 - End haul variables.

(End haul volume is calculated assuming 10% waste).*

Using the values in table 18 and the formulae below, the production and efficiency of the operation can be calculated.

$$T_{Btlneck} = T_{2\text{-}1} + T_{Load} + T_{1\text{-}2}$$

$$T_{un} = T_{load} + T_{1\text{-}3} + T_{Dump} + T_{3\text{-}2} + T_{turn} + T_{2\text{-}1}$$

Step 1.- Determine T_{total}

$$T_{Load} = 8\ m^3/1.14\ m^3 \times 17.47\ sec$$
$$= 122.6\ sec$$

$$T_{1\text{-}3} = (1000\ m + 500\ m)\ /\ 2.74\ m$$
$$= 547.4\ sec$$

$$T_{dump} = 104\ sec$$

$$T_{3\text{-}2} = 500\ m\ /\ 2.74\ m/s$$
$$= 182.5\ sec$$

$$T_{turn} = 36\ sec$$

$$T_{2\text{-}1} = 1000\ m\ /\ 1.36\ m/s$$
$$= 735.3\ sec$$

Therefore: $T_{un} = T_{load} + T_{1\text{-}3} + T_{Dump} + T_{3\text{-}2} + T_{turn} + T_{2\text{-}1}$

$$T_{un} = 1727.8\ sec$$
$$= 28.8\ min$$

Now:

$T_{2\text{-}1}$ = 200 m / 1.36 m/s

= 147 sec

T_{load} = 122.6 sec (as above)

$T_{1\text{-}2}$ = 200 m / 2.74 m/s

= 73

Therefore:

$T_{Btlneck} = T_{2\text{-}1} + T_{Load} + T_{1\text{-}2}$

$T_{Btlneck}$ = 342.6 sec

using 3 trucks:

n x $T_{Btlneck}$ = 342.6 sec x 3
= 1028 sec
= 17 min

So, since T_{un} > n x $T_{btlneck}$, then:

T_{total} = <u>T_{un} = 28.8 min</u>

Step 2.- Calculating the cost of end-hauling

One truck cycle/hr = 60 / 28.8 min

= 2.08 cycles / hr

@ 3 trucks = 2.08 cycles / hr x 3

= 6.25 trucks / hr

@ 8 m^3/truck = 50 m^3 / hr

8 hours production per day = 8 x 50
= 400 m^3 / day

Therefore daily cost:

3 trucks x \$ 66 / hr x 9.5 hrs (Payed)
= \$ 1881 / day

1 excavator x \$100 / hr x 9 hrs (Payed)
= \$ 900 / day

Total	**= \$ 2781 / day @ 400 m^3 / day**
	= \$ 6.95 / m^3

7.2.1.3.4 How to Minimise Costs

End-hauling is expensive, but there are ways to minimise the total costs.

- ***Avoiding End haul Construction***

The cheapest option is to avoid end-haul construction altogether. Remember though, that any alternatives may need to be approved by the council through the consent process. However, there is still a risk of fill slope failure if suitable methods are not used.

- ***Minimising Earthworks***

Every bucket load of material loaded onto a truck for disposal incurs a cost. Minimising the total number of bucket loads required will reduce the total cost. Pegs can be placed to show the top of the cut batter (figure 63) to ensure that the correct formation is constructed (see chapter 6).

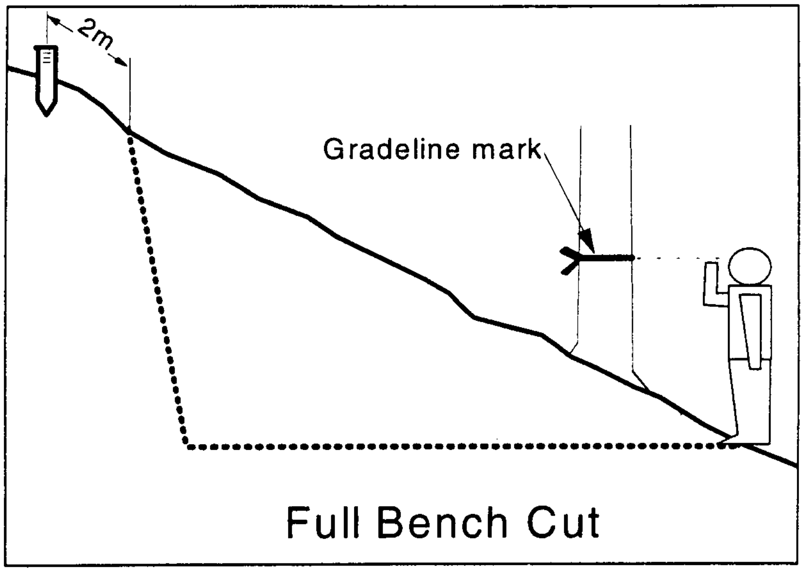


Figure 63 - Set-out of cut batter peg

- ***Truck Size***

Specialised dump trucks such as the Bell 6x6 are designed specifically for moving large quantities of earth. They have a capacity of 15 m^3, and their all-wheel drive and large tyres allow them to travel quickly over rough terrain. Also they can also drive on soft and wet ground without the need for aggregate which can be applied once the road formation has been completed. The effect on end haul cost using other types of machinery can also be evaluated.

- ***Disposal Site Distance***

Disposal site distance (D) has the largest impact on costs - cost increases directly with an increase in disposal site distance. The optimum number of trucks will also increase, since it takes longer for trucks to return to the loading position. The effect of increasing dump site distance on cost is illustrated in figure 64.

Careful inspection of the area is required to identify the closest possible dump sites. Ideally these dump sites should be flat, e.g. abandoned landings or roads. More than one dump site may be required, and it is important to plan their location to avoid delays during construction.

- ***Passing Bays***

Sufficient passing bays are required to reduce the waiting time for the excavator. Usually, bays can be constructed within naturally occurring areas where the terrain is flatter. Where no flat areas exist, a passing bay should still be constructed so that maximum turnout spacing does not exceed 300 m. If the number of trucks used is less than the optimum, the constructed passing bays will be under-utilised and full savings will not be realised.

Varying any of the inputs contained in table 18 will allow the efficiency and total cost of the operation to be calculated. This allows variations in the number of trucks used, turnout spacing and disposal site distances to be compared.

