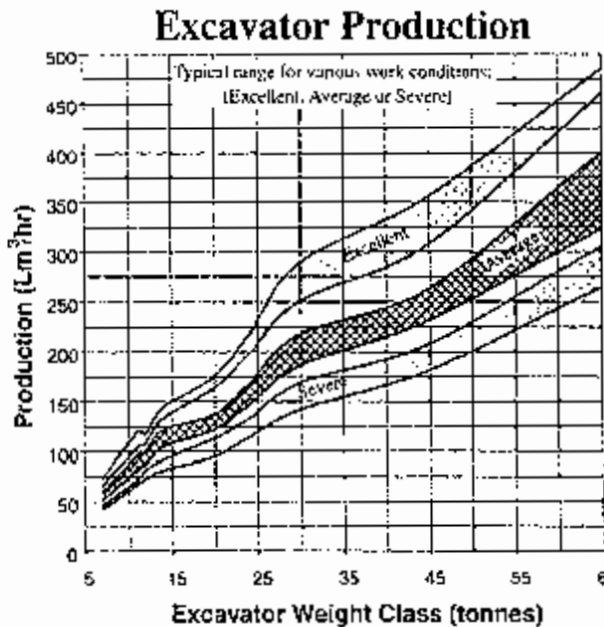


Liro Forestry Solutions
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New Zealand

Forest Roding Manual



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Prepared By:

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INTRODUCTION

CHAPTER 1 - INTRODUCTION

1.0 NEW ZEALAND FORESTRY AND FOREST ROADING

There are now 1.5 million hectares of production forests in New Zealand [NFOA, 1997]. It is estimated that forest production will increase from 15 to 30 million m³ in 2010, and much additional roading will be required to access these new forests. There is the potential for significant savings in roading costs if better technical information were available on their planing, design, construction and maintenance.

Studies in New Zealand and overseas have shown that roads, tracks, and landings contribute significantly to sediment mobilisation [O'Loughlin, 1979; Vaughan, 1984; cited in Wallis and McMahon, 1994]. Sedimentation may result from movement of soil and debris during road construction, surface erosion of roads, water tables, fill and sidecast materials, or mass movement due to the failure of over-steepened slopes. Anderson (1976) found that as much as 90 percent of the erosion in a catchment comes from roads. Sedimentation from roads can be significantly reduced through proper planning, design, construction, and routine maintenance [Packer and Laycock 1969, Megahan 1972; cited in Leaf 1974]. Many regional councils have produced erosion control guidelines as part of their responsibility under the Resource Management Act 1991 [Handyside, 1992; Environment B.O.P, 1993; Bay of Plenty Regional Council, 1993]. These guidelines show various simple and inexpensive erosion protection measures, which can significantly reduce sedimentation.

Forest roads in New Zealand are generally constructed to a high standard, but this generally owes more to the experience of the roading supervisor, rather than to any formal qualifications and training. When an experienced roading supervisor leaves a job, his/her knowledge goes too. His/her replacement will often have to learn the best roading practices by trial and error. This manual cannot replace the experience of roading supervisors or engineers, but it is intended to assist in overcoming some common engineering problems.

1.1 SCOPE OF MANUAL

Considerable literature is available in New Zealand describing research and technical information on forest roading. Much of this information is difficult to obtain, and is not written with forest operations in mind. Until now there has been no single document which collates all the required information using an easily understood format which can be applied by the forest roading supervisor or new engineer. This manual is based on a comprehensive literature search of New Zealand and overseas information on unsealed and forest roads. New and innovative practices and procedures have been identified through consultation with roading engineers, supervisors and other associated personnel.

The *Forest Roading Manual* covers all aspects of the planning, design, construction, and maintenance of unsealed forest roads. It has been prepared for people who have only a limited civil engineering background.

This publication is not intended to replace any existing operational instruction in the various road construction agencies, or forest companies. Rather, it is intended to fill a void by providing, in one document, information on well understood techniques as well as the latest developments and practices for unsealed roads. It does not cover areas relating specifically to sealed roads, rigid pavements, detailed bridge construction, or detailed product ranges. Most of this information is available from other manuals, manufacturers brochures, and other publications. Some recommended references have been given to point the reader to this information.

Chapter 16 contains a bibliography of reference manuals and relevant material, and provides an excellent source of roading documentation. This is a comprehensive list of references which readers can use, should they need more detailed information and specifications to suit their needs.

1.2 ACKNOWLEDGEMENTS

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AIM and OBJECTIVE

CHAPTER 2 - AIM and OBJECTIVE

2.0 AIM

To provide a Rooding Manual which can be easily understood and applied by those who are responsible for unsealed forest rooding.

2.1 OBJECTIVE

To produce a manual which covers all aspects of the planning, design, construction and maintenance of forest roads and landings and which promotes sound construction techniques, a safe working environment and the maintaining of environmental values.

3

3

USE OF THE MANUAL

CHAPTER 3 - USE OF THE MANUAL

3.0 INTRODUCTION

Unsealed road construction is the primary form of road construction in the forestry industry. A few exceptions occur in larger established forests which may have major sealed arterial routes through the forest. Sealing of forestry roads is usually undertaken if the roads have a high level of traffic flow, and where speed and safety is a requirement.

The Forest Roding Manual is not intended to be read from start to finish. Each chapter covers a different aspect of the road planning, design, construction or maintenance. Sections of each chapter, or perhaps an entire chapter, may not be relevant to the reader, depending on their specific requirements. The flow diagram in figure 1 shows the general procedures to follow when planning, designing and constructing an unsealed road.

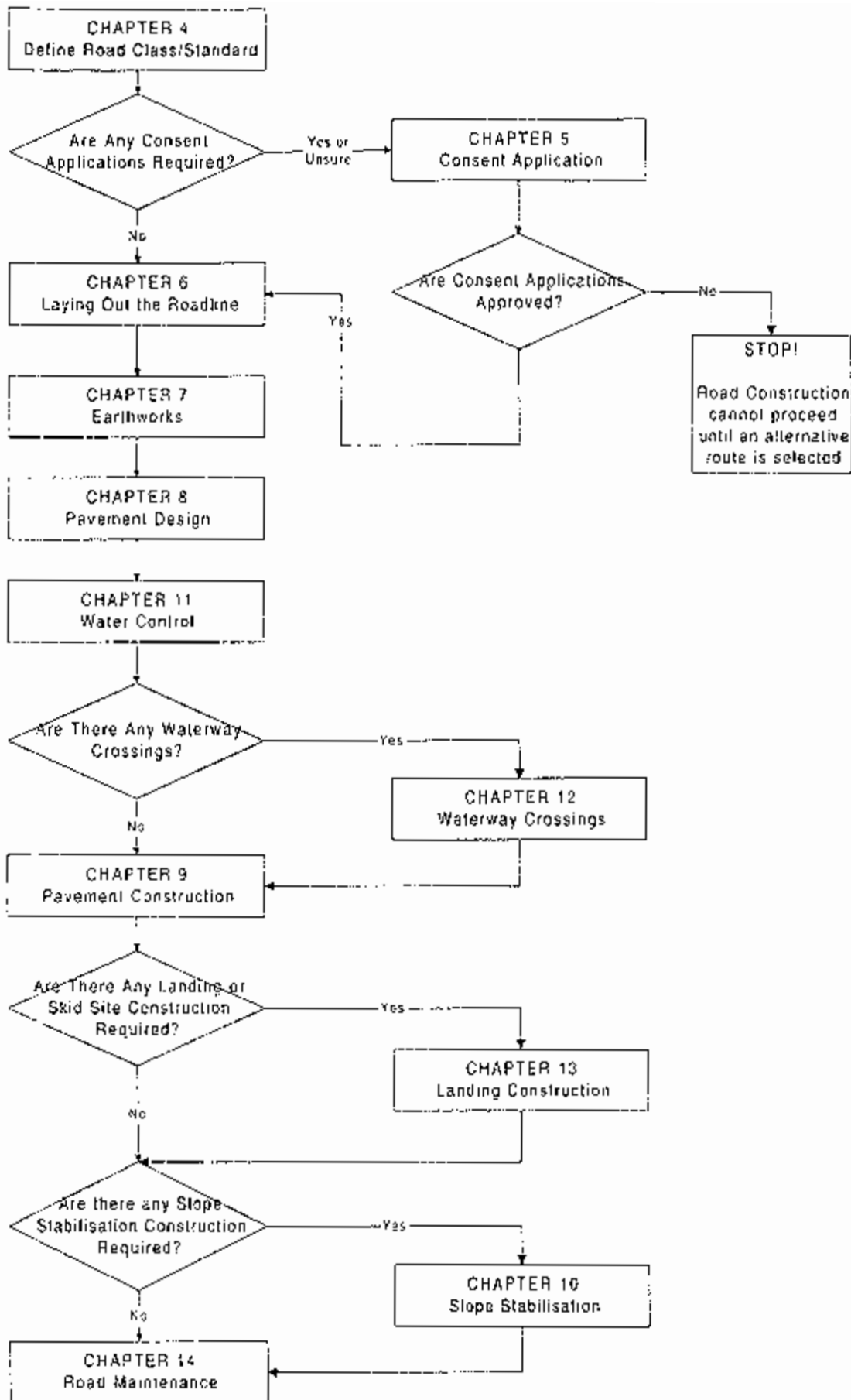


Figure 1 - Road Planning, design, and construction procedure

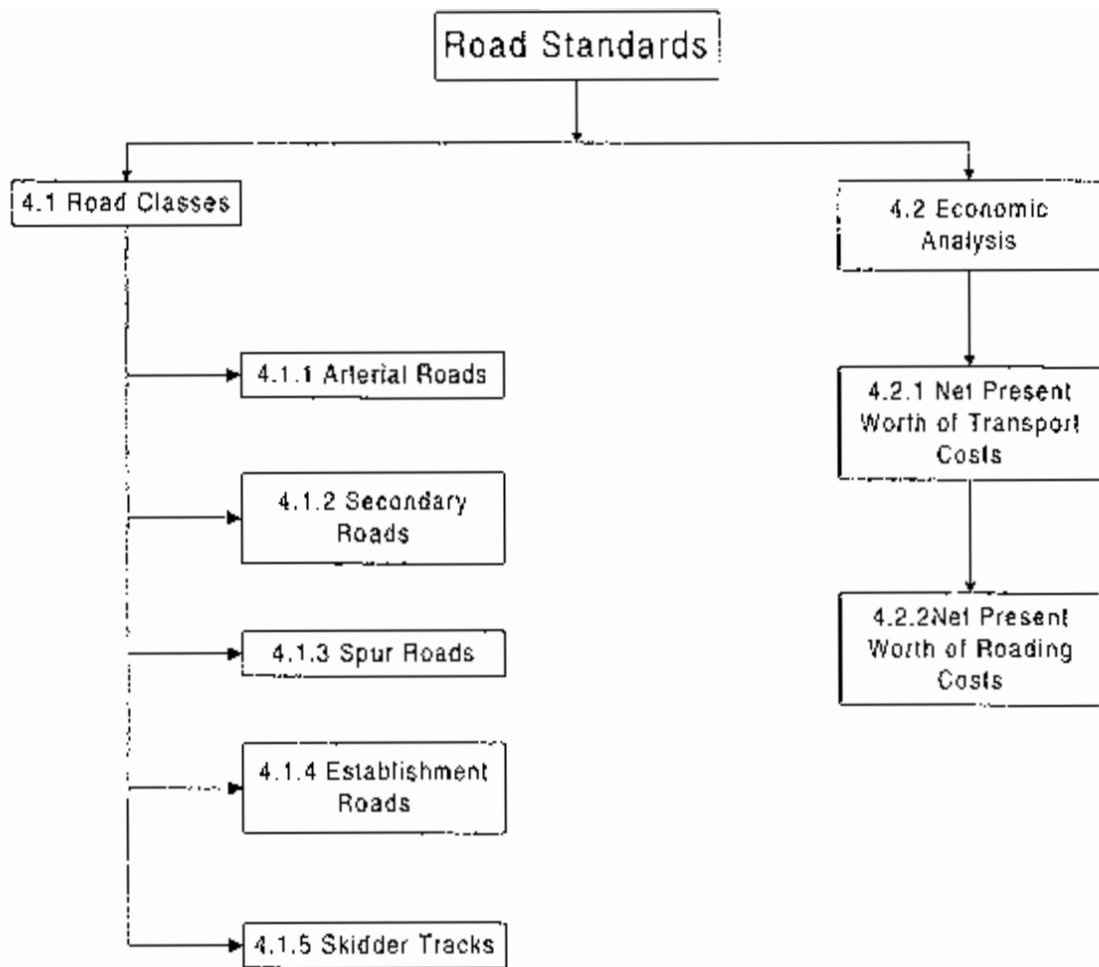


Figure 2 - Chapter 4 "Road Standards"

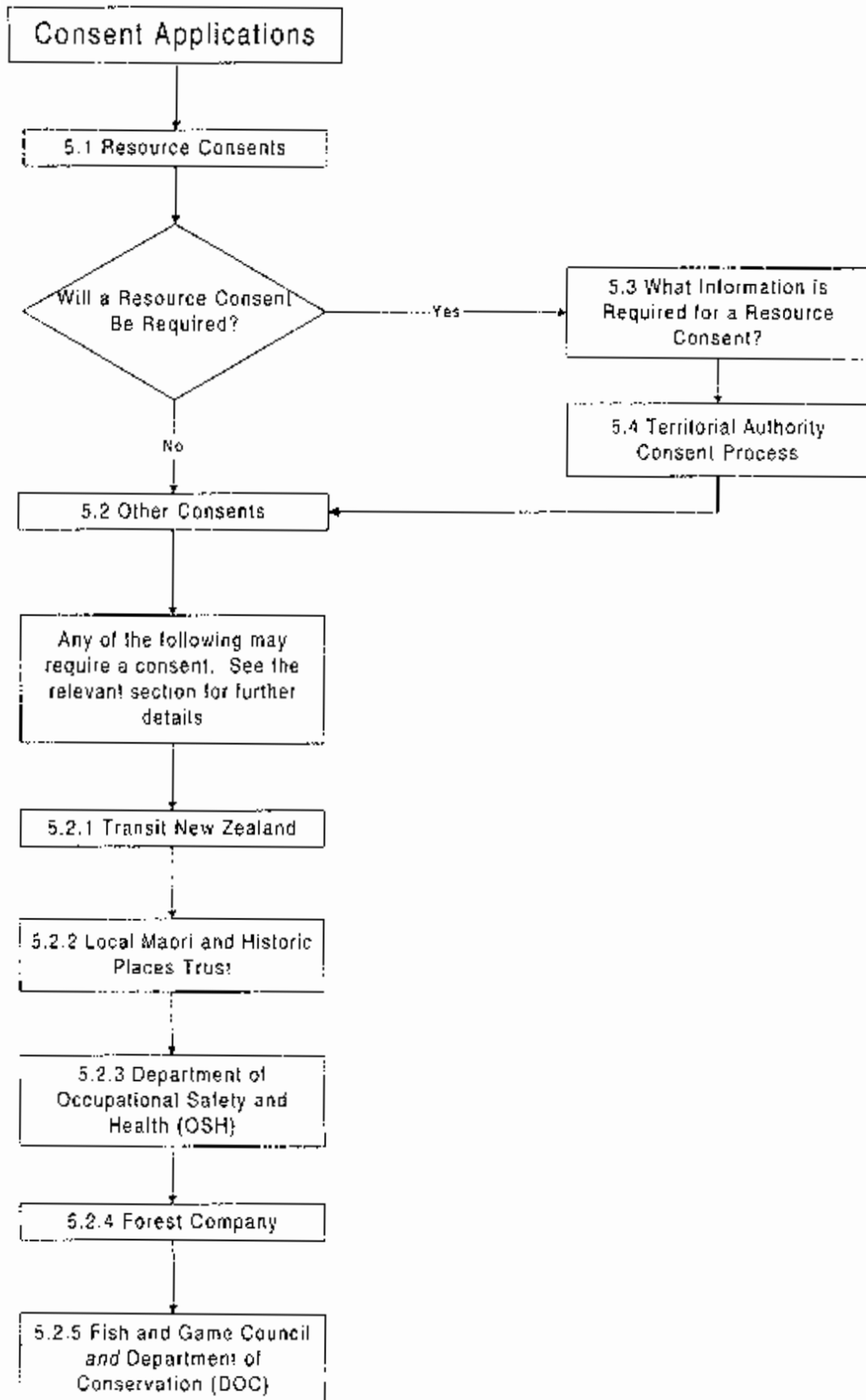


Figure 3 - Chapter 5 "Consent Application"

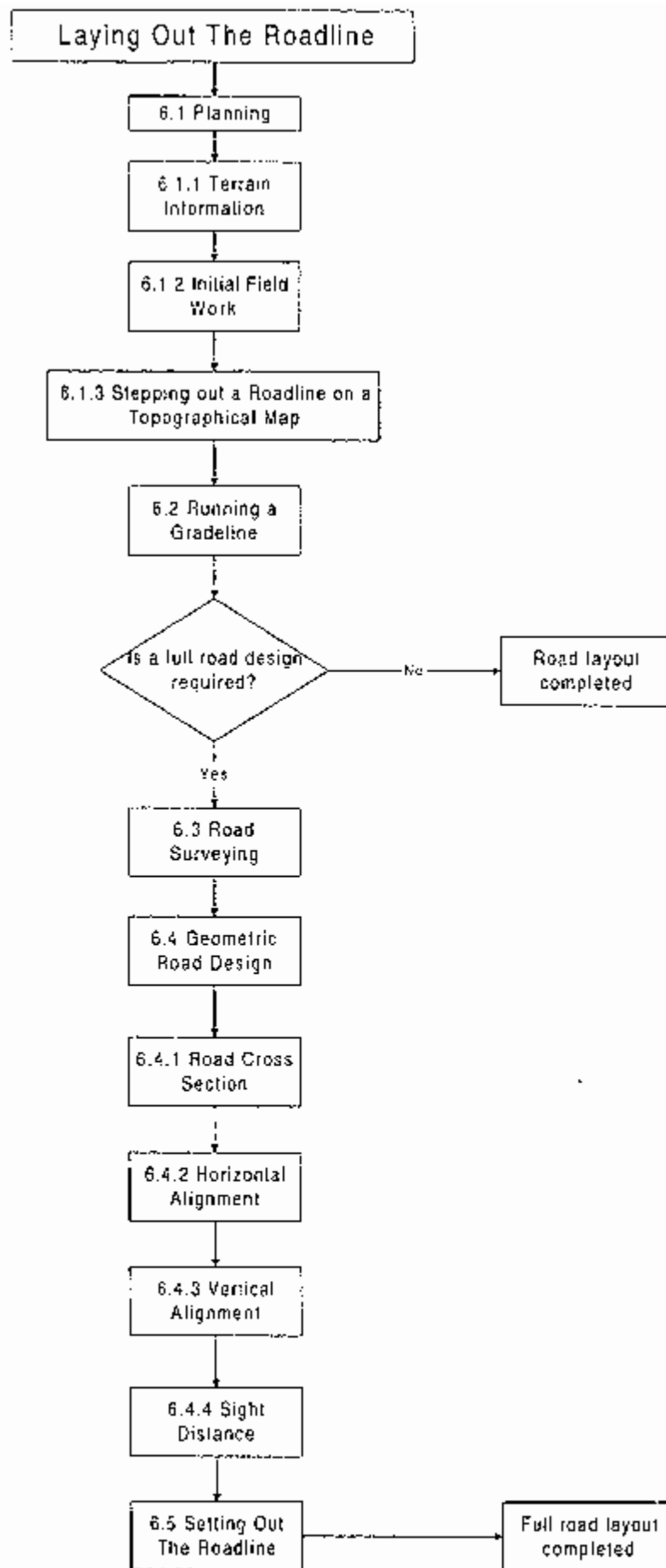


Figure 4 - Chapter 6 "Laying Out The Roadline"

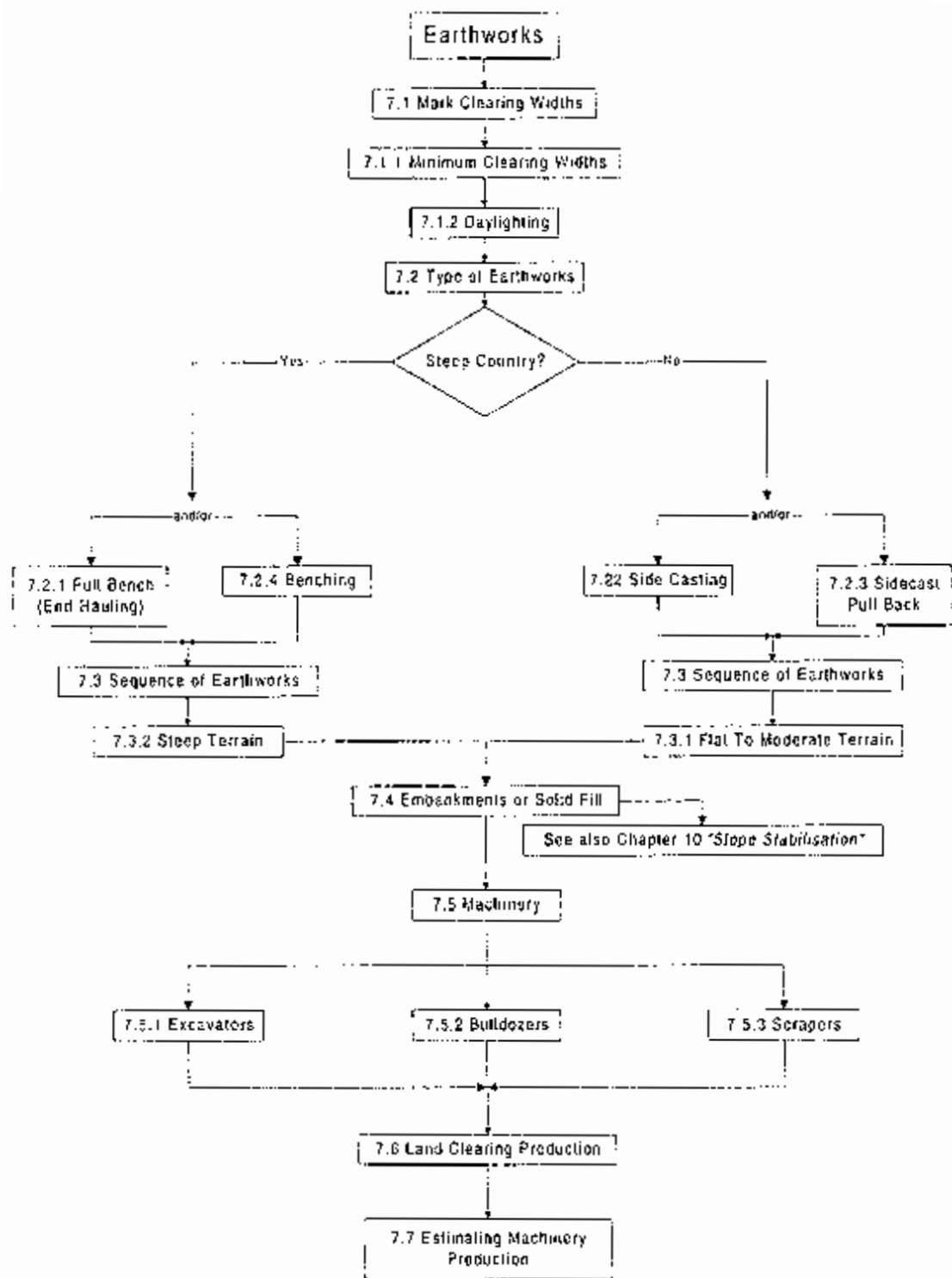


Figure 5 - Chapter 7 "Earthworks"

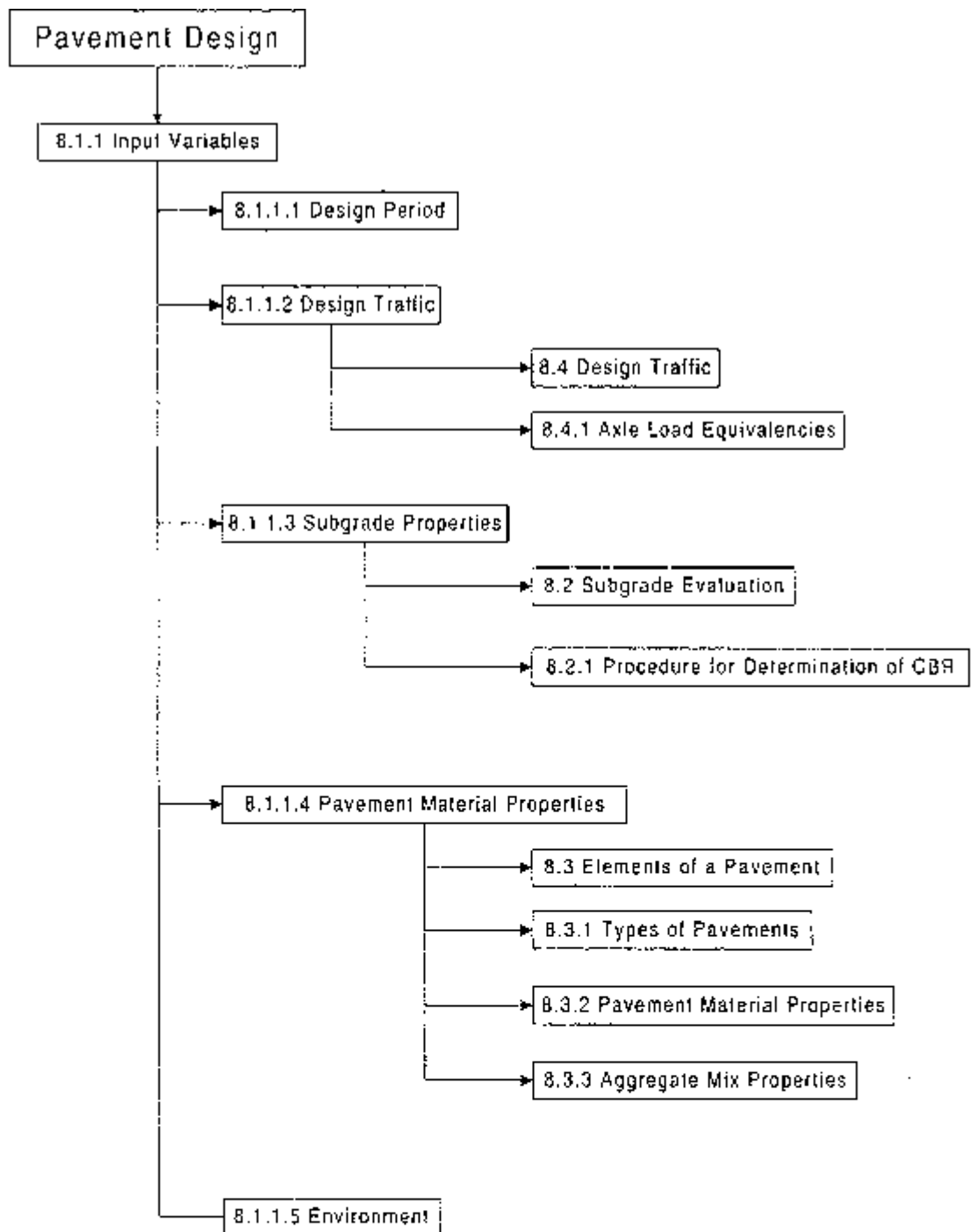


Figure 6 - Chapter 8 "Pavement Design"

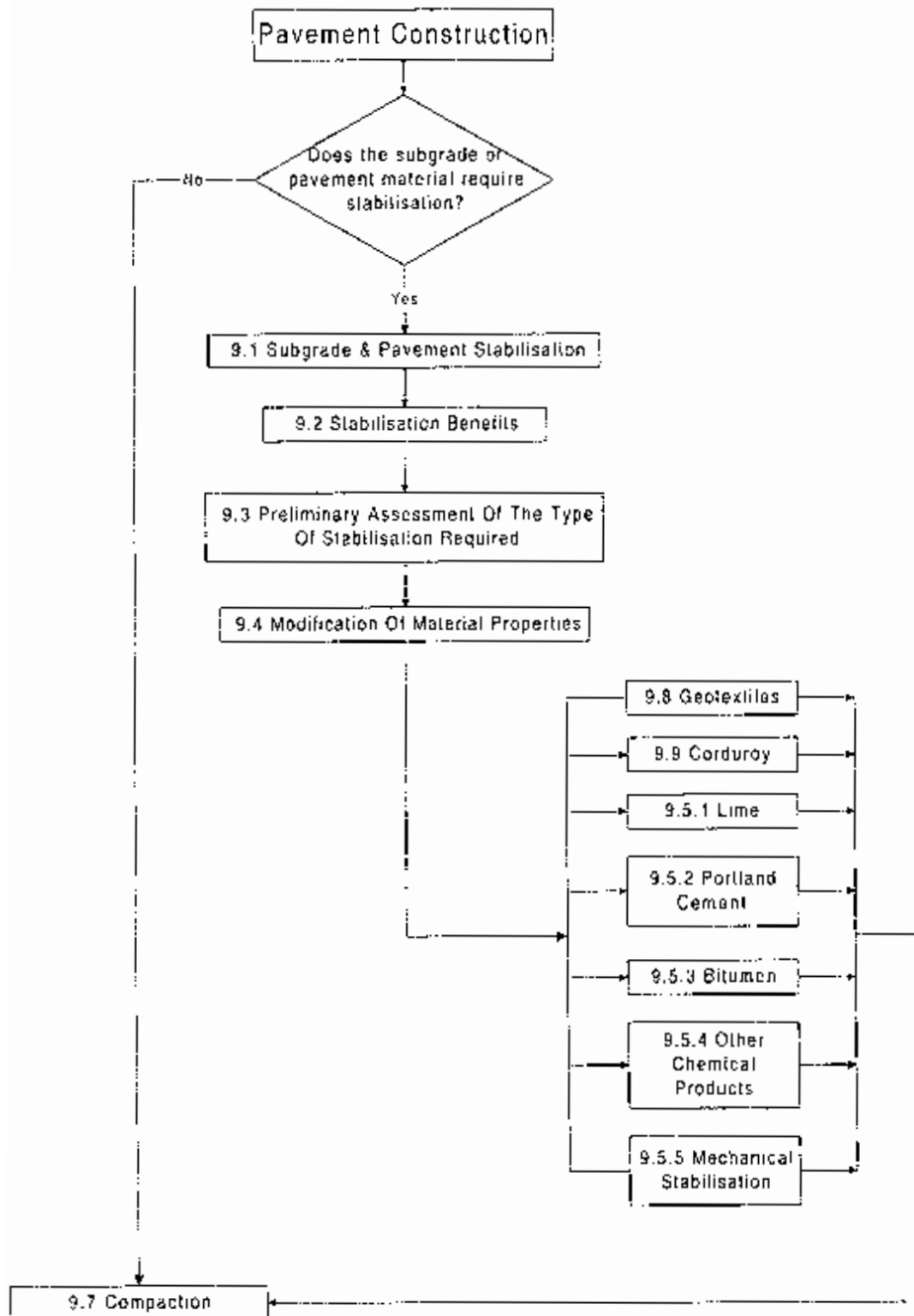


Figure 7 - Chapter 9 "Pavement Construction"

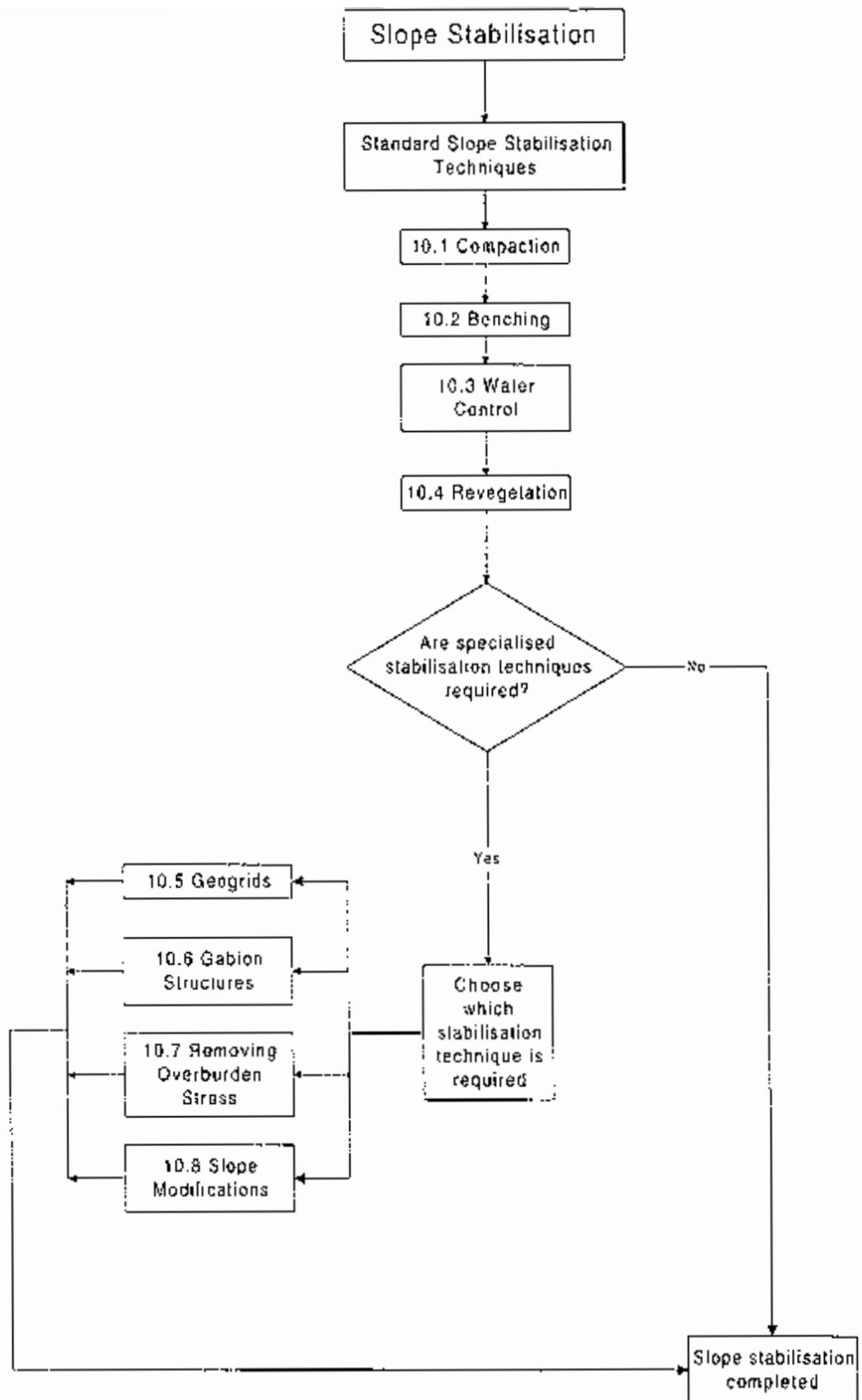


Figure 8 - Chapter 10 "Slope Stabilisation"

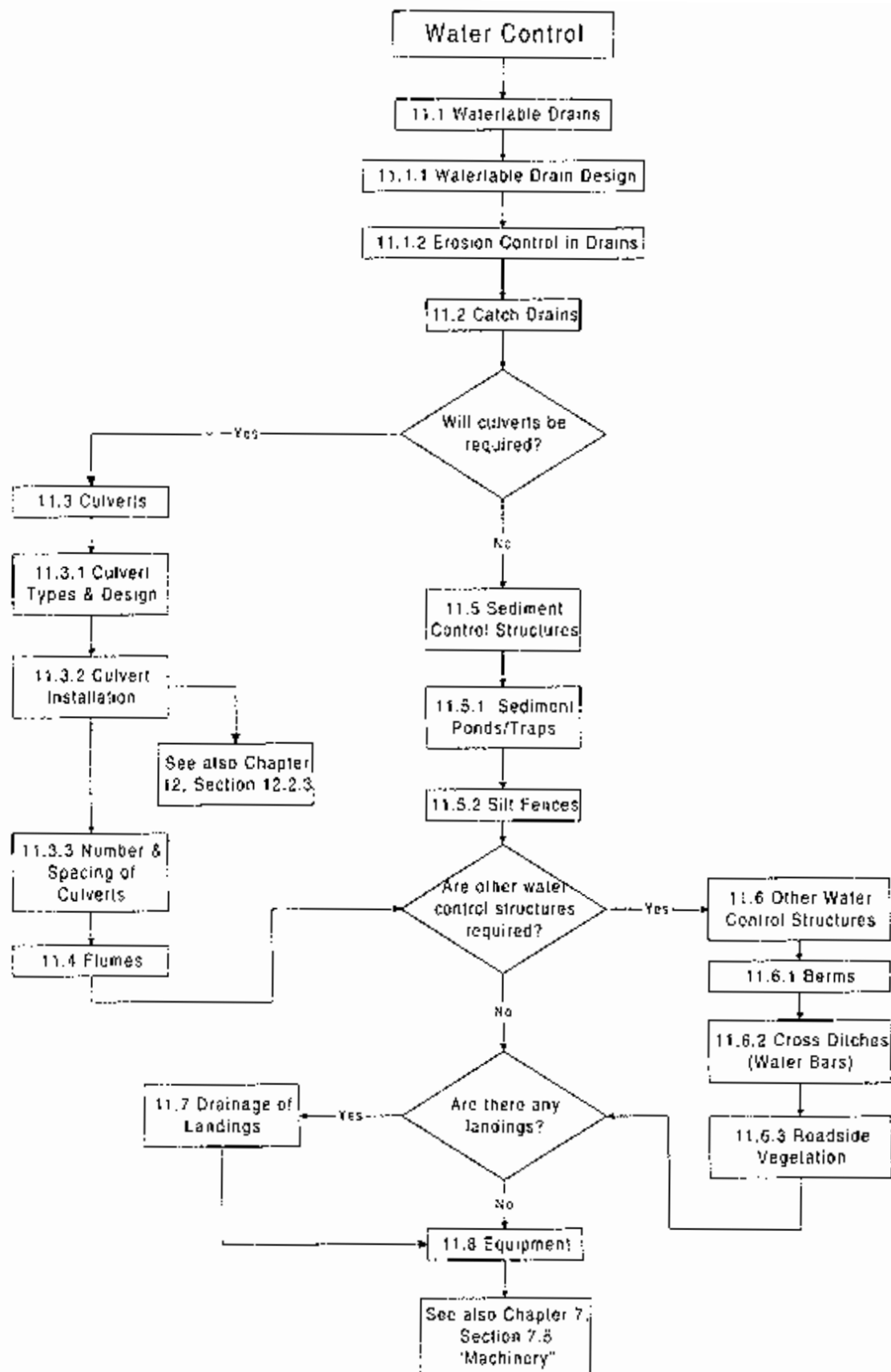


Figure 9 - Chapter 11 "Water Control"

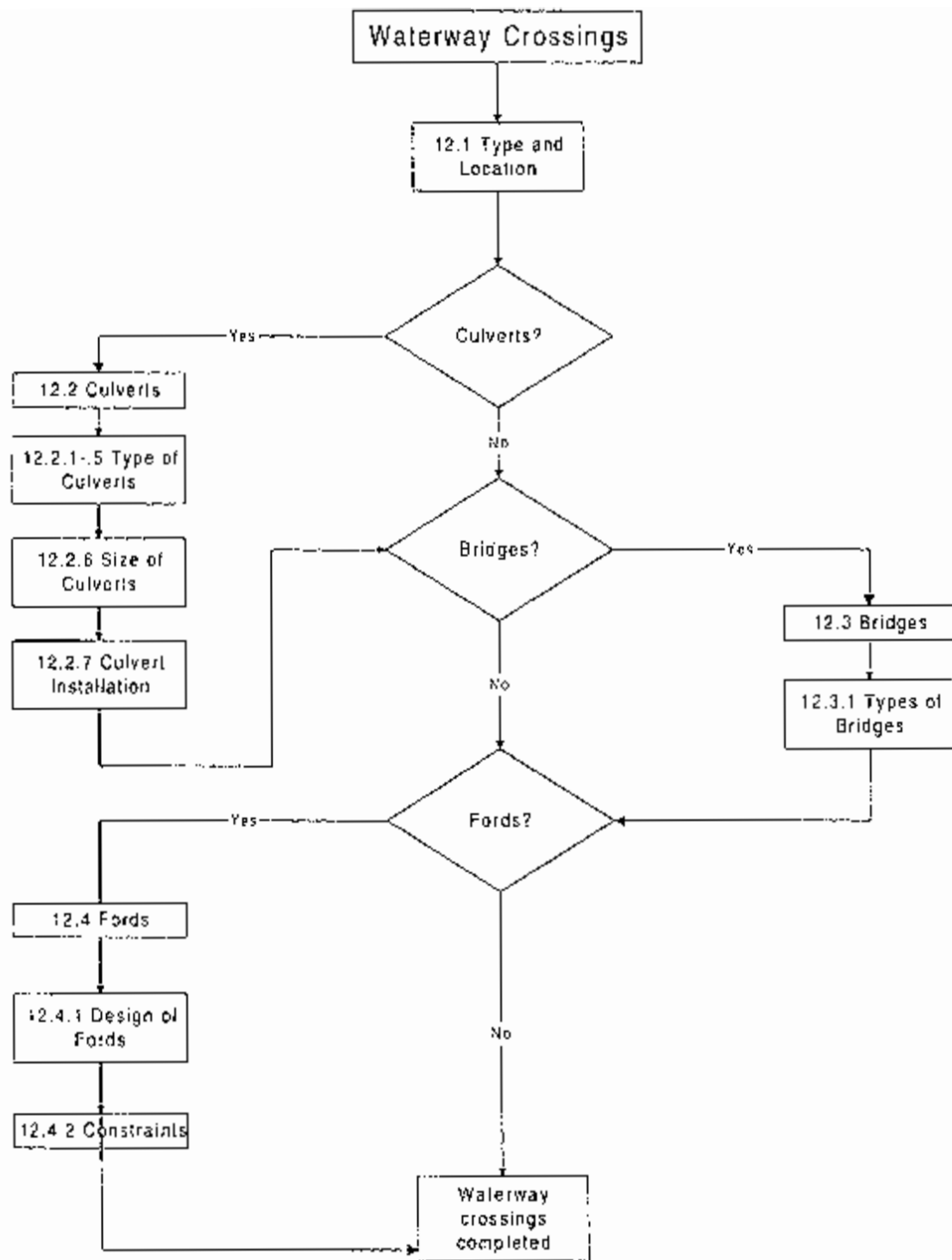


Figure 10 - Chapter 12 "Waterway Crossings"

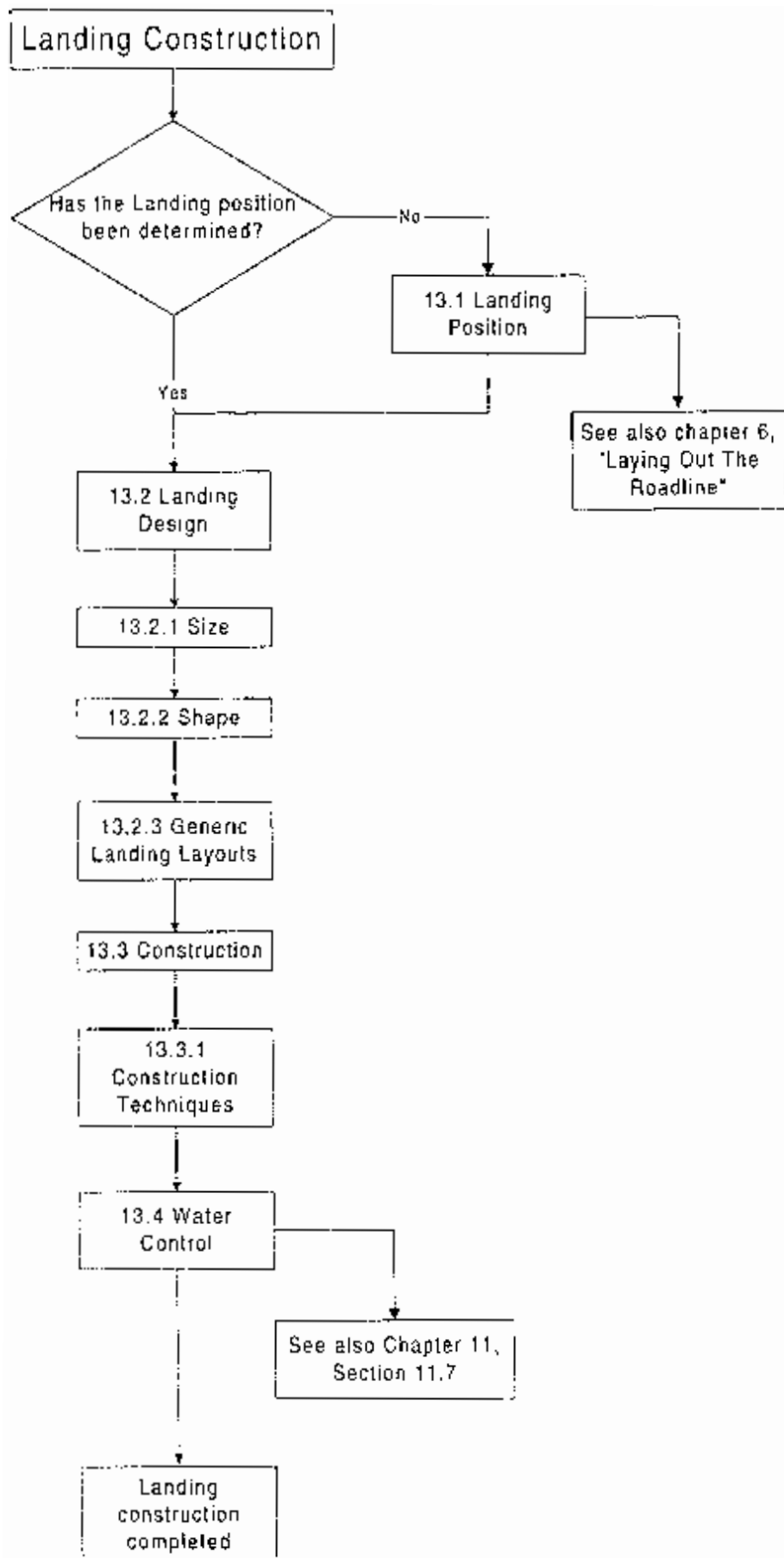


Figure 11 - Chapter 13 "Landing Construction"

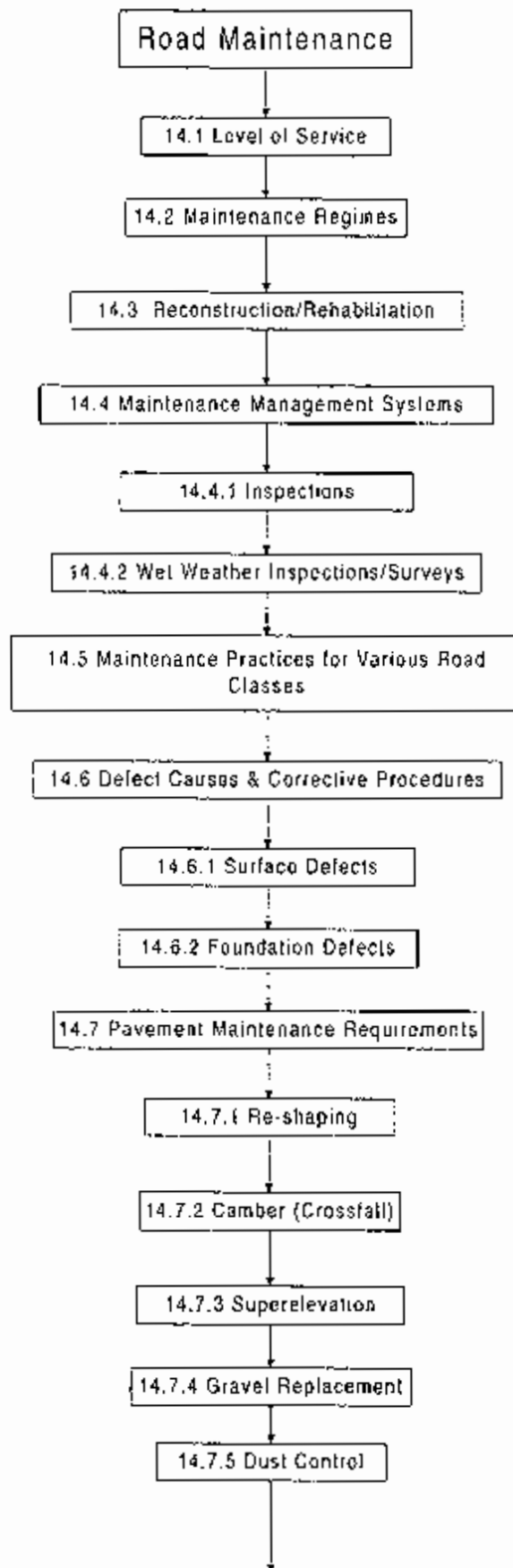


Figure 12 continued

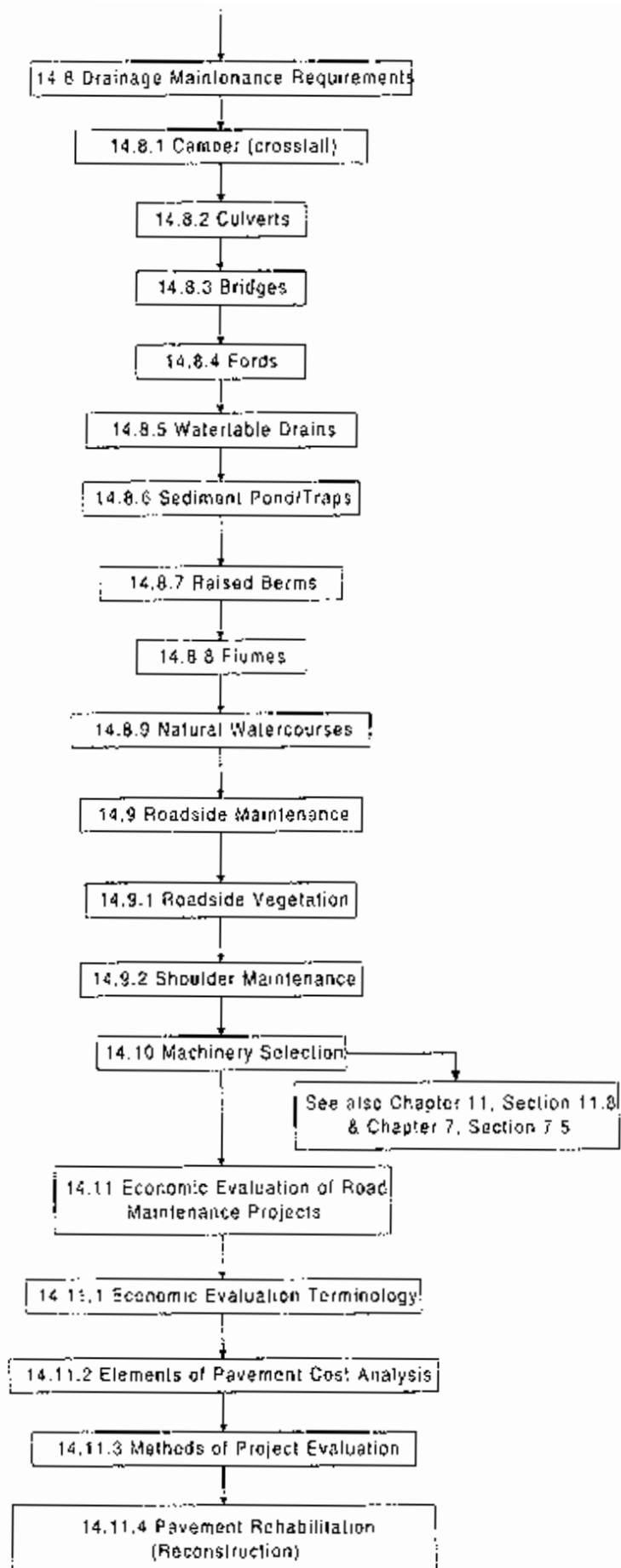


Figure 12 - Chapter 14 "Road Maintenance"

ROAD STANDARDS

CHAPTER 4 - ROAD STANDARDS

4.0 INTRODUCTION

The determination of appropriate road and construction standards, in terms of geometrics and pavement materials, requires technical evaluation of anticipated road usage and function. The optimum road standard is defined by the minimum combined cost of road construction and maintenance, and truck hauling (figure 13). By choosing an appropriate roading standard, the total costs to the forest owner will be reduced.

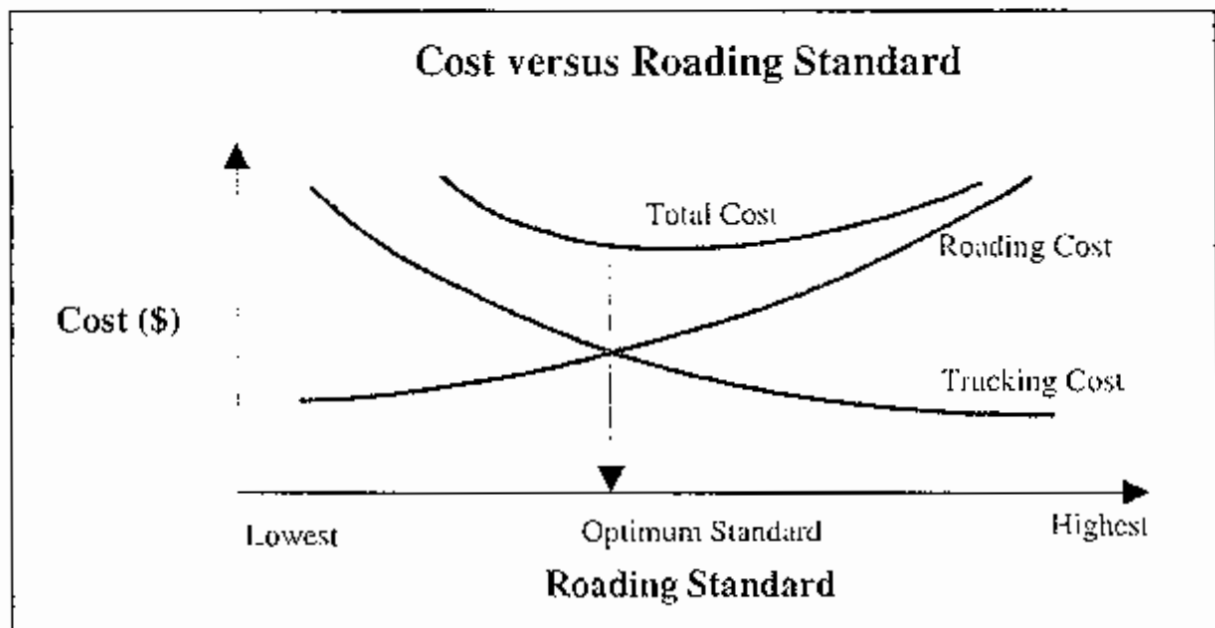


Figure 13 - Roading standard effect on overall transport and roading costs.

In theory, the task is simply one of determining the location, width and alignment which gives the lowest combined cost for road construction, maintenance and haulage. The following section offers some guidelines for choosing the appropriate roading class and geometric standards. There is an additional section on simple economic comparison of proposed roading standards to aid in decision making.

4.1 ROAD CLASSES

Roads within the forest can be divided into five broad classes or categories:

1. Arterial
2. Secondary
3. Spur
4. Establishment
5. Skidder Tracks

Figure 14 shows the general layout of the road classes, and table 1 shows the distribution of the roading classes within a typical forest roading network. The geometries noted for each roading standard are guidelines only as they may differ from forest to forest. To determine the most suitable geometric standard, section 4.2 on economic analysis can be used.

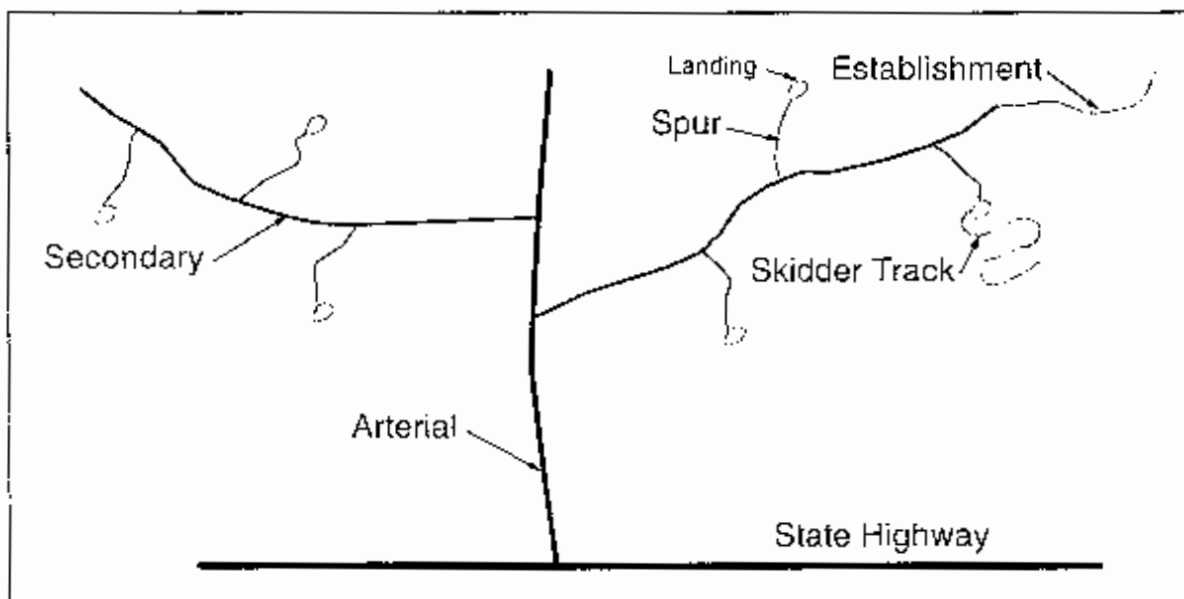


Figure 14 - Typical forest road classes

Road Class	Speed	Road Width	Max. Gradient	Volume	Description
Arterial	70 km/h	9 m	5 %	>250,000 t pa	Highest Standard
Secondary	50 km/h	7 m	7 %	60,000-250,000 t pa	Medium Standard
Spur	30 km/h	4.3 m	10 %	<60,000 t pa	Lowest Standard
Establishment	25 km/h	2.5 m	25%	Light Vehicles	Temporary Tracks
Skidder tracks	20 km/h	2.5 m	25%	Skidders	Temporary Tracks

Table 1 - Distribution of roading classes within a typical forest roading network

4.1.1 Arterial Roads

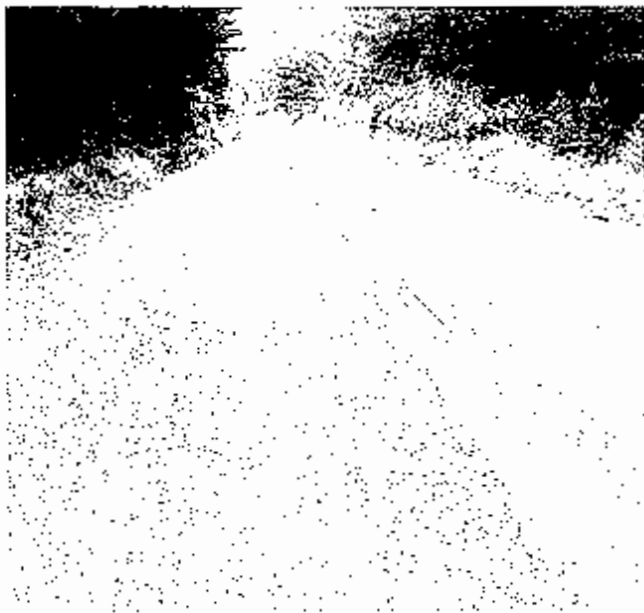


Figure 15 - A typical arterial road

- Carry more than 80 hvpd (>250,000 tonnes pa.)
- Permanent two-lane roads constructed to the highest standard often sealed.
- Designed for a minimum speed of 70 km/h for flat and rolling terrain, and 50 km/h for mountainous terrain.
- Have a road way width of 9 m for flat and rolling terrain, and 8 m for mountainous terrain.
- Have a desirable maximum gradient of 5% (6.7% for short distances) for flat and rolling terrain, and 6.7% (10% for short distances) for mountainous terrain.

4.1.2 Secondary Roads



Figure 16 - A typical secondary road

4.1.3 Spur Roads



Figure 17 - A typical spur road

- Feeder roads from spur to arterial roads.
 - Carry between 20 and 80 hvpd (60,000 - 250,000 tonne pa.)
 - Unscaled permanent two lane roads constructed to a high standard.
 - Are designed for a speed of 50 km/h for flat and rolling terrain, and 40 km/h for mountainous terrain.
 - Have a road width of 7.3 m for flat and rolling terrain, and 6.7 m for mountainous terrain.
 - Have a desirable maximum gradient of 5% (6.7% for short distances) for flat and rolling terrain, and 6.7%(10% for short distances) for mountainous terrain.
-
- Short temporary roads that feed from the landing to the secondary road.
 - Carry less than 20 hvpd (<60,000 tonnes pa.)
 - One-lane roads constructed to the lowest pavement standard
 - Designed for a speed of 40 km/h for flat and rolling terrain, and 30 km/h for mountainous terrain.
 - Have a road width of 4.25 m
 - Have a desirable maximum gradient of 6.7% (12.5% for short distances) for flat and rolling terrain, and 8.3% (12.5% for short distances) for mountainous terrain.

4.1.4 Establishment Roads



Figure 18 - A typical establishment road

4.1.5 Skidder tracks



Figure 19 - A typical skidder track

- One-lane earth tracks used by light vehicles to access new areas for planting and silviculture.
 - Can support light vehicles only, and are generally more suited to 4wd's.
 - Designed for a speed of 25 km/h.
 - Have a road width of 2.5 m.
 - Have a desirable maximum gradient of 16.7% (25% for short distances). Its location should consider future use which may require much less gradient.
-
- One-lane earth tracks used by skidders and other forest machines to transport felled trees to the landing.
 - Only suitable for large rubber-tired or tracked machines.
 - Only necessary in steep terrain where ground base crews are working.
 - Can be referred to as contour tracking with a road width of 2.5 metres.
 - The maximum side-slope that can be safely logged using tracks is 75%.
 - Often not permitted due to environmental concerns. In this situation, haulers are used to log steep terrain.

4.2 ECONOMIC ANALYSIS

The objective of this section is to determine a roading standard which minimises the total cost to the forest owner. Truck haulage costs for proposed roading options are combined with an estimate of roading costs to determine the most economical roading option.

The method used for economic analyses is the Net Present Worth (NPW), where all future costs are discounted to a present day value. Future costs are discounted because the community places a higher value on costs and benefits which arise in the near future than on those which arise at a later date. The discount rate represents the rate at which present benefits and costs can be exchanged for future benefits and costs. Figure 20 outlines the process involved.

Often, the provision of roading is determined by the need to minimise the combined costs of roading and harvesting. NPW techniques are often used to justify road upgrading or sealing for major routes.

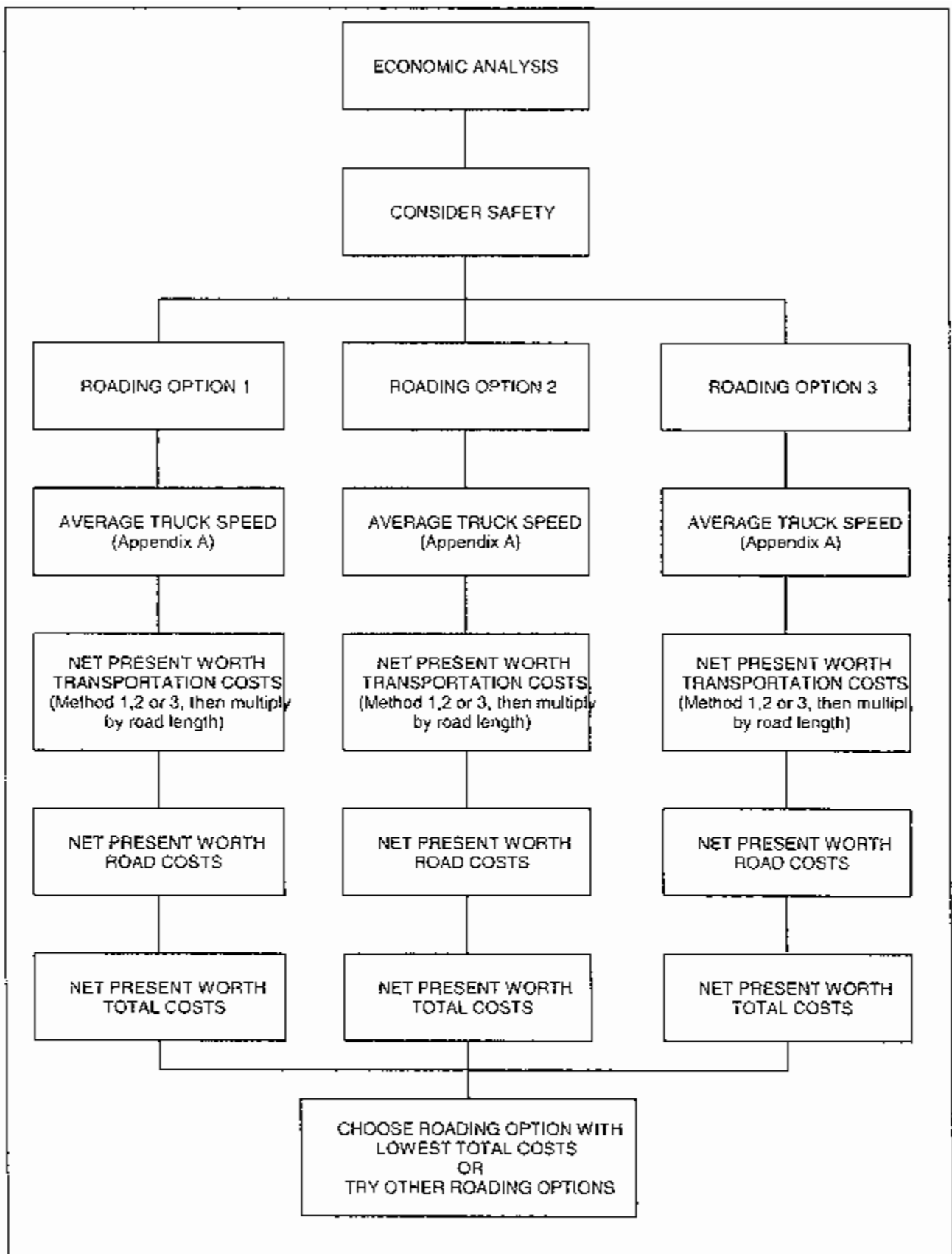


Figure 20 - Economic analysis of various roading options

4.2.1 Net Present Worth of Transportation Costs

Use one of the following three methods to calculate the NPW of transportation costs:

Note: The NPW of transportation costs are calculated per kilometre of road. Multiply this cost by the length (in km) of the proposed road to determine the total NPW of transportation costs.

Method 1

A quick method of estimating NPW of transportation costs by estimating from a chart. This should only be used if the parameters do not vary (refer to figure 21) and a rough estimate only is required.

Method 2

A formula to calculate the NPW of transportation costs. This method should only be used if the volume carted per annum is constant over the life of the road.

Method 3

The traditional method of calculating the NPW of transportation costs by tabulating costs that are incurred each year, and then discounting accordingly. This method can be used for all situations.

4.2.1.1 Method 1

The NPW of transportation costs can be quickly estimated using figure 21, but only if the inputs used to calculate the transportation costs are the same. If the inputs are not the same, then use either method 2 or method 3 to calculate the NPW of transportation costs. The average design speed can be estimated using the procedure described in Appendix A.

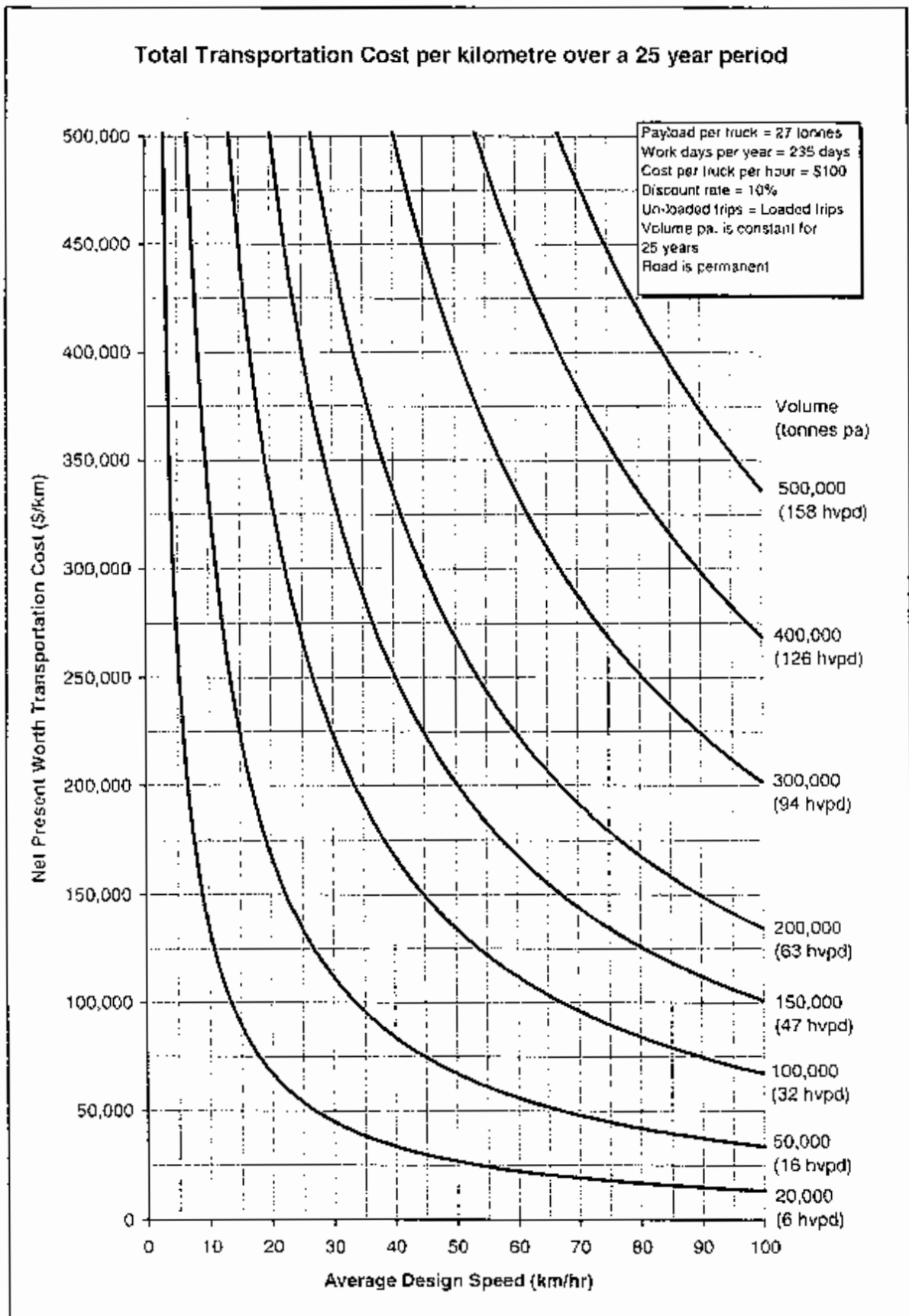


Figure 21 - The effect of average design speed on the Net Present Worth of transportation costs

4.2.1.2 Method 2

The following formula can be used to determine the NPW of transportation costs per kilometre over the life of the proposed road. This formula can only be used if the volume carted per annum is constant over the life of the road and the number of loaded trips is the same as the number of un-loaded trips. Use method 3 if this is not the case.

$$T = \frac{1}{v} \times 2 \times \frac{V}{P} \times C \times (pwf)$$

where:

- T = NPW of Transportation Costs
- v = The combined average truck speed of un-loaded and loaded travel (refer to Appendix A to estimate the average speed)
- V = Volume carted per year (tonnes)
- P = Average truck payload (27 tonnes for on-highway)
- C = Trucking costs per hour per truck (100 \$/hour, 1995)
- pwf = Present Worth Factor of an annuity of \$1 per period for n periods. This can be chosen from table 2, or calculated using the formula:

$$pwf = \left(1 - \frac{1}{(1+k)^n} \right) \frac{1}{k}$$

where:

k = interest rate (%/100)

n = number of periods (years)

Present Worth Factor of an annuity of \$1 per period for n periods			
Life of Road (years)	Discount factor at 10%	Discount factor at 5%	Discount factor at 15%
1	0.9091	0.9524	0.8696
2	1.7355	1.8594	1.6257
3	2.4869	2.7232	2.2832
4	3.1699	3.5460	2.8550
5	3.7908	4.3295	3.3522
6	4.3553	5.0757	3.7845
7	4.8684	5.7864	4.1604
8	5.3349	6.4632	4.4873
9	5.7590	7.1078	4.7716
10	6.1446	7.7217	5.0188
11	6.4951	8.3064	5.2337
12	6.8137	8.8633	5.4206
13	7.1034	9.3936	5.5831
14	7.3667	9.8986	5.7245
15	7.6061	10.3797	5.8474
16	7.8237	10.8378	5.9542
17	8.0216	11.2741	6.0472
18	8.2014	11.6896	6.1280
19	8.3649	12.0853	6.1982
20	8.5136	12.4622	6.2593
21	8.6487	12.8212	6.3125
22	8.7715	13.1630	6.3587
23	8.8832	13.4886	6.3988
24	8.9847	13.7986	6.4338
25	9.0770	14.0939	6.4641

Table 2 - Present Worth Factor of an annuity

4.2.1.3 Method 3

The costs incurred each year are simply tabulated and discounted accordingly. The resulting costs are summed to determine the NPW of the transportation costs over the life of the road. Table 3 is used where the number of un-loaded and loaded trips are the same. Table 4 should be used where the number of un-loaded and loaded trips differ.

Year <i>n</i>	Discount Factor $DF = \frac{1}{(1.1)^n}$	Volume (t) <i>V</i>	Transportation Costs $T = \frac{1}{v} \times 2 \times \frac{V}{P} \times C \times (pwf)$	Net Present Worth $NPW = T \times DF$
0	1.0000			
1	0.9091			
2	0.8264			
3	0.7513			
4	0.6830			
5	0.6209			
6	0.5645			
.....			
.....			
25	0.0923			
TOTAL				

Table 3 - Calculating the NPW of transportation costs
where un-loaded trips = loaded trips

Where:

$$DF = \text{Present Value of \$1} = \frac{1}{(1+k)^n} \quad k = \text{interest rate (\%/100)} \text{ (normally = 10\%)}$$

$$n = \text{number of periods (years)}$$

- V = Volume carted per year (tonnes)
- v = Average speed of both loaded and un-loaded travel, where the loaded traffic = un-loaded traffic (km/hr)
- P = Average truck payload in tonnes (usually = 27 tonnes for on-highway)
- C = Cost in \$ per hour for a truck (100 \$/hour, 1995)
- NPW = Net Present Worth of transportation costs.

If the number of loaded trips is not equal to the number of un-loaded trips then add an extra two columns to calculate the un-loaded and loaded costs separately as shown in table 4.

Year	Discount Factor	Vol pa (t)	Loaded Costs	Un-Loaded Costs	Transport Costs	Net Present Worth
"	$DF = \frac{1}{(1.1)^n}$	V	$L = \frac{1}{v_l} \times \frac{V}{P} \times C$	$U = \frac{1}{v_u} \times \frac{i}{(1-i)} \times C$	$T = L + U$	$NPW = T \times DF$
0	1.0000					
1	0.9091					
2	0.8264					
3	0.7513					
4	0.6830					
5	0.6209					
6	0.5645					
.....					
.....					
25	0.0923					
TOTAL.						

Table 4 - Table used to calculate the NPW of transportation costs where the loaded traffic is not equal to the un-loaded traffic

Note: i = the percentage of traffic that is unloaded as a decimal (i.e. %/100).

Where:

v_l = Average speed of a loaded truck (km/hr)

v_u = Average speed of a un-loaded truck (km/hr)

4.2.2 Net Present Worth of Roothing Costs

Calculating the NPW of roading costs is similar to the method 3 above - the roading costs incurred each year are simply tabulated, discounted accordingly, and then summed. When comparing two different roading standards at the same location, the road maintenance costs for both options are likely to be the same. Therefore, for purposes of comparison, the road maintenance costs can usually be ignored if the same roading material is used.

Year n	Discount Factor $DF = \frac{1}{(1.1)^n}$	Roothing Costs $X = C + (M) + (R)$	Net Present Worth $NPW = X \times DF$
0	1.0000	C	C
1	0.9091	M (+R)	
2	0.8264	M (+R)	
3	0.7513	M (+R)	
4	0.6830	M (+R)	
5	0.6209	M (+R)	
6	0.5645	M (+R)	
.....	
.....	
25	0.0923	M (+R)	
TOTAL			

Table 5 - Calculating the Net Present Worth of roading costs.

Note: C = Initial Capital Cost to Construct Road;

M = Annual Maintenance Costs;

R = Additional Rehabilitation Costs if Required.

Using table 5 enables various roading materials (stabilised, sealed etc) and staged construction to be compared economically, provided that the maintenance and construction costs are known.

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CONSENT APPLICATIONS

CHAPTER 5 - CONSENT APPLICATIONS

5.0 INTRODUCTION

Depending on the proposed road construction, a Resource Consent may be required from the District and/or Regional councils. In addition, a consent or written approval may also be required from other authorities, organisations or persons.

Everything, from the amount of earthworks required to the distance from streamside management zones or waterways, will determine whether a Resource Consent is necessary. These limits and conditions are set by the local authorities, and are included in their District or Regional Plans.

Other details - such as access and egress onto local and state roads, and the position of archaeological and historical sites - will determine whether a consent *or* consultation is required from other authorities or organisations.

Detailed requirements for every authority or organisation cannot be included in this manual, owing to the complex and detailed nature of many of the consents. However, this chapter informs you of the *likely* path which is to be expected for a roading application procedure.

Note: For the purposes of this publication, "Territorial Authority" refers to both the District and Regional Authorities.

5.1 RESOURCE CONSENTS

5.1.1 What is a Resource Consent?

The Resource Management Act 1991 (RMA) introduced a new system of managing and protecting the environment. Sustainable management of natural resources is promoted by the RMA through Resource Consents obtainable from territorial authorities.

A Resource Consent is a document authorising the holder to use or take resources from, or to discharge water or wastes into, the natural environment.

5.1.2 Will a Resource Consent be required?

This can be determined from the District or Regional Plan, which are set out by the territorial authority in accordance with the RMA (1991). The proposed activity will be classed as one of the following five types:

- Permitted
- Controlled
- Discretionary
- Non-complying
- Prohibited

Some councils require a consent for even the smallest amount of earthworks, e.g. 2m³ or more, whereas other councils do not require any consents for earthworks. A check with the relevant territorial authority plan will determine if a consent is required, and how it should be applied for.

5.1.3 Which territorial authority should be applied to?

Due to the organisation of the territorial authorities throughout New Zealand, it is often difficult to determine which authority is to be approached for the purposes of obtaining a resource consent. When considering a roading proposal, the best idea would be to consult with the appropriate authorities to determine the consents which may be required.

5.1.4 What activities usually require a Resource Consent?

Resource Consent may be required for the following activities:

- Earthworks
- Removal of vegetation

- Aggregate extraction from rivers or quarries
- Diverting water runoff into streams and rivers
- Stockpiling of spoil and waste material
- Erecting/installing stream and river crossings, including temporary river diversion for the purposes of installing a bridge, culvert etc.
- Discharge of contaminants into the air, land or water

5.2 OTHER CONSENTS

It would be wise to consult with the following organisations to get their input into who may be interested or effected parties.

5.2.1 Transit New Zealand

5.2.1.1 State Highways

Any new access onto a state highway will require permission from Transit New Zealand who will be concerned with:

- Highway access design-marking and signage
- Visibility from the access
- Visual distractions (advertising signs etc.)
- Landscaping and vegetation which may cause obstruction, shading or otherwise impair visibility
- Glare from lighting
- Traffic flows expected

Transit New Zealand has developed a guideline document to help applicants assess the effects of their activity on the state highway network. A copy of this document, *Highway Planning Under the Resource Management Act 1991*, is available from all Council and Transit New Zealand offices, and it should be consulted when preparing your consent application. Section 8, *Effects of Access on Safety and Efficiency of the State Highway*, and Section 13, *Effects of Glare and Light overspill*, are the most

relevant to forestry roading. For more complex applications, you may need professional assistance from either resource management staff, survey or engineering consultants, or legal advisers.

When applying for approval from Transit New Zealand, your application should include all of the following:

- A detailed description of the proposed activity, including expected traffic generation
- Locality and site plans to scale showing :
 - buildings
 - access
 - driveways
 - parking
 - topography
 - location of side roads
 - distance to roadside
 - signage
 - access visibility
 - landscaping etc.
- A full assessment of the effects on the highway
- A copy of the relevant Certificate of Title.

5.2.1.2 Local Roads

District or Regional Plans, available from your territorial council office, will advise of any policies and rules or guidelines regarding activities affecting local roads.

In particular, they will be concerned with:

- Total number of traffic movements
- Effect on intersections
- Impact on road pavements

5.2.2 The Historic Places Trust, and Local Maori

Historic Places Trusts may require a consent application, and local Maori may require consultation if construction involves either crossing or clearing land on or near:

- a site of significance to Maori
- a historic places site
- an archaeological site

Under the Historic Places Act 1980 it is an offence to destroy or damage an archaeological site or a site with important historical or traditional values. This Act refers to both land and buildings. Territorial authorities usually register such sites in their district scheme, however, sometimes archaeologists or historians may need to be employed to correctly identify and map any relevant sites, since not all sites are recorded.

Contact:

Planning Officer with your District or Regional Council, specialised staff in the Department of Conservation, or staff from the Historic Places Trust.

5.2.3 Department of Occupational Safety and Health (OSH)

OSH may have regulations and guidelines dealing with:

- Road width
- Road Grades
- Construction activities
- Road surfacing

See the *Forest Industry Approved Code of Practice, Safety and Health in Forest Operations*, which was under development when this manual was produced.

5.2.4 Forest Company (If relevant)

- May have in house operational requirements affecting:
 - Environmental
 - Planning/Operational

- Safety
- Geometry

5.2.5 Fish and Game Council, and Department of Conservation (DOC)

The Fish and Game Council and DOC will be concerned with stream crossing design, and restricting waterway contamination, in order to protect fish passage up or down the stream. They will provide guidelines for protecting:

- Flora and fauna habitat
- Fish spawning habitat
- Soil and water values

Note: Before the proposal is submitted to the District or Regional council, the above authorities and organisations should be consulted. This will speed up the consent process, and prevent any unnecessary delays or unwelcome surprises.

When dealing with any of the above authorities or organisations it is advisable to obtain all decisions in writing, and to keep copies of all correspondence. This will ensure a backup if a dispute occurs during road construction.

Many of the above requirements are controlled and regulated by various legislation.

5.3 WHAT INFORMATION IS REQUIRED FOR A RESOURCE CONSENT? (See also Appendix B)

When approaching a council or other authority for a Resource Consent, a professional presentation will ensure that the application proceeds smoothly. A Resource Consent application *must* include:

- An assessment of actual or potential effects that the activity may have on the environment, and the ways in which any adverse effects may be avoided, remedied or mitigated.
- A location plan
- Who you have consulted, and their comments, if any

The application form will generally ask for the information needed by the council in deciding whether to approve your application. However, you may be asked to supply further information during the process of considering your application.

Full engineering design drawings and calculations are often required for Resource Consents. These drawings will show the quantity of earthworks required as well as other engineering measurements and quantities. They will also demonstrate to the council the advanced level of planning used. Often council staff will not need to visit a proposed roading site to approve a consent. Engineering drawings and computer modelling are covered in chapter 6 of this manual.

A job description or prescription outlining all proposed construction operations should be provided with the road design. The following information may be required:

- Earthworks quantities
- Vegetation removal (quantity, type, and method of removal)
- Batter slope grades
- Runoff expected and drainage structures
- Erosion control structures of batter slopes
- Stream crossings (number, type and size)
- Silt traps and other sediment control measures (if required)
- Soil types
- Aggregate extraction (quantity and location)
- Any temporary construction works necessary
- Land slope and contours
- Construction methods

- Timing of works
- Construction techniques (i.e. endhauling vs sidecasting (*see chapter 7*))
- Any problems that may be encountered, and their solutions

5.4 TERRITORIAL AUTHORITY CONSENT PROCESS

Figure 22 demonstrates the usual consent process required for obtaining a consent from territorial authorities. Two avenues of application are shown, *notification* and *non-notified*. The territorial authority will determine which path you follow.

Councils have strict time limits that are followed for various aspects of the resource consent process.

The time period between lodging the application and the notice of decision is approximately one month for non-notified applications, and 3 Months or more for notified applications.

Any request by the council for further information automatically “stops the clock” on the process until the information is provided. This can significantly lengthen the time-frame, but it can be overcome by ensuring that adequate information is provided at the outset. See table 6 for a detailed breakdown of time frame for a notified application.

