LOGGING INDUSTRY RESEARCH ASSOCIATION

NEW ZEALAND

PROJECT REPORT

CONSTRUCTION COST ESTIMATION FOR FOREST ROADS

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Project Report

P.R.50

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CONSTRUCTION COST ESTIMATION FOR FOREST ROADS

(Using historical productivity information and modifying factors)

P.R.50 1990

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For those who require a copy of the spreadsheet "ROADCOST", it is available on request from LIRA.

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ABSTRACT

The cost of road construction for forest operations may be an important factor in the economic viability of a forest either at the establishment phase, or as is more likely, at the harvesting phase. The harvesting of many forests established on hilly and/or unstable country, remote from processing plants and ports, will depend on efficient harvesting techniques and a cost effective roading network.

This report and LIRA's construction cost estimation spreadsheet program provide roading supervisors and planners with a simple but useful method to better estimate future roading costs when historical cost records are not available. The method applies to construction by a single bulldozer, although the technique is easily extended to excavators, multiple machine crews, and also to other construction methods if sufficient historical data is available.

Provision is made in the spreadsheet programme for multiple machines.

INTRODUCTION

Forest roads are constructed for purposes of forest management and harvesting. In New Zealand, the construction of access roading usually precedes the establishment of plantation forests and these roads are often located for ease of forest management or least initial cost. However, the ultimate purpose of a forest roading network is to provide the means by which forest produce can be transported from the skid to the sawmill or port. During the life of a forest crop, forest management roads are gradually upgraded through widening, and additional metal[1] dressings, to become the main roads for transporting the forest produce. If a narrow short term view of roading and its associated costs is taken, there is a very real danger that roads may not be in the most suitable location for harvesting the tree crop.

In taking a long term view of roading it is vital to be able to adequately cost out road construction. This report presents one simple method of construction cost estimation based on historical productivity information.

The methods used in this report are based on factors derived from field observations of 18 different construction works. Because these works primarily used a single bulldozer, the factors given here are totally valid only for that construction technique. They can reasonably be extended to multiple machines.

In general the cost estimating procedure is to:

1. Break the overall operation into its major cost components.

2. Calculate costs for each component.

3. Add the calculated costs together to arrive at a total cost.

It should be noted carefully that cost estimating deals with future expected costs. In this report the method of calculating cost components is based on historical productivity information, not direct costs.

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1. *Metal is a common usage term in New Zealand for gravel, crushed rock, aggregate, etc.*

PLANNING AND DESIGN

There are five major components to be considered in the cost of constructing a forest road. They are:-

- planning and design
- formation (including compaction)
- culverting
- surfacing
- grading

Planning involves the evaluation of alternative routes and the effect that each of these has on the overall roading network and the transportation cost. The chosen route is invariably a compromise between having a high construction cost, but low trucking and road maintenance cost, and vice versa. In certain areas the topography is such that roading may be restricted to ridgetops or the choice of route is otherwise limited. However this should not be an excuse to avoid investigating alternative routes to what may seem to be the obvious cheap alternative.

The objective should be to choose a route that fulfils all the harvesting and management requirements and has the shortest possible travel time.

Roads are required to transport logs from the skid to the mill/port and production is directly related to the travel time and load carried. A good standard of road will have a higher construction cost than a mediocre standard road but the truck operators will achieve improved truck performance, lower repair costs, less down time, lower fuel consumption per tonne hauled and therefore lower transportation costs. However in New Zealand where a high proportion of trucking uses the state highway network, the benefits of a higher standard of road construction for the in-forest section are not easily quantifiable although some previous LIRA publications are helpful in this area. For example seven and eight axle units have less gradeability than many five and six axle units (Goldsack, 1988) but are most economical for on-highway haul (Taylor, 1989).

Improvements to the public highway system may lead to much greater gains in efficiency and reduced costs but transport operators have little influence over making improvements.

Design involves an evaluation of the economics of constructing roads to different specifications by considering gradient, formation width, pavement width, drainage, curvature, sight distance, compaction, surfacing materials, and safety. It may also involve a field survey with batter peg staking or grade-line marking. A cost-benefit analysis may also be done particularly if the road is planned for use as a major off-highway sealed route.

Sealing of the road may greatly affect the cost-benefit analysis and this must also be considered. The effort that goes into planning and design should be in proportion to the value of the job and the projected volume of timber carried over the road.

Planning and design will vary between 1 and 5% of the total construction cost. The latter figure would be applicable for the route investigation and design of an arterial road whereas the former would be typical for a spur road to a skid site. Some organisations may exclude planning and design costs from the road construction cost but these are real costs and should be considered in any cost estimating procedure.

FORMATION COST

The main factors which affect the cost of road formation are the topography, side slope, underlying material, soil stability and drainage, type and power of construction machine, quality of operator, and weather.