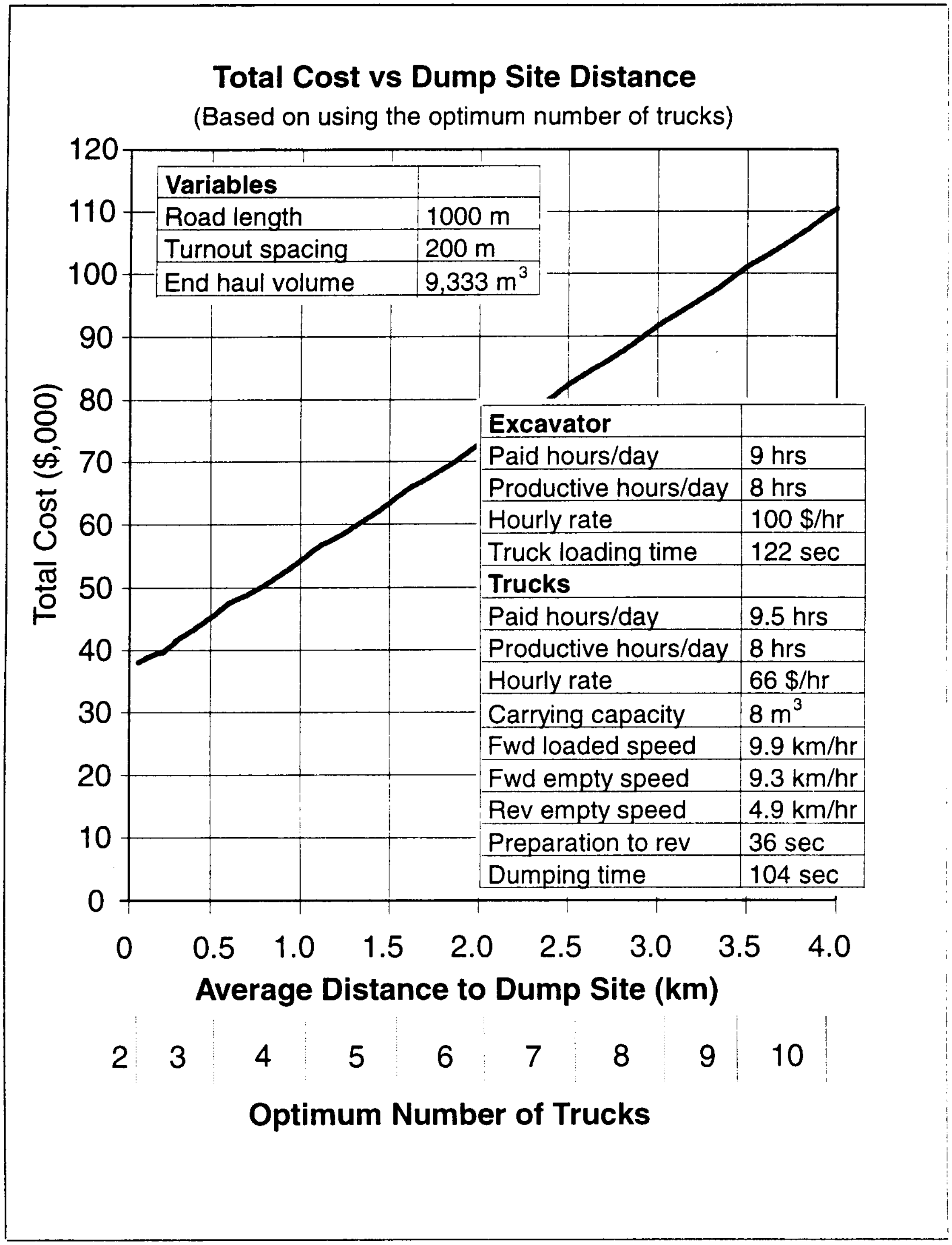


Figure 64 - The effect of changing disposal distances on cost

7.2.2 Side-casting

The side-casting method is used for most road construction in low to moderate terrain. A percentage (possibly all) of the excavated material is "sidecast" on to the hill slope (figure 65). During the process, it is critical to avoid the side-cast material entering streams. Nor should it be placed on unstable areas where it might erode.

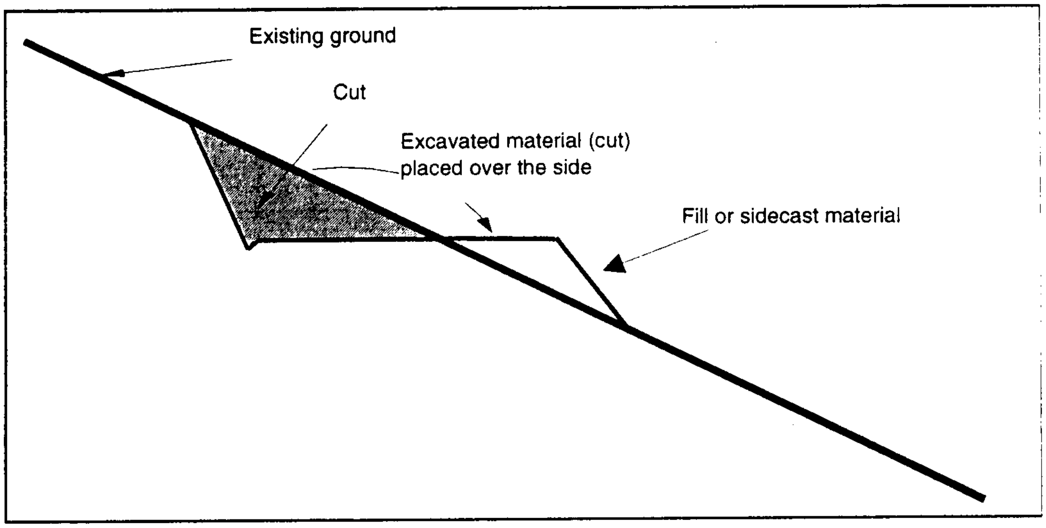


Figure 65 - Sidecast construction

7.2.3 Sidecast Pull Back

Sidecast pull back is where usual side casting methods of road construction are used, with either an excavator or dozer. After logging, when the road is no longer needed, an excavator pulls back onto the road as much of the sidecast material as possible. This method does not eliminate the risk of sediment entering the waterways, but it does the quantity available for mobalisation. This is because, at best only half of the sidecast material can be recovered and the rest still has the potential to move down the slope into the gullies and waterways.

Sidecast pull back is not strictly end hauling and approval from the council may be required.

7.2.4 Benching

Benching can be used to contain the sidecast fill, preventing it from sliding down the hill into the gullies or waterways. A small bench is constructed below the road formation to catch the sidecast material (figure 66).