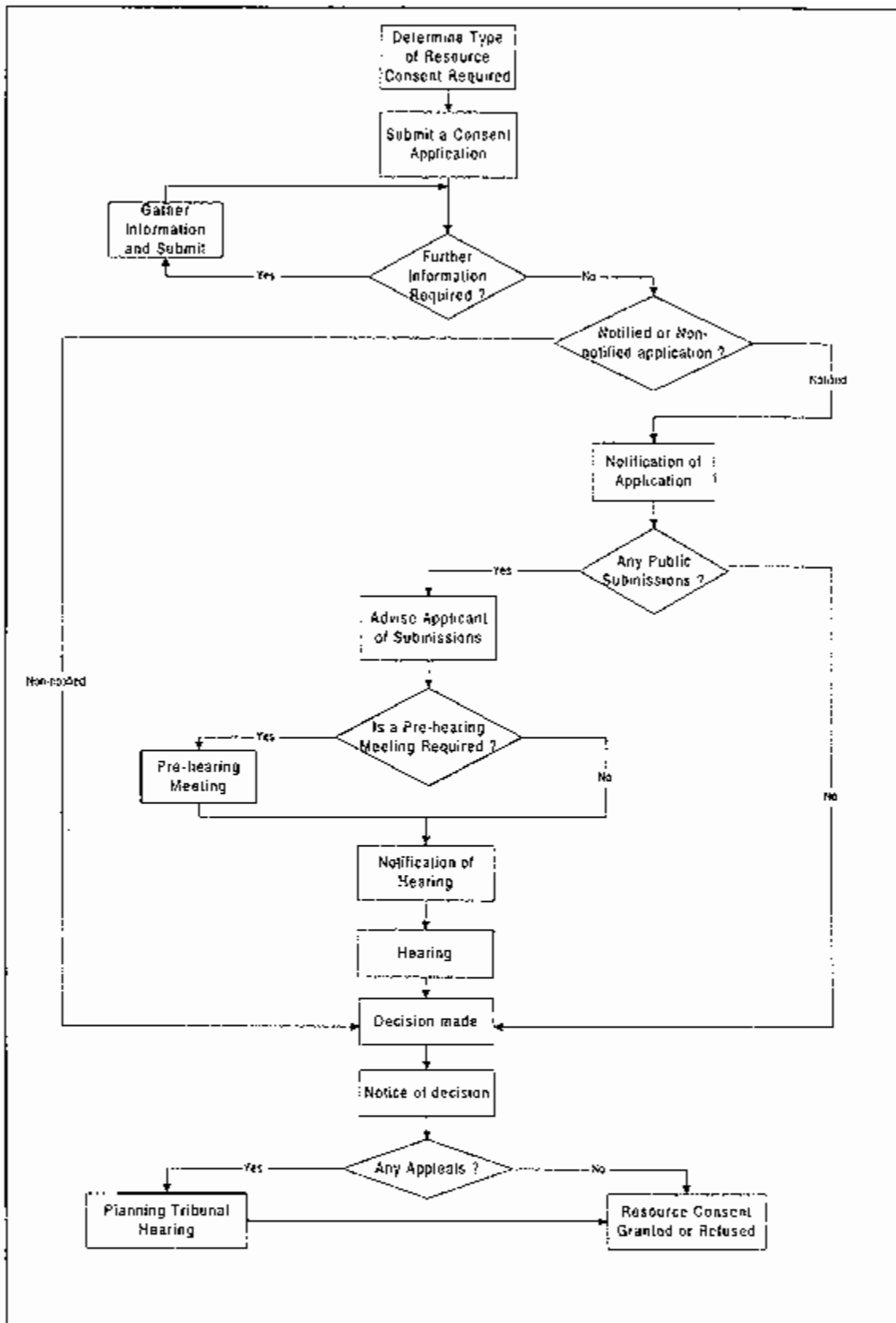


Figure 22 - The process of applying for a Resource Consent

PROCEDURE	COUNCIL TIME-FRAME
Resource Consent Application submitted	Council acknowledges receipt of consent within five working days
Council notifies application and seeks submissions	Within 10 working days of receiving the complete application
Submissions close	Within 20 working days of public notification
Hearing of resource consent application (If required)	Within 25 working days of the close of submissions
Council's decision	Within 15 working days after hearing
Appeal to Environment Court	Within 15 working days of notice of the councils decision
Environment Court decision	Commonly 6-12 months after the appeal is lodged

Table 6 - Time-frame for Resource Consent Applications

In dealing with the process of obtaining a Resource Consent it is advisable to start the process well before the construction is due to commence. Two years or more can be required for consents which require notification or consultation, or those situated in a sensitive area. Some applications can take extra time if public submissions and objections to the project have to be worked through.

5.4.1 Controlled activity

A controlled or discretionary activity, as outlined by the local authority, will usually not require public notification, and a Resource Consent application can be dealt with quickly by the local authority. This type of discretionary activity may not even require consent, but it may have some conditions associated, such as limiting construction through a sensitive site.

5.4.2 Non-controlled activity

A non-controlled activity will require public notification, which usually involves notifying the local residents who may be directly affected (this can include Transit New Zealand and Tranz Rail). In addition, a submission calling for the general public to express their views must be displayed in the local newspapers.

5.4.3 Resource Consent Implementation

The RMA requires consent holders to initiate their work within two years of the consent being issued. If this is not complied with, the consent lapses and is no longer valid. However, an application to extend the lapsing period can be sought from the council.

Each consent may have varying terms, depending on what the consent is for. The term of a consent cannot be extended, even by application. For example, a stream crossing consent may be for 35 years but an earthworks consent may have a term of only two years.

LAYING OUT THE ROADLINE

CHAPTER 6 - LAYING OUT THE ROADLINE

6.0 INTRODUCTION

This chapter describes how to plan a road location on a topographical map, and locate its position in the field for construction. There are also sections which explain geometric road design, how to check for adequate sight distance, and the setting out of a designed road for construction.

The flow chart in figure 23 shows procedure which should be followed when planning and setting out a roadline in the field. The sight distance section (6.4.4) may be used separately when checking for available sight distance on existing roads.

6.1 PLANNING

The first step in harvest planning is to locate the landings, since their position is critical in ensuring an efficient harvesting operation. It is then assumed that the start and end points of the roads are known since the positions of the landings have already been planned. However, there may be occasions when it is not possible to get a road to a proposed landing at a reasonable cost. In this situation, the landing position will need to be changed, or an alternative harvesting system used (e.g. two staging).

6.1.1 Terrain Information

Terrain information is vital to road planning. There are several sources that are used in combination:

Field Work

There is no substitute for a physical inspection of the road settings. A first visit should take place before any detailed planning work has begun. The visual image gained from this inspection will make the interpretation of aerial photographs and maps much easier. The site should also be re-inspected during the planning process to check the feasibility of any proposed roads.

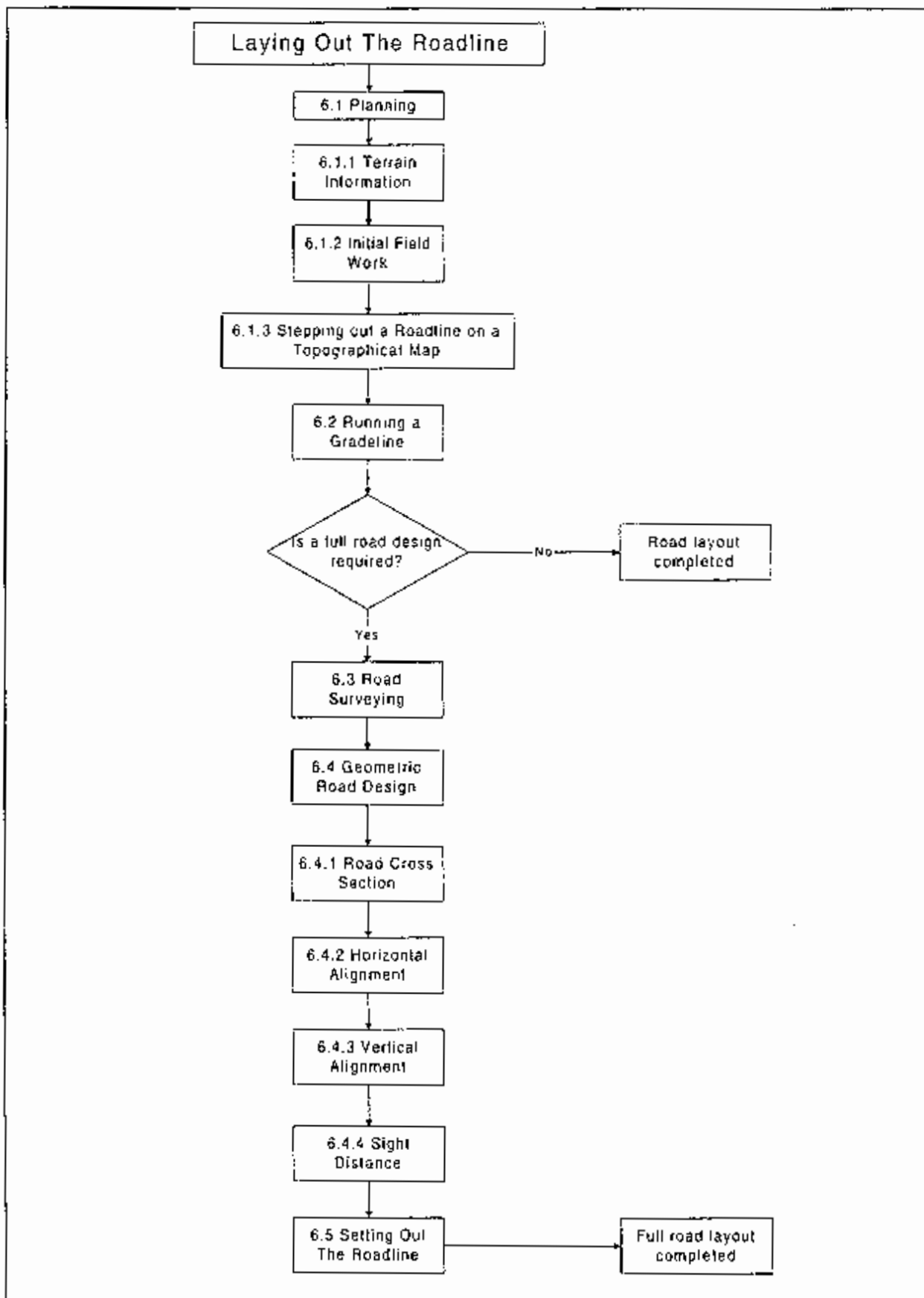


Figure 23 - Procedure for planning, designing and setting out a roadline

Note: the numbers refer to the sections of chapter 6

Aerial Photographs

Aerial photographs taken without extensive tree cover are used to show visible ground features, such as bluffs, swamps, and suitable stream crossings. Stereoscopic images, if available, are an ideal aid for locating suitable locations for roading. However, although aerial photographs show ground features in their relative positions, they do not allow accurate determination of areas or distances unless calibration measures are taken.

Topographical Maps

A topographical map is helpful in determining the feasibility of a proposed roadline. The roadline can be stepped out on the map at a known grade from a start point to a finish point. Section 6.1.3 describes this procedure.

6.1.2 Initial Field Work

Knowledge of the ground features is an essential part of locating a road.

Any features (either good or bad) of the topography and ground conditions which will affect road construction should be noted on the map. Use aerial photographs and any other information which will aid in determining locations that do not favour road construction.

Locate and mark on the map and areas which do not favour road construction, e.g:

- Rock bluffs
- Ponds and lakes
- Excessively steep terrain
- Unstable soils
- Slips
- Swamps
- Environmentally sensitive areas
- Culturally sensitive areas

Also, locate and mark features which will favour economical construction. These can be marked as possible control points (points which the road must pass through):

- Reasonable side slopes
- Desirable stream crossings
- Saddles (passes) in ridge lines

- Areas suitable for switchback construction
- Start and finish points (junctions and landings)

After a field inspection of the area, the roadline on the map can be re-worked either back at the office or while in the field. Careful attention must be given to ensure that the road is located in favourable areas, and not in areas which would be too expensive and difficult to road.

Figure 24 shows a roadline marked on a contour map, with control points at A, B, C and D.

6.1.3 Stepping Out A Roadline On A Topographical Map

This is a useful technique for testing the feasibility of a roadline of a given average slope. The average slope in steep terrain is usually the maximum grade that a logging truck can sustain over long distances. Typically this grade is 10%, but it can range from flat to as high as 16% for favourable grades (20% is the maximum legal grade). It is better to make the grade steeper on straights and considerably flatter on the curves giving an undulating grade (i.e. where steeper and flatter sections alternate) rather than to have a sustained single grade. Also, consider the season(s) during which the road will be used - during the winter, the road may be slippery, and the adverse grade may need to be kept below 10%.

The procedure for stepping out a roadline is:

1. Mark known control points on the map

Control Points are points which the road must pass through (see 6.1.2) they include:

- The start point or area (usually an existing road)
- The finish point (landing)
- Any known stream crossing sites
- Any other points that the road must pass through (e.g. other landings)

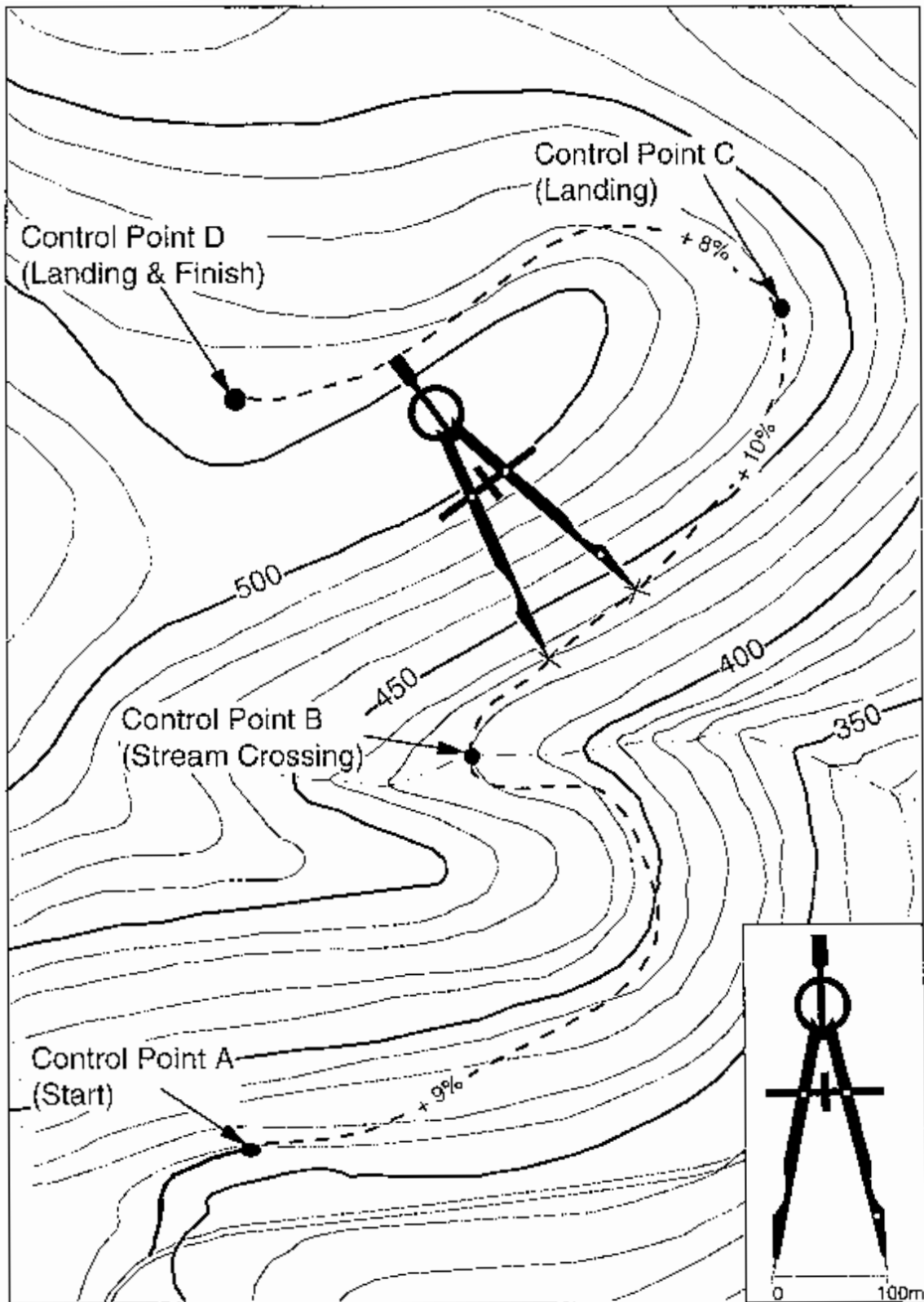


Figure 24 - Typical roadline stepped out on a topographical map through control points A, B, C and D.

2. Determine an appropriate grade

Use either:

- Maximum grade for steep terrain (e.g. 10%) or
- The average grade between adjacent control points. This can be calculated using the following formula:

$$G = \frac{100 \times (E_B - E_A)}{D_{AB}}$$

Where:

G is the average grade between control points A and B (%)

E_A, E_B are the elevations of A and B

D_{AB} is the distance between A and B

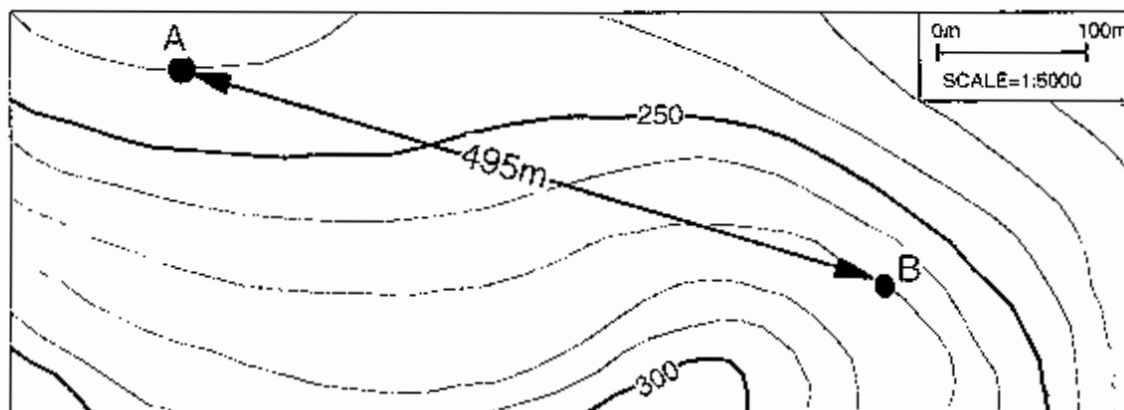


Figure 25 - Measuring distance on a topographical map.

The elevations of the control points are estimated from the contours on the topographical map. The distance between the control points is measured with a ruler on the map, and then the map scale is used to determine the actual distance. Alternatively a scale rule can be used, and the distance read directly from it.

Note: If $G >$ Maximum grade (e.g. 10%) then use the maximum allowable grade.

Example (see figure 25)

The elevation of control points A and B are read from the topographical map as: $E_A = 240\text{m}$, $E_B = 270\text{m}$. The distance between A and B is measured and scaled as: $D_{AB} = 495\text{m}$. The average grade can then be calculated:

$$G = \frac{100 \times (270 - 240)}{495} = 6.1\%$$

Table 7 can be used to convert between the different methods of measuring grade.

Percent	1 in x	Degrees
0.0	-	0.0
0.5	200.0	0.3
1.0	100.0	0.6
1.5	66.7	0.9
2.0	50.0	1.1
2.5	40.0	1.4
3.0	33.3	1.7
3.5	28.5	2.0
4.0	25.0	2.3
4.5	22.2	2.6
5.0	20.0	2.9
5.5	18.2	3.1
6.0	15.7	3.4
6.5	15.4	3.7
7.0	14.3	4.0
7.5	13.3	4.3
8.0	12.5	4.6
8.5	11.8	4.9
9.0	11.1	5.1
9.5	10.5	5.4
10.0	10.0	5.7
10.5	9.5	6.0
11.0	9.1	6.3
11.5	8.7	6.6
12.0	8.3	6.8
12.5	8.0	7.1
13.0	7.7	7.4
13.5	7.4	7.7
14.0	7.1	8.0
14.5	6.9	8.3
16.0	6.7	8.6
16.5	6.5	8.8
16.0	6.3	9.1
16.5	6.1	9.4
17.0	5.9	9.6
17.5	5.7	10.0

Table 7 - Grade relationship-converting percent to degrees

3. Step out the road between the control points using dividers

It is often sensible recommended to start from the log landing at the end of the road and work backwards, since the log landing is usually fixed but the start of the road (usually an intersection with an existing road) can change.

Set the dividers to a distance which will achieve the required grade between adjacent contours. This distance is given by the following formula:

$$D_{\text{Dividers}} = \frac{D_{\text{Cont}} \times 100,000}{(G \times X)}$$

Where:

D_{Dividers} is the spacing that the divider is to be set to (m)

D_{Cont} is the map contour interval (m)

G is the average grade determined in step 2 (%)

X is the map scale (1:X)

The dividers are then used to step out a trial roadline between the two control points. Starting at the most critical control point e.g. the landing at the end of the road, step from one contour to the next until you reach the end control point. Sketch the roadline along the points that were marked by the dividers on the contours. Figure 26 illustrates this process.

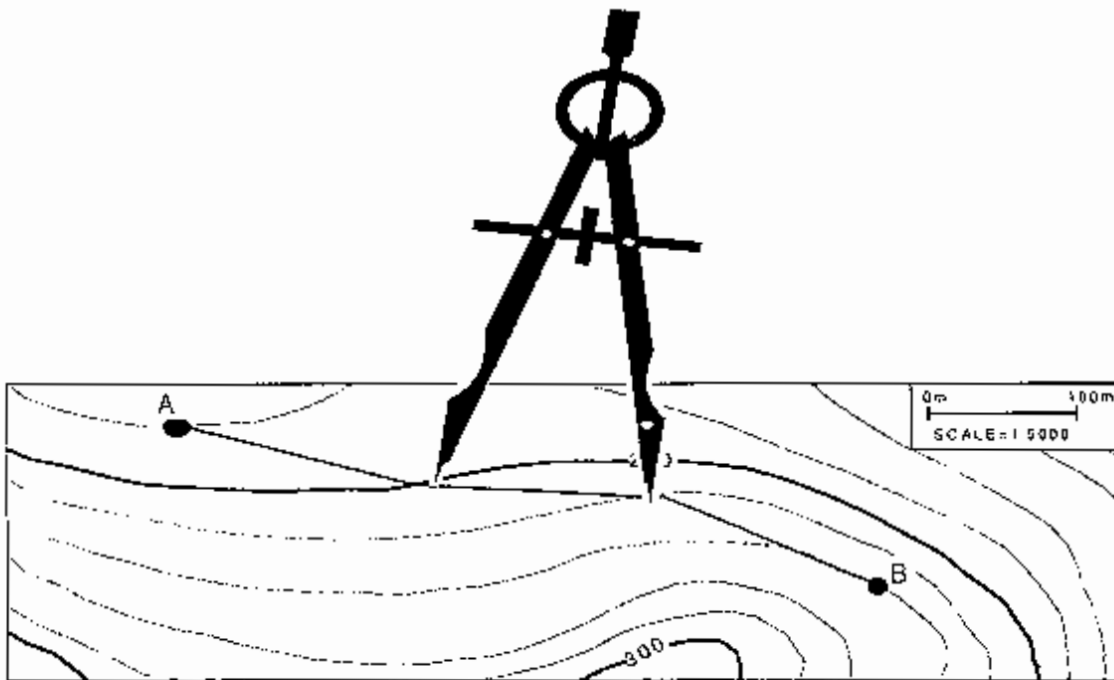


Figure 26 - Using dividers to step out a roadline.

There are cases where the grade needs to be made flatter by drawing the roadline by hand parallel to the contours, these are listed below:

- Crossing streams (0%)
- Crossings saddles (0%)
- Crossing gullies (0%)
- On curves (use 0%)
- Around tight ridges (0%)
- Approaching landings and road intersections (<6%)

Plotting a roadline on the topographical map is only an initial step to ensure that the proposed road is feasible. This roadline must be checked onsite, re-marked on the topographical map, and then correctly set out in the field by running a grade-line.

6.2 RUNNING A GRADELINE

Points are marked on trees or bushes approximately 20 metres apart at eye level to denote the finished road centreline along a chosen longitudinal gradient.

Equipment

Gradelines can be set with an Abney Level or Clinometer (figure 27).

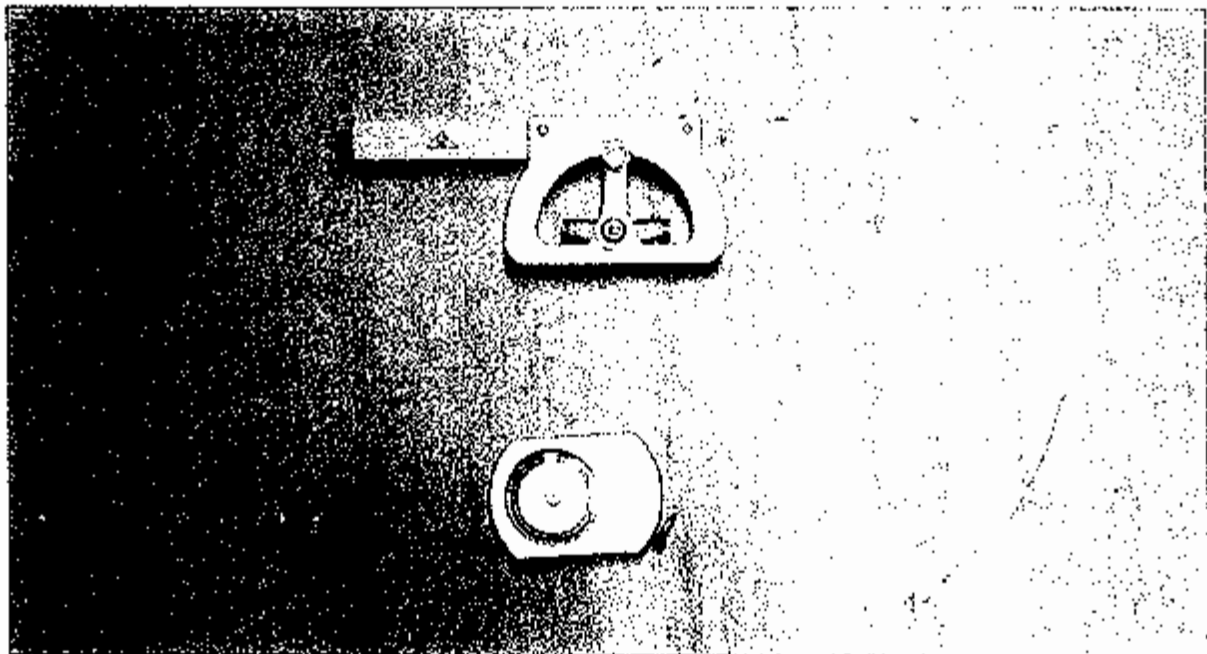


Figure 27 - Abney and Clinometer used to measure slope between control points

Marking a Gradeline

Ribbon tied around trees and bushes at eye level should be used in preference to paint, since it is more permanent and easier to see.

A two-man party for gradeline installation is usual, but it can be done by one person (however, safety implications must be recognised) see figure 28.

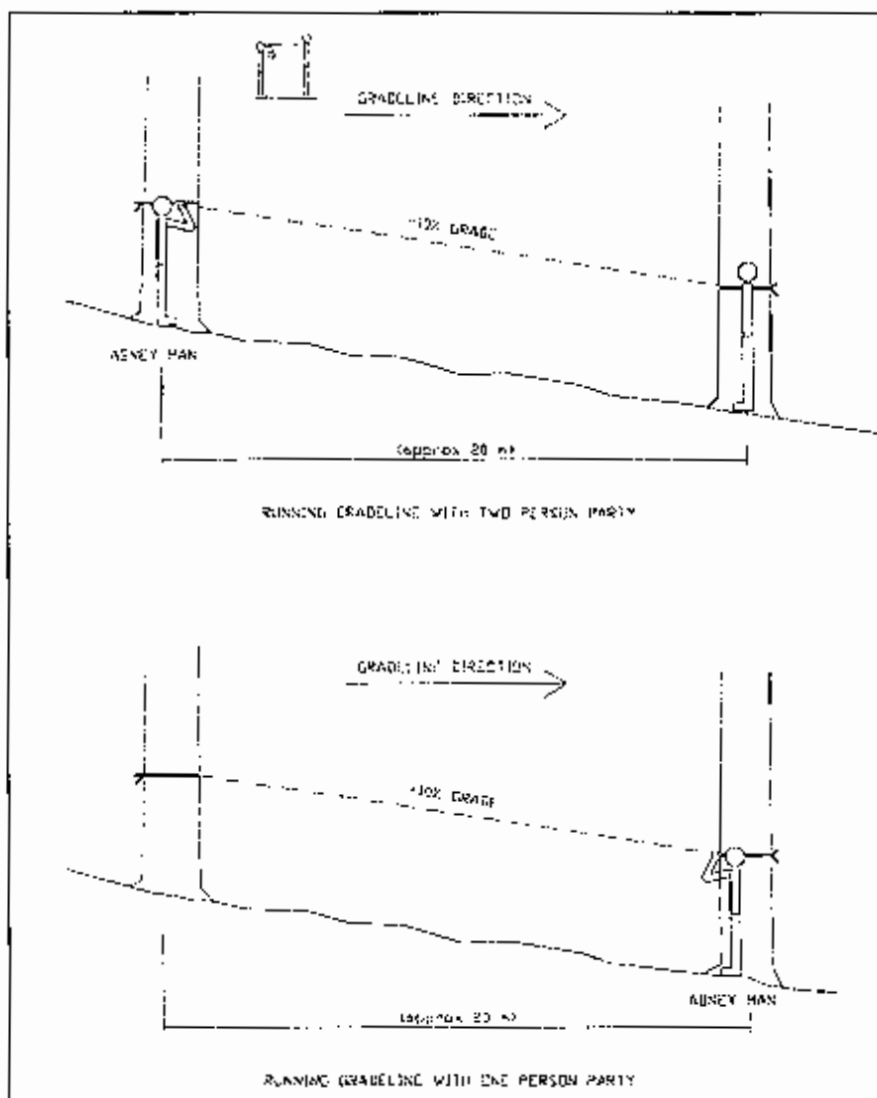


Figure 28 - Marking a gradeline

With a two-man party, the Abney man starts by setting a ribbon at eye height on a tree or bush, and sending the second man ahead about 20 metres inline. The direction to the next

control point can be established from a topographical map containing the marked roadline. The Abney man directs the second man to stand next to a tree which is nearly on grade, and which is likely to be marked. This man holds out some ribbon at the eye height of the Abney man and, at his direction, moves up or down the sideslope until he is on "grade". When he is on grade, he attaches the ribbon to a nearby tree or bush at this elevation. This procedure is repeated until the start and finish control points have been joined.

If only one person is available, gradelines can be set by pacing ahead of a grade mark, turning around, and then moving up and down the sideslope until the abney sight is on the grade mark. At this point another grade mark is set, and the procedure is repeated until the desired control point is reached.

Difficulties in maintaining a gradient can occur when:

- adjusting the gradeline to accommodate an intermediate control point
- crossing a steep hollow or draw
- going around a long sharp ridge
- continuing around a switchback

Procedures to overcome these problems are presented in Appendix C.

6.3 ROAD SURVEYING

Where a full road design is required (see section 6.4), the road will need to be surveyed by conducting a traverse survey, and taking cross-sections at regular intervals, so that a plan, longitudinal section and cross-sections can be produced. There are many variations in methods of road surveying, and in the setting out of a field book which mostly depend on personal preference or established formats. One method of a standard forest road survey is outlined below.

Equipment required for surveying (figure 29)

- Cloth (fibreglass) Tape
- Suunto (or Abney), or similar clinometer
- Compass
- Field Book
- Spray Paint and/or Ribbon and Waterproof Marker Pen
- Stakes (optional)
- Sledge Hammer (optional)

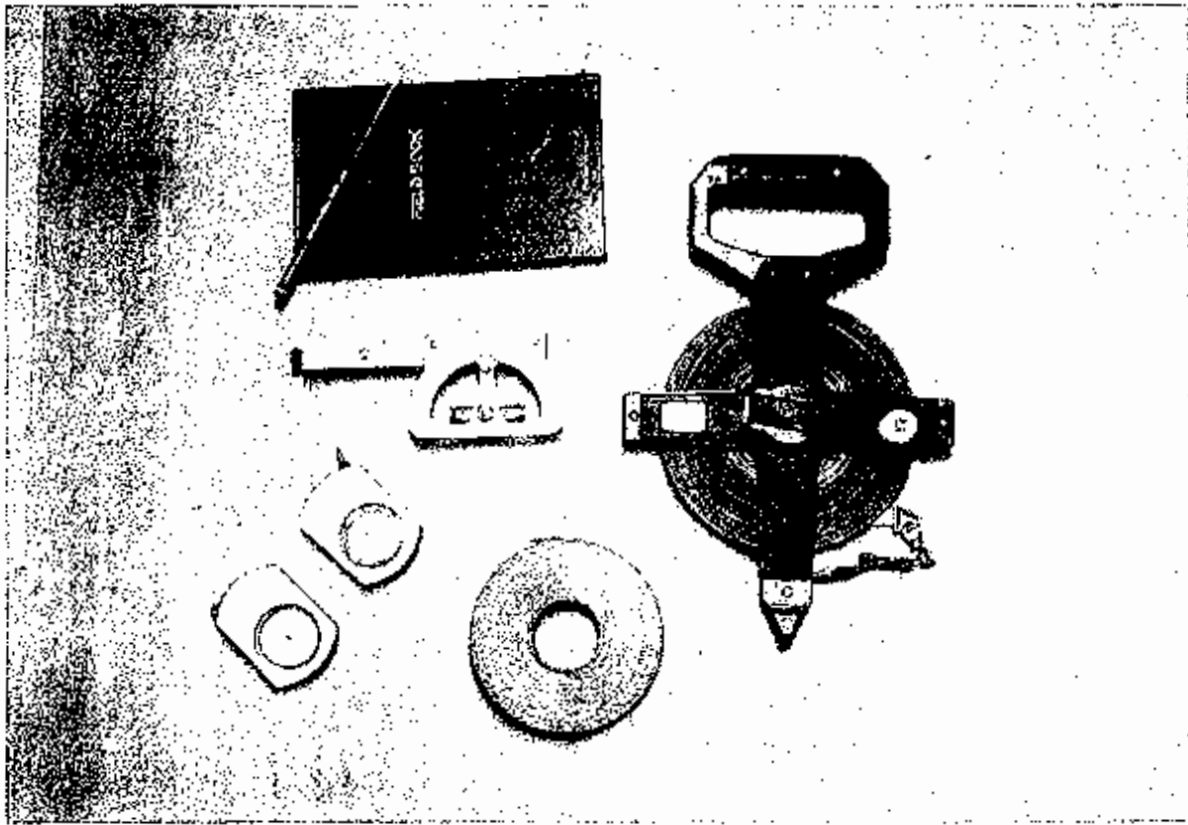


Figure 29 - Typical surveying equipment

Before beginning the survey, it is important that the gradeline has already been established, or that an approximate road centreline has been marked. This ensures that the road survey line is reasonably close to the final road location which will reduce errors and problems when designing the roadline.

The surveying process involves:

- Establishing stations at approximately 20m intervals near the proposed road centreline or gradeline (road centreline will move left or right after geometric design). Stations should also be placed wherever there are any hollows and ridges. Stakes can be driven, or the nearest available tree marked as a station. These stations are labelled 1,2,3,.... etc. (or any other convention can be used i.e. distance) for future reference.
- Taking and recording compass bearing, slope and distance from station to station.

- Taking and recording cross-sections, by measuring slope and distance either side of the station.

Slope can be measured in either % or degrees depending on the instruments, and road design methods (software) used. Some design packages can only accept degrees, while others can only accept %. Downhill slopes are recorded as negative values.

The slope and distance of side-shots (cross-sections) can be measured from point to point, or from a change point to point (figure 31). Point to point is where the surveying “leap-frogs” to the next point to take a measurement, while change point to point is where the surveyor stands in one position to take several side-shots. The choice depends on the easiest method in the field, and also on the road design software that will be used. The number of side-shots taken is dependent on how many shots the road design software can accept, as well as the number required to adequately represent the ground surface.

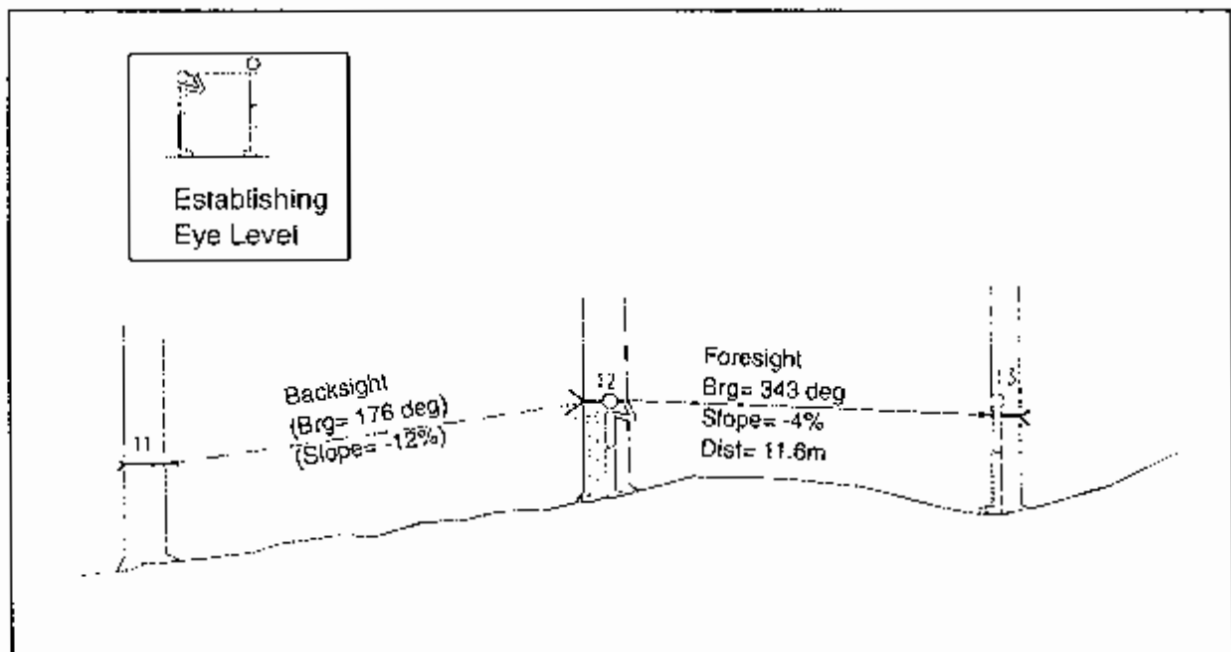


Figure 30 - Taking and recording slope, bearing and slope distance between survey stations

Note: Trees can be replaced with pegs

It is important to realise that the survey stations are not necessarily the same as the gradeline marks (which may be used just as a guide). The survey stations represent changes in topography, and it is common to push stakes into the ground to represent survey stations, rather than to use ribbons on trees. The stakes can be easily distinguished, and placed where

needed rather than having to use a nearby tree. Also trees are often felled before road construction, and, any tree marks are therefore lost.

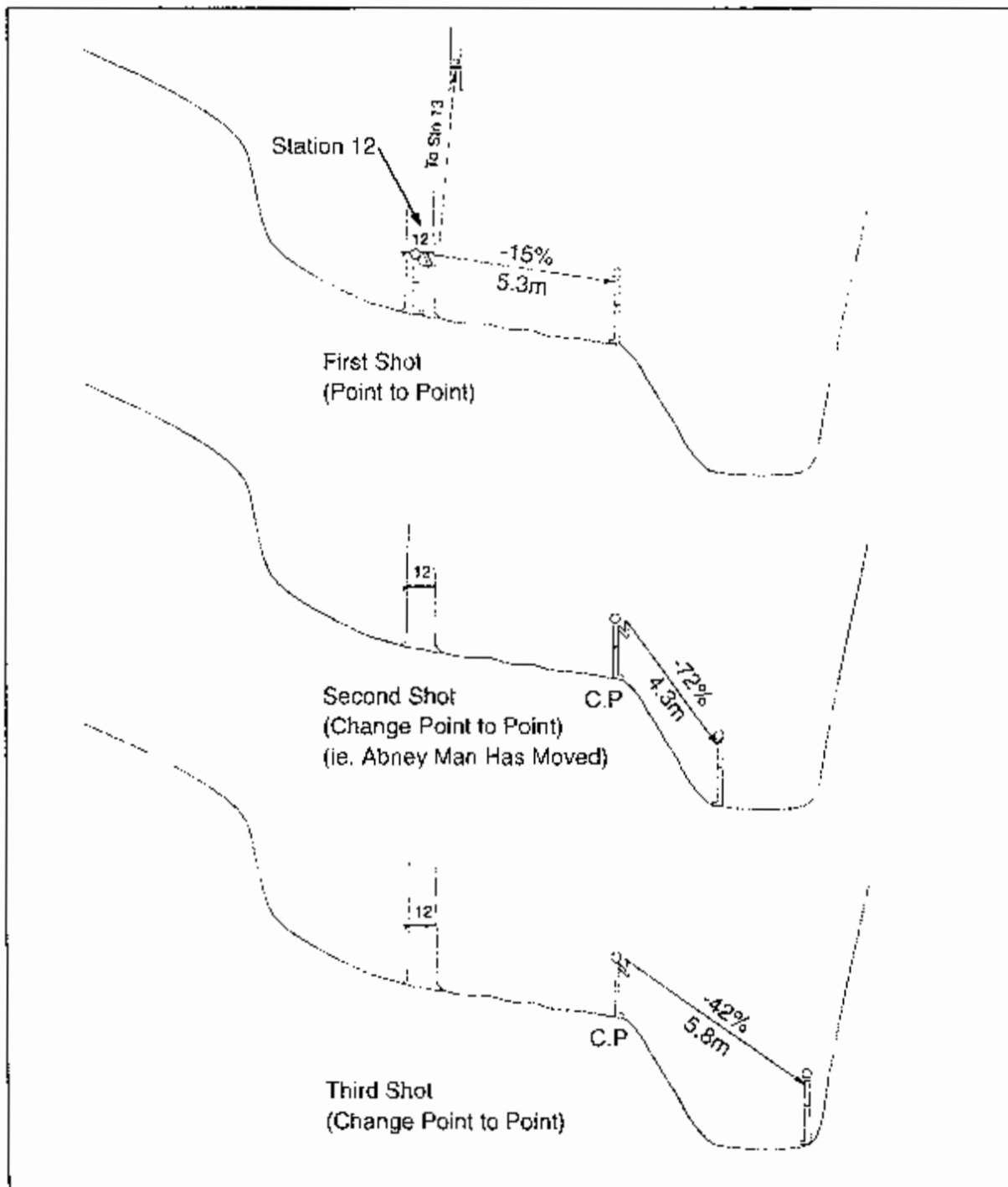


Figure 31 - Measuring the slope and slope distance for RHS (Right Hand Side) cross-section

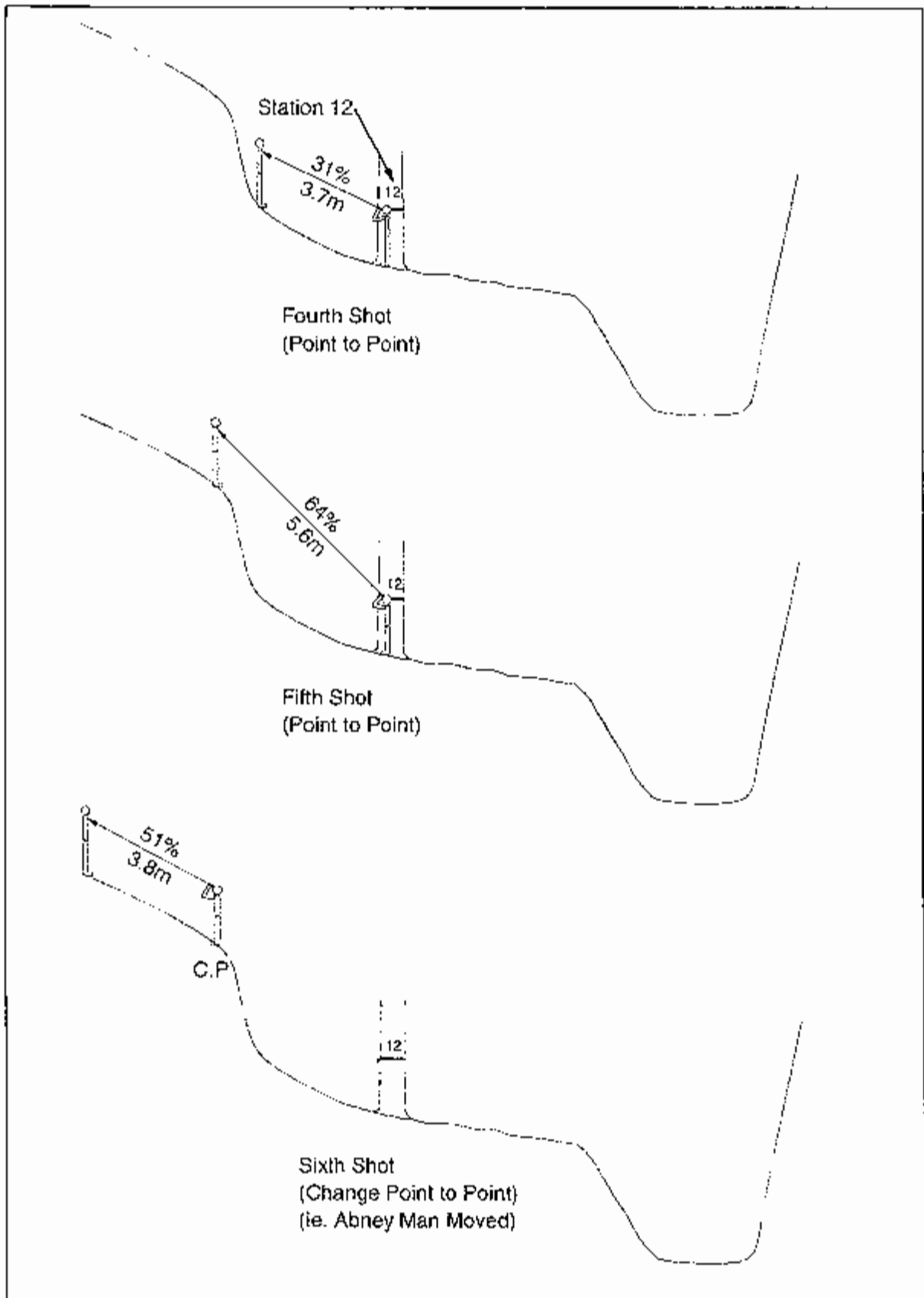


Figure 32 - Measuring the slope and slope distance for LHS (Left Hand Side) cross-section

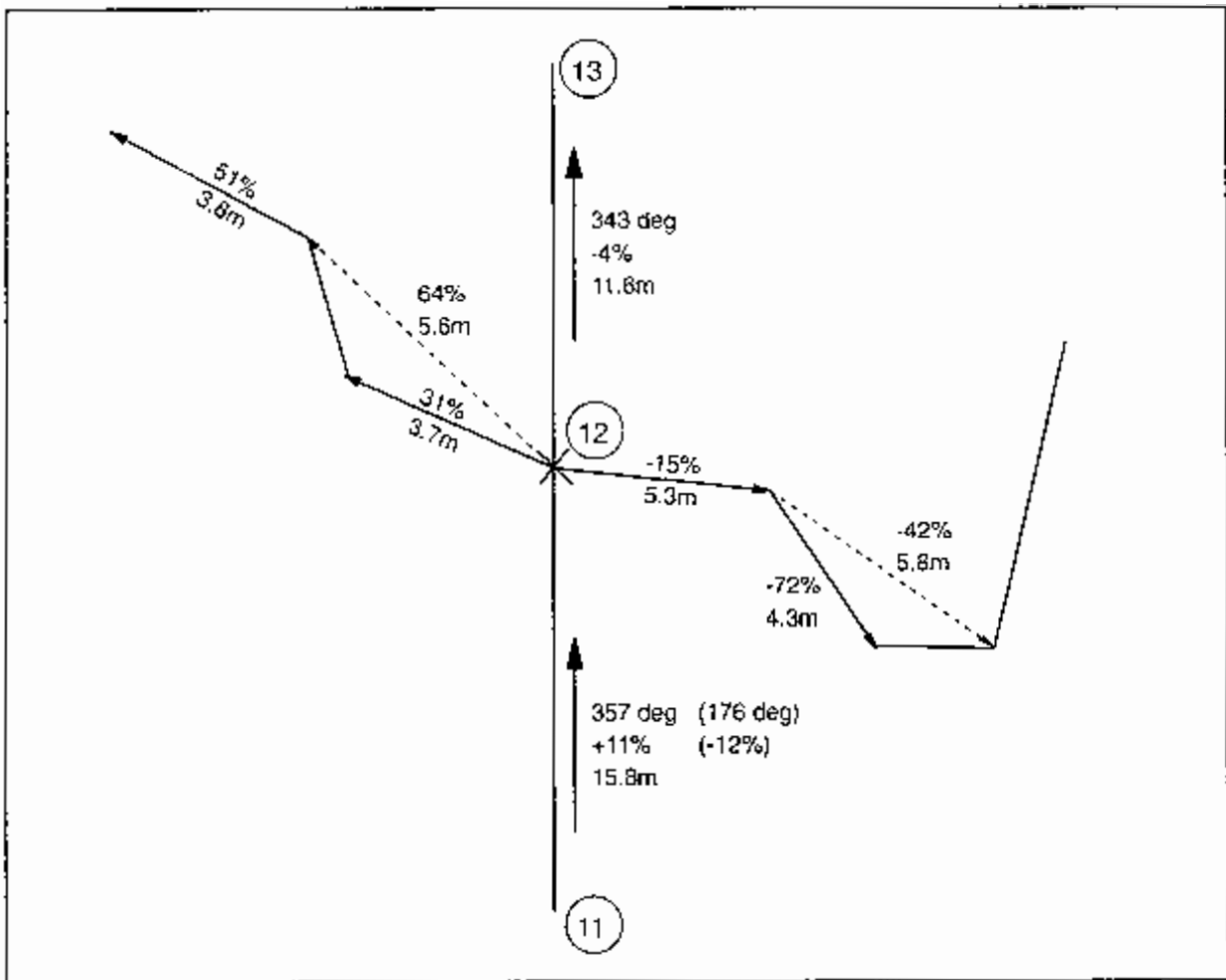


Figure 33 - Typical field book setout.

With experience, the field book can be set out using columns of numbers to speed up the process (table 8). However, a common mistake is to miss out the negative sign for a downhill slope, which could go unnoticed without a sketch of the cross-section. Tabular methods are recommended only for experienced survey crews.

				Cross-Sections							
Stn	Brg	Slope	Dist			LHS				RHS	
11											
	367	11%	16.8m								
	(176)	(-12%)									
12						CP		CP	CP		
	343	-4%	11.6m		61%	64%	31%	0	-16%	-72%	-42%
					3.8m	6.6m	3.7m	0	6.3m	4.3m	6.8m
13											

Table 8 - Typical field book setout using columns.

6.4 GEOMETRIC ROAD DESIGN

Geometric road design is the combination of horizontal and vertical alignments (figure 34) which are designed for safety, speed and manoeuvrability. Engineering drawings and costings can be produced for setout and earthwork quantities. Consideration should be given to determining the appropriate road standard (see 4.1), which will give road width and design speeds for the vertical and horizontal alignment. When a design speed is cited, it means that a vehicle can travel at that speed without being exposed to hazards arising from inadequate sight distance, inappropriate superelevated curves, severe grades, or road widths that are too narrow. The design speed is the speed which 86% of vehicles do not exceed.

The process of geometric road design is more efficiently achieved using a specialised road design software package. Some examples are ROADENG, GEOCOMP, LUMBERJACK,

and SDR Mapping and Design. These packages can be used successfully only by people who understand the longhand method of road design.

There are a number of advantages for undertaking a full geometric road design:

- The proper engineering design of Forest Roads can reduce costs and the risk of road failure.
- The forest owner does not need to rely on guesswork to ensure that the road reaches the required destination at an acceptable gradient, and with suitable corner radius.
- If the road is designed and setout correctly, the situation where 75% of the road is constructed, and the remaining 25% cannot be completed at less than the desired critical grade should not occur.
- Road costing can be more accurate where there are engineering drawings and earthwork quantities available.
- Roading contracts can be let on a unit rate (e.g. per metre of road constructed) rather than on an hourly rate.
- A mistake in the final road construction may be able to be checked against the setout pegs to determine where the fault lies - (with either the contractor or the designer surveyor/engineer).
- Better decisions can be made as to whether or not a road is feasible in marginal locations.
- The design software can assist in minimising cut and fill depths.
- A full engineering design has an advantage for RMA consents, particularly where there are limits on batter lengths. It can also demonstrate the advanced level of planning used.
- Where the road is designed and pegged accurately, a corridor can be marked to fell only the trees that are necessary, thereby minimising the number of trees to be felled.
- Road location can be optimised within the survey corridor.

It is important to realise that computer road design software packages are only a tool to assist the designer. The design packages do not *automatically* produce a design which will work and will minimise earthwork quantities. The final design is only as good as the user's expertise in geometric road design - a sound knowledge is required of how combinations of grade and curve radii restrict truck manoeuvrability. If the designer does not understand the road geometry and design parameters, then it is quite possible to design a road that trucks will be unable to negotiate.

The following sections include guidelines on the minimum requirements for a highway legal logging truck. Other off-highway vehicles (e.g. double and treble bailey units, and full tree

length cartage) may require special roading requirements, such as larger radii, increased road width, and flatter gradients.

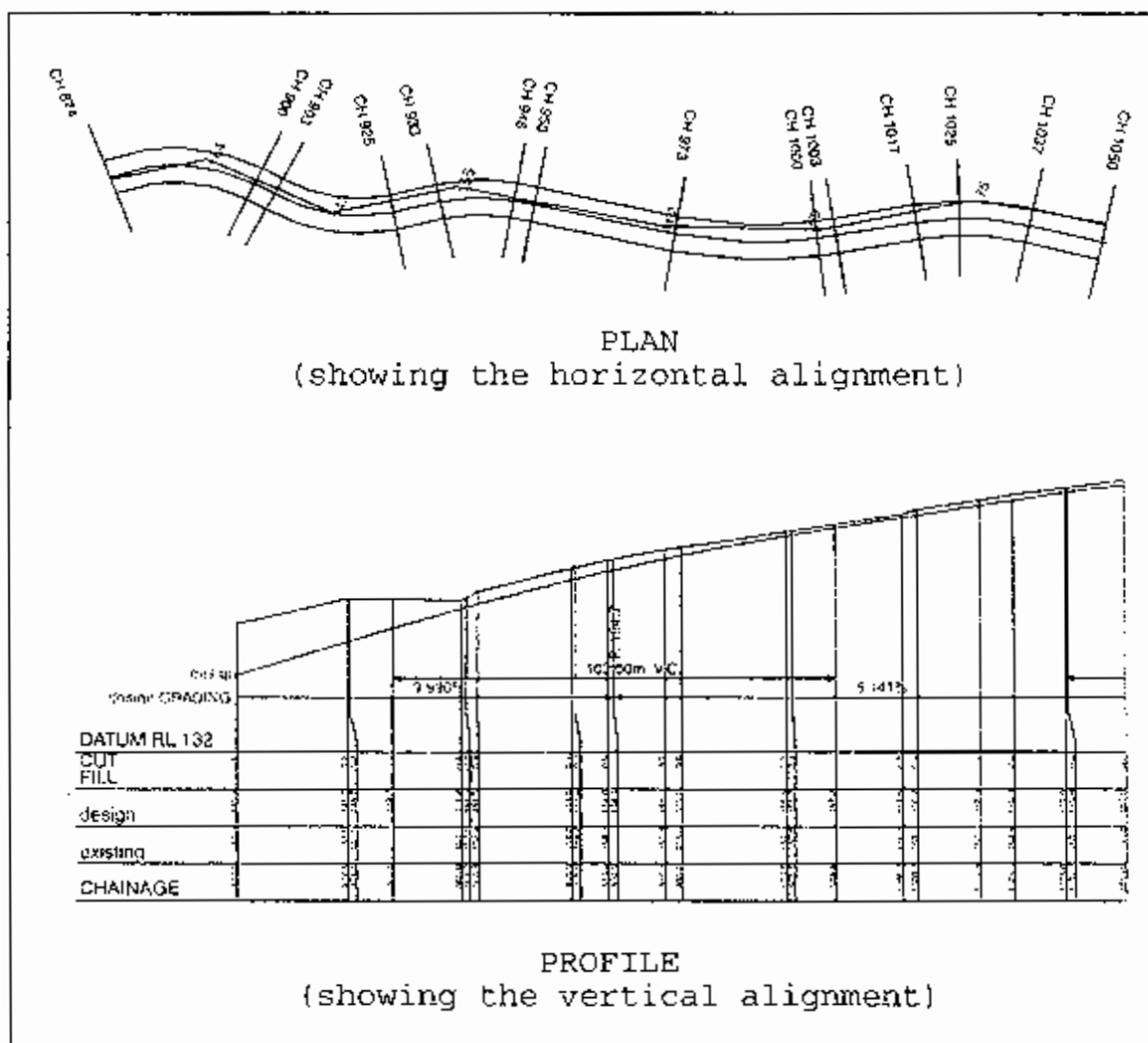


Figure 34 - Horizontal and vertical alignments of a road designed using GEOCOMP

It is important to realise that computer road design software packages are only a tool to assist the designer. The design packages do not *automatically* produce a design which will work and will minimise earthwork quantities. The final design is only as good as the user's expertise in geometric road design - a sound knowledge is required of how combinations of grade and curve radii restrict truck manoeuvrability. If the designer does not understand the road geometry and design parameters, then it is quite possible to design a road that trucks will be unable to negotiate.

The following sections include guidelines on the minimum requirements for a highway legal log truck. Other off-highway vehicles (e.g. double and treble bailey units, and full tree length

cartage) may require special roading requirements, such as larger radii, increased road width, and flatter gradients.

6.4.1 Road Cross-Section

Appropriate road cross-sections need to be determined to establish the road templates (i.e. the shape of the new road) figure 35. The road cross-section (or template) may be different for various sections of the road, for example, the cut slope can change depending on the material in the hillside, or additional widening may be required on corners.

The major cause of road deterioration is water entering the pavement. This is commonly due to the road surface having insufficient side-slope (cross-fall) or the drainage ditches being too shallow to clear the water away from the pavement. Sufficient cross-fall (4-6%) should be provided to allow easy run-off of surface water, which will help prevent potholes from developing. For a two-lane road, the cross-fall should always meet at the centre of the road, producing a crown. For a single-lane road, it may be easier for maintenance practices to have the cross-fall slope one way, rather than producing a crown.

The amount of cross-fall desirable for heavy vehicles on steep gradients is very low, therefore, the actual cross-fall selected may need to be a compromise between that required for drainage, and that suitable for heavy vehicles.

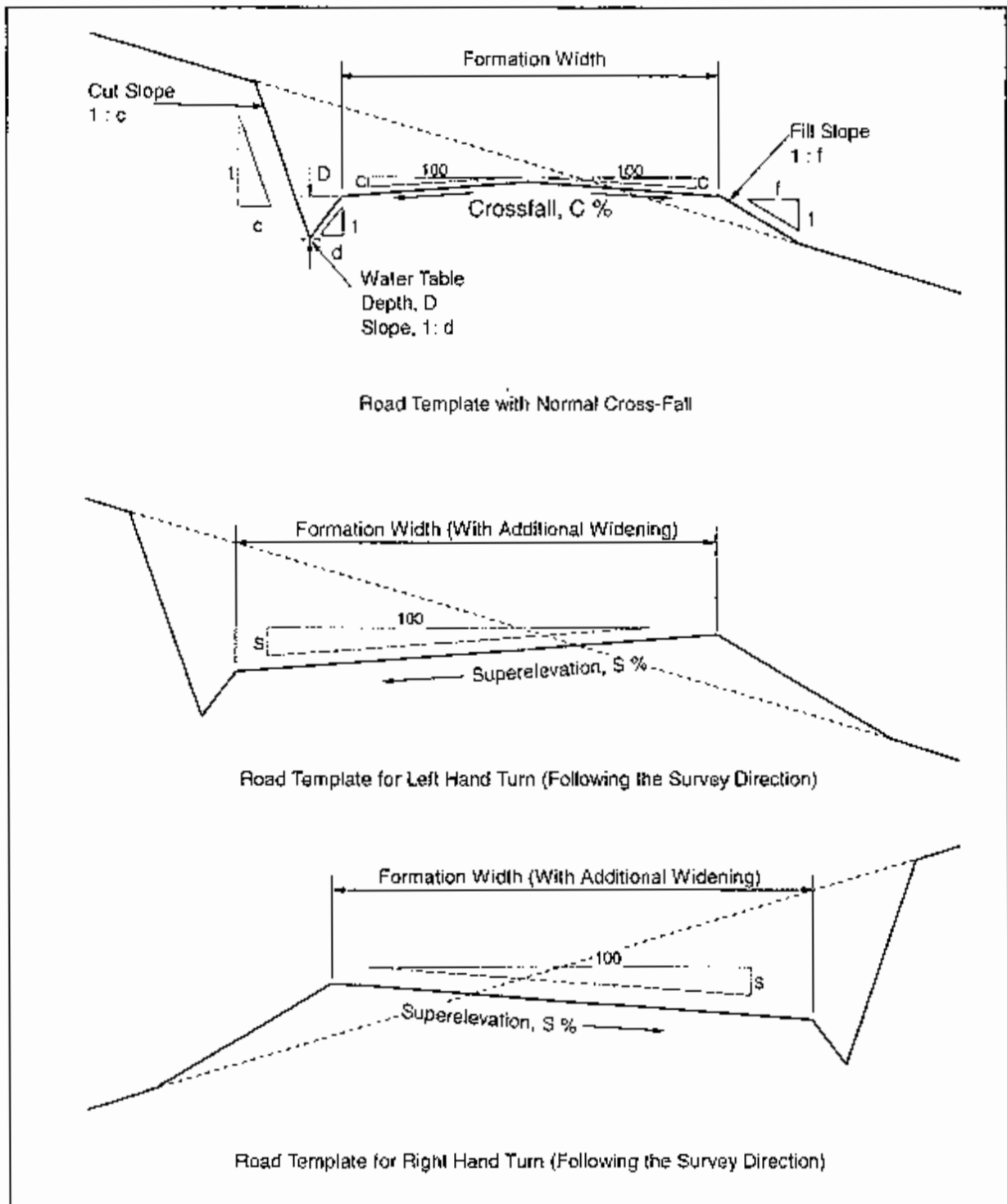


Figure 35 - Standard road cross-sections (templates)

Explanatory notes for figure 35 follow:

Cut Slope: 1:c - The slope specified is less than or the same as the maximum stable slope which can be attained. This is very dependent on soil type and local conditions. A good indicator is existing cut slopes on other well established roads in similar soil types.

Fill Slope: 1:f - The fill slope, when used as a road foundation, is usually 1:2 but can be as steep as 1:1.5.

Water Table: Depth (D) is dependent on local conditions, but is usually 0.6 m. Slope (1:d) is about 1:2. See Chapter 11 for more detailed design.

Formation Width: This is the full construction width, and usually goes at least 0.6 m beyond either side of the aggregate width (or carriageway width).

Superelevation, S %: This is the slope of the road surface (for the whole road width) provided at curves, to decrease sideways forces when cornering. For low speed forestry roads, superelevation is not usually used.

Cross-fall, C %: This is the slope applied on the road to aid in shedding water, and should be applied to all roads.

Curve Widening

Additional widening at curves may be required to cater for trailer off-tracking (figures 36 & 37). Curve widening is necessary to eliminate the impact that off-tracking wheels will have on road shoulders, and to improve safety.

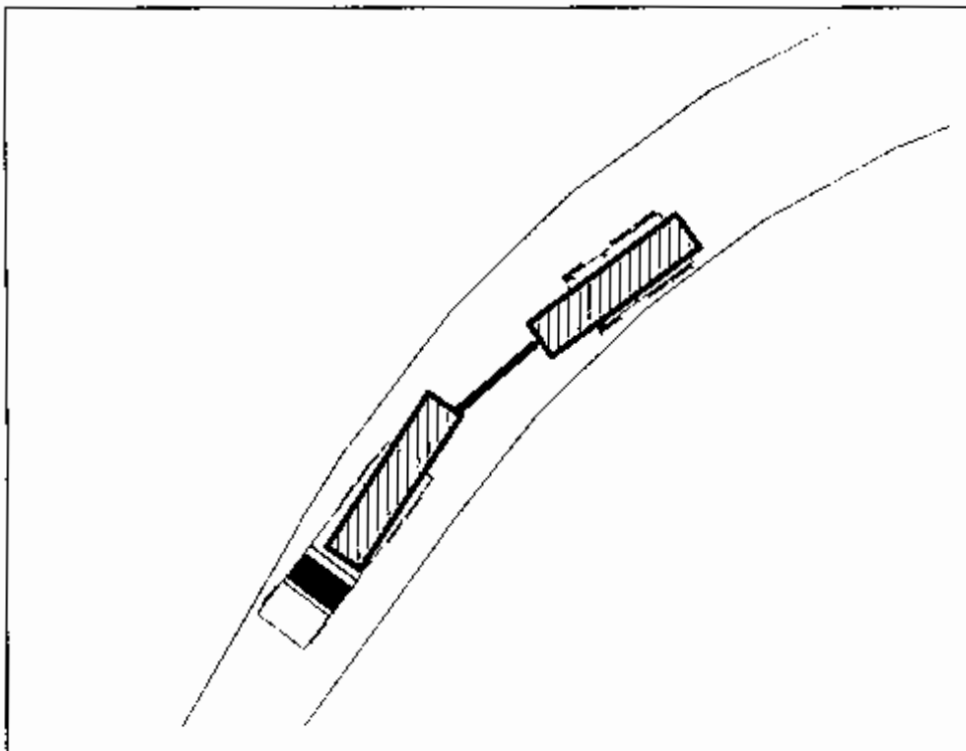


Figure 36 - Trailer off-tracking on a curve

Figure 37 shows the additional curve widening required for two different truck configurations:

- *Off-Highway Double Bailey Unit*

This truck configuration is not permitted on public roads, but operates on private forestry roads. If another trailer is added to this configuration - to give a treble unit - there will be a significant further increase in curve widening required.

- *On-Highway Bailey Bridge*

This configuration is the one of many that can be legally used on New Zealand public roads. It was chosen to represent the legal configuration with the greatest trailer off-tracking.

6.4.2 Horizontal Alignment

In terms of safety, a consistent alignment which provides no "surprises" for the driver is more important than an absolute design speed standard. The coordination of horizontal and vertical geometry is important to ensure:

- safety and visibility
- good traffic flow
- desirable visual impact

Figure 38 shows how different curve radii and values of superelevation affect the design speed.

Alternatively, the minimum radius (R_{min}) required for a given design speed and superelevation can be derived from the following formula:

$$R_{min} = \frac{V^2}{127(n+f)}$$

where:

- V = Design Speed in km/hr
- n = Superelevation (m/m or %/100)
- f = Coefficient of friction (use 0.08 for gravel roads)

The design speed (V) is determined by the desired road standard (see section 4.1) and the terrain.

The superelevation (n) is the slope of the road surface (figure 35) and is expressed as a decimal. A maximum of 0.0626 (6.26%) is appropriate for logging trucks. For speeds of less than 26 km/hr, superelevation is not needed and normal cross-fall is used.

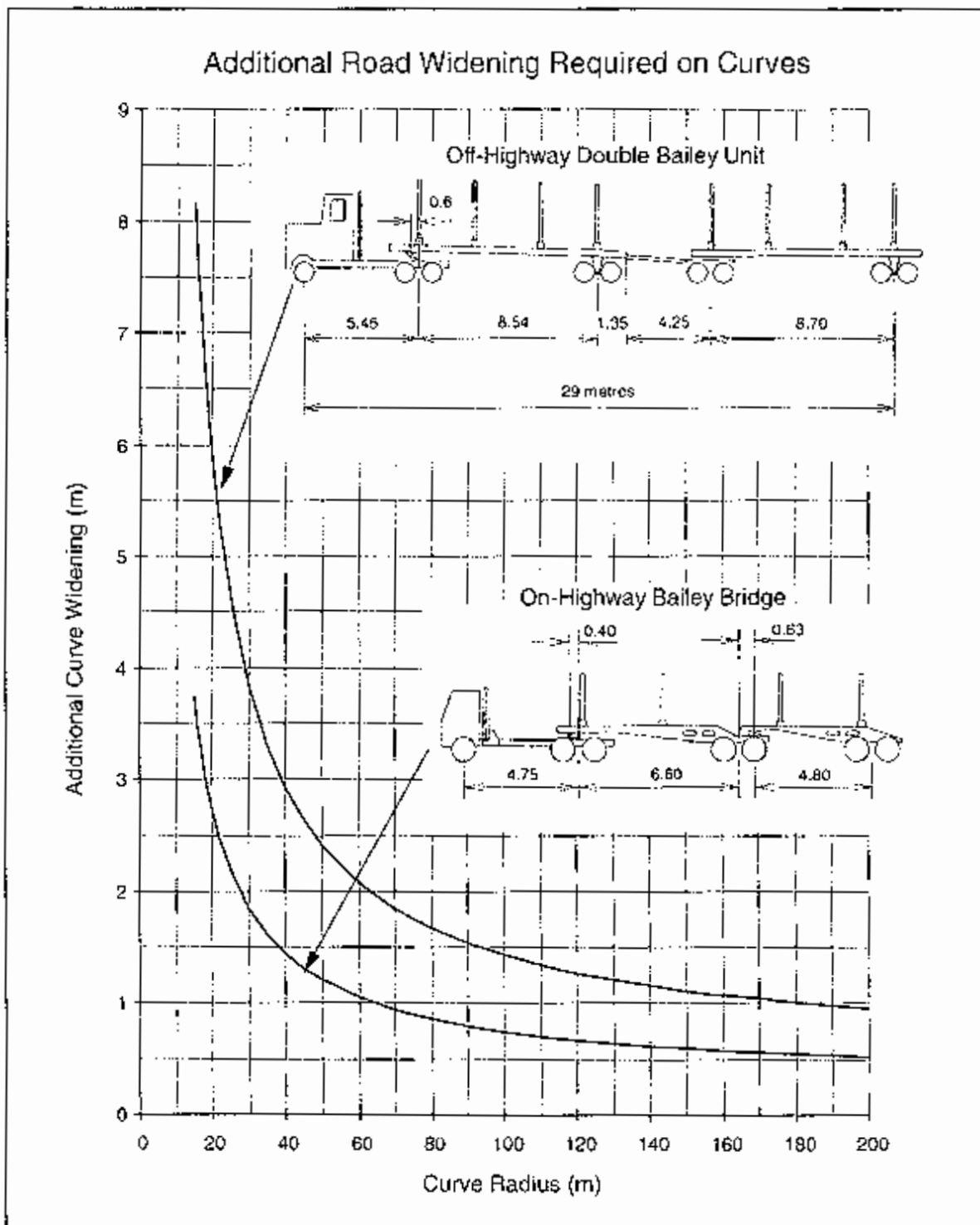


Figure 37 - Additional curve widening required for a off-highway and on-highway log truck.

Curve Radius, Superelevation and Design Speed Relationship

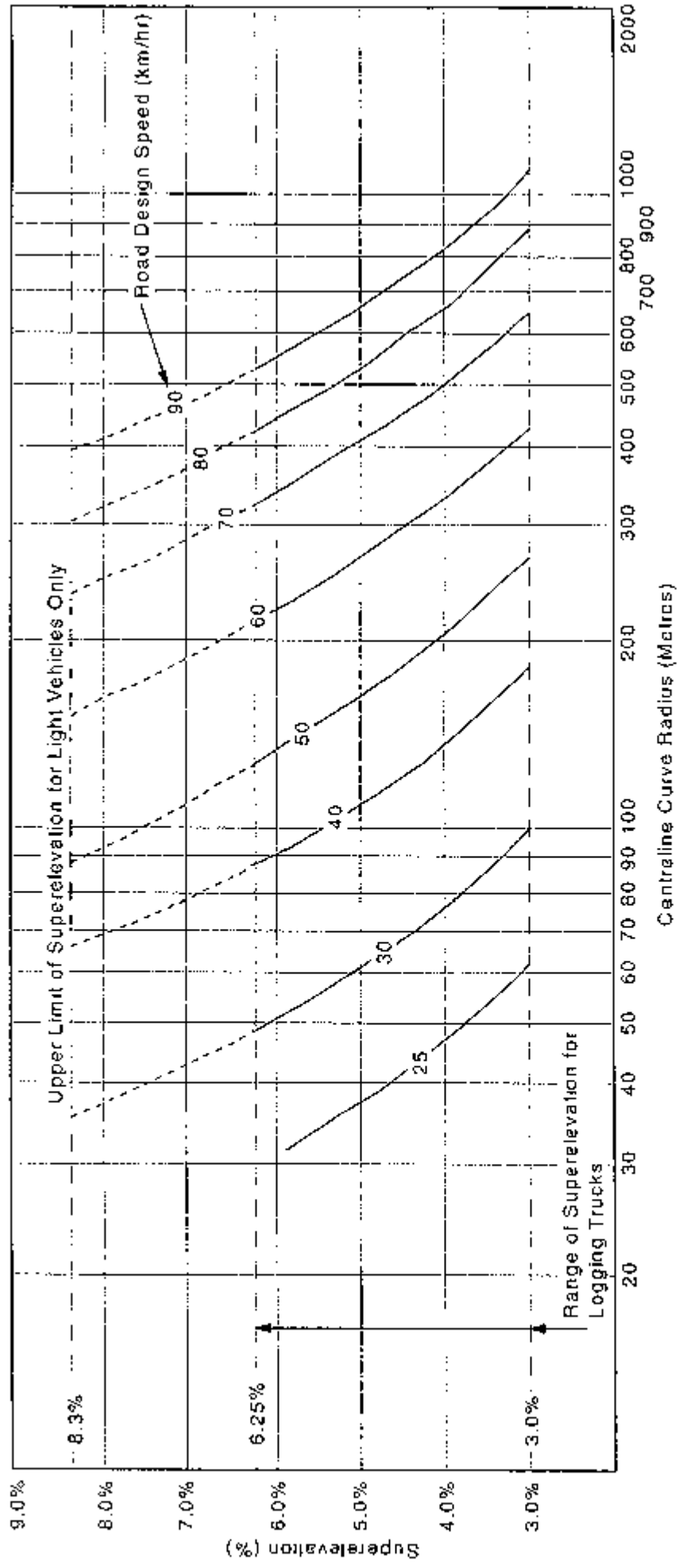


Figure 38 - Curve radius for a given design speed and superelevation

6.4.3 Vertical Alignment

Table 9 recommends the grade limits which should not be exceeded for curves of different radius. They apply to New Zealand on-highway legal log trucks, and are a guide only.

Horizontal Radius (m)	Maximum Grade	
	Adverse (%)	Favourable (%)
16 to 26 m	6.9 %	10.0 %
26 to 40 m	8.3 %	10.0 %
40 to 60 m	10.0 %	11.1 %
>60 m	10.6 %	11.8 %

Table 9 - Recommended grade limits

Note: where adverse grade represents the maximum grade of a loaded log truck travelling up-hill and favourable is the maximum downhill grade of a loaded log truck.

In addition, it is recommended that within 60 m of intersections and landings the grade should be less than 6%.

6.4.4 Sight Distance

Allowances may need to be made to the cross-section, the vertical alignment or the horizontal alignment to provide adequate sight-distance to allow adequate stopping distance in an emergency (especially on one-lane roads with two-way traffic). The following shows how to estimate the sight distance available, and hence the required stopping distance.

Sight distance is limited by either the vertical or horizontal alignment. Sight distances are calculated from both alignments and the shortest of the two distances is the limiting factor.

The process involves calculating the sight distance on a crest vertical curve (section 6.4.4.1), or on a corner (section 6.4.4.2), and then comparing these to the safe stopping distance required to avoid a collision (section 6.4.4.3). If the sight distance is less than the required stopping distance, then either the design must be altered, or other provisions must be made to prevent an accident.

6.4.4.1 Sight Distance And Vertical Alignment

Two different formulae are used to calculate available sight distance on a crest vertical curve (figure 39):

1. If $S < L$ (Sight Distance < Vertical Curve Length):

$$S = \frac{L}{2} + \frac{C}{2A}$$

2. If $S > L$ (Sight Distance > Vertical Curve Length):

$$S = \sqrt{\frac{LC}{A}}$$

where:

S = Sight distance (m)

h_1 = Height of eye above road (m)

h_2 = Height of object above road (m)

$$C = 200(\sqrt{h_1} + \sqrt{h_2})^2$$

L = Vertical curve length (m)

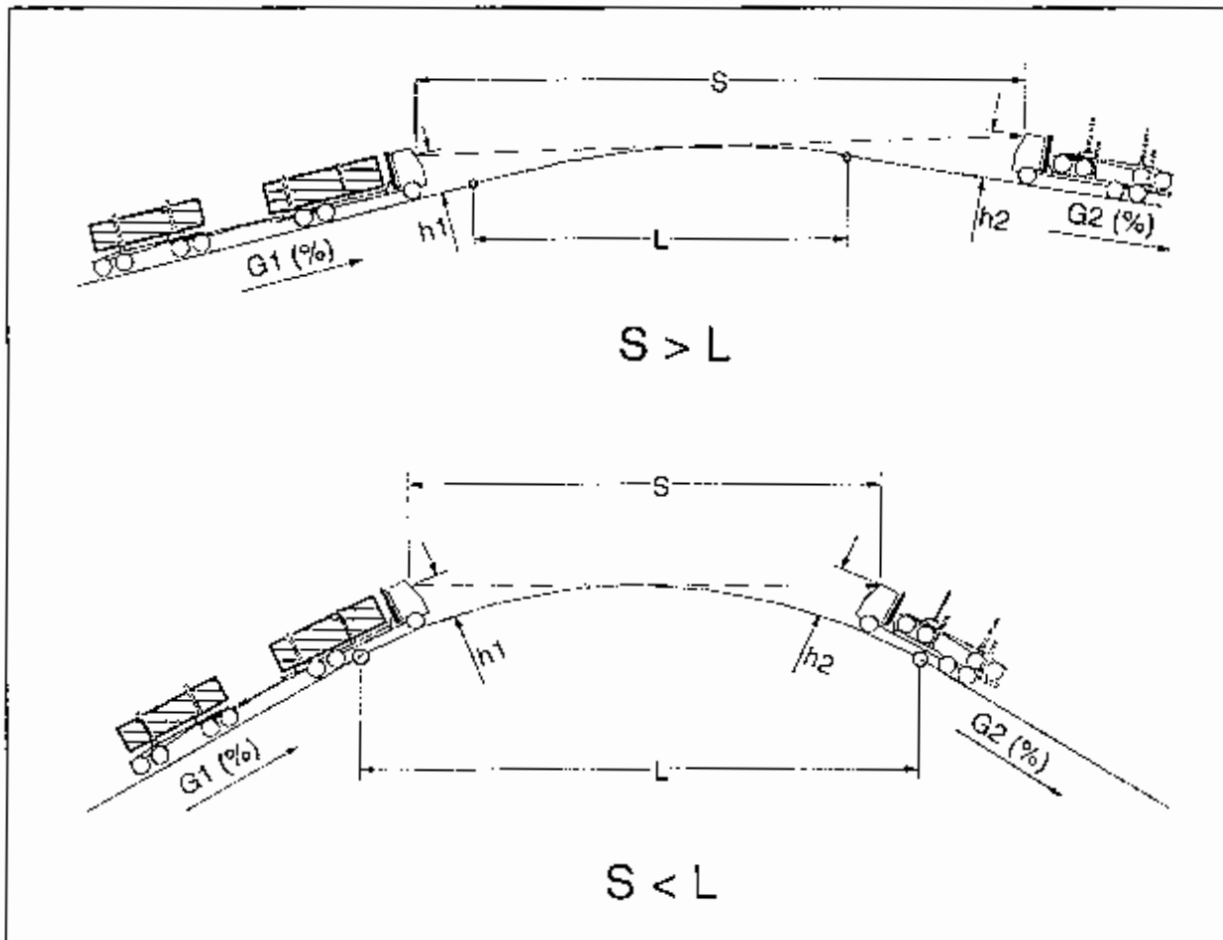
A = Difference in grade ($G_1 - G_2$) (%) (*Note: that G_2 is negative if downhill*)

The recommended sight distance (Austroads, 1993) is calculated for a car approaching a stationary object on the road (e.g. a fallen tree), where:

$$h_1 = 1.16\text{m (eye height of driver in car)}$$

$$h_2 = 0.2\text{m (height stationary object above the road)}$$

Figure 40 can be used to estimate the available sight distance, or the formulae above can be used for specific heights of driver and object (e.g. for a truck approaching truck).



Source: ARRB 1993: Unsealed Roads Manual Guidelines to Good Practice
 Figure 39 - Sight distance on a crest vertical curve

6.4.4.2 Sight Distance And Horizontal Alignment

Figure 41 shows how an obstruction (such as a cut slope) can affect sight distance.

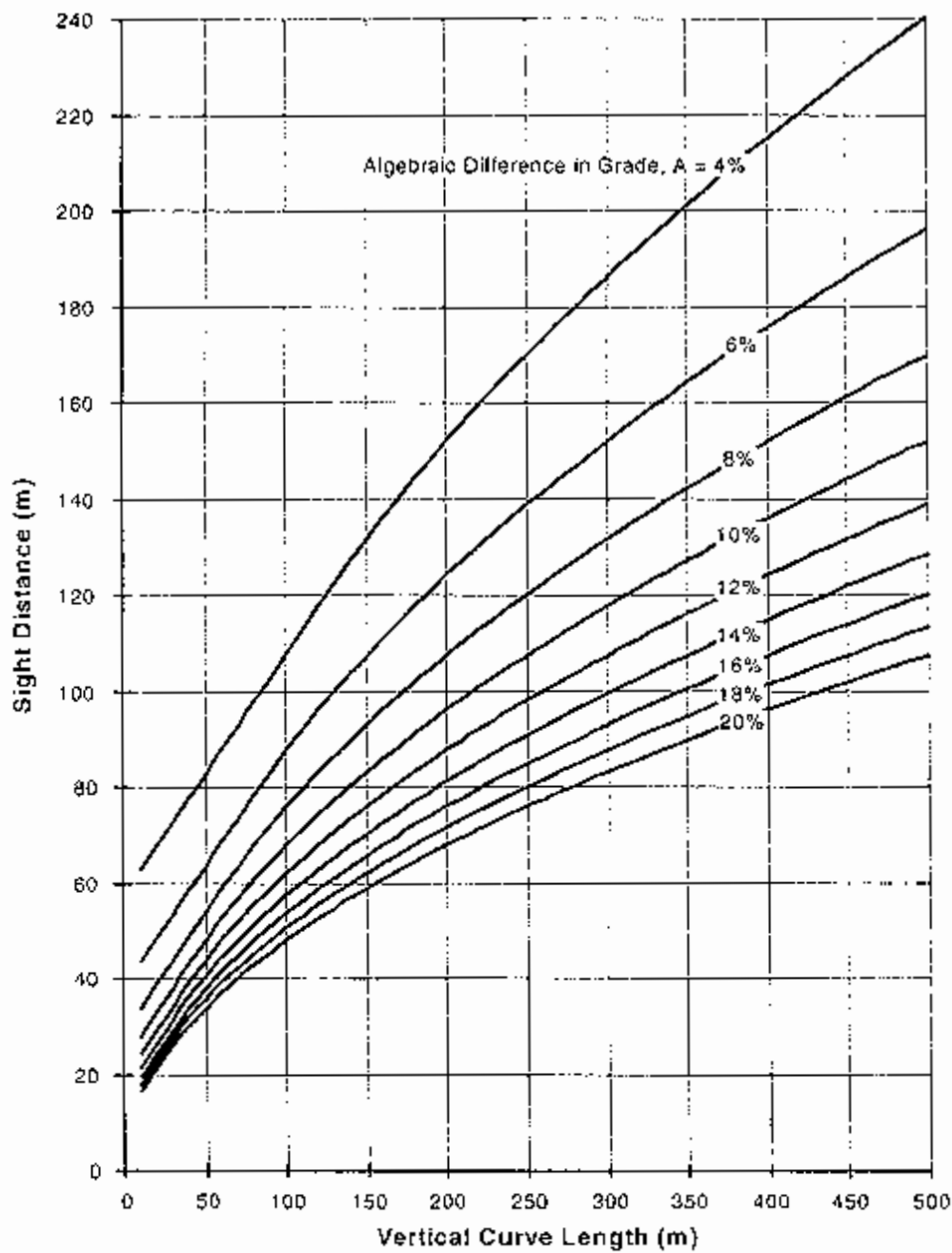
The following formula can be used to calculate the sight distance, or figure 43 can be used to estimate it.

$$O = R \left[1 - \cos \left(\frac{28.65 S}{R} \right) \right]$$

$$D = \frac{R}{28.65} \left[\cos^{-1} \left(\frac{R - O}{R} \right) \right]$$

Sight Distance on Crest Vertical Curves

($h_1=1.15\text{m}$ & $h_2=0.2\text{m}$)



Source: Austroads 1993: Rural Road Design

Figure 40 - Sight distance on a crest vertical curve.