BASIC COST

In this cost estimation spreadsheet the basic construction rate of road formation has been set at 50 hours per kilometre. It is derived from costing data for road formation in silty and sandy clay material on moderate ground, using a 200/220 KW bulldozer.

TOPOGRAPHY FACTOR

Topography and side slope may be combined into a single profile factor. These figures include no allowance for end hauling, block cuts or similar techniques. Four categories have been defined as shown in Table 1.

TABLE 1 : PROFILE FACTOR

Slope (degrees)	Description	Profile Factor
<10 deg	easy	0.75
10 - 25	moderate	1.0 (normal case)
> 25	steep	1.25 - 1.75
> 40	v. steep	2.0

Once the side slope angle exceeds 30 degrees a bulldozer becomes less effective due to difficulties in starting the bench and disposing of spoil. For very steep terrain, the use of an hydraulic excavator in conjunction with a bulldozer provides a more effective construction unit than a tractor working on its own. In New Zealand two methods have been used. In the first method a small to medium excavator forms a pilot track and bench from which a heavy tractor can operate. This is most effective when the slope is steep but the material is easily broken out. With harder material such as compacted sandstone or granite a heavy excavator in the 25 to 30 tonne range is used as the prime earthmover with a small dozer being used to tidy up. If the formation width is narrow then a large excavator with a long or standard boom may have trouble manoeuvring on the site. It is important to ensure that the excavator can be used efficiently and this will involve the correct choice of buckets, booms and operator.

The combination of excavator and dozer should be seriously evaluated for all roading work.

Experience in the Nelson area shows that in their situation a dozer, or dozers working alone are never the best or cheapest construction tool. Although no factors are presented for excavator construction, due to lack of data, the method and the spreadsheet could be easily modified to this form of construction (if some historical data is available).

The cross-sectional area of a sidecast road can be calculated from a formula which will show that:

Area is proportional to (width)^2

Figure 1 presents this in a graphical form.

Figure 2 illustrates the effect of slope angle on sidecast volume for a 4.5m and 6.0m formation width road with a 1/2 to 1 (horizontal to vertical) cut batter slope. The narrower formation width results in a