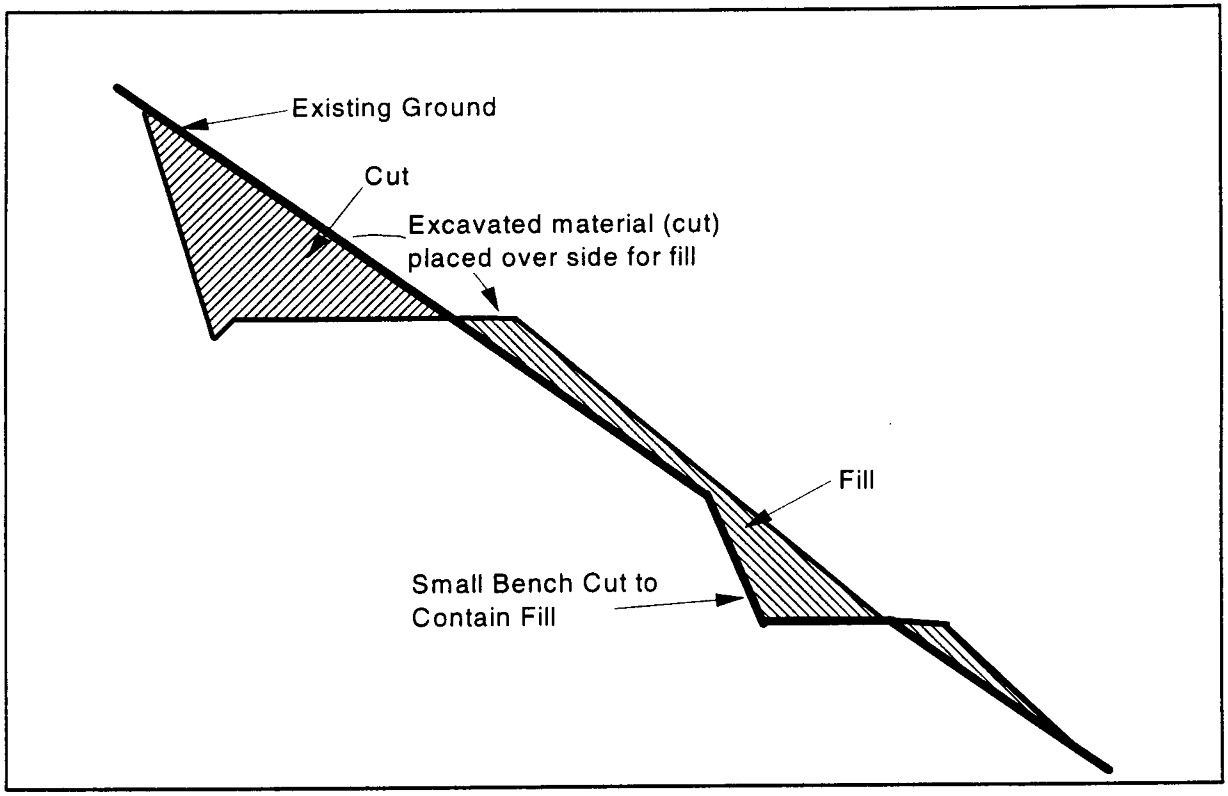


Figure 66 - Bench cut to contain sidecast fill.

On steep slopes, the fill material cannot be compacted, so vegetative cover (e.g. via hydroseeding) may be required to prevent erosion.

7.3 SEQUENCE OF EARTHWORKS

7.3.1 Method One - Flat to Moderate Terrain

As discussed above, the sidecast method can be used for flat to moderate terrain. The sequence of earthworks is as follows:

1. Remove any trees, stumps, or other vegetation, and either remove then from the site or place then on the side of the hill
2. Strip off the topsoil, and either remove it or place it over any stumps (Do *not* use this material as fill)
3. Form the road by cutting and sidecasting material over the side
4. Form the batter slope to its correct angle
5. Shape the road camber and watertable to allow effective drainage

7.3.2 Method Two - Steep Terrain

If end haul methods are to be used for steep terrain, the steps involved are:

<u>One pass method</u>

1. Remove any trees, stumps, or other vegetation, and either remove them from the site, or place them over the hillside
2. Faces the cut slope (in the direction of the road) with the excavator, and remove the material from the slope, swinging 180 degrees to load it into trucks
3. Form the batter slope at the correct angle
4. Shape the road camber and watertable to allow effective drainage

<u>Two pass method</u>

1. Place pilot track at $\frac{3}{4}$ mark by stripping any trees or stumps, vegetation, top soil and sidecast
2. Facing back down the road, the excavator digs beneath itself backing along the pilot track. In this case the excavator only swings 90 degrees to load the trucks
3. Form the batter slope at the correct angle
4. Shape the road camber and watertable to allow effective drainage

7.4 EMBANKMENTS AND SOLID FILL

The choice of material for the construction of embankments and solid fill is critical to ensuring a long life for the road. Organic material, stumps and other vegetation should not be used as fill material, Since it will not compact to a hard surface, and may eventually break down, leaving soft spots which could develop into holes and embankment failures.

Correct compaction of fill material will ensure that natural settlement is minimised, this increasing the life of the road. The following guideline should be followed when compacting fill material.

Vibrating Roller Mass in Tonnes (Static)	Loose Layer Depth (mm)		
	Towed Roller	Self Propelled	Tandem
4	250	-	-
5	500	400	350

Table 19 - Loose layer depth for compacting clean sand

Vibrating Roller Mass in Tonnes (Static)	Loose Layer Depth (m)	
	Towed Roller	Self Propelled (single drum)
5	1.0	-
10	1.5	1.0
15	2.0	1.5

Table 20 - Loose layer depth for compacting coarse rockfill

Best compaction of a soil is achievable at its optimum moisture content (OMC). To achieve OMC:

- If too dry add water during cutting for mechanical mixing during handling, followed by further watering during placement of the fill.
- If too wet provide good drainage during earthworks to stop materials becoming too wet, should leave work at end of day lightly compacted and shaped to shed water.

7.5 MACHINERY

7.5.1 Excavators

- The excavator has a workzone that allows it to obtain materials that are inaccessible to a bulldozer.
- The excavator operator has much better control over the materials being moved and he can efficiently sort out those that are undesirable for structural fill and thereby improving the

quality of road being built.