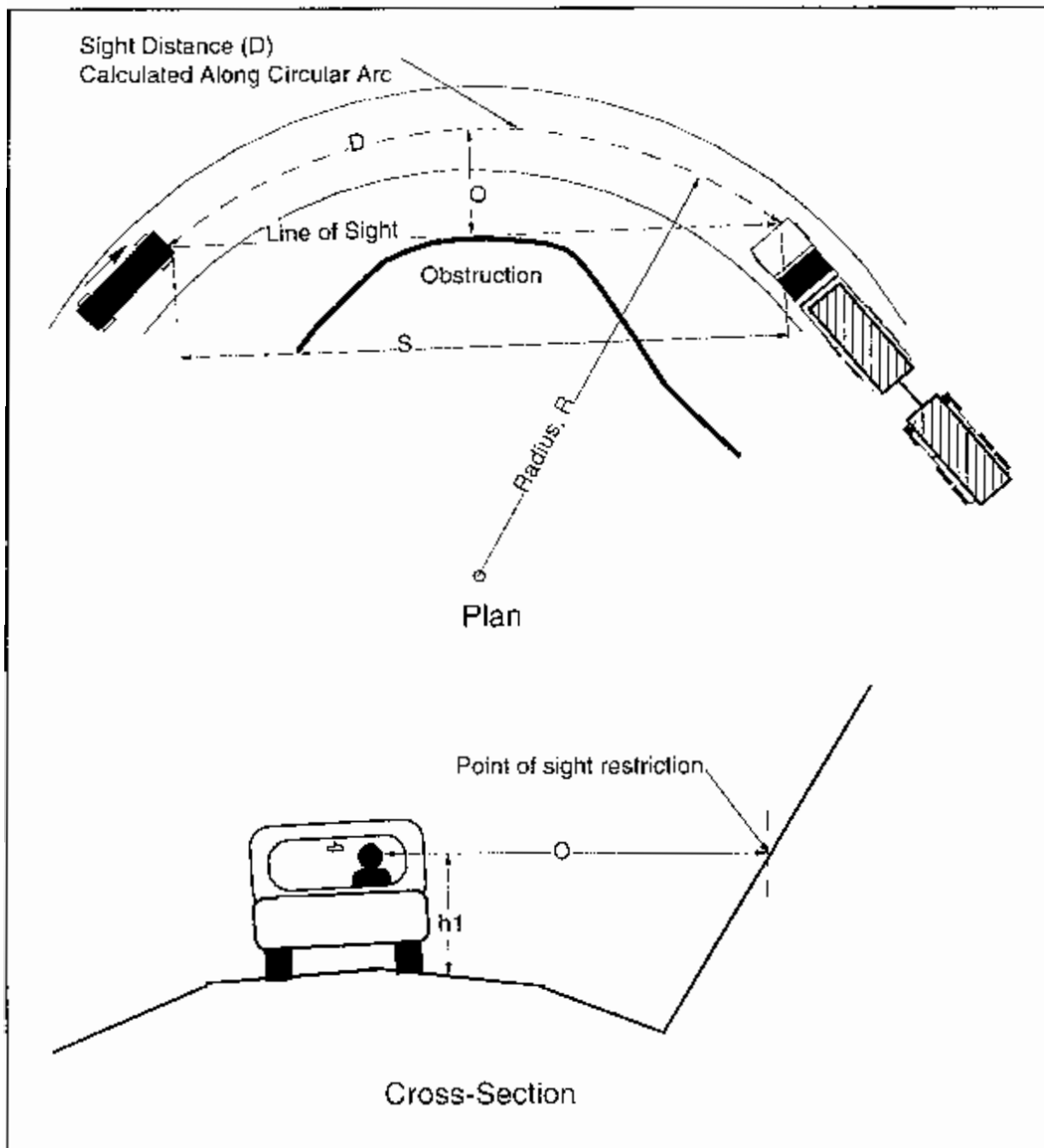


Figure 41 - Sight distance on a horizontal curve

Where:

h_1 = Height of eye above road (m)

R = Radius (m) (can also be estimated in the field using the formula below, figure 42)

D = Sight distance (m)

O = Offset (m)

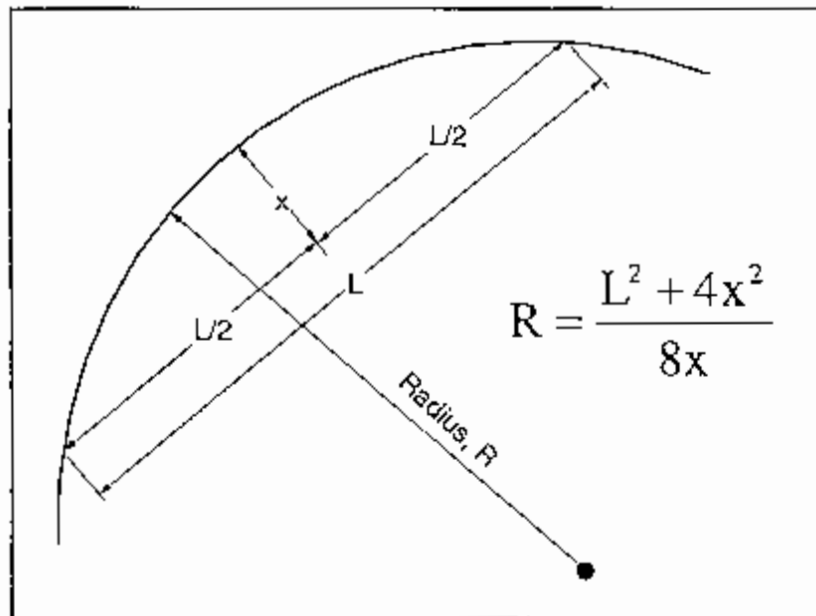


Figure 42 - Calculating the curve radius

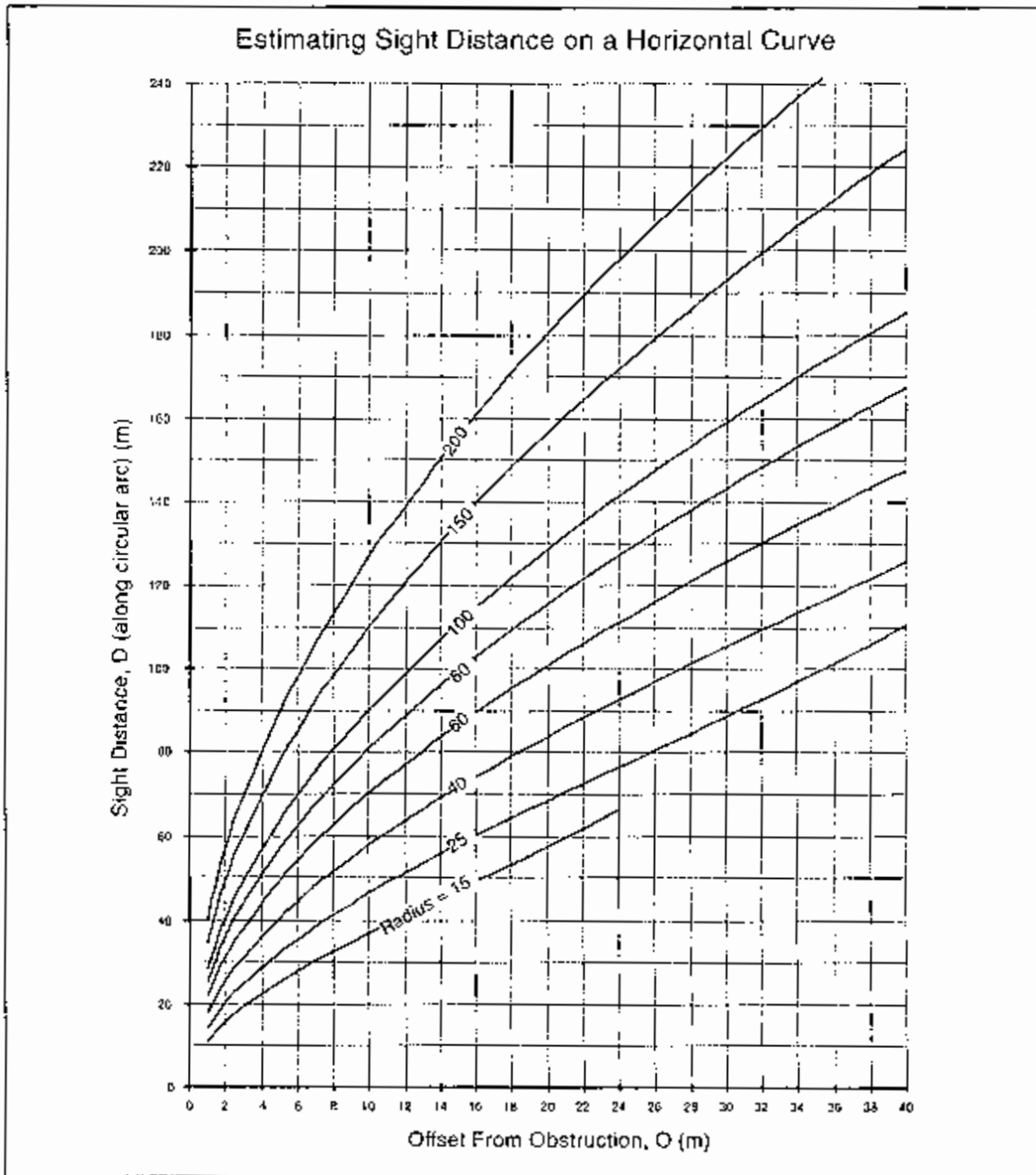
6.4.4.3 Calculating The Safe Stopping Distance

The deceleration values are those recommended by Austroads (1993), and the reaction time is assumed to be 2.0 seconds. Using those figures, and the following formula, the required stopping distance at various speeds is shown in table 10:

$$S = vt + \frac{v^2}{2a}$$

Where:

- S = stopping distance (m)
- v = initial velocity (m/s)
- t = reaction time (2.0 secs)
- a = deceleration (m/s²)



Source: Austroads 1993; *Rural Road Design*

Figure 43 - Estimating sight distance on a horizontal curve.

Initial Speed (km/hr)	Deceleration ($g = 9.81 \text{ m/s}^2$)	Stopping Distance	Two-Way Traffic on One-Lane Roads (Stopping Distance is Doubled)
10	0.62g	6	13
20	0.62g	14	28
30	0.62g	23	47
40	0.62g	34	69
60	0.62g	47	93
60	0.48g	63	126
70	0.46g	82	163
80	0.43g	103	206
90	0.41g	128	266
100	0.39g	166	313

Table 10 - Stopping distance required to avoid a collision

(deceleration values from Austroads, 1993).

For safety, the sight distance available (from 6.4.4.1 and 6.4.4.2) needs to be greater than the stopping distance required. If the sight distance is less than stopping distance, then either the design needs to be changed, or other steps must be taken:

- *Possible changes to Vertical Alignment (in order of preference)*

1. Re-design the vertical curve - make the vertical curve length longer and/or reduce the grades.
2. Widen the road to two lanes, and place "keep left" signs.
3. Place a warning sign to reduce traffic speed (e.g. 30 km/hr restriction)

- *Possible changes to Horizontal Alignment (in order of preference)*

1. Re-design the horizontal curve - increase the curve radius.
2. Clear the edge of road to increase the sight distance - widen the cut bank, remove trees or vegetation.
3. Widen the road to two lanes and place "keep left" signs.
4. Place a warning sign to reduce traffic speed (e.g. 30 km/hr restriction)

Having made some change(s), the sight distance should be re-checked against the stepping distance.

6.5 SETTING OUT THE ROADLINE

At the very least, the road centreline (or the gradeline) will be marked, and after the trees have been cleared, the road centreline may need to be re-established. In this situation it is important to have an experienced roading contractor, and to provide adequate supervision to ensure that the road is constructed to grade.

The scale plot of the cross-sections is commonly used for setout. Measurements on the cross sections are simply scaled for setting out. Figure 44 shows typical cross-section outputs from a road design software package. A typical method of setting out the road is shown in figure 45.

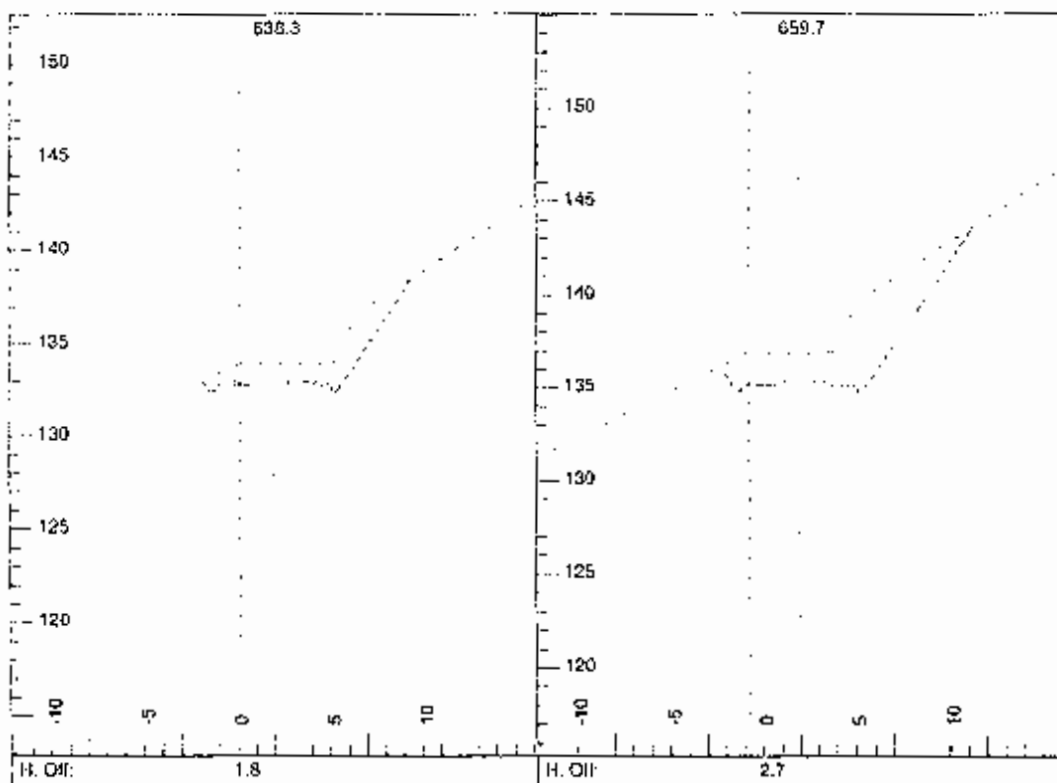


Figure 44 - Typical cross-sections generated in ROADENG version 2.0.

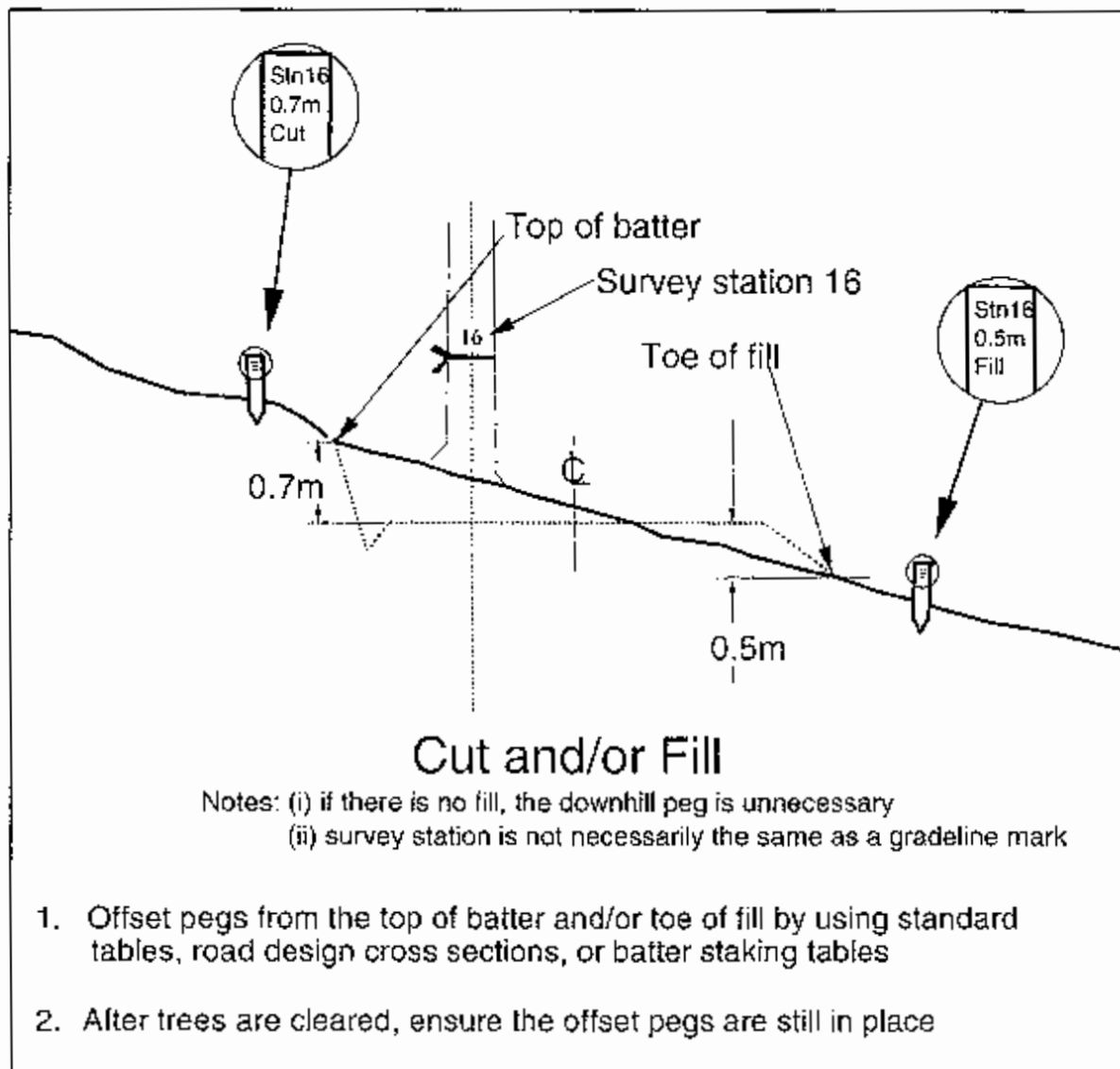


Figure 45 - Setting out of earthworks

Initially, pegs are set out offset from the uphill side from the top of batter, and offset from the downhill side from the toe of fill. This allows a logging crew to remove the trees from the roadline. After the trees have been removed, the pegs are checked to ensure that they are still in place. The station number, and depth of cut (from the top of batter) or depth of fill (from the toe of fill), together with offset information is written on the peg.

6.6 FURTHER READING

The following references are recommended further reading on harvest planning, marking a roadline and geometric road design:

Austrroads 1993. Rural Road Design, Guide to the Geometric Design of Rural Roads. Austrroads, Sydney. 1993.

Walbridge, T. 1990. The Direct Location of Forest Roads. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 1990.

Walbridge, T. 1991. The Paper Location of Forest Roads. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 1991.

Walbridge, T. 1991. Field Tables for the Direct Location of Forest Roads. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 1991.

ARRB. 1993. Unsealed Roads Manual. Guidelines to Good Practice. Australian Road Research Board Limited. May 1993.

EARTHWORKS

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).

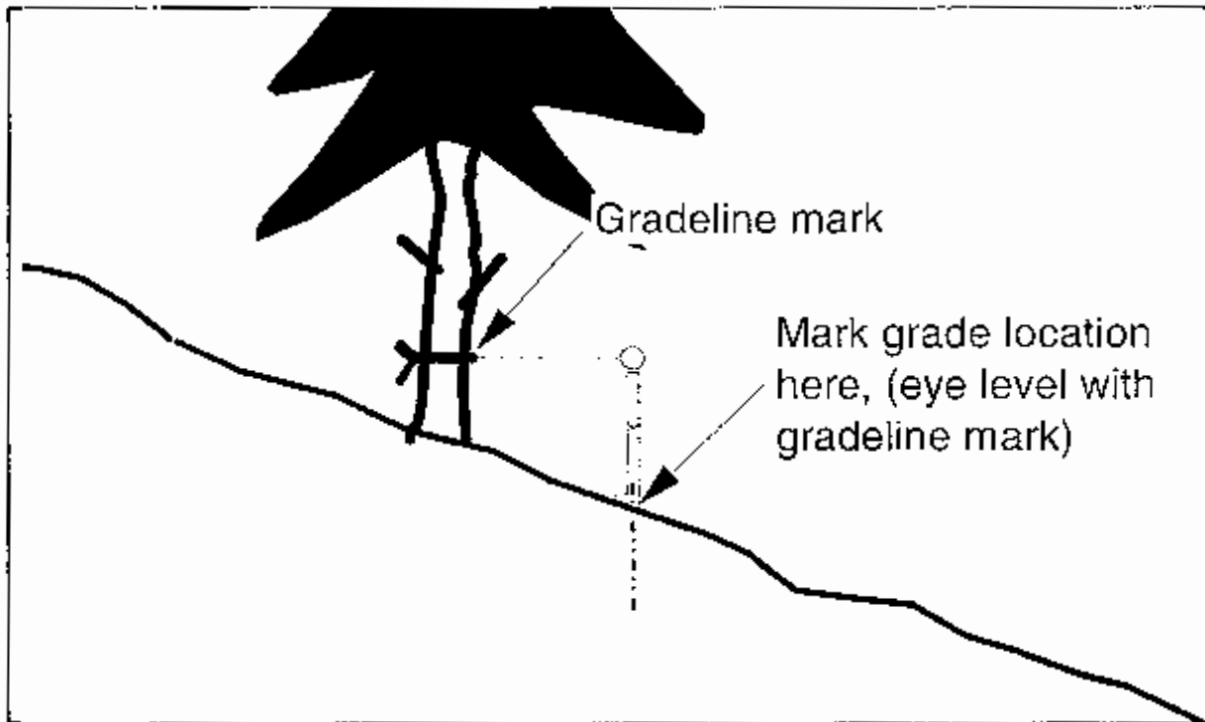


Figure 46 - Gradeline location

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.

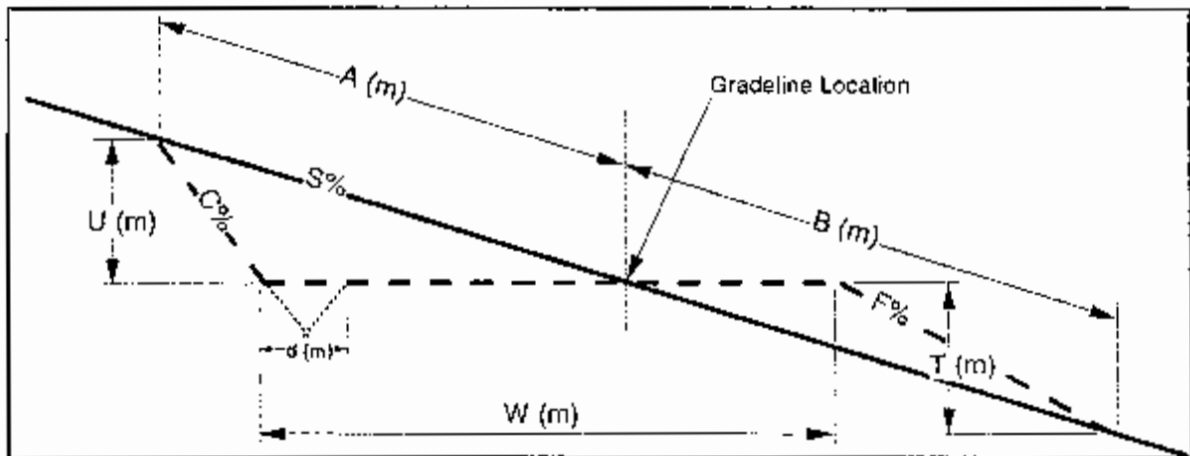


Figure 47 - Typical road cross-sectional layout

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).

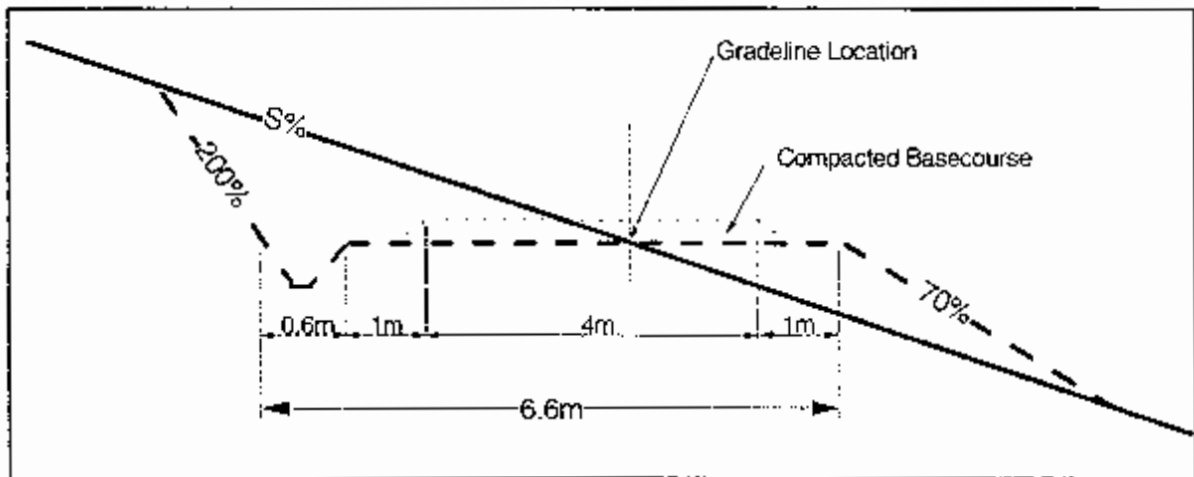


Figure 48 - Set out of a standard road cross-section.

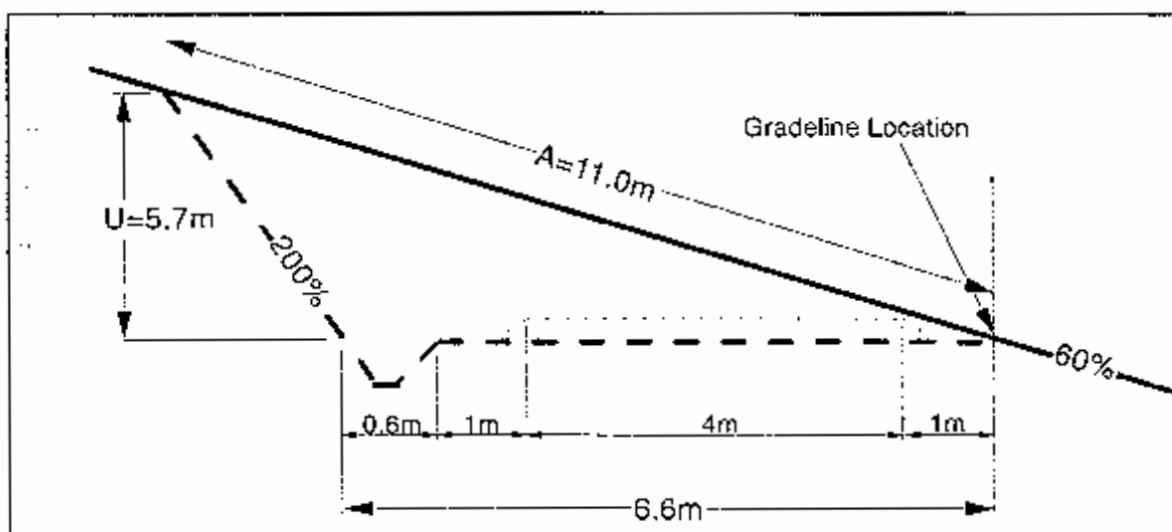


Figure 49 - Setout information for road cross-section with a side slope of 60%.

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	Offset Cut	Depth Cut	Offset Fill	Depth Fill
S%	A	U	B	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).

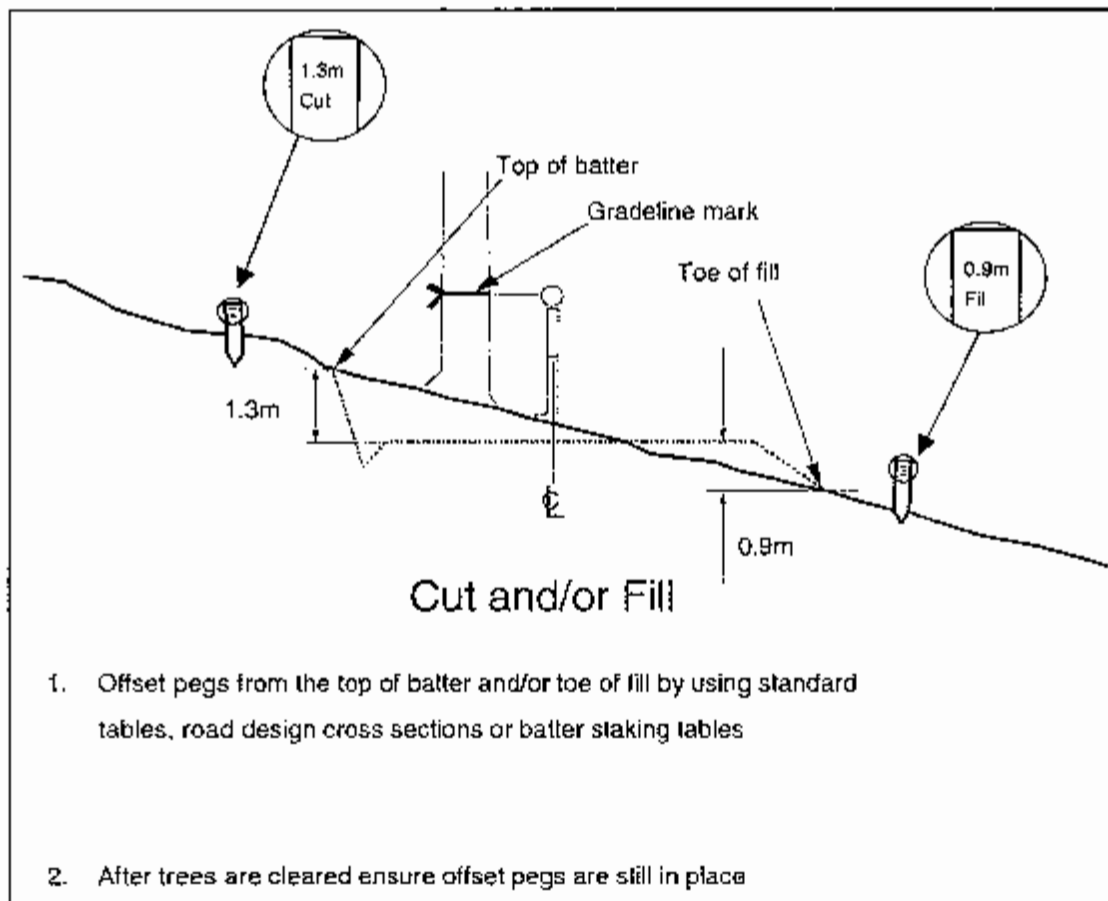


Figure 50 - Setting out road using pegs.

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

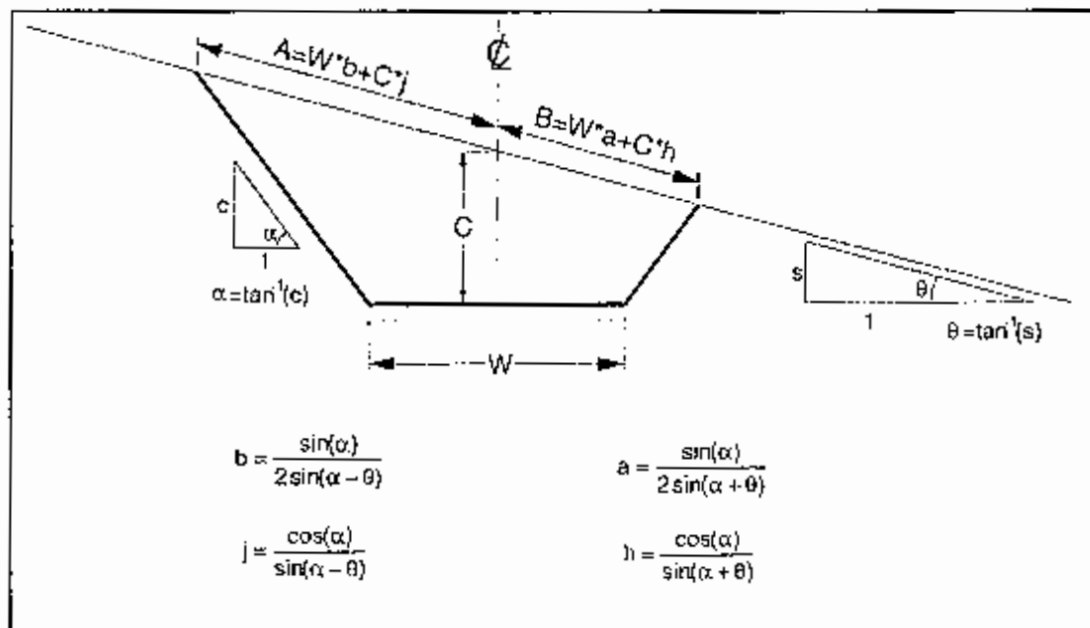


Figure 51 - Calculating the offsets for the top of a batter for an all cut cross-section

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:

$$A \text{ (uphill offset)} = W \times b + C \times j = 7.7 \times 0.77 + 1.5 \times 0.77 = 5.4 \text{ m}$$

$$B \text{ (downhill offset)} = W \times a + C \times h = 7.7 \times 0.45 + 1.5 \times 0.45 = 3.7 \text{ m}$$

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.

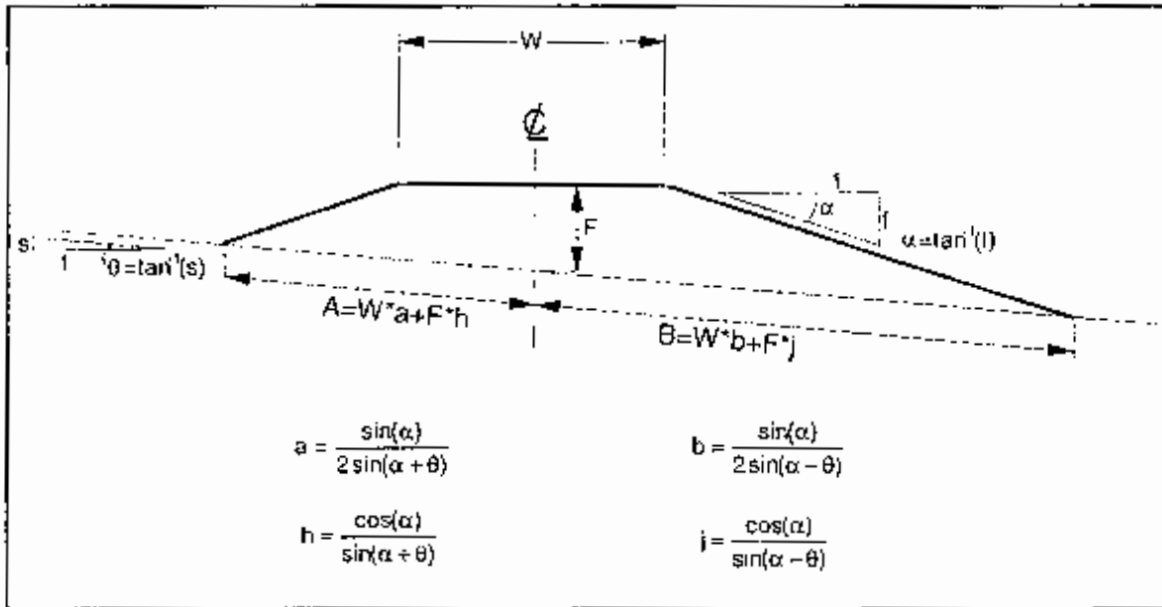


Figure 52 - Calculating the offsets for the bottom of a batter for an all fill cross-section.

Calculating Batter Peg Offset 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:

$$A \text{ (uphill offset)} = W \times b + C \times j = 7.7 \times 0.34 + 1.5 \times 0.98 = 3.7 \text{ m}$$

$$B \text{ (downhill offset)} = W \times a + C \times h = 7.7 \times 1.27 + 1.5 \times 3.59 = 13.7 \text{ m}$$

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).

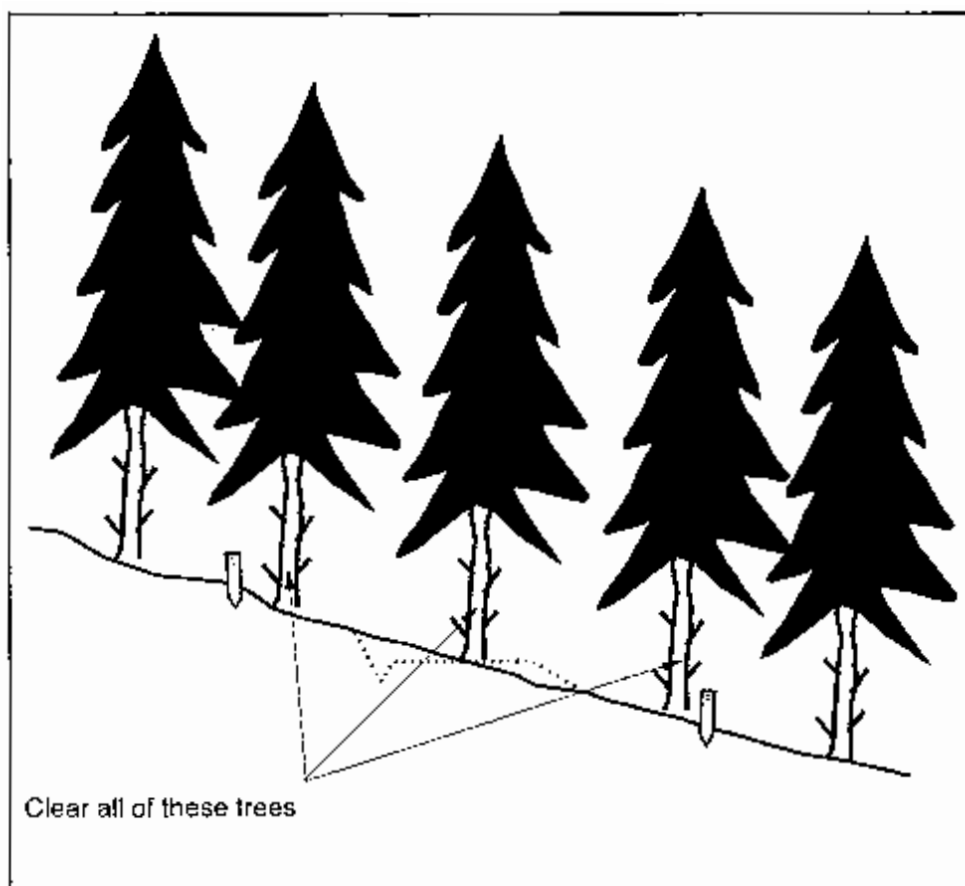


Figure 53 - Trees that are to be cleared for earthworks.

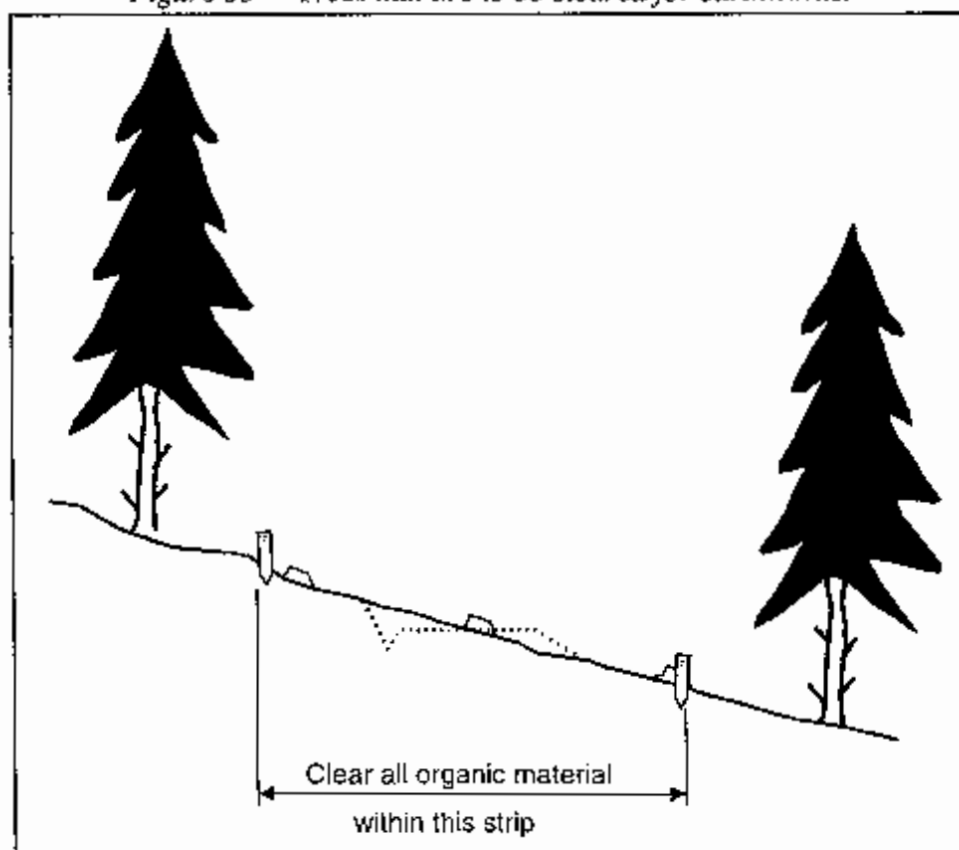


Figure 54 - Width to be cleared of all organic material for earthworks.

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.

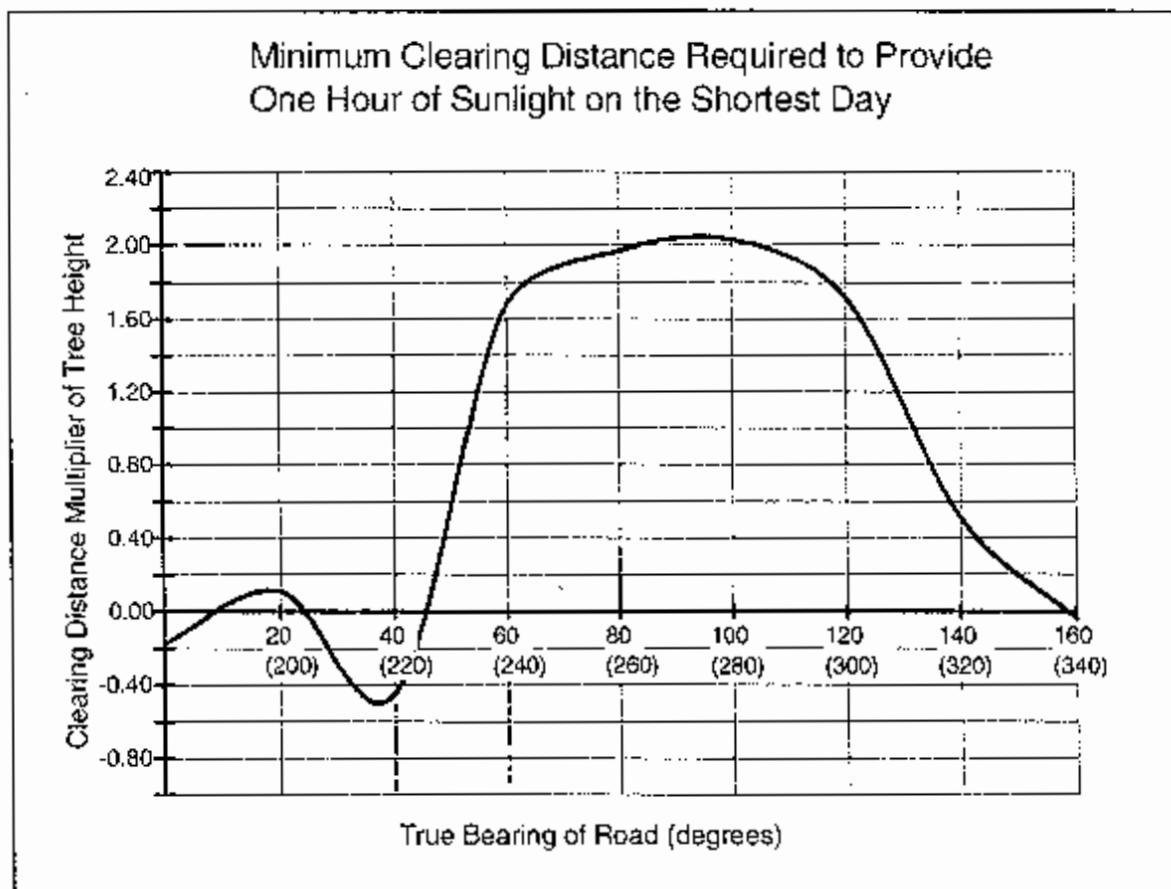


Figure 55 - The minimum clearing width required to provide at least one hour of sunlight on the road for the shortest day.

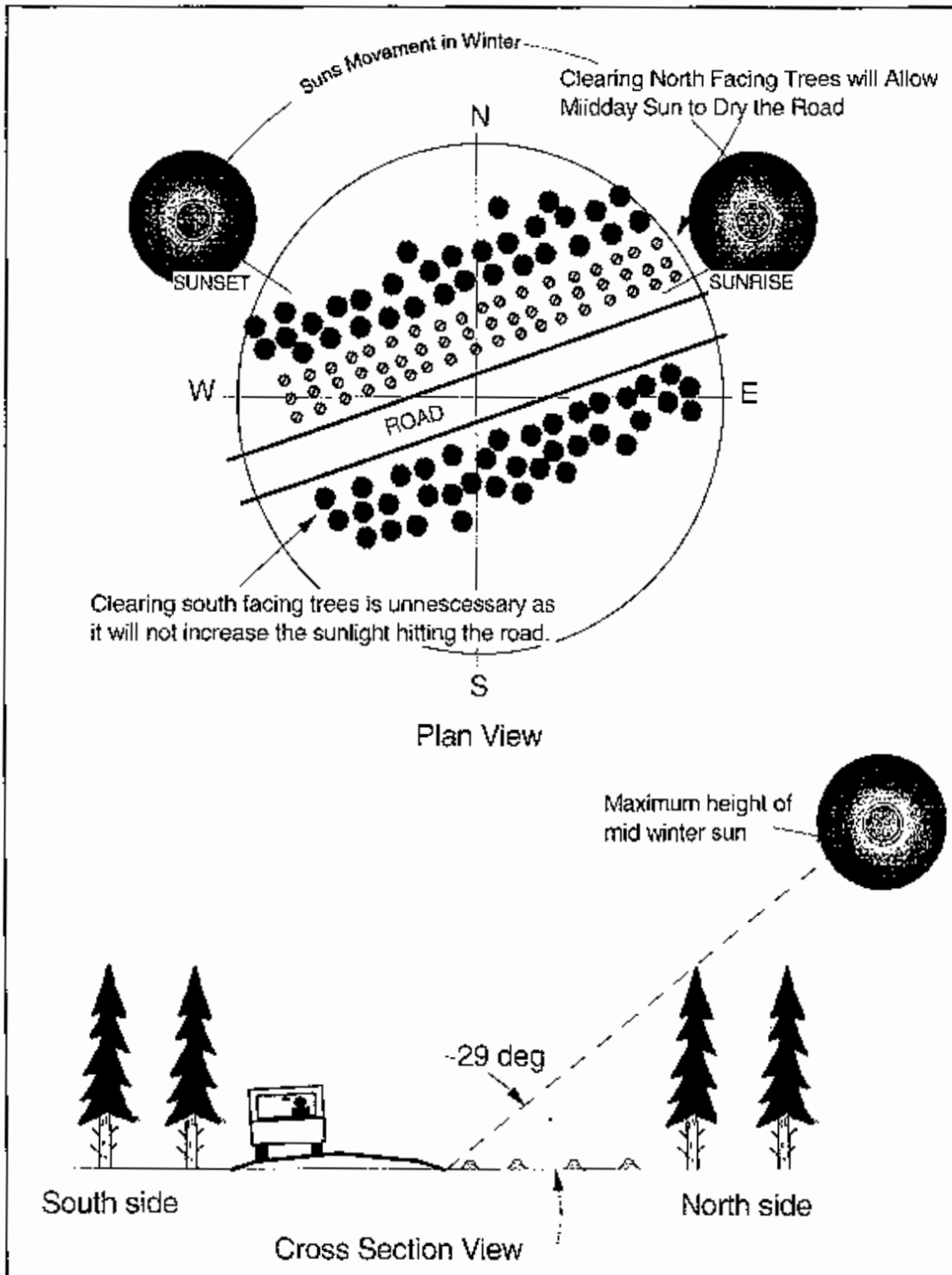


Figure 56 - Position of mid winter sun and the effect of cutting north-facing trees for daylighting.

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.

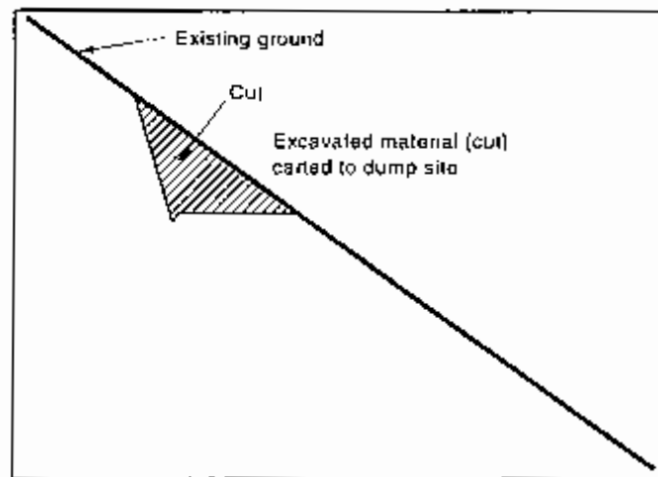


Figure 57 - End haul construction

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

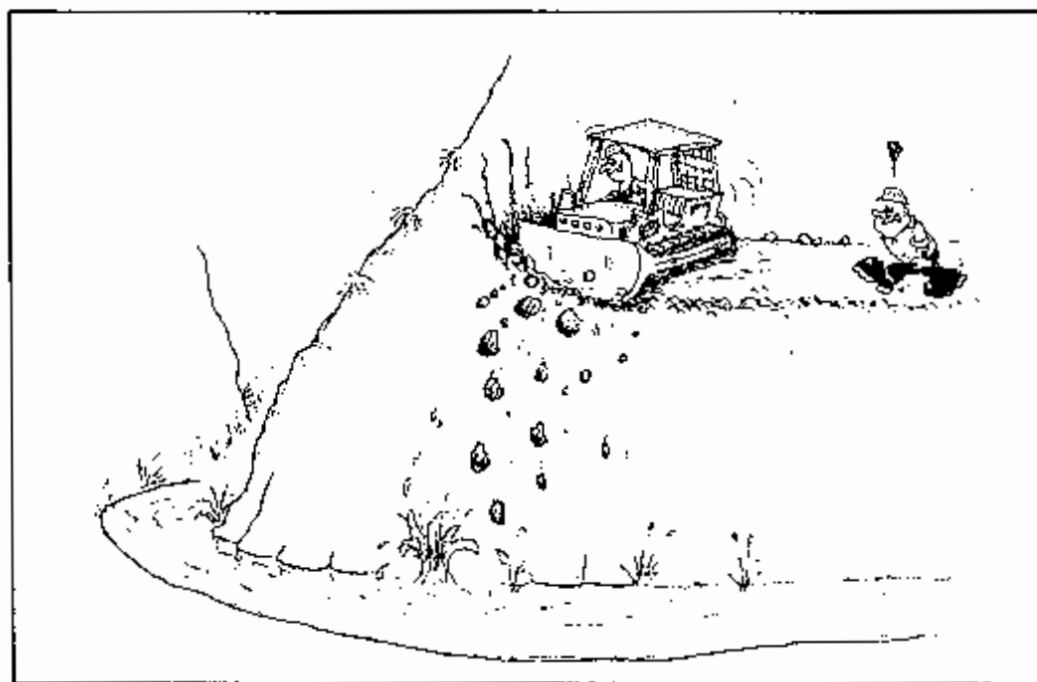
On steep slopes > 70% (35 degrees), fill material cannot be supported on the slope. The result is a very long, unconsolidated, fill slopes which are prone to erode and move down the slope. In addition, the fill has insufficient strength to support vehicle weight.

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 erodible 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

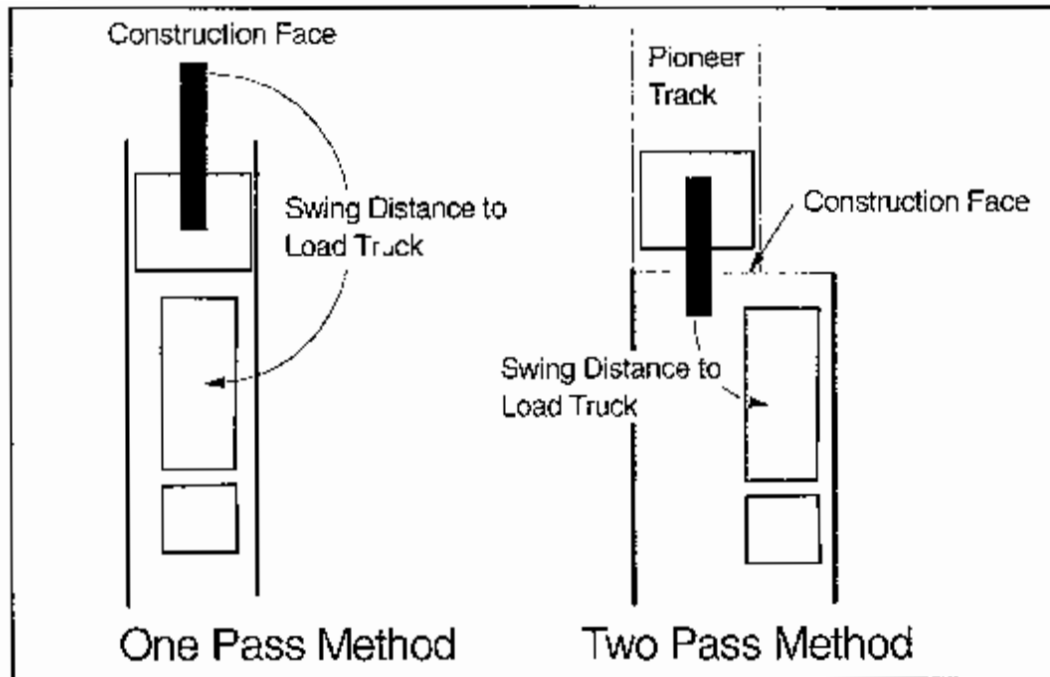
Newly constructed roads which can be seen from public roads or townships have a high visual impact. They result in conspicuous lines on the landscape, through contrast between existing vegetation cover and the exposed underlying lighter coloured soil. Most people will accept a small amount of visual 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.

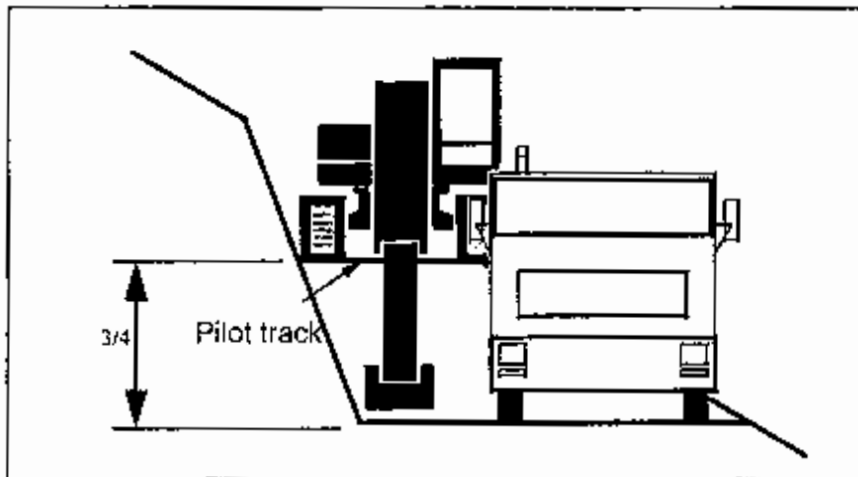


Figure 60 - The two pass method

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 ($T_{\text{Bt(neck)}}$)

Therefore:

$$T_{\text{Total}} = \max(T_{\text{Un}}, n \times T_{\text{Bt(neck)}}$$

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).

$T_{Bilneck}$ = 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):

$$T_{Bilneck} = T_{2-1} + T_{Load} + T_{1-2}$$

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

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

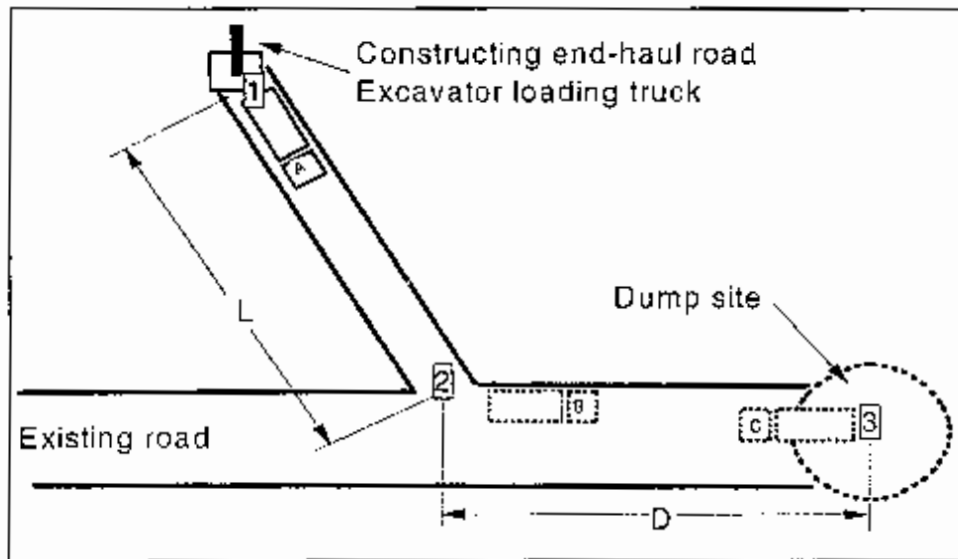


Figure 61 - Typical end-haul scenario

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 m³ 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 ($T_{\text{bottleneck}}$) is reduced.

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

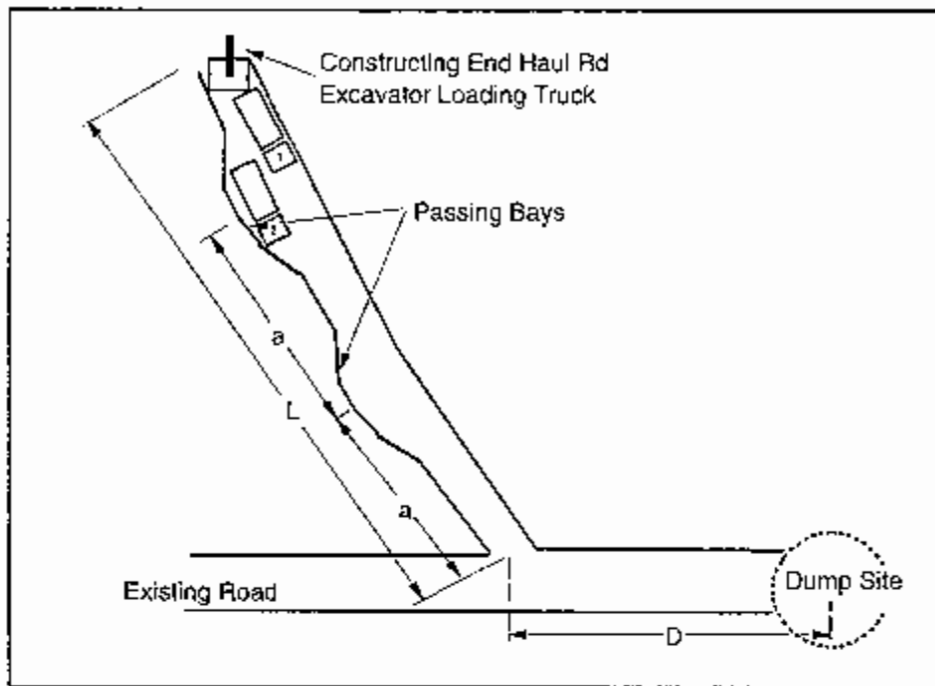


Figure 62 - Typical end-haul road construction with passing bays.

- *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.

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

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

Step 1.- Determine T_{total}

$$\begin{aligned} T_{\text{Load}} &= 8 \text{ m}^3 / 1.14 \text{ m}^3 \times 17.47 \text{ sec} \\ &= 122.6 \text{ sec} \end{aligned}$$

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

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

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

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

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

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

$\begin{aligned} T_{\text{un}} &= 1727.8 \text{ sec} \\ &= 28.8 \text{ min} \end{aligned}$
--

Now:

$$\begin{aligned}T_{2-1} &= 200 \text{ m} / 1.36 \text{ m/s} \\ &= 147 \text{ sec}\end{aligned}$$

$$T_{\text{load}} = 122.6 \text{ sec (as above)}$$

$$\begin{aligned}T_{1-2} &= 200 \text{ m} / 2.74 \text{ m/s} \\ &= 73\end{aligned}$$

Therefore:

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

$$T_{\text{Binneck}} = 342.6 \text{ sec}$$

using 3 trucks:

$$\begin{aligned}n \times T_{\text{Binneck}} &= 342.6 \text{ sec} \times 3 \\ &= 1028 \text{ sec} \\ &= 17 \text{ min}\end{aligned}$$

So, since $T_{\text{un}} > n \times T_{\text{binneck}}$, then:

$$T_{\text{total}} = T_{\text{un}} = \underline{28.8 \text{ min}}$$

Step 2.- Calculating the cost of end-hauling

$$\begin{aligned}\text{One truck cycle/hr} &= 60 / 28.8 \text{ min} \\ &= 2.08 \text{ cycles / hr}\end{aligned}$$

$$\begin{aligned}\text{@ 3 trucks} &= 2.08 \text{ cycles / hr} \times 3 \\ &= 6.25 \text{ trucks / hr}\end{aligned}$$

$$\text{@ } 8 \text{ m}^3/\text{truck} = 50 \text{ m}^3 / \text{hr}$$

$$\begin{aligned}
 \text{8 hours production per day} &= 8 \times 50 \\
 &= 400 \text{ m}^3 / \text{day}
 \end{aligned}$$

Therefore daily cost:

$$\begin{aligned}
 \text{3 trucks} \times \$ 66 / \text{hr} \times 9.5 \text{ hrs (Paid)} \\
 &= \$ 1881 / \text{day}
 \end{aligned}$$

$$\begin{aligned}
 \text{1 excavator} \times \$100 / \text{hr} \times 9 \text{ hrs (Paid)} \\
 &= \$ 900 / \text{day}
 \end{aligned}$$

Total	$= \$ 2781 / \text{day} @ 400 \text{ m}^3 / \text{day}$ $= \$ 6.95 / \text{m}^3$
--------------	---

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).

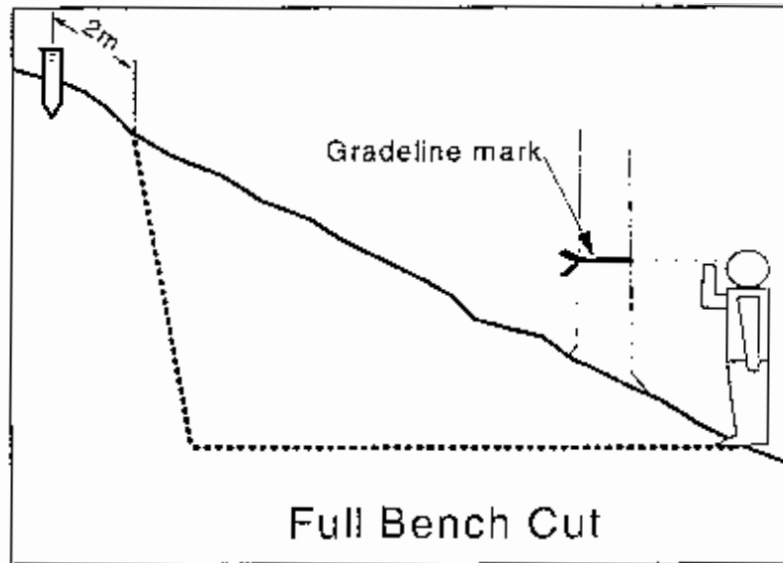


Figure 63 - Set-out of cut batter peg

- *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 m³, 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.

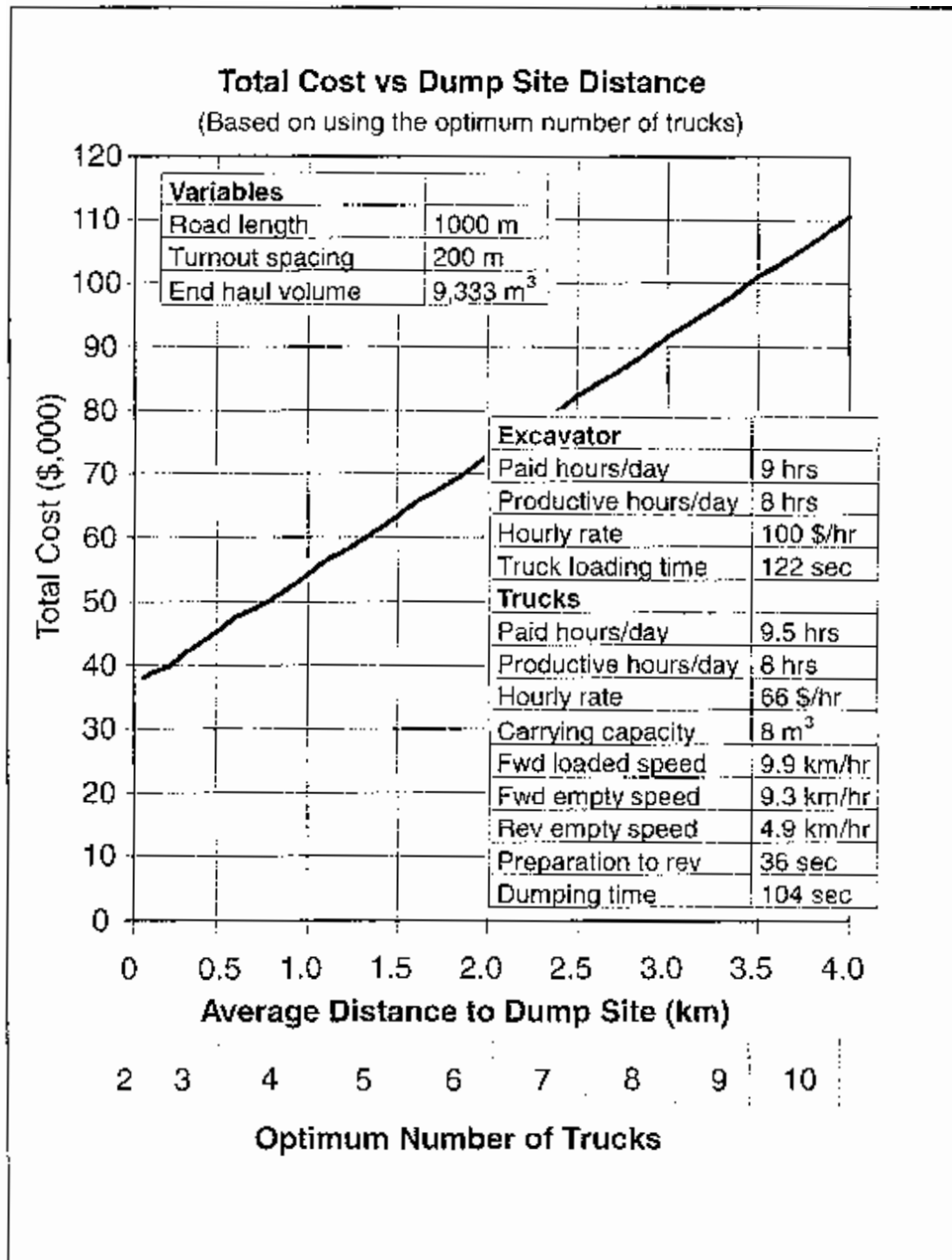


Figure 64 - The effect of changing disposal distances on cost

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.

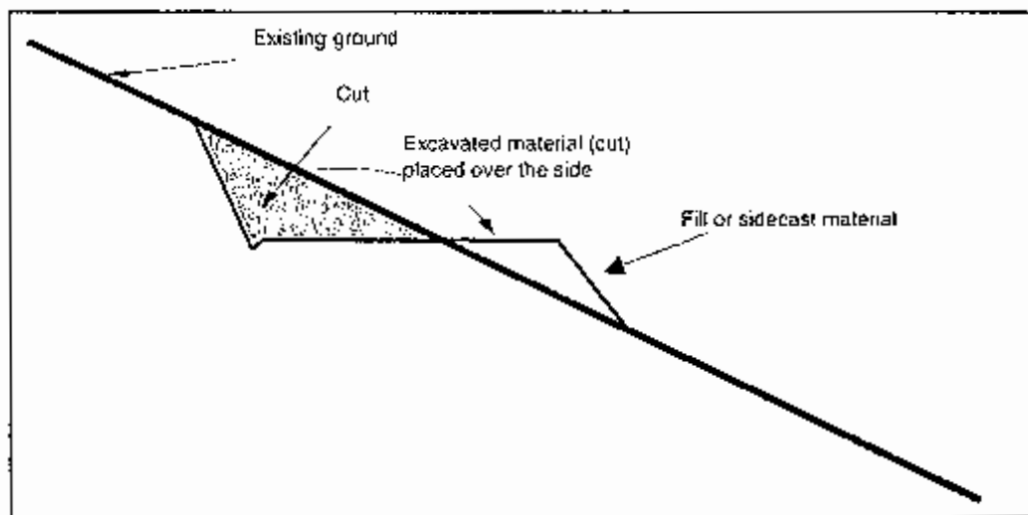


Figure 65 - Sidecast construction

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 mobilisation. 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).

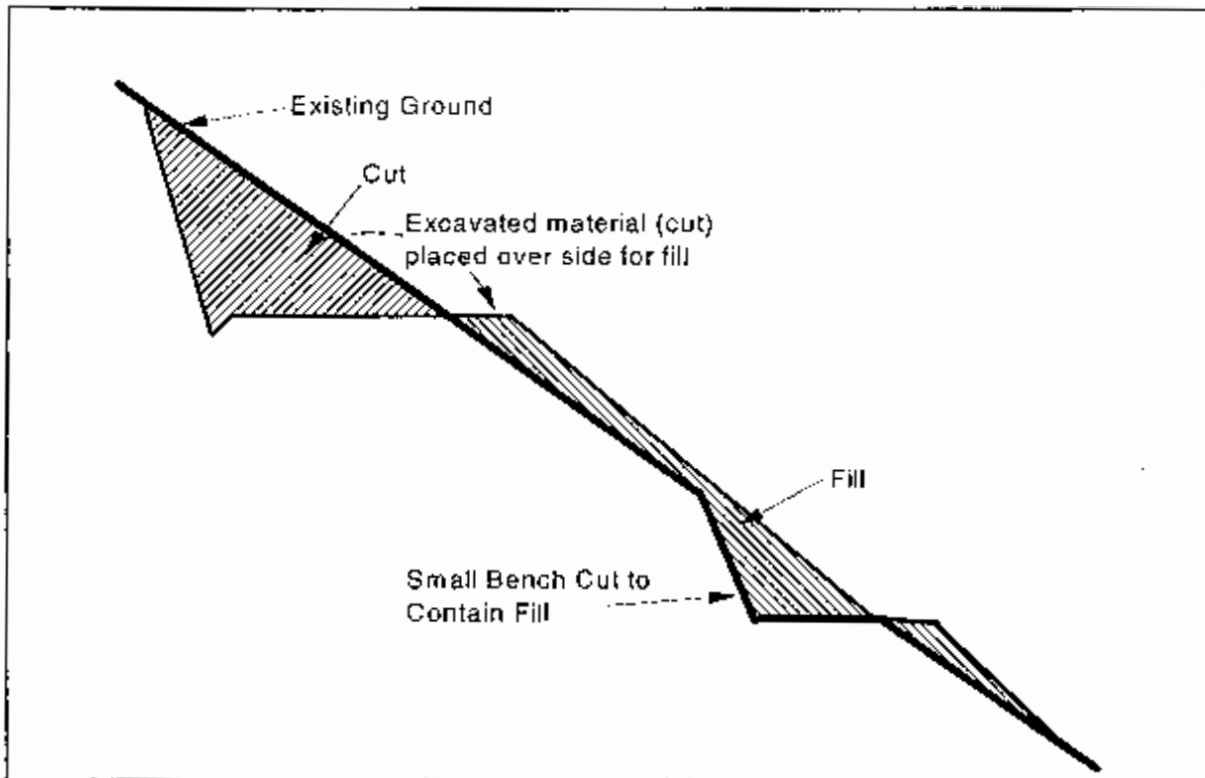


Figure 66 - Bench cut to contain sidecast fill.

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 them from the site or place them 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:

One pass method

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

Two pass method

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 its 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 disadvantage 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 m³ (Ln³), 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/Lm³, 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 manoeuvring 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 Cushion 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 through 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.

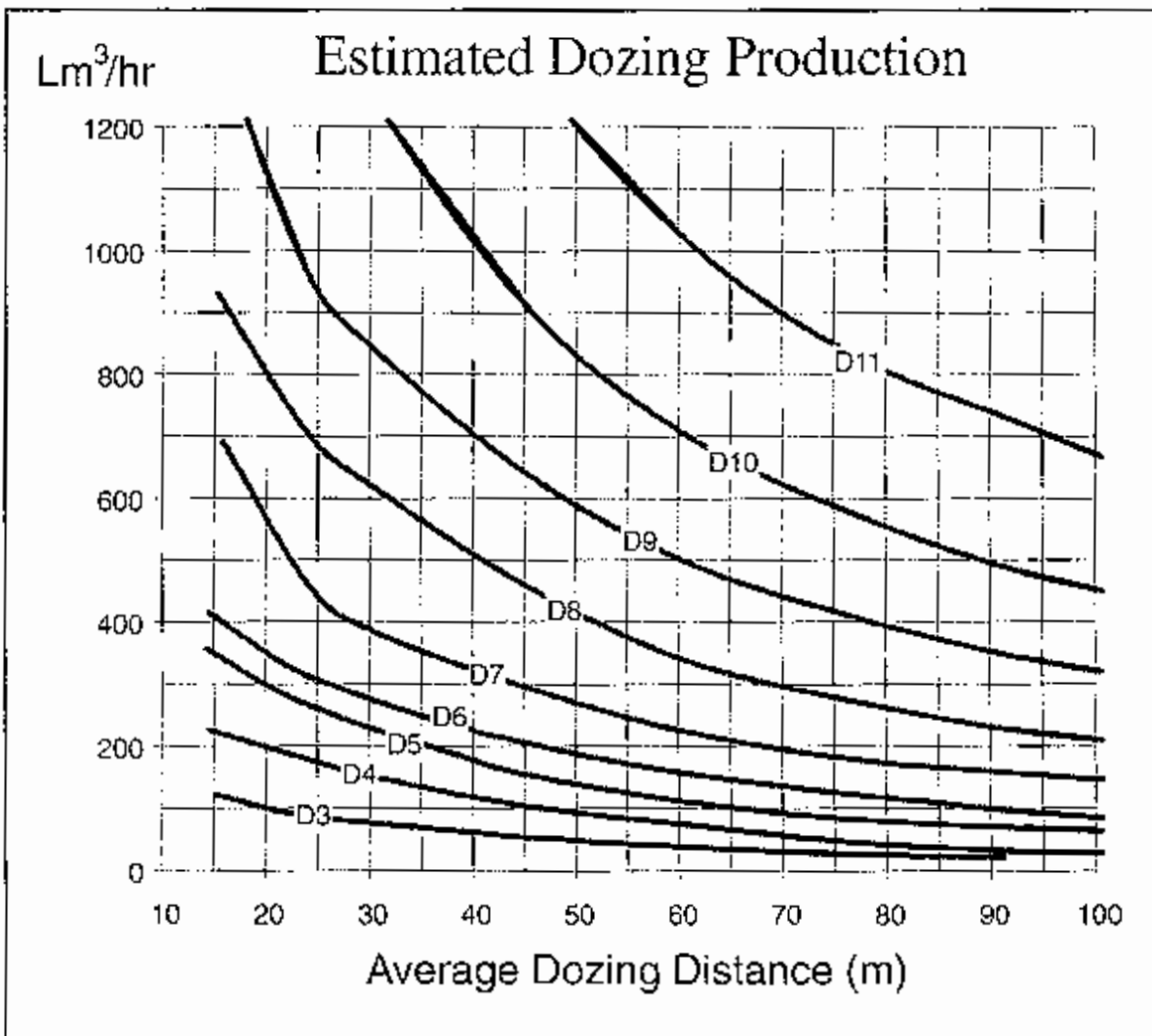


Figure 67 - Dozer production chart

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 (Lm³/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) (\$/m³):

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

where:

- V = Total in-place volume of earthworks (m³)
- S = Soil swell factor (table 22)
- P = Dozer production (Lm³/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

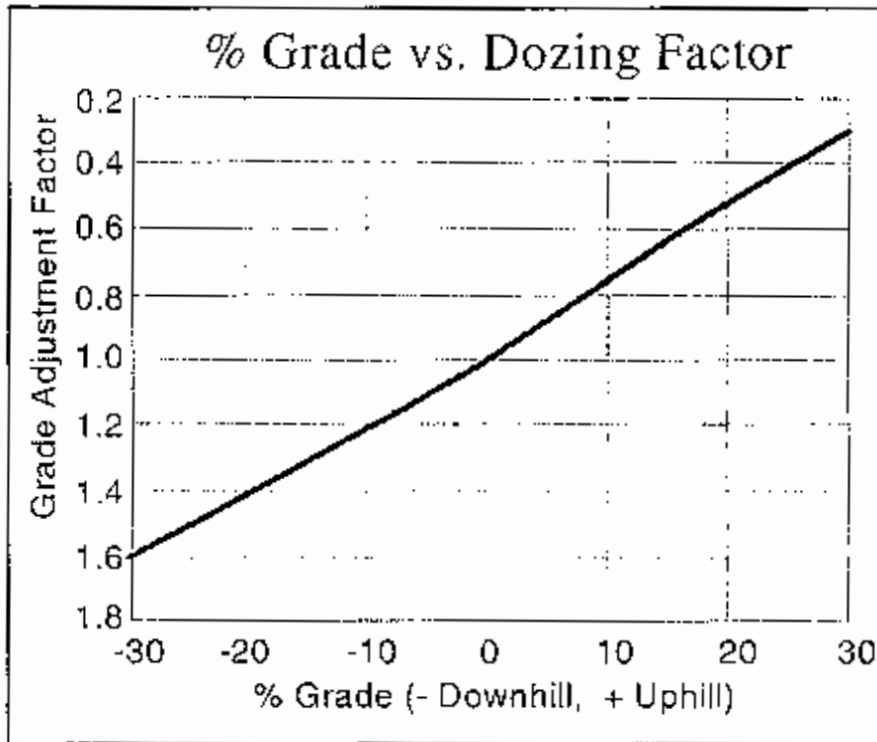


Figure 68 - Grade adjustment factor

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:

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

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.

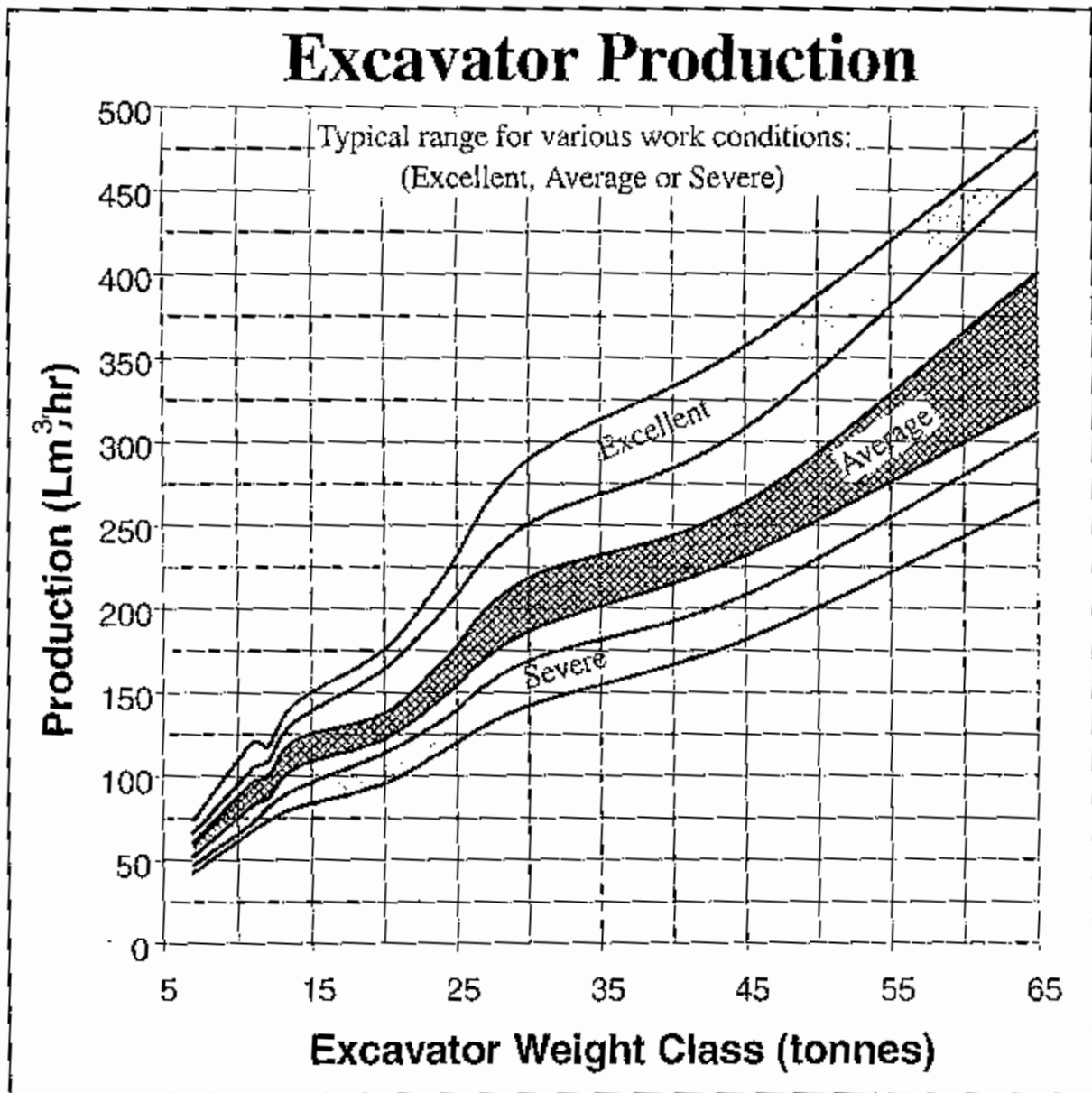


Figure 69 - Excavator production for various work conditions

(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 (m³)
- S = Soil swell factor (table 22)
- P = Dozer production (Lm³/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)	Trips	Transport Costs, T (\$/km)	
			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.

PAVEMENT DESIGN

CHAPTER 8 - PAVEMENT DESIGN

8.0 INTRODUCTION

The three main functions, of a pavement are:

1. To provide a durable, all-weather surface which will provide an acceptable level of travelling comfort, safety and service.
2. To distribute traffic loadings so that its intensity can be supported by the foundations (subgrade).
3. To have sufficient inherent strength to minimise deterioration under traffic loads or the effects of moisture.

The objective when designing a pavement is to produce a road which will perform the above functions with minimal maintenance during its life. To achieve this, an important factor is determining the pavement design thickness, but the support which can be provided by the subgrade material needs to be determined before this design thickness can be determined.

Subgrade strength, and its susceptibility to strength and volume changes with variations in moisture conditions are important factors influencing the pavement design. The subgrade strength is dependent on its physical and mineralogical characteristics, and its density and moisture content both during compaction and while in service.

Subgrade strength can then be utilised to determine the quantity and quality of aggregate material required for overlying pavement design. The axle loads being applied to the pavement, and the required amount of load distribution determine the thickness and material strength used in the pavement. A weak subgrade will require a thicker pavement to distribute the applied traffic loads. This load distribution by the pavement layer is very important, since most subgrade materials will not withstand a large number of heavy axle loads applied directly to it.

8.1 PAVEMENT DESIGN

A systematic approach must be used when designing a pavement structure. Many variables and interactions can make the process a very complex problem. Figure 70 is a flow chart showing one procedure which can be followed.

8.1.1 Input Variables

The following input variables are to be considered when designing a pavement.

8.1.1.1 Design Period

The design period is that period of time for which a pavement is desired to serve without requiring major rehabilitation or restructuring. The design period is influenced by a number of factors including the cost of capital expenditure, road classification, intended usage, and location. For example, there is no need to design a secondary road to withstand the expected traffic loadings for 10-20 years if it is only likely to be used for a number of months.

8.1.1.2 Design Traffic

The level of current traffic or expected traffic must be determined when designing a pavement. Any expected change in traffic volumes occurring over time should also be taken into account (i.e. estimate the growth rate). Specific data required for the design traffic analysis includes:

- Axle numbers
- Load distribution
- Loading rate
- Tyre pressure

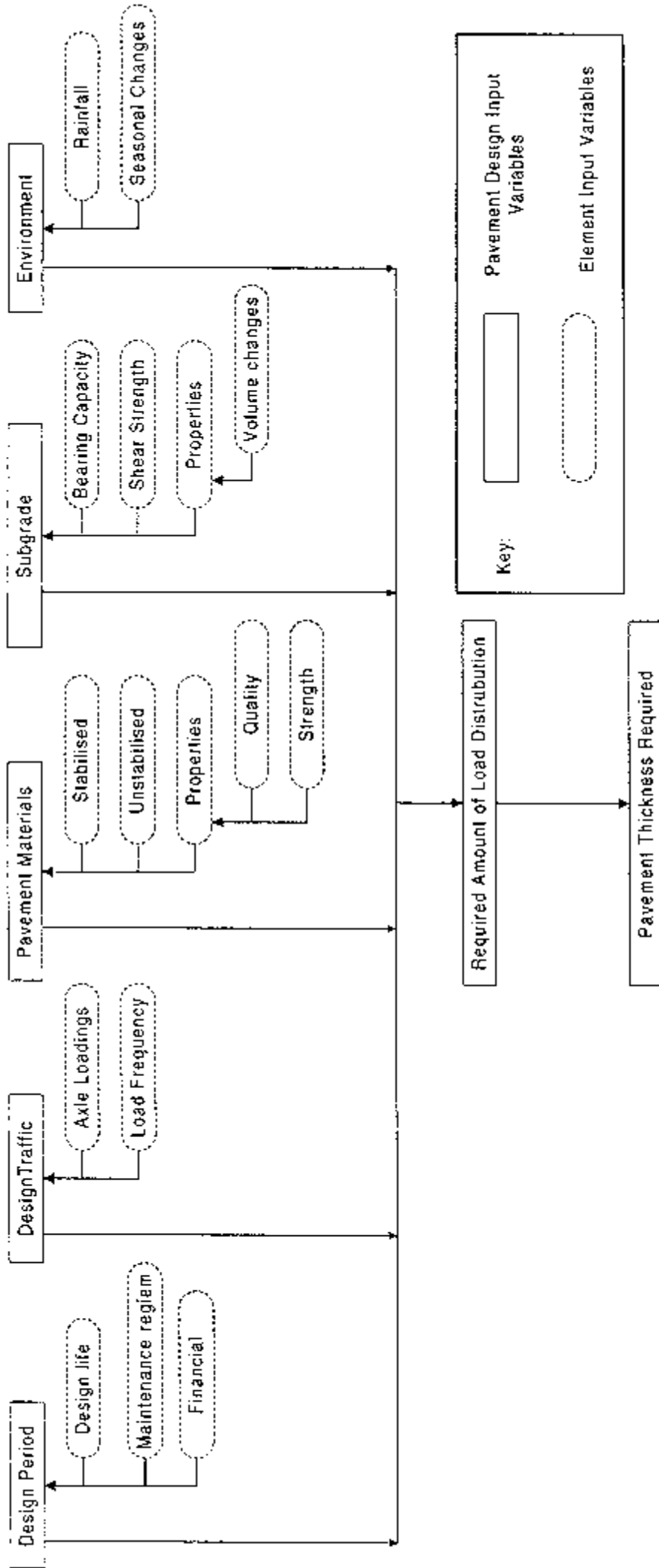


Figure 70 - Pavement design diagram

The design traffic is expressed in terms of the equivalent number of standard axles (ESAs) which are predicted to traverse the pavement during the design period. This number of ESAs is regarded as having an equivalent damaging effect as the axle loads to which the pavement will be actually subjected.

Note: The ESA criteria is a concept that was designed for sealed roads, however it is also widely used for unsealed roads.

8.1.1.3 Subgrade Properties

Subgrade material must be evaluated to determine the properties which influence the pavement design. The main properties of interest are the subgrade strength, and its susceptibility to strength and volume changes with variations in moisture.

Subgrade strength is influenced by the physical and mineralogical characteristics of the material, and its density and moisture content, both when compacted and later in service.

In some situations, the pavement design over a subgrade which is highly susceptible to volume and strength changes will become expensive and impracticable. In these situations, changes to the subgrade may be needed.

8.1.1.4 Pavement Material Properties

Knowledge of the pavement material properties and characteristics is essential to the design of a pavement. Substandard quality material will require careful consideration when determining pavement depth, and load bearing and load distribution properties - additional pavement depth of stabilised material may be required. Material properties are discussed in section 8.3.

8.1.1.5 Environment

The environment can affect both the subgrade and pavement materials. Changes in moisture and temperature can influence the properties of a material, and therefore the overall performance and serviceability of a pavement structure. Pavement design must take into account the moisture and temperature (both averages and ranges) which the pavement and subgrade will encounter during service. The significance of environmental effects will depend on the materials which are selected for the pavement, and the period during which the heaviest loads will use the pavement.

8.2 SUBGRADE EVALUATION

The support provided by the subgrade is an important factor in determining the required pavement design thickness. The most commonly used measure of subgrade support is the California Bearing Ratio (CBR). The aim of subgrade evaluation is to determine, a subgrade CBR value for the density and moisture conditions which are expected to prevail in service. A design CBR must be determined for each different instance of topography, drainage and soil type.

In variable soil conditions more measurements are warranted. Correct documentation of the changes in soil type and CBR sample positions will provide accurate information for the subsequent pavement design.

8.2.1 Procedure for Determination of CBR

Several procedures are available for determining the design subgrade CBR, based on field or laboratory testing or on previous experience. The procedure used is influenced by factors such as the importance of the road, and the amount of experience the designer has had with similar subgrade material in similar locations and environments.

The following three procedures can be used to determine the subgrade CBR:

1. In situ determination using field CBR equipment, dynamic cone penetrometer, or impact test equipment
2. Laboratory determination
3. Presumptive CBR based on experience

A detailed description of each follows.

8.2.1.1 In situ Measurements of CBR

This test requires the subgrade material to have similar density and moisture conditions to those which are likely to occur in the subgrade during service. In areas where adverse weather conditions are likely to make the pavement and subgrade material very wet during service, tests should be conducted under the wettest condition which is likely to occur. This will be the most critical time, and the pavement needs to be designed to compensate for the lack of subgrade support. A danger with this method is the tendency to design the pavement for the relatively short time period during the wet season. An alternative is to design the pavement to cope with 85 - 90% of the conditions, and during the other 15 - 10% of the time, to limit access to light traffic only.

The procedure to determine the design subgrade CBR is:

1. Select sections of the existing road with conditions matching those of the road being designed. When selecting corresponding sections, the following features should be examined:
 - subgrade material properties
 - granular paving material properties (e.g. permeability)

- positions of catch drains, table drains and subsoil drains
- type cross section (boxed or drained, sealed or unsealed shoulders)
- depth of cut or height of fill
- shoulder cross fall
- longitudinal grade.

The greater the similarity between existing and proposed road sections, the more applicable will be the results of the subgrade evaluation. The reliability of this method decreases significantly where the above features are dissimilar, and if this is the case, a different method should be used to determine the CBR.

Because these features are frequently similar in widening and duplication work, the method is usually quite reliable for these jobs.

2 Within these sections, select a number of test positions. The tests are to be carried out in lateral positions, which correspond to critical positions in the new pavement - generally taken as the outer wheel path. Test positions should be chosen in areas free of cracking, to eliminate the effects of infiltration or evaporation through the pavement surface. However, the number of tests to be carried out will depend on the variability of the subgrade, the traffic usage and class of the new road, and other available information on the subgrade material.

3 With insitu CBR equipment, the subgrade CBR at a single depth is measured at each test. The dynamic cone penetrometer permits the measurement of CBR throughout the full depth of penetration. Accordingly, procedures for determining a representative CBR for each position may differ depending on the test method.

The dynamic cone penetrometer test is most reliable in fine-grained soils. High subgrade CBRs obtained from this penetrometer test in sands and gravels should be further checked using laboratory testing or insitu CBR equipment.

In situ CBR Equipment

Assess the subgrade by visual inspection, supplementary tests with the dynamic cone penetrometer or on the basis of experience with similar subgrades to determine its uniformity with depth. If the subgrade is essentially uniform with depth, measure the CBR at a depth 100 - 200 mm from subgrade level. If layers exist in the subgrade (e.g. as for a duplex soil subgrade) measure the CBR for each distinguishable layer.

Dynamic Cone Penetrometer

The dynamic cone penetrometer measures the CBR for a range of depths between 50 and 800 mm below the subgrade surface. From the CBR profile of the soil the vertical uniformity of the subgrade material properties can be determined.

- Uniform with depth

The representative CBR is taken as the minimum CBR value determined in this depth over an interval of at least 100mm.

- Non-uniform with depth (i.e. layers are present)

Providing that these layers will be present in the final subgrade material, the representative CBR value is taken as the minimum CBR value determined over an interval of at least 100 mm in each layer.

If the upper subgrade layers are weaker than lower layers, then the upper layer will control the pavement performance and the design should be based on the CBR of this weaker layer.

If the lower layer is weaker than the upper layer, then the pavement thicknesses should be designed for both layers, taking into account the thickness of stronger layers above the lower weaker layers. The layer, which then requires the thicker pavement, will control the design.

Figure 71 can be used to determine the CBR value of the subgrade material from the blows per mm ratio obtained from the penetrometer tests.

Impact Soil Test – (Clegg Hammer, and Loadmaster)

The impact soil test is a dynamic test procedure using a falling weight onto the pavement. Several dynamic falling weight apparatus are available, including the Loadmaster, and the Clegg Hammer Impact Soil Tester. The basic principle of this impact test is that the peak deceleration of the compaction hammer (when it is brought to rest) is directly related to the resistance offered at contact. This resistance results from the stiffness and shearing resistance of the material.

From intensive comparison tests it has been shown that there is a correlation between the impact test results and the CBR of the material. In the case of the Clegg Hammer this relationship is of the form $CBR = 0.07(IV)^2$, where: IV = Impact Value. Although this relationship must be used with some caution, the impact test procedure has wider applications including checking variations during construction, and monitoring changes over time.

For further information on the equipment and test procedures consult the manufacturers or suppliers of the soil impact test equipment.

Penetrometer Conversion Chart For Equivalent CBR

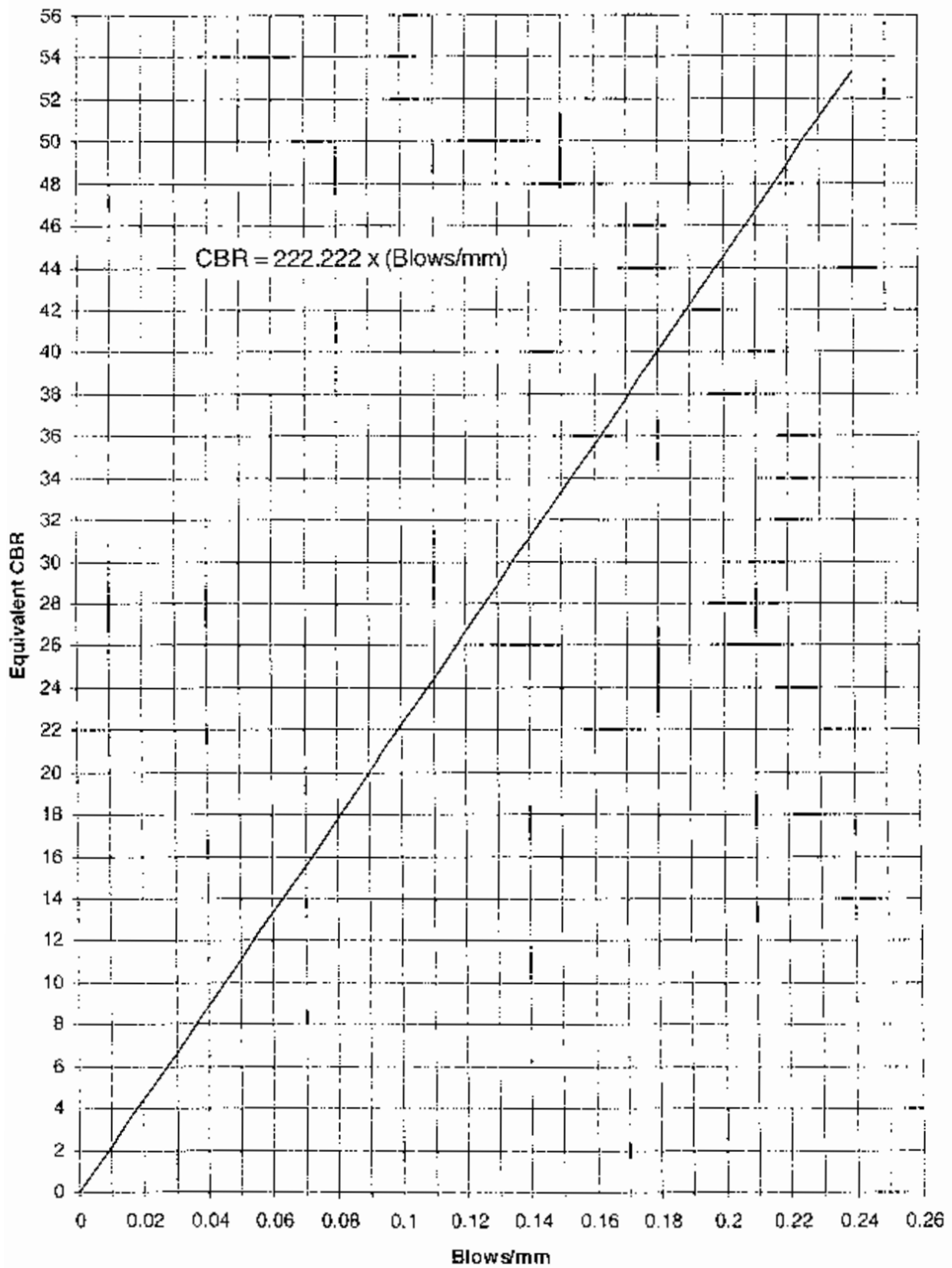


Figure 71 - Penetrometer to CBR conversion graph

8.2.1.2 Laboratory determination of CBR

For these tests sufficient subgrade samples of material are required and an estimate can be made of the likely subgrade density and moisture conditions in service.

Note: The Laboratory CBR tests are usually used as a control for field penetrometer determinations.

There are a number of different procedures available for determining laboratory CBR values including:

1. Measure the CBR at the design moisture content and at a density representative of subgrade conditions in service. Two tests should be completed of each sample and the lower value taken as the design value.

This procedure provides no indication of the subgrades sensitivity of CBR to moisture content changes, and therefore there is no indication of possible errors due to the inaccuracy of the design moisture content adopted.

2. Measure the CBR for a range of moisture contents and densities, and interpolate the CBR at the design conditions. This procedure should be used where in-service conditions will experience a significant range of moisture contents or where the subgrade material is sensitive to moisture changes.

3. Measuring the CBR soil samples which have been soaked in water for four days. This test should be completed when the subgrade is likely to experience any of the following:

- Flooding travelling over the pavement
- Cuttings are positioned below the water table, or when seepage is likely
- Water table within one metre of subgrade level

- Other situations where, because of factors such as high rainfall and high traffic axle loads and volumes, soaked conditions are chosen to minimise the risk of failure.

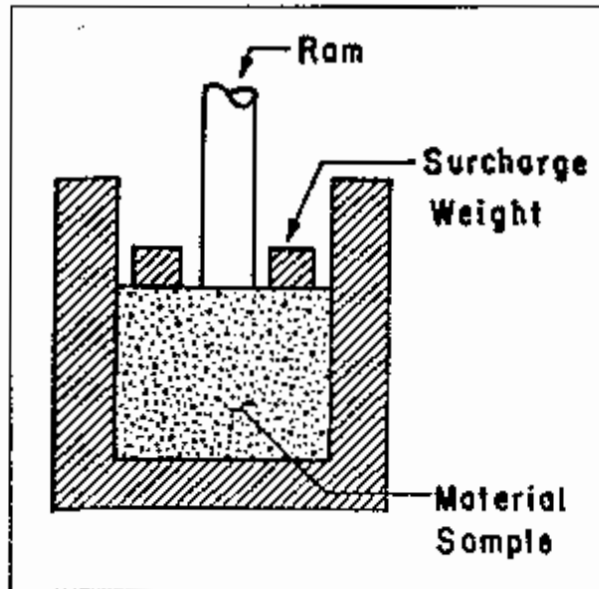


Figure 72 - CBR test apparatus

Since soil samples should be tested at in service conditions, the sample needs to be compacted. The density of the soil sample should be selected as one of the following:

- In situ density of undisturbed or reworked subgrades (e.g. cuts and fills) as appropriate
- Minimum standard of compaction achieved in construction of the subgrades i.e. embankments
- Density after volume changes have occurred from construction conditions to service conditions

The reduction in density due to swelling in expansive soils can be considerable, particularly if compaction is carried out at low moisture contents.

8.2.1.3 Presumptive Design CBR

The third procedure is based on experience and the analysis of available information and is particularly useful for lightly trafficked roads in situations where extensive investigations are not warranted, or where subgrade and climatic conditions are similar over large areas.

Making use of historic data and experience for specific soils types in local climatic and topographical conditions will reduce the cost of subgrade evaluation, and will also help ensure a consistent approach to the determination of subgrade CBR for that local area.

8.2.2 CBRs Less Than 3%

If the subgrade material has a CBR of less than three then some form of stabilisation treatment will be required. Stabilisation techniques are introduced later in this chapter and extended further in chapter 9.

The use of a cone penetrometer for the measurement of CBR in soils with a CBR < 3 will give unreliable results. This is due to the tendency of the penetrometer to sink into the soil under its own weight.

Pavement material depth

The Graph below has been developed to give an indication of pavement depth requirements for various subgrade CBR values and axle loadings. For ranges outside the scope of this graph the associated equation can be used to determine the pavement depth required.

CBR GRAPH

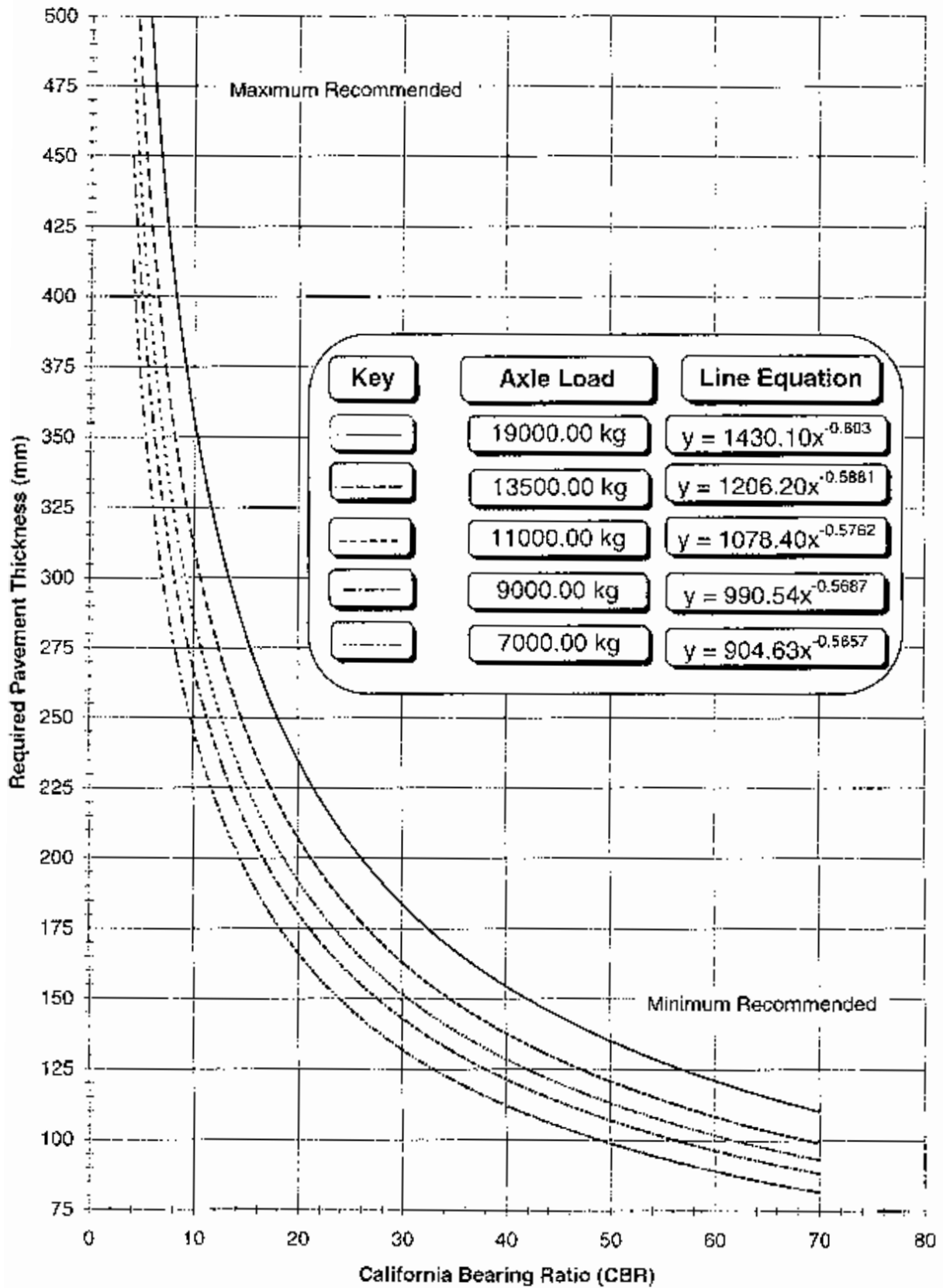


Figure 73 - CBR vs pavement thickness

8.3 ELEMENTS OF A PAVEMENT

There are three sections to an unsealed pavement, all of which contribute to the load distribution. These are shown in figure 74, and outlined below:

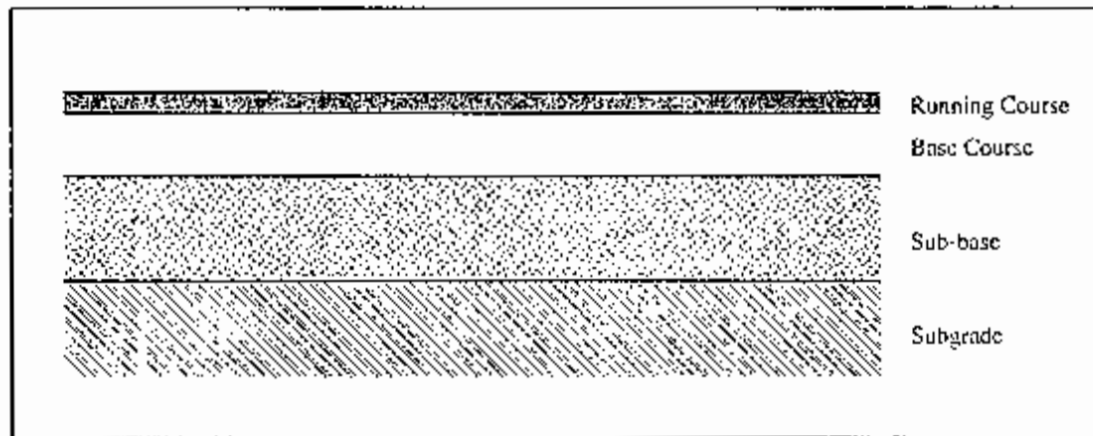


Figure 74 - Elements of a pavement

1. Running course

- | | |
|----------|--|
| Function | <ul style="list-style-type: none">- Wet and dry stability- Good skid resistance- Running surface- Smooth finish- Resistance to ravelling and scouring- Low permeability |
|----------|--|

- | | |
|----------|---|
| Material | <ul style="list-style-type: none">- Even graded aggregate |
|----------|---|

2. Base Course

- | | |
|----------|---|
| Function | <ul style="list-style-type: none">- To withstand the high stress concentrations immediately below the traffic load and distribute the stress to the lower levels of the pavement and onto the subgrade. |
|----------|---|

- Material
- Well graded with:
 - Good compaction to achieve a high binding effect
 - Good crushing strength
 - Good proportion of broken faces to distribute load and take shock load

3. Sub-base

- Function
- Distribute load onto subgrade, using cheaper material than the base course

- Material
- Good compaction
 - Good proportion of large aggregate material
 - Usually lower quality aggregate (e.g. rotten rock) since its position low down in the pavement means that it is subject to less stress.

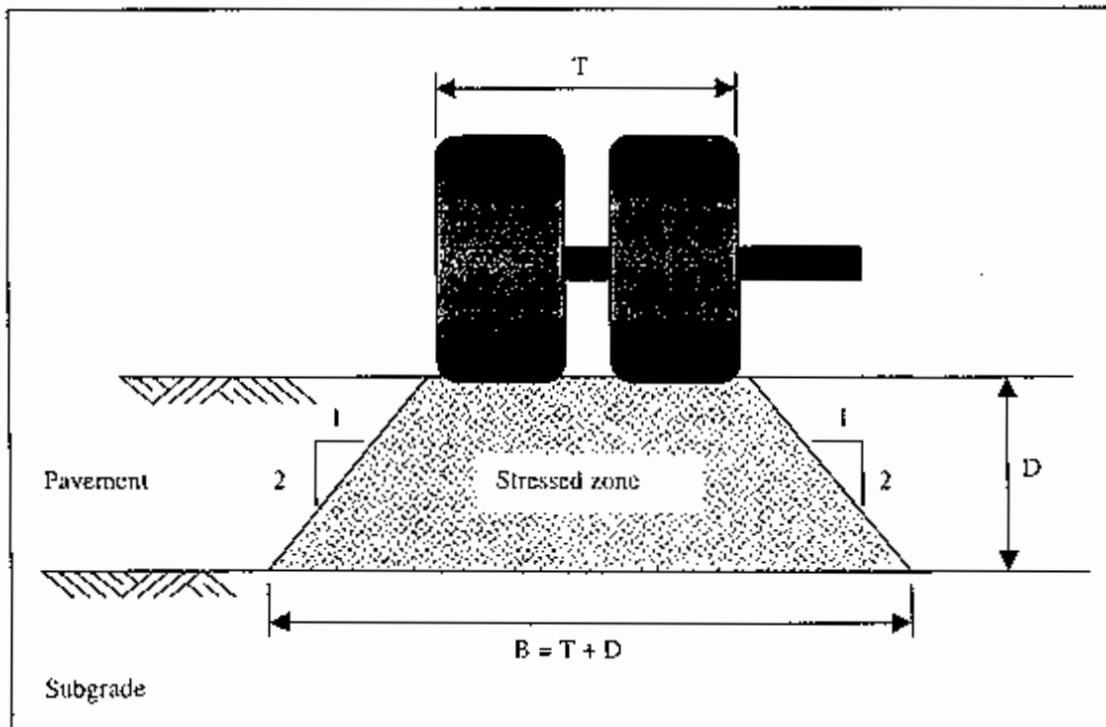


Figure 75 - Pavement cross section showing idealised load distribution

8.3.1 Types Of Pavements

Three main types of pavements are currently used for road formation:

Rigid - Concrete pavements are load-bearing structures, which do not deform under loading.

Semi-rigid - An asphaltic or bound material within the pavement provides a limited amount of load bearing capability.

Flexible - These pavements are either chip sealed or unsealed roads which deform under loading and have no load bearing capability. The applied load is therefore distributed completely through the pavement and onto the subgrade material.

Most forest roads in New Zealand are flexible pavement designs, therefore the following sections deal only with this type.

8.3.2 Pavement Material Properties

Pavement material selection is a process of providing a suitable material for the job, and at a reasonable cost. A number of factors determine material selection, including:

- Material availability
- Cost of transportation
- Structural properties
- Durability
- Workability

Often in a forestry situation the cost of transporting high quality aggregate may be prohibitive. In these cases it may be more appropriate to use local material, which requires little transportation, but, if it is of poorer quality additional quantities may be needed to provide the design performance. The upper pavement section can use

higher cost material if required. Three main pavement and surfacing materials commonly used are:

- Earth
- Gravel or Aggregate Surfacing
- Sealed or paved surface

Earth

Usually these roads, constructed from insitu material, are only a pilot track or light vehicle track for establishment or silvicultural work. In flatter country, earth roads which are excavated out of the insitu material down to a solid base are often lower than the surrounding environment, and this become a waterway.

They are therefore used in situations where constant usage, load bearing capacity and traction are not essential, or where the soil type is such that the excessive waterflow and lack of load-bearing is not a major concern, for example pumice soil which is very fast draining, and can carry a significant load.

Clay-based soils can provide a good dry weather surface, but will rut and become slippery during wet periods.

Gravel or Aggregate Surfacing

Unsealed road pavements are the most common type of forest road construction. The aggregate material acts to distribute the applied load over the subgrade, assuming that the aggregate is well compacted. This is achieved through:

- **Depth of material** The thicker the pavement, the greater the load distribution capability (and therefore, load bearing capacity, figure 76).
- **Aggregate gradation** Well-graded material will perform better than an open graded material of a single size. Well-graded material has a good proportion of all size of material, filling the voids between the larger particles. This:

- Eliminates the entrance of air and water
 - Provides surface friction between particles
 - Improves compaction and binding
- **Quantity of broken faces** Aggregate material gains some of its strength from surface friction between the particles. An increase in the number of broken faces will increase the surface contact area between the aggregate material (figure 77) and therefore increase the load bearing capability of the material.
 - **Crushing strength** Soft material which is easily broken will quickly deteriorate under the constant motion provided by the applied traffic loadings. This results in degradation of the pavement material, which lowers the bearing capacity.
 - **Low absorption rate** Aggregate material which absorbs water from the environment will generate problems with shrinkage and swelling, as well as freezing and thawing during winter periods. Freezing causes not only a build up of ice on the running surface of the pavement, but also expansion within the aggregate material which causes material to fracture and break down into fine material with a decreased load bearing capacity.

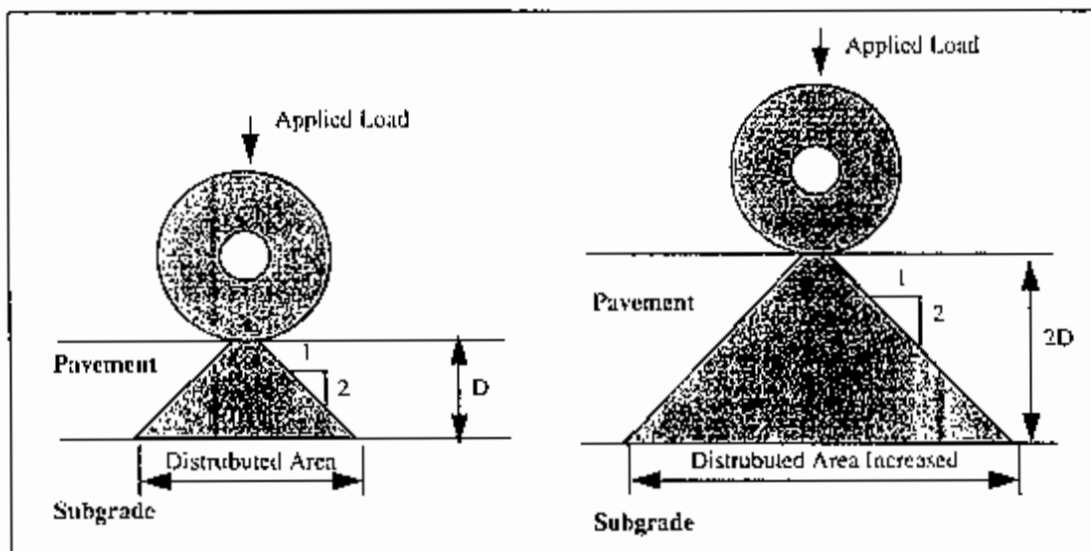


Figure 76 - Load bearing capacity of various pavement depths

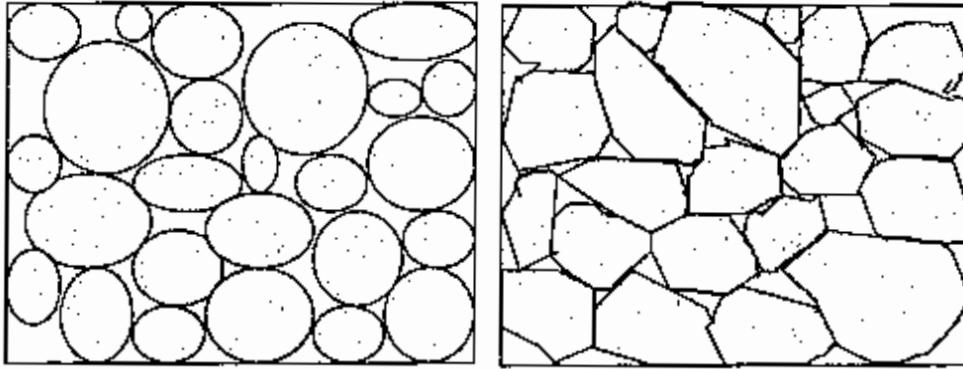


Figure 77 - Surface contact is increased with broken faces

Sealed Or Paved Surface

Sealed or paved surfaces provide a waterproof running surface with good drainage, and a friction surface for vehicle traction and skid resistance. They are used in high traffic areas where it is essential that the road is maintained and constantly open, or where high maintenance costs justifies sealing. Examples of paved or sealed surfaces include:

- Standard Chip Seal
- Asphaltic concrete
- Concrete

There are currently a number of good manuals available to roading engineers who wish to use some form of paving or surfacing. These are:

Giummarra George J. *Sealed Local Roads Manual* 1995 ARRB Transport Research Ltd

National Roads Board New Zealand. *State Highway pavement Design and Rehabilitation Manual* 1987

Transit New Zealand. *Bituminous Sealing Manual*. 2nd edition *Transit New Zealand Manual* 1993

Base Course Thickness

A minimum course thickness must be applied to ensure that adequate pavement performance is achieved. The overall minimum pavement depth recommended is 150mm of granular material, and the maximum depth recommended is 475mm. Designs requiring more than this should consider stabilising the subgrade to withstand greater applied loads.

8.3.3 Aggregate Mixture Properties

Material properties and characteristics are the most important factor when determining which material to use for a pavement, but other factors which must also be considered are cost, availability, and environmental factors. Often, the material is selected as a compromise between achieving the desirable properties and acceptable overall costs. The most desirable material qualities required for an unsealed road pavement are:




- load bearing capacity
- workability and ability to “bind”
- strength
- compactibility
- crushing strength
- well graded

The material property which has a great influence on many of the above characteristics is the particle size distribution. Particle size distribution is described in terms of standard particle size classifications (e.g. gravel, sand, silt and clay) or alternatively, the fractions which pass various sieve sizes. A soil-aggregate consisting of a well-graded gravel sand mixture with a small proportion of clayey fines will usually be the most desirable material for an unsealed surface since it has a good particle size distribution. Figure 78 shows the main characteristics and workability properties of:

- a good particle size distribution material
- a coarse material lacking in fines
- a material with excess fines

The coarse material lacking in fines will be a porous material, lacking in stability, which makes it no good for a base course or wearing course, but ideal as a subbase material.

Properties of aggregate mixtures

DIAGRAM			
Type of mixture	Coarse stone low fines	Well graded coarse to fine	Excess fines
Compaction	Difficult	Moderate	Easy
Flexibility	Relatively stiff after compaction	Moderate	Relatively pliant
Stability	Variable	Good	Fair
Frost	Not affected	Susceptible	Very susceptible
Drainage	Good	Low	Variable
Affect of water saturation on strength	Not much	Moderate	Very significant strength loss
Chemical stabilisation	Not very suitable	Suitable	Very suitable
Dust	Low	Moderate	High
Roughness	High	Moderate	Variable
Capillary effects	Very low	Beneficial suction	High suction potential instability

Source: New Zealand Supplement to the ARRB Unsealed Roads Manual

Figure 78 - Aggregate mix properties and workability

	Gravels	Sands	Silts	Clays
Water Content	Dry	Little effect on strength	Low strength unless well graded	High strength when compacted
	Moist	Little effect on strength	Improves cohesion	Improves cohesion of uncompacted clays. Reduces strength of compacted clays
	Wet	Little effect on strength	May lose strength due to particle separation	Weak. Water lubricates and separates particles
Density	Low	Low strength	Low strength, unless confined	Low strength
	High	Increased strength by improving interlocking of particles	Increases strength, by improving interlocking of particles	Increases strength
Particle Size Distribution	Poorly Graded	Lower strength due to less interlocking	Low strength	-
	Well Graded	Increases strength by better interlocking of particles	Increases strength	-
Particle Mineralogy and Shape		Strength reduced by weak or weathered particles	Shape and mineralogy may influence elasticity	May have significant effect on plasticity and shrinkage

Table 25 - Material properties table

Modified Granular Materials

The addition of stabiliser or binder products to aggregate material produces a layer within the pavement with increased strength and rigidity. The purpose of using binder products is to reduce the quantity of valuable aggregate required for the pavement, or to allow low quality aggregate sources to be used.

Cements/Lime

Cement or lime can be used to add strength to granular materials. Care must always be taken when modifying any granular material since an incorrect application rate of binder material will generate difficulties and result in unsatisfactory performance.

Most binder materials work by effectively dehydrating the aggregate material thereby reducing the shrink and swell effects caused by water entering or leaving the material.

Thermal and shrinkage stresses inevitably produce cracking in cemented materials. Crack propagation has an influence on the pavement performance, depending on:

- width of cracks
- durability of cemented layers
- subbase material properties
- location of the cemented layers in the pavement design
- properties of the overlaying material

Bitumen

Bitumen stabilisation can be used on a wide range of aggregate materials, including gravels, fine crushed rock, and sandy material such as loams and clays. Bituminous stabilisation does not effectively increase the strength properties of a material, rather it reduces the effects of moisture shrinkage and swelling (owing to the waterproofing nature of bitumen) and therefore reduces the permeability of an aggregate material or layer within a pavement. Bituminous stabilisation is therefore used for floodway

pavements, or other pavements subject to saturation conditions, and for waterproofing layers or barriers.

Other alternative stabilisation products or methods, including geotextiles and corduroy road construction methods can also be used to enable the subgrade to withstand the applied loads and reduce the quantity of valuable aggregate used. These techniques as well as the above stabilisation products, are discussed further in chapter 9.

8.4 DESIGN TRAFFIC

There are a number of traffic loading factors which affect pavement deterioration:

- tyre contact areas
- tyre contact pressures
- axle loadings
- frequency of loadings
- quantity and severity of shock loadings (braking)
- number and spacing of axle groups

Pavement design for forestry roading is unusual in that there is always a high proportion of high axle loadings being applied to the pavement, and only lower volumes of low impact, light vehicular traffic. Another aspect unique to forestry roading is the use of off-highway, oversize, heavy vehicles which can have axle loadings that exceed the legal highway axle loading.

The design traffic is expressed in terms of the number of standard axle load repetitions in one lane. The design traffic is given in terms of the Equivalent Number of Standard Axles (ESAs), and is determined by:

- present or expected traffic volumes
- distribution of vehicles
- axle types and loadings

- traffic growth rates
- design life of the road (before major rehabilitation is required)

8.4.1 Axle Load Equivalencies

The cumulative damaging effect to the pavement of the design traffic expressed in ESAs is similar to that which would result from the actual spectrum of axle loads.

A wide variety of axle spacings and configurations of tyres and axle sets are used for heavy vehicles working within the forest. To undertake pavement design, these configurations need to be simplified into a small group of standard axle sets and loadings. The standard axle used is an 80 kN dual-tyred single axle. This is a single isolated axle (not in any closely spaced group) which carries a load of 80kN (8.155 tonnes). Each dual wheel load is taken as being applied to the pavement on two circular areas with centres 330 mm apart, and with a uniform contact pressure of 550kPa (figure 79).

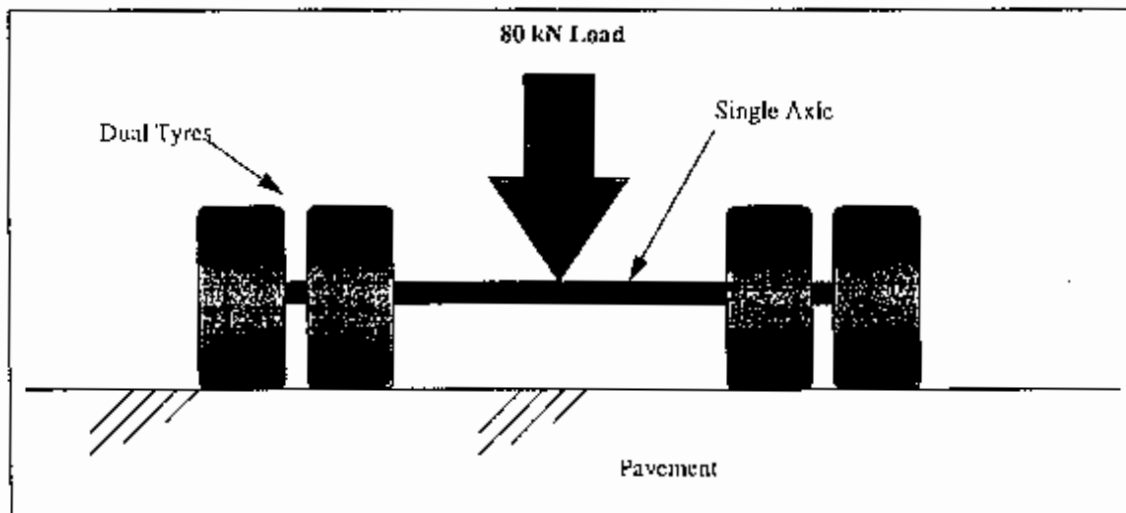


Figure 79 - Standard 80 kN axle

For design purposes, axle group loadings are generally considered in terms of the following four types:

- single axle with single wheels
- single axle with dual wheels

- tandem axles with dual wheels
- triaxles all with dual wheels

Table 26 shows the loads on each of these axle configurations, which are considered to cause the same amount of pavement damage as the standard axle.

Axle Configuration	Single Single	Single Dual	Tandem Dual	Triaxle Dual
Load (kN)	53	80	135	181
Load (tonnes)	5.4	8.2	13.8	18.5

Table 26 - Axle loads causing equal damage

Notes:

- Tandem axles which have dual wheels on one axle and single wheels on the other may be considered to be equivalent to tandem axles with dual wheels on both.
- Tandem axles with wide axle spacings (in excess of 2.4m) can be considered to be single axles with the total load on the spread tandem configuration being divided equally between the two single axles.
- Twin steer axles can be considered to be equivalent to tandem axles both with dual wheels, which are loaded to 1.5 times the load on the twin steer axles.
- For other axle groups not expressed in the above table, the damaging effect is expressed as the number of standard axles which produces the same damage, and is calculated using the following equation:

$$\text{No. of Standard axles for same damage} = \left[\frac{\text{Load on axle group}}{\text{Appropriate load from Table 7.1}} \right]^{\text{EXP}}$$

The exponent (EXP) value is dependent on the pavement material type and the pavement configuration. Typical values for EXP are given in table 27.

Dominant Distress Mode	Value of EXP
Subgrade Rutting	4
Asphalt Fatigue Cracking	5
Fatigue Cracking of Cemented Material	12

Table 27 - Load equivalence exponent

Axles passing over a pavement generate stresses within the pavement which are transferred to the subgrade. There are two main types of stress induced within the pavement:

- Resilient Strain - deforms as the axle load is applied, but rebounds when load is removal
- Permanent strain - deformation remains after axle load has passed

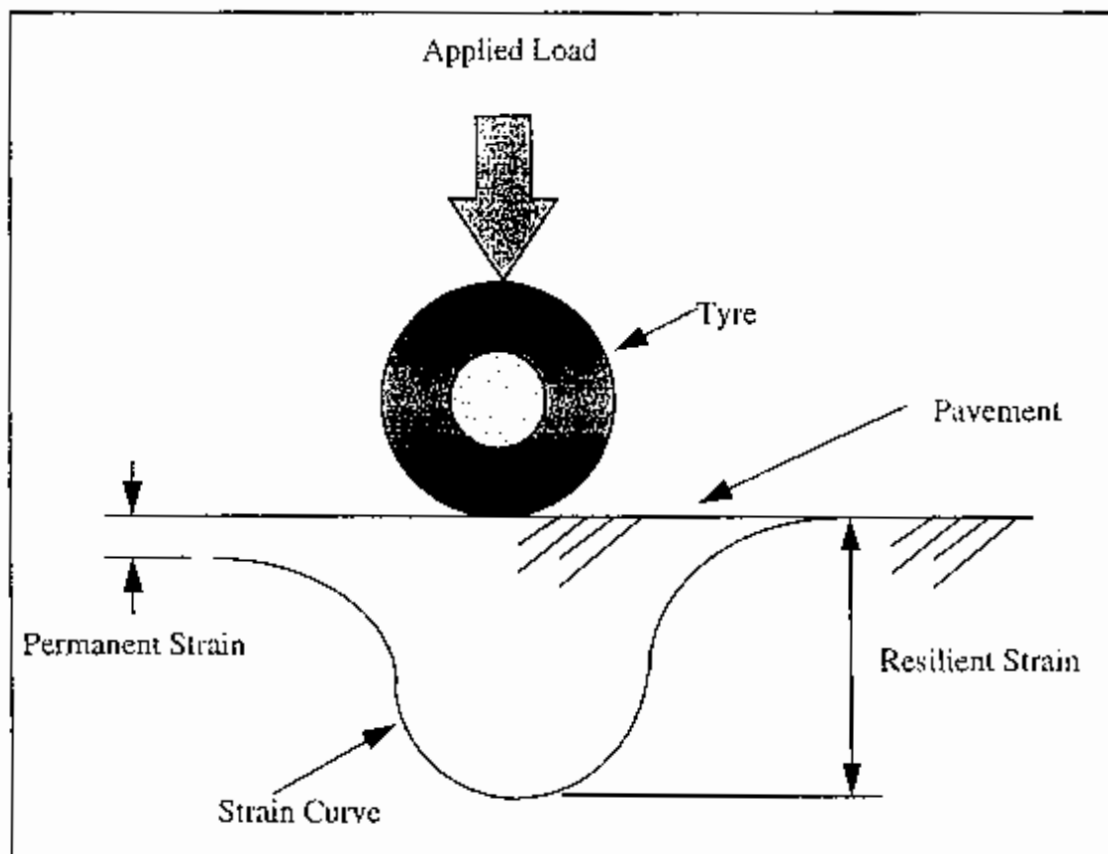


Figure 80 - Permanent and Resilient Strains

The permanent strain causes damage to the pavement. Every time an axle group crosses a given point on a road, it causes a minute amount of permanent, incremental damage to the pavement, (figure 80).

When the number of passes of the configuration is equal to the number of ESA loads for which the pavement was designed, the pavement will (in theory) have deteriorated to the point where it is no longer useable, and needs to be rehabilitated.

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PAVEMENT CONSTRUCTION

CHAPTER 9 - PAVEMENT CONSTRUCTION

9.0 INTRODUCTION

For a long period, most of New Zealand's roads including forest roads have been constructed from aggregate (premium and marginal) which, over the years, has seen the resources of these aggregates being depleted at an increasing rate. There is now more than ever a responsibility to preserve these and other resource supplies and optimise the use of materials in the most appropriate situations.

With the onset of the resource depletion, there is now a need to source alternative materials, and to stabilise or modify them to meet the strength and durability requirements of the pavement.

The pavement needs to suit the site conditions, design traffic loadings, and to utilise local materials imported and insitu in the most cost effective manner.

This requires the "designer" and/or contractor to have a knowledge of:

- The end use load conditions and the material properties needed to meet these conditions,
- The properties of the available materials they are dealing with,
- In what way the properties don't meet the pavement requirements,
- How those properties may be altered by stabilisation with the appropriate binders and specified/constructed in an appropriate manner, to meet the pavement requirement.

A number of products and techniques used for subgrade and pavement stabilisation are described in this chapter.

9.1 SUBGRADE AND PAVEMENT STABILISATION

There is a very wide range of soil types in New Zealand, and many plantation forests are located in areas where the soils are weak or unstable. To provide a pavement with sufficient strength to support a fully laden logging truck requires a good quality aggregate pavement. However, good quality aggregate is a scarce resource. Stabilisation techniques can be used to improve the properties of the subgrade or the pavement, and thus provide useful savings in good quality aggregate, which will reduce road construction and maintenance costs as well as vehicle operating costs.

Road pavement materials which are generally considered unsuitable can be modified using stabilisation techniques and products to improve their deficiencies, allowing them to be used to advantage in road pavement structures (e.g. reducing particle loss due to dust, rutting, potholes and corrugations). Stabilisation can therefore be used to reduce maintenance costs, improve material properties and provide a better wearing, all-weather road pavement.

Modifying a material's properties by stabilisation generally reduces its plasticity, and controls the range and variation in strength, which occurs naturally. Most often this form of stabilisation is used for clays where shrinkage and swelling factors vary the material strength, workability and performance. Modification of this material makes it more workable and more predictable, improving its usefulness as a pavement or subgrade material.

Materials stabilised by modification do not always increase in strength. Cementation stabilisation however, will increase strength and stiffness, allowing, in some cases, a reduction in pavement thickness.

Note: Where unsealed road pavements are routinely graded and reshaped during regular maintenance, the wearing course is usually only stabilised by modification. Pavements which are stabilised by cementing action cannot be easily maintained by grading.

To choose the stabilisation product best suited to a material and operation, a number of factors need to be considered. As mentioned above, there are two main stabilisation techniques: modification and cementation. Either will give the basic stabilisation required, but other factors will influence the final decision, including:

- Weather conditions. Extreme conditions can influence the type of stabilisation product to be used. For example, mechanical stabilisation techniques can generally be used in any condition, whereas lime stabilisation is generally best suited to hot, wet conditions, and bitumen is best suited to hot dry conditions. Cement may encounter difficulties in any extreme conditions.
- Maintenance regimes. If regular grading and surface reshaping is part of the maintenance regime then modification stabilisation techniques will be required.
- Overall cost. Some stabilisation techniques and products can be expensive. Gains from the stabilisation need to outweigh the cost.

Stabilisation Method	General Range of Additive (% of Total Mass)	Soil Type				
		Sands	Sandy Gravels	Sand - Clays	Silty Soils	Heavy Clays
Mechanical	10 - 50	Variable	Good	Good	Fair	Difficult
Cement	1 - 6	Variable	Variable	Good	Fair	Difficult
Lime	2 - 4	Poor	Poor	Good	Good	Fair
Bitumen	1 - 10	Fair to Good	Good	Good	Fair	Difficult
Emulsions	4 - 10	Fair to Good	Good	Fair to Good	Fair	Difficult
Chemical Geotextile	See text for comment on these methods of stabilisation					
Notes: 1. The range of additive to be used is a guide only 2. Lime contents are expressed as equivalent 100% pure hydrated lime 3. Advice on the correct amount of additive to use should be sought following a thorough analysis of materials and conditions for use						

Source: ARRB 1993: Unsealed Roads Manual

Table 28 - Results of treating various soil types with common methods of stabilisation

9.2 STABILISATION BENEFITS

Stabilisation can be defined as the treatment of materials to improve and maintain the engineering properties of soils.

Stabilisation can provide major recognised benefits for forestry roading of all sizes and significantly offers an acceptable, cost effective, environmental alternative to conventional designs that rapidly diminish resources of premium products.

The properties that are usually altered by stabilisation include:

- **Strength** Strength increases occur with increasing binder content for any given aggregate or soil

For modified soils and aggregates the shear and bearing strength increases with binder contents with little to no increase in tensile strength. With cemented soils and aggregates a further increase in shear and bearing strength occurs, with development of significant tensile strength and increases in stiffness.
- **Stiffness** Bitumen will retain flexibility in materials while achieving long term strengths
- **Volume Stability** Lime reduces plasticity by increasing the plastic limit and decreasing the liquid limit all of which improve the engineering properties and the sensitivity to changes in moisture content.
- **Plasticity** KOBM binder and Durabind™ reduces plasticity and neutralises clay swelling minerals within an aggregate which improve the engineering properties

Even small amounts of binder can greatly reduce moisture-induced swelling and shrinkage

- **Durability**
The chemical reaction products of binders with soil and water are semi-permanent in that they are not reversed by the presence of water. However, external influences such as traffic loadings, wetting/drying and frost can cause physical damage to the stabilised material if design, construction or maintenance is inadequate.
- **Workability & Permeability**
Decreased permeability thus giving more protection to subgrade. If a material has too high a permeability, softening of the pavement or subgrade may occur due to water penetration resulting in damage by traffic loading

Stabilised soils resist alternating wetting and drying or freezing and thawing to an increasing extent as the binder content is increased.
- **Water**
Prolonged exposure to water produces only slightly detrimental effects
- **Cracking**
In practical terms, cracking in pavements is not a problem with KOBM binder and cement or Durabind™ modified materials, given adequate pavement strength

For cemented materials (i.e. cement applications of 3%+) adequate design considerations need to be addressed to eliminate cracking potential.

Most stabilisation treatments will alter many or all of these properties at the same time and the correct use of stabilisation requires identification of the properties that require

altering, and the effect the stabilising process will be on these properties. Many types of stabilising additives are available, but the most common types are:

- Lime Oxide
- Bitumen
- KOBM binder
- Cement
- Durabind

Soils and aggregates have a wide range of properties. Consequently the reaction of a specific material with any particular stabiliser cannot be determined by simple observations, or by defining the soil type. Instead, some form of laboratory testing should be carried out to determine the response of the particular soil with the stabilising agent(s) being considered and consultation with industry specialists should be carried out.

9.2.1 Stabilisation of Pavement Layers

Terminology for the pavement layers is shown in figure 74. The pavement layers, with the benefits to each from stabilisation, are described below.

Subgrade:

When a relatively weak subgrade is stabilised insitu by lime, cement, KOBM Binder™ or Durabind™ to a designed depth, it replaces that thickness with a material with much greater strength. This offers the following benefits:

- Reduces the thickness of granular cover required over the subgrade with significant cost savings.
- Provides a working platform to allow access for construction.
- Creates a solid foundation on which pavement layers can achieve subsequent higher compaction density results.

- Reduces or eliminates intrusion of the subgrade material into the subbasecourse and basecourse.
- Provides a relatively moisture-tolerant support for the pavement.
- Construction activities are more expedient and simplified than alternative methods i.e. digout replacement methods.

These benefits can result in cost and construction time advantages. The cost advantages are likely to extend to future maintenance and rehabilitation cost savings.

Sub-base course:

Stabilisation of the sub-basecourse, using either imported or insitu materials, can offer these benefits:

- Provide a working platform over a weak subgrade.
- Reduce the required thickness of the base layer.
- Reduce or eliminate intrusion of subgrade material into the base.
- Provide a relatively moisture-tolerant pavement layer.
- Enable the use of a “marginal” aggregate as a premium aggregate at a relatively lower cost.

Basecourse:

Stabilisation of the basecourse layer can offer these benefits:

- Compensate for deficiencies in the basecourse aggregate.
- Reduce the sensitivity of the basecourse aggregate.
- Increase tolerance of the basecourse to heavy axle loads.
- Increase the life of the wearing surface by reducing pavement deflection.
- Enable the use of a “marginal” aggregate as a premium aggregate at a relatively lower cost.

Running course:

Generally cement, lime, KOBM Binder™ or Durabind™ and bituminous stabilisation will not provide a surface that is sufficiently resistant to traffic for their use as a permanent wearing course on sealed roads.

For unsealed roads, stabilised bases or wearing courses are usually significantly more wear-resistant than unbound aggregate but they will still require maintenance.

This maintenance frequency however will be significantly reduced in comparison to a conventional unbound aggregate option.

9.3 PRELIMINARY ASSESSMENT OF THE TYPE OF STABILISATION REQUIRED

To gain a preliminary assessment of the type of stabilisation required for a particular pavement material, particle size distribution and Atterberg limits are commonly used.

The usual range of suitability of various types of stabilisation is based on the percentage of material passing the 75µm sieve. This provides a guide for more detailed studies with particular materials and particular stabilising binders.

Adequate targeted testing needs to be undertaken to result in the most appropriate stabilisation option. A tool available is the CBR quick test which will give an indication of reactivity, and effectiveness of the stabilisation option, within a very short time allowing quick on site assessment of options.

The applicability of the different types of stabilisation to a range of sizes of soil particles is indicated in table 29 & 30 (Ingles & Metcalf 1972).

Volcanic soils:

The difference between most volcanic soils compared with other soils is the rate at which reaction occurs. Any improvement which is to be gained by mixing lime with

volcanic soils is gained within hours of mixing, consequently any pre-treatment or conditioning is undesirable.

Overwet soils:

Excessive water can be removed from soils too wet for treatment in the normal manner, using quicklime in the powder form. When the excess water has been removed so that the water content of the treated material is within 3% of its optimum water content, stabilisation is carried out in the normal way to produce the desired strength in the layer being upgraded.

	CLAY	SILT			SAND			GRAVEL		
		F	M	C	F	M	C	F	M	C
	0.002	0.006	0.02	0.06	0.2	0.6	2	6	20	60
LIME										
LIME & CEMENT										
KOBM BINDER™										
KOBM BINDER™ & CEMENT										
DURABIND™										
CEMENT										
BITUMIN										

Source: Ingles & Metcalf 1972

Table 29 - Applicability of stabilisation methods based on soil particle size

TYPE OF STABILISATION	PROCESS	EFFECTS	APPLICABLE SOIL TYPES
LIME	<p>Chemical alteration of clay minerals.</p> <p>Cementitious inter-particle bonds developed.</p>	<p>Improves handling properties of cohesive material. Reduced plasticity.</p> <p>Low additive contents: - Decreases susceptibility to moisture changes. - Improves strength.</p> <p>High additive contents: - Increases modulus and tensile strength.</p>	<p>Suitable for cohesive soils. Requires clay components in soil that will react with lime.</p> <p>Organic material will retard or prevent effective reactions.</p> <p>Sulphates can cause swelling.</p>
CEMENT	Cementitious inter-particle bonds are developed.	<p>Low additive contents: - decreases susceptibility to moisture changes - Increases strength.</p> <p>High additive contents: - Increases stiffness and tensile strength significantly.</p>	<p>Not limited – some deleterious components (organic, sulphate etc) can retard or prevent effective cement reactions.</p> <p>Suitable for granular soils but inefficient in mainly one sized materials.</p>
KOBM BINDER™ & DURABIND™	<p>Modifies particle size distribution and develops cementitious inter-particle bonds</p> <p>Chemical alteration of clay minerals to hydration products</p>	<p>Increases Strength</p> <p>Reduced plasticity.</p> <p>- Increases modulus and tensile strength.</p>	<p>As for cement stabilisation – can be used when soils are not reactive to lime.</p> <p>Suitable to alter marginal aggregates to equivalent premium grade Organic material will retard or prevent effective reactions.</p>
BITUMEN	Agglomeration of fine particles	Waterproof – also improves inter-particle cohesive strength.	Applicable to granular low cohesion, low plasticity materials.

Table 30 - Application of stabilisation (after NAASRA 1986)

9.4 MODIFICATION OF MATERIAL PROPERTIES

Modes of stabilisation:

UNBOUND MATERIALS – materials such as natural gravels, crushed rock and fine grained soils which do not exhibit significant tensile strength and resist traffic loading through a combination of cohesion and internal friction between particles.

MODIFIED MATERIALS – Unbound materials to which small amounts of stabilising binder have been added, usually to either:

Correct a material deficiency (e.g. to reduce plasticity), without causing a significant increase in structural stiffness; Increase the strength, and/or reduce the moisture susceptibility of fine grained soils to form a working platform or lower sub-basecourse layer.

At low binder application rates, the cementitious bonds are likely to be weak relative to applied traffic and thermal stresses and may be discontinuous.

The modified material is likely to have:

- No significant tensile strength
- Decreased permeability, although permeability may increase in clayey soils.

Modified materials are usually considered to behave structurally as unbound granular materials. However, some modified materials gain sufficient strength with time to be considered as bound materials and should therefore be assessed as bound materials for long-term performance considerations.

KOBMbinder™ or DURABIND modification process: KOBM (Kontinuous Oxygen Blast Maxiite) binder is a by product from the steel making process at Glenbrook Steel Mill. Lime is added to the smelt to remove impurities from the steel products some of which is retained in the resulting KOBM binder.

The molten slag leaves the furnace in large crucibles which are tipped into a bunded area, quenched liberally with water and allowed to weather.

The composition of ready to use KOBM binder is:

Ca(OH) ₂	calcium hydroxide or free lime
C ₂ F (substituted)	dicalcium ferrite
Glassy material	

A reaction occurs between the hydrated lime in the slag and the clay minerals in roading aggregates and is complemented by complex reactions with a substituted dicalcium ferrite in KOBM binder. Chemical initiators, such as cement for KOBM binder, or other initiators contained in the purpose designed Durabind blend, are required for the reaction to occur within a sensible timeframe and to increase the hydration products generated.

BOUND MATERIALS - are produced by the addition of stabilising binders (usually cementitious in nature) to granular materials in sufficient quantities to produce a bound material with significant tensile strength. The bound material acts like a 'beam' in the pavement to resist traffic loading and has considerably increased structural capacity compared with unbound granular and modified materials, but shrinkage cracking needs to be controlled in pavement base layers.

It greatly reduces the moisture susceptibility of some soils, giving enhanced volume and strength stability under variable moisture conditions.

It can cause the development of inter-particle bonds in granular materials, endowing the stabilised material with tensile strength and high elastic modulus.

Volume and Moisture Stability

Small additions of cementitious binders have large effects on the volume stability of expansive materials without necessarily leading to significant strength gains.

Cementitious binders, by binding the particles, will greatly reduce moisture induced shrinkage as well.

Therefore, while the plastic properties are widely used to classify the volume stability of pavement materials, they are not appropriate for cementitously-bound materials.

Water Quality

Water for cement stabilisation should be potable, free from organic material and contain less than 0.05% sulphates.

Where possible, the actual water source to be used in the field should be used for the laboratory testing programme.

The water source for curing cement-stabilised materials should also be assessed. Care should be taken when using saline waters for curing as they can cause a build up of surface salts which can interfere with the adhesion of future seal coats.

9.5 STABILISATION TECHNIQUES

9.5.1 Lime

Lime can be applied to soils in either the subgrade, subbase or basecourse layers. Which layers to treat is an engineering decision of some importance. The term "lime" is commonly used to describe a number of products including quick or burnt lime, and hydrated or slaked lime. Quick lime and slaked lime are the only types of lime which can be used for stabilising soils or aggregates for road pavement construction. Slacked lime is quick lime which has been hydrated, left to set, and then crushed into a workable powder.

Many clay soils (though not all) are improved by stabilising them with lime. Improvements include:

- Soil strength is usually increased

- Shrinkage and swell actions are reduced
- Water content of the natural soil is reduced, (quicklime requires water to react)
- Clay becomes more friable and easier to work
- Clay becomes slightly more porous, allowing better drainage

Lime stabilisation improves the durability and smoothness of unsealed roads. It can also help reduce dust problems. For forest roads, a stabilisation depth of 150 mm would be appropriate. Additional information on lime stabilisation is available in Transit NZ publication TR2 *Lime Stabilisation for NZ Roads* by R.J. Dunlop.

Lime stabilisation is still an expensive treatment for forest roads. However, although the initial costs are high (approximately \$4.50/m² for 150 mm thick stabilised layer), the overall cost of the stabilisation should be weighed against the benefits of lower road maintenance and vehicle operating costs, and a possible reduction in the amount of aggregate required. Mechanical properties of lime stabilised materials increases with curing time.

For each material type there is an optimum quantity of lime content beyond which the addition of further quantities will provide little or no additional benefit. The correct amount of lime to be used (percent by mass) depends on the amount and type of clay mineral predominating in the material. Small quantities of lime (1 to 3%) may reduce the plasticity index, and be sufficient to stabilise some materials such as clayey gravel which have good grading but moderately high plasticity.

Materials: Lime reacts with most plastic materials. However, testing is necessary to determine the reactivity of the material to lime. It has been found that some poorly graded clayey sand and gravels, when treated with small percentages of lime, can become friable and even completely non-cohesive leading to failures.

Procedure: Construction of a lime-stabilised material is essentially very simple:

1. spread lime onto the material
2. mix and add water to improve compacability
3. compact the material to seal the surface
4. leave to completely cure before either allowing traffic to pass over the material or the placement of pavement material

General Observations:

- Lime treatment is not a single one-way process
- Subgrade stabilisation with lime is not recommended where heaving occurs due to freeze-thaw action
- Organic soils, or soils containing significant percentages of organic material, do not react to lime
- Trial sections of road are usually the best way of determining the performance of a stabilised road pavement
- Adequate drainage must be supplied during and after stabilisation
- Shaping of the surface should be undertaken to encourage drainage and provide a tight surface finish
- Sufficient time must be allowed after stabilisation before trafficking the road

9.5.2 Portland Cement

Cement does have an effect on clay soil but in most cases the improvement is not as great as for lime. However, cement can be most suitably used to upgrade poor quality rock, gravel or sand.

Technical and construction details are contained in Transit NZ publication *Cement Stabilisation for NZ Roads* by J.B. Tait.

Generally, if cement stabilisation is being considered, then professional engineering advice should be sought before proceeding, since the amount of cement applied and the use of correct application techniques are critical for success.

Cement blends with lime, slag or bitumen are commonly used to make the process more workable (i.e. less susceptible to delay in compaction, less likely to crack over time), and to reduce the cost of using large quantities of cement. Fly ash mixtures can reduce the Optimum Moisture Content for compaction. Lime and cement mixes can be used to stabilise clay-based, or high clay content gravels.

What Does Cement Do?

Cementation is the formation of cementitious hydrates which increases the cohesion between soil particles. The mechanical properties of cement-stabilised materials improves both with cement content (up to a point), and with time. The effect of Portland cement on granular material is to "glue" the particles together to form a stronger mass. The cement effectively reduces the material's susceptibility to moisture, thereby reducing shrinkage and swelling. A typical quantity for the treatment of gravel pavement is 1 to 3% by weight. Additional cement can be detrimental, leading to cracking of the surface layer which allows water to enter the pavement.

Use Of Cement On Forest Roads

In many forest areas there is a lack of good quarry aggregate for road maintenance and pavement construction. In most cases the local aggregate can be upgraded by adding a small amount of cement. With cement there is only a limited time in which to work before setting of the cement takes place - normally there is no second chance in the event of a sudden change in the weather. Mixing of the cement and aggregate should be completed before water is applied.

Cement Stabilisation

Cement stabilisation procedures are not commonly used for unsealed road pavement designs. Cement is generally not an appropriate form of stabilisation due to the bonds formed between particles being very weak and unable to resist traffic action. Using cement stabilisation for the running/wearing course restricts the maintenance practices because reshaping etc breaks the cemented bonds. Cement stabilisation is however, suited to sub-base stabilisation.

Procedure: Unlike lime stabilisation, cement cannot be reworked following initial mixing. After the addition of moisture, adequate compaction must take place to ensure that the material is compacted and shaped before the cement sets.

9.5.3 Bitumen

Bitumen stabilisation is effective on granular materials, and on sandy soils which have low cohesion and low plasticity. These stabilising agents act as cohesion agents in granular soils, and as waterproofing agents in clayey soils. This is a relatively short-term pavement improvement solution involving the spraying of emulsion (a mixture of bitumen and water) on the loose aggregates. The process involves the use of a power grader for scarifying and mixing the aggregate. A water tanker with or without pressure spray is used to apply the emulsion and then the materials are mixed, laid out, shaped and compacted. The treatment will improve the stability of the basecourse as well as reducing dust. Depths of from 0 to 150 mm can be treated.

Applications of thin films of bitumen produce a stronger material, and thicker films create a weaker, less permeable material.

Applying emulsion to an existing pavement is a simple and cost effective operation, however, it will need to be repeated at intervals of approximately 6 months.

Bituminous Stabilisation

Bitumen stabilisation is essentially limited to stabilisation of the wearing/running courses of unsealed pavements. The bitumen binder provides cohesion for non-plastic materials and acts to waterproof the pavement. Bitumen stabilisation is generally best suited to granular materials such as gravels, sandy loam, sand-clays and crushed rock.

Procedure: Construction practices are generally similar to other stabilisation products, except that compaction is generally delayed to allow the mix to aerate, and excess water to evaporate.

9.5.4 Other Chemical Products

There are various other products on the market which claim to be effective in reducing dust and stabilising pavements.

Chemical Stabilisation

Chemicals are used for chemical stabilisation including:

- *Calcium Chloride* - a salt chemical which acts to bind the material and form a hard surface. Good mixing of the chemical with the material provides for a good effect, and two separate light applications at different times provides a better service than one single application.
- *Sodium Chloride* - has a similar action to calcium chloride.
- *Magnesium Chloride* - Not often used in New Zealand.

Some chemical stabilisation compounds provide not only a binding action to form a hard surface but also some limited dust suppressant action. However, chemical stabilisation can have detrimental effects, including:

- chemical leaching into waterways

- causing (or worsening) rusting in vehicles
- low life expectancy

Enzymes - are a natural biological product, which are becoming increasingly common for use as the basis of a variety of stabilisation and dust suppressant products. The mechanism by which enzymes stabilise a material is a very complex molecular process. Essentially, when the enzymes of a soil stabiliser are mixed with water and applied to the soil, they can act by breaking down the clay lattice (i.e. breakdown of clods) or combining clay particles with organic molecules.

Enzyme stabilisers are especially designed to stabilise clay-based materials.

9.5.5 Mechanical Stabilisation

For the satisfactory performance of an unsealed pavement, the correct material properties and grading are required, (see chapter 8). Essentially, the addition of sands, clays etc. modifies the particle size distribution (grading), plasticity, strength or shrinkage characteristics. The required result can be achieved by either importing quality material which has the necessary qualities, or modifying the existing or available material to improve its quality. Mechanical stabilisation involves the mixing of two or more selected materials to modify the particle size distribution or plasticity. Mixing can be carried out onsite or at a quarry or pit prior to transportation. An alternative is to use rock crushers or grid rollers onsite to crush existing material.

Static or portable vibrating screens can be used to separate material into appropriate sizes (and gradings) prior to delivery and mixing. Laboratory tests of both the material to be treated and the stabilising material is necessary to ensure that the desired end result will be achieved.

An example of mechanical stabilisation is the blending of a granular material lacking in fines with a sand/clay mix. The finished material will have improved strength, abrasive resistance, imperviousness, and compactibility.

9.6 STABILISATION EQUIPMENT

A variety of machinery and equipment can be used for stabilisation products and procedures. Various purpose-built machines have been designed to mix the material and add the stabiliser at the same time, generally giving uniformity of mixing. However, in most forestry situations, the addition and mixing of stabilisation is usually completed using graders, rotary hoes, water tankers and spreaders.

The choice of machinery used for a project is determined by a number of factors, including:

- Source of material to be stabilised - insitu or imported
- Size of the project
- Type of material to be stabilised
- Availability of machinery
- Availability of trained personnel
- Type of stabiliser to be used

9.7 COMPACTION

All "virgin" natural soil, as well as loose soil, contains many air-filled spaces. These spaces lead to shrinkage when pressure is applied. To be able to use any soil as the base of a road, it must be stabilised to improve it to a standard which allows it to carry traffic even under unfavourable conditions of wetting and drying. One method of stabilisation is to compact the material to form a hard base.

9.7.1 Natural Consolidation

Consolidation of soil will occur naturally, over a long period of time, as a result of:

- The action of gravity
- Varying weather conditions (e.g. shrinkage due to moisture reduction or decomposition)

Natural consolidation is not the preferred method of compaction of forestry roads.

9.7.2 Compaction or Controlled Densification

Compaction consists of reducing the apparent volume of the soil by mechanical action. Compaction reduces the void's increasing the soils density, and therefore its bearing strength. The goal is to re-arrange the particles in such a way as to give the greatest density. This also leads to less water absorption.

9.7.3 Optimum Moisture Content

A small amount of water in the soil acts as a lubricant, and helps to re-arrange the soil particles in relation to each other, aiding in the expulsion of air voids from between the particles. Excess water will prohibit effective compaction. There is a moisture content level at which maximum compaction for a given amount of effort is readily obtained this is known as the Optimum Moisture Content (OMC). Optimum Moisture Content varies between soil types. In the field, the water content of soil is likely to vary considerably, and adding or removing water to achieve OMC may be necessary. OMC tests can be completed in the laboratory using soil samples. However, for most forestry roads this is too expensive, too time consuming, and requires reasonable technical knowledge. Prior knowledge by the roading engineer, and a few on-site field tests is the most commonly used alternative. These field tests include:

- Firmly squeezing handful of soil. If the finger imprints can be seen in the soil without any water oozing through the fingers, then the soil is likely to be near its optimum moisture content.
- Rolling the earth into a ball. The ball should be smooth when it is rolled once or twice in the hand.
- Rolling a piece of clay into a thread. When the clay starts to crumble on reaching a diameter of 6mm or slightly less, then the clay is near the correct water content for compaction. This test can also be used for silt-clay mixture soils.
- Visual inspection. Silt should look dry and a light colour before compaction. If the silt darkens after the first roller pass, then the moisture content is probably too high.

Compaction is usually achieved using a vibrating or non-vibrating steel drum roller, a pneumatic-tyred roller, or a grid or cleated roller. They all have their own applications, section 9.3.4 describes compaction equipment in detail. A large steel drum vibratory roller is often considered the best for general purpose use.

Prior to the compaction process, the layers should be checked to ensure that the moisture content is uniform, and that there are no patches of segregated material. Equipment should also be checked for ballasting of rollers and pneumatic tyre pressures.

Compaction will improve the soil properties without admixtures by removing air voids, increasing the soil's durability and resilience, and decreasing its compressibility, permeability and expansion.

9.7.4 Compaction Equipment

There is a wide variety of compaction equipment available, following are descriptions of various compaction equipment and the situations that each is best suited for.

Power Rammer

These are small compacters, usually operated by hand and hence with a relatively low output in terms of volume of compacted soil/hour. Generally these compacters are used for compacting material which has been backfilled into excavations in confined spaces, such as in trenches, around culverts etc. Compaction of material using a power rammer should be completed in layers - for granular soils, layers should not be more than 230mm thick, whereas for cohesive soils, layers should be no more than 200 mm thick. Power rammers have a vertical movement ranging from 12mm to 150mm at frequencies of 20 to 200 blows per minute.

Vibrating Plate Compacters

These compacters are available in weights ranging from 50 to 150 kg, and have an operating frequency of 400 to 10,000 vibrations per minute, with low amplitude. Vibrating plate compacters are used to compact layers of 75mm to 110mm compacted thickness of most materials, and are ideal for small areas (up to 20m²) requiring 4 to 6 passes for optimum compaction.

Single Drum Vibratory Rollers

These compacters are hand operated, and are ideal for granular materials with compacted layer depths of up to 120mm with 4 to 6 passes. They operate in the high frequency, low amplitude mode.

Powered Deadweight (Static) Rollers

Powered deadweight rollers compact material by pressure only. Loose layer thickness of 100 to 150mm of material are compacted at any one time, and a large number of passes are generally required to obtain full-depth compaction. These rollers compact from the top down - only the first 50mm of material is usually compacted by the first four or five passes, and a further 20 or 30 passes may be necessary to complete compaction. One major disadvantage in the use of these rollers is the breakdown of the upper compacted material which can produce excessive fine material, affecting the quality of the basecourse. Various types of rollers are available including tandem and three steel wheeled 8 to 12 tonne rollers, sheepfoot and grid rollers which are used for bulk material compaction.

- Smooth-wheeled rollers

Used for the compaction of crushed rock, gravels, sands and other granular materials, in general they are not best suited to silts or clays. The performance of smooth-wheeled rollers depends on the mass of the roller, and the width and diameter of the

rolls. The compaction depth of the layer for satisfactory results depends on the mass of the roller, but can be up to 450mm for embankments, and 150mm for subgrades.

- Multi-tyred Pneumatic-tyred rollers

These rollers are usually self-propelled, with smooth tyres on two axles in an odd-even number arrangement so that the wheels on one axle track in the gaps between the wheels on the other axle. The mass of the roller can be increased by attaching ballast, and the tyre pressure is sometimes variable. Fine soils with little or no cohesion (e.g. silts, sandy silts, well-graded sands, and clay soils) compact well using these rollers. The layer thicknesses should not exceed 230mm when compacted, and the performance of the roller is a function of tyre pressure, tyre contact area, and weight.

- Heavy Pneumatic-tyred rollers

These rollers have four equally-spaced independently suspended tyres, and can be loaded up to a total mass of 50 tonne on the axle. They are towed, and are suitable for similar soils to the multi-tyred pneumatic-tyred rollers, as well as for gravels and finer silts. The difference between these and multi-tyred pneumatic-tyred rollers is that the Heavy Pneumatic-tyred rollers can compact deeper layers, and the surface density is greater.

- Sheep-foot rollers

The sheep-foot name comes from the tapered prong feet on the steel drum. These rollers can be either towed or self-propelled, and their mass can usually be increased by filling the drum with water, or with sand and water. Performance is best on cohesive soils at, or dry of, OMC. During use these rollers can be observed “walking” out of the fill as compaction occurs.

- Tamping-foot rollers

Similar to sheep-foot rollers however, the feet are wider, shorter and closer than sheep-foot feet, they are also often diamond-shaped. They can be self propelled or towed, and will compact a wider range of soils than sheep-foot rollers, including silts, and rock fragments, but not uniform sands.

- Grid rollers

The rolls on grid rollers are manufactured from a mesh of usually 20mm diameter bars spaced 100 to 150 mm in both direction. Alternatively they may be smooth drums with a pattern of square holes formed in the surface. They are particularly useful for scoria-type fill (random mixtures of large and small particles, usually angular and fairly soft). Their particular use is in breaking down oversized stones, and forcing them below the compacted surface.

Vibratory Compactors

These rollers have a rotating eccentric weight to produce a vertical acceleration which helps to compact the material. The force applied to the soil is proportional to the acceleration in the vertical direction, and therefore they have a better performance than the static rollers. Vibrating rollers are suitable for compacting non-cohesive soils, compacting from the base up towards the surface, which always leaves a layer of looser material at the surface. This is caused by the bouncing effect among the particles of that layer as the vibratory effect is transferred downwards. This can be easily overcome by using a compactor with medium to low weight and low amplitude, or by turning off the vibration.

The primary characteristics of vibratory compactors are the weight of the vibrating component (drum or plate), the weight applied through the component to the ground, and the frequency and normal amplitude of the vibration. Heavier weight rollers with high amplitude and relatively low frequency (200 - 1800 vibrations per minute) can compact very thick lifts (up to 1.5 meters) in some granular materials, and up to 300

mm in clay materials. With less weight, lower amplitudes and generally higher frequencies, a reduced layer thickness can be compacted. Frequency is not generally critical except that the higher it is, the fewer passes are required, or, the faster the compactor can travel to obtain optimum compaction per pass.

When using a vibratory compactor, a pattern must be adhered to, to avoid gaps in the pass coverage. It is also important not to over compact the material. When the drum bounces on the hardened surface, a distinct 'ringing' noise can be heard. This can cause damage to the roller, and it will also reduce the density of the material. Thus for very thin layers (30mm), particularly of granular or sandy materials, two passes may be sufficient, and four passes may be too many.

Large Dual Vibrating Drum Rollers

Granular materials of up to 250mm can be successfully compacted in 4 to 10 passes with these rollers, providing they are correctly calibrated to obtain the most appropriate weight, frequency and amplitude. To complete the compaction it is generally necessary to operate the roller without vibration for 2 to 4 passes to consolidate the surface.

Earth Vibratory Compactors

These are generally of the large single vibratory drum type with large rubber driving wheels. They are used for difficult terrain and thick layers of earth. Some rollers of this type are fitted with rubber coated drums which have proved effective for the compaction of chips in chipseal construction.

9.7.5 Compaction Procedure

The following points should be noted to ensure the best possible results:

- Rolling should commence at the outer (lower) edge of the pavement and progress towards the centreline (or upper edge, if superelevated). Rolling with the passes progressing towards the lower edge will cause material to move downhill, resulting in loss of shape.
- A forward and reverse pass is made over the same section of pavement before moving to the adjacent section. It is important to check that this is done at the edges of the pavement. When changing direction, the roller should be on the previously compacted section.
- An overlap of up to 500mm over the previous pass to ensure complete coverage should be completed.
- A space of 200 to 300 mm should be left on the outside edge of the pavement if this is unsupported. Rolling of this section should take place later with a lighter roller.
- Vibrating rollers should have the vibrator turned off when the roller is stopped or turning.
- Rollers jolting during reversing can encourage surface roughness, as can sharp turns or changes in direction, and therefore this should be avoided.
- Static drum rollers should have the drive wheels leading on the initial pass to avoid pushing material ahead of the drum.
- Good compaction can be achieved with a vibrating roller by using a sequence of: a non-vibrating pass, followed by several high amplitude passes, and finishing with low amplitude passes.

HEAVY CLAY		CLAYEY SAND	CLAYEY GRAVEL	PAVING GRAVEL	SILTY SAND	ROCK & SAND
SHEEPFOOT						
	WEDGE FOOT					
			STEEL CYLINDER			
			VIBRATING SMOOTH DRUM			
VIBRATING SHEEPFOOT						
			PNEUMATIC TYRED			
			GRID			

Figure 81 - Economic use of rollers

The range of material that can normally be compacted economically with each type of roller is shown in figure 81. In addition to their normal compaction applications, smooth drum-vibrating rollers and pneumatic-tyred rollers are used as finishing rollers for clay and clayey sand subgrades, as sheepfoot and tamping rollers do not produce a smooth surface. Also, a pneumatic-tyred roller may be used to seal off earthworks from rainwater.

9.8 GEOTEXTILES

Geotextiles are used to reduce the quantity of pavement material required by providing a separation layer between the pavement material and soft subgrade materials. They can act as a drainage filter, restricting water movements into the subgrade or pavement, as well as providing a separation layer preventing fines from sinking into soft subgrade material. Geogrids are able to provide additional strength, but their application requires specialised design skills.

9.8.1 Types Of Geotextiles

The main types of geotextiles are:

- **Woven**

Woven synthetic material made from a polymer (plastic) by weaving the yarns together. Usually made of polypropylene. Higher strength and stiffer than non-woven fabrics

- **Non-Woven**

Usually more expensive but much better than woven fabrics in some applications. Made by bonding together randomly orientated polymer fibres. Usually made from polyester. Used more extensively than woven fabrics. The predominant application is for roading.

- **Geogrids**

Manufactured by extruding a sheet of polymer, punching roughly rectangular holes in it, and stretching it. Quite stiff relative to woven and non-woven. Usually made of polypropylene.

With all geotextiles, the exposure time to sunlight should be as short as possible since many fabrics degrade under ultraviolet light.

9.8.2 Applications

In most forest roading applications, the geotextile will be serving one or more of these functions (figure 82):

- **Separation Layer**

Prevents the mixing of two different materials whose engineering properties would change should the mixing take place. For example a geotextile can be used between a weak subgrade and the basecourse to prevent the basecourse being contaminated by the subgrade.

- **Filtration**

Used to stop the migration of fine soil particles from aggregate material while under pressure from water movements. For example, a geotextile wrapped around coarse gravel which fills a trench excavated along the watertable, allows water to pass across the soil/fabric interface while retaining soil particles.

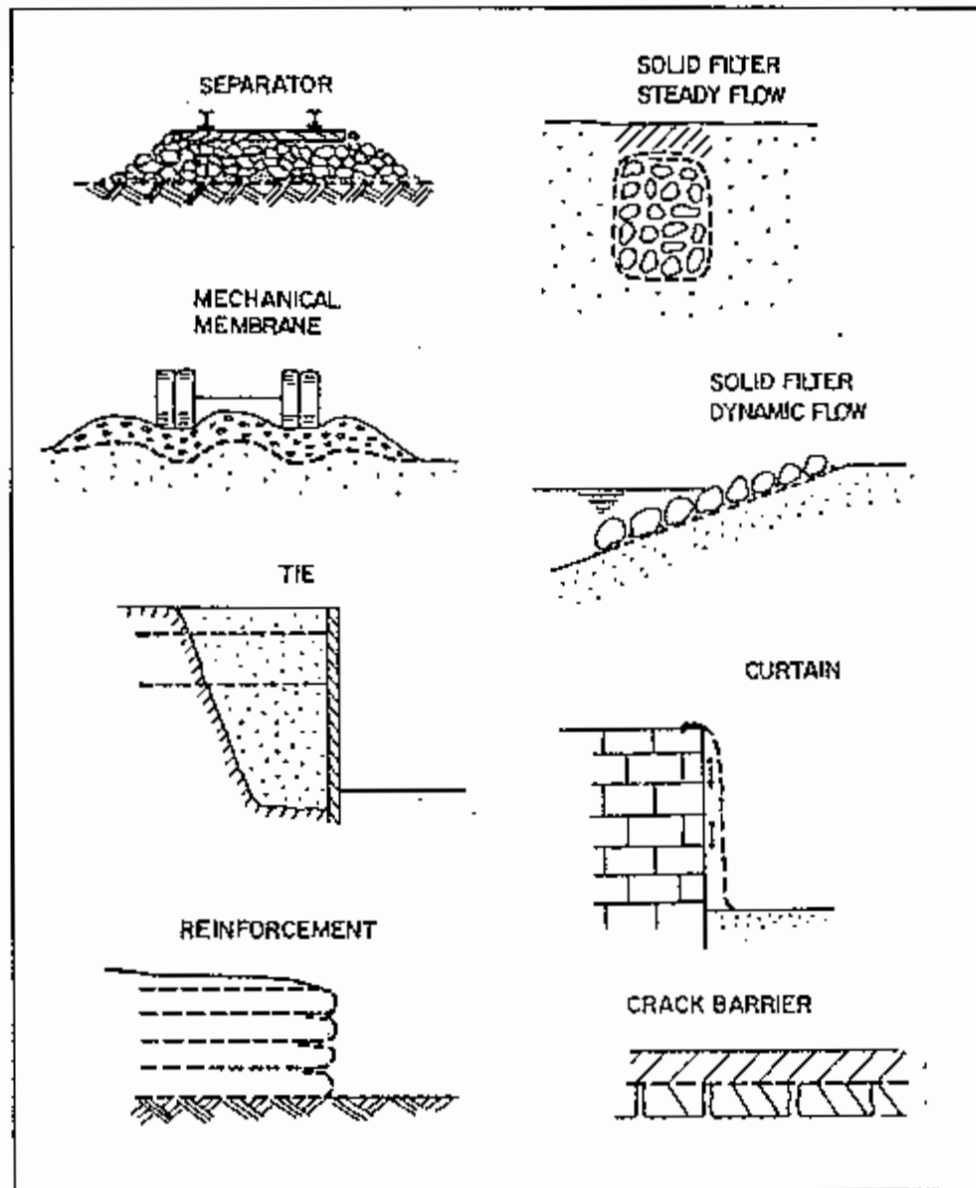
- **Drainage In The Plane Of The Fabric**

Some non-woven geotextiles are quite thick, and can pass water along their length as well as across their thickness. This improves drainage of excess water pressure in the soil.

- **Reinforcement**

The woven and geogrid geotextiles are used to impart extra strength and stiffness to a filling. An unstable slope can be reinforced in this way or tie back a retaining wall, but the most common example is to provide temporary roading at a construction site. By Laying suitable fabric over areas of soft soil before laying basecourse material, the area can be made to carry construction traffic with up to 40% reduction of crushed rock. In this application the fabric is performing a separation function as well as providing strength. Development of strength depends on deformation of the geotextile, and is generally only useful for temporary works requiring large

depths of base material. Geogrids, with careful design in the correct circumstances, can provide additional strengths.



Source: Douglas A. Roadnotes Vol. 2 No. 8

Figure 82 - Uses for Geotextiles

Guidelines For Geotextile Use In Forest Roding

Never use a geotextile when a cheaper, equally effective method is available. For example, a layer of readily available brush or other form of corduroy may solve a subgrade stabilisation problem more economically than a geotextile.

When used as a separation layer over a weak subgrade and under the basecourse, the geotextile performance depends heavily on its pore size relative to the grain size distribution of the soil represented by it will come into contact with, and also on the fraction of the geotextile's overall area represented by the holes. The most desirable properties for geotextiles for use in this situation should be, high modulus (high strength at low strains), and good resistance to creep, puncturing and tearing.