- It is usually not practical for the excavator to go outside its workzone to get material since it's travel speed is much slower than the bulldozer's (4 vs 10 km/h).
- The excavator's ground pressure is lower than the bulldozer's allowing it to work in areas where the bulldozer cannot.
- A narrower right of way is required when an excavator is used which decrease the area exposed to erosion.
- An effective drainage system can be put in place with the excavator reducing the need for borrow pits.
- Correct excavator specifications are important to obtain the best performance. Some components such as the stick and bucket, affect the resulting tooth forces which in turn determine the range of applications and, in part, the production rate.
- The main function for the excavator is probably to build the subgrade, spreading the fill as it is being dumped. Levelling may then be done with a relatively small amount of bulldozer time.
- The excavator is the best machine for culvert installation.
- Compacting with the excavator is not very efficient due to the slow travel speed and low ground pressure.
- Productivity can be increased if bulldozers and excavators are used in combination.
- Excavators may have distinct advantages when upgrade old roads, to load gravel, to extract hard fill and to work in environmentally sensitive areas such as stream crossings.
- Excavators with other attachments can be used to load wood or break rock.
- For excavating hard materials a short stick and a short tip radius bucket achieves the highest tooth forces.
- Using a short stick will reduce the reach by 0.8 to 1.5 m but it will increase the digging force by 25 to 35%.
- A short tip radius bucket will increase the breakout force by 5 to 12%, but the reduction in reach is 0.05 to 0.20 m.
- As a rule, the softer the material the wider the bucket can be used and vice versa. In hard rock reduce the bucket width to apply a higher force per mm of cutting edge.
- A wider bucket can shorten the stick life through the twisting action, which occurs when the bucket corner hits a "fixed" object while digging.

- A longer stick has a higher potential for damage due to swinging into things.
- There are several classes of buckets. They range from: *extra heavy duty* ones for tough rock and other severe applications; *heavy duty* for use where rock is encountered occasionally; and *medium and light duty* buckets for soft materials.
- The local conditions will determine which stick and bucket combination will give optimal production.

Bucket capacities

- Buckets can be changed in a matter of minutes using a quick coupling system. Such a system allows the use of a wider bucket for soft materials, e.g. sand, organic soils and a narrower one for removing stumps and excavation of harder materials.
- Several different types, makes, and sizes of buckets are available for any specific size of a hydraulic excavator.

Boom

- There is usually a choice of one-piece or two-piece booms for excavators.
- The one-piece boom is used in forest road construction. It has a long reach, good digging depth and lifting capacity. In addition it is cheaper than the two-piece boom.
- The two-piece boom is more versatile since the foreboom extends or retracts to two or three positions. This gives varying reach in height and depth but also varying stability and lift capacity. Larger buckets can be used with the foreboom in a fully retracted position and using a short stick. A two-piece boom is good for truck loading applications.

Undercarriage

- Undercarriage on an excavator deteriorates due to fatigue from repeated point loading, impact loading and bending.
- Excavators working on relatively flat soft ground, free of rocks and stumps generally have few, if any undercarriage problems.
- In more severe conditions deterioration of the undercarriage can occur very quickly.
- The narrowest track satisfying the flotation requirements in your work conditions should be

used.

- To increase the life of wide tracks it is beneficial to equip the machine with full-length track guiding guards. These will improve track alignment with the rollers, sprockets and idlers.
- Single grouser shoes give the best traction, which may be useful in hilly terrain, but they may make it more difficult to turn the machine in cohesive soils. Double and triple grouser shoes are also available.
- The operator can help increase the undercarriage life by:
    - maintain level underfoot conditions rather than point supports on a few rocks
    - operate over the front rather than the side. Otherwise lift-off would occur causing link, roller, pin and bushing wear.
    - make gradual turns to reduce side thrust
    - maintain proper track tension

Extra Guarding

- Additional protection is required when working in a forest.
- Protective plate under the upper structure to protect against debris being pushed up from underneath.
- A wear plate on the stick where the bucket teeth can make contact may be useful.
- A Rollover Protective Structure (ROPS) canopy may be required.

7.5.1.1 Hydraulic Excavator Operating Techniques

- The techniques used are to a large degree related to the terrain.
- Construction of forest roads normally follow a standard sequence of events:
    - road layout
    - cutting of the right-of-way
    - staking
    - grubbing
    - subgrade construction
    - levelling and compacting of subgrade
    - culvert installation
    - application of aggregate

Road layout

- The unique capabilities of a excavator allow a road to go through areas that otherwise would be, considered unsuitable:
    - swamps that are too big for a bulldozer to cross on its own;
    - wet areas where careful sorting of road materials is required;
    - areas of abundant rock outcrops, where the road building material is located in small pockets that are inaccessible to a bulldozer.

Cutting of the right-of-way (ROW)

- The ROW cut maybe in a staggered pattern so that the excavator always has one side of the road free from which it can obtain fill.

Staking

- Staking the main roads during the construction is important for two reasons: to maximise the efficiency of the construction machine and to produce quality road alignments.

Grubbing with a bulldozer/excavator combination

- Grubbing involves the handling of waste materials of non-uniform size and shape to prepare the ground before the subgrade fill is put down. These include unmerchantable trees, stumps, branches, boulders and organic soils. Such material is probably moved more efficiently with a bulldozer blade than with a excavator bucket. In certain conditions, the grubbing maybe better done with the excavator. This will be discussed later.

- The two ways to treat the waste material are dependent on the material, individual company policies, terrain conditions and the class of road being built:
    - Use it in the road base to elevate the subgrade and to fill up depressions
    - Remove it from the roadbase with or without burial.

- In situations where the waste materials are not required or wanted in the roadbase
    - The standard practice has been to windrow them along the edges of the ROW.
    - They may be buried in the ditches that the excavator creates beside the road when building the subgrade. The bulldozer may therefore push the waste materials into a windrow on one side of the centre line or into windrows on either side.
    - The windrows must be far enough away to allow for the width of the road plus a ditch. After the excavator has removed the fill, the bulldozer can backfill the ditches with the materials in the windrow.

Grubbing with excavator

- Conditions where a bulldozer is unsuitable for grubbing include swamps and other wet areas, steep rocky hills and boulder fields.

- The superior flotation on the excavator allows it to put in a brushmat over a swamp if there are trees available within its reach. Providing there is fill below the swampy material the excavator can usually dig up to 5-7 metres below the surface.

- A excavator may still be able to cross a swamp area, which could not be traversed by a bulldozer.

- It should be noted here that using the corner of the bucket to pull down large trees can impart a twisting force in the stick, which could damage the stick yoke.

- In wet areas with unstable soil conditions:
    - the excavator does a better job than the bulldozer in removing wet topsoil without mixing it with good fill. It is also less likely to disturb any rootmat if it is best left in place.

- In steep rocky terrain, the excavator can work more easily than the bulldozer.
    - It can grub and gain access to pockets of fill, which would be inaccessible to the bulldozer blade.
    - Working a steep sidehill cut is easier with the excavator since less material needs to be moved. Unlike a bulldozer which would have to construct a ramp to reach the material.
    - The excavator is also superior for backsloping and for working around rocks.

- One technique for constructing a road, using only a excavator is:
    - The excavator travels in the ditchline and grubs from the centre line outwards. The waste material is windrowed between the edge of the road to-be and the ditch. The process is then repeated on the opposite side of the road.