However, many case histories indicate that worthwhile benefits can be obtained using geotextiles with low modulus - the benefits presumably resulting mainly from separation alone, rather than from both separation and reinforcement.

If specific characteristics are ignored when selecting the geotextile, it is likely that the geotextile will fail. This can happen because:

- The geotextile pores may become clogged.
- Water may be trapped beneath the fabric, softening the subgrade.
- Fines may migrate up into the base material despite the presence of the geotextile.

A geotextile used in a thin road fill serves as a separator rather than a reinforcer. The need for adequate overlap and anchorage for the geotextile must be emphasised. Slippage will reduce or eliminate the reinforcing function - one manufacturer recommends overlaps of 0.5m to 1m, depending on soil conditions. The direction of the lap should be such that the aggregate being spread does not push the fabric apart. At least 300 mm aggregate cover is required over a geotextile to avoid problems with placement and operational performance.

In summary when used properly, geotextiles can save money, particularly when basecourse is expensive and soils are very soft, or when slumping of embankments or subsidence causes continual maintenance problems.

The use of geotextiles in both separation and fill reinforcement modes predominates on weak and wet soils. The benefits from its use in these situations is readily

apparent, and it is difficult to envisage the use of geotextiles in soils of any strength, except as a drainage layer. Soils need to be very weak to gain advantage for the use of geotextiles.

However, the wrong choice or application of geotextiles may result in construction failure. If in doubt, seek professional advice.

9.9 CORDUROY

Corduroy for forestry roads is a valuable stabilisation alternative to geotextiles, stabilisation chemicals and other products. Corduroy involves laying a mat of brush or logs on top of the subgrade. Aggregate is then positioned over the mat to produce a road or landing. The major advantage of using corduroy is that the corduroy mat acts to distribute the applied loads evenly to the subgrade material, thereby reducing the quantity of valuable aggregate material required for pavement construction.

Using corduroy for forestry road or landing construction:

- enables construction over very weak subgrades
- has the potential to reduce the quantity of expensive aggregate required
- allows the road to be used immediately after construction
- minimises exposed earth that could erode, (often built on top of existing vegetation)
- allows aggregate and corduroy to be recovered from roads that have been abandoned
- provides a separation layer and improves drainage

The corduroy acts as a structural and separation layer as well as a drainage layer, but it requires considerable machine and labour time, and often uses wood that could otherwise be sold. However, corduroy may be the only cost-effective option for constructing roads over very weak and wet subgrades.

9.9.1 How Does Corduroy Work?

Separation

A layer of brush, branches or logs between a weak subgrade and the quality aggregate serves to stop any intermixing of the two. This ensures that the load bearing functions of the basecourse are performed without contamination from the weaker subgrade. When aggregate comes into contact with the weak subgrade, it becomes slippery, which reduces the particle interlock (bearing capacity), and consequently the road may fail.

Reinforcement

The effect of corduroy laid across the subgrade is to spread the load. The load is redistributed over the whole length of the log (figure 83), effectively increasing the load bearing area. Reinforcement is greater with log corduroy than with brush corduroy since the logs act as a rigid platform.

Absorption of Shock

Movement and deformation in the corduroy absorb the shock impact from a loaded vehicle. By lowering the shock load transmitted to a road, the likelihood of cracking is reduced.

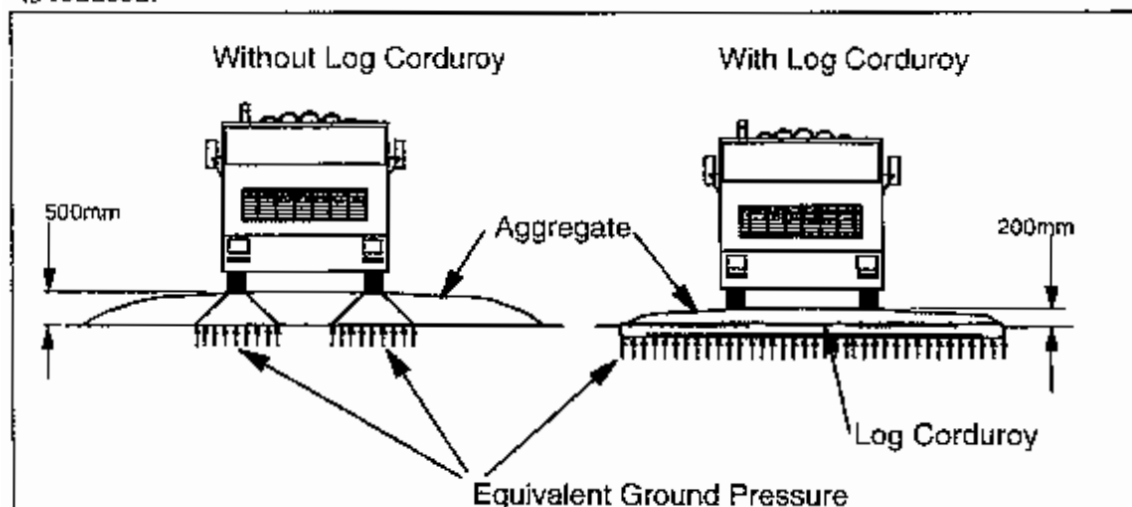


Figure 83 - Reinforcement using log corduroy

Improved Drainage

Brush corduroy can improve drainage by providing a permeable layer between the base-course and the subgrade. Water on the road surface percolates through the base-course, and then flows along the corduroy plane, as shown in figure 84.

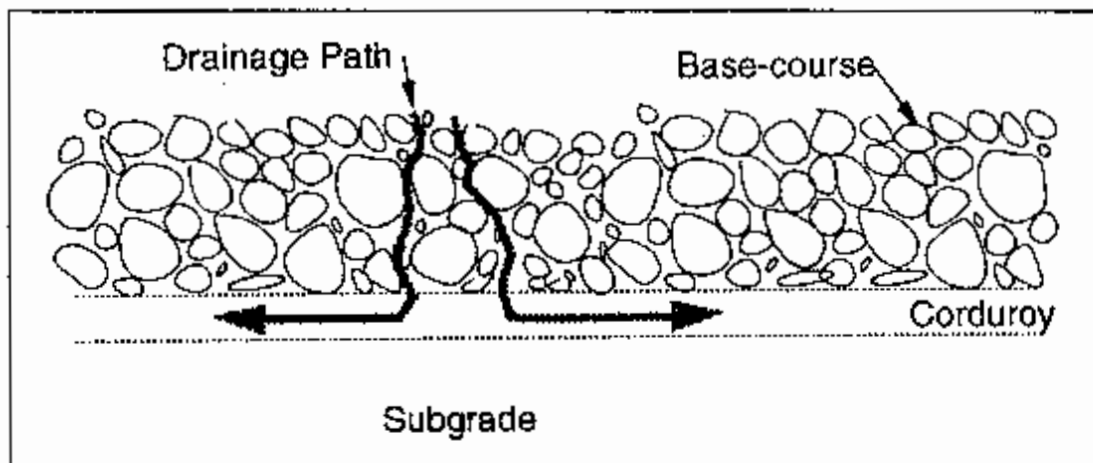


Figure 84 - Flow of water along corduroy plane

9.9.2 Corduroy Types

Brush Corduroy

Brush corduroy involves the spreading of brush (such as slash or undergrowth) on top of the subgrade to form a brush mat. Aggregate is then placed on top to form the road, as illustrated in figure 85. More aggregate material is required for the brush corduroy construction than for the log corduroy construction because the voids in the brush require fill material. Only minimal reinforcement is provided by the mat.

Log Corduroy

Pulp logs are placed side by side over the subgrade, at right angles to the direction of travel, to form the corduroy mat. Figure 86 shows the aggregate distributed over the logs. The logs provide significant structural reinforcement, reducing the depth of

aggregate required. Approximately 80m³ of saleable pulpwood is used per 100m of road, and therefore the cost of construction may rise beyond an acceptable level.

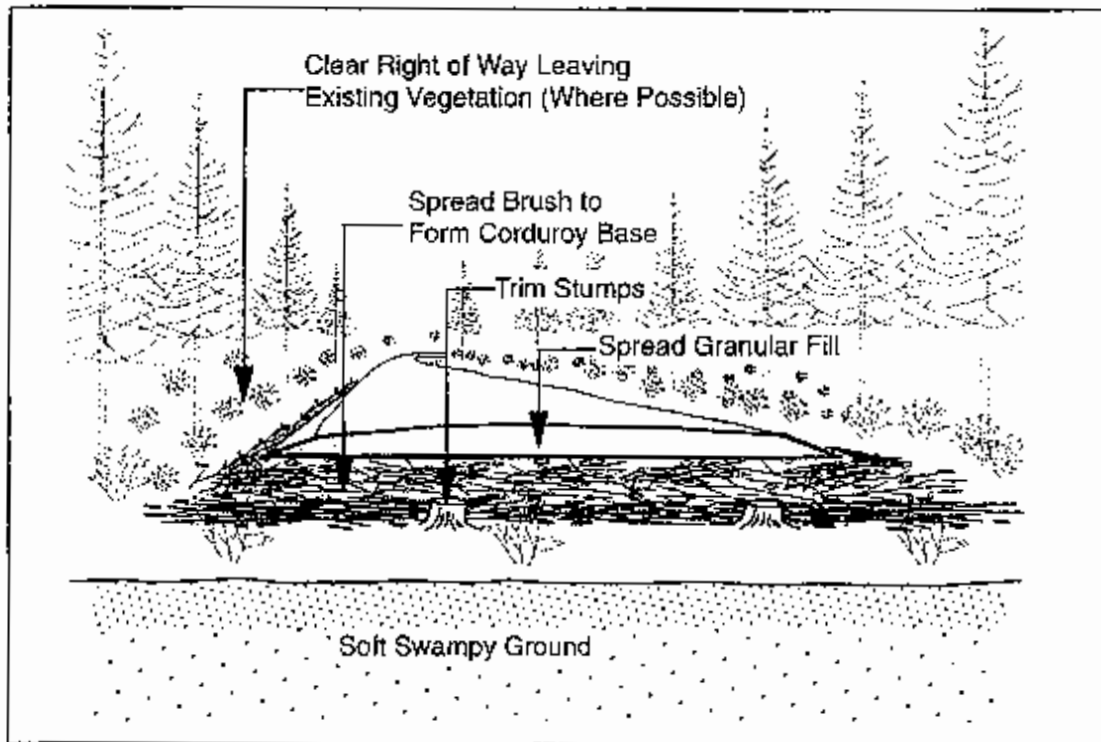


Figure 85 - Corduroy road construction using a brush mat

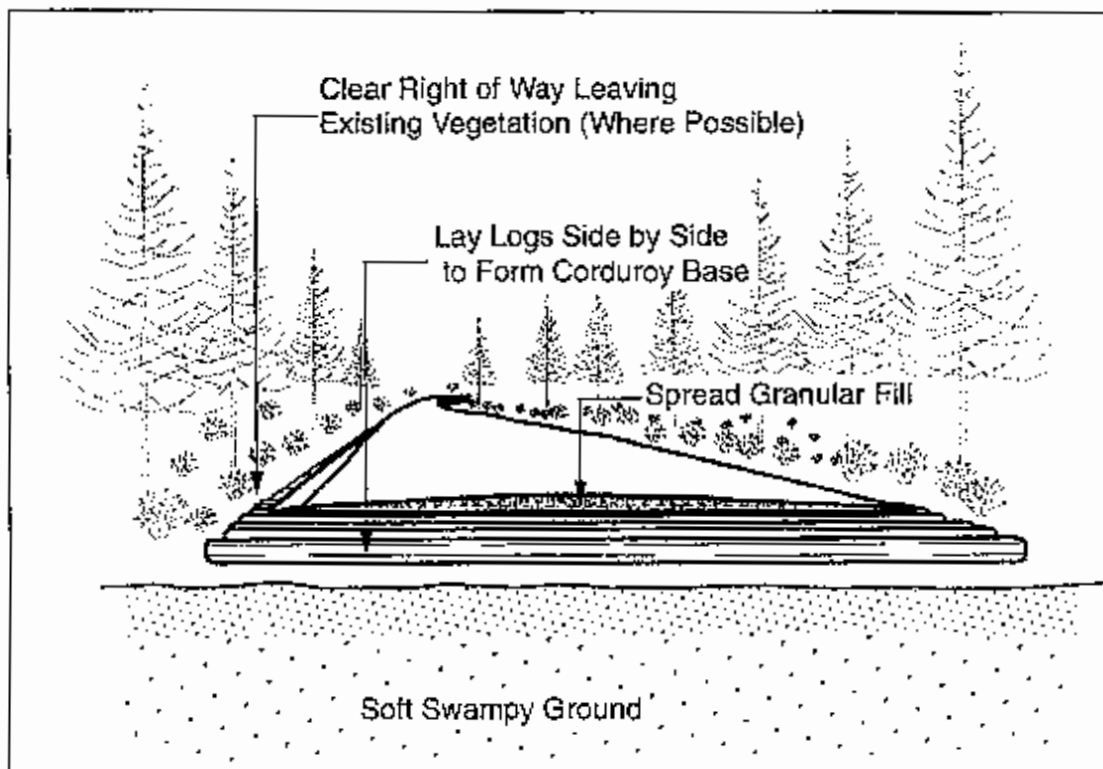


Figure 86 - Corduroy road construction using logs

Mill Slabs

Mill slabs are offcuts from a timber mill. These are placed side by side on top of the subgrade, at right angles to the direction of travel, in a similar fashion to log corduroy. Formation of the road is completed by spreading aggregate material over the slabs. The mill slabs provide some reinforcement, and usually only 200mm of aggregate is needed.

Polythene Pipes

Polythene pipes held together by wire rope (known as "Columbus Mats") are used as a structural layer between the subgrade and pavement aggregate (figure 87). They are strong, lightweight, flexible, easy to handle and reusable. Although their initial cost can be up to three that of log corduroy, the effective cost per use since low as they can be used many time

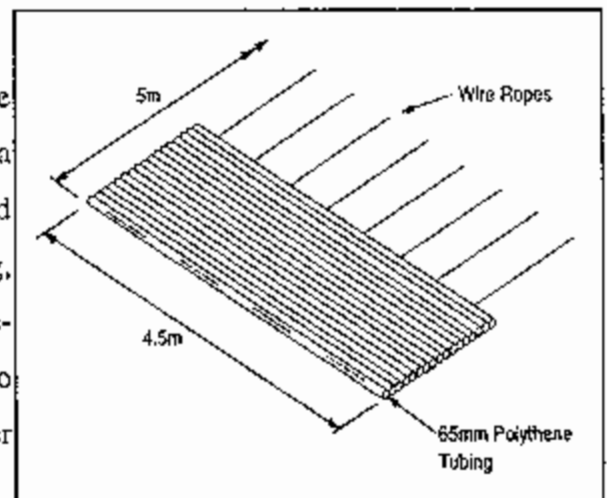


Figure 87 - Columbus mat

9.9.3 Design Of Log Corduroy Roads

As explained earlier, failure of road pavements over soft subgrades is generally caused by bearing failure of the subgrade material. There are two main types of bearing failures, and they both involve shear failure of the subgrade, as illustrated in figure 88.

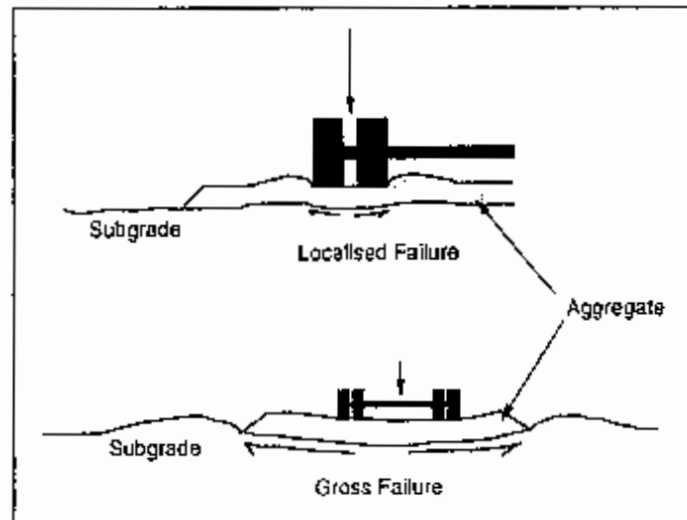


Figure 88 - Two types of subgrade shear failure

The localised failure is independent of fill weight, and dependent on wheel load and soil strength. Gross failure occurs when deep fills are used, and the combined weights of the fill and axle loads exceed the bearing capacity of the soil. This failure covers the full width of the road, and uplift of soil along the side of the road will be evident.

The design charts in figures 90 and 91 can be used to determine the quantity of fill required for both common aggregate fill and a lightweight pumice fill. The depth of fill with or without log corduroy can be estimated from the design charts (which are a guide only). The pavement depth is the minimum required to prevent bearing failure under a 8.2 tonne dual-tired axle. The methodology used is based on static loads, and does not consider the effect of multiple vehicle passes, therefore a factor of safety of 2 or greater is recommended. This accounts for dynamic loads - which can fluctuate by up to 50% above the static load - and variability in soil strength properties.

Note: For weak soils with a shear strength less than 15kPa, log corduroy or some other reinforcement technique such as geotextiles should be used. This is because the weak soil is unable to support the combined weight of the aggregate and the axle load.

Shear Strength

The shear strength of a soil can be easily measured in-situ using a “hand vane tester”.

The equipment consists of a stainless steel vane of four rectangular blades mounted on the end of a high tensile steel rod (figure 89).

To make a measurement, the vane is pushed into the soil, and the head is turned slowly until the soil shears. The maximum torque required for failure is read from the dial, and is converted to shear strength (c), using the formula:

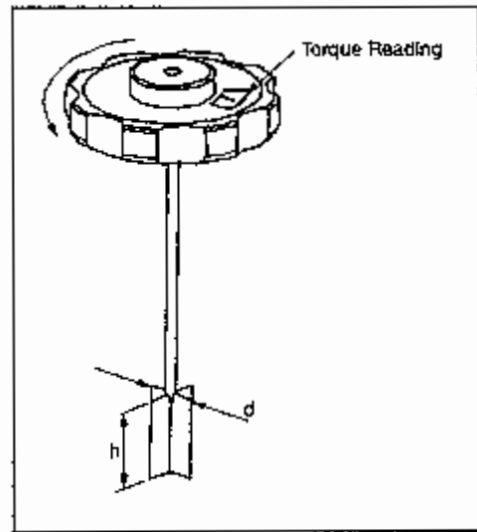


Figure 89 - Hand Vane Tester

$$c = \frac{T}{\pi(d^2h/2 + d^3/6)}$$

Where:

T = torque at failure

d = overall vane width, and

h = vane length.

Alternatively, simple field tests as detailed in table 31, can also be used to estimate the soil shear strength.

TERM	SHEAR STRENGTH (Kpa)	FIELD TEST
Very Soft	0 - 24 kPa	Squeezes between fingers when fist closed
Soft	24 - 48 kPa	Easily moulded by fingers
Firm	48 - 96 kPa	Moulded by strong pressure of fingers
Stiff	96 - 144 kPa	Dented by strong pressure of fingers
Very Stiff	144 - 192 kPa	Dented only slightly by finger pressure
Hard	> 192 kPa	Dented only slightly by pencil point

Table 31 - Field tests used to estimate the shear strength of a soil

Depth of Fill Required to Prevent Bearing Failure

To support a 8.2t dual tyred axle and overlying aggregate (density = 20 kN/m³)

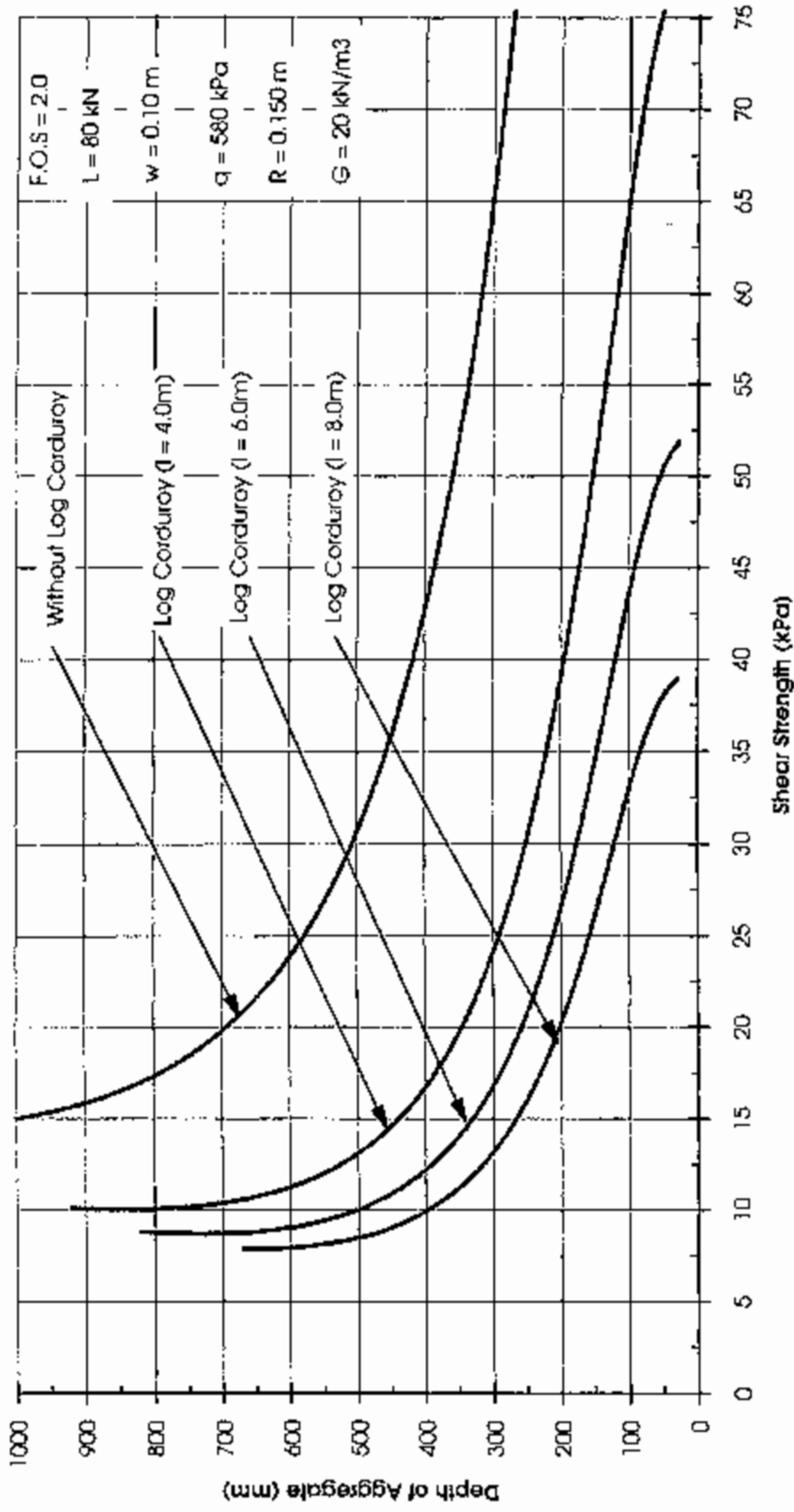


Figure 90 - Depth of aggregate fill required to prevent bearing failure

Depth of Fill Required to Prevent Bearing Failure

To support a 8.2t dual tyred axle and overlying pumice (density = 9 kN/m³)

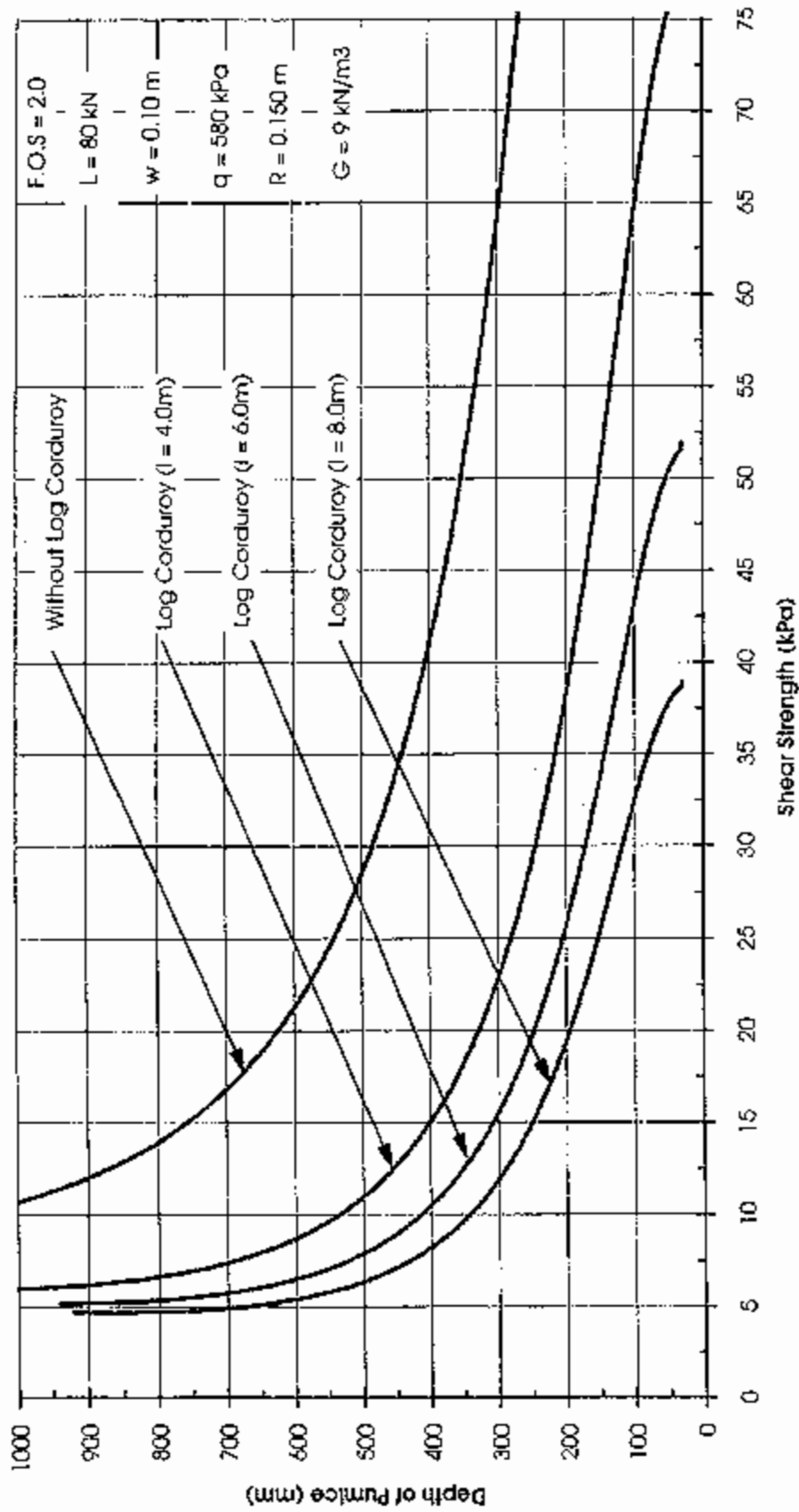


Figure 91 - Depth of pumice fill required to prevent bearing failure

The following equations have been used to produce the graphs in figure 90 and 91:

Fill only (no log corduroy):

$$c = \frac{(F.O.S)q}{5.14} \left[1 - \left(\frac{1}{1 + (R/z)^2} \right)^{\frac{3}{2}} \right] + \frac{(F.O.S)Gz}{5.14}$$

Fill and log corduroy:

$$c = \frac{(F.O.S)L}{5.14 \times l \times w} \left[1 - \left(\frac{1}{1 + (R/z)^2} \right)^{\frac{3}{2}} \right] + \frac{(F.O.S)Gz}{5.14}$$

Where:

- F.O.S = Factor of safety
- q = Tyre pressure (Kpa)
- L = Axles load (kN)
- l = Length of log corduroy (m)
- w = Diameter of log corduroy (m)
- R = Effective load radius (m) = $\frac{1}{2} \sqrt{\frac{2L}{\pi q}}$
- G = In-place fill density (kN/m³)
- z = Fill depth (m)
- c = Soil shear strength (kPa)

Aggregate Coverage for Brush Mats

If a brush mat is chosen for the corduroy mat, then the depth of aggregate fill required will be greater than for a log corduroy mat since the brush mat will have significantly more voids that require filling, and will provide only limited reinforcement. The graphs in figures 90 and 91 can be used for brush corduroy construction provided the depth of aggregate determined is multiplied by a factor of three to account for the voids and limited reinforcement.

9.10 ECONOMICS OF THE STABILISATION OPTION

The economics of stabilisation should be reviewed during the consideration of pavement options, as then factors affecting construction costs are more accurately known. These factors include the thickness of the pavement layers and the application rates for the proposed binders.

Several stabilisation options may need to be costed to select the most economic balance between binder application rates, stabilised layer thickness and possibly density and unbound layer thickness. Non-stabilisation options may also be included in the evaluation.

Comparison of the construction costs of these options will allow selection of the lowest cost pavement option.

Compared to non-stabilised layers, stabilisation often has advantages additional to those shown merely by the construction costs. These may include some combination of the following:

- Reduced sensitivity to moisture and hence more tolerance to pavements with mediocre drainage and/or weak subgrades.
- Speed of construction, particularly for new pavements over very weak subgrades.
- Ability to strengthen the pavement while maintaining the existing pavement surface levels.
- Reduction of trips to truck out existing materials and truck in new materials. This reduces wear on other roads and reduces CO₂ emissions.

- Conservation of aggregate resources.

9.11 RECOMMENDATIONS

As the resources of aggregates are being depleted, there is now a need to source alternative materials, and to stabilise or modify them to meet the strength and durability requirements of the pavement.

The pavement needs to suit the site conditions, design traffic loadings, and to utilise local materials imported and insitu in the most cost effective manner.

Stabilisation can provide major recognised benefits for forestry roading of all sizes and significantly offers an acceptable, cost effective, environmental alternative to conventional designs

Most stabilisation treatments will alter many material properties at the same time and the correct use of stabilisation requires identification of the properties that require altering, and the effect the stabilising process will be on these properties.

Laboratory testing should be carried out to determine the response of the particular soil with the stabilising agent(s) being considered and consultation with industry specialists should be carried out. Adequate targeted testing needs to be undertaken to result in the most appropriate stabilisation option.

Subgrade stabilisation reduces the thickness of granular cover required over the subgrade with significant cost savings.

Subbasecourse stabilisation enables the use of a "marginal" aggregate as a premium aggregate at a relatively lower cost.

Basecourse stabilisation compensates for deficiencies in the basecourse aggregate.

Modified materials are produced by the addition of only enough binder(s) to address the material property problems and are usually considered to behave structurally as unbound granular materials

Cemented materials are produced by the addition of stabilising binders (usually cementitious in nature) to granular materials in sufficient quantities to produce a bound material with significant tensile strength.

Compared to non-stabilised layers, stabilisation often has advantages additional to those shown merely by the construction costs such as reduced sensitivity to moisture, speed of construction, reduction of trips to truck out existing materials and truck in new materials and conservation of aggregate resources.



SLOPE STABILISATION

CHAPTER 10 - SLOPE STABILISATION

10.0 INTRODUCTION

Slope stabilisation is an important aspect of road design and construction. It can save time and money, and may be required because of visual impacts or Resource Consents. Inappropriate practices, and failure to stabilise slopes can result in roads becoming impassable, incurring additional expense to rectify the problems. Cut and fill slopes, riverbanks, and bridge abutments can be inherently unstable and prone to erosion. The following stabilisation techniques will help to stabilise material and to reduce erosion.

10.1 COMPACTION

All embankment material should be constructed in layers and then compacted. Compaction machinery and techniques are outlined in chapter 9. The layer thickness should be appropriate to the maximum size of the material being placed, and the compaction equipment being used. Layers of loose soil typically 150 to 250 mm should be compacted. For sand and rock, tables 32 and 33 give an approximate loose layer depth.

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

Table 32 - Loose layer depth for compaction of clean sand

Vibrating Roller Mass in Tonnes (static)	Loose layer Depth (mm)	
	Towed Roller	Self Propelled
5	1000	-
10	1500	1000
15	2000	1500

Table 33 - Loose layer depth for compaction of coarse rockfill

Water control is very important when compacting soil. The water content must be uniform throughout the material, and close to the optimum moisture content (OMC), to achieve a high degree of compaction (See chapter 9 for description of OMC and field tests to determine OMC).

Note: It is important in any construction situation to provide adequate drainage to prevent the material becoming saturated and unworkable. An example of this is to leave work lightly compacted, finished with a flat drum roller and shaped to shed the water at the end of a day's work - this can reduce the downtime due to any overnight rainfall.

10.2 BENCHING

A small bench can be constructed below the road formation to catch the side-cast material, preventing it from sliding down the hill and into the gullies (figure 92).

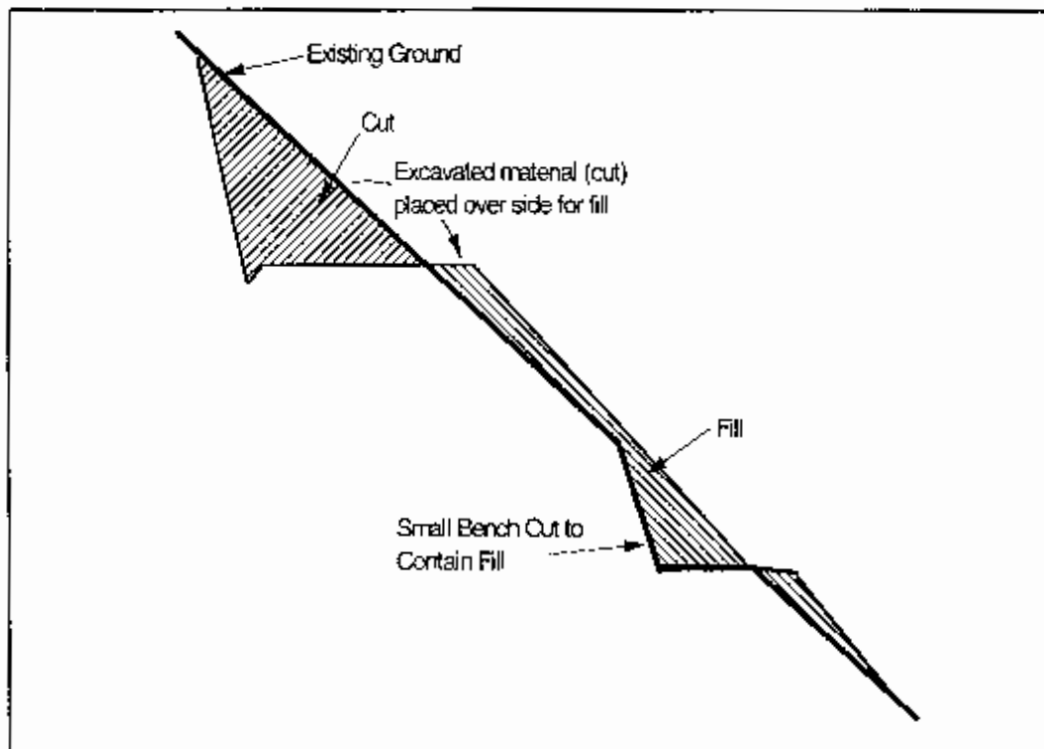


Figure 92 - Bench cut to contain side-cast fill.

On steep slopes, the fill material is not compacted, therefore re-vegetative methods (such as hydroseeding) are required to prevent erosion.

10.3 WATER CONTROL

Fill slopes are easily eroded by water. An effective way to reduce this erosion is to limit the amount of water which flows over the slope. This can be achieved by providing adequate culverts and fluming to ensure that the water runoff, is discharged onto solid ground or into waterways.

10.3.1 Slope Drainage

Adequate drainage of side slopes will relieve the pore pressure within the slope, thereby reducing the risk of slope failure. Drainage of slopes is essential when there is to be a supporting wall, such as gabion baskets (see section 10.6) or blockwork. Without drainage, water will build up behind the wall, forcing it outward, or possibly forcing water under the road.

Drainage of slopes may be completed simply by having adequate watertable drains, which will allow water to flow out of the slope and away from the road and batters. Alternatively, holes may be drilled into the slope to facilitate drainage.

10.4 RE-VEGETATION

Re-vegetation of batters and all exposed soil should be undertaken as the earthworks progress. Topsoil and mulch salvaged during the clearing stage of the work can be re-used and placed on slopes to encourage vegetation growth. The salvaged material may contain sufficient seed to re-establish the area. Re-vegetation work should be completed as soon as possible to limit any soil movement or subsidence. This will also maintain the live plant material in good condition for re-use, and will help minimise erosion during later construction stages.

Batter surfaces should be left rough, so that they will hold the topsoil. In some situations it may be necessary to cut steps in the batter to hold the soil.

10.4.1 Hydroseeding

Hydroseeding is one method of re-vegetative treatment of major construction sites will have long exposed slopes. A mixture of water, seeds, fertilisers, organic binders and even mulch material is sprayed onto the surface to be re-vegetated. If the hydroseeding mix is suited to the conditions then grass can be established within 14 days.

Hydroseeding is a very common and effective way of limiting both the erosion and the visual impact of fill slopes.

10.4.2 Handsowing

Another method of re-vegetation of side slopes is to hand broadcast grass seed onto the slopes. This method is ideal if there is sufficient organic matter on the slope to encourage plant growth. The ideal time to complete this work is just before a heavy dew or light rain, since this will help stop seeds from blowing away, and help it become established. Fertilisers can also be hand broadcasted at the same time if necessary.

10.5 GEOGRIDS

Geogrids are formed by Heating and stretching sheets of high-density polyethylene into which a pattern of holes has been pre-punched, (figure 93). These grids hold soil particles within the grid, binding the material, and allowing efficient load transfer from the soil to the grid. There is a wide variety of geogrid systems available, for complete product ranges and their application, contact the manufactures or suppliers.

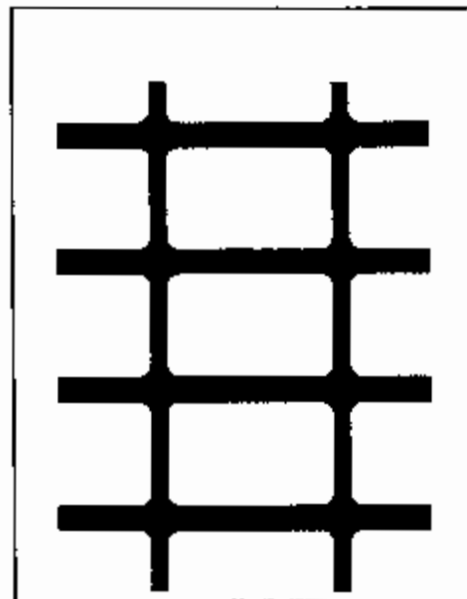


Figure 93 - Typical geogrid formation

Typically there are two main mechanisms which geogrids use to support slopes and retaining walls. In the case of retaining walls the geogrid is used to “tie back” the wall to the soil behind it (figure 94).

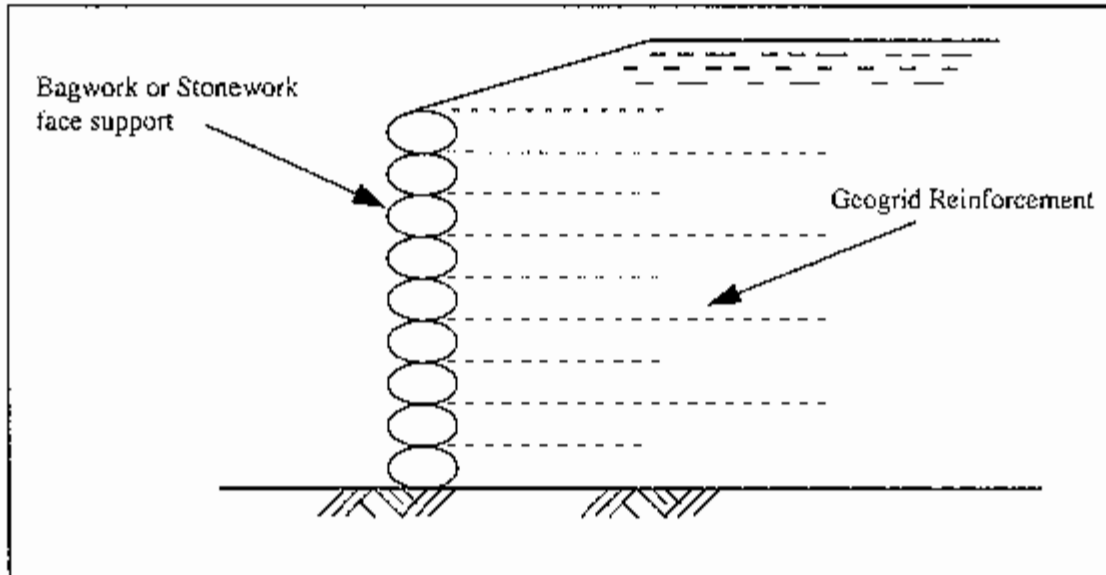


Figure 94 - Slope stabilisation using the “tie back” method

For cut and fill slopes, geogrids are placed on the surface of the slope to support the slope, and to minimise local slumping and erosion (figure 95). Some geogrids used in this way also promote re-vegetation by providing a mat type surface to support organic material and seeds.

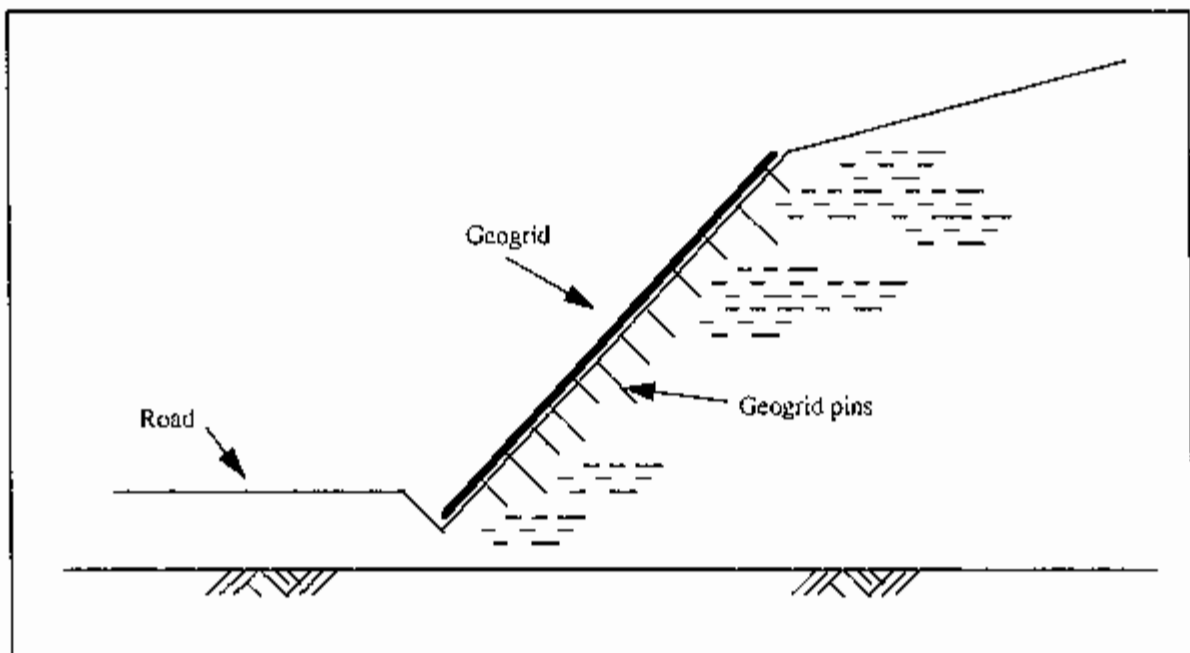


Figure 95 - Slope stabilisation using surface geogrids

Geogrids can be used for a number of slope stabilisation applications including stabilisation of fill and cut slopes, bridge abutments and culvert approaches and outlets (see the manufactures' brochures and recommendations).

10.6 GABION STRUCTURES

Gabion structures are designed to support slopes, and to provide erosion protection. Wire mesh baskets are filled with stones, rock or rubble, and are laced together to form a continuous structure. There are two main types of gabion structures:

- Gabion baskets are designed to use their mass to support a toe of a slope, or to provide an effective retaining wall.
- Gabion mattresses may be used to overlay a riverbed or other surface, to reduce the erosion effect of water flow.

Both gabion mats and baskets are extremely flexible because of the combination of mesh and rock fill. This flexibility allows them to be used in variable conditions, such as soft or unstable ground where movement is expected due to settlement or frost heave etc. They are ideal for river and waterway erosion control, bridge abutments and approaches, slope stabilisation and toe support.

Gabion walls are a very effective, and often very cost effective, option for supporting a slope. They use material that is usually obtainable on site - any solid, hard material such as rubble, broken rock or concrete - to fill the baskets or mattresses.

Mattresses

Gabion mattresses (figure 96) are generally manufactured 6 meters in length, 2 meters in width and 0.24 meters in thickness. They are most often used for protecting river and waterway beds, but can also be used to protect cut and fill slopes. They are flexible and therefore can fold to accommodate changing ground conditions. The high porosity of the gabion mats generates free drainage through the structure, which

reduces hydrostatic pressure build-up. This gives them an advantage in areas where high seepage flows are expected, but if seepage through the mat is expected to cause problems, or additional erosion control is required, the mats can be overlaid with concrete.

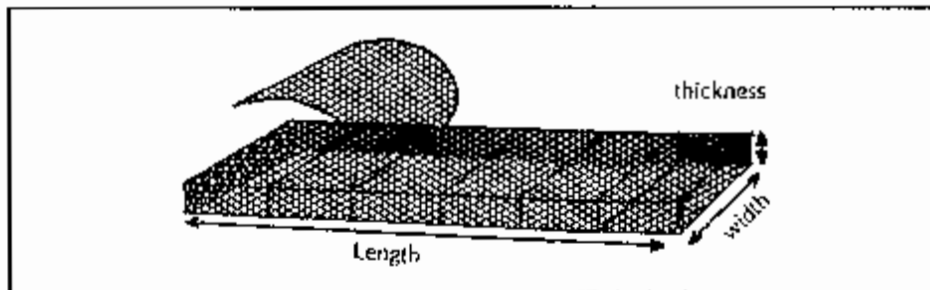


Figure 96 - Gabion mattresses

Additional support can also be obtained by encouraging vegetation to grow over the mats, this will also help to hide the structure.

Baskets

Gabion baskets are manufactured in a range of sizes from 2 meters in length, 1 meter in width, and 0.5 meters in height, up to 4 meters in length, 1 meter in width and 1 meter in height (figure 97). They can also be purpose built from special chain mesh netting. Generally these baskets are used to support the toe of a cut or fill slope, bridge abutments and approaches, and culvert inlets, or to act as retaining walls.

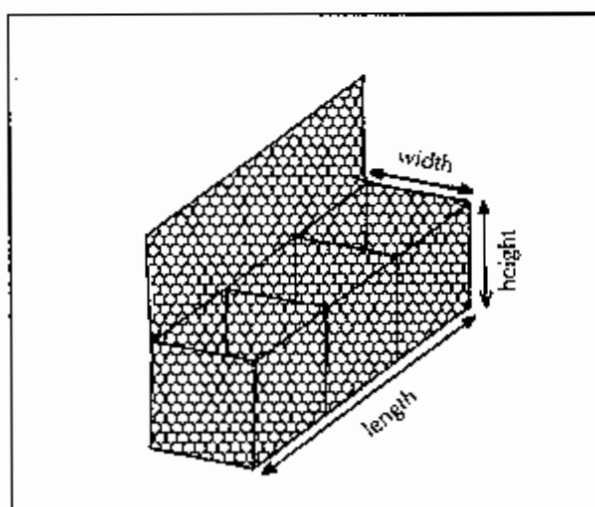


Figure 97 - Gabion baskets

Figure 98 shows the use of gabion walls, in conjunction with plant material, to support a road which has been eroded by a river below the road. The plant material (willow) helps to tie the gabion wall to the slope, giving extra support.

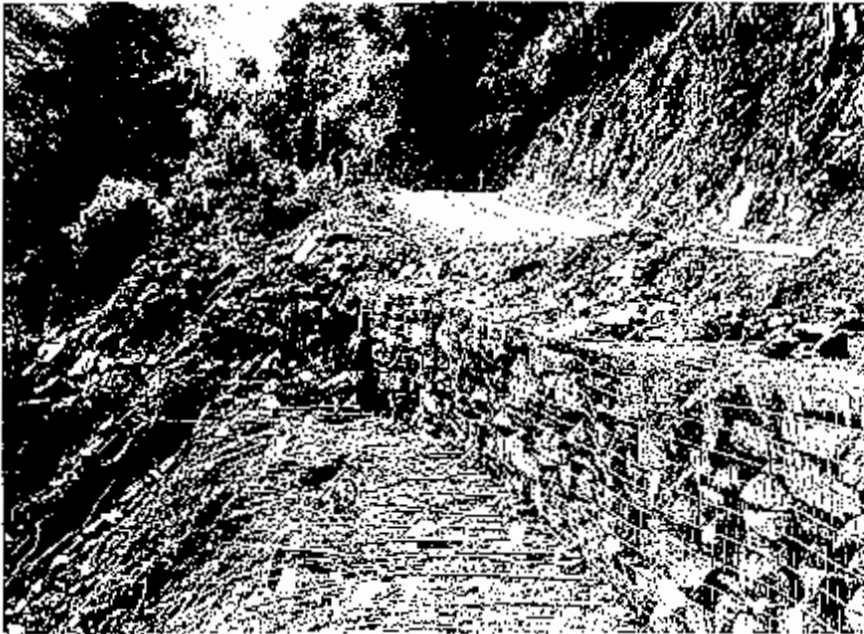


Figure 98 - Gabion wall supporting a fill slope

10.6.1 Retaining Walls

Gabion baskets are ideal for use in a gravity retaining wall to support steep cut and fill slopes. This may occur in steep country, where the ideal cut or fill slope angle would produce a large exposed surface, or where the fill slope would otherwise encroach into a waterway.

The retaining wall can be stepped, sloped, or vertical, depending on the situation.

10.6.2 Geogrid/Gabion Combinations - Reinforced Earth Retaining Walls

The combination of gabion baskets and geogrids can make an excellent reinforced earth retaining wall. The geogrid is used in the "tie back" method described earlier to tie the gabion baskets back into the slope.

This situation combines the weight of the baskets and the frictional properties of the geogrid system to support the slope, making this combination ideal for bridge abutments and approaches. Again, the front face can be vertical, sloping, or stepped to suit the loading situation and the existing ground contours.

10.6.3 River Walls

River walls are designed as retaining walls to support existing banks, roads and other structures. Gabion baskets can be positioned below the maximum expected scour depth to reduce the risk of undermining of the gabion wall. The surface roughness of the gabion wall acts to slow the water flow, thus reducing erosion effects.

10.6.4 Channel Linings

Channel linings are usually completed using gabion mattresses. The mattresses are faced together to form a continuous mat overlaying the waterway bed (figure 99). The stones within the mattresses reduces water velocity, which eliminates scour of the waterway bed. For water velocity calculations in determining culvert and bridge sizes (see chapter 11), Manning's Coefficient of roughness $n = 0.025$ can be used for ungrouted gabion mattresses, and $n = 0.017$ for grouted mattresses.

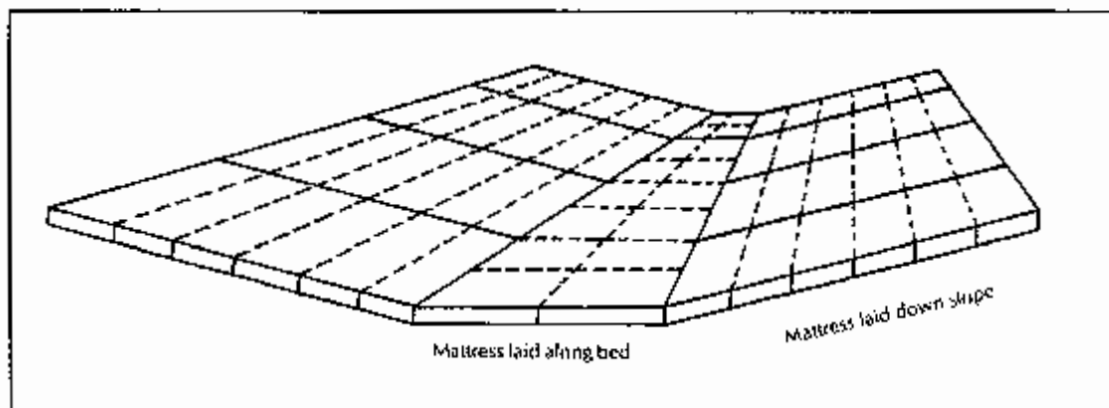


Figure 99 - Gabion mattresses used to line a waterway

An alternative to lining the waterway completely is to line the bed with a mattress, and use gabion baskets to support the riverbed walls (figure 100).

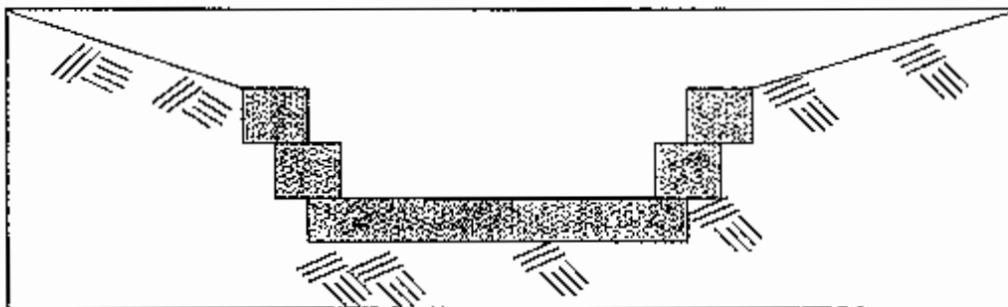


Figure 100 - Gabion mattresses and basket combination lining a waterway

10.6.5 Weirs

Silt or gravel traps, and other energy dissipating structures can be eroded by the action of fast-flowing water at the downstream end of the structure. Gabion baskets or mattresses can be used to line them in order to reduce the water velocity, and eliminate erosion. Figures 101 and 102 show typical designs.

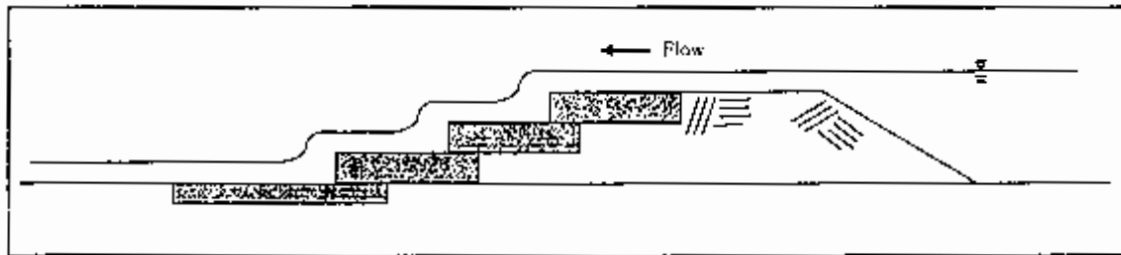


Figure 101 - Stepped gabions used as velocity and erosion control over weirs

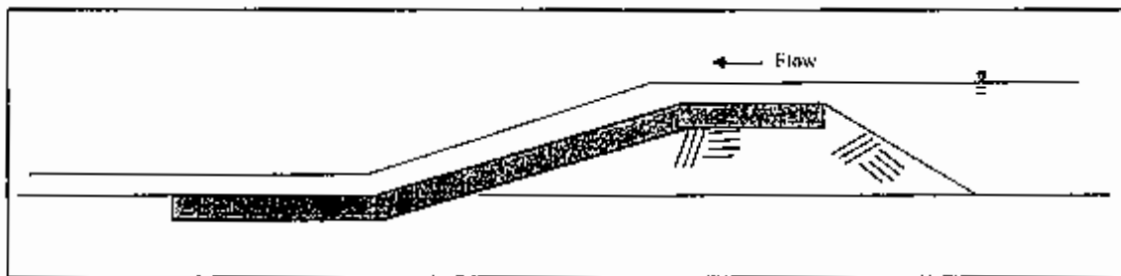


Figure 102 - Sloped gabions used to protect weir structures

10.6.6 Bridge Abutments

Gabion baskets and mattresses can be used on their own, or in combination, to form effective bridge abutments. Geogrids can also be introduced to give additional protection and support, either using the "tie back" (figure 103), or surface methods. Gabions can also be used to provide erosion protection of existing abutments and piers.

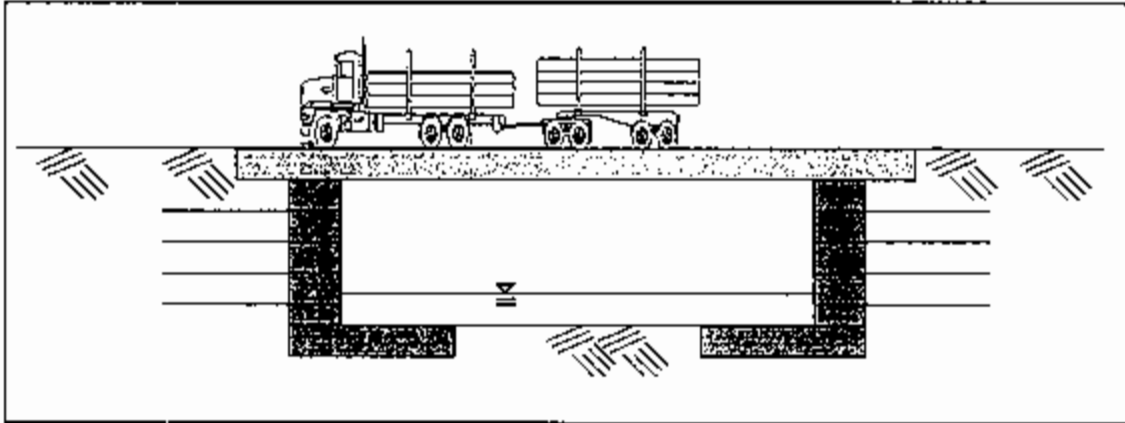


Figure 103 - Gabion mattresses, baskets and geogrid used for bridge abutments

10.7 REMOVING OVERBURDEN STRESS

Large cut slopes can be unstable owing to the effect of gravity working downward on the material in the slope. The toe of the slope must support all of the material above it, so by removing of some of the overburden material, some of the downward pressure is relieved. An example of this is the benching of cut slopes at strategic places (figure 104).

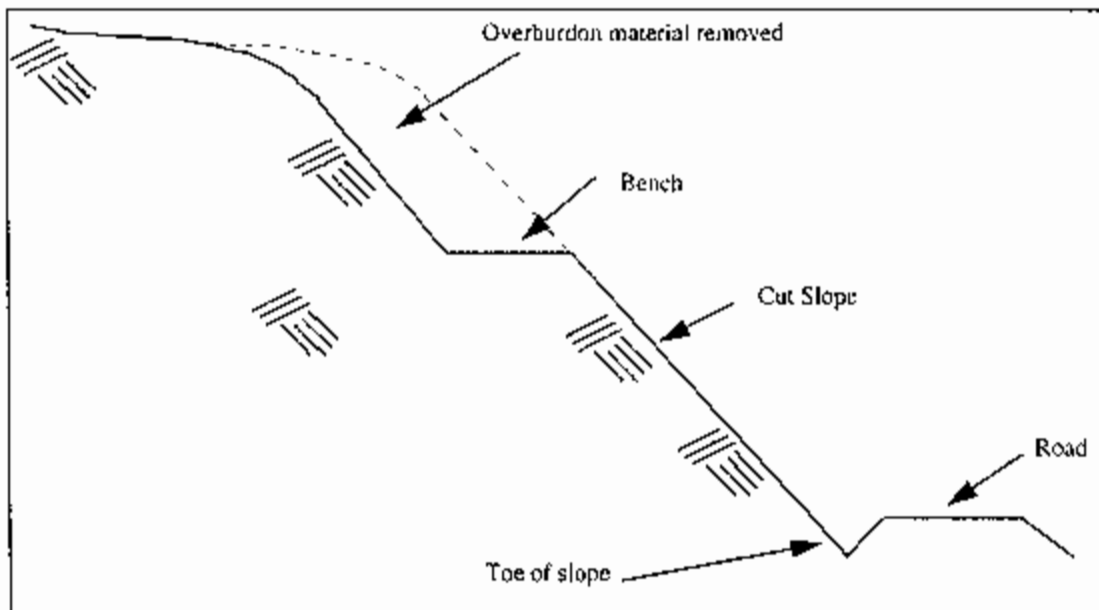


Figure 104 - Removal of overburden material

Figure 104 shows that the toe of this slope now only has to support approximately $\frac{2}{3}$ rds of the original overburden material.

10.8 SLOPE MODIFICATION

Slope modification is a simple design feature which can be used during construction to reduce the erosion of slopes. Flattening the gradients of earth cuts and fills can reduce slope instability, reduce erosion, and encourage revegetation.

Soil material has a natural angle of repose, and any slopes steeper than this angle will be inherently unstable. Flattening earth cuts and fills involves adding more fill, or taking out more cut material, than would otherwise be the case, in order to create a more stable angle. An example of this technique is flattening a slope in fine sand material to 2:1, resulting in greater stability and quicker re-vegetation.

Once a stable angle of repose is reached, there is little benefit in further flattening, since this will only increase the area of exposed soil, and therefore the susceptibility to erosion. Changes in slope angles should be rounded to reduce erosion potential, and to blend with the natural landscape. Rounding is particularly important at the top of cut excavations.

Another technique is the roughening of slope surfaces. This will reduce the amount and velocity of run-off travelling down the slope, increases infiltration, and causes some of the sediment to be intercepted before it reaches the toe of the slope. A simple method of roughening the surface is to run a bulldozer or other tracked machine up and down the slope. This will leave a pattern of tread imprints parallel to the slope contours. The tread indentations will trap seeds, encouraging plants to become established. The tracks also reduce the velocity of run-off.

WATER CONTROL

CHAPTER 11 - WATER CONTROL

11.0 INTRODUCTION

Controlling water drainage from roads and landings is a fundamental part of maintaining an efficient, long-lasting road. A well-drained road can withstand higher axle loads and traffic volumes, will require less maintenance, and will be able to be used all year long. Uncontrolled water can cause an enormous amount of damage in a very short space of time, even destroying a road pavement. The washout of a culvert or bridge embankment, or the scouring of watertable drains can render a road impassable, causing enormous expense and considerable transportation delays.

It must be remembered that any earthworks will change the natural surface and sub-surface watercourses. Proper channels for water flow must be constructed both during and following completion of the road. If not designed correctly, culverts, bridges and other water crossings can restrict the flow of water, especially at high water flows, which can lead to problems with blockages and the build up of debris, causing washouts.

There are many water control structures designed for the efficient flow of water from roads and landings back into natural drainage systems. This chapter outlines these structures, and good construction practices.

11.1 WATER TABLE DRAINS (Side Drains)

Correct crossfall and camber on the road carriageway will ensure that water runs directly off the road and into the watertable drains. Guidelines for crossfall are given in section 6.4.1.

Watertable drains usually run parallel with the road, draining water from the road carriageway and adjoining slopes. They are usually designed with a flat bottom to eliminate scouring and erosion from waterflow (figure 105). Lining of the drain bed is only necessary if there is likely to be a scouring problem, in which case they are usually lined with rock or gravel, or simply grassed.

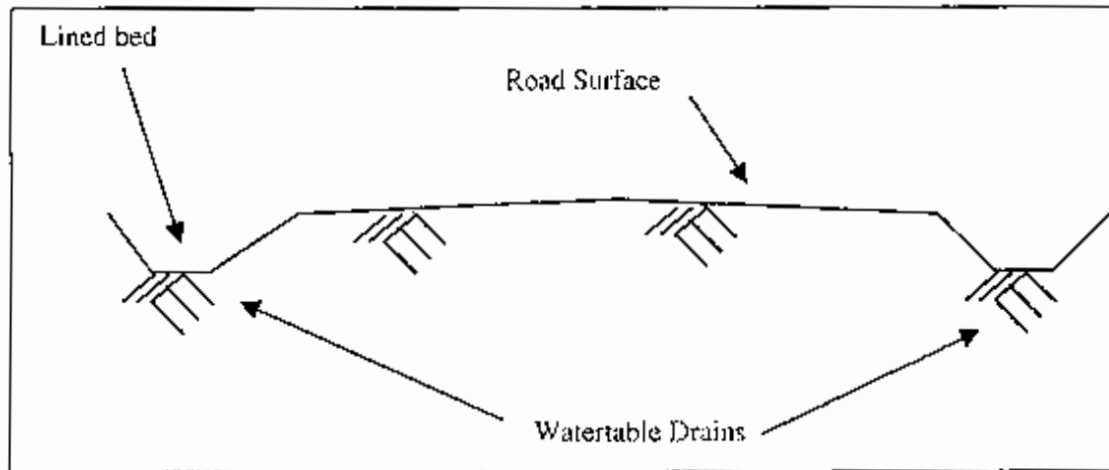


Figure 105 - Watertable drains

Watertable drains on the cut bank side of a road flow into gullies, and feed water into cross culverts which direct water under the road. Drains on the outside of the road flow into side drains or turn offs (figure 106).

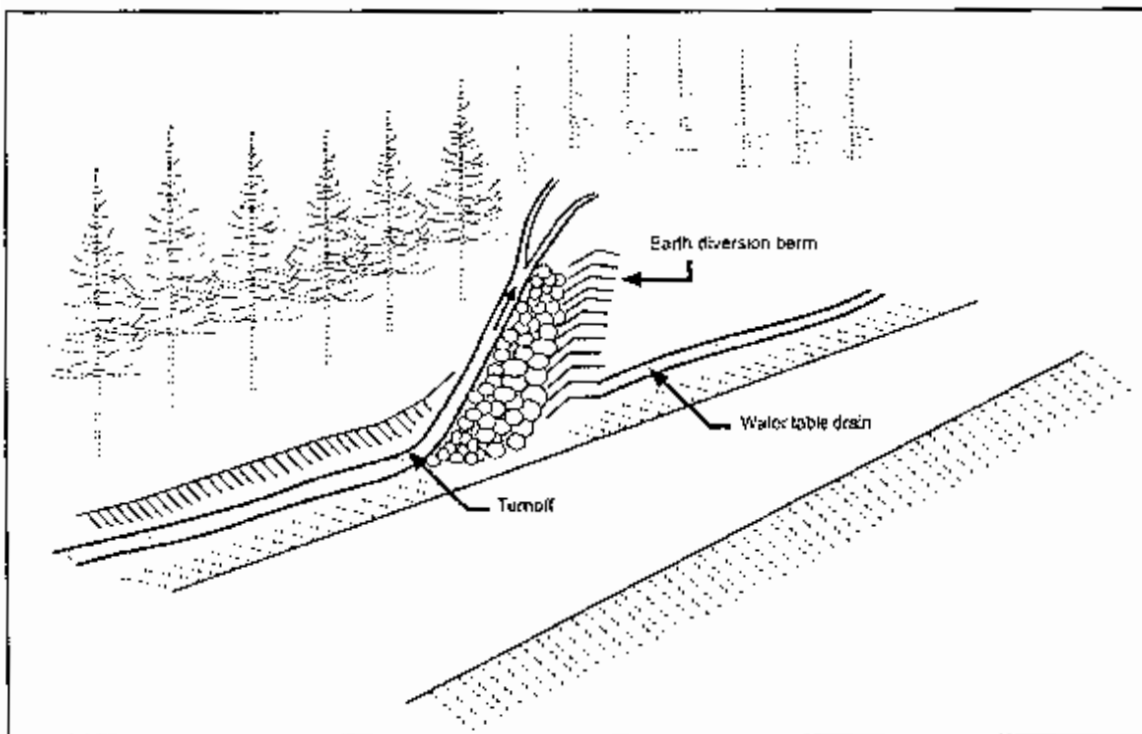


Figure 106 - Water runoff using turnoffs and watertable drains

11.1.1 Watertable Drain Design

Figure 107 shows the basic design for a trapezoidal drain for controlling water from a road surface. Alternatively, a v-shaped drain (figure 108) may be used if the area has

low rainfall and stable soil which will not scour. In some instances, a straight line from the crown of the road to the bottom of the drain can be adopted. The advantage of this design is that it is quick and easy to maintain with a grader.

The longitudinal slope of the waterable drains is very important. A slope which is too shallow will not let the water drain quickly, causing flooding and silting of the drain bed. A slope which is too steep will allow fast water flow, producing scouring and erosion of the drain bed.

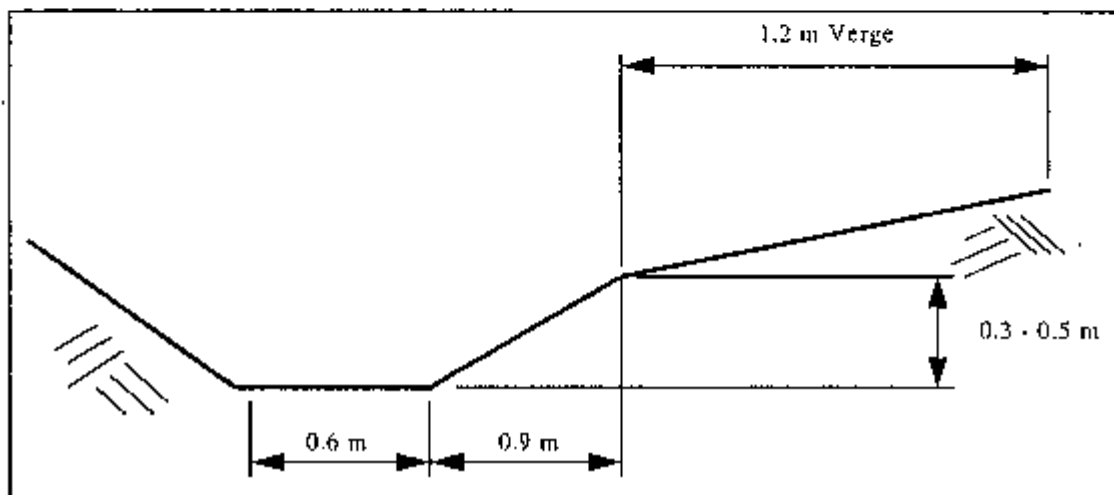


Figure 107 - Trapezoidal Drain

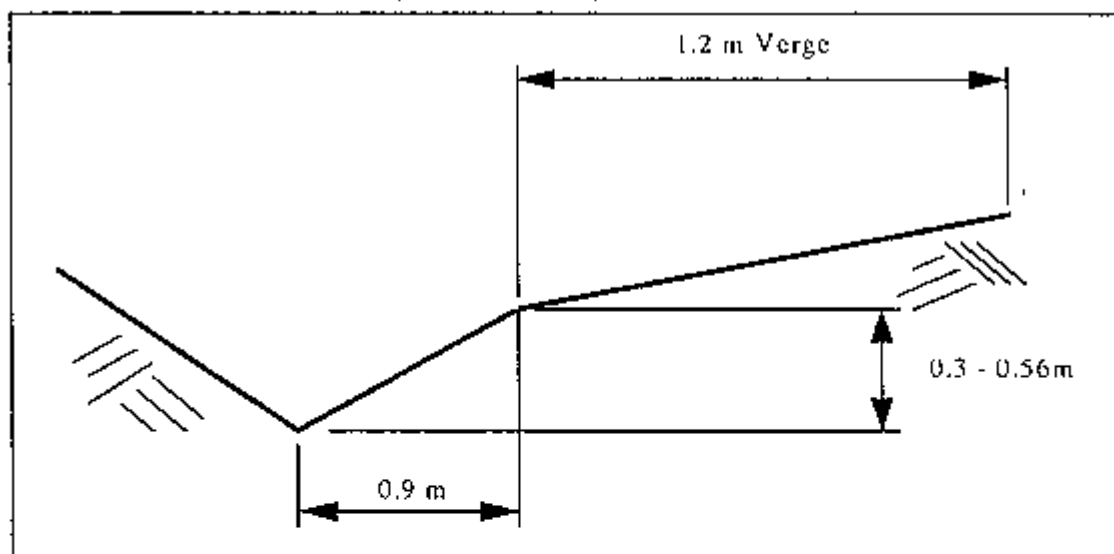


Figure 108 - V-drain

As a rule of thumb, to avoid silting a slope of 0.5% (1:200) is recommended. To avoid scouring, a maximum slope of 5% (1:20) is recommended. However this is highly dependent on material type. In many cases it is recognised that, owing to

topographical constraints, the longitudinal slope cannot be restricted to 5%, and therefore erosion control measures or extra cross culverts will be required if the soils are erodable.

On major arterial routes, drains are designed so that, where possible, the water level is maintained at least one metre below the road surface where possible. Ideally, roadside ditches must not divert water runoff directly into natural streams and waterways. Water should flow over land to filter through natural vegetation before entering the waterway. This will help control any sediment carried by the water, preventing it from travelling into the waterway.

11.1.2 Erosion Control in Drains

Dropwalls and check walls/dams (figure 109) can be used at intervals within the drain to *step* the water down, slowing the water flow. These methods are very good at controlling longitudinal erosion, but can cause problems with localised erosion at the base of each step. Lining these areas with rock, large gravel and grass can help to eliminate such problems.

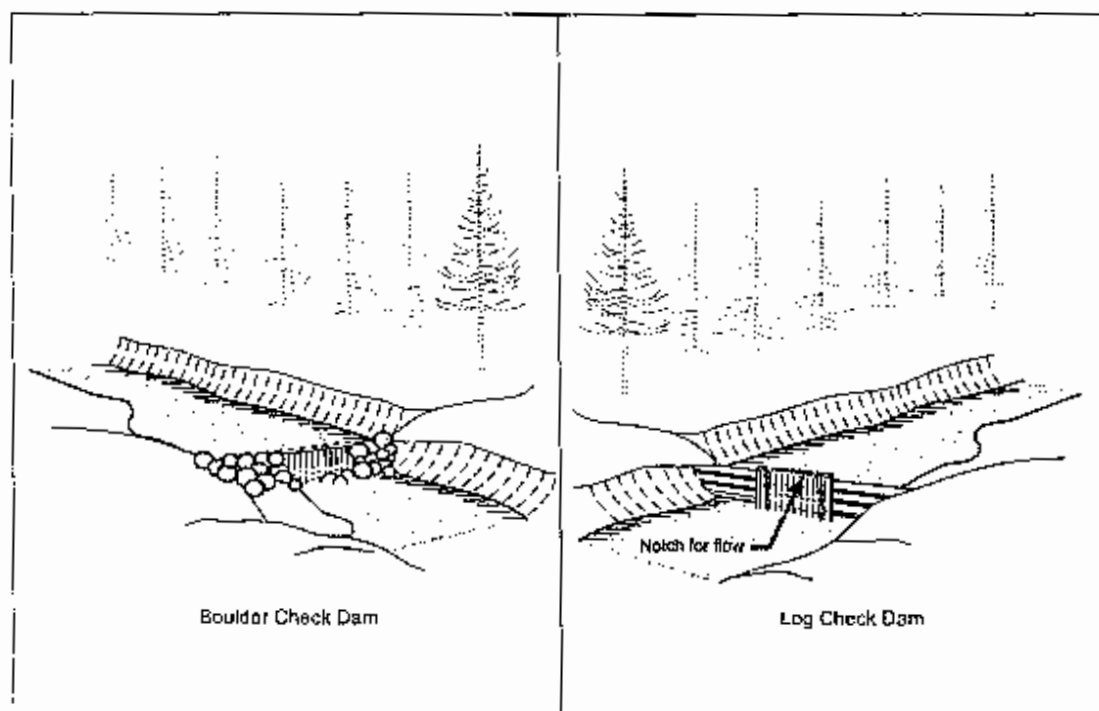


Figure 109 - Boulder check dam and Log check dam

Check dams can be constructed using logs, rock and boulders, sandbags, gabions or virtually any available erosion-resistant material.

The dam must be constructed below the natural level of the drain bed to eliminate undermining. It is constructed by placing the selected material across the drain, perpendicular to the flow. It should have a central weir size large enough to prevent washing and eroding around the dam edges. As a guide, the dam should not be higher than 600 mm, and the weir should be at least 150 mm lower than the outside edges.

Alternatively, intermediate cross culverts (or take off drains), leading into flumes, can be used to reduce the water flow velocity.

11.2 CATCH DRAINS

Catch drains are used to direct water flow from the surrounding area towards the road in a controlled manner. Often these drains are positioned at the top of batter slopes (figure 110) and they are usually designed similarly to watertable drains. If the material is prone to erosion and scouring, an alternative is to use berms or banks to direct the water flow.

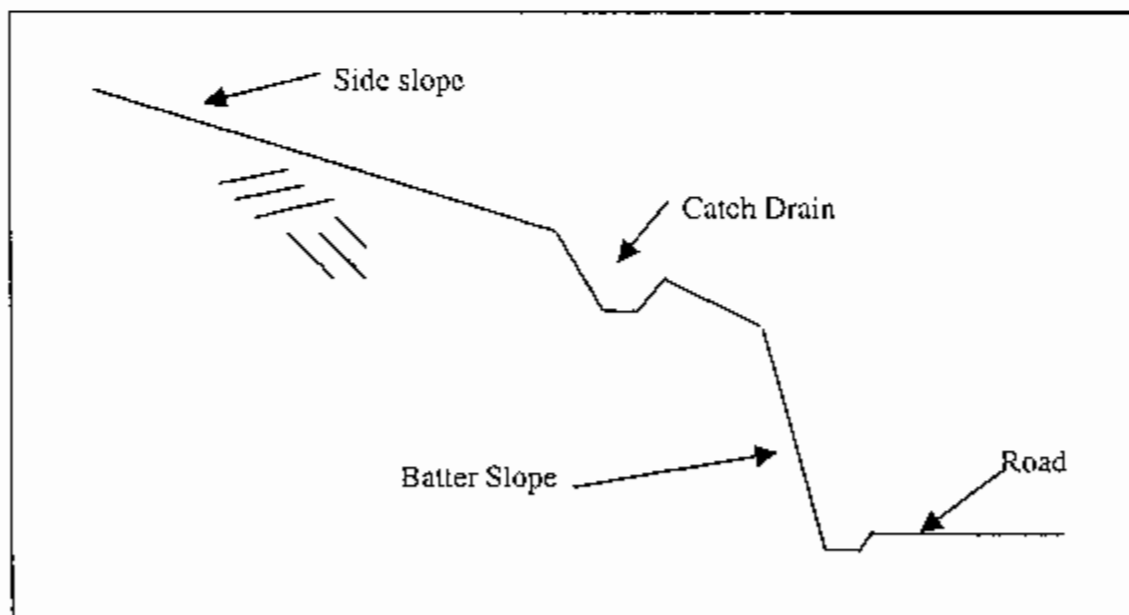


Figure 110 - Position of catchdrain

11.3 CULVERTS

Culverts are the most commonly used water control structure for forestry roads in New Zealand. They are easy to install and relatively cheap, and if designed, constructed and maintained correctly, they will deliver good service for many years. Designing a culvert to accommodate the flow discharge from a catchment area can be completed a number of ways; using empirical formulas, templates, or by other methods see chapter 12. However, as a rule of thumb, a culvert diameter 375 mm or greater should be used for drainage, since anything less could result in the culvert becoming blocked with debris causing scouring, erosion or flooding problems.

11.3.1 Culvert types and design

A short design return period (i.e. a 2 to 5 year flood event) means the discharge from the catchment is of a greater magnitude than the culvert design discharge which causes some ponding of water upstream, or temporary surface flooding of the road. For this to work effectively, there needs to be a low drop-section (spillway) in the road gradefine to allow some of the flow of water to pass over the road with minimal obstruction. The maximum depth of water on the road should not exceed 150mm. For problem areas or for larger catchments, a spillway (figure 111) or an axillary culvert, can be constructed to control the excess water flow under and across the road.

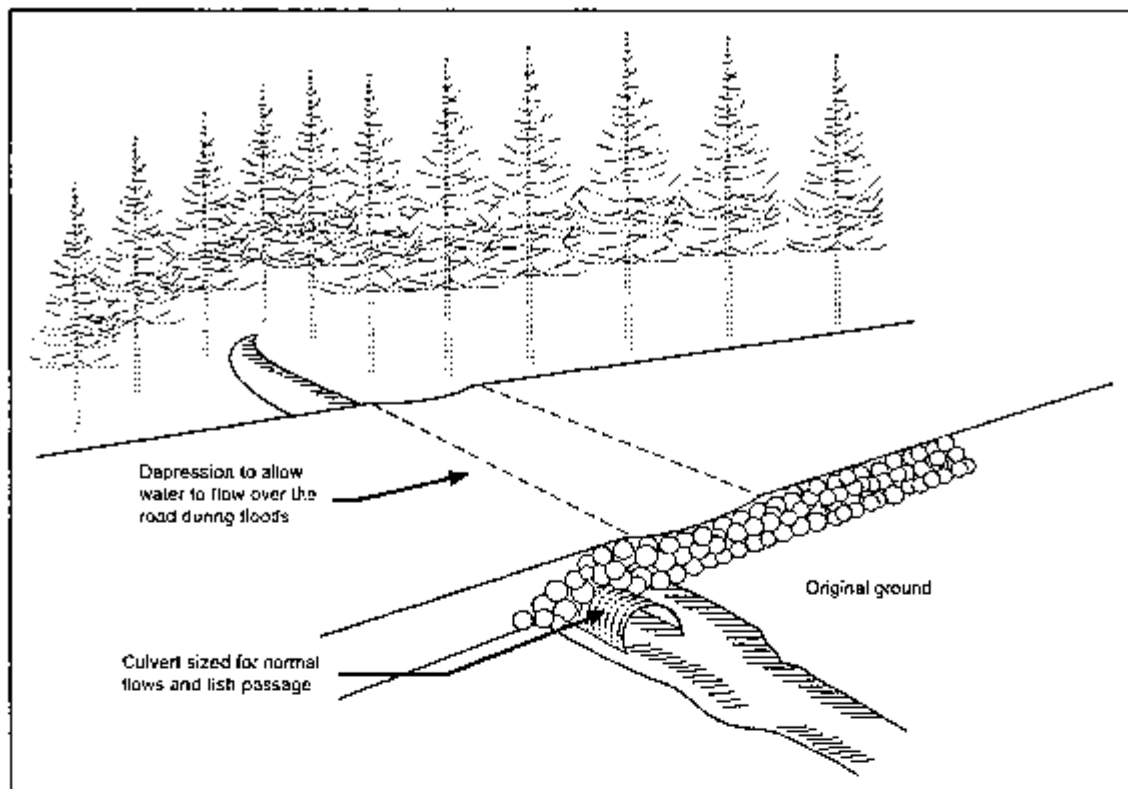


Figure 111 - Position of spillway

There are many types of pipes which are suitable for waterway crossings and drainage culverts. The service life, ease of construction, economics, and soil and ground conditions will determine which type of pipe is to be used. Various factors, as detailed below, will determine the type of culvert for each situation.

- Fish resource
 - Arch pipes and inverted U-box culverts are good as they do not change the stream bed
 - Concrete pipes or concrete lined pipes are also recommended
- Ground acidity
 - In acidic soils a non-corrosive pipe material such as plastic may be required
- Re-useability on temporary roads
 - Concrete pipes can be extracted and used again once the road is no longer in use. Metal and plastic pipes tend to be damaged during extraction.

- **Length and diameter of culvert**
 - Some products are only available in specific lengths and diameters which may restrict their use or impeding their practicality for the job.
- **Machinery available/required**
 - In situations where heavy machinery is not available, large concrete pipes will be difficult to use.

11.3.1.1 Cross culverts

Cross culverts are used to drain water from one side of the road to the other. They are used for small creeks or for drainage of inside watertables

11.3.1.2 Waterway Culverts

Waterway crossings occur where the road crosses a natural water course which has a defined channel. Waterway culverts used to drain this water under a road should be designed for a short return period (2 to 5 years) on low volume roads, and a higher return period for high volume arterial roads. See Chapter 12 for detailed comments on the design of waterway culverts.

11.3.1.3 Drainage culverts

Drainage culverts are required to pass local surface flows, channelised by the road construction, which have no defined water channel and where there is no fish resource present. Most of the time these channels and culverts will be dry and will only be in use when it is, or has been, raining.

11.3.1.4 Open-Top Culverts

Open-top drains across a roadway will not only act as a cross culvert, but will also intercept surface run-off, stopping longitudinal scouring of the road carriageway.

They have a very simple design (figure 112) which can use on-site products, but they are particularly susceptible to being blocked by debris.