Subgrade construction

- Excavators are most often used to construct the subgrade after the grubbing is completed.
- In most terrain conditions there is enough fill within reach of the excavator (8-12 metres at ground level) to allow it to work from a position on or beside the roadbed, or in the ditchline.

- This is an advantage since the bulldozers, if used for the grubbing, should have left a fairly even surface with an excavator to travel on. The smoother that surface is, the less wear on the excavator undercarriage and the greater the operator comfort.

There are a number of different methods used to construct the subgrade with a excavator.

1. Heaping the fill material

- A bulldozer is unable to work successfully with very wet fill. It is therefore common practice to heap up such fill to let it drain. The time it takes before a bulldozer can spread it varies between a few days to a year, depending on the soils involved.
- A excavator can remove very wet unwanted fill and then spread each bucket of desirable fill as it is being dumped. Spreading the fill will dry it out faster than when it is heaped up. Another advantage is that the operator can determine the correct amount of fill that is required. A skilled excavator operator can build a level subgrade, which requires little or no bulldozer work afterwards.
- Using the side of the bucket as a blade to spread the fill after it has been dumped will wear out the bucket and create detrimental side forces on the stick and boom. It is preferable to use a bulldozer to create a smooth subgrade.

2. *While digging out the fill, the excavator can be located in various positions*

- **The ditchline** - a excavator working from a position in the ditchline can do the digging over the front of the undercarriage to reduce wear. It can also reach further from the road to obtain the necessary fill.

- **Between the ditchline and the roadbase** - the excavator leaves a strip of ground slightly wider than the undercarriage. This is an advantage from a road safety point-of-view, but digging is done over the side of the undercarriage, which will increase wear.

- **On the roadbase** - The operator has the best, view of the road alignment from this position. Digging from this position is also over the side of the undercarriage.

- Two excavators can work together to build one half of the subgrade each for a wide road.

When the amount of soil obtainable with the excavator while sitting on the roadbed or in the ditch is insufficient for the subgrade.

  - A bulldozer can be used to push the material to within reach of the excavator.
  - Alternatively the excavator can be used to feed the bulldozer which then pushes it onto or along the road.

Levelling and compaction of the subgrade

- Levelling of the subgrade is usually done with a bulldozer.

- If the excavator spread the material during the dumping cycle and the operator kept an eye on the grade, the amount of levelling work with the bulldozer is minimised.

- If the material is heaped up, the bulldozer must be used for levelling.

- Few companies use compacters.

> ***Note:*** *Track compaction or no compaction will only be sufficient if the road pavement is left to settle and naturally consolidate for at least 6 to 12 months. If traffic is to use the road before this time compaction with rollers etc will be required. See chapter 9 section 9.4 "Compaction".*

Culvert installation

- Installation of culverts, is easily done with a excavator. Installation time can be as little as one third that required with a bulldozer.

- Less material has to be moved and the excavator can lift the culvert in and secure it by carefully placing *selected* fill around it. There is also less risk of damage to the culvert. *See chapter 11 Waterway Control and chapter 12 Stream Crossings*

Gravelling

Less gravel and less grader time are required to produce a level road when the subgrade is carefully built and compacted.

7.5.2 Bulldozers

Bulldozers are commonly used to clear the right of way, to cut and fill, and to construct an even subgrade. They have the disadvatage that their undercarriage wears out from the constant travel.

Bulldozer Blade Options

There are a range of bulldozer blades available, although which are dependent on the individual machine. An indication of a blade's ability to penetrate and obtain a blade load is kW per metre of cutting edge - the higher the kW/m, the more aggressive the blade. Kilowatt per Loose m^3 (Lm^3), the greater the blade's potential capability for carrying material at a greater speed. The following blade options show their best application situations:

- "U" Universal, large wings for moving large loads over long distances.
- "S" Straight, most versatile.
- "A" Angling, can be positioned straight or angled 25° to either side for side casting.
- "C" Cushion, designed for large tractors for push-loading scrapers, but may be used for general dozing jobs.

Production dozing tools:

U - Universal blade - The large wings on this blade include one end bit and at least one section of cutting edge which makes it efficient for moving big loads over long distances as in land reclamation and stock pile work. Has a lower kW/m of cutting edge than the S or SU blades and is best for lighter or relatively easily dozed material. A tilt cylinder (only available on some tractors) improves its ability to ditch, pry out, and level.

SU - The Semi Universal Blade combines the desirable characteristics of S and U blades into one package. Increased capacity through the addition of short wings, which include only the dozer end bits. The wings provide improved load retention, while maintaining the blade's ability to penetrate and load quickly in tightly packed materials and to handle a wide variety of materials in production oriented applications. The SU blade has the production advantages of the S blade, although it does not have the same ability to spread material in finish grading applications.

General purpose dozing tools:

S - The straight blade provides excellent versatility. Since it is physically smaller than the SU or U-blade, it is easier to manoeuvre and can handle a wider range of materials. It has a higher kW/m of cutting edge than the SU or U-blade; consequently the S is more aggressive in penetrating and obtaining a blade load. A tilt cylinder increases both the productivity and versatility of this dozer. With a high kW/Lm^3, the S-blade can handle heavy material easily.

P - The power angle and tilt blade. Versatility is the key feature with its ability to perform a variety of site development to general dozing work as well as heavy-duty applications.

A - Angling blade can be positioned straight or angled 25 degrees to either side. It is designed for side-casting, pioneering roads, backfilling, cutting ditches and other similar tasks. It can reduce the amount of manoeuvering required to do these jobs. Its C frame can be used for attachments such as pushing, land clearing, or snow removal tools. A-blades are not recommended for heavy rock or severe applications.

AEM VR Blades (Variable Radius):

The Balderson Variable Radius Semi-U-Blade combines the benefits of a semi-U-blade such as cutting ability and ground penetration with U-blade characteristics of better load retention and less side spill. This is achieved with the variable radius mouldboard, which causes dirt to move to the centre of the blade creating more rolling action. The extended side plates retain the load and increase capacities. The variable radius semi-U-blade is an excellent tool for land improvement, soil conservation, site development, or general construction.

Special Application Dozing Tools:

Special blades are designed to increase production while performing certain tasks. However specialisation reduces the blades versatility.

C (AEM) - The Balderson Cusion blade is used on the D8N through to the D11N for on the go push loading. Rubber cushions allow the dozer to absorb the impact of contacting a scraper push block. When not push loading, the dozer can be used for cut maintenance and other general dozing jobs. The narrow width of the C-blade increases machine manoeuvrability in congested cuts.