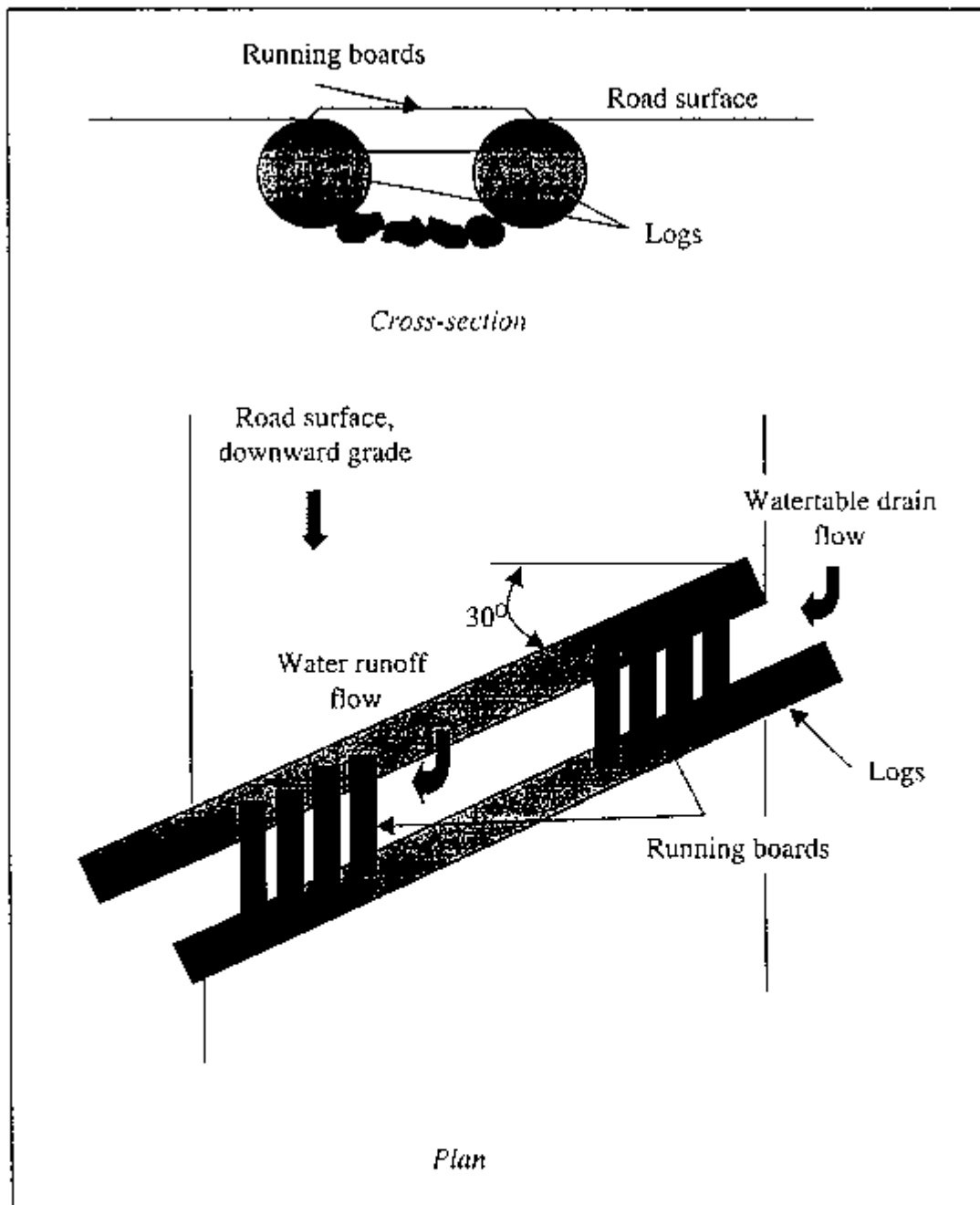


Figure 112 - Open ditch drainage system using log culverts

11.3.2 Culvert Installation

Correct installation procedures are critical to the long-term success of a long lasting, effective culvert. Generally, a waterway crossing culvert and a drainage culvert should be installed using the same procedures (see chapter 12).

11.3.2.1 Drainage Culvert Installation

For drainage culverts where it is impractical to have the specified depth of one pipe diameter of fill material above the culvert pipe, some special procedures or construction techniques will be required. However, allowing the culvert to be placed with 25% of the pipe diameter below the original ground level will cause the culvert to fill with sediment, and a culvert positioned too high will not perform its job correctly, and may be undermined.

11.3.2.2 Cross Culvert Installation

Cross culverts used for drainage of water from one side of the road to the other should be angled across the road at no less than 30 degrees. See Chapter 12 for more details on installation.

11.3.3 Number and Spacing of Culverts

Figure 113 shows the spacing required for culverts in various soil and road gradient situations. To use this diagram:

1. Select the road gradient
2. Move upward to the line for the appropriate soil type
3. Move across and read the culvert spacing off the side axis

Culvert Spacing for up to 380mm Dia. Pipes

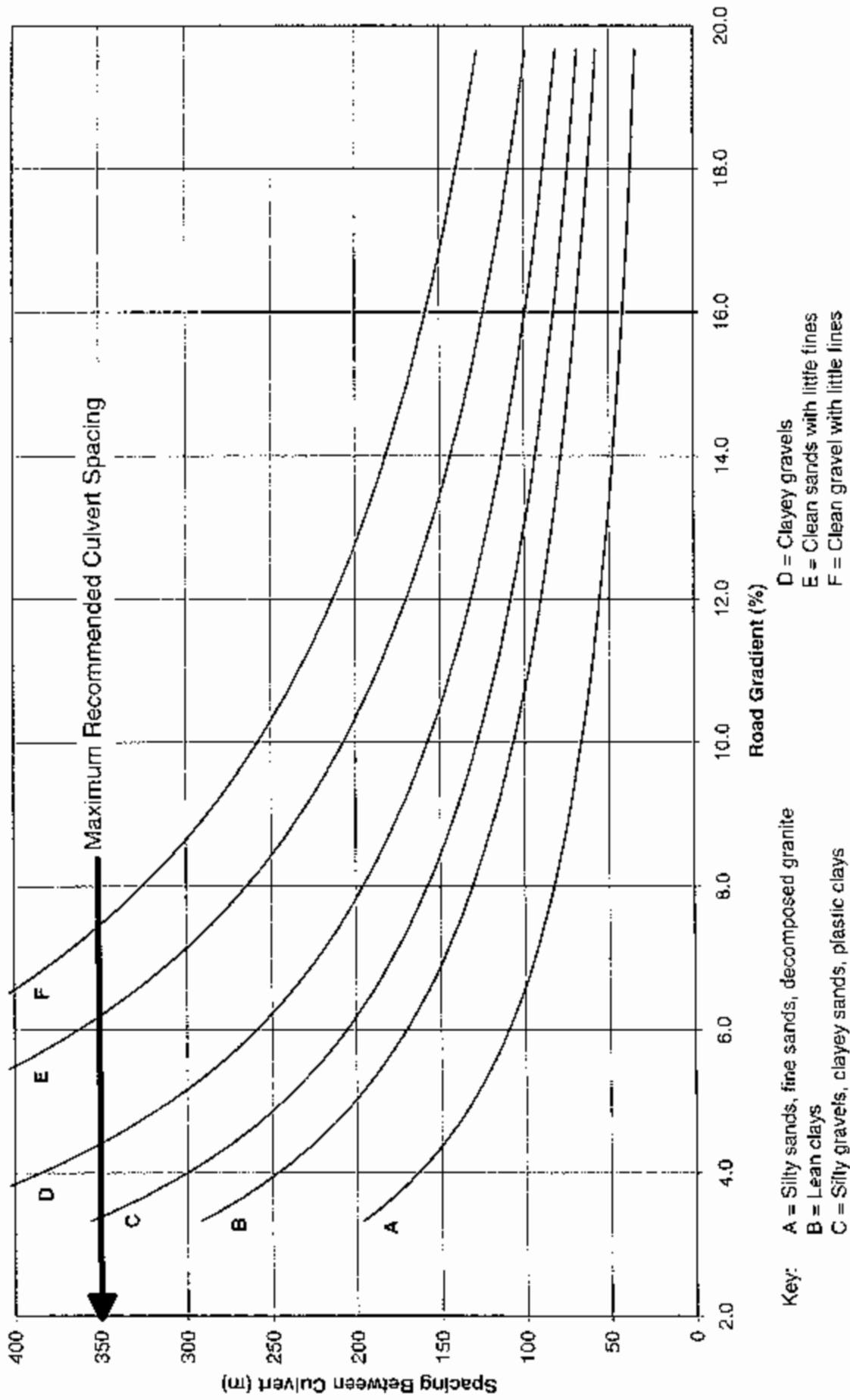


Figure 113 - Culvert spacing for 380 mm diameter pipes

For larger diameter pipes, table 34 can be used as a guide for culvert spacings.

Ground Slope	Erodible Silt-Clay	Normal Soils, Loams	Rock Soil, Sand & Gravel
Gentle (Under 5%)	300 m	600 m	No Limit
Moderate (5-10%)	150 m	300 m	600 m
Steep (Over 10%)	100 m	150 m	300 m

Table 34 - Culvert spacing for pipes greater than 380 mm in diameter.

Note: If erosion control measures and check dams are provided in the road-side ditches, these distances may be increased.

11.4 FLUMES

Flumes are designed to carry water from turn-off drains, culvert outlets and other directional structures over batter slopes, to prevent them from scouring. Wherever possible, they should discharge into a water channel or onto solid ground. Where there is a high sedimentation problem, the flume should direct water overland for filtering. Flumes work by directing water gradually down to ground level, thus eliminating erosion holes below the culvert due to the water dropping straight down (figures 114 and 115).

Flumes are usually constructed from corrugated roofing iron or timber, or from specifically designed products available from pipe manufacturers.

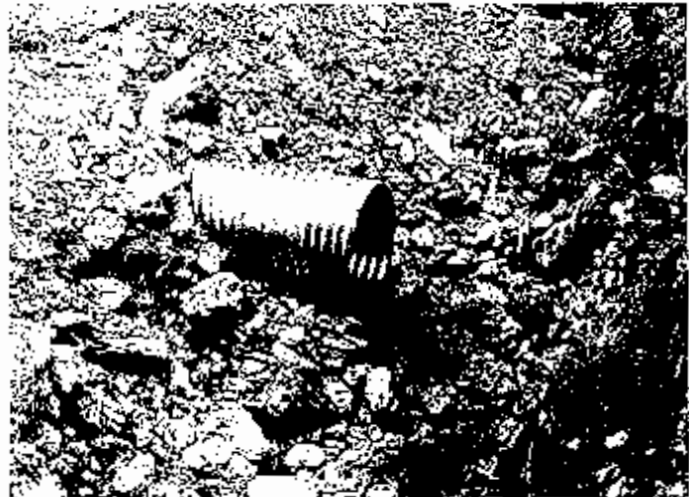


Figure 114 - Without fluming



Figure 115 - With fluming

11.5 SEDIMENT CONTROL STRUCTURES

11.5.1 Sediment Traps

Sediment traps can be used to monitor the quantity of sediment produced from a road or landing. They also reduce the amount of sediment entering the waterways, however it is difficult to build them of suitable size.

A sediment trap should be located close to the source of the sedimentation, but should not be located in a natural water channel, or watertable drain. The trap works by reducing the water flow velocity, allowing soil particles to drop and settle on the bottom. However, only the large sediment particles are removed, and the trap becomes ineffective when it is full, requiring periodic extraction of material. Sediment traps should only be used for short periods, until planting of trees and grasses in the catchment above the trap prevent soil erosion, they should not be used as a permanent means of sedimentation control.

The length to width ratio should be 2:1 or greater, and pipe or ditch inlets and outlets can be used, with the outlet protected to control any erosion or scouring.

11.5.2 Silt Fences

Silt fences are installed to collect sediment from small areas during construction. They are most likely to be used:

- At the toe of an embankment slope
- Along the bank of a sensitive stream
- At the down stream end of an erodible earth cut

These fences act as a strainer, trapping silt and sand on the surface of the fence, while letting water pass through. An added advantage is that they reduce the velocity of the water flowing helping to control erosion and scouring.

11.5.2.1 Construction of Silt Fences

Silt fences are usually made from geotextile fabric. Alternatively straw bales can be used by placing them in the path of flowing water. Silt fences should always be constructed before commencement of the earthworks, and removed once sedimentation levels have dropped, they should not be used as a permanent means of sedimentation control.

11.6 OTHER WATER CONTROL STRUCTURES AND METHODS

11.6.1 Berms

Raised berms are usually constructed on the fill slope side of the roadway. They are used to control the water flow running off the road by directing it to a turn-off, flume or stream. This stops the water from spilling uncontrollably over the batter slope which can cause scouring and erosion.



Figure 116 - Grassed Berms

These berms act like a dam, keeping water on one side. They should be built from compacted material, with grass or other vegetation sown on them to control scouring. It is important that inspection and correct maintenance are carried out on a regular basis.

11.6.2 Cross-ditches (Water bars)

These water control devices are commonly used on temporary roads. They provide an effective, inexpensive method of diverting water from the road carriageway. They remove water from the waterable drains, eliminating longitudinal erosion, as well as catching and diverting carriageway water runoff. The disadvantages of cross ditches are that they increase travel time (since traffic must slow to cross them), they can wear out or scour quite quickly, and they are difficult to maintain. Therefore they are recommended only for low volume, low standard roads.

For a cross ditch to effectively drain water from the carriageway with minimal erosion, it must be excavated into the mineral soil or subgrade, and not just into the soft surface layer. Cross ditches should be positioned at a 30-degree angle to the road centerline, and the ditch and berm should be carefully extended to the cut bank in order to eliminate ditch water bypass. The berm should be placed in the cut bank waterable drain to divert water along the cross ditch. Figure 117 shows a cross ditch design layout. Correct maintenance is needed to ensure that the berm is not compressed down by traffic.

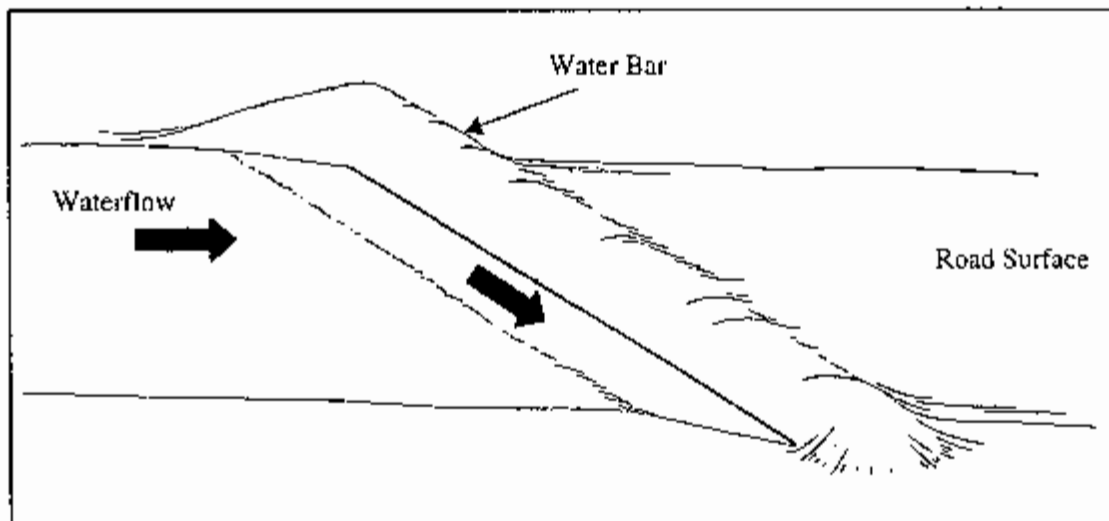


Figure 117 - Cross ditch design

11.6.3 Roadside Vegetation

- Sowing grasses on batter slopes and embankments helps to control scouring, slipping and erosion
- By reducing the velocity of free flowing surface water, and holding soil in place
- It can also lower the water table level, and
- Prevents the establishment of weeds.

Erosion control planting of trees and grasses will help to stop erosion of batter slopes, (figure 118), water drains and ditches, roadside berms, culvert inlets, spillways and flume outlets. Trees and shrubs may be planted to control erosion, however care must be taken to ensure that they will not shade the road, causing problems with moisture and ice during winter.

The trees best suited to erosion control are poplars and willows, and most suitable grasses are perennial rye grass, cocks foot, brown top, and red clover

Using a variety of species will increase the likelihood of success. In some cases, fertiliser can also be added at the time of planting - this is particularly important where organic material has been removed during construction. The key elements are nitrogen, phosphorus, potassium and sulphur, but this will depend on local soil types and conditions.



Figure 118 - Batter slopes grassed to control erosion

When considering which type of seed mix to use for grass control, preference should be given to those which are:

- fast growing
- easy to sow
- adaptable to the local soil type(s) and environment
- regrowth in subsequent years
- commercially available
- low maintenance and low cost

11.6.3.1 Planting

The optimum time to plant is when temperatures are just beginning to rise, and there is plenty of moisture and sunlight - usually during Autumn and Spring.

Best results can be achieved if the seed is evenly distributed, is in contact with the soil, and has a light covering of soil. However, this may be impractical, and heavy rainfall or strong winds soon after planting may wash or blow the seed away. Therefore, the best time to plant is before a light shower of rain or a heavy dew. This will help the seed to get established.

11.6.3.1.1 Hydroseeding

Most of the seed distribution can be completed by hand-broadcasting seeders. Another method is hydroseeding in which a mixture of seed, mulch, fertiliser (if required), and water or is sprayed onto the batter slopes. The advantage of this method is that the seed is held on the batter slopes by the mulch, which not only is a fertile material but also helps to prevent the seed from being washed away in heavy rain, or blown away in high winds. This process is effective for large steep areas with very infertile soils. Another option for infertile soils, or in areas where the organic material has been removed, is to add a layer of fertile soil, and then sow the seed.

11.7 DRAINAGE OF LANDINGS

(See also Chapter 13)

Steps to be taken both during construction and following the completion of a landing include:

- Always have good drainage around the bottom of landings
- Compaction of landings in layers during construction using a roller or rubber tyre machine will help eliminate natural consolidation.
- Have a bench around landings to allow for any slippage of uphill material and logs/debris.
- Slope landings and skid sites back away from the edge by a minimum of 3% for good drainage.
- Roll the final skid level for good water drainage.

When constructing a landing or skid site, keep a watch on local weather conditions for adverse weather approaching. Putting in good drains at the end of each day will help to drain any overnight rain quickly, allowing further work to continue sooner.

11.8 EQUIPMENT

The equipment used for culvert installation and the construction of ditch drains include bulldozers, excavators, backhoes, front-end loaders, graders and dump trucks, most of which will be present at the time of road construction. However, some culverts are positioned after construction of the road, and this is usually completed using an excavator or backhoe.

See section 7.5 for machine types and production rates.

WATERWAY CROSSINGS

CHAPTER 12 - WATERWAY CROSSINGS

12.0 INTRODUCTION

A significant proportion of the total road construction cost can be due to the waterway crossing structures required, therefore, if at all possible, they should be avoided or minimised to as few as possible when planning a road layout (see chapter 6).

However, where waterway crossings are required they must be correctly designed and constructed to ensure a long and trouble-free working life.

The potential for contamination of the waterway is significantly increased at the point of crossing, not only during construction, but also as vehicles pass over the waterway crossing structure, and if there should be any undermining of the approaches and abutments.

12.1 TYPE AND LOCATION

The following factors have the most influence on the type of waterway crossing that should be used:

- Intended use
 - includes fish channels
 - logging traffic versus light vehicles
- Size of the waterway
- Waterway bed and bank material and stability
- Peak water flow level and design peak flow level
- Topography and catchment characteristics
- Geology
- Water quality requirements

The major types of waterway crossings in New Zealand are:

- Culverts - including arch (half-pipe), box, and oval culverts

- Bridges - including permanent structures as well as temporary portable structures
- Fords - including open and concrete pad fords
- Temporary waterway crossings - including corduroy log bridges
- Combination - battery culverts

The initial planning of a road construction project will identify potential waterway crossing sites. The requirements for a potential crossing are that it should cross the narrowest point of the waterway at right angles, and the banks are stable. Fords or battery culverts should be positioned at shallow points which have low stable banks, and a stable bed.

12.2 CULVERTS

Culverts are the most common waterway crossing structure used for water control in forestry roads in New Zealand. Compared with other waterway crossing structures, culverts are easy to install and relatively cheap, and, if designed, constructed and maintained correctly, they will deliver good service for many years.

Culvert sizes must be calculated to cope with the peak water flows from the catchment. An engineer's input will usually be obtained when designing major culverts to ensure that they satisfy regional council requirements. A major culvert which is to be constructed on a permanent arterial road must be designed for a 50 to 100 year storm event. This will eliminate major damage to the road and culvert, and to any other water control structures. Therefore, the road will remain open during high storm and flood events. However, due to the low traffic volumes along secondary forestry roads, the cost of delays due to surface flooding is usually low, therefore, the design discharge of a culvert can be lower than the catchment discharge, and a recommended 5 to 10 year flood return period should be used for the design. This design criterion, with the added floodway development, allows excess water to pass over the road without any major damage to the road or culvert.

Culverts are best suited for situations where medium to low water volume flows are experienced, and where there is medium to low debris potential.

12.2.1 Pipe Culverts

Types of pipes most commonly used are:

1. Reinforced concrete pipes have very good hydraulic characteristics, and are excellent for situations where a high load bearing capacity is required. They can be re-used very easily, and will last for long periods without corroding or losing their structural strength. One disadvantage of concrete pipes is that they are heavy, and therefore hard to handle and place into position - heavy equipment is required to transport, load, unload, and position them. However, despite these constraints, concrete pipes have been used successfully for culverts for many years, and will continue to be used in the future.

2. Corrugated Galvanised Steel and Plastic culverts are made from pipe sections, which are, butted together, locked, or overlapped to give a snug watertight fit. Because of their lightweight construction, they can be assembled on the job, and require only one or two people lay them into position. Also, transportation and handling costs are reduced due to their lightweight design. The corrugated pipe construction means that these galvanised steel and plastic culverts have a lower water discharge capacity, (diameter for diameter), than the commercial smoothbore reinforced concrete pipes.

3. Corrugated Aluminium pipes could be used in situation where the soil or water is likely to corrode alternative pipes. Due to their non-rusting characteristic they have a longer life potential in harsh environments. Also they are also lightweight therefore easy to handle and transport.

12.2.2 Box Culverts

There are many different types of box culverts available, including a U-shaped trough with a lid, and an inverted U founded on a concrete base (figure 119). Box culverts

have a distinct advantage over other culvert type structures - they can cope with large flows where headroom is limited, and for an equivalent waterway area, box culverts can accommodate significantly larger flows than corrugated alternatives

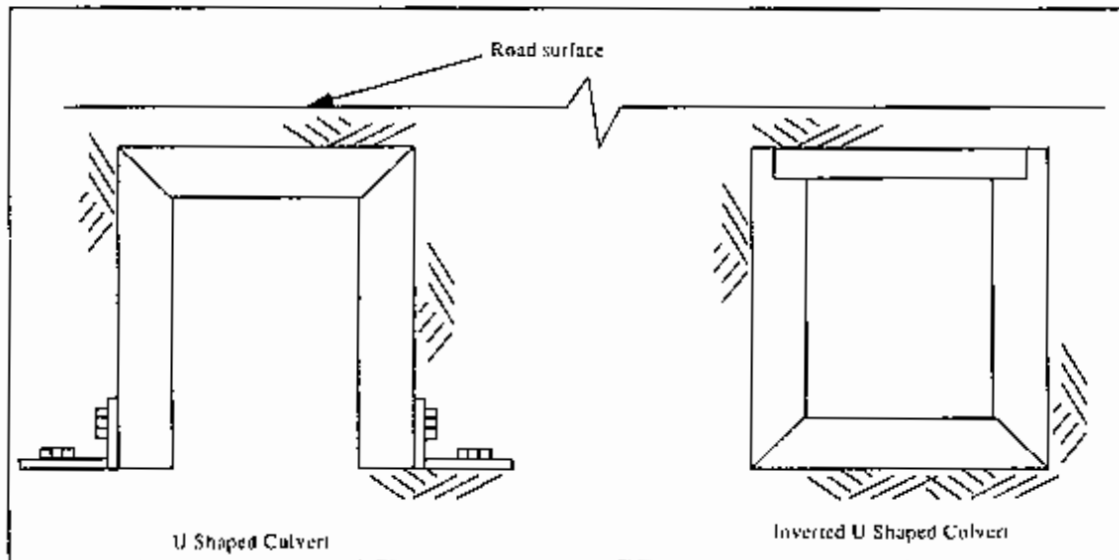


Figure 119 - Box Culvert designs

Another advantage of box culverts is the minimal excavation and back filling required, they are therefore ideal for placing in areas which are difficult to excavate such as solid rock. They are also designed to withstand heavy wheel loadings and can therefore cope with little or no fill material placed over the culvert to distribute the load. This design allows the box culvert to be used for "instant" waterway crossings, allowing for minimal traffic disruption or delays, since traffic does not have to wait for fill to be compacted or other in-situ construction techniques to take place.

12.2.3 Battery Culverts

The battery culvert (figure 120) is suited to situations where there is a requirement to keep vehicle wheels dry during normal flow, but during high flow events overtop flow is acceptable. The finished design height should be as low as possible to allow continued water flow. They are ideal for situations where a fish passage must be maintained, and they have no load restrictions, making them suitable for all forestry and logging traffic. Overall, the battery culvert is a low cost alternative to an equivalent high-level bridge.

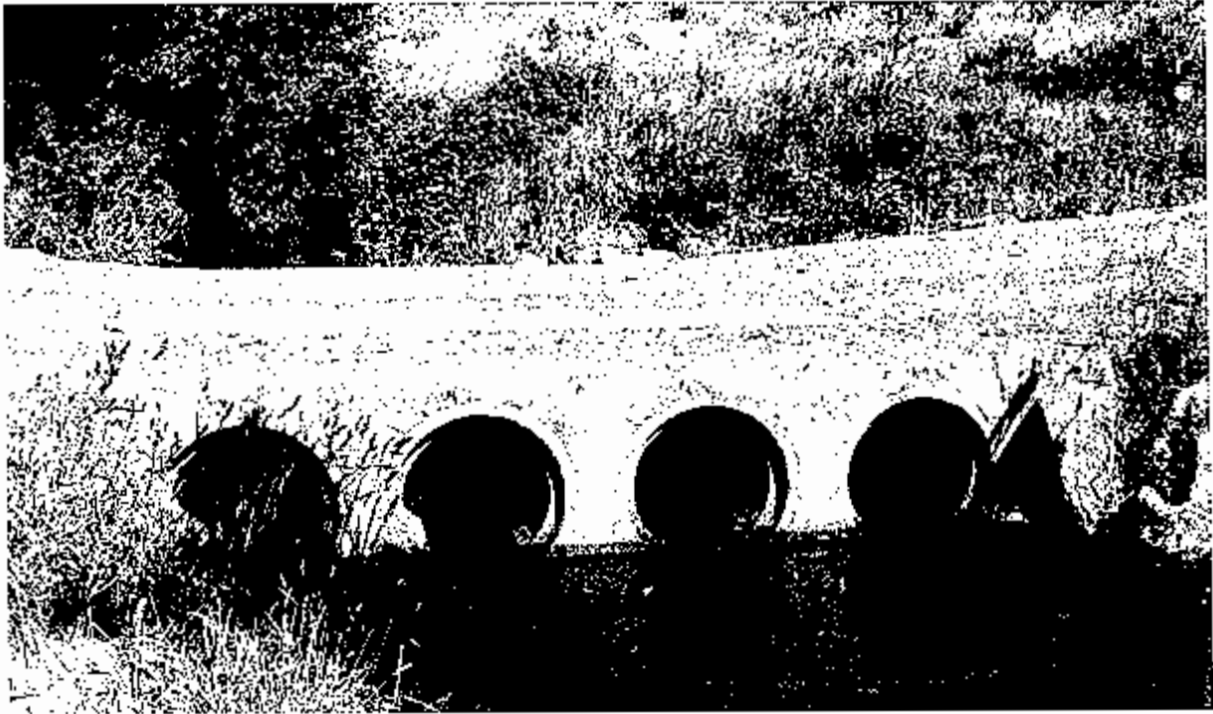


Figure 120 - Battery Culvert

12.2.4 Arch (half-pipe) Culverts

Arch culverts can span up to approximately 12m, and can cope with flow rates of up to 75m³ per second. They can be used where there are fish present since they allow the natural streambed to be retained.

The limited amount of design work required, and their ease of installation make the arch culvert an attractive alternative to a bridge.

12.2.5 Log Culverts

Log culverts (figure 121) can be very inexpensive, since most of the materials required are available on-site or near by. They are ideal in situations where small streams are to be crossed without disturbing the stream bank or bed, and are especially good for steep gradient streams, and streams where ongoing minor debris problems are expected. A log culvert should be considered as only a short-term structure for temporary roads, or, on permanent roads, as a temporary structure until a permanent structure can be installed.

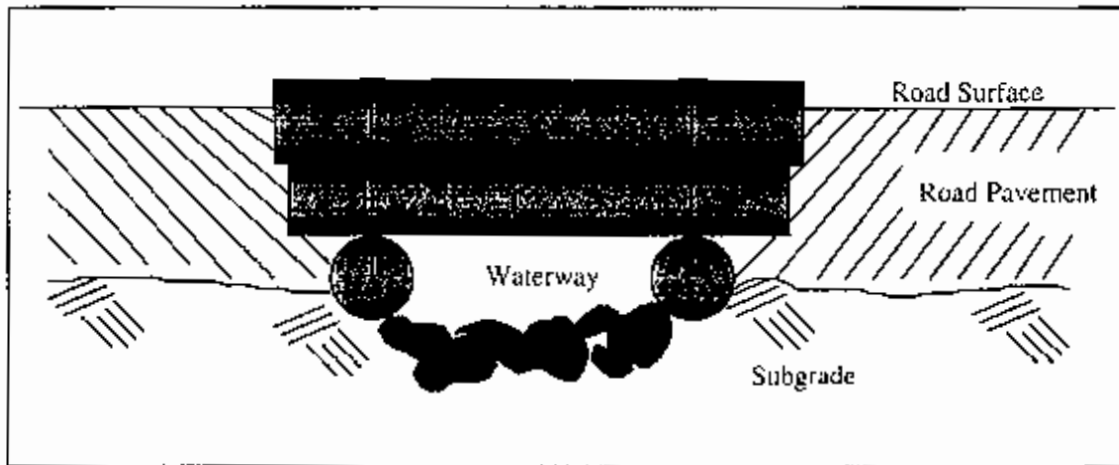


Figure 121 - Log Culvert

12.2.6 Size of Culverts

There are three main methods used to estimate culvert size:

- (i) Old culverts at the proposed waterway crossing site (or culverts up or down stream on the waterway, within the same catchment) can be inspected and used as a design template.
- (ii) An empirical formula can be used to directly determine the required size of the culvert opening.
- (iii) A formula can be used to determine the amount of water reaching the culvert, then a second formula or a graph is used to determine the culvert size required to carry that amount of water.

12.2.6.1 Determining Size by Inspection

Existing culverts within the same catchment can be used as a design template if they have been in place for a significant amount of time without needing constant maintenance, and have not been hindered by undermining, scouring or by-passing.

This is the most widely used method of determining culvert sizes for water control. However, it must be done with an some caution owing to possible changes in upper catchment vegetation, increasing the catchment water volume discharge. Also, care is

needed crossing large waterways where high water flows are expected, and with culverts built during drought years may be inadequate in the future.

12.2.6.2 Use of an Empirical Formula

An estimation of the design peak flow discharge can be obtained from hydrological measurements obtained from catchment rain gauges (Pluviometers) and then applied to standard methods, such as flow frequency analysis and unit hydrographs, to determine the culvert diameter required. A check with the New Zealand Meteorological Service, Regional Authorities, or the National Institute of Water and Atmospheric Research (NIWA) will determine if up-to-date hydrological measurements are available in the catchment area. For catchments that do not have gauges, the design discharge must be estimated by empirical methods.

There are many empirical formulas which can be used to determine the culvert size required for any given catchment area, topography type, and rainfall intensity. Most of these formulas calculate the design peak discharge, which can then be used to determine the culvert diameter, using the appropriate nomograph.

Of the many formulas, the four most commonly used in New Zealand are:

Formulas determining discharge from a catchment:

1. *Technical Memorandum No. 61 (TM 61)* - Developed specifically for New Zealand conditions, and can be applied to catchments up to 1000 km², (100 000 ha) (with some conditions applied). However, some evidence suggests that this formula underestimates design peak discharges for small catchments of 1 to 25 km² (100 ha - 2500 ha) in the **Northland** and **Auckland** regions. There is also evidence that in some areas of the Central North Island, TM61 overestimates discharge. TM61 is widely available in many libraries. See "A method for estimating design peak discharge TM61" Planning and Technical Services, Water and Soil Division, Ministry of Works and Development, June 1984.

2. **Rational Method** - Acceptable when applied to small catchments of between 1 and 25 km² (100 ha - 2500 ha). This formula is also specifically design for New Zealand and appeals because of its simplicity.
3. **Synthetic Unit Hydrograph Method** - Used for very large catchment areas and can be more reliable than the results obtained from TM61. A very useful but elaborate method as described by Linsley *et al* (1958, pp.203-208) and Gray (1970, pp.8.36-8.47). *Note: This method is not developed further in this manual.*

Formulas directly determining actual culvert size required:

1. **Talbot Formula** - This formula gives the culvert size directly and therefore is constantly used in New Zealand. However, it is an empirical formula based on a large number of observations in the U.S.A and is therefore not directly relevant to New Zealand conditions. It also often over-designs in areas of low rainfall. This formula should be used with caution and results obtained should be checked using a New Zealand specific formula. Various modified Talbot Formula methods are documented from the USA and New Zealand.
2. **Manning's Formula** - This is a widely used formula to determine the flow from a catchment. It relies on the easily determined characteristics of the water flow channel and the surrounding floodplain.

The Rational Method, Manning's Formula and Talbot Formula procedures and examples can be found in Appendix D, following this section of the manual.

Note: It must be recognised when using any of these formulae that there is always an element of error associated with every empirical design method. Some formulae will underestimate, and others will overestimate, so all results should be used with caution

12.2.7 Culvert Installation

Correct culvert installation is essential to the end performance and life of a culvert. Correct compaction of material surrounding the culvert will eliminate the effects due to natural culvert settlement, and also stop the culvert from being crushed under loading. Other procedures, such as maintaining the desired grade through the culvert, will help to reduce the sediment content, and stop debris settling in the bottom, increasing the risk of blockages. A grade which is too steep will increase the water flow velocity and increase the risk of scouring both in the pipe and at the pipe outlet. The resulting undermining of the culvert pipe will cause erosion of the batters and roadway.

Where culverts are to be placed in a natural waterway, they should be placed along the general grade of the stream. If the foundation is not firm enough to support both the culvert and the applied loads, then a trench should be excavated to at least $\frac{1}{3}$ the diameter of the pipe, and back-filled with a good quality "all in one" aggregate. Good compaction of this material will form a firm base which will reduce culvert settlement.

The gravel on top of a culvert distributes the applied live load and also decreases shock loadings produced by passing traffic.

12.2.7.1 Flexible Culverts

Flexible culvert pipes are usually manufactured from plastic, steel or aluminium, and are designed to flex and deform under loading. This allows a significant proportion of the applied vertical load to be transferred to the surrounding sidefill material, producing a more balanced situation than for a rigid pipe design (figure 122). It is important, therefore, that excavation for the trench be backfilled with well-compacted material. Figure 124 gives recommendations as to the size of the trench required.

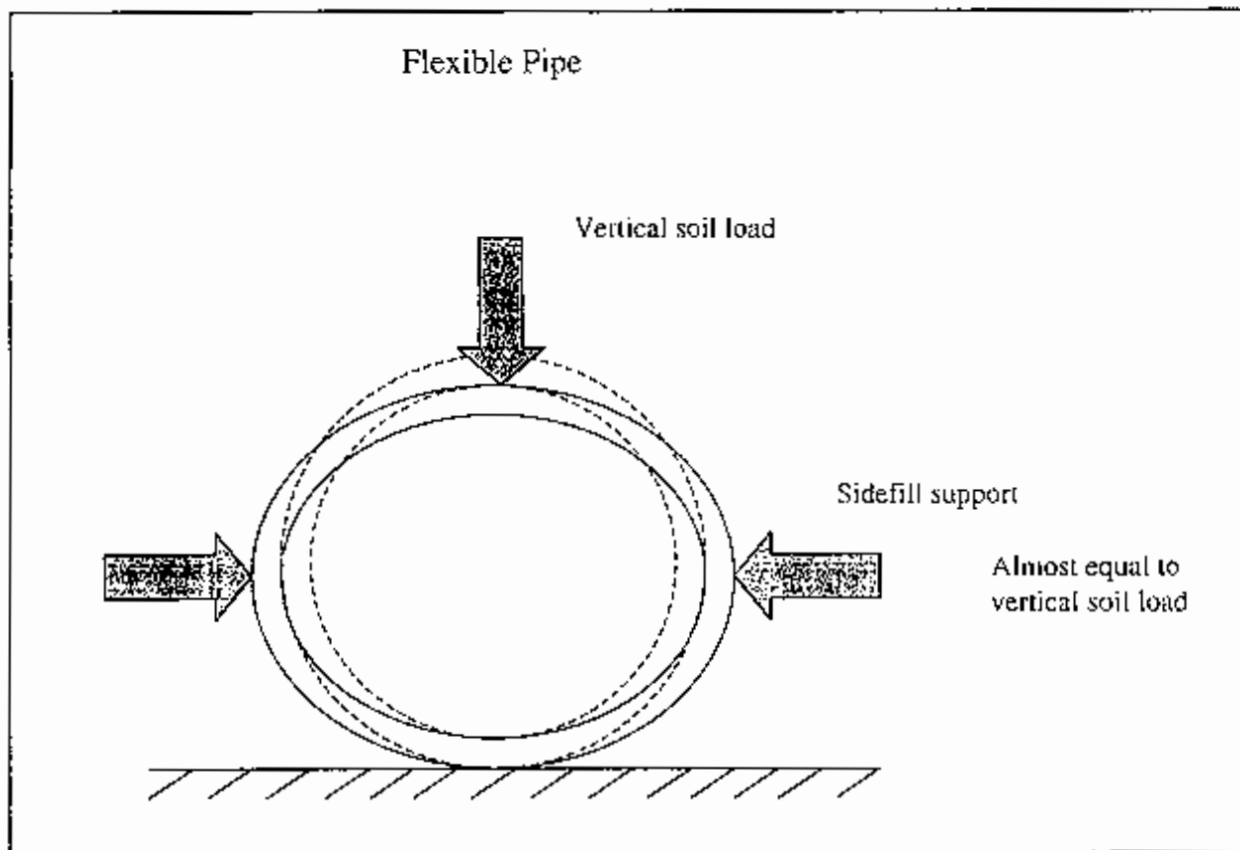


Figure 122 - Flexible pipe load transfer

12.2.7.2 Rigid Culverts

Rigid culverts, such as concrete pipes or box culverts, are designed to take the applied loads from vehicle movements over the pavement above. The rigid pipe must support most of the applied vertical load, transferring only some of this load to the surrounding fill material. Therefore, little, or in some cases no side-fill support is developed (figure 123).

12.2.7.3 Foundations

When constructing the foundation, care must be taken to avoid having large rocks which would damage the pipe, or force it to be skewed sideways. This is particularly important for concrete, steel and aluminium pipe culverts, but may not be as necessary for plastic culverts since they can be slightly diverted around an obstacle. In situations where some settlement is expected, it is advisable to curve the foundation upward near

the centre of the culvert, so that, after settlement, the pipe should be at the desired grade, rather than having a sag in it.

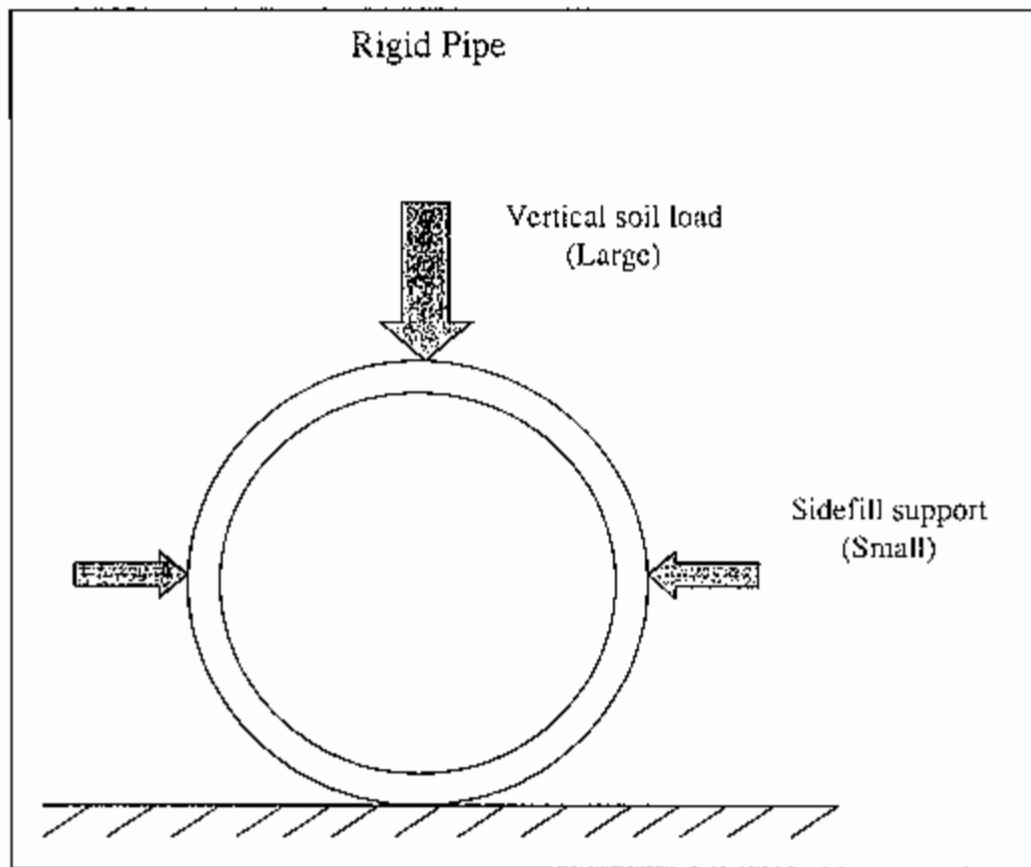


Figure 123 - Rigid pipe load transfer

12.2.7.4 Backfilling

Backfilling around a culvert must be completed correctly to ensure that the pipe will not sag after natural settlement, and to help distribute the applied loads. For flexible culvert pipes, the correct compaction of material around the pipe will ensure efficient load transfer - without correct compaction the pipe may be crushed under loading. The backfill material also distributes the shock loading applied during traffic movement over the culvert. The material used for backfilling should be an "all-in-one" grade material that will compact easily. To achieve good compaction, and eliminate natural settlement, the material should be placed and compacted in layers of 150 to 200 mm. Ideally the optimum moisture content (OMC) should be achieved during compaction.

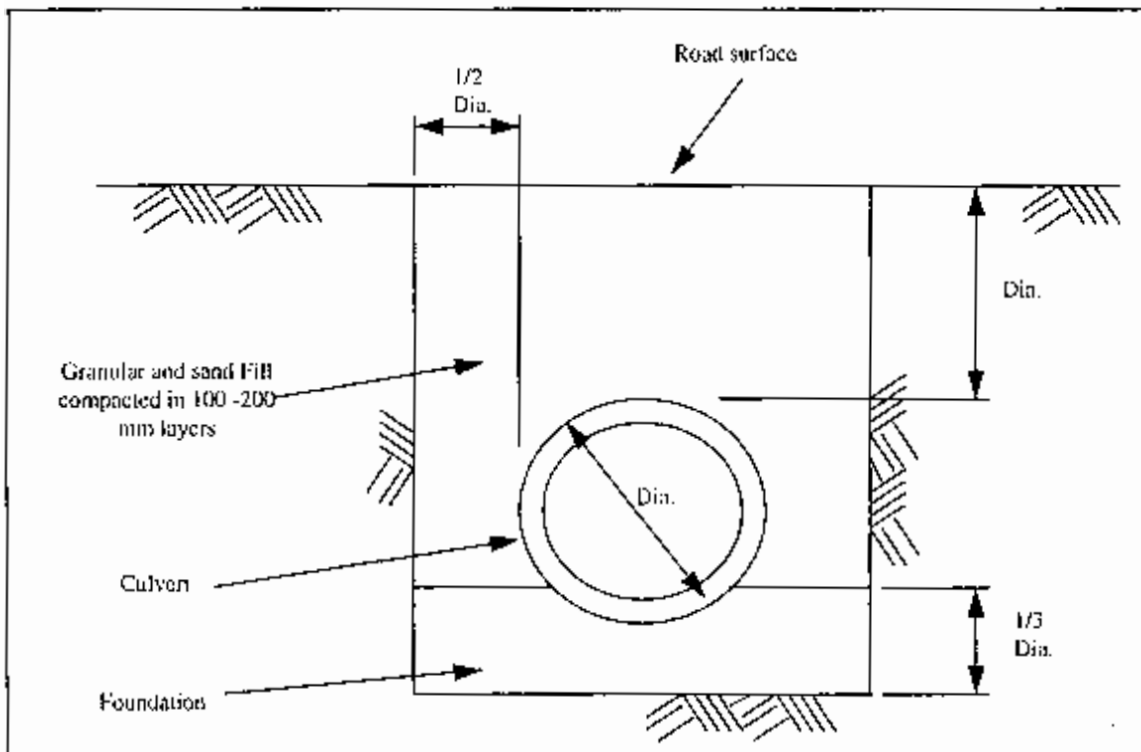


Figure 124 - Culvert installation practices.

Note: Most pipe and culvert manufactures and suppliers will have their own practices and procedures on how their products should be installed. This information would supersede any information presented in this manual.

12.2.7.5 Construction of a culvert in a flowing stream

When constructing a culvert in a flowing stream, the flow must be temporally diverted clear of the proposed culvert line using pipes, flumes or drainage ditches (figure 125). Where the flow is too large to divert, it will be necessary to let it remain in the channel, and to construct the trench for the culvert alongside the channel. A solid block of earth or rock upstream can be used to stop the flow of water into the construction site until the culvert is completed.

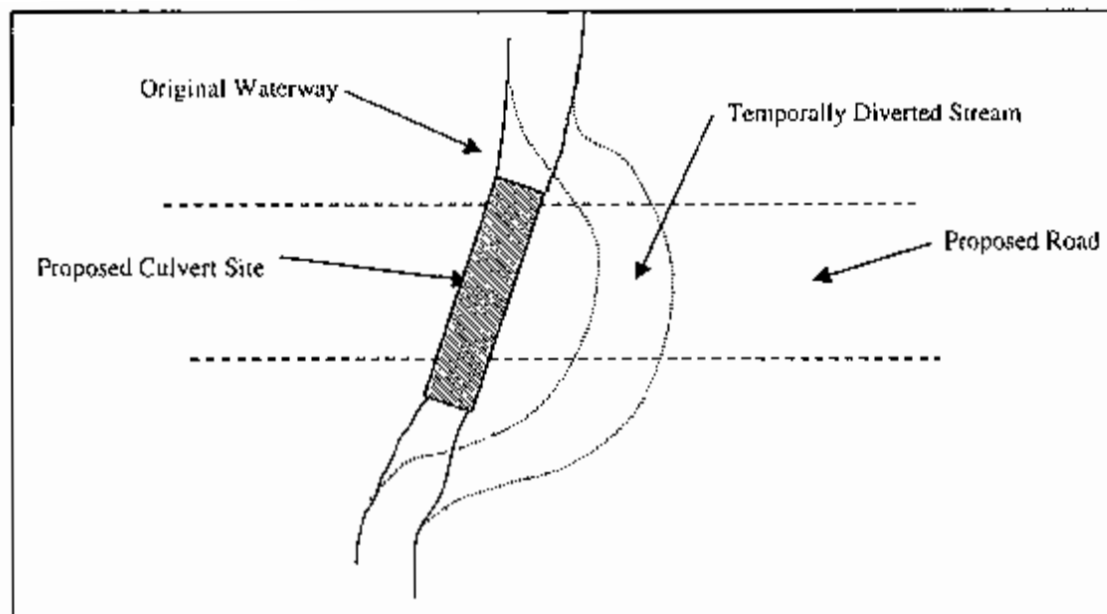


Figure 125 - Temporarily diverted stream for construction of culvert

12.3 BRIDGES

Permanent forestry bridges in New Zealand are normally used on arterial roads, and on some secondary roads where it is essential that access be maintained. Bridges are normally used in situations where resource restrictions prevent the use of culverts, due to their restrictive nature, or where the waterway span is too large for a culvert. Bridges are less likely to block than culverts.

In some instances, temporary portable bridges are used for logging traffic for short-term harvesting and transport access. These bridges are usually low-level structures used to eliminate sediment from vehicles travelling through the waterway or are required for access into blocks with difficult terrain.

Bridges are recommended for use when the following conditions exist:

- Medium to high traffic flows
- Significant fish resource
- Large and variable water volumes
- High debris potential
- Sensitive channel bed and banks
- High waterway banks

12.3.1 Types of Bridges

There are many bridge designs for both permanent structures and temporary waterway crossings. However, since bridges must be designed to carry heavy loads, usually in high volumes, then the design should be completed by a qualified civil engineer.

12.3.1.1 Permanent Bridges

Permanent bridges should be used on major arterial roads, and on secondary roads which have high traffic volumes. They are designed with enough clearance to allow high floodwaters and debris to flow underneath. The clearance required will depend on local authority regulations, the flood return period chosen for design, and the debris potential in the catchment above the bridge site. Many prefabricated designs allow for quick assembly and easy installation in a remote forestry situation. However, limitations on their use may result due to limited access through tight corners and steep slopes. This should be checked before initial design work is started.

12.3.1.1.1 Log Bridges

The design and construction of log bridges is similar to that of log culverts but on a larger scale. However, because it has a longer span, the log bridge may be required to support the entire weight of a fully loaded logging truck or other machine. Therefore, the design of such a structure requires certification from a civil engineer. The construction of log bridges is a very complex and detailed process. This manual does not give detailed design and the following reference should be consulted for design practices and procedures (Nagy M et al, 1980 *Log Bridge Construction Handbook* FERIC).

Log bridges covered with earth are subject to rot and in New Zealand is seldom an economic method of bridging.

12.3.1.2 Temporary Bridges

When short term access (less than six years) across a waterway is required for harvesting operations, portable or removable bridges are an attractive alternative. Using portable bridges can allow greater flexibility for positioning roads, and skidder tracks, and, if used over a number of sites, the initial capital cost can be spread over all sites. Portable bridges have the following advantages:

- The cost distributed over a number of sites
- The waterway is easily restored to its original condition
- There is minimal waterway disturbance
- They have a simple, rugged, lightweight design
- They are easy to transport from site to site

Portable bridges are designed for rapid construction and dismantling most consist of prefabricated beams and decking which is transported to the site, and placed over the waterway, however, some are constructed on-site using second-hand materials.

Spans of up to 25 m can be bridged with prefabricated beam structures, requiring a loader, excavator, or crane to place them into position. Most of the machinery required for the construction of these bridges, is readily available in most forests, so cost of construction is less. Smaller bridges can be unloaded by a loader, and dragged into position with a skidder.

Abutments are usually constructed using large logs, or sometimes concrete, depending on the ground conditions and potential traffic loadings, and the waterway bank stability. All abutments should be designed by a civil engineer.

Bridges used only by forestry machines can be, stream crossing mats, dam bridges, or steel bridges.

Bridges to be used by logging trucks are usually constructed from stress or glue laminated beams, pre-stressed concrete, or taped steel beams.

Alternatively low-cost short span bridges can be built using open railway wagons placed side-by-side across a waterway (figure 126).



Figure 126 - Portable temporary bridges using railway wagons

12.4 FORDS

Fords are used in situations where the waterway has stable banks which lead across a natural low section of the waterway, making it easy for the road grade to be brought down to the level of the channel bottom. A stable waterway bed with low to medium water flow is essential for the viability of a ford. Fords are ideal for situations where:

- High debris potential is expected
- There is no fish resource present
- Low traffic volumes or intermittent use are expected

The potential for sedimentation from a ford is significantly greater than from other forms of waterway crossings, and care must be taken to limit this. Environmental considerations such as damage to habitat, reduction of water quality downstream, and the effects on fauna and flora can be controlled using correct design and construction techniques and procedures.

Most fords are only used for temporary crossings for logging vehicles or, possibly for more permanent use for silvicultural vehicles. Due to the potential risk of flooding and the ford becoming impassable, they are only used where it is *not* essential that vehicle access be maintained.

Concrete pads are sometimes used on the riverbed to give a good traction surface and to reduce sedimentation. This will also reduce the risk of erosion of the waterway bed, and is usually only completed at permanent ford structures.

12.4.1 Design of Fords

The best solution to a successful ford is to maintain the natural grade of the waterway as much as possible. Initial planning should allow favourable grades to lead to, and from the crossing. Large diameter tailings from a quarry or river can be used for the downstream edge of the ford, producing a weir type structure which will reduce the erosion of the waterway bed. This should only be undertaken if a fish resource is not present, and upstream access for fish is not required.

The road profile should be designed so that it will dip into and out of the waterway, in a concave shape which is sufficiently deep to prevent water from being diverted down the roadway. The crossing should always be at right angles to the stream.

12.4.2 Constraints

The manner of use, and level of maintenance of a ford is critical to ensuring its long life. In order to eliminate any structural or environmental damage from occurring:

- Nothing should be allowed to be dragged or skidded across the ford
- Vehicles using the ford should not leak fuel, oil or other fluids
- The ford should not be used if the water depth is above the axle of the crossing vehicle
- Restrictions on the time periods allowing crossing (where necessary) should be strictly adhered to

Further Reading

Frechette, J. 1989: *The Use of Gabion Abutments For Light Bridge Construction on Private Woodlots*. Forest Engineering Research Institute of Canada (FERIC) Field Note Number: Roads and Bridges - 13

Froehlich, H.A. 1990: *Pipe-arch Culverts*. Forest Engineering Department Oregon State University

Makkonen, I. 1991: *Portable Forwarder Bridge*. Forest Engineering Research Institute of Canada (FERIC) Field Note Number: Roads and Bridges - 25

Moll, P.E. Mason, L.E. 1995: *Pipe Bundle and Pipe Mat Stream Crossings*. United States department of Agriculture Forest Service (USDAFS)

Murphy, G. Marvin, R.P. 1989: *Cost-Effective Selection of Culverts for Small Forest Streams*. Journal of Forestry Volume 87 No 10.

Nagy, M. Trehett, J. Wellburn, G. Gower, L. 1980: *Log Bridge Construction Handbook* FERIC

LANDING CONSTRUCTION

CHAPTER 13 - LANDING CONSTRUCTION

13.0 INTRODUCTION

The construction of landings and skid sites is relatively straight forward. A landing can be thought of as simply an extension of the access road, where the road becomes wider and flat. Therefore, the initial planning, setting out, and construction procedures and techniques are very similar to those for road construction.

13.1 LANDING POSITION

During the initial planning stages (see chapter 6) the landing position(s) should be determined. The site will be determined by the harvesting system, road access points etc.

13.2 LANDING DESIGN

There are many variations of landing design. Which design to use is usually determined by a number of factors. These factors include:

- Available area
- Terrain
- Soil type
- Types of machinery to be used on landing (i.e. hauler vs skidder, Madill 071 vs Thunderbird Swing Yarder, Rubber tyred front-end loader vs excavator etc.)
- Number and size of log stacks
- Processing area requirements
- Tree length (i.e. $\frac{3}{4}$ length required to land log on landing)
- Loading out facilities
- Access points (i.e. roads entering at a certain point)
- Truck maneuverability requirements
- Storage requirements
- Machinery production (i.e. to reduce effects of bottle necks)

When designing a landing layout several general rules should be followed to maximise the area utilisation:

- Stack logs around perimeter
- Keep fastest moving logs in the most accessible location
- Keep all log but ends in the same direction for easy loading

13.2.1 Size

As a rough guide to the size required for various landings, the following formulas can be used:

Hauler Landings:

$$A = 0.015 + (0.00022 \times A.L.L(m)) + (0.014 \times N.L.S)$$

Where: A = Landing area in hectares
 A.L.L = Average Log Length (m)
 N.L.S = Number of Log Sorts

Skidder Landings:

$$A = 0.01 + (0.0005 \times P (m^3/Day) + (0.016 \times N.L.S)$$

Where: A = Landing area in hectares
 P = Production (m³/day)
 N.L.S = Number of Log Sorts

13.2.2 Shape

The shape of a landing will be determined by a number of factors, including:

- Topography
- Number and length of log stacks
- Type and quantity of machinery working on the landing
- Roading access options
- Loading facilities

The three basic landing shapes used are circular, rectangular and square. Table 35 gives the comparative landing dimensions and available perimeter size for a 0.24ha landing of various shapes.

Landing Dimensions	Area	Available Perimeter
28 m Radius	0.24 ha	176 m
49 x 49 m square	0.24 ha	196 m
60 x 40 m Rectangle	0.24 ha	200 m
80 x 30 m Rectangle	0.24 ha	220 m
100 x 24 m Rectangle	0.24 ha	248 m

Table 35 - Comparative landing dimensions

13.2.3 Generic Landing Layouts

1. Drive-Through Landings

Drive-through landings (figure 127) are used where a loop road allows trucks to enter the landing from one end, continue through the middle of the landing, and leave via the other end. This reduces the area required for turning circles. Logs can be stacked on both sides of the road allowing the truck to be loaded from either side.

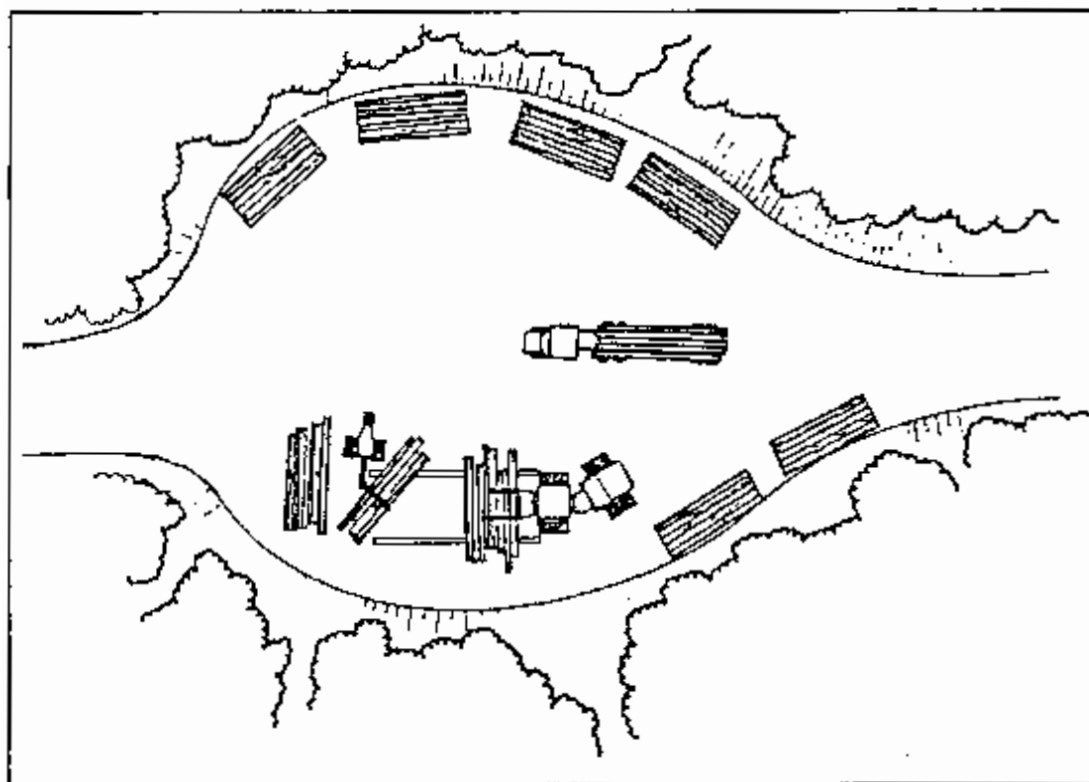


Figure 127 - Drive through landing

2. Roadside Landing

This design (figure 128) is very similar to the drive-through landing, however the landing is positioned to one side of the road only. The main disadvantage of this design is that trucks can only be loaded from one side.

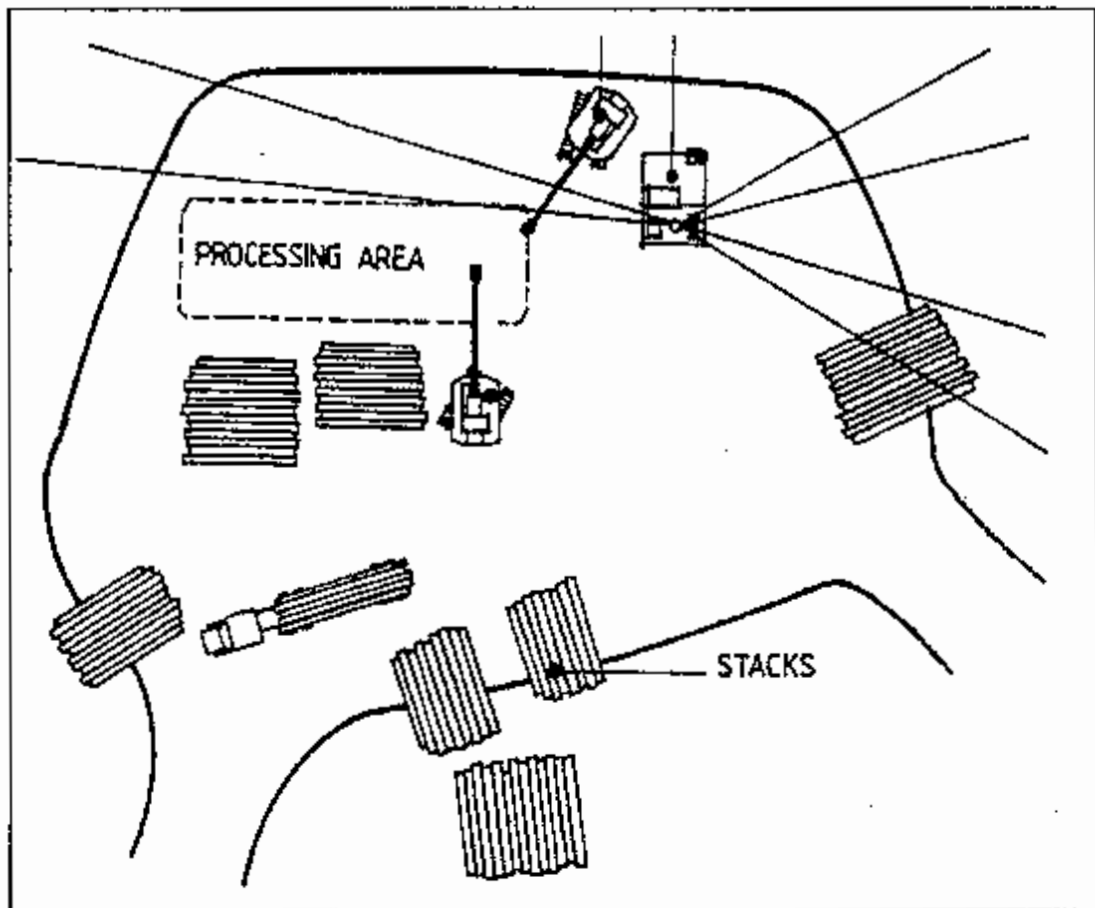


Figure 128 - Road side landing

3. Spur Road End Hauling

These landings (figure 129) are used in difficult terrain where access is difficult, or construction is too costly to provide a through road. The landings are larger, since a turning area is required for trucks, wasting space which would otherwise have been used for log stacks or processing.

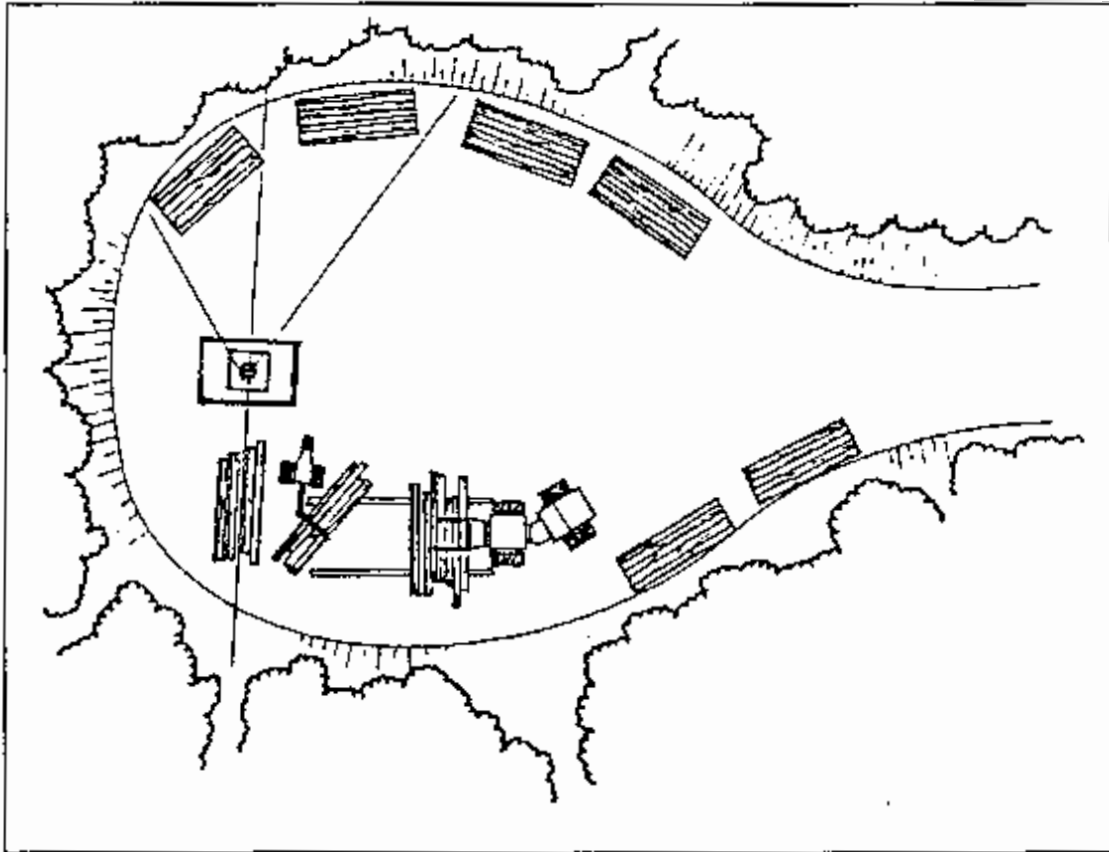


Figure 129 - Spur road end hauling landing

4. Split-Level Landings

Split-level landings (figure 130) are an option in steep country. The hauler is sited the upper level, and the lower level is used as the landing and processing area. The advantages of split-level landings are that they require less earthworks, and their batter slopes can be shorter. This results in less scouring and improvements to the visual impact.

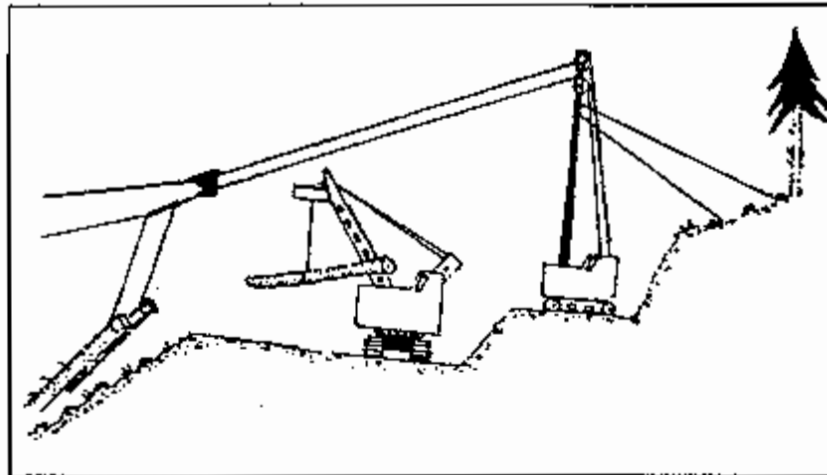


Figure 130 - Split-Level Landing

5. Two Stage operations

Two stage operations use two (or more) landings or skid sites - where one is used to land logs, and the other is used to process, stack, and load out. They are ideal for steep or difficult country, where the construction of a full-size landing may:

- Require extensive earthworks
- Create difficulties for trucks accessing the landing i.e. two steep approach
- Generate adverse environmental aspects from large quantities of earthworks

Two-stage operations require a skidder or forwarder to move the logs from the landing to the processing area.

13.3 CONSTRUCTION

Landing construction requires a similar process to road construction. The landing site should be marked out, by completing the following steps:

1. Position the cut and fill pegs as for road construction (treat the landing as if it were an extremely wide but very short road).
2. Mark the trees which is to be removed to allow earthworks to be completed.

3. Mark the trees to be removed to allow sight distances to be improved (for entering and exiting traffic).
4. Mark trees to be cut high for hauler guyline anchorage points
5. Remove all marked trees
6. Construct landing

An excavator or dozer usually completes construction of a landing or skid site. The top organic material is stripped off the landing site and disposed of. The dozer or excavator then strips further material until the desired final landing level is achieved.

13.3.1 Construction Techniques

Three main methods of landing construction can be used. The soil type and the environmental considerations such as stream sedimentation and visual effects will determine the construction method chosen.

1. Sidecasting

Utilising a crawler tractor or hydraulic excavator, the landing can be formed by sidecasting material onto the cutover.

Potential Adverse Impacts -

- Sedimentation and runoff from landing surface and sidecast spill may cause reduction in water quality
- Risk of scouring or slumping on unstable sites
- Loss of productive forest land or permanent reduction in site productivity from removal of top soil and compaction
- Visual impact on steep terrain

Methods of Reducing Adverse Impacts -

- Locate landings on stable sites by identifying and avoiding unstable areas
- Prevent runoff on to landings or fill
- Compact landing prior to use
- Locate away from water courses and avoid depositing spoil in waterways
- Ensure landing runoff is filtered through sediment traps or existing vegetation before entering waterways
- Use cut and fill or endhaul techniques on sensitive sites
- Re-vegetate batters and spill where necessary
- Avoid construction in wet conditions
- Allow sufficient time for stabilisation before use
- Use small logs to corduroy wet sites and spread load

2. Cut and Fill

This technique is essentially the same as sidecasting however the fill material is placed and compacted in place instead of being pushed into position. Usually any combination of a, bulldozer, excavator, motor scraper, compactor or grader, are used for cut and fill operations.

Potential Adverse Impacts -

- The adverse effects of this technique are very similar to sidecasting, but less risk of high quantities of sediment.

Methods of Reducing Adverse Impacts -

- As for sidecasting the same techniques can be utilised to overcome the adverse effects.

3. End Hauling

End hauling operations cut all material from the landing site and transport this material to a dump site. No sidecasting or fill construction is completed. This method is ideal for steep or difficult country where adverse environmental effects would be encountered with other construction techniques.

13.4 WATER CONTROL

As for a road pavement, water control is critical to the survival of the landing or skid site. A few simple methods which will help to control water runoff are:

- Compact layers of material during construction.
- Place benches around the bottom of the landing to eliminate debris and water from cascading down the cutover.
- Slope the landing backwards away from the landing edge by at least 3%.
- Position a drainage channel at the back of the landing to collect and direct water runoff.

See also section 11.7

13.5 SUMMARY

Useful techniques for construction of Landing sites:

- Do not push too much material over the edge when sidecasting
- Always strip and remove organic material from the construction site
- Soil compaction during construction reduces the time-frame between construction and utilisation and help drainage
- Benching around landings will control slippages or other material from rolling down the cutover
- Slope landings away from the edge by approximately 3% for good drainage
- Always have good drainage away from the landing sites

When construction is being undertaken care should be taken to limit the risks that adverse weather may have on the site. Putting in good temporary drainage systems at the end of each day's construction will enable the site to be drained quicker, and therefore construction can continue earlier once the weather clears.

ROAD MAINTENANCE

CHAPTER 14 - ROAD MAINTENANCE

14.0 INTRODUCTION

Every pavement, no matter how well designed and constructed, will deteriorate due to traffic, weather conditions, and material properties. Regular maintenance is therefore required to provide the desired level of service for each road. Efficient scheduling of maintenance will prolong the life of the road by decreasing the rate at which deterioration occurs.

Maintenance practices need to be specifically designed for the pavement type, and for the traffic volume, frequency and axle weights. Unsealed roads are very susceptible to rapid deterioration caused by traffic damage and water entering the pavement. Maintenance not only preserves the road, but also protects other resources, maintains user safety, and provides efficient travel along the route.

14.1 LEVEL OF SERVICE

A level at which the road is allowed to deteriorate before maintenance is required, must be determined. This level is completely arbitrary and is specific to each situation. It may be the level of roughness, or simply the time it takes a vehicle to travel over the road. It is essential to have such a measure, since without specific indicators it is very easy to do too much maintenance and therefore waste money.

Forestry roading is usually only maintained when the severity and frequency of defects such as corrugations, potholes, rutting, and loss of crossfall becomes noticeable. This is therefore usually used as the level of service indicator.

14.2 MAINTENANCE REGIMES

There are two types of maintenance which are used for any road network:

Preventative maintenance

Under this regime, the road is constantly maintained from the time it is constructed, to help prevent any major defects and pavement damage from occurring. This prolongs the life of the road, but it may have a high cost since it has a high demand on resources, and therefore may not be economically viable. Preventative maintenance usually has:

- A higher initial cost
- An increased service life of the road
- Reduced vehicle costs
- An increase in safety for road users
- More efficient use of maintenance resources.

Figure 131 shows a typical preventative maintenance regime and associated user travel time, vehicle operation, accident and discomfort costs.

Note: Even if preventative maintenance strategy is adopted, some on demand maintenance may be required when unforeseen events occur.

On-demand corrective maintenance

Irregular maintenance which corrects any defect as they arise (figure 132). This prevents maintenance that attempts to predict defects in advance. This level of maintenance is low cost but the road may require rehabilitation earlier.

On-demand maintenance procedures can:

- Reduce the overall efficiency of maintenance resources
- Result in higher vehicle operating costs

- If defects are left too long they can cause severe damage which may require extensive pavement rehabilitation.

The maintenance strategy to be adopted will be determined by the importance of the road link in the network. Major roads will require preventative maintenance, whereas lower grade roads can be maintained simply on-demand.

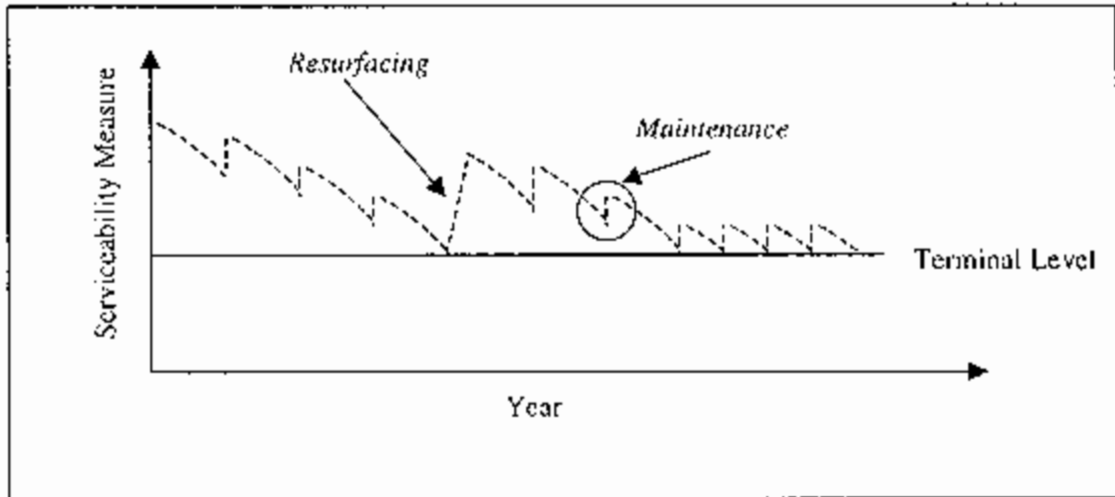


Figure 131 - Preventive maintenance regime

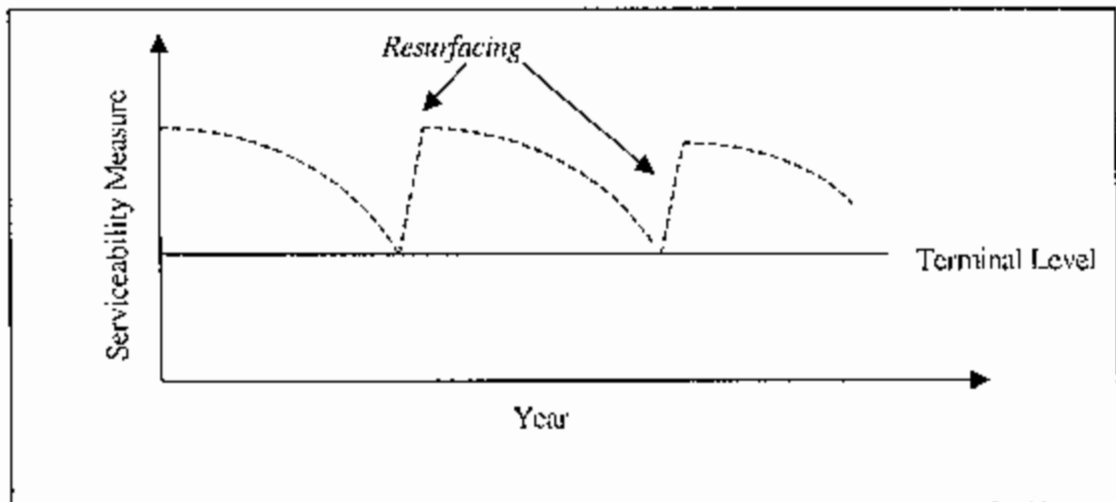


Figure 132 - On-demand maintenance regime

14.3 RECONSTRUCTION/REHABILITATION

Major repairs to the pavement, waterable drains, culverts, bridges etc will need to be completed when their level of service reaches a critical condition. These repairs include major maintenance or reconstruction to restore the road to (or near to) their original service level. The length of time between reconstruction varies depending on the volume of traffic, climatic conditions, materials used, and the maintenance regime chosen.

14.4 MAINTENANCE MANAGEMENT SYSTEMS

To ensure that a pavement is maintained correctly, regular inspection is required to identify problem, or potential problem areas. Various techniques can be employed for pavement inspection, including a regular inspection schedule based on the traffic volume, axle weights, and pavement material used. Alternatively a Road Condition Rating System (RCRS) can be used. These tools use rating indices to quantify the road pavement condition.

14.4.1 Inspections

Features which should be noted during an inspection include:

Pavement Surfaces:

- Flat crown
- Depressions
- Potholes
- Soft spots
- Shoving
- Slippery surfaces

Unsealed Shoulder Surfaces:

- Ruts

- Potholes
- Soft spots
- Low and High shoulders
- Scouring

Grassed Shoulder Surfaces:

- Build up
- Soft spots
- Poor slope
- Ruts
- Debris
- Height of grass

Water Channels:

- Debris build up
- Blockages
- Scour
- Vegetation growth

Other:

- Excessive dust
- Encroaching vegetation

14.4.2 Wet Weather Inspections

During, or soon after wet weather it is advisable to complete a road and drainage system inspection, identifying problems which may have been missed during dry conditions. This will give an indication of how well the pavement drainage system is operating, and how well culverts and other water control structures cope. Possible problems are:

- Ponding - on the road surface and in the watertable drains
- Surface flooding
- Blockages
- Leaking flumes
- Leaking culvert joints
- Seepage up through the pavement
- Water runoff across the road instead of into the watertable

The results from these surveys should then be used to develop a maintenance plan to suit the situation.

14.5 MAINTENANCE PRACTICES FOR VARIOUS ROAD CLASSES

(See chapter 4 for a detailed description of each road class)

Establishment tracks:

Usually, only light silvicultural vehicles travel over these road carriageways, therefore little, if any, maintenance is required. However, these roads should still be maintained to a level which will allow access for fire-fighting machinery.

Spur:

Spur roads are usually only maintained during the period of time they are required. The level of maintenance required is minimal, depending on the level and frequency of use. During harvesting, wood extraction operations may result in high numbers of heavy vehicle movements on the roadway, whereas during other periods, only light silvicultural traffic movements are likely.

Secondary:

Secondary roads are the feeder roads which link the spur roads and arterial routes. Most secondary roads have a steady flow of both heavy traffic and light vehicles. Over an extended period of time the level of usage will vary with the quantity of harvesting and other forestry work being completed within the secondary road catchment. This level of constant vehicle movements means that constant maintenance of these roads is needed. Although the level of maintenance may vary over time.

Arterial:

Since these roads are the major feeder routes into and out of the forest block, they must remain open. A constant, high level of maintenance must therefore be maintained. Preventative maintenance as well as on-demand maintenance is necessary to keep traffic movement constant without delays and blockages.

14.6 DEFECT CAUSES & CORRECTIVE PROCEDURES

There are many types of defects which can occur within a pavement or shoulders, they may be aggravated by a number of factors such as the presence of water, the level of traffic movement and loading, and the type of pavement materials used.

14.6.1 Surface Defects

Surface defects affect the top running surface of a pavement. These defects lead to discomfort for drivers, and damage to vehicles and goods, and they can eventually lead to greater pavement or even subgrade defects if left unattended. The following are a list of surface defects:

14.6.1.1 Corrugations

Description - Material is displaced, and arranges itself into parallel ridges which lie at right angles to the direction of the traffic.

Cause - Corrugations are caused by the bouncing movement (oscillations) of vehicles as they travel over the pavement. The mass of a vehicle can determine the level of movement - a loaded vehicle will cause little damage, whereas an unloaded vehicle will bounce significantly more, especially when travelling up slopes. Once corrugations start to form they induce further vehicle movement which increases the rate of damage to the pavement. Any irregular surface feature will initiate vehicle oscillations, causing corrugations to occur. The type of vehicle suspension can also contribute to the problem.

Corrective procedure - In dry conditions the underlying material beneath the corrugations is usually not affected. Cutting to the depth of the corrugation and respreading the material usually rectifies the problem. In wet conditions the corrugations sometimes move down, and deform the basecourse and lower pavement layers. In these cases the pavement should be left to dry, and reshaping and compaction of the material is required to form a surface for water run off.

Longer-term corrective measures include the addition of a clay binder or lime stabilisation of the pavement, and the importation of a higher quality crushed aggregate for isolated trouble spots. Where corrugations occur at the approaches of bridges, on steep grades, or on low-radius curves, sealing will provide the necessary control.

Preventative procedures - Lightweight drags towed behind a vehicle can be an effective preventative treatment. Other equipment such as a lightweight grader or brushes attached to, or pulled by, a utility or tractor can be used to pass over the surface on a regular basis. Compaction after maintenance grading may also help.

14.6.1.2 Potholes

Description - Potholes are round or oblique holes formed in the upper surfaces of the pavement. They generally occur:

- in the wheel paths

- in low lying areas
- in shaded areas where the road is constantly wet
- where there is little or no crossfall (e.g. at bridges approaches, where the alignment changes from left to right, on superelevation at S bends, and at intersections.

Cause - Potholes are generally caused by poor pavement drainage due to low (or non-existent) crossfall. Water will lie on the surface of the pavement and seep into the top layers. Movement of vehicles over the area strips the surface material allowing more water to enter the pavement. Fine material is then suspended in the water and carried away.

Corrective procedures - The only remedy is to restore the crossfall and superelevation to its original level, to ensure adequate drainage. This can be easily achieved by cutting the surface, and grading the pavement back to a correct crossfall. In severe situations, new material will be required to replace what has been lost, and mixing and re-shaping is required. Crossfall superelevation should not be too high for heavy vehicles - 6% is suggested as an absolute maximum.

Preventative procedures - Increasing (or constructing) crossfall will encourage water runoff. Also, stabilisation of the pavement, or the use of a moisture-retardant can be used in areas where the pavement is constantly shaded and wet.

14.6.1.3 Ice formation on surface

Description - In shaded areas the roadway can become iced over during the winter months. Roadside trees can prevent the sun from melting this ice, resulting in the road being slippery all day, and compounded during the next night.

Preventative procedures - Using a sharp, large aggregate will cause it to protrude above the ice formation, providing a safer running surface. Also, trees can be removed from the sides of the road to allow sun onto the pavement (see section 7.1.2).

14.6.1.4 Surface scour

Description - Scouring can occur in both the longitudinal and transverse directions. Shallow or sometimes deep scouring of material from the running surface of a pavement can occur, causing problems for traffic, as well as opening up the pavement to the weather which may cause further deterioration and defects.

Cause - Scouring is caused by the flow of water over the pavement due to:

- Lack of compaction or lack of basecourse binding
- Excessive grades
- Lack of crossfall
- Buildup of debris on shoulders preventing drainage of surface water

Pavements with high fine contents and small aggregate sizes and insufficient binding are more susceptible to scouring.

Corrective procedures - Cutting, grading and compacting the affected material ensuring the crossfall and superelevation is reconstructed is the best option to overcome scour. Cleaning out waterable drains and shoulders will ensure that water is directed away from the roadway.

Preventative procedures - Attention to crossfall detail, and cleaning waterable drains and shoulders will prevent scouring. The use of a high quality mechanical interlocking aggregate, and stabilisation of the pavement can also be employed.

14.6.1.5 Soft surfaces

Description - Movement of material within the pavement causes localised soft spots (figure 133). Generally these are found in the wheel paths, but they can also occur elsewhere across the pavement surface.

Cause - Material containing a high proportion of fines and which has not been well

compacted will move under loading. This movement can cause soft spots to occur. Another possible cause is the entry of water into the pavement, either from the surface or seeping up through the base from the subgrade via capillary action.



Figure 133 - Pavement showing soft spots

Corrective procedures - Extracting and replacing the affected material with correctly graded or stabilised material will help overcome the formation of soft spots. Good compaction of this material will help to ensure that the problem will not recur.

Preventative procedures - Correct compaction at optimum moisture content (OMC) of well-graded aggregate material will reduce the risk of soft spot formation. Maintaining good superelevation and crossfall will ensure adequate drainage. Good waterable drainage will prevent water from ponding, and reduce the chance of water entering the pavement from the surrounding environment. In some cases, subsoil drainage may be required.

14.6.2 Foundation Defects

Foundation defects are caused mainly by the introduction of water into the pavement and subgrade, either by inadequate surface drainage or by seepage from the surrounding environment. They are generally expensive to fix, but need to be rectified, otherwise ongoing problems will occur.

14.6.2.1 Rutting

Description - Longitudinal deformations in the wheelpaths caused by the passage of traffic. The repeated passage of traffic compacts the material directly under the wheel creating rutting. Rutting in dry conditions occur in non-cohesive materials such as sands or gravels which have a low fines content. In wet conditions rutting usually occurs in materials which are sensitive to water or have a high water content.



Figure 134 - Rutted pavement

Cause - Rutting is due to failure of the subgrade, basecourse or surface material. Excessive quantities of water entering the pavement or subgrade, along with any number of the following contribute to rutting formation:

- Poor grading of pavement material (Excessive fines)
- Poor compaction of pavement material
- Inadequate pavement depth

Corrective procedures - Maintaining or rehabilitating the crossfall and surface crust provide good drainage will reduce surface rutting. As with corrugations and potholes, ruts can be removed by cutting the surface to just below the rut, and reshaping and compacting the pavement. For subgrade failure, additional material is required to increase the pavement depth and therefore distribute the applied load.

Preventive procedures - To reduce the risk of rutting correct material gradation is required. Addition of fines or larger material to obtain the correct grading will help to prevent rutting. Maintaining crossfall and optimum compaction of pavement material will also reduce the risk of rutting. Ensuring that adequate pavement depth is maintained will better distribute the load onto the weak subgrade.

14.6.2.2 Subgrade Failure

Description - Subgrade failure is usually identified by large, soft or depressed areas within the roadway. They primarily occur in the wheel paths, but can be found across the entire road pavement.

Cause - Subgrade failures are caused by the subgrade material settling and heaving while under loading. Soft, unstable, and poorly graded material all have the potential to generate subgrade failure, especially if water enters the material.

Corrective procedures - The only solution to subgrade failure is to remove all of the affected material extracting all soft and poor quality material. The depth of extraction should continue until a firm solid base is found. Backfilling will be required with good quality aggregate compacted to form a stable base, and with sub-surface drains may also be needed.

Preventative procedures - The addition of aggregate material is a preventative measure, since this increases the pavement depth and thus the distribution of the applied loads onto the subgrade. Shaping the subgrade material will encourage water run off before and during construction, and in the event of any water entering the pavement. In situations where a stable base cannot be achieved, stabilisation with lime, cement or other chemical product may be required. For arterial roads which would benefit from high initial construction costs, low maintenance costs, and low disruption to traffic, the use of geotextiles or corduroy should be investigated. These procedures stop the mixing of pavement and subgrade materials which can cause foundation defects, and they also help to spread the applied load evenly over the soft subgrade. In situations where the road is low lying, and where water entering the pavement is

considered to be a potential problem, sub-surface drains in the subgrade and pavement will help to drain the affected area, reducing the risk of subgrade failure.

14.7 PAVEMENT MAINTENANCE REQUIREMENTS

Maintenance practices normally consist:

- Reshaping the pavement cross-section
- Light grading to remove corrugations, ruts and pot holes
- Re-gravelling the pavement, if required
- Moving displaced running course back onto the roadway
- Restoring road signs

14.7.1 Re-shaping

One of the most critical aspects of unsealed roads is correct crossfall and superelevation. Ensuring that this is maintained will provide effective runoff of water from the pavement. The importance of maintaining effective crossfall cannot be over emphasised. The best procedure to re-shape the crossfall involves:

1. Scarifying the surface
2. Adding material - either imported, or extracted from the edges of the road
3. Mixing and shaping the surface to form a crown (see chapter 6 for crossfall design parameters)
4. Finally, compacting at the optimum moisture content.

The loss of shape of a roadway can be attributed to improper grading practices, loss of material, settlement, poor construction, or inadequate drainage. The only way to effectively re-shape the road carriageway is to heavily grade the surface, re-shape and then compact.



Figure 135 - Grader re-shaping road pavement

14.7.2 Camber (Crossfall)

The grading frequency will depend on the traffic volume, axle weights, materials involved and the skill of the operator. Grading should begin at the edge of the road, and work towards the centre. The cutting depth will depend on the re-shaping procedure required. The windrowed material is positioned at the centre of the road, and then spread evenly back across the cut surface on the final pass(es). This procedure is then repeated for the other side of the road carriageway. It is important that the grader does not make a final pass down the centre of the road with the blade horizontal, since this will remove the crown.

14.7.3 Superelevation

Maintaining superelevation on the curves provides effective drainage of water from the carriageway as well as providing easier cornering for vehicles. The main important feature of superelevation between the tangent and the straights must be preserved. A sudden change from superelevation back to a normal camber can spell disaster for a loaded vehicle, and can cause damage not only to a vehicle, if it were to roll over, but also damage the pavement. Care must be taken not to create superelevation by dropping the inside edge of the road.

14.7.4 Gravel Replacement

The road surface is worn away by traffic at varying rates. This is influenced by a number of factors including:

- Weather
- Weight, speed and frequency of traffic
- Gradients
- Tightness of curves
- Depth of the running surface
- Type of pavement material used

All maintenance plans should include provision to provide sufficient replacement of the loss of this running course material. As a rough guide, this running course should not be allowed to become less than 25 mm thick. The running surface gives the traffic a smooth surface to travel over and stops traffic wearing the protective basecourse, which provides drainage, and load distribution.

In wet conditions heavy traffic can accelerate the wearing process causing rapid deterioration. In dry conditions aggregate is lost through raveling and dust. Replacement of this lost material is a necessary part of any maintenance strategy.

If material removed from the running course is not replaced then basecourse material will also be eventually lost. This will reduce the depth of the pavement, ruts will appear due to the lack of load distribution and the subgrade will fail under loading. Replacing gravel before subgrade failure occurs is an integral key to long lasting pavement performance.

14.7.5 Dust Control

The control of dust from a road carriageway is not only a safety issue, but it is also an economic and environmental issue. Dust is caused by the loss of very fine particles from the road surface due to the loosening of the pavement materials, and the disturbance of the running course by passing traffic. This loss of material increases the

permeability of the surface, which accelerates the pavement deterioration. The removal of fines also exposes coarser material which increases vehicle operating costs and makes driving over the affected area less comfortable. This lost material must be replaced.

Short term or seasonal dust suppressants can be used in situations where there is moderate to low traffic flows. For a more permanent solution, however, the road should be sealed. Using such measures to reduce or eliminate dust levels brings a number of benefits, including:

- Reduction of accidents
- Less degradation of produce being transported
- More acceptable level of social and environmental impact
- Reduction in maintenance costs
- Lower surface roughness, decreasing vehicle operating costs

14.7.5.1 Types of Dust Suppressants

- *Chlorides (salts) such as calcium, sodium, and magnesium*

Reduce the repulsive forces acting within soil particles, and also absorb water from the surrounding atmosphere to help keep the road surface moist.

Note: Sodium chloride requires a humidity of at least 70%, and calcium and magnesium chlorides require a humidity of 30-40%

- *Lignin Sulphonates (Adhesives)*

Provide a seal over the pavement surface, and act to disperse clay particles

- *Petroleum Based (Diesel, Oil)*

Bind together fine soil particles to prevent them from becoming airborne

- *Surfactants (Wetting agents such as detergent and soap)*

Moisten the surface material, and help to bind particles together. Surfactants are only a short-term measure, and in more severe conditions they may require daily application.

A major disadvantage to the use of most of the above suppressants is the risk of leaching during rainfall. Also, the pavement surface can become slippery in wet weather. Correct application (following the manufacturers' specifications) and maintenance techniques will lessen these risks.

Most dust suppressants stabilise the surface layer of the road carriageway. The important properties of dust suppressants are:

- Preventing dust particles from becoming airborne
- Material resistance to traffic wear
- Easy and cheap application
- Application with common road construction or maintenance equipment
- Chemical retention within the pavement

14.7.5.2 Procedure for applying dust suppressants

Unstable soft areas within the pavement should be removed and replaced with well compacted aggregate. The pavement must be dry (unless application of the dust suppressant requires moisture), and a well-maintained water table and camber must be developed on the road carriageway. Application of the dust suppressant can then proceed following the manufacturers instructions.

The use of a dust suppressant is primarily intended for low volume roads which have a properly designed and maintained subgrade. This will ensure that the dust suppressant will perform as intended.

14.8 DRAINAGE MAINTENANCE REQUIREMENTS

Providing an effective camber and superelevation which will encourage water drainage off the carriageway, must be complemented with an effective drainage system.

Drainage systems (which includes the road camber, shoulder slope, watertable drains, culverts, bridges and any other water control structures) need proper maintenance to prevent major damage to the pavement. Ponding water in hollows within the pavement and shoulders, combined with traffic action and wheel loading, can lead to potholes and subsequent weakening of the pavement structure (figure 136).



Figure 136 - Poorly drained pavement

14.8.1 Camber (Crossfall)

To promote good drainage of surface water, a good camber is required. Shoulders should also have sufficient slope to encourage quick water flow into watertable drains. However, care must be taken to ensure that the camber and shoulder slopes are not too steep otherwise problems can occur, including traction problems for trucks, and scouring due to the higher velocities of shedding water.

Grading to restore camber and control potholes and ruts is the most common form of maintenance for unscaled roads. It ensures a comfortable riding surface, and allows for effective drainage. This work is best carried out after rain, while the pavement is still wet, to help bind and compact the material.

14.8.2 Culverts

Maintaining culverts will ensure that adequate drainage is maintained. Culvert maintenance practices include:

- Keeping culverts clean and free of debris
- Repairing any damaged or broken culvert entrances
- Replacing any broken culverts
- Any necessary clearing and repairs to flumes, headwalls and spillways

As with other water control structures, this maintenance work should be completed with care in order to prevent or minimise the downstream effects due to sedimentation and debris flow. Debris should be removed from culverts by hand rather than by using heavy equipment, which can easily damage the culvert end.

Additional cross culverts may be required to be placed after construction. Areas where this is likely to occur include:

- Where there is permanent water seepage from the batter slope.
- Where the watertable changes from rock, or some other erosion resistant material, to a soft clay or easily erodible material.
- Where a curve in one direction is directly followed by one in the other direction - the change in curvature produces a short flat area without camber or superelevation which can cause water to leave the watertable and run across the road carriageway.

14.8.2.1 Scouring

Due to the constricting nature of a culvert, forcing water to flow through a reduced opening, scouring can occur around the inlet and outlets (figure 137). This is a result of the flow velocities increasing around the pipe edges as water is forced into a small opening. Wing walls, aprons, cut-off walls, and embankment paving can prevent scouring of the stream bed and embankments.

Maintenance of these structures will ensure that scouring is eliminated or controlled for the life of the culvert. The main cause of scour protection failure is damage caused by debris. Periodic checks to ensure that no debris buildup occurs will improve the chances of long lasting scour protection life. Alternatively, debris control structures upstream of the culvert can prevent debris from even entering the culvert area. Periodic inspection of these structures is also necessary.



Figure 137 - Poorly protected culvert

14.8.2.2 Corrosion

In concrete culverts, signs of cracking and rust from protruding reinforcing steel should be repaired immediately. With galvanised steel culverts, rust formation (especially along joints) should be repaired to prevent further corrosion.

14.8.3 Bridges

Structural members such as abutments, piers, ties, stringers, needle beams, curbs, rails, delineators etc should be inspected on a regular basis (i.e. every six to twelve months) depending on the level of use. Any repairs or replacement structures should be carried out where damaged or decayed members are located.

Abutments should be well maintained to ensure that scouring from water flow does not occur. Rutting and stripping of pavement material by traffic should be minimised or an alternative is to stabilise or seal the bridge approaches to eliminate material removal.

Sometimes a stream channel cuts next to and/or underneath an abutment. It may then be necessary to obtain a bulldozer or excavator to straighten the stream channel. A resource consent is usually required for this type of operation (Refer to the Resource Consents section of this manual). If there is a substantial drop in the stream bed level - falling below the foundation level of the abutments - then a weir built just downstream of the bridge will stop continued erosion. The level of this weir should be at least 450 mm above the foundation level of the abutments. Downstream protection below the weir will be require to stop erosion and undermining of the weir. This can be completed using a concrete or rock apron.

Piers should be cleared of any debris buildup, to eliminate the risk of blockages and possible resulting damage to the bridge or surrounding embankments. Bridge decks should also be cleaned of gravel and debris. Painting of steelwork will ensure that corrosion is minimised.

14.8.4 Fords

Fords are generally low-maintenance structures, however some maintenance practices are required, including:

- Monitoring of catchment areas to identify and remove debris from upstream water channels

- Removal of debris from the ford itself
- Grading of the running surface, with replacement of material, where necessary
- Maintenance of the approaching road grades to eliminate water drainage along the road carriageway

Maintenance of fords must be completed with extreme care in order to minimise the amount of sediment and other debris travelling downstream.

14.8.5 Water Table Drains

These can be cleared using of an excavator or grader, or by manual labour. The method of removing obstructions will depend on the following factors:

- The size of the obstruction
- The type of watertable drain design (see chapter 11)
- The depth of the drain

Where ditches or drains have a significant accumulation of silt then the eroding source must be identified, and measures taken to stop or limit any further erosion. Methods available for controlling erosion include:

- Baffles
- Check dams (see chapter 11)
- Paving
- Vegetation plantings
- Silt fences



Figure 138 - Water table showing signs of scouring

When excavating obstructions from the watertable drain, care must be taken not to cut material from the drain. Banks and beds which are disturbed during maintenance can begin eroding, causing ongoing problems. Also, cutting may produce flat sections or hollows where water can pond, or they may produce steep sections which increases the risk of erosion from fast flowing water. The use of excavators will prevent fine material being spread on the roadway, a problem when a grader is used.

14.8.6 Sediment Ponds/Traps

These should be cleaned out as required, measuring the quantity of material removed for monitoring processes. (To give an indication of the quantity of material being lost, over a period of time from the road above). This work can usually be completed by an excavator or backhoe.

14.8.7 Raised Berms

Raised berms are usually constructed on the downhill side of a road carriageway (Chapter 11). They control water flow along the road by directing it into diversion channels at the desired point.

Berms act in a similar manner to a dam, and must therefore be watertight. Regular inspection of the berms should be conducted to identify any areas which may have been damaged by vehicles. Any debris on the inside face of these berms, and any blockages at the diversions points should be removed, to ensure free water flow.

14.8.8 Flumes

Flumes should be kept clear of debris to allow the water to flow freely. Maintenance practices should replace any broken or worn sections of a flume as required. The flume should be kept as watertight as possible to prevent batter slope erosion. Any supporting trestles should also be inspected, and any rotten or damaged sections replaced.

14.8.9 Natural Watercourses

Some watercourses may be dry for significant periods, however, they must still be maintained since they will carry water during wet weather. Watercourses must be kept free from scouring and erosion, and from debris and any other obstacles which could damage the bed or banks. Common maintenance work required for watercourses includes:

- **Vegetation Control** - Vegetation growing in or around the banks of a watercourse can trap debris as it flows downstream and block the flow. Trimming this vegetation is preferable to removing it altogether since it may be helping to stabilise the banks and bed.
- **Debris Removal** - Rocks, vegetation and other debris which has entered the watercourse either during a flood event or through normal flow need to be removed. If this is not removed it has the potential to block the course causing flooding.
- **Scouring Repair** - Many methods of eliminating or controlling scour are available - rock buttresses, aprons, gabions, or blankets.

14.9 ROADSIDE MAINTENANCE

14.9.1 Roadside Vegetation

Controlling and maintaining roadside vegetation may not be as critical for forestry roads as it is for public highways. However, some vegetation maintenance can improve driver safety and reduce maintenance through:

- Improving sight distances around corners and approaching bridges and intersections
- Creating a wider road for passing traffic
- Overgrown vegetation will tend to shade the road especially during winter which :
 - Increases the risk of ice formation
 - Prevents the road surface from drying out increasing the risk of pavement damage.



Figure 139 - Cleared roadside vegetation

Vegetation on batter slopes should be maintained to encourage continued growth which can provide continued protection from scouring. Control of vegetation in watertable drains will stop blockages from occurring, thus avoiding damming and eventual washouts. Watertable drains can be mowed or sprayed (with a non-toxic chemical) to ensure that vegetation does not hinder water flow or cause problems with other maintenance tasks - too often culverts and watertable drains are damaged because machinery operators cannot see the culvert ends through brush and other vegetation growing in the drain. However, care should be taken not to eliminate all vegetation from the drain, or scouring could result.

Most roadside vegetation maintenance needs to be completed during the growing months of spring and summer. Typically, equipment can efficiently cut material which is below 100 mm in diameter, so maintenance should be completed before vegetation reaches this stage.

14.9.2 Shoulder Maintenance

Shoulder maintenance will help to :

- Improve vehicle safety by giving an area for a disabled vehicle to park, allowing room for passing vehicles and provides a safety strip to avoid accidents,
- Help maintain truck maneuverability at corners (To accommodate trailer off-tracking)
- Provide a pavement draining area
- Reduces the risk of pavement edge defects

Common defects that occur in shoulders include potholes, corrugations and rutting, all of which are aggravated by incorrect crossfall allowing water to pond on the surface. Typically, shoulder slope should not exceed 5% (1 in 20). Traffic movement over the affected surface during or just after rainfall aggravates such defects.

Other shoulder defects include:

- Natural compaction - Natural settlement usually occurs in pavements and shoulders. However, shoulders can settle more due to incorrect compaction at the time of construction. Often shoulders are not constructed to the same standard as the rest of the pavement, therefore increased natural settlement occurs.
- Shoulder material build up - Grass shoulders can trap air and water borne particles which causes an excess build up of material. This build up creates poor drainage and water ponding occurs. Water can also be diverted laterally along the road way rather than across the shoulder into the watertable drain (figure 140).

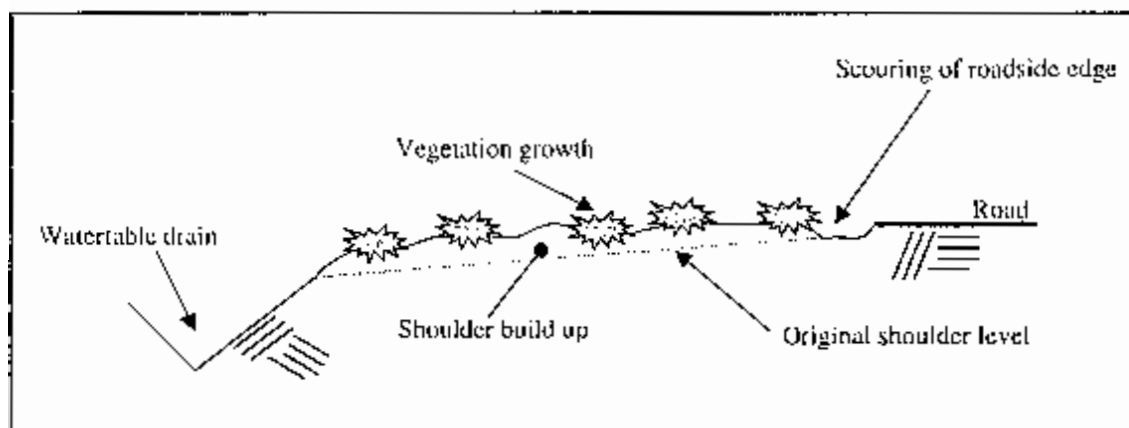


Figure 140 - Shoulder build up

In these situations it may be necessary to remove the buildup, and re-shape the shoulder. Shoulder maintenance can be completed by grading and replacing lost material. This should be completed after a soaking rain and include compaction. If rain has not fallen recently then applying water will help the compaction process. However, careful material selection and/or stabilisation of shoulder material can be an option in severe conditions.

Inadequate shoulder maintenance can accelerate pavement deterioration and subsequent failure. Maintenance of shoulders should be completed at the time of pavement maintenance.

14.10 MACHINERY SELECTION

Choosing the correct machinery for maintenance practices will improve the overall efficiency and production. Using experienced and trained personnel will ensure a good quality job that will reduce the quantity of future maintenance. However, in some situations maintenance practices have to be completed with what machinery is available due to economic constraints. Therefore, matching the machinery that is available as best as possible, and correctly timing maintenance will ensure good maintenance practices are achieved.

Routine maintenance practices typically require the following machinery:

- **Light grader** - Used to reshape the road. Grade out any corrugations, ruts, potholes etc, and produce a quality running surface. They can also be used, if situations allow it (see chapter 11) to clear out waterable drains.



Figure 141 - Light grader

- **Rubber tyred roller** - These can be either towed or self-propelled. They are used to finish off the surface of a pavement which contains a well-graded material.
- **Smooth drum steel roller** - Either a static or vibrating roller should be used in situations where there is a high proportion of large material and a small proportion of fines.



Figure 142 - Smooth drum roller

- **Water carts** - Used to apply water to the pavement so that compaction can be achieved at optimum moisture content. They can also be used to apply dust control and stabilisation agents.
- **Gravel trucks** - Used to deliver material for replacing soft spots, and to spread over the road replacing any lost running surface material. Bottom dumpers are often used because of their increased accuracy and higher production rate.



Figure 143 - Gravel truck

- **Excavator or backhoe** - Used to excavate any soft spots within the pavement, and also to clear out culvert inlets, outlets and watertable drains. Cleaning out sediment traps can also be completed with an excavator



Figure 144 - Excavator

Other Machinery Used For Maintenance Practices:

- **Drawn Grader** - This is a basic grader blade drawn by a light tractor or utility. Usually this type of grader is used for light grading work such as grading shoulders.
- **Construction Grader** - These graders are self propelled and come in a variety of weights, engine sizes, blade widths, method of blade control, and arrangement and size of driving wheels. These can be used for heavy construction and maintenance practices. They do not require transportation to a site and can be used for light maintenance as well as heavy reconstruction or rehabilitation work, if the hire rate can be justified.
- **Front End Loaders** - For maintenance work the wheeled front end loader is ideal since it does not require transportation to a site. Used for small excavation jobs where the material is either loaded onto trucks or transported a short distance by the loader.

14.11 ECONOMIC EVALUATION OF ROAD MAINTENANCE PROJECTS

An economic evaluation of any roading project may be undertaken for a number of reasons:

1. To evaluate alternative projects and scheduling of maintenance practices

2. To determine which maintenance strategy gives the optimum use of resources
3. To evaluate road user and authority costs

Figures 145 and 146 show the relationship between the user's costs and the serviceability level for two maintenance strategies. Figure 145 shows an on-demand maintenance strategy with major resurfacing required when the serviceability level falls below the terminal level. The second strategy (figure 146) shows preventative maintenance being conducted, effectively increasing the length of time before major reconstruction is required, however, more costs are incurred by the road user because of constant maintenance requirements.

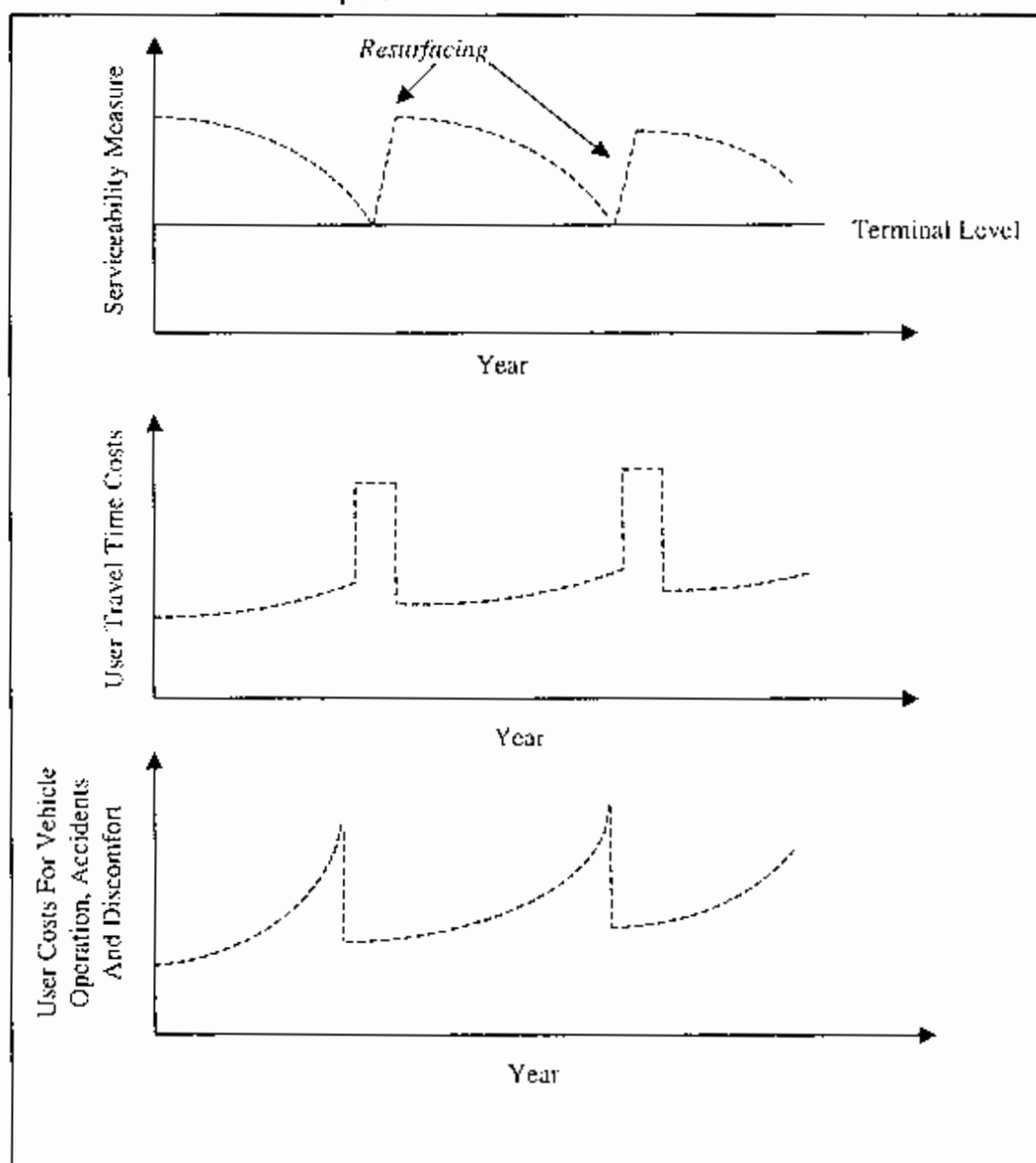


Figure 145 - User costs for an on-demand maintenance regime

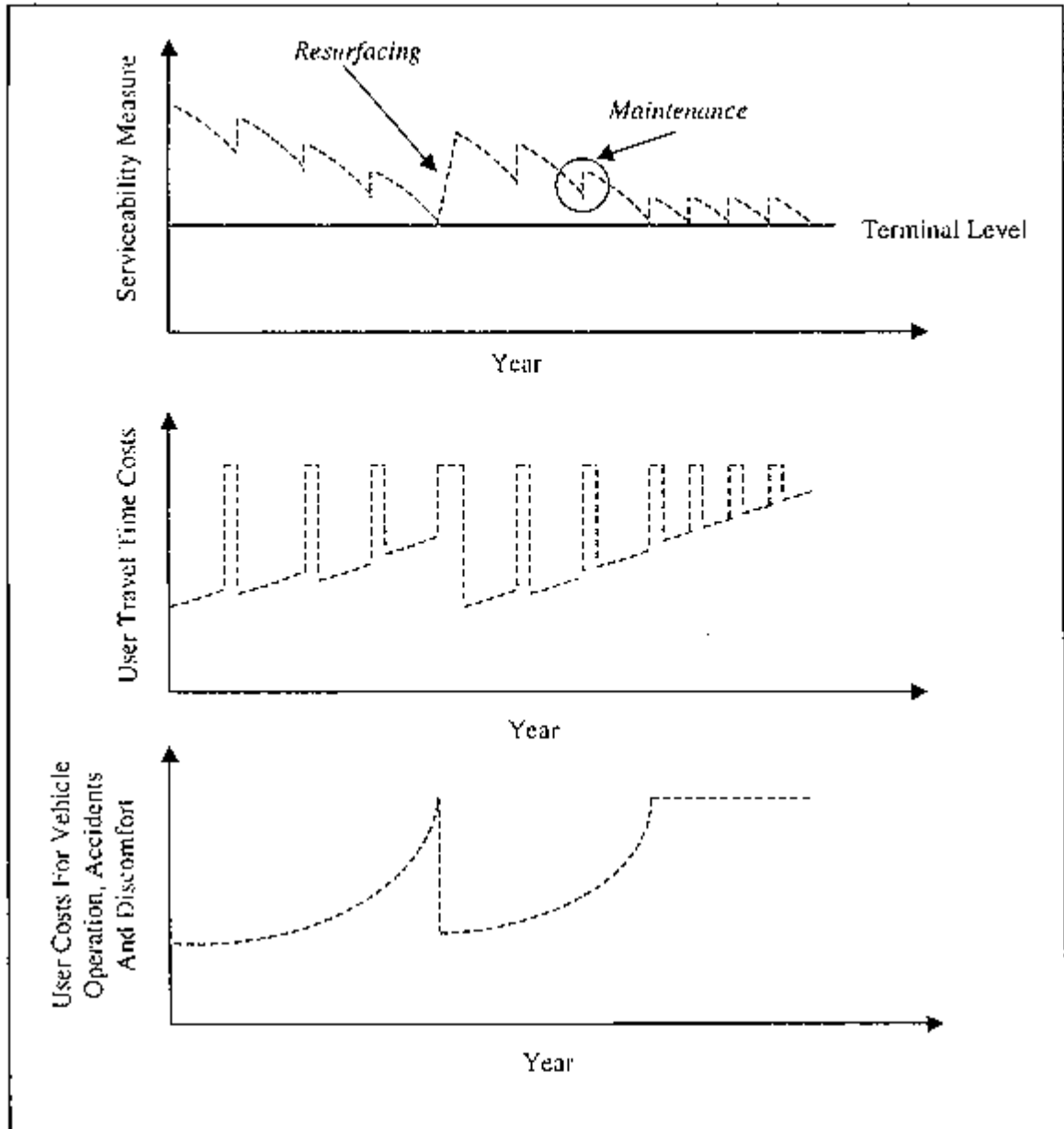


Figure 146 - Users costs for a preventative maintenance regime

14.11.1 Economic Evaluation Terminology

Life Cycle Costing

Life cycle costing is used to evaluate alternative projects by summing all expenditures (and income) occurring over the lifetime or analysis period of the venture, adjusted to a common base time or value. The elements of the life cycle costing include both the agency and user costs (or income).

Time Value of Money (Intrinsic value)

Discounting includes the effects of interest and inflation, and compensates for the fact that the community place a higher value on costs (or benefits) which arise in the near future than on those which arise at a later date.

Design Period (Analysis)

The analysis design period is the entire life of the pavement over which an economic analysis is calculated, during which major reconstruction may be completed.

Design Period (Structural)

The structural design period is the time during which the pavement will perform to a certain standard or serviceability without major reconstruction.

14.11.2 Elements Of Pavement Cost Analysis

14.11.2.1 Roading Owner Elements

Initial Capital Cost

The initial capital cost includes the cost of in-place materials in a pavement structure, equipment and labour necessary to prepare, place, and finish the pavement structure.

Rehabilitation Costs

Rehabilitation costs include future overlays or upgrading made necessary when the pavement distress, skid resistance, structural capacity, or riding quality reach the limits of acceptability.

Rehabilitation costs are dependent on accurate predictions of the time it takes a pavement structure to reach terminal serviceability after an initial construction or overlay.

Maintenance Costs

A comprehensive analysis should include an estimation of all costs that are essential to maintain the pavement at a desirable level of service.

Salvage Value (Residual)

The salvage return of a strategy is the value of a pavement at the end of its analysis period. Computation of this cost allows for comparison of designs with different serviceability's at the end of the analysis period.

14.11.2.2 Users Elements:

Traffic Delay Costs

Overlay and maintenance operations disrupt traffic flow and cause vehicle speed fluctuations, stops and starts, and time losses. The user cost incurred related to these disruptions is often a significant portion of the total cost and should be included in the economic analysis.

User Operational Costs

Each pavement design involves costs to the user that must be included in a rational economic analysis. User costs are related to the serviceability and deterioration history of the pavement.

Vehicle operating costs:

- Fuel consumption

- Tyre wear
- Vehicle depreciation
- Vehicle maintenance
- Oil consumption
- Parts replacement

Travel Time Costs:

- Based on the extra travel time a user incurs as a result of a road in poor condition

Accident Costs:

- Due to accidents caused because a road was not built or improved

Discomfort Costs:

- User annoyance and discomfort due to poor pavement serviceability or geometrics

Roading owner and user elements of a pavement cost analysis are inter-related. An increase in the roading owner costs has an opposite effect for the users costs, and vice-versa (figure 147). A balance between the two must be obtained. This can be achieved by projecting all current and future costs and benefits attached to the project, discounted to a common baseline (i.e. time zero).

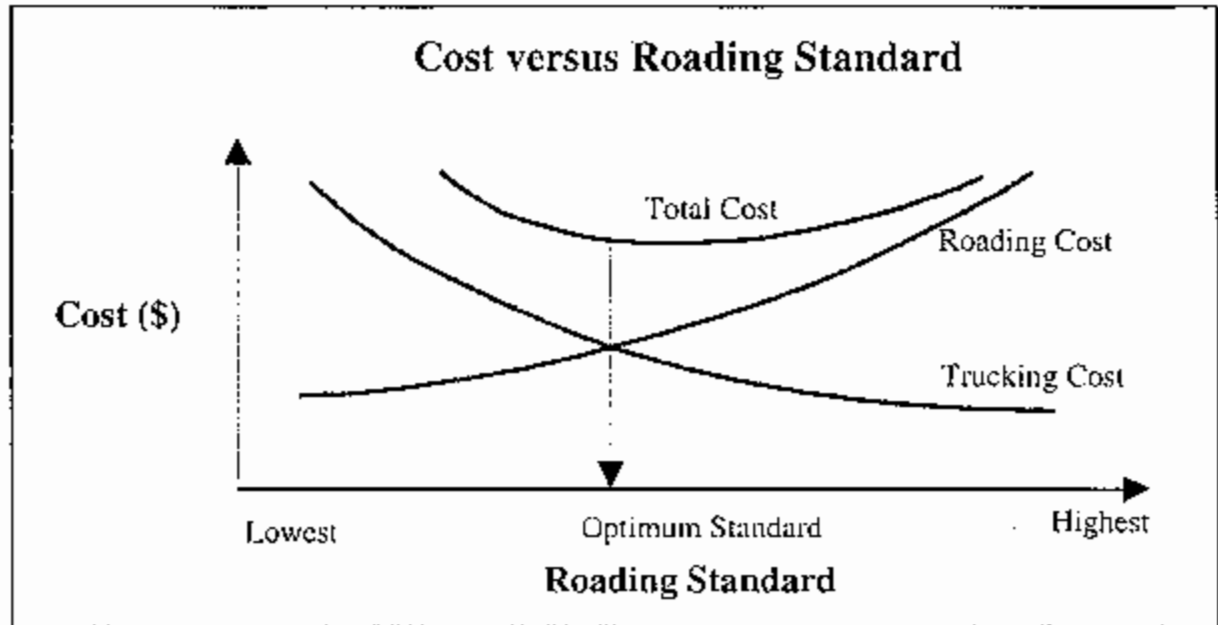


Figure 147 - Road owner versus road users costs

14.11.3 Methods Of Project Evaluation

When evaluating which maintenance strategy should be used for a particular road class, an economic evaluation should be completed. Initial construction costs require no adjustment since these are costs at time zero. However, maintenance costs in the future need to be adjusted to calculate their present worth or present value (PV), i.e. they need to be discounted back to time zero to take into account the changing value of money with time due to interest rates and inflation.

Present Worth

This method of economic analysis can consider either costs alone, benefits alone, or costs and benefits together. It involves the discounting of all future sums to the present, using an appropriate discount rate.

Single Payment Present Worth Factor (SPPWF)

If in the future a single cost or benefit arises then the following formula should be used to calculate the PV.

$$\text{SPPWF} = \frac{1}{(1+i)^n} = \frac{1}{1.10^n} \text{ for a 10\% discount rate.}$$

Where:

n = Number of years between time zero and the cost or benefit arising

i = Discount rate

Then:

$$\text{PV}_{\text{(of costs or benefits)}} = \text{SPPWF} \times \text{Cost or Benefit at time } n$$

Example:

A section of unsealed road network will require a major upgrade at age 9 years. The cost of this work is \$35,000. The PV of the upgrade, assuming a discount rate of 10%, will be:

$$\text{PV} = \$ 35,000 \times \text{SPPWF}$$

$$= \$ 35,000 \times \frac{1}{(1.10)^9}$$

$$= \$ 35,000 \times 0.4241$$

$$= \$ 14,843$$

Uniform Series Present Worth Factor (USPWF)

If the maintenance practices are spread over a period of years (e.g. as routine grading and re-shaping) then uniform series present worth factors should be applied to calculate their PV. Note that the assumption is made that the annual costs (or benefits) are evenly spread over each year, and are continuously compounded.

The formula for USPWF is:

$$\text{USPWF} = \frac{(1 - (1 + i)^{-n})}{\log_e (1 + i)}$$

Then:

$$\text{PV of costs (or benefits)} = \text{Annual costs (or benefits)} \times (\text{USPWF}_e - \text{USPWF}_s)$$

Where:

s = Start time

e = End time

Example:

If a project has a series of costs of \$7,000 per year, evenly distributed over a period of 11 years, and with a discount rate of 10%, the PV is as follows:

$$\begin{aligned} \text{PV} &= \$ 7,000 \times (\text{USPWF}_e - \text{USPWF}_s) \\ &= \$ 7,000 \times ((1 - (1 + i)^{-n}) / \log_e (1 + i) - (1 - (1 + i)^{-n}) / \log_e (1 + i)) \\ &= \$ 7,000 \times ((1 - (1 + 0.1)^{-11}) / \log_e (1 + 0.1) - (1 - (1 + 0.1)^{-0}) / \log_e (1 + 0.1)) \\ &= \$ 7,000 \times 6.815 \\ &= \$ 47,702.59 \end{aligned}$$

Arithmetic Growth Present Worth Factor (AGPWF)

A more realistic situation would exist if the costs (or benefits) increase or decrease each year due to maintenance requirements determined by traffic loadings and unforeseen weather conditions. Arithmetic growth present worth factor (AGPWF) together with the corresponding USPWF factors shall be applied to calculate their PV's. *Assumption:* That the annual costs or benefits occur continuously throughout the year, and are continuously compounded. The formula for determining these AGPWF factors is:

$$\text{AGPWF} = [\log_e (1 + i)]^{-2} - n(1 + i)^{-n} [\log_e(1+i)]^{-1} - (1 + i)^{-n} [\log_e (1 + i)]^{-2}$$

$$\text{PV of costs or benefits} = \text{Annual Cost (or benefits)} \times \{(\text{USPWF}_e - \text{USPWF}_s) + R \times (\text{AGPWF}_e - \text{AGPWF}_s)\}$$

Where:

R= The arithmetic growth rate at time zero

s = The start time

e = The end time

Example

The annual maintenance costs are \$ 25,000 with a growth rate of 3% per year that is to continue for 27 years at a 10% interest rate. Also, the construction starts and finishes two years from time zero. The maintenance costs PV is:

$$\begin{aligned} \text{PV} &= \$ 25,000 \times [(\text{USPWF}_e - \text{USPWF}_s) + 0.03 \times (\text{AGPWF}_e - \text{AGPWF}_s)] \\ &= \$ 25,000 \times (9.692 - 1.821) + 0.03 \times (80.073 - 1.760) \\ &= \$ 25,000 \times 10.22 \\ &= \$ 25,550 \end{aligned}$$

14.11.4 Pavement Rehabilitation (Reconstruction)

A pavement naturally deteriorates over a period of time due to traffic loadings, weather conditions, pavement material deterioration etc. Preventative, or on-demand maintenance practices can be utilised to extend the life of the pavement and therefore slow the rate of deterioration by periodically lifting the service. However the pavement will continue to deteriorate and one of the following factors will determine that the pavement requires rehabilitation:

- Serviceability falls below the minimum acceptable level
- Structural capacity is inadequate
- Distress is too high
- Safety is inadequate (Skid resistance)
- High maintenance costs
- Users costs are too high

Rehabilitation of a pavement usually means construction work to stabilise, reshape, and rejuvenate the pavement to increase the user safety, and decrease the user cost and maintenance costs. This period of time is usually taken as the end of a pavements useful life and a new economic analysis is completed for the next design period.

GLOSSARY OF TERMS

CHAPTER 15 - GLOSSARY OF TERMS

AADT Average Annual Daily Traffic flow. The total yearly traffic volume divided by 365. (both directions; all lanes)

AASHO American Association of State Highway Officials.

ABNEY LEVEL A hand-held level which measures angles of depression and elevation.

ABRASION The removal of material from the surface of a solid by a grinding or rubbing action.

ABSORPTION The entry of fluid into a solid by virtue of the porosity of the latter. Often in conjunction with capillary action.

ABUTMENT An end support of a bridge or similar structure.

ADHESION

(a) The molecular attraction between bodies in intimate contact.

(b) The property by means of which a fluid or plastic substance sticks to the surface of a solid body.

ADMIXTURE A material that is added to the principal substance of a mixture.

ADVERSE GRADE An uphill grade for a laden vehicle.

AERIAL PHOTOGRAPH A photograph of part of the earth's surface. Often used as pairs to give a stereoscopic view. This stereo effect exaggerates vertical scale.

AGGREGATE A general term for mineral particles which through the agency of a suitable binder can be formed into a solid mass.

ALIGNMENT The geometric form of the centre line of the carriageway.

ALLUVIAL SOIL A soil formed from materials which have been transported and deposited by flowing water.

ANGLE OF REPOSE The angle from the horizontal which the sloping face of a bank of loose material assumes.

APRON A layer of concrete, stone, timber or other permanent material placed at the entrance or outlet of a structure (such as a culvert) to prevent scour by the water.

ARC Segment or portion of the circumference of a circle.

ARTERIAL ROAD Main feeder road out of the forest. High standard, permanent, two lane road.

ASSUMED DATUM Refer datum line.

BACKFILL Earth or other material used to replace material removed during construction, such as in subdrain trenches or behind culvert and bridge abutments.

BACKSLOPE The portion of the earth grade or roadway in cut sections which is beyond the side ditches, and rejoins the original ground.

BANK

- (a) An embankment or fill.
- (b) A fill in the line of a road.
- (c) The cut face near the edge of a road.

BARRIER A temporary obstruction placed to prevent direct access to a particular area.

BASE COURSE On sealed roads it is the primary load spreading aggregate course in the pavement other than the sub-base. On unsealed roads it is the principal aggregate course (or layer) immediately beneath the running course.

BATCH (N) The quantity of materials mixed at the same time.

BATTER(N)

- (a) The uniform side slope of walls, banks, cutting, etc.
- (b) The degree of such slope, usually expressed as: horizontal to one vertical.

BATTER (V) To form a uniform side slope to a wall, bank or cutting.

BATTER BOARD A board inclined at the same angle as a proposed batter cut, to assist operators in maintaining an even batter cut.

BATTER PEGS A stake or board positioned at the proposed head of a cut or toe of fill, indicating the amount of cut or fill required at that point.

BATTER (STEPPED) A batter cut having benches to avoid a long batter slope.

BEARING (DIRECTION) The direction a line has or points in relation to the compass points.

BEDDING A layer of suitable material (often crushed stone) placed on a foundation to provide uniform support for a structure.

BEDROCK The solid rock underlying superficial formations. It may be unweathered or partially weathered.

BENCH

- (a) A ledge cut or formed in the batter of a cutting or bank to provide greater security against slip material depositing on the roadway, or to provide visibility on a curve.
- (b) A ledge cut or formed below the road formation to contain side cast fill.

BENKLEMAN BEAM A device used to measure road pavement deflection under vehicle wheels.

BERM A formed upstand of compacted fill material. Usually used to direct water run-off.

BIND

- (a) To hold or stick together aggregate in a mass.
- (b) To fill the interstices between small stones or coarse gravels with finer material to provide mechanical and physical bonding.

BINDER A material of cementitious nature to hold an aggregate firmly comprising either:

- (a) Fine graded particles and/or,
- (b) Liquid or material which changes viscosity by cooling or by chemical reaction.

BITUMINOUS MATERIAL A substance containing bitumen or constituting the source of bitumen.

BLIND (V) To spread a thin layer of suitable material to absorb excess binder or to assist in remedying a slippery or loose condition, or to fill excess surface voids.

BLOCK CUT A solid cut on a road formation, i.e., a cut batter both sides of the road.

BOND (N) The adhesion between different materials in composite construction, e.g., reinforced concrete, prestressed concrete.

BOND (V) To place materials with their surfaces in intimate contact, e.g., to bed stones in mortar.

BORROW (N) Filling obtained by excavating at some point other than the cuttings, required for the construction of the road.

BORROW (V) To obtain filling from some point other than the excavation required, for the work.

BORROW PIT An excavation outside the formation limits for obtaining borrow material.

BOULDER A rounded or sub-angular stone or piece of rock of large size, usually larger than 150mm.

BOUNDARY LINE A line between land of different ownership e.g., between public road and private land.

BOWL That part of a motor scraper or scoop that holds the spoil.

BOX CULVERT A drainage structure of rectangular cross-section.

BOX CUTTING That portion of the road where both sides are in cut.

BRAKING DISTANCE The distance travelled by a vehicle in the period between the initial application of the brakes and coming to rest plus reaction time.

BREAKING OF EMULSION The separation of the dispersed material from the water.

BRIDGE (N) A structure designed to carry a road or path over an obstacle by spanning it.

BROKEN STONE Natural rock, gravel, or pebbles broken to a suitable size for use.

BROOMING The use of a broom for:

- (a) Distributing aggregate or binder over the surface of a pavement, or
- (b) Removal of loose material from a pavement prior to priming or sealing or
- (c) Roughening the surface of concrete.

BUILDING LINE A line within a road frontage property. A building or part of a building may not be erected between this line and the road boundary. It may also be a reference line in the layout of a construction work.

BULK DENSITY The weight of a unit volume of material, including voids.

BULKING

- (a) The increase in volume in a material resulting from disturbance, or from changes in its condition.
- (b) The increase in volume of a mass of sand or other fine granular, material due to the combined effects of moisture and disturbance.

BY-PASS An alternative road constructed to enable through traffic to avoid some areas or obstructions. Usually to divert heavy vehicles away from particular areas.

CALCAREOUS LIMESTONE A natural rock of sedimentary origin composed principally of calcium carbonate.

CALIFORNIA BEARING RATION (CBR) The ratio expressed as a percentage between a test load and an arbitrarily defined standard load. The test load is that required to cause a plunger of standard dimensions to penetrate at a specified rate into a specifically prepared soil specimen.

CAMBER The degree of cross fall on a road from centre line to side.

CAPILLARY ACTION When water is induced to rise above the free water table level by the fine nature of the material.

CAR PARK A place set aside for the parking of vehicles.

CARRIAGEWAY (Roadway) That portion of the road devoted particularly to the use of vehicles, inclusive of shoulders and auxiliary lanes.

CATCH DRAIN A surface channel constructed along the high side of a road or embankment, outside the batter line to intercept surface water and divert it from the road cut batter face.

CATCHMENT AREA That area determined by topographical or equivalent features upon any part of which rain falling will contribute to the discharge of the stream at the point under consideration.

CAUSEWAY A raised road having water (or swampy ground) on both sides.

C.B.R. Californian Bearing Ratio - a test carried out to determine the strength of a road surface, sub-base or base course. In simple terms it gives an expected performance percentage when compared to a good road aggregate.

CEMENT (General) The medium that binds aggregate.

CEMENTED MATERIALS Those produced by addition of cement, lime or other hydraulically binding agent to granular materials in sufficient quantities to produce a bound layer with significant tensile strength.

CEMENT STABILISATION Chemical stabilisation of soil by the application of small (up to 5%.) quantities of cement.

CENTRE LINE The basic line, at or near the centre or axis of a road or other work, from which measurements for setting out or constructing the work can conveniently be made.

CHANNELISATION A system of controlling traffic by the introduction of an island or islands, or markings on a carriageway to direct traffic into predetermined paths usually at an intersection or junction.

CHAIN An imperial unit of measure equivalent to 22 yards, 66 feet or 20.1 1 68m.
- A steel band used to measure distances. Named because in its original form it was made of 1 00 links in a 'chain' configuration.

CHANGE POINT Used in levelling. It is not necessarily a fixed point but indicates a temporary holding point for the levels when the level is moved to a new location.

CHECK DAM Obstruction placed within drain to STEP water down, slowing the water flow velocity (DROPWALL, CHECK WALL).

CHIPSEAL A pavement seal coat consisting of stone chips partially imbedded in a membrane of sprayed bitumen.

CHORD A straight line joining any 2 points on the circumference of a circle.

CLAY Colloidally fine complex silicates formed by the natural decomposition of rocks.

CLEARING The removal of vegetable or other obstacles preparatory to the commencement of earth-works, drainage, etc.

COARSE AGGREGATE A general term used to differentiate between various sizes of aggregate, usually material retained on a 4.75mm sieve.

COBBLE OR COBBLESTONE

- (a) A water-worn rounded stone usually between 75mm and 300mm.
- (b) A class of paving originally made from cobblestones but now often used to refer to concrete block paving.

COHESION The ability of a material to resist by means of internal forces the separation of its constituent particles.

COMPACT (V) To reduce the volume of a material by inducing the closer packing of its particles by rolling, tamping, or other mechanical means.

COMPACTION The process of reducing the volume of a material by inducing the closer packing of its particles by rolling, tamping or other mechanical means.

COMPACTION FACTORS The varying ratios expressing the volume that different materials-compact to - in relation to the loose state expressed as 1.

COMPACTED MEASURE As distinct from loose measure or bank-measure. The measure when laid and compacted in the road.

COMPASS magnetic direction finder.

CONCRETE An intimate mixture of aggregate and a binding material (usually defined in relation to the nature of the binding material (i.e. Portland cement concrete or asphalt concrete).

CONTROL POINT Point where road must pass through.

CONSISTENCY A general term for the physical state of a semi-fluid or plastic material associated with its resistance to deformation or to flow.

CONSOLIDATE To reduce in volume naturally.

CONSOLIDATION The process by which earth or soil reduces in volume over a period of time usually involving loss of water.

CONSTRUCTION JOINT A joint in concrete construction to separate the mass of the work into several portions for convenience of construction or to help prevent or control shrinkage cracking.

CORDUROY Brush, scrub, timber or logs over a swamp or low bearing surface to spread the load. It can also act as a filter layer.

CORRECTIVE COURSE A layer of variable thickness applied to base or old pavement to correct the longitudinal and/or cross sectional shape and improve the riding qualities.
(REGULATING COURSE)

CORRECTIVE MAINTENANCE Irregular maintenance to correct defects as they occur.

CORRUGATION A surface deformation into wavelike shapes at approximately equal distances and transverse to the line of traffic.

COURSE a layer of metal or fill.

COVER (N) The depth of material between the surface of the ground or carriageway and the top of a culvert or pipe.

CREEP

- (a) A slow natural movement of a material.
- (b) A slow plastic deformation of a material under stress.

CROCODILE CRACKING The cracking of a surface layer into small irregularly shaped areas.

CROSSFALL The slope at right-angles to the main alignment direction.

CROSSING A formal area set aside for other modes of transport to cross the road.
(RAILWAY, PEDESTRIAN, CYCLE)

CROSS DITCHES Used on temporary roads to remove water from water table drains
(WATER BARS, CUT-OFFS).

CROSS SECTION The profile of the ground more or less at right angles to a traverse or main directional line.

CROWN The highest point on the cross-section of a carriageway with two way, crossfall.

CRUSHED GRAVEL A gravel in which all or some of the particles have been crushed.

CRUSHED ROCK Aggregate made by crushing rock, as distinct from crushed gravel.

CRUSHER DUST Fines left after crushing and screening aggregate off.

CRUSHER-RUN The product of the crushing plant without being screened or separated into various sizes.

CULVERT One or more adjacent pipes or enclosed channels for conveying a watercourse or stream below formation level.

CURE (V)

- (a) To mature or harden as in the case of concrete.
- (b) To provide an environment which will facilitate stiffening or hardening.

CURTAIN WALL A thin wall used as a shield or protection (as distinct from a retaining wall).

CURVE DEFLECTION see deflection angle.

CURVE RADIUS The radius made by a curve in a road.

CUT (N) The depth from natural surface of the ground to the subgrade level. Also used as a term to describe the volume of earthwork material to be moved.

CUT-OFF see cross ditches.

CUT-OFF WALL A watertight wall for preventing seepage or movement of water under or past a structure.

CUT SLOPE Specified slope that is less than or equal to the maximum stable slope.

CUTTING That portion of the road where the finished road surface is below natural surface.

CUTTING EDGE Hardened metal plates fitted to the mould-boards (or blades) of graders or bulldozers.

DATUM Datum line - a fixed point of reference from which all measurements are taken.

DAY LIGHTING Cutting back, or down, a cut batter to improve visibility, as distinct from a cutting required for soil stability.

DEBRIS Rubbish and waste material

DEFLECTION ANGLE The difference in the bearing of the inlet and outlet straights of a road curve. (CURVE DEFLECTION).

DEGRADATION The changes in the mineral fragments of a pavement caused by rubbing, or grinding against each of them within the mass. Can also be caused by chemical or weathering processes.

DESIGN PERIOD A period considered appropriate to the function of the road. It is used to determine the total traffic for which the pavement is designed i.e.: Life of a project (structural or economic).

DESIGN SPEED A speed fixed for the design and correlation of those geometric features of a carriageway that influence vehicle operation.

DESIGN TRAFFIC The equivalent number of standard axles in one direction in the design lane over the design period (ESAs)

DEVIATION An alteration to the alignment of a portion of a road, usually involving significant departure from the existing route.

DISCHARGE The volumetric rate of flow of water, usually measured in cumecs (m^3/sec).

DISPERSING AGENT A deflocculating medium, such as sodium hexametaphosphate, used in hydrometer analysis.

DITCHLINE Construction line for the formation of waterables and side drains

DOLOMITIC LIMESTONE A magnesium limestone, composed essentially of the mineral dolomite - a double carbonate of calcium and magnesium.

DRAG (N)

- (a) A simple towed frame used to redistribute running course.
- (b) Resistance to forward motion of a vehicle.

DRAG (V) To smooth a road or surface or spread materials by means of a drag.

DRAIN (N) A channel formed at the surface of culvert or pipe or other similar construction for drainage.

DRAINAGE Provision for the disposition of water.

DRAINAGE SYSTEM Combination of water control structures that provide for the disposition of water.

DROPWALL see checkdam

DRY DENSITY The weight of a dry unit volume of a substance.

DUMP (N)

- (a) A stockpile of material.
- (b) A pile of spoil or waste material.
- (c) A place for disposal of spoil or waste material.

DUST SUPPRESSANT Substance used to reduce dust generated from an unsealed pavement.

E.S.A. Equivalent Standard Axle. A reference value which causes one unit damage of pavement wear, used for pavement design life analysis.

EARTH Any naturally occurring loose or soft deposit forming part of the earth's crust and resulting from weathering or breakdown of rock formation.

EARTHWORKS All operations involved in loosening, removing and depositing or compacting earth, soil, or rock; or the material when so placed.

EMBANKMENT A raised mass of soil or rock used to carry a road over low areas.

EMULSIFIED BITUMEN An emulsion of bitumen and water containing a small amount of emulsifying agent.

EMULSION The suspension in a liquid of another liquid in a state of extremely fine division; the term is commonly applied to a suspension of bitumen in water.

END AREAS Cross sectional end areas used in calculating the volume of earthworks between two such end areas.

END HAUL CONSTRUCTION see full bench construction.

ENVELOPE TEST A particle size distribution test on engineering soils.

ESTABLISHMENT TRACK Low maintenance access track for light silvicultural vehicles

EXCAVATOR An earthmoving machine.

FACE The vertical or near-vertical working surface of a quarry, rock excavation, or gravel pit.

FAVOURABLE GRADE A down hill grade for a loaded vehicle.

FEATHER EDGING The tapering of metal at the edges of a metal running course.

FIELD BOOK Note book for recording survey information.

FILL (N)

(a) The depth from the finished road surface to the natural depth.

(b) That portion of a road where the pavement surface is above the natural surface.

FILL (V) To deposit excavated material.

FILLS SLOPE Specified slope that is less than or equal to the maximum stable slope (usually 1:2).

FILLER Relatively fine material mixed with an aggregate for the purpose of reducing the voids.

FILLING (N) Excavated material that has been deposited.

FILTER FABRIC A material which allows water to pass through but prevents the passage of fines. A type of geo-textile.

FILTER MATERIAL Granular material, the grading of which has been selected so that it will allow water to pass through it, while retaining solid matter.

FINE AGGREGATE A general term used to differentiate between various sizes of aggregate, usually material passing a 4.75mm sieve.

FINE CRUSHED ROCK A graded aggregate prepared by crushing stone for use as a gravel for pavement construction, normally 19.0mm to 26.5mm maximum size.

FLAT CROWN Pavement with no cross-fall preventing effective drainage.

FLOODGATE

- (a) A gate placed in a channel or drain to control the passage of flood or tidal water in the upstream direction yet impose a minimum effect on water flowing downstream.
- (b) A gate placed in a fence where it crosses a watercourse or drain to permit the passage of stormwater or floodwater but at other times providing enclosure by the fence.

FLUME An open channel or conduit of metal, concrete or timber, bedded in natural ground or supported on trestles, to carry water run-off from the road surface clear of embankment slopes to discharge in a safe place.

FORD A relatively shallow place in a stream where the bed may be crossed by traffic. The ford bed can be natural gravel or concrete.

FORM To carry out earthworks to levels and dimensions required for road construction.

FORMATION The final surface of the ground, excluding any side slopes after completion of the earthworks.

FORMATION WIDTH The entire width of new formation excluding batters.

FREE WATER Water that is free to move through a soil mass under the influence of gravity.

FRIABLE A soil that can be readily ruptured and crushed with the application of moderate force.

FRONT END LOADER An earthmoving machine.

FRICITION COURSE Open graded sealed surfacing to provide water drainage and high grip to vehicle tyres.

FROST HEAVE The movement in a road caused by water freezing in the road structure.

FULL BENCH CONSTRUCTION Road construction technique where all excavated material is transported and dumped away from the site. Material is not sidcasted.

GABION A rectangular basket constructed of wire mesh packed with stones or boulders used for protection of river banks, etc.

GAP GRADED MATERIAL. Graded material in which one or more of the intermediate sizes are absent.

GEOMETRIC ROAD DESIGN Horizontal and vertical alignment of a road designed for safety, speed and manoeuvrability.

GRADE The longitudinal profile of the centre of the roadway, or its rate of rise or fall; to establish a profile by cuts and fills or earthwork.

GRADED

1. The sorting of particles in a soil sample. i.e., Can be well graded or poorly graded.
2. Pertaining to the surface of an aggregate roadway.

GRADED MATERIAL Material having a wide and continuous distribution of sizes from coarse to fine, the large size being several times larger than the small size.

GRADER Road building machine used to give final shape. Often used for repair and maintenance of road surfaces.

GRADIENT

- (a) A length of carriageway sloping longitudinally,
- (b) The rate of longitudinal rise or fall of a carriageway with respect to the horizontal expressed as a ratio or as a percentage.

GRADING (N) The percentage of the various grain sizes present in a soil or other material. Usually graphically illustrated as a particle size distribution plot.

GRANITE One of the most common igneous rocks. It is a coarse-textured, crystalline rock consisting primarily of feldspar, quartz, and white or black mica.

GRATING OR GRATE A grid of metal or other suitable material to prevent debris from entering a drain or pit, and to provide protection for pedestrians and vehicles.

GRAVEL

- (a) A mixture of mineral particles, which may or may not include fine material, occurring natural deposits, passing a 75.0mm sieve.
- (b) A loosely used term for aggregate.

GRAVEL PAVEMENT A pavement with a gravel surface.

GRID ROLLER A roller constructed of heavy crossed mesh.

GRIT Fine sharp aggregate or coarse sand; fine screenings substantially free from dust, usually passing a 4.75mm sieve.

GRITTY Applicable to fine-grained soils containing a relatively small proportion of coarse grains but sufficient to give the characteristic feel.

GROSS VEHICLE WEIGHT The loaded weight of a vehicle including its own weight (tare).

GROUSER The individual metal pieces that form a track of a bulldozer.

GROUTING The operation of pouring or forcing liquids such as tar, bitumen or cement mortar into the interstices of a pavement surfacing, of a structure or of a natural formation.

GULLY A pit, usually of concrete or brick, forming an entrance at the face of a concrete or clay product, not penetrating deeply.

HAUL (N) The distance through which material is transported between points of loading and unloading.

HEAD WALL A retaining wall at the end of a culvert barrel.

HEAVE Upward movement of soil caused by expansion or displacement. Resulting from phenomena such as moisture absorption, removal of overburden, pile driving, or frost.

HORIZONTAL CURVE A curve in the plan or horizontal alignment of a carriageway. Expressed as a radius in metres.

HUMUS A dark brown material formed by the partial decomposition of vegetable or animal matter.

HYDRATED LIME Flaked Calcium Oxide $\text{Ca}(\text{OH})_2$ used as an additive in soil stabilisation.

HYDROCARBONS A group of substances composed only of carbon and hydrogen, i.e., kerosene, petrol, etc.

HYDROMETER A float of which the depth of immersion indicates the specific gravity of a liquid.

HYDROSEEDING Process by which seed, mixed with mulch, fertiliser and water, is sprayed onto area to be revegetated.

IMPERVIOUS Impassable or impenetrable. Usually means in roading work that there is no way for water to pass through. Applicable to soil or other materials which are very resistant to penetration by water.

INERT MATERIAL Components of a mixture which exhibit no binding or cementitious properties or chemical reaction.

INSPECTION/SURVEYS Visual survey to identify any problems with the road surface and/or drainage system.

INTERMEDIATE CONTROL POINT Used at the initial road survey stage to indicate and mark a change in direction in the ground profile. Side slope measurements are usually taken at these points.

INTERMEDIATE COURSE Any course between the base and surface courses.

INTERNAL FRICTION The resistance to motion of soil particles over each other caused by the roughness of the surface and the shape and size of the individual particles.

INTERSECTION The place at which two or more roads cross.

INTERSECTION AT GRADE An intersection or junction where carriageways cross or meet at a common level.

JUNCTION The place at which two or more roads meet.

LANDING Forestry processing area used by cable haulier based operations to process and store logs before transportation

LANDSLIDE A movement of, shallow or deep, the surface of a hillside, resulting from natural causes.

LEVEL OF SERVICE (LOS) Measure of serviceability that a road provides for the users. LOS decreases as pavement distress increases.

LIFE CYCLE COSTING A summation of all expenditures and incomes occurring over the lifetime or analysis period of a venture, adjusted to a common base time or value.

LIME MORTAR A mixture of cement or lime and sand with water.

LINE OF SIGHT The direct line or uninterrupted view between a driver and an object of specified height and location.

LIQUID BITUMEN Bitumen which is liquid at 25 degrees C. It being judged liquid if its consistency is so thin that it cannot be determined by the penetration test.

LOESS A wind-blown silt or silty clay having little or no stratification. Some of its peculiarities are the light colour, the fine state of subdivision, the sharpness and angularity of its particles, the porosity and coherence.

LONGITUDINAL SECTION A section, usually with an exaggerated vertical scale, showing the existing surface levels along a road centre line. It commonly shows also reconstruction levels, gradient, cut and fill.

MAINTENANCE Work carried out on a construction to maintain its efficiency or quality to the design level but not changing its capacity.

MAINTENANCE MANAGEMENT SYSTEM A system to predict the likely maintenance requirements of a new or existing road pavement.

MARKER POST Edge delineator posts at the side of the roadway to indicate a curve.

MARGINAL AGGREGATE An aggregate which does not meet conventional aggregate specifications but which may be suitable for specific use.

MARKINGS Any line painted on the road to assist traffic movement or parking.

MAXIMUM DRY DENSITY The maximum density of a soil that can be achieved by a specified amount of compaction. The moisture content at which this is achieved is called the optimum moisture content.

MECHANICAL BOND The bond obtained in a sealed or unsealed pavement due to the interlocking of angular fragments of aggregate.

MESH The clear spacing of wires or the like in a woven sieve. The mesh indicates the aperture size and is designated in millimetres for sizes 1 mm and above, and in micrometers (microns) for sizes less than 1 mm.

METAL A loosely used term for aggregate. It can be either crushed or rounded river stone.

MICA Primary aluminosilicate minerals in which two silica layers alternate with one alumina layer. They separate readily into thin sheets or flakes.

MICRON 1 / 1 000th of a millimetre.

MODE Some form of transport, i.e., foot, car, bus, air, water, etc.

MODIFIED MATERIALS Granular materials to which small amounts of stabilising agent have been added to improve their performance without causing a significant increase in structural stiffness. Modified materials are considered to behave as unbound materials.

MOISTURE CONTENT The quantity of water which can be removed from the soil by heating at 105 degrees C usually expressed as a percentage of the dry weight.

MOISTURE-RETARDENT A stabilisation product which reduces the permeability of a material.

MOULDBOARD The blade of a grader or bulldozer so shaped as to roll cut material away from the path of the machine.

NATURAL WATERCOURSE The natural drainage channel that water usually takes.

NET PRESENT WORTH (NPW) Discounting all future sums to the present, using an appropriate discount rate.

NON-COHESSIVE MATERIAL Material with low fines content such as sands and gravels.

ONE-WAY ROAD A road or street on which all vehicle traffic travels in the same direction.

OPEN SUB-SOIL DRAIN An open drain provided for the collection and removal of sub-soil water rather than surface water.

OPTIMUM MOISTURE CONTENT (OMC) That moisture content of a soil at which a specified amount of compaction will produce the maximum dry density.

ORGANIC MATERIAL see humus

OVERBURDEN Soil or other mineral matter which has to be removed to enable the material beneath it to be quarried or excavated.

OVERLAY A layer of material constructed on top of an existing panel to improve its shape or increase the strength.

OVERPASS A grade separation where the subject highway passes over an intersecting highway or railway.

PASSING BAY A widened length of a narrow carriageway at which vehicles can pass each other.

PATCHING The filling up or repair of depressions, holes, or other defective places in a carriageway with additional material to restore the surface.

PAVEMENT Constructed layers of a road surface which reduce/disperse loads to levels which are within the bearing capacity of the subgrade.

PAVEMENT RATING A method of systematically describing a pavements condition usually by visual inspection.

PEAT Unconsolidated soil material consisting largely of undecomposed or slightly decomposed organic matter accumulated under conditions of excessive moisture.

PERMEABILITY The property of a soil which permits the passage of water through open pore spaces.

PENETRATION (Used in rating Bitumens). The vertical distance passed through by a thin cylindrical rod of standard dimensions entering a bituminous material under specified conditions of weight, time and temperature.

PENETROMETER A test instrument measuring penetration versus standard weight drop. Tests soil strength.

PERVIOUS Allowing the passage of water through.

PIONEERING The initial bulldozing cut at the top of the batter. The start of earth works on the road.

PIPE DRAIN A drain constructed with pipes or in the form of a pipe.

PIT-RUN GRAVEL The material is obtained from a natural deposit of gravel without separation or addition of other material.

PIVOT STEER A machine hinged or pivoted between both sets of wheels.

PLANE (N) A towed wheeled frame with adjustable cutting blade.

PLANE (V) To smooth the surface of a road by means of a planer.

PLASTIC MATERIAL A material in a condition when it can be easily remoulded. i.e., damp clay.

PLATE COMPACTOR A hand operated vibrating compactor, mounted on a flat plate.

POORLY GRADED MATERIAL Material with excess particles of a given size.

PONDING Water not draining away from the road surface or drainage system.

PORTLAND CEMENT Binding agent used in concrete see cement.

PORTLAND CEMENT CONCRETE A mixture of water, portland cement, fine aggregate and coarse aggregate combined into a solid mass as a result of chemical reaction between the cement and water.

POT-HOLE A hole in the roadway surface.

PRESENT WORTH see Net Present Worth.

PRESTRESSED CONCRETE Concrete in which tensile stress, under given conditions of loading, is eliminated or reduced to safe limits by the imposition of permanent compressive forces of predetermined magnitudes and directions, the steel to achieve this being stressed either before the concrete is set (pre-tensioned) or after the concrete has hardened to an adequate strength (post-tensioned).

PREVENTATIVE MAINTENANCE Constant maintenance of a road to prevent major defects and pavement damage occurring

PRIMING COAT An application of light tar or other bituminous material to a prepared pavement preparatory to the initial application of a tar or other bituminous seal.

PRIVATE ROAD A road not available for general public used. If the public have access, whether by rights or not, then the Transport regulations apply.

PROFILE Refer to Long section.

PUGMILL A type of mixing equipment in which the container is stationary and the revolving blades mix the material.

QUARRY An open-surface working from which stone is obtained.

QUARRY DUST The produce of a crushing or screening plant mainly passing a

2.36mm sieve. See also CRUSHER DUST.

QUARRY FACE The vertical or near-vertical working surface of a quarry, rock excavation or gravel pit.

QUARRY FINES The smallest sized material produced from a particular crushing or screening plant.

QUARRY WASTE Reject material from a crushing and/or screening plant. It may contain a wide range of sizes.

QUARTZITE A dense sandstone rock which has been thoroughly cemented by silica, or which has been hardened by a recrystallisation process.

QUICKLIME Calcium Oxide (CaO) used as an additive in soil stabilisation.

RAPID HARDENING PORTLAND CEMENT Rapid hardening portland cement as defined in AS 1 31,5, Portland Cement.

RATIONAL METHOD A method of stream flow calculation under standard conditions of ground cover and rainfall intensity. Preferred in some cases over the use of TM 6 1.

REDUCED HEIGHT OR LEVEL The height at each peg or point on a traverse.

RAVELLING The loosening of stones or particles forming the surface course of a pavement.

RE-SHAPING Procedure to restore crossfall to a pavement

REHABILITATION An area treatment to improve the serviceability of a pavement.

REINFORCED CONCRETE Concrete strengthened within its mass by rods, bars, or mesh (usually of steel).

RESIDUAL see salvage value.

RETAINING WALL A wall constructed to resist lateral pressure from the adjoining ground, or to maintain in position a mass of earth.

RETARDER (in concrete) An admixture which reduces the rate of hardening of cement, thus increasing the time during which concrete may be worked.

REVETMENT A facing of stone or other material laid on a sloping face of earth to maintain the slope in position or to protect it from erosion.

RING ROAD A road or highway roughly circular about the centre of an area and permitting traffic to avoid the centre of such an area.

RIP RAP Loose stone deposited to protect against scour.

RIPARIAN STRIP Areas running alongside streams or rivers.

ROAD The entire way devoted to travel, including berms etc. The whole width between abutting property boundaries where the road is in a surveyed road reserve.

ROUGHNESS Unevenness of a pavement which is commonly assessed by the ride it provides.

ROUGHMETER A device for measuring vehicle response to roughness. Usually sums the vertical displacement of an axle to a vehicle body.

RUBBER TYRED ROLLER A road building compaction machine used to finish off the surface of a pavement.

RUBBLE Material consisting of stone of irregular shapes and sizes, broken brick or the like, used to provide a stable or permeable filling or for other purposes.

RUN-OFF That part of the water precipitated onto a catchment area which flows from the catchment area past a specified point.

RUT A depression in the wheel path of the carriageway caused by vehicles.

RUNNING COURSE (wearing course) A thin layer of loose stone which protects the crust or surface of an unsealed road.

RUNNING DISTANCE The cumulative distance at each point on a traverse or long section.

RUNNING PLANKS The boards in a longitudinal direction on a bridge deck. They are sacrificial and intended to take the surface wear.

SADDLE Low point in a ridge, having higher ground in both directions along the ridge.

SAFE STOPPING DISTANCE Stopping distance required to avoid collision.

SAG CURVE A vertical curve between two gradients to provide a gradual rather than sharp change in direction.

SALVAGE VALUE Value of a project at the end of its analysis period (RESIDUAL).

SAMPLING The selection of a representative portion of a material for the purpose of ascertaining its characteristics.

SAND Produce of rock weathering, generally siliceous, free from appreciable quantities of clay or silt, and consisting of particles usually less than 2.80mm in size and retained on a 0.75mm sieve.

SCARIFYING The systematic disruption and mechanical loosening of the top of a pavement or of natural ground.

SCALE Ratio representing the reduction or enlargement factor in a drawing.

SCALE RULE A ruler with markings which enable direct reading of distances from maps and plans.

SCREEN A large sieve used in industrial processes usually mechanically operated. The sieving surface may be either flat or cylindrical in form.

SECONDARY AGGREGATE A non-premium aggregate with sufficient durability to support its economic use on unsealed roads.

SEVICABILITY RATING Assessed in terms of several characteristics of a facility and describes the degree to which relevant requirements or standards are met.

SCOOP An earthmoving machine towed by and operated from a dozer.

SCOURING Ruts and/or channels formed by the action of flowing water.

SCRAPER An earthmoving machine.

SCREENINGS Aggregate of small size, usually passing a 26.5mm sieve and retained on a 4.75mm sieve.

SEALCOAT Colloquially equivalent to a chipseal.

SECONDARY ROAD High standard feeder road linking spur roads to arterial roads.

SEDIMENTATION Suspended material in a flowing liquid. As the liquid flow slows the suspended material falls onto the ground surface producing sedimentation.

SEDIMENT POND / TRAP Structures used to monitor the sediment produced from an area during construction and/or reduce the quantity of sediment entering a waterway.

SEEPAGE The extrusion of small quantities of water by percolation. The escape of water through the soil, or water emerging from an area of soil along an extensive line of surface, in contrast to springs where the water is localised and greater in volume.

SELECTED FILL Filling in accordance with requirements or specifications set out.

SETTLEMENT A downward movement of the soil or of the structure it supports by the reduction of the voids in the underlying ground.

SHOULDER The portion of the road continuous and flush with the pavement on either side of the road, which is not used by the travelling traffic.

SIDE CASTING Pushing excavated material to one side, usually over the edge of the road being constructed. Nearly always associated with hill side roads where the spoil is wasted.

SIDECAST PULL BACK Pulling side cast material back onto the road after road no longer needed.

SIDE DRAIN see watertable drain.

SIDE CHANNEL See Surface Water Channel.

SIDE LINES (EDGE LINES) Line marking indicate the edge of the trafficable roadway.

SIEVE A box or tray whose base is made of woven wire or similar material or of perforated metal plate, having apertures of defined shapes and sizes.

SIGHT DISTANCE The distance, measured along the carriageway, over which visibility occurs between a driver and a specified object.

SILT A material intermediate in particle size between sand and clay. It is usually non-plastic.

SILT FENCE Temporary structure used to collect sediment from small areas during construction. Usually made from geotextiles or straw bales.

SINGLE-SIZE MATERIAL An aggregate, a major proportion of whose particles are of size lying between narrow limits.

SKID SITE Forestry processing area used by ground based operations to process and store logs before transportation

SLAG The stony product resulting from certain smelting processes.

SLIP A movement or fall of earth.

SLOT DOZING When pushing spoil in a 'ditch' and spoil is constrained to within the 'ditch'. Because spoil cannot escape around the end of the blade it helps keep the blade 'full'.

SLOPE

- (a) The inclination of a surface with respect to the horizontal expressed as rise or fall in a certain longitudinal distance, i.e., 1 in 10 or as a percentage 10% or as an angle 5.72 degrees.
- (b) An inclined surface.

SMOOTH STEEL DRUM ROLLER A road building compaction machine. May be static or vibrating.

SOAK PIT A large hole maybe filled with rock or stone to create a large surface area in the surrounding ground so that surface run-off can soak away.

SOFFIT The highest portion of the internal surface of a culvert or arch.

SOFT SPOT Localised movement of material within the pavement under loading.

SOIL Any naturally occurring loose or soft deposit forming part of the earth's crust and resulting from weathering or breakdown of rock formation.

SOIL STABILISATION Any process aimed at maintaining or increasing the stability or strength value of a soil, as a constructional material, often by admixtures. Most Soil Stabilisation processes reduce the effect that water has on the material. In general the more moisture in a soil the less strength that soil has.

SOUNDNESS TEST An assessment of the soundness of a material as determined by some specific test.

SPALL (SPAWL) A piece of rock, usually of dimensions suitable for feeding into a crusher, broken from a larger mass.

SPECIFIC GRAVITY The ratio of the density of a substance to the density of water at 4 deg. C.

SPOIL Disturbed material. Usually during earthmoving.

SPUR ROAD A short temporary access road usually to a landing or skid site.

STABILISE (V) To modify any natural material to improve or maintain its load-carrying capacity. (Usually by adding lime, cement, emulsion or water).

STABILISED GRAVEL Any natural material which has been modified to improve or maintain its load-carrying capacity. Modification may be by the addition of other natural materials such as bitumen, lime, cement, or other synthetic material.

STEMMING (N) The filling material used in a drillhole either between the explosive charges or between the explosive charges and the ground surface.

STEP To form a ledge or bench.

STOCK PILE A heap or stack of material held in stock for future use.

STRATA Layers (usually) of rock, sand silt etc.

STRIPPING The removal of the upper layer of soil or overburden (including contained roots, humus or stones); or the material so removed.

SUB BASE Area below the basecourse construction.

SUB-GRADE The trimmed or prepared portion of the formation on which the pavement is constructed. Generally taken to relate to the upper line of formation.

SUB-GRADE DRAIN A sub-soil drain to drain water from the sub-grade.

SUBSIDENCE A downward movement resulting from consolidation or displacement of the underlying material.

SURFACE DEFECTS Defects affecting the top running surface of a pavement.

SUPERELEVATION Slope of road surface on corners.

SUUNTO Survey equipment used to measure slope angles

SWITCHBACK Acute angled corner enabling the road to meander up steep slopes

TEXTURE

- (a) A term indicating the coarseness or fineness of a soil. The texture of soils for pedagogical classification is determined by a triangular chart and is based on the results of mechanical analysis.
- (b) Surface texture of a chip sealed roadway.

THEODOLITE A survey instrument used to measure horizontal and vertical angles.

TM 61 (Technical Memorandum 1961) A procedure for calculating the stream flow under standard conditions of ground cover and rainfall intensity. This method of stream flow calculation is not generally suited to small streams and requires some skill and experience in its use and particularly in the interpretation of results. The RATIONAL method is preferred for small stream catchments.

TOE Bottom of fill or batter.

TOE WALL A low retaining wall constructed at the foot of an earth slope.

TOMMING

- (a) The provision of additional vertical support beneath an existing structure.
- (b) The provision of temporary vertical support.

TOPCOURSE The layer of pavement between the basecourse and the surface layer.

TOPO MAP A map showing general information. It may not but usually will include contours.

TOPPINGS Fine material from rock crushing, usually including dust, passing a 4.75mm sieve.

TRAFFIC DELAY COSTS User cost incurred by disruptions caused by maintenance operations.

TRANSITION CURVE A curve of changing radius allowing an easy change from a straight to a constant radius curve.

TRAVERSE A line of bearing and distances used in road surveys to determine location.

USER OPERATIONAL COSTS Total costs incurred by the road user.

VEHICLES PER DAY The number of vehicles observed passing a point on a road in both directions for 24 hours.

VERGE The edge of a road reserve between the side channel and road.

VERTICAL ALIGNMENT

VERTICAL CURVE A curve in longitudinal profile of a carriageway to provide for gradual change of grade.

VISCOSITY Internal friction due to molecular cohesion in fluids.

VIBRATING ROLLER A roller uses vibration to assist compaction. Characterised primarily by frequency, amplitude and mass.

VOIDS The voids in a soil refer to that volume not occupied by solid materials and include the volume occupied both by water and by air.

WASTE A term used for spoil not used in a filling.

WATER BARS see cross ditches.

WATER CEMENT RATIO The ratio of the weight of water to the weight of the cement in concrete or mortar.

WATER CONTENT The quantity of water which can be removed from the soil by heating at 105 degrees C usually expressed as a percentage of the dry weight.

WATER TABLE

- (a) The level at which ground water would finally stand in an unpumped borehole, well, or other depression, when equilibrium has been reached.
- (b) See Side Channel.

WATER TABLE DRAINS Drains running parallel to the road to drain water from the road carriageway and adjoining slopes.

WEARING COURSE (Running course) That part of the surface course that directly supports the traffic.

WEATHERED Partly decomposed or otherwise affected by exposure to weather.

WEATHERING The physical and chemical disintegration and decomposition of rocks, and minerals.

WHEEL RUTS Longitudinal depression formed in a road by the passage of vehicles. Often caused by compaction due to wheel loads.

WINDROWED Material formed into a long ridge.

WING WALL Culvert or bridge approach protection wall, eliminating erosion by fast moving water.

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CHAPTER 16 - BIBLIOGRAPHY

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APPENDIX A

ESTIMATING AVERAGE TRUCK SPEED

APPENDIX A - Estimating Average Truck Speed

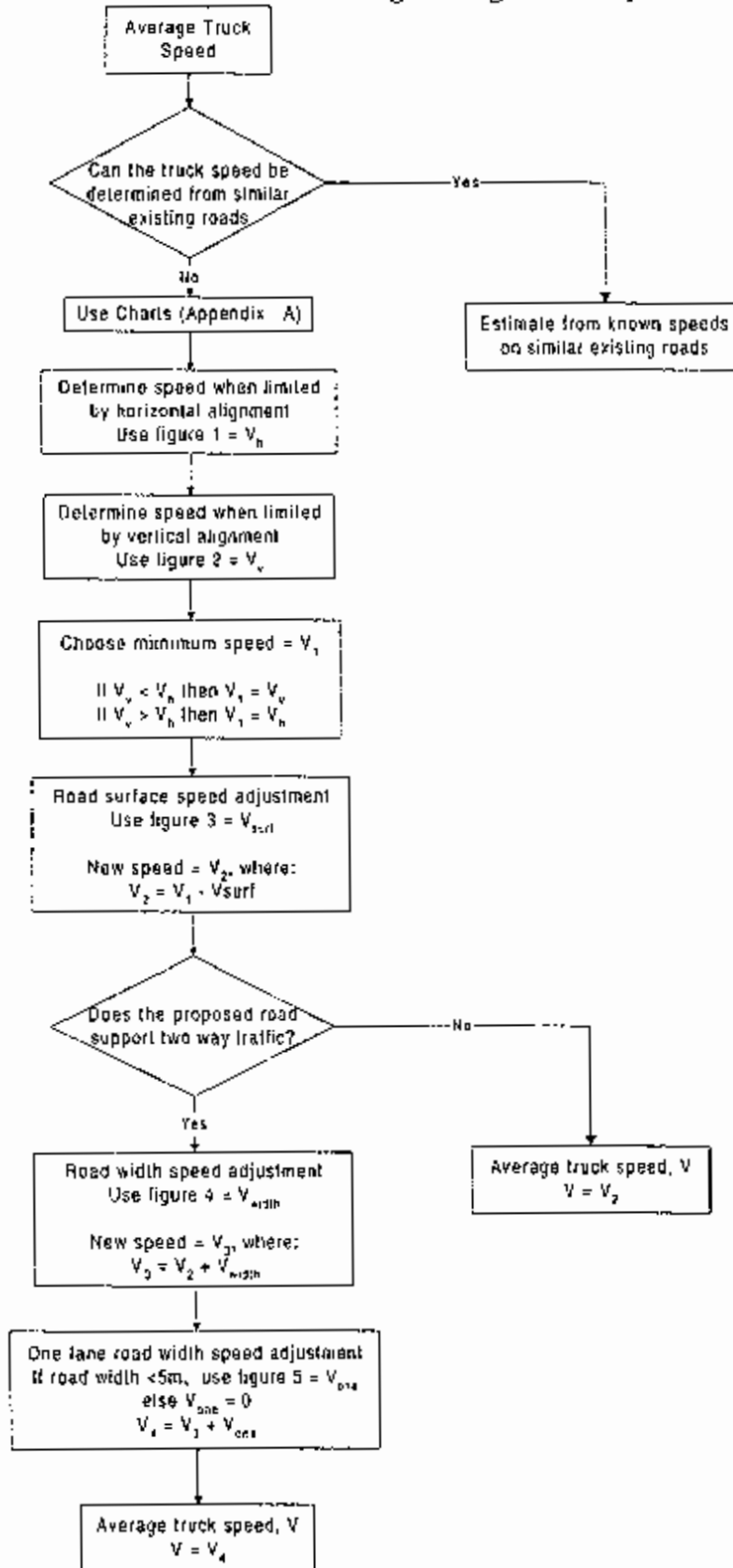


Figure 148 - The process of estimating average truck speed

1. Initial average speed governed by either grade or horizontal alignment.

Choose the minimum average speed either from figure 149 or figure 150.

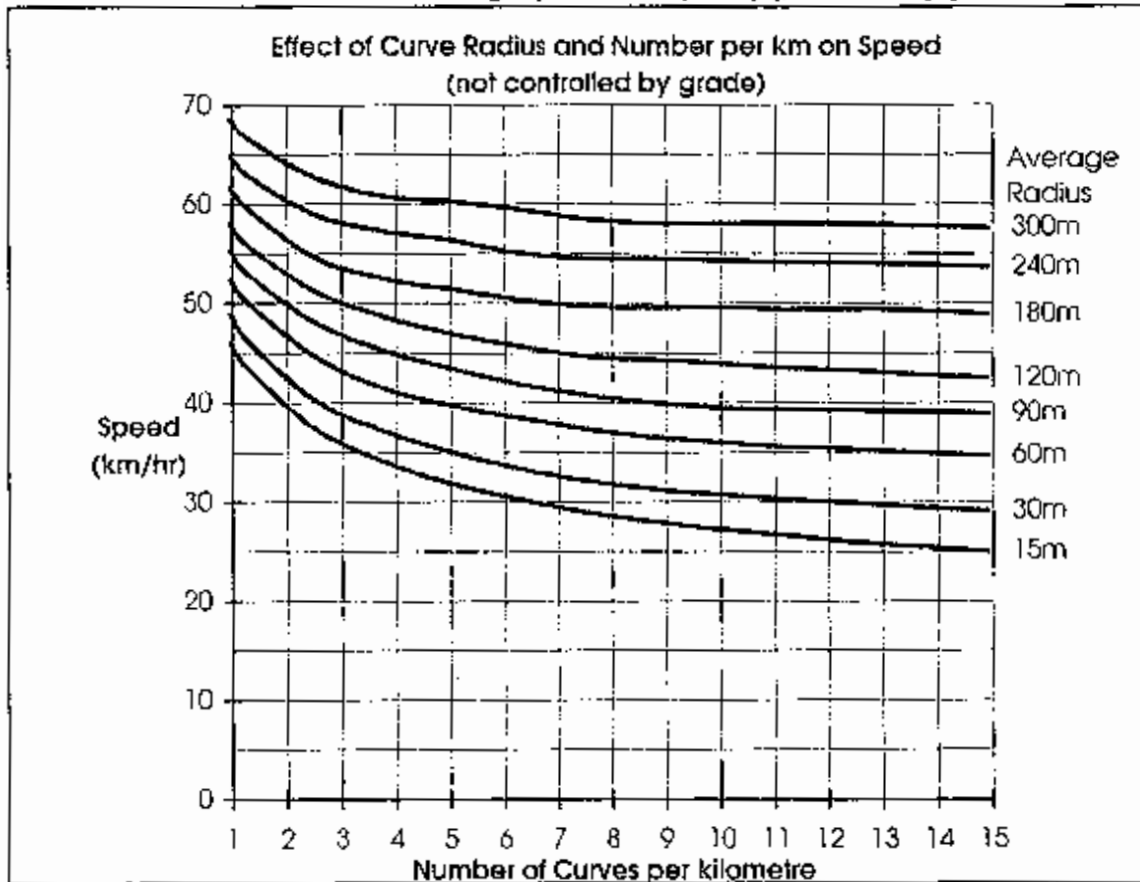


Figure 149 - The effect of curve radius and number on speed.