AEM U-Blades - Balderson and Weldco-Beales offer a variety of U-blades for use in a wide range of applications. They provide high volume movement of light non-cohesive materials such as coal and woodchips. Heavier U-blades are also offered for production dozing and reclamation work.

K/G - Offered by Rome, the K/G-blade is used in many land clearing applications. In addition to cutting trees this versatile blade can pile vegetation, cut v-type drainage ditches and build woods roads and firebreaks. Weldco-Beales offers a blade of similar design called the One-Way Brush Cutter.

V-Tree Cutter - Rome, Balderson and Weldco-Beales offer this clearing blade for shearing trees, stumps and brush at ground level. A sharp angle or V, formed by two cutting blades, utilises tractor weight and horsepower though the centreline of the cutter. Utilisation of tractor force allows most growth to be cut at a steady pace and cast to the sides.

Rakes - Rome, Balderson and Weldco-Beales offer a variety of rakes for use in land clearing applications. They handle vegetation up to tree size, and offer good soil penetration for removal of small stumps, rocks and roots. In most cases rake tines are replaceable.

Properly matching dozer and blade is a basic requirement for maximising production. First consider the kind of work the tractor will be doing most of its life. Then evaluate:

1. Materials to be moved

Most materials are dozeable. However, dozer performance will vary with material characteristics such as:

Particle Size & Shape - The larger the individual particle size, the harder it is for a cutting edge to penetrate. Particles with sharp edges resist the natural rolling action of a dozer blade. These particles require more horsepower to move than a similar volume of material with rounded edges.

Voids - Few voids means individual particles have more surface area in contact with other particle causing a stronger bond. A well-graded material, which lacks voids, is generally heavy and is hard to remove.

Water Content - The lack of moisture increases the bond between particles and makes the material difficult to remove. A high moisture content makes the material heavier and requires more force to move. Optimum moisture content is best.

2. Tractor Limitations

The weight and horsepower of the machine determines its ability to push. Various terrain and under-foot conditions on the job limit the tractor's ability and overall production.

7.5.3 Scrapers

- Scrapers are employed where large volumes of subgrade materials have to be transported over longer distances than the bulldozers can economically push them.
- Scrapers require special skilled operators to work efficiently and effectively

7.5.4 Others

Front-end loaders, gravel trucks and graders are used in the last phase of the road construction to give the road surface its final shape. Compacters are also sometimes used - see section 9.4 "Compaction"

7.5.5 General Overview

General guidelines to be considered when evaluating which machinery to use:

1. ***Earthwork material is removed by:***

- *dozing-up to 50m*
- *scrapers - 1.2 to 2km*
- *loading and carting by truck for longer distances, or when there is insufficient volume to use scrapers*
- *small quantities can also be sidecast by a grader.*

2. ***Plant Selection and Usage:*** *(Tracks or rubber tyres?)*

- *tracked machines are slower than rubber tyred but can handle rougher terrain.*
- *rubber-tyred machines require a better surface on which to operate.*
- *rubber-tyred machines produce better compaction results*

7.6 LAND CLEARING PRODUCTION

The first stage in earthworks is to clear the road right of way, by removing the trees, stumps and topsoil. The logging cost ($/tonne) is largely dependent on the log haul distance and piece-size of the trees.

The additional time required to remove stumps, and to correctly dispose of the organic material needs to be added on to the machine's productivity estimated in the following sections.

7.7 ESTIMATING MACHINERY PRODUCTION

7.7.1 Bulldozer Production

Estimate the bulldozer production using the production curves shown in figure 67. It should be noted that other factors need to be applied to these production estimates dependent on the work conditions.

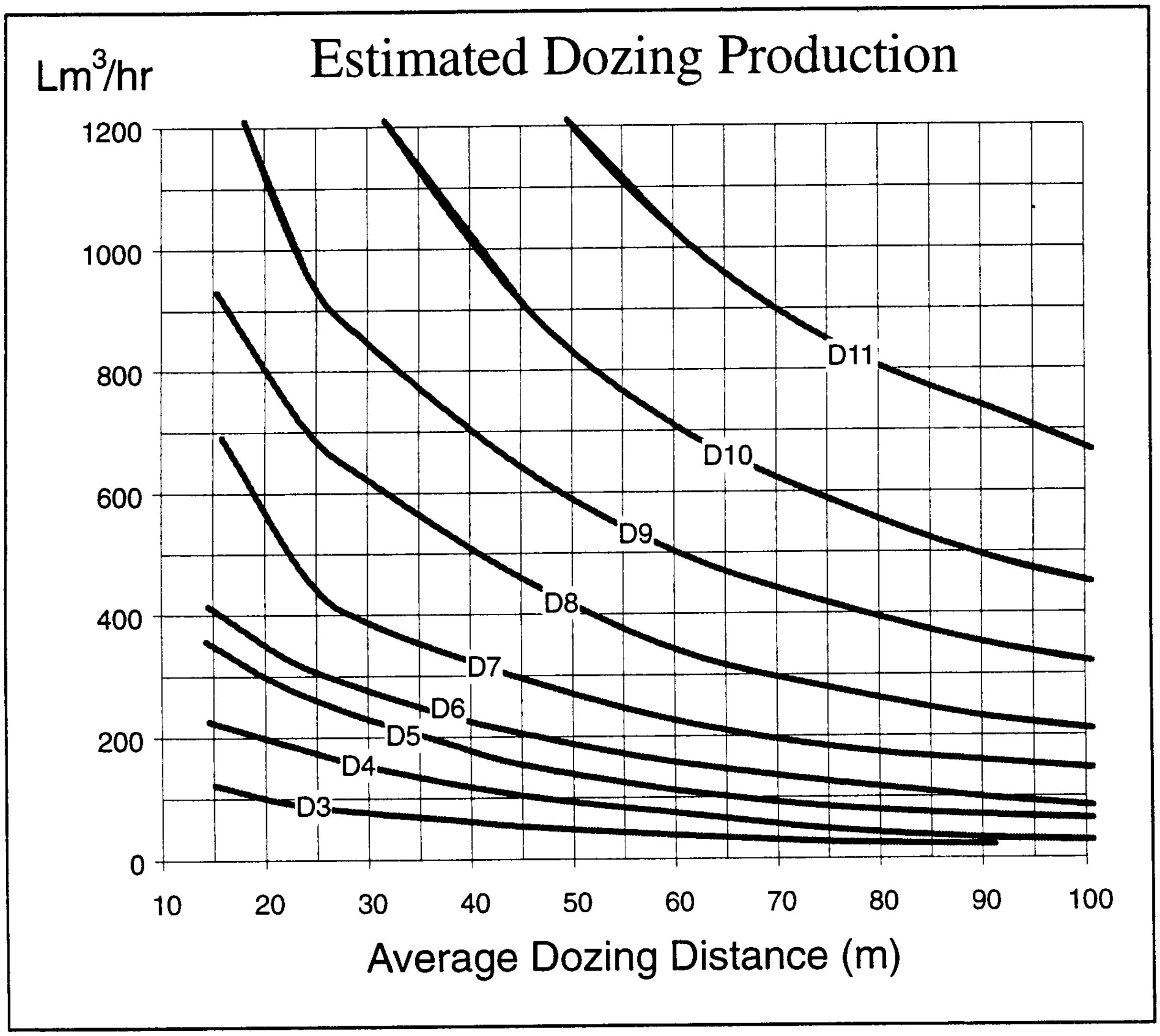


Figure 67 - Dozer production chart

For forest road construction, where sidecasting is applied, an average dozing distance of 30 m is considered appropriate. Table 21 lists the estimated production in loose cubic metres per hour (Lm^3/hr).

Dozer Type	Weight tonnes	Prodn (P) Lm^3/hr	Rate (R) *($/hr)	Transport Costs, T ($/km)		
				Trips	Loaded	Empty
D11	110	1800	459	2	$5.50	$3.00
D10	77	1250	373	2	$5.50	$3.00
D9	49	850	274	2	$5.50	$3.00
D8	42	720	230	1	$5.50	$3.00
D7	28	380	188	1	$5.50	$3.00
D7	21	280	140	1	$5.50	$3.00
D5	15	230	114	1	$2.70	$2.30
D4	11.7	150	100	1	$2.70	$2.30
D3	8	80	87	1	$2.70	$2.30

Table 21 - Estimating costs of production and transport for various dozer types

***Note:** Long term hourly rates may be lower than those listed.*

** Rates quoted from 1997 Contracting Industry Directory*

Use the table above (or your own figures) to calculate earthworks cost (C) ($/m^3):

$$C = \frac{V}{P} F \times S \times R + T$$

where:

V = Total in-place volume of earthworks (m^3)

S = Soil swell factor (table 22)

P = Dozer production (Lm^3/hr)

R = Hourly charge out rate, including operator ($/hr)

T = Total cost to transport dozer to site (multiply km from depot to site by the appropriate cost per km, and add the unloaded and loaded costs)

F = Job adjustment factor - multiply together all the factors that apply below (table 23)

ATTRIBUTE	CORRECTION FACTOR
Clay - Natural bed	1.22
Dry	1.23
Wet	1.25
Clay & gravel - Dry	1.18
Wet	1.18
Decomposed rock -	
75% Rock, 25% Earth	1.43
50% Rock, 50% Earth	1.33
25% Rock, 75% Earth	1.25
Earth - Dry packed	1.25
Wet excavated	1.27
Loam	1.23
Granite - Broken	1.74
Gravel - Pitrun	1.12
Limestone	1.79
Sand	1.12
Sand & clay - Loose	1.27
Sand & gravel - Dry	1.12
Wet	1.10
Sandstone	1.77
Shale	1.33
Stone	1.77
Top Soil	1.43

Table 22 - Soil swell factors

ATTRIBUTE	CORRECTION FACTOR
OPERATOR	
Excellent	1.0
Average	0.75
Poor	0.70
MATERIAL	
Loose stockpile	1.20
Hard to cut; frozen	
with tilt cylinder	0.80
without tilt cylinder	0.70
cable controlled blade	0.70
Hard to drift; "dead"	
very sticky material	0.80
rock, ripped or blasted	0.70-0.80
SLOT DOZING	1.20
SIDE BY SIDE DOZING	1.15-1.25
VISIBILITY	
Dust, rain, snow, fog or darkness	0.80
JOB EFFICIENCY	
50 min/hr	0.83
40 min/hr	0.77
DIRECT DRIVE TRANSMISSION	
0.1 min fixed time	0.80
USING A-BLADE OR C-BLADE	0.50-0.75
GRADES	See figure 68

Table 23 - Job Condition Correction Factors

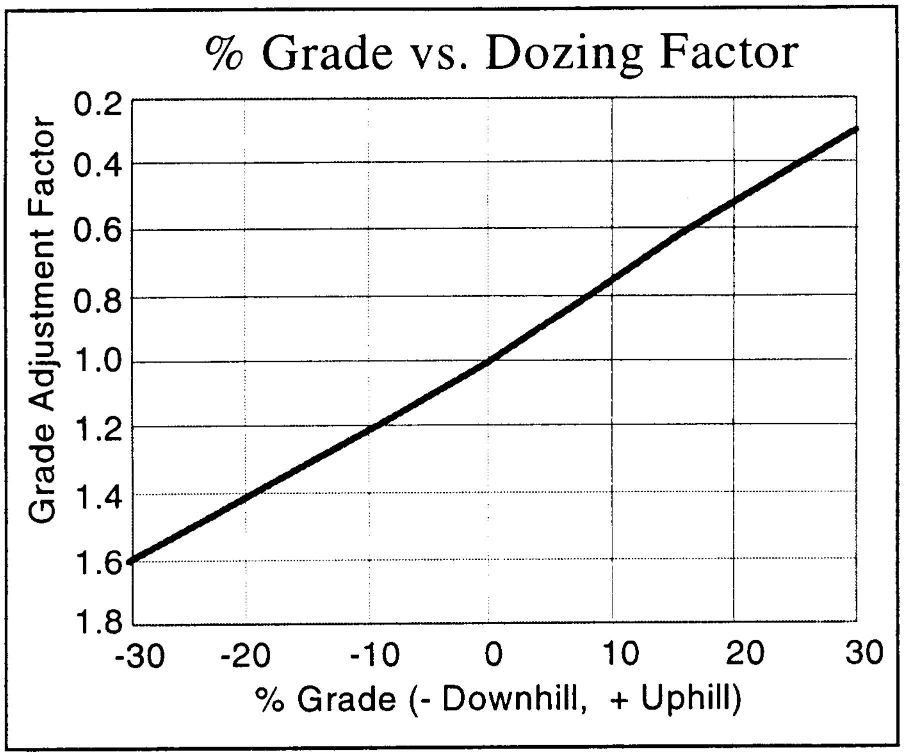


Figure 68 - Grade adjustment factor

7.7.2 Excavator (backhoe) Production

Excavator earthmoving production is dependent on average bucket payload, average cycle time and job efficiency. The production can be derived from the following formula:

$$P\ (m^3/hr) = \text{Cycles/hr} \times \text{Avg Bucket Payload}\ (m^3)$$

The digging cycle of the excavator is composed of four segments:

1. Load Bucket
2. Swing Loaded
3. Dump Bucket
4. Swing Empty

Excavator production can be estimated from figure 69.