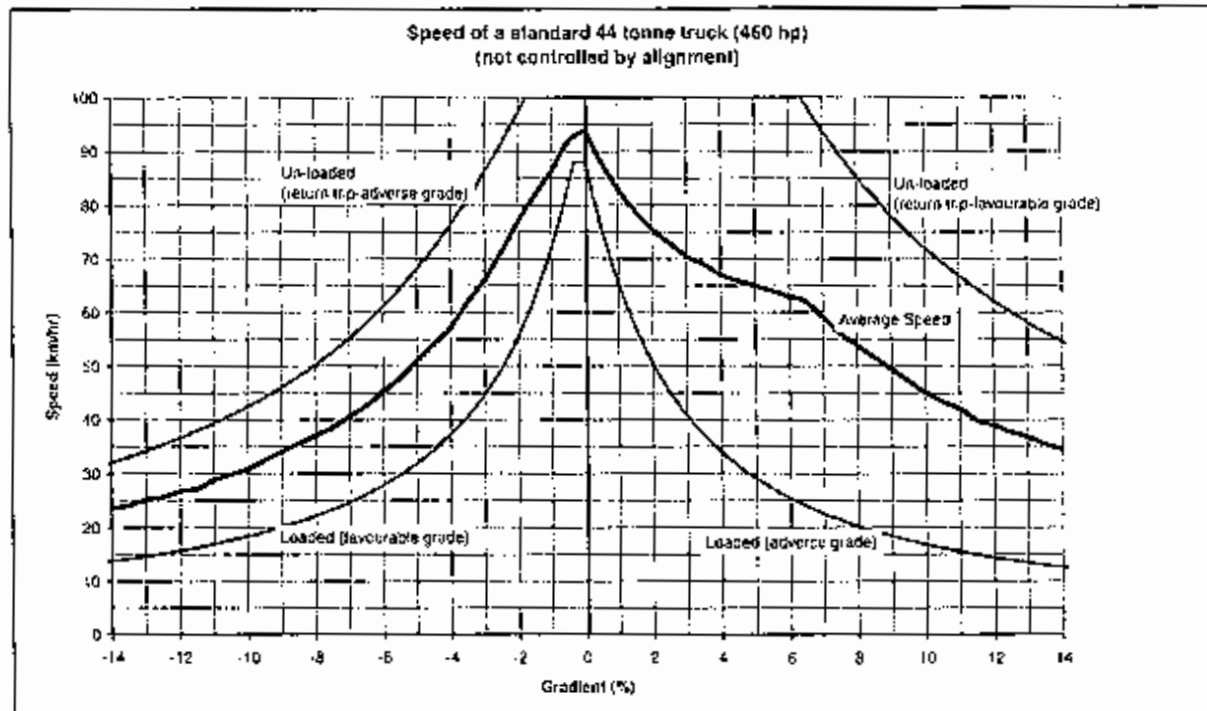


Figure 150 - The effect of grade on speed.

2. Adjustment of speed for type of road surfacing.

Use figure 151 to find a speed adjustment - either a reduction or an increase. No speed adjustment is required for a gravel road in good condition. A dirt road represents a road with no metal, or a rough metal road that is likely to reduce speed. The sealed road represents a sealed road, or a very smooth and firm gravel road, where the speed is likely to be higher.

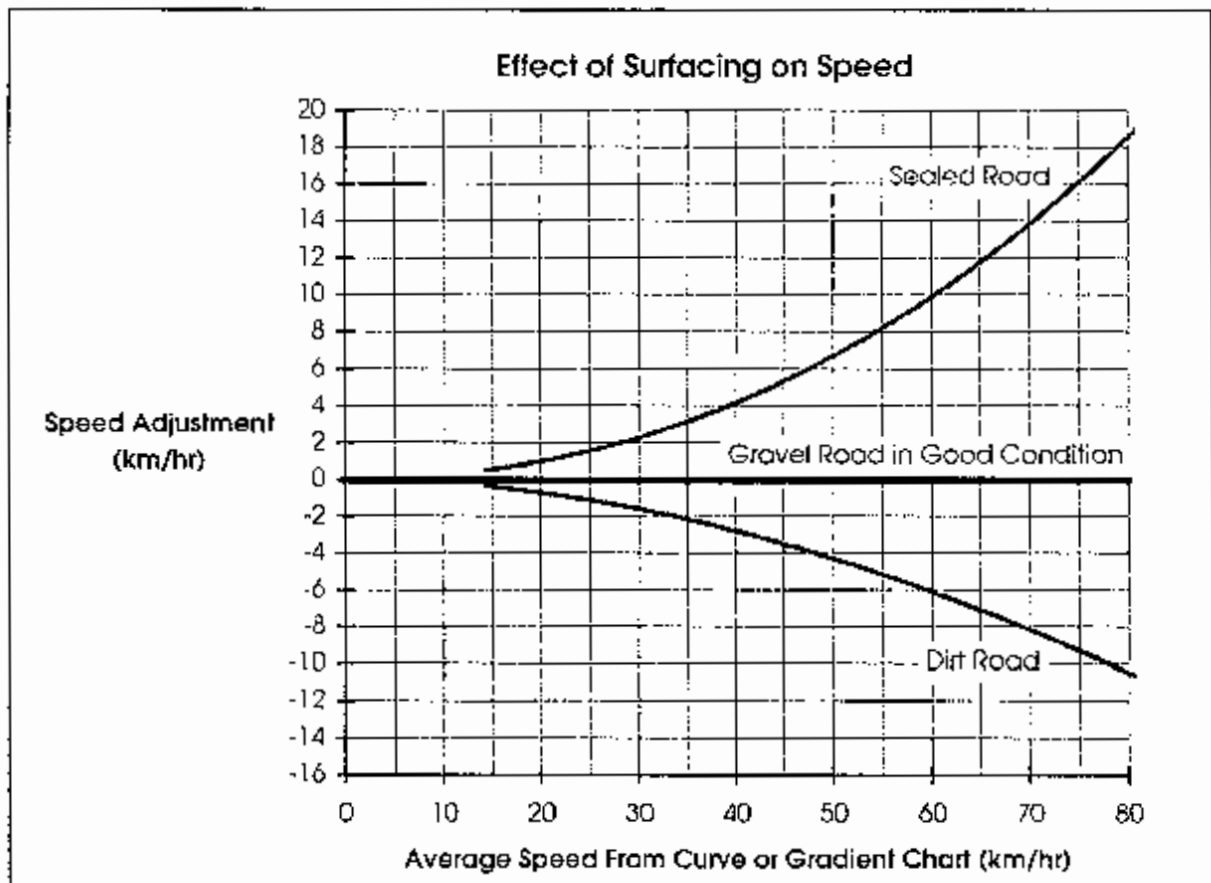


Figure 151 - Road surfacing speed adjustment

3. Adjustment of Speed for Road Width.

This speed adjustment is due to the drivers' perception and driving comfort - as the road gets narrower, the speed is decreased so that oncoming traffic can be avoided.

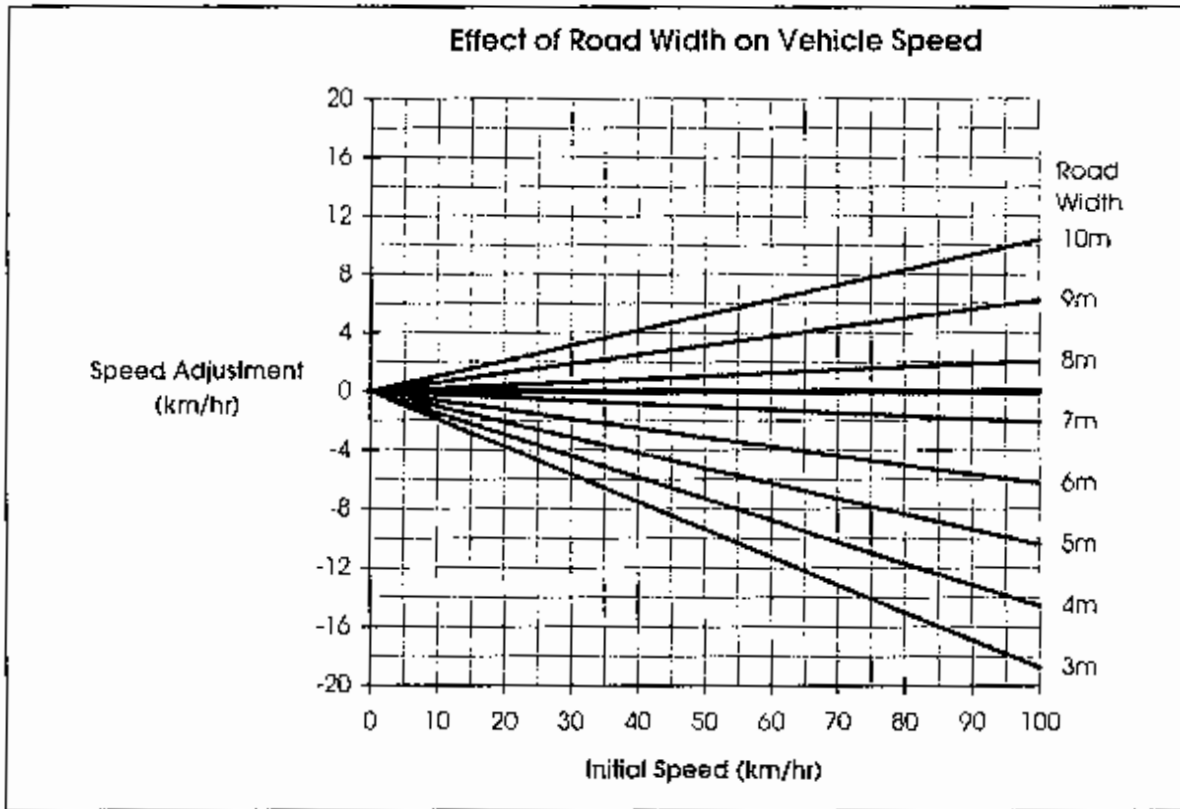


Figure 152 - Road width speed adjustment

4. Additional speed adjustment required for one-lane roads (less than 5m in width) for two-way traffic with turnouts.

This decrease in speed is due to vehicles waiting in a turnout area for another vehicle to pass. It is dependent on the number of heavy vehicles per day (hvpd). Figure 153 has been calculated for a turnout spacing of 1500 metres which is considered to be a maximum length because of the time any one vehicle has to wait for another to pass (approximately 3 minutes).

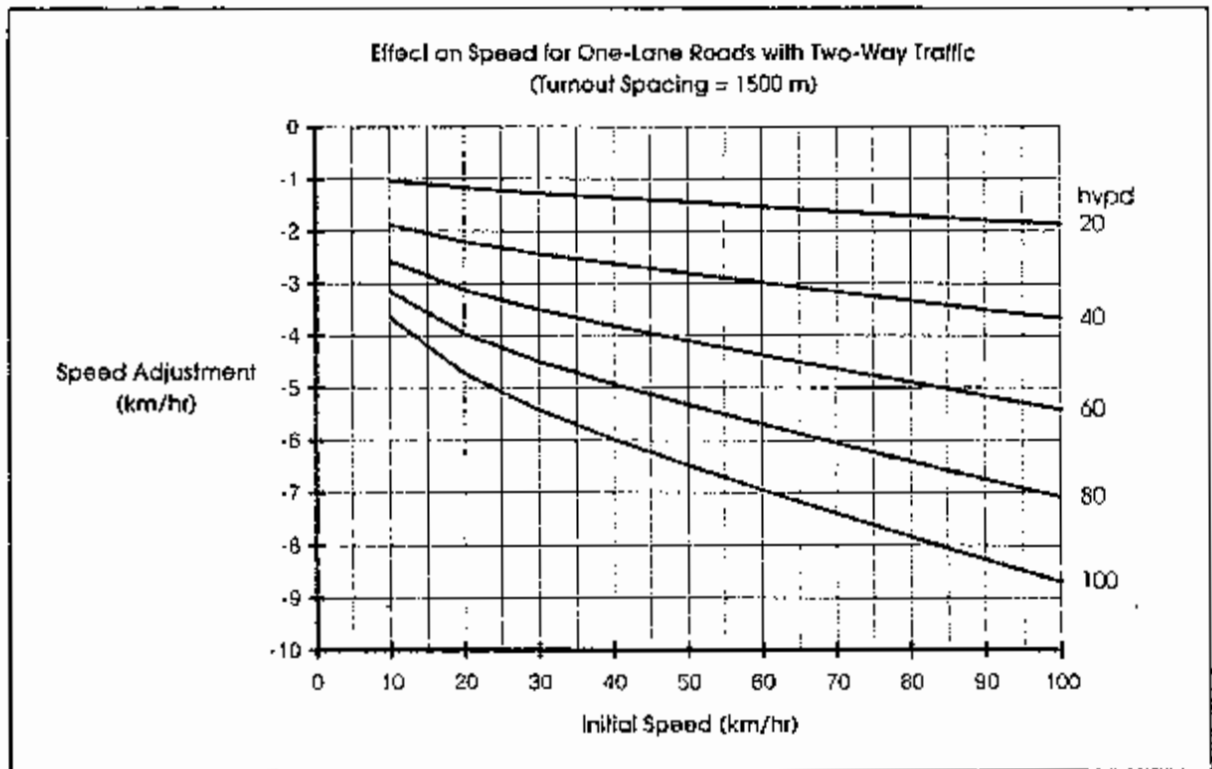


Figure 153 · Speed adjustment for a one-lane road supporting two-way traffic.

Note: hvpd = heavy vehicles per day. This is the total number of passes of a truck in one day and includes both directions (ie: loaded and un-loaded). It was assumed to be equal traffic in both directions.

The number of heavy vehicles per day is given by:

$$hvpd = 2 \times \frac{V}{P} \times \frac{1}{W}$$

where:

- 2 = the multiplier for the return unloaded trip
- V = Volume of wood carted over the road (tonnes per annum)
- P = Average payload (tonnes per truck - 27 tonnes for a standard on-highway truck)
- W = The number of days per year that wood is carted (typically = 235 days)

Note: When calculating the average speed on one-way roads carrying traffic in one direction only the speed adjustments in sections 3 and 4 above are not used.

APPENDIX B

RESOURCE CONSENT APPLICATIONS

APPENDIX B - Resource Consent Applications

The following information is quoted from, Vaughan, L. 1990: Logging Industry Research organisation (LIRO) *New Zealand Forest Code of practice*. Updated by Viser, R & Smith, M. 1993.

1. Relevant legislation

HEALTH AND SAFETY IN EMPLOYMENT ACT (1992)

Purpose

The focus of this act is on prevention of harm arising out of work activities not only to employees but other people, including members of the public. The three means to achieve the object are:

- The promotion of excellence in health and safety management by employers
- Prescription of duties to employers and others, to prevent harm to employees
- Provision for the making of regulations and approved codes of practice relating to specific hazards e.g. Safety Code for Forest Operations

Implications

Employers have a duty to take all practicable steps to ensure the safety of employees while at work. They must **identify hazards and eliminate, isolate or minimise** them. Employers must involve their employees in the development of health and safety procedures relating to the management of hazards and dealing with emergencies and imminent dangers. The responsibility is with the employer to assess what the hazards are and deal with them.

Administering Agency

Occupational Safety and Health Service of the Department of Labour

Allied Legislation

Employment Contracts Act 1991

Accident Rehabilitation and Compensation Insurance Act 1992

Contact for Information

Bush Inspectors at the regional offices of the Occupational Safety and Health Service of the Department of Labour

Note

Replaces the Bush Workers Act 1945 but the Safety Codes for Forest Operations remain in place.

HISTORIC PLACES ACT 1980

Purpose

This Act provides for preservation of New Zealand's historic heritage, both buildings and land.

Administering Agency

The Historic Places Trust, a quango of the Department of Conservation.

Implications

It is an offence to destroy or damage an archaeological site or a site with important historic or traditional values. Local authorities usually register such sites in their district scheme. Some major forestry organisations have employed archaeologists and/or historians to survey their land prior to starting operations. Where sites are of lesser importance, modification may be permitted once they have been surveyed and consultation with local Tangata Whenua taken place.

Contact for Further Information

Planning Officer with District Council, specialised staff in the regional offices of Department of Conservation, or staff in the Historic Places Trust.

Allied Legislation

Antiquities Act 1975

RESERVES ACT 1977

Purpose

The Reserves Act 1977 provides for the purchase and management of areas of special interest for public use.

Administering Agency

Department of Conservation.

Implications

Areas of publicly-owned land can be designated as recreation, scenic, historic, native or scientific reserves. Activities that will adversely affect the plant life or wildlife of a reserve are not permitted. For most forest owners, the only major problem would be burning-off operations where it was not possible to firebreak the boundary with the reserve.

Contact for Information

Regional or district staff of the Department of Conservation.

RESOURCE MANAGEMENT ACT 1991

Purpose

The Resource Management Act 1991 deals with the management of natural and physical resources. The Act promotes sustainable management of those resources.

Administering Agency

Ministry for the Environment, with implementation through Regional and District Councils.

Implications

The Act provides a framework for resource management with emphasis on the effects and outcomes rather than control of specific activities. The Act provides a common set of principles to be applied to management of all resources.

The responsibilities of central government, regional and district councils and individuals are set out in the Act. The procedures for resource-use applications are similar to those used previously however every consent application must be accompanied by an assessment of the effect the activity will have on the environment. The information required may need to be more detailed than under the previous system, depending on the significance of the proposal. The Act requires a consent applicant to have considered the off site effects any activity will have. Any adverse effects must be avoided, minimised or mitigated and a statement of how this will be achieved must accompany the consent application.

Contact for Further Information

Planning and operational staff with the Regional and District Councils and Ministry for the Environment.

WILDLIFE ACT 1953

Purpose

This Act provides for the conservation and protection of absolutely or partially protected species of native animals, lizards, birds, insects etc.

Administering Agency

Department of Conservation

Implications

The term “wildlife” has a very wide definition as being any animal that is living in a wild state...”. However it does not include animals such as deer, chamois, goat, opossum, pig, thar or wallaby, which are wild animals subject to the Wild Animal Control Act 1977.

The Wildlife Act provides for the protection of wildlife through wildlife sanctuaries, reserves and refuges, prescribes hunting seasons for game animals and authorises the appointment of rangers.

Contact for Information

Regional offices of Department of Conservation.

Local Fish and Game Councils.

Associated Regulations

There are many sets of regulations and orders establishing particular sanctuaries and refuges.

2. Documents of Interest

- **Purposes and Principles of the RMA (Sections 5 to 8)**
- **Fourth Schedule of the RMA (assessment of effects on the environment)**
- **General Duties of Employers in Health and Safety in Employment Act (Section 6)**
- **Fish Regulations (selected sections)**

PURPOSE AND PRINCIPLES OF THE RMA, 1991 (PART II, SECTIONS 5- 8)

5. PURPOSE

(1) The purpose of this Act is to promote the sustainable management of natural and physical resources.

(2) In this Act, "sustainable management" means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while -

- (a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonable foreseeable needs of future generations; and
- (b) Safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and
- (c) Avoiding, remedying, or mitigating any adverse effects of activities on the environment.

6. MATTERS OF NATIONAL IMPORTANCE

In achieving the purpose of this Act, all persons exercising functions and powers under it, in relation to managing the use, development, and protection of natural and physical resources, shall recognise and provide for the following matters of national importance:

- (a) The preservation of the natural character of the coastal environment (including the coastal marine area), wetlands, and lakes and rivers and their margins, and the protection of them from inappropriate subdivision, use, and development:
- (b) The protection of outstanding natural features and landscapes from inappropriate subdivision, use, and development:
- (c) The protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna:
- (d) The maintenance and enhancement of public access to and along the coastal & marine area, lakes, and rivers:
- (e) The relationship of Maori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, and other taonga.

7. OTHER MATTERS

In achieving the purpose of this Act, all persons exercising functions and powers under it, in relation to managing the use, development, and protection of natural physical resources, shall have particular regard to -

- (a) Kaitiakitanga:
- (b) The efficient use and development of natural and physical resources:
- (c) The maintenance and enhancement of amenity values:
- (d) Intrinsic values of ecosystems:
- (e) Recognition and protection of the heritage values of sites, buildings, places, or areas:
- (f) Maintenance and enhancement of the quality of the environment:
- (g) Any finite characteristics of natural and physical resources:
- (h) The protection of the habitat of trout and salmon.

8. TREATY OF WAITANGI

In achieving the purpose of this Act, all persons exercising functions and powers under it, in relation to managing the use, development, and protection of natural and physical resources, shall take into account the principles of the Treaty of Waitangi (Te Tiriti o Waitangi).

FOURTH SCHEDULE OF THE RMA, 1991
(ASSESSMENT OF THE EFFECTS ON THE ENVIRONMENT)

1. Matters that should be included in an assessment of effects on the environment

Subject to the provisions of any policy statement or plan, an assessment of effects on the environment for the purposes of section 88 (6)(b) should include -

- (a) A description of the proposal;
- (b) Where it is likely that an activity will result in any significant adverse effect on the environment, a description of any possible alternative locations or methods for undertaking the activity;
- (c) Where an application is made for a discharge permit, a demonstration of how the proposed option is the best practicable option;
- (d) An assessment of the actual or potential effect on the environment of the proposal activity;
- (e) Where the activity includes the use of hazardous substances and installations, an assessment of any risks to the environment which are likely to arise from such use;
- (f) Where the activity includes the discharge of any contaminant, a description of
 - (i) The nature of the discharge and the sensitivity of the proposed receiving environment to adverse effects; and
 - (ii) Any possible alternative methods of discharge including discharge into any other receiving environment;
- (g) A description of the mitigation measures (safeguards and contingency plans where relevant) to be undertaken to help prevent or reduce the actual or potential effect;
- (h) An identification of those persons interested in or affected by the proposal, the consultation undertaken, and any response to the views of those consulted:
 - (i) Where the scale or significance of the activity's effect are such that monitoring is required, a description of how, once the proposal is approved, effects will be monitored and by whom.

2. Matters that should be considered when preparing an assessment of effects on the environment.

Subject to the provisions of any policy statement or plan, any person preparing an assessment of the effects on the environment should consider the following matters:

- (a) Any effect on those in the neighbourhood and, where relevant, the wider community including any socioeconomic and cultural effects:
- (b) Any physical effect on the locality, including any landscape and visual effects:
- (c) Any effect on ecosystems, including effects on plants or animals and any physical disturbance of habitats in the vicinity:
- (d) Any effect on natural and physical resources having aesthetic, recreational, scientific, historical, spiritual, or cultural, or other special value for present or future generations:
- (e) Any discharge of contaminants into the environment, including any unreasonable emission of noise and options for the treatment and disposal of contaminants:
- (f) Any risk to the neighbourhood, the wider community, or the environment through natural hazards or the use of hazardous substances or hazardous installations.

SECTION 6 OF THE HEALTH AND SAFETY IN EMPLOYMENT ACT, 1992

6. EMPLOYERS TO ENSURE SAFETY OF EMPLOYEES

Every employer shall take practicable steps to ensure the safety of employees while at work; and in particular shall take practicable steps to -

- (a) Provide and maintain for employees a safe working environment; and
- (b) Provide and maintain for employees while they are at work facilities for their safety and health; and
- (c) Ensure that plant used by any employee at work is arranged, designed, made, and maintained that is safe for the employee to use; and
- (d) Ensure that while at work employees are not exposed to hazards arising out of the arrangement, disposal, manipulation, organisation, processing, storage, transport, working, or use of things -
 - (i) In their place of work; or
 - (ii) Near their place of work and under the employers control; and
- (e) Develop procedures for dealing with emergencies that may arise while employees are at work.

**FRESHWATER FISHERIES REGULATIONS, 1983 & CONSERVATION LAW
REFORM ACT, 1990 (SELECTED SECTIONS)**

The following information is quoted from, C.P. Mitchell (1990). Fish Passes for Native Fish: A Guide for Managers. New Zealand Freshwater Fisheries Miscellaneous Report No. 45.

The Department of Conservation has the responsibility for the protecting and maintaining New Zealand's native fish populations under the Freshwater Fisheries Regulations 1983 and the Conservation Law Reform Act 1990. These acts specify:

- (a) "No person shall construct any culvert or ford in any natural river, stream or water in such a way that the passage of fish would be impeded." (Section 42);
- (b) "...The Director General of DOC may require that any dam or diversion structure proposed to be built include a fish facility." (Section 43);
- (c) DOC also has the power to specify design and operation criteria of any fish passage. (Section 44: Appendix 1).

APPENDIX C

GEOMETRIC DESIGN

APPENDIX C - Geometric Design

1. Intermediate Control Points

Intermediate control points are required where a small (or occasionally large) hill is inline with the new road. In this situation, rather than trying to form the road over top of a rock bluff, a box cut is made through the hill to the required grade. Refer figure 154.

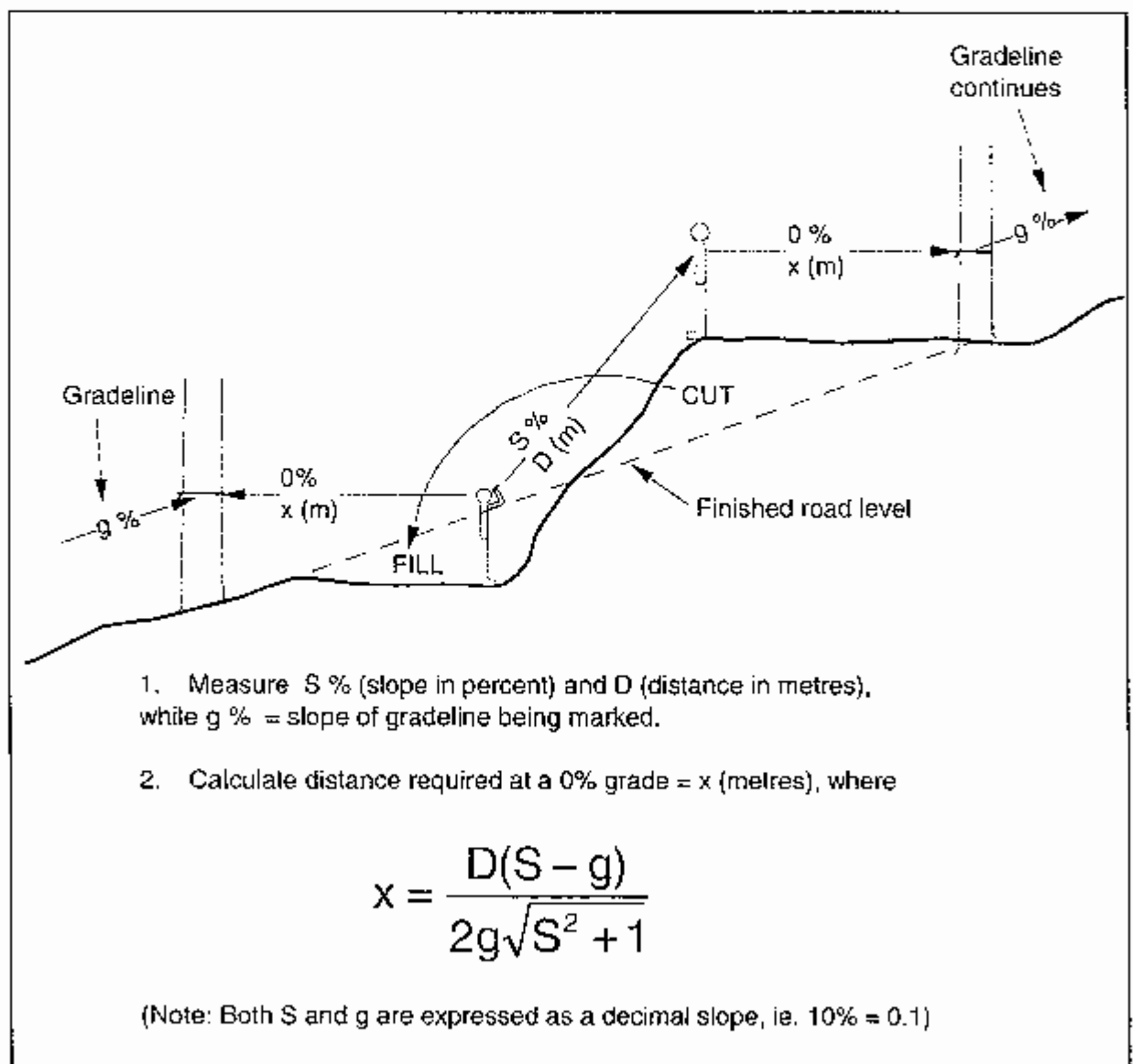


Figure 154 - Intermediate control points over a rock bluff.

2. Crossing Hollows or Draws

In crossing a hollow or draw, the gradeline must not be continued so far up into the hollow that construction of the minimum radius curve will materially increase the finished grade of the road. The best way to avoid this problem is to "shoot" a level grade across the hollow at a point where it is twice as far to the other side as the radius of the desired curve in the hollow.

For example, if the radius of the curve in the hollow is to be 26 metres, the Abney man should stop setting grade when he is about perpendicular and 60 metres from one side of the hollow to the other. At that point he should set the Abney at zero and "shoot" across the hollow and make a grade mark (figure 155). He can then go across the hollow and continue setting grade at that point. This procedure will ensure that the desired grade will not have been increased.

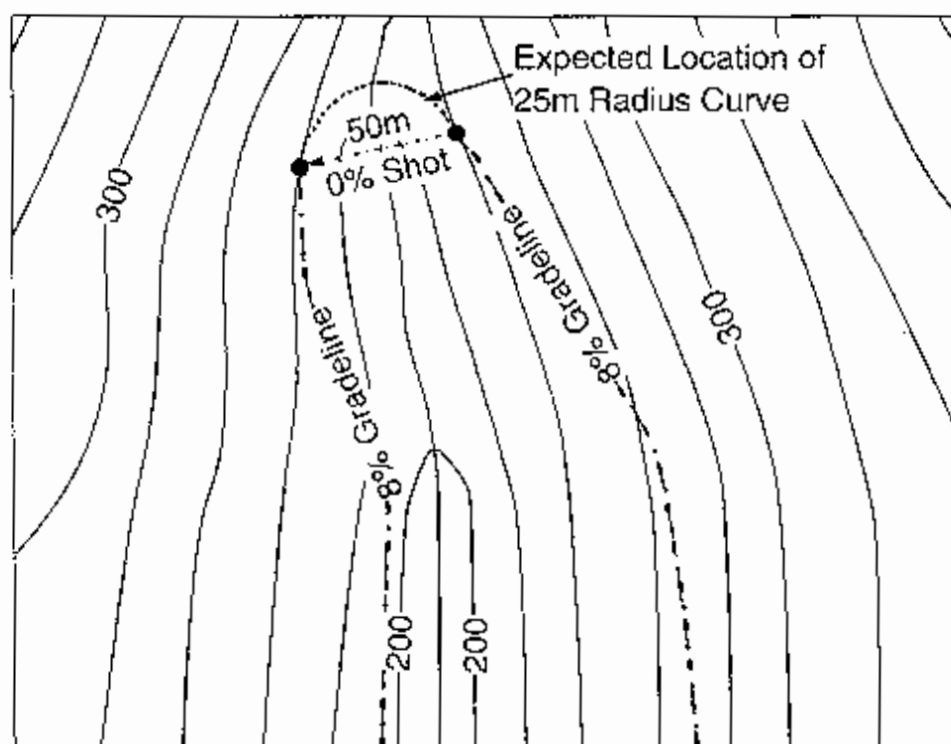


Figure 155 - Procedure of shooting 0% across hollow

If gaining every possible metre of elevation is imperative, then the shot across the hollow can be on a gradient, but it should not be more than one half of the grade being run.

3. Running Around Long Narrow Ridges

This problem is similar to crossing hollows. It is best to run around the ridge on a zero percent grade from the point where you want the curve to begin, to the point where you want it to end. At this point, the gradeline can be continued and allow construction of the desired radius curve and lower the grade around the curve. Running a continuous gradeline around the nose and constructing a larger radius curve will cause the gradient to increase and the curve would be in a through cut for nearly its entire length.

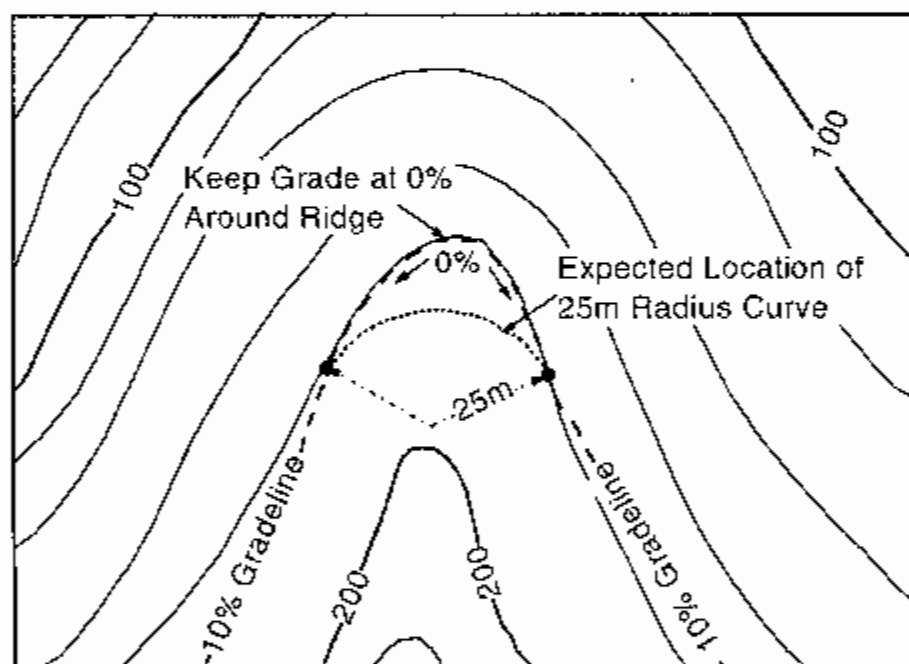


Figure 156 - Running around the nose on a zero percent grade.

Walk around the ridge on a zero percent grade and estimate where the curve will end to begin the next gradeline section.

4. Switchback Layout

In most cases, the slope of the ground in the switchback area will be greater than the gradient that is being run. The problem then, is how to modify the gradeline to allow construction of the desired grade around the switchback.

For example, let us assume that the switchback area has a side slope of 30% and you wish to build a switchback with an 26 meter radius on a 6% grade, and that the road grade on the straights is 10%. If the switchback is a full half circle, then the elevational distance on the ground between the beginning and the end of the switchback is 16 metres ($2 \times 26 \times 0.3$), and the length of the switchback is 79 metres ($26 \times \Pi$).

If the switchback is to be built to 6% it will only use 4.74 metres (79×0.06) of the elevational difference between the beginning and end of the switchback. The difference between 16 metres on the ground and the 4.74 metres used in the construction must be compensated for. This can be done by cutting half of the difference $\left(\frac{16 - 4.74}{2} = 5.13m \right)$ on the uphill side of the switchback, and filling the same amount on the downhill side of the switchback.

To be a continuous grade, the cutting and filling must start beyond the beginning and ending of the switchback. This distance is provided for by laying out a 0% grade for 51.3 metres up to the beginning of the curve, and for 51.3 metres beyond the end of the curve ($51.3 \times 0.1 = 5.13$). In this case, the field procedure would be to run the 10% grade to within 51.3 metres of the beginning of the curve, run a 0% grade for 51.3 metres, layout a half circle with an 26 metre radius, run 0% for 51.3 metres, and then continue the gradeline at 10%.

Considering the impact of steep ground on switchback construction costs, it becomes obvious that locating suitable switchback areas is very important. In some situations they can be the most important control point on the entire road.

Use the table and figures below to aid in the calculations required for gradeline setout.

	Symbols	Example
Side Slope (%/100)	S	0.3
Road Grade (%/100)	G	0.1
Curve Radius (m)	R	25
Grade on Curve (%/100)	g	0.06
Elevational Diff (m)	$E = (2 \times R \times S)$	$2 \times 25 \times 0.3 = 15$
Curve Deflection (degrees)	θ	180
Curve Length (m)	$C = (R \times \pi \times \theta / 180)$	$25 \times 3.142 \times 180 / 180 = 79$
Elevation gained on curve (m)	$H = C \times g$	$79 \times 0.06 = 4.74$
Cut and Fill Depth (m)	$D = (E - H) / 2$	$15 \times 4.74 / 2 = 5.13$
Dist at 0% Grade Before Curve (m)	$X = D / G$	$5.13 / 0.1 = 51.3$
Dist on ground from A to B (m)	$F = \sqrt{(2R)^2 + (E)^2}$	$\sqrt{(2 \times 25)^2 + (15)^2} = 52.2$

Table 36 - Calculating switchback layout

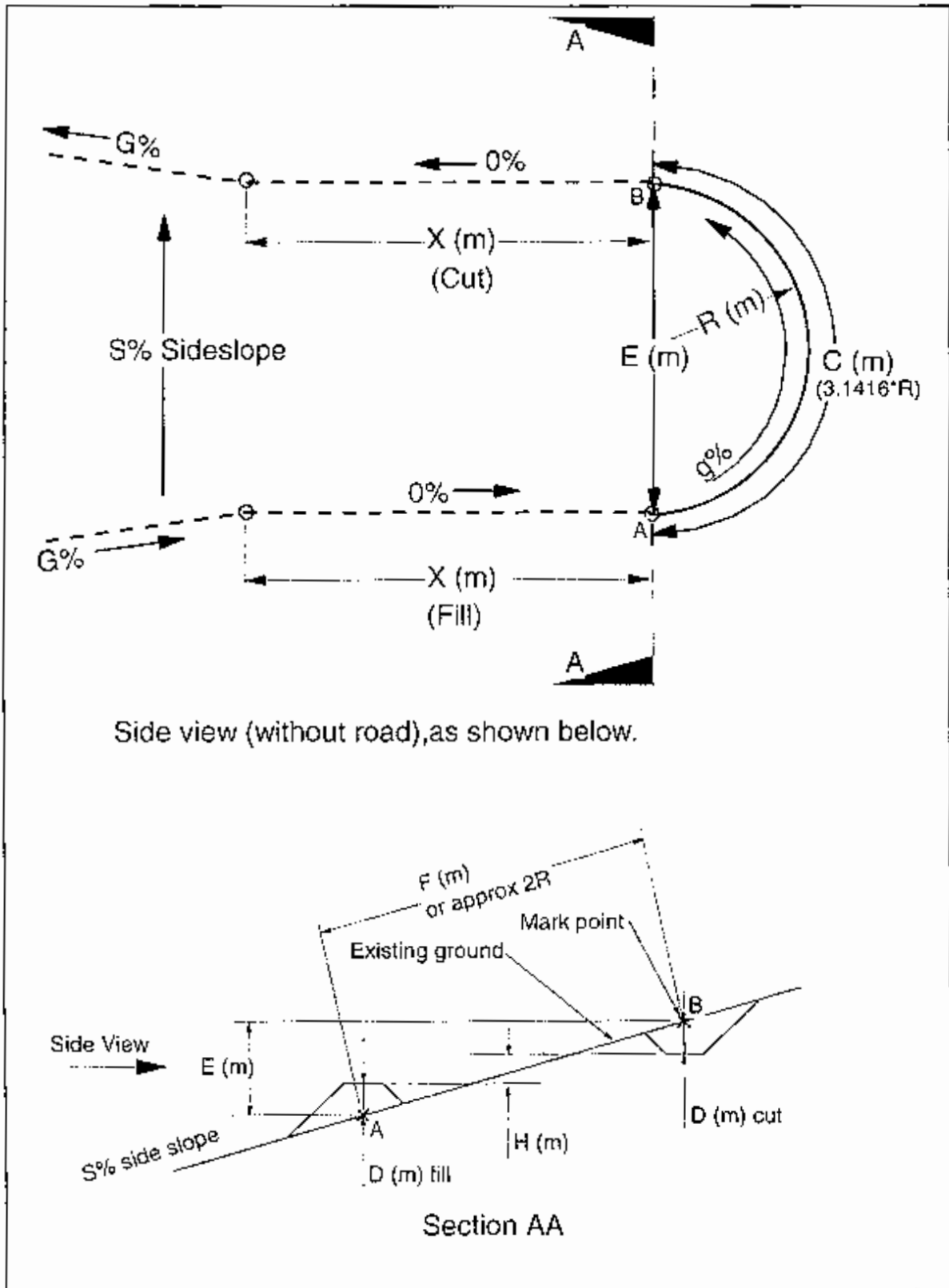


Figure 157 - Switchback layout.

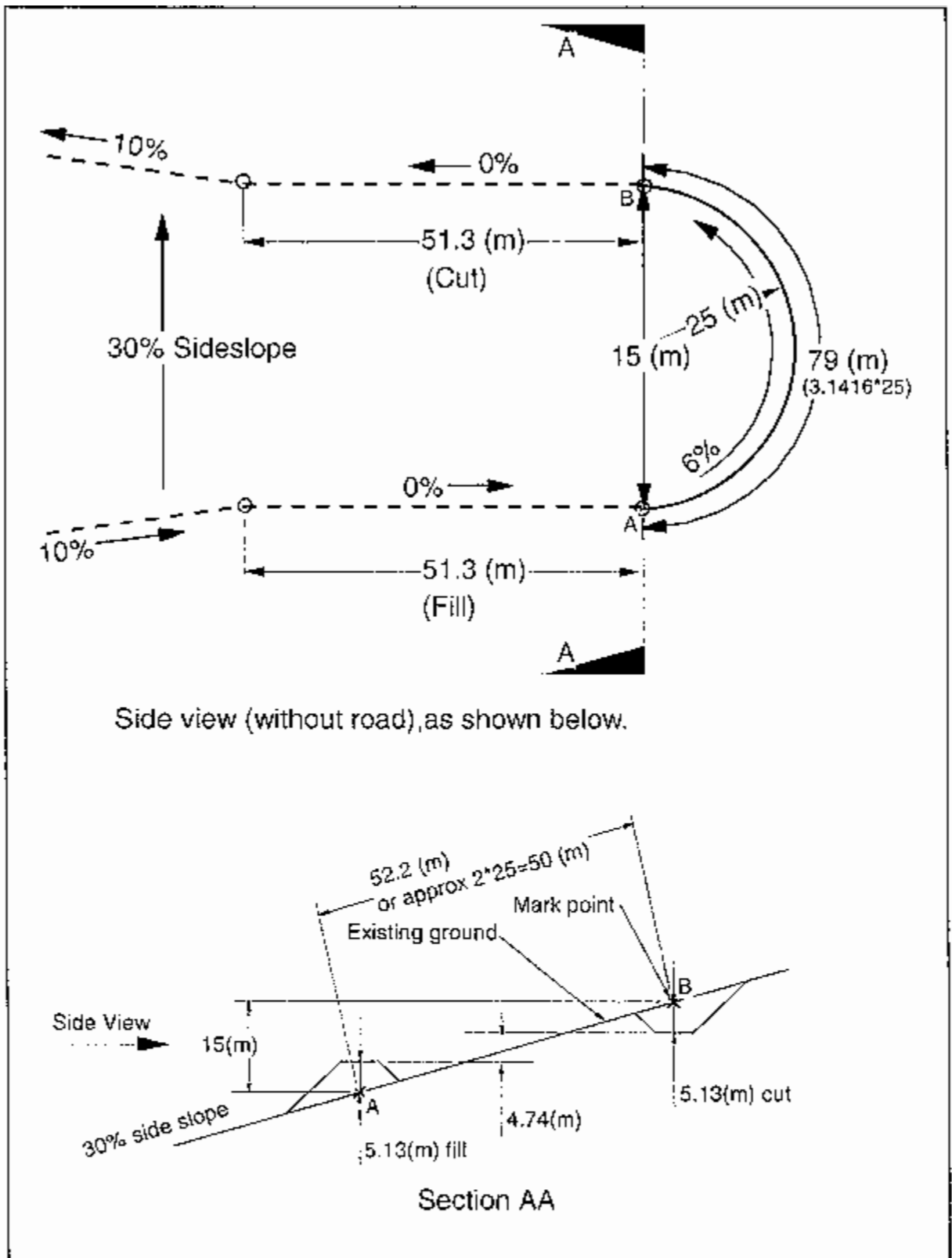


Figure 158 - Switchback layout example.

APPENDIX D
CULVERT DIAMETER SIZE
FORMULAE AND CATCHMENT
WATER DISCHARGE

APPENDIX D - Culvert diameter size formulae and catchment water discharge

Talbot Formula – Source: N.Z. Forest Service 1973: Civil Engineering Bulletins.

The following formula can be used to directly calculate the required culvert cross-sectional area:

$$A = C \sqrt[4]{M^3} \quad (\text{Imperial})$$

where:

A = Required culvert size, in sq. ft.

M = Catchment area, in acres

C = coefficient (as below)

or:

$$A = 0.183C \sqrt[4]{M^3} \quad (\text{Metric})$$

where:

A = Required culvert size, in sq. metres.

M = Catchment area in Hectares

then:

$$D = 2\sqrt{\frac{A}{\pi}}$$

where:

D = Diameter of culvert pipe required (in feet or metres depending on which formula is used above)

The coefficient C depends on the size, shape and contour of the catchment area. The following values are recommended for the various conditions:-

$C = 1$ For steep and rocky ground with abrupt slopes (100% water runoff).

$C = \frac{2}{3}$ For rough hilly country with moderate slopes (66% water runoff).

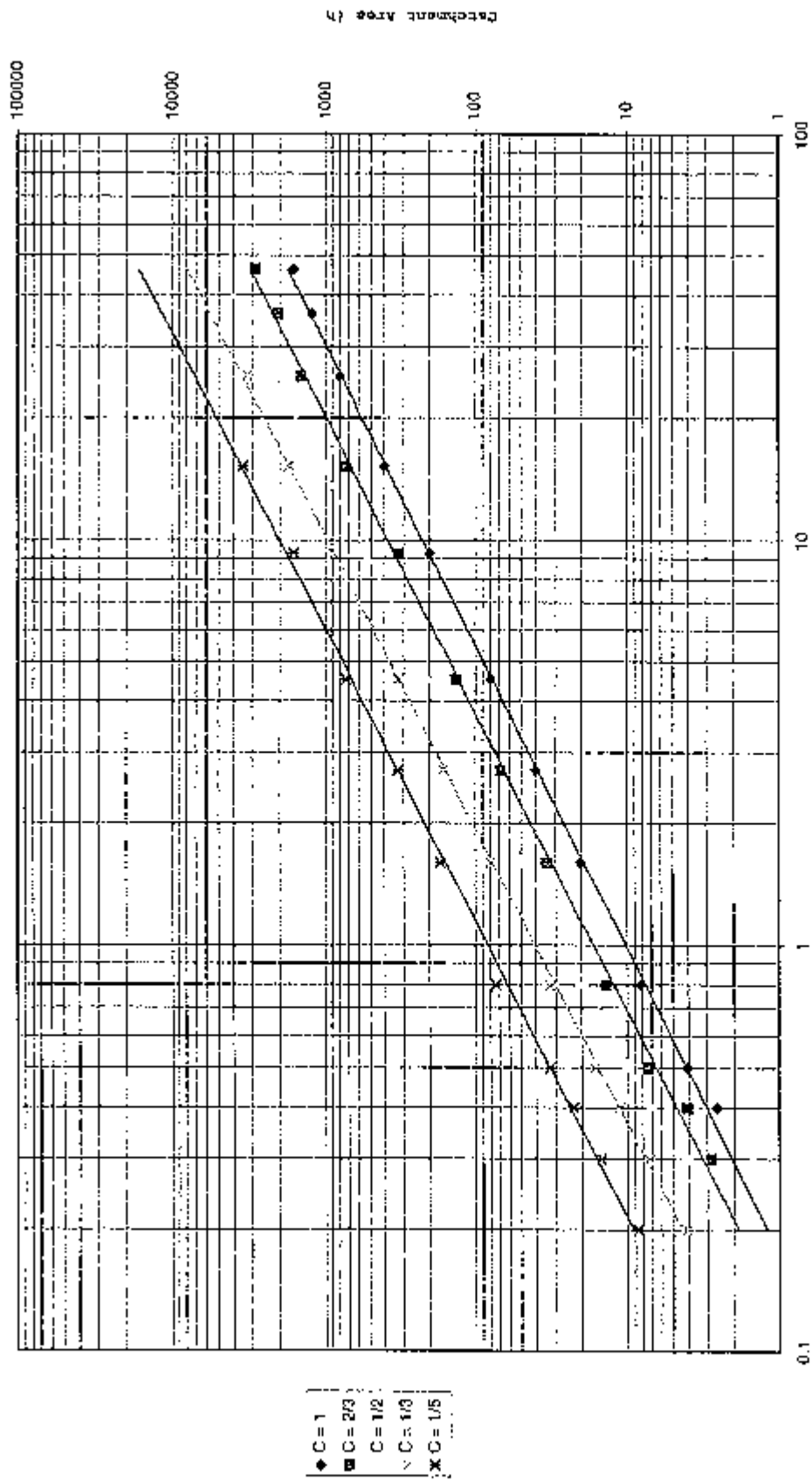
$C = \frac{1}{2}$ For uneven valleys, very wide compared to length (50% water runoff).

$C = \frac{1}{3}$ For rolling agricultural country where the length of valley is three or four times the width (33% water runoff).

$C = \frac{1}{5}$ For level catchments not affected by snow or severe floods.

For still milder conditions, or from subdrained lands, decrease C as much as 50 percent, but increase C for steep side slopes or where the upper part of the valley has a much greater fall than the channel of the culvert (20% water runoff).

Alternatively, figure 159 and table 36 can be used to determine the culvert diameter required. To do so locate the catchment area on the vertical axis of figure 159, locate the intersection of that with the curve for the appropriate C value, and trace down to find the required culvert cross-sectional area on the horizontal axis. Using this value in table 36, read off the culvert pipe diameter.



(NOTE: THIS GRAPH MAY BE INACCURATE BELOW 4.1 HECTARES AND ABOVE 910 HECTARES)

Figure 159 - Graph solution for Talbot Formula

AREA (M ²)	DIAMETER (M)	AREA (M ²)	DIAMETER (M)
0.1	0.36	6.0	2.76
0.2	0.50	7.0	2.99
0.3	0.62	8.0	3.19
0.4	0.71	9.0	3.39
0.5	0.80	10	3.57
0.6	0.87	20	5.05
0.7	0.94	30	6.18
0.8	1.01	40	7.14
0.9	1.07	50	7.98
1.0	1.13	60	8.74
2.0	1.60	70	9.44
3.0	1.95	80	10.09
4.0	2.26	90	10.70
5.0	2.52	100	11.28

Table 37 - Conversion from culvert area to diameter

Example: Find the cross-sectional area of a culvert suitable for draining 90 hectares in level country, assuming $\frac{1}{5}$ as the value of C.

Using Talbot's formula:

$$\begin{aligned}
 A &= 0.183 C^2 \sqrt{M^3} \quad (\text{Metric}) \\
 &= 0.183 \times \frac{1}{5} \times \sqrt{90^3} \\
 &= 1.07 \text{ m}^2
 \end{aligned}$$

which gives

$$\begin{aligned}
 D &= 2 \sqrt{\frac{A}{\pi}} = 2 \sqrt{\frac{1.07}{\pi}} \\
 &= 1.17 \text{ m}
 \end{aligned}$$

Rational Method – Source: Robertson, N.G. 1963: The frequency of high intensity rainfalls in New Zealand

This formula determines the discharge from a catchment area:

$$Q = 0.278 C I_t A \quad \text{[Formula 1]}$$

Where:

Q = peak discharge (m^3/s)

I_t = average rainfall intensity for critical time period t (mm/hr)

The average rainfall intensity I_t is determined from the following formula:

$$I_t = \frac{\text{design storm rainfall depth (D) (mm)}}{\text{time of concentration (T) (hr)}} \quad \text{[Formula 2]}$$

A = drainage area (km^2) (i.e. $1\text{km}^2 = 100 \text{ ha}$)

C = runoff coefficient obtained from table 40 or 41.

Procedure:

- Step 1. Determine the value of C from table 40 or 41.
- Step 2. Attain rain gauge (Pluviometer) data if available.

If pluviometer data is available:

Step 3.

- (a) For each duration time period, plot on figure 160, the rainfall depths for the given return periods. This will give several corresponding depth-frequency lines.

- (b) If necessary, extend the depth-frequency lines to the return period of the design storm.
- (c) Locate the return period of the design storm and read off the rainfall depths for each depth-frequency line.
- (d) Using figure 161 plot the above rainfall depths and draw the depth-duration curve for the selected return period.
- (e) The depth for a duration time equal to the time of concentration of the catchment can then be determined from the depth-duration line.

Step 4. Go to Step 6 of A2.2

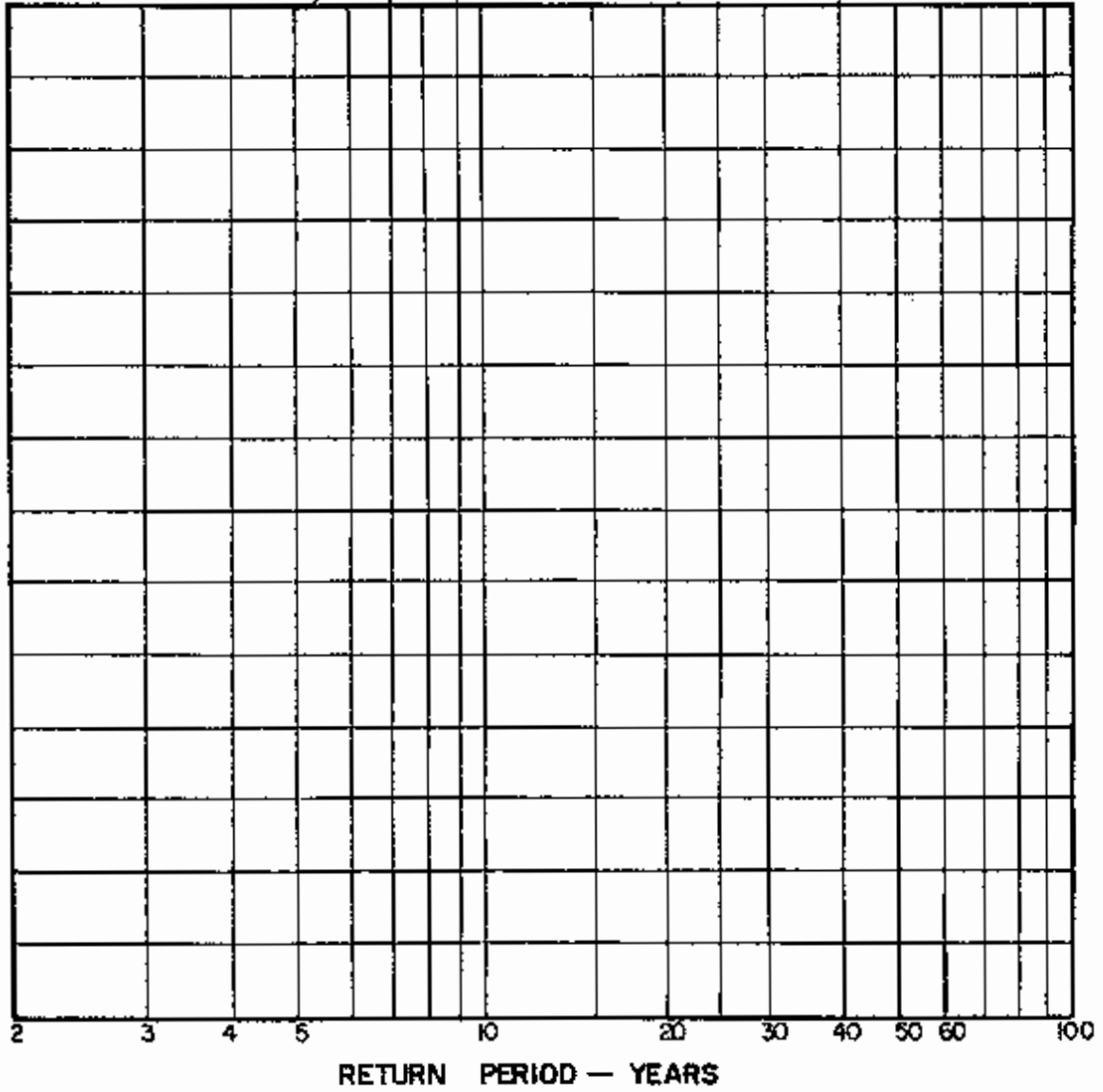


Figure 160 - Return Period Plotting Diagram

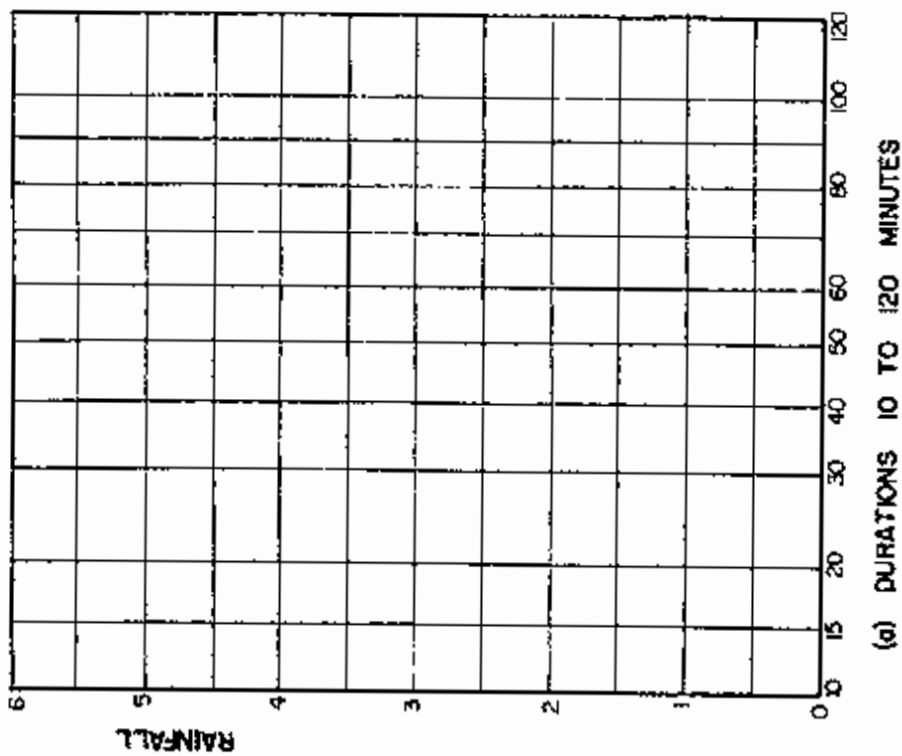
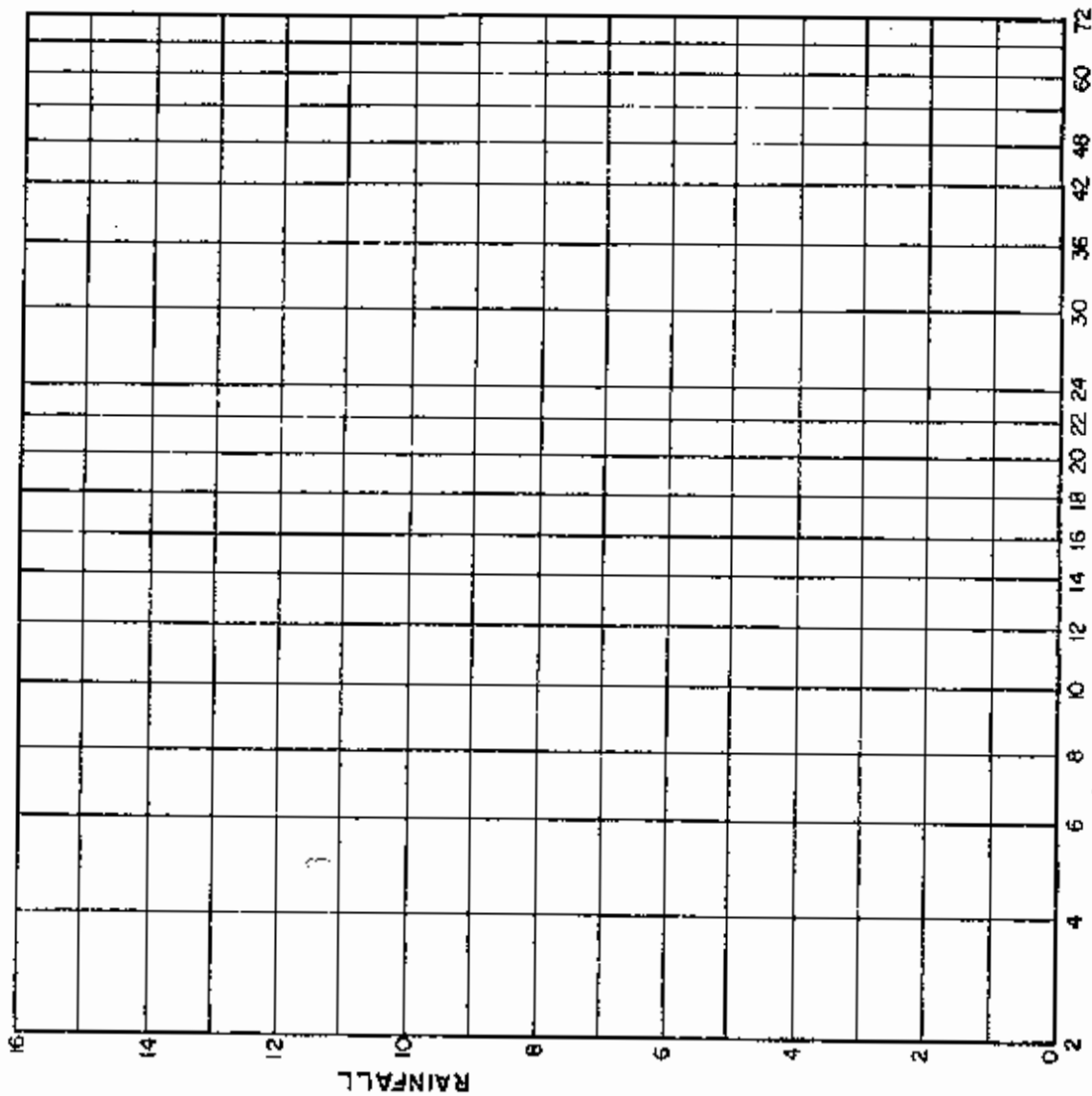


Figure 161 - Depth-Duration Plotting Diagrams

Example:

A given catchment has a time of concentration of 90 minutes and the following depth-duration-frequency data (table 38) has been obtained from the Meteorological Service.

Return Period	Rainfall Duration Time				
	10 Min	20 Min	30 Min	1 hr	2 hr
2 Years	7	10	12	17	23
5 Years	9	13	16	21	29
10 years	10	15	19	24	32
20 years	11	17	21	26	36
50 years	13	20	24	30	41

Table 38 - Catchment raingauge data (Note: Rainfall depths are given in mm)

The design requirements call for a design storm event return period of 100 years.

Solution:

Using figure 160 the rainfall depths are plotted and the associated depth-frequency line is produced.

Now read off the rainfall depths for the 100-year return period (table 39) and plot these on figure 161. This will give the 100-year depth-duration line.

Rainfall Duration Time	Rainfall Depth for 100 year return Period
10 Min	14 mm
20 Min	22 mm
30 Min	27 mm
1 hour	32 mm
2 hour	44 mm

Table 39 - Rainfall depth data obtained from figure 160.

From this 100-year depth-duration line the depth corresponding to a duration of 90 Min (i.e. time of concentration). This value is the design storm rainfall depth (D) (i.e. 40 mm)

Use this value in Formula 2 to determine the average rainfall intensity I_t and then use Formula 1 to determine the peak discharge Q.

If pluviometer data is not available and map data has to be used:

Step 3. Determine the value of T (Time of Concentration) [see Note 1 and Note 3 below]

Note 1: For information on the catchment characteristics and the hydrological data, Local Authorities, The Meteorological Service, or NIWA should be contacted. [These agencies may be able to help with values for time of concentration (T), the runoff coefficient (C), and other parameters.]

Step 4. Determine the Required Return Design Period for the Design Storm [see Note 2 below]

Note 2: The choice of the return period will take into account the following factors:

1. The expected life of the structure
2. The general economic consequences of failure
3. The loss of life and livelihood that may result

[Many bridges are designed for a 50, 100 or 200 year peak discharge, whereas small culverts are often designed for the 10 or 20 year peak discharge.]

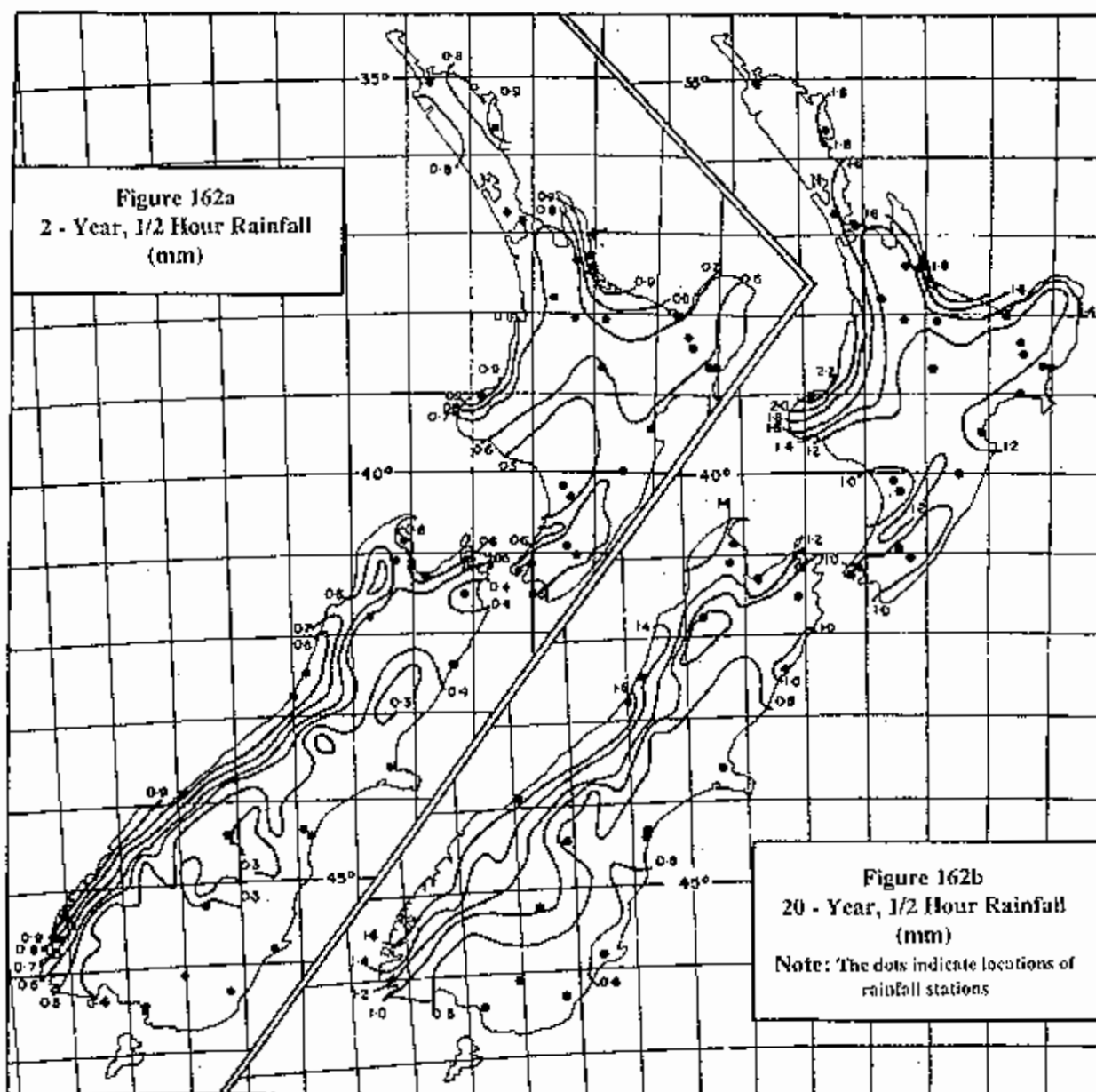
Step 5. Calculate the value of D (Design Storm Rainfall Depth) as follows:

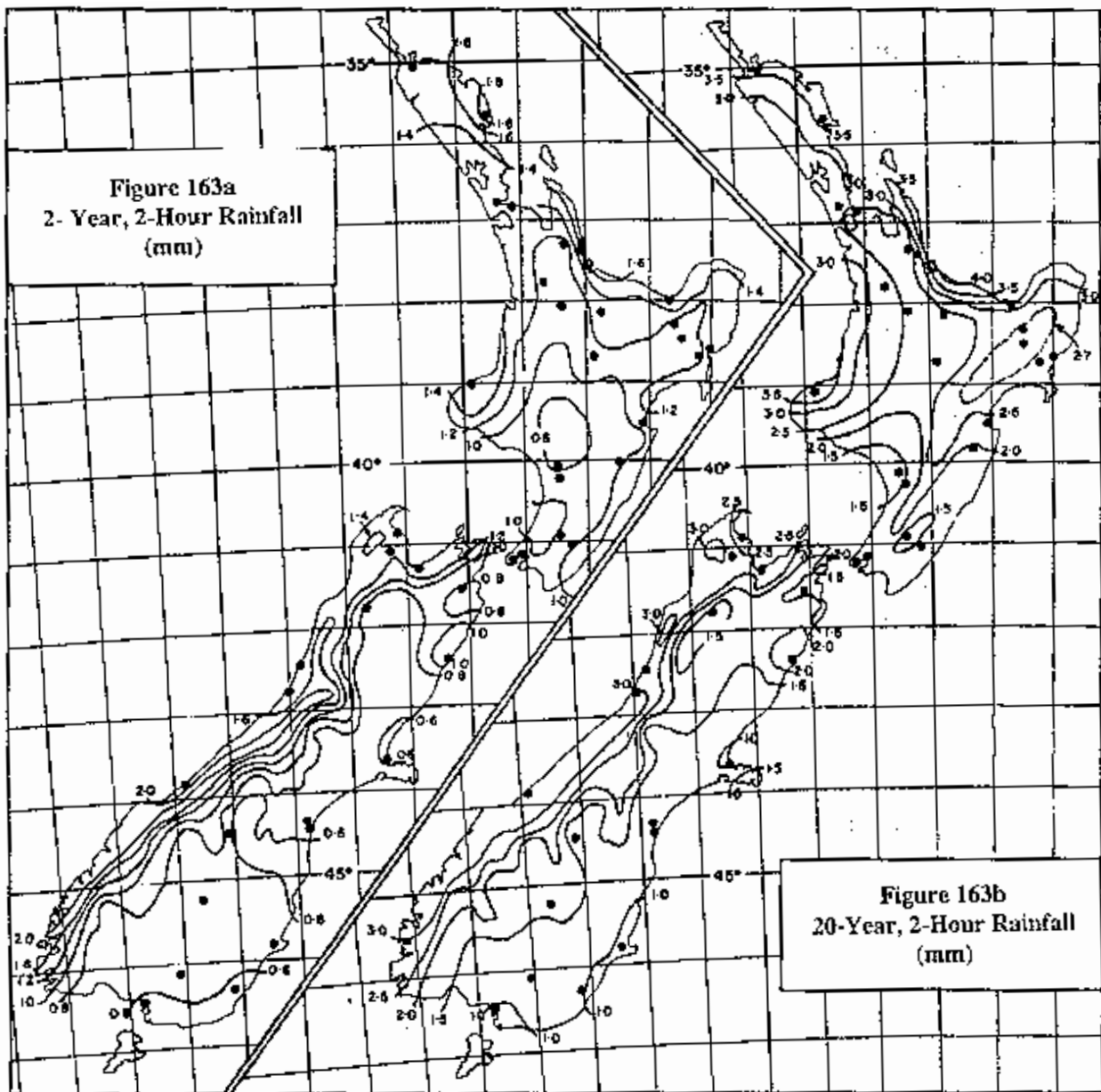
- (a) From figures 162a and 162b determine the 2-year and 20 year rainfall depths for the 1/2-hour duration. (Interpolation allowed)
- (b) From figures 163a and 163b determine the 2-year and 20 year rainfall depths for the 2-hour duration. (Interpolation allowed)
- (c) Using figure 160 plot the 2-year and 20 year depths for each of the two duration times. This will give the corresponding depth-frequency line.
- (d) If necessary, extend the two depth-frequency lines to the return period of the design storm.
- (e) From each of the two depth-frequency lines read off the rainfall depth corresponding to the return period of the design storm.
- (f) Now using figure 161, plot these depths and determine from the resulting depth-duration line the rainfall depth for a duration equal to the time of concentration (T). This value is the design storm rainfall depth.

Note 3: When the time of concentration exceeds 2 hours, the above procedures are still used except the 24 hour rainfall depths are used in place of 1/2 hour depths. The 24-hour rainfall depths are obtainable from Robertson's (1963) data for the daily rainfall stations.

Step 6. Use this formula to calculate the value of I_t (average rainfall intensity (mm/hr) for critical time period t). [Formula 2.]

Step 7. Calculate the Peak Discharge (Q)(m^3/s). [Formula 1.]





Note 4: Because the Rational Method is an empirical method, it should only be used to estimate the design discharge when hydrological data is unavailable or insufficient for a detailed and precise analysis. Furthermore, in view of the inherent uncertainties with empirical methods, two methods should be used, with each providing a check on the results from the other.

Example:

Catchment area (A) of 1.2 km² Located in the Gisborne district (figure 162 a & b)

Catchment characteristics are as follows:

- Rainfall Intensity: 75 - 100 mm/hr
- Relief: Rolling with average slopes 5% - 10%
- Surface retention stream and surface storage: Negligible
- Infiltration: Loam soils
- Cover: 87% of area covered by improved pasture

Time of Concentration (T) of 1.5 hrs

Return Period for the design storm is 10 years

Solution:

1. From table 40 the following value of C can be determined:

Rainfall intensity :	(0.30)
Relief :	(0.00)
Surface retention stream and surface storage:	(0.10)
Infiltration:	(0.10)
Cover:	(0.05)

Therefore $C = 0.30 + 0.00 + 0.10 + 0.10 + 0.05 = 0.55$

2. From figure 162a the 2 year, 1/2 hour duration rainfall depth for the catchment

$$= 14 \text{ mm}$$

From figure 162b the 20 year, 1/2 hour duration rainfall depth for the catchment

$$= 32 \text{ mm}$$

3. From figure 163a the 2 year, 2 hour duration rainfall depth for the catchment

$$= 32 \text{ mm}$$

From figure 163b the 20 year, 2 hour duration rainfall depth for the catchment

$$= 69 \text{ mm}$$

4. Plot the depth-frequency lines on figure 160 from the 2-year and 20-year data obtained above.

5. From these lines read off the rainfall depth corresponding to a 10 year return period for the design storm.

6. Plot these values on figure 161 and draw the resulting depth-duration line. From this the design storm rainfall depth value can be determined for a time of concentration of 1.5 hours ie: 51 mm.

7. This value can then be used to calculate Q using firstly Formula 2 and then formula 1.

Runoff-Producing Characteristics	
Catchment Characteristics	
Rainfall Intensity	(0.3) 75 - 100 mm per hour
Relief	(0.10) Steep rugged country with avg. slope above 20%
Surface retention stream and surface storage	(0.10) Negligible; few surface depressions; water courses steep with thin film of overland flow
Infiltration	(0.25) No effective soil cover; either solid rock or thin mantle of negligible infiltration capacity
Cover	(0.25) No effective plant cover
	(0.05) 50 - 75 mm per hour
	(0.05) Hilly with average slopes of 10% - 20%
	(0.05+) Well defined system of small watercourses
	(0.10) No effective soil cover; either solid rock or thin mantle of negligible infiltration capacity
	(0.25) No effective plant cover
	(0.15) 25 - 50 mm per hour
	(0) Rolling with average slopes of 5% - 10%
	(0) Considerable surface depressions; overland flow is significant; some farm ponds and swamps; some contour banks and furrows
	(0.20) Slow water infiltration; eg. clay soils where surface sealed or saturated
	(0.20) Sheet eroded native pasture; less than 10% of area under good native or improved pasture; clean cultivated crops
	(0.05) 25 mm per hour
	(0) Relatively flat land with average 0% - 5%
	(0) Poorly defined and meandering stream courses; large surface storage; water and soil. Tree covering on 90% of the catchment
	(0.05) Deep sands or well gravelly soil
	(0.05) About 90% of area with improved pasture

Table 40 - Estimation of the runoff coefficient C for use with the rational Formula for catchments less than 2.5 km²

1. Procedure for estimating C: (a) for each of the 5 listed catchment characteristics, select or interpolate a value representative of the catchment from the values in brackets;
(b) sum the five values
2. Reduce C by 10% to allow for interception in thick forest.

Runoff-Producing Characteristics				
Catchment Characteristics	(0.15)	(0.10)	(0.10)	(0.05)
Rainfall Intensity	25 - 50 mm per hour	13 - 25 mm per hour	13 mm per hour	Below 13 mm per hour
Relief	Steep rugged country with avg. slope above 20%	Hilly with average slopes of 10% - 20%	Rolling with average slopes of 5% - 10%	Relatively flat land with average 0% - 5%
Surface retention stream and surface storage	Negligible; few surface depressions; water courses steep with thin film of overland flow	Well defined system of small watercourses	Considerable surface depressions; overland flow is significant; some farm ponds and swamps; some contour banks and furrows	Poorly defined and meandering stream courses; large surface storage; water and soil. Tree covering on 90% of the catchment
Infiltration	No effective soil cover; either solid rock or thin mantle of negligible infiltration capacity	Slow water infiltration; eg. clay soils when surface sealed or saturated	Loam soils or well structured clay soils	Deep sands or well gravelly soil
Cover	No effective plant cover	Sheet eroded native pasture; less than 10% of area under good native or improved pasture; clean cultivated crops	About 50% of area with improved cover; not more than 50% cultivation; open woodlands	About 90% of area with improved pasture

Table 41 - Estimation of the runoff coefficient C for use with the Rational Formula for catchments from 2.5 to 25 km².

1. Procedure for estimating C: (a) for each of the 5 listed catchment characteristics, select or interpolate a value representative of the catchment from the values in brackets;
(b) sum the five values
2. Reduce C by 10% to allow for interception in thick forest.

Manning's Formula

Manning's formula estimates discharge, and relies on channel or pipe characteristics

$$Q = n^{-1} A R^{2/3} S^{1/2}$$

where:

Q = discharge (m³/s)

A = cross sectional area of the stream (m²)

R = hydraulic radius (m), (area/wetted perimeter of the channel)

S = slope of the water surface

n = roughness coefficient of the channel (see table 42)

Natural Stream Channels	"n"
1. Regular section:	
Some grass, little or no brush.....	0.030 - 0.035
Dense growth of weeds, depth of flow greater than weed height.....	0.035 - 0.050
Some weeds, light brush on banks.....	0.035 - 0.050
Some weeds, heavy brush on banks.....	0.050 - 0.070
Some weeds, dense willows on banks.....	0.060 - 0.080
Trees within channel, with branches submerged at high stage; increase above values by.....	0.010 - 0.020
2. Irregular sections:	
Water pools, slight channel meander; increase values above by.....	0.010 - 0.020
3. Mountain streams, no vegetation in channel, banks steep, trees and brush along banks submerged at high stage:	
Bottom of gravel, and few boulders.....	0.040 - 0.050
Bottom of rounded gravel with large boulders.....	0.050 - 0.070

Table 42 - Manning's n for natural stream channels (Highway Task Force, 1971)

The area and wetted perimeter for the calculation of the hydraulic radius R is determined by a field inspection of the stream and its surrounding floodplain. Identifying the high water marks on the stream banks (figure 164), scour and soil erosion on the floodplain, debris in the vegetation, and marks on tree trunks, of the surrounding trees and bush, will indicate the high water level for a 10 year flood. Flow levels can then be determined for higher recurrence intervals using table 43.

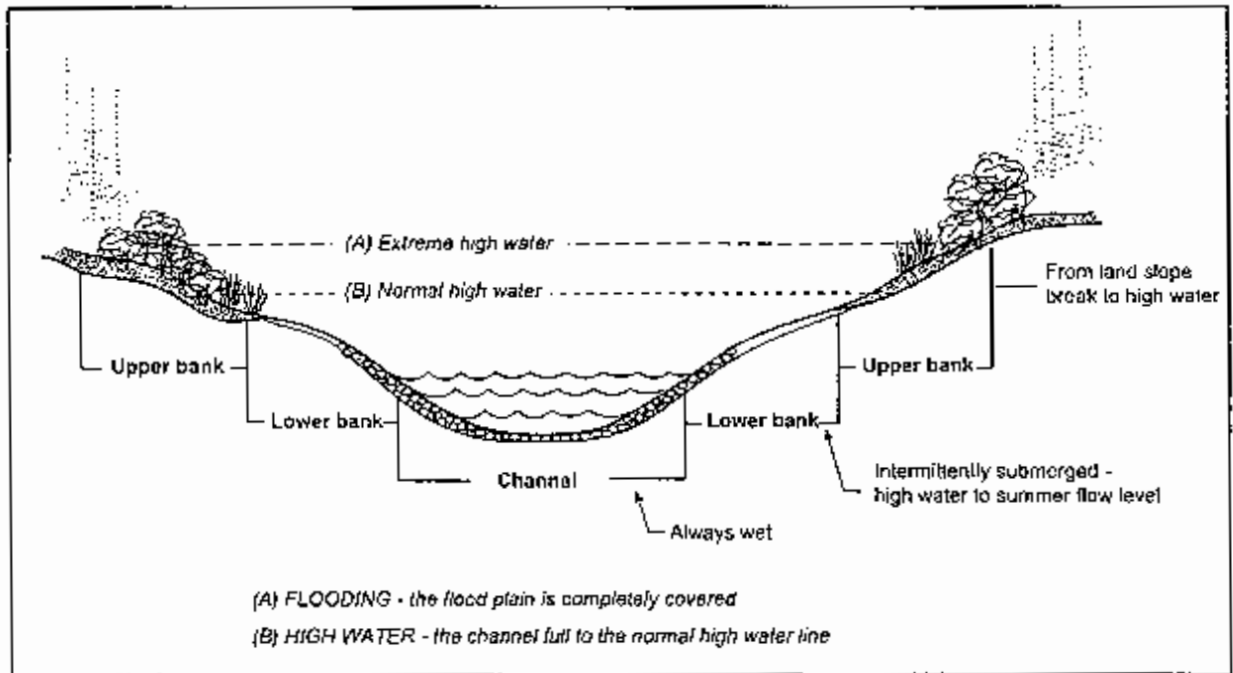


Figure 164 - Determining water levels of stream channel

Peak Flow Return Period (years)	Factor of Flood Intensity (10 Year peak flow = 1.00)
10	1.00
25	1.25
50	1.50
100	1.80

Table 43 - Peak flows for higher return periods

Note: The inaccuracies encountered during the examination of the stream site and floodplain make Manning's formula very subjective and user specific. Therefore this formula should be used with caution. Also, the assumption that there is a uniform, steady flow in the stream will also generate some inaccuracies.

Example: A stream channel has a trapezoidal channel of straight alignment and has a uniform cross section. The side slopes are 1:1, channel slope 'S' is 0.005, has a stream bed width of 12.5 metres, and a high water depth (10-year event) of 6 metres. The channel has some weeds and light brush on the banks.

1. The wetted perimeter is calculated as

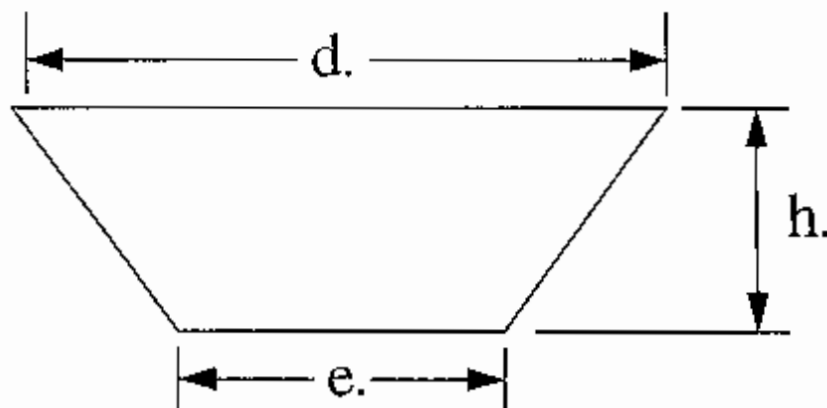
$$\text{Width} + 2 \times (\text{High Water Depth} / \cos(\text{Side Slope}))$$

$$12.5 + 2 \times \left(\frac{6}{\cos 45} \right) = 29.47 \text{ m}$$

2. The cross sectional area 'A' is equal to

$$\frac{1}{2} \times \text{sum of parallel sides} \times \text{perpendicular height}$$

$$\text{(i.e. area of a trapezoidal)} \quad \frac{1}{2} \times e+d \times h$$



$$\frac{1}{2} \times (12.5 + 24.5) \times 6 = 86 \text{ m}^2$$

3. Hydraulic radius 'R':

Cross sections area \div wetted perimeter

$$\frac{86}{29.47} = 2.92 \text{ m}$$

4. Manning's n from table 42:

$$n = 0.0425$$

5. Discharge:

$$Q = n^{-1} A R^{2/3} S^{1/2}$$

$$Q = 0.0425^{-1} \times 86 \times 2.92^{2/3} \times 0.005^{1/2} = 292.31 \text{ m}^3/\text{sec}$$

(Velocity can be determined if required by $\frac{Q}{A} = 3.4 \text{ m/sec}$)