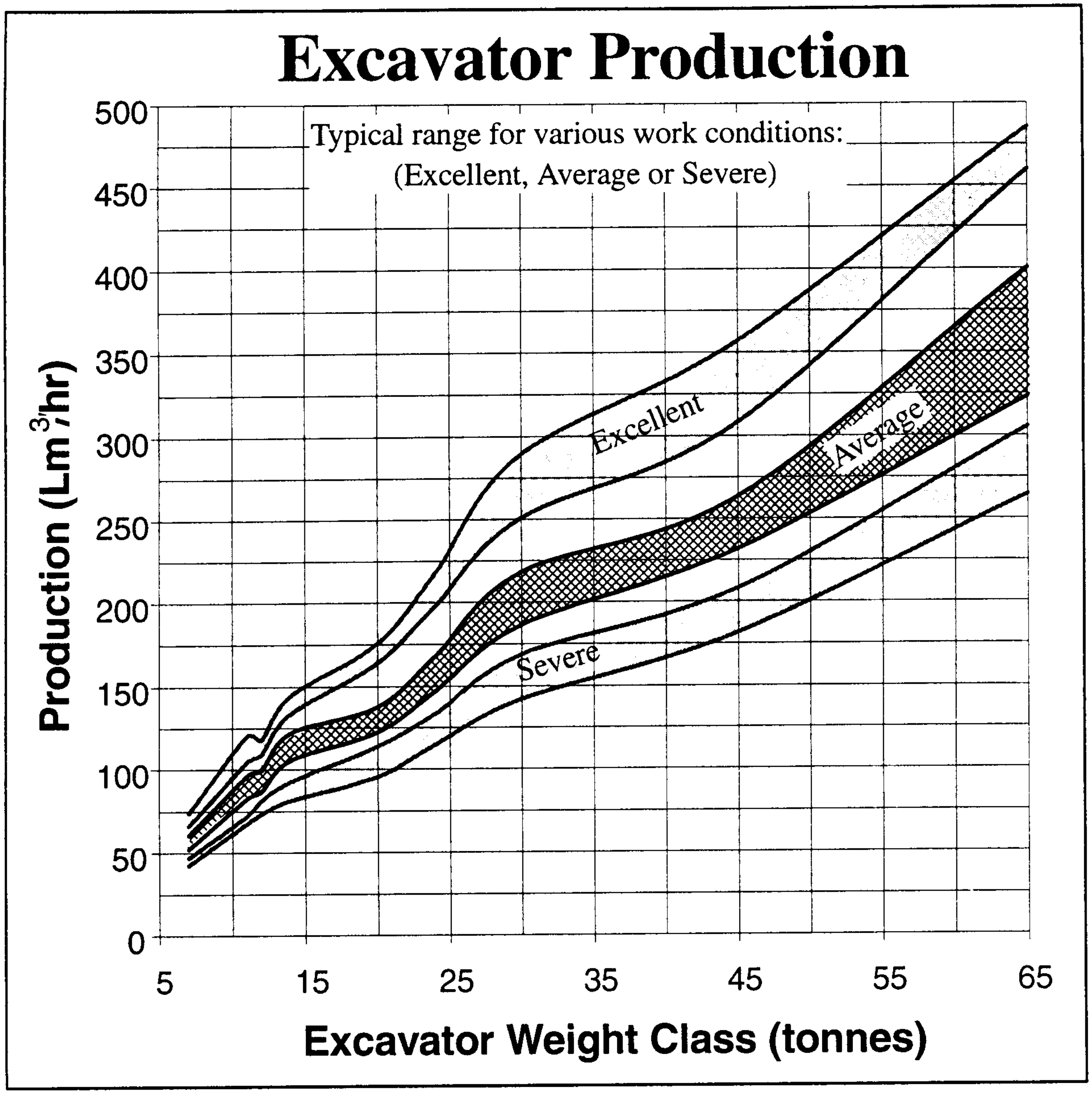


Figure 69 - Excavator production for various work conditions

(Production is in loose cubic metres and should be divided by the appropriate soil swell factor, table 22)

The work conditions are defined as follows:

Excellent:

- Easy digging (unpacked earth, sand gravel, ditch cleaning, etc.)
- Digging to less than 40% of machine's maximum depth capability
- Swing angle less than 30° - Dump onto spoil pile or truck.

- No obstructions
- An experienced operator.

Average:

Higher production:

- Medium digging (packed earth, tough dry clay, soil with less than 25% rock content)
- Depth to 50% of machine's maximum capability
- Swing angle to 70° - Large dump target
- Few obstructions.

Lower production:

- Medium to hard digging (hard packed soil with up to 50% rock content)
- Depth to 70% of machine's maximum capability
- Swing angle to 90° - Loading trucks with truck positioned close to excavator.

Severe:

Higher production:

- Hard digging (shot rock or tough soil with up to 75% rock content)
- Depth to 90% of machine's maximum capability
- Swing angle to 120° - Shored trench - Small dump target
- Working over pipe crew.

Lower production:

- Toughest digging (sandstone, caliche, shale, certain limestone, hard frost)
- Over 90% of machine's maximum depth capability
- Swing angle over 120° - Dump into small target requiring maximum excavator reach
- People and obstructions in the work area.

For a known volume of earthworks, work conditions, type of excavator and hourly rate the cost can be calculated using the following formula. Table 24 gives some indication for the cost of transport and excavator.

$$C = \frac{V}{P} F \times S \times R + T$$

where:

V	= Total in-place volume of earthworks (m^3)
S	= Soil swell factor (table 22)
P	= Dozer production (Lm^3/hr)
R	= Hourly charge out rate (includes operator) ($/hr)
T	= Total cost to transport dozer to site (multiply the kilometres from depot to site by the appropriate cost per km and add the unloaded and loaded costs)
F	= Job adjustment factor and is the multiplication of all the factors that apply (table 23)

Excavator Weight (tonnes)	Rate (R) *($/hr)	Transport Costs, T ($/km)		
		Trips	Loaded	Empty
7	70.50	1	$2.70	$2.30
11	83.50	1	$2.70	$2.30
12	83.50	1	$2.70	$2.30
14	79.50	1	$2.70	$2.30
20	97.50	1	$5.50	$3.00
24	107.50	1	$5.50	$3.00
30	127.50	2	$5.50	$3.00
45	174.00	2	$5.50	$3.00
75	287.50	2	$5.50	$3.00

Table 24 - Excavator production and transport costs

(Rates quoted from 1997 Contracting Industry Directory)

***Note:** Long term contract rates will be less than those specified above.*