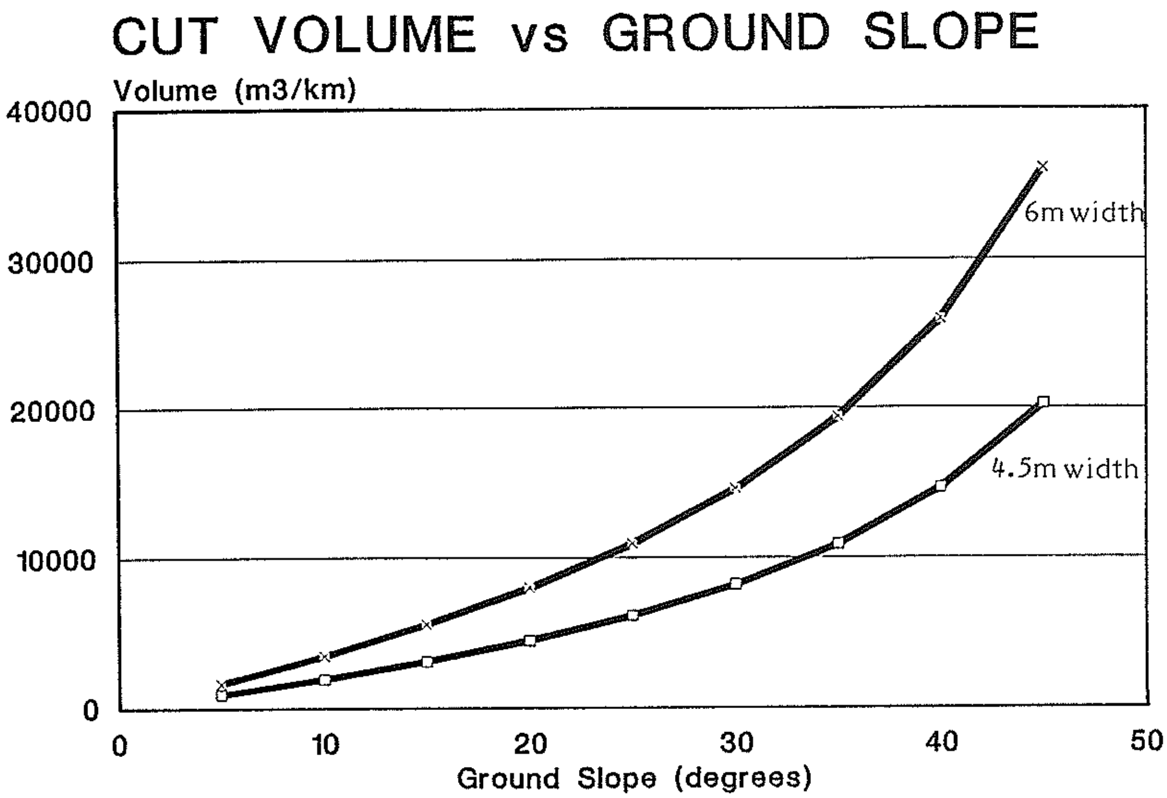


Figure 1 - Cut Volume versus Ground Slope

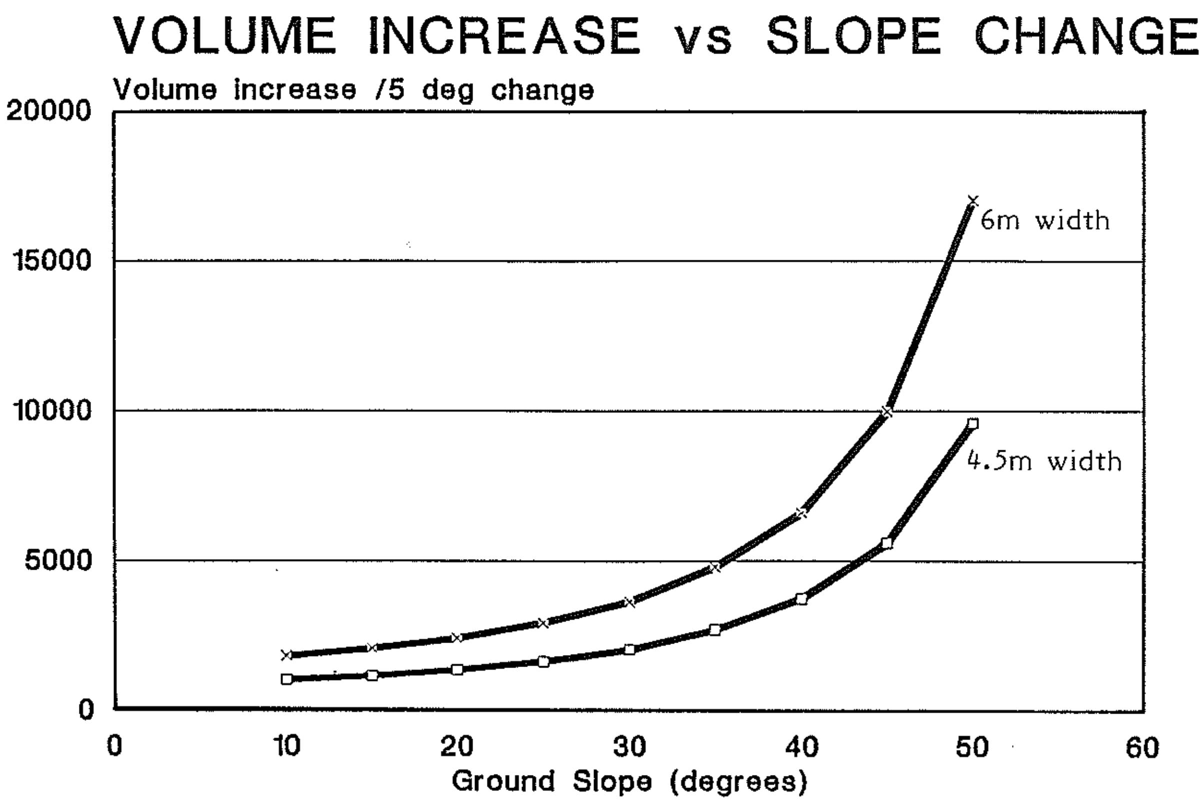


Figure 2 - Volume Increase versus Slope Change

a large reduction in volume regardless of slope angle. No allowance has been made for watertables. It can be seen from Figure 2 that the volume increase per 5 degree change of slope increases significantly above 25 degrees. Once the average slope exceeds 30 degrees careful consideration must be given to reducing formation width if costs are to be contained. Often this fact alone can justify steeper sections of road, even though the trucking cost on this steep road may increase.

MATERIAL FACTOR

The underlying soil material affects the cost of formation, particularly when hard rock is combined with a steep profile. Generally the steeper the profile the harder the underlying material. Four categories have been defined for the material type and any material not covered by the description or for material combinations can be factored to suit by interpolation.

TABLE 2 : MATERIAL FACTOR

Material Type	Description	Factor
Pumice/sand	easy	0.75
Clay	average	1.0
Soft rock	difficult	1.5
Hard rock	v. difficult	2.0 - 2.5

The hard rock factor will depend on the proportion of ripping required and the structure of the rock. Dense tightly compacted soft to medium hard rock may require as much ripping effort as harder but more openly structured rock.

MACHINE FACTOR

The machine type has a variable effect on the cost of formation. A small to medium sized machine in easy country (up to 15 degree side slope) with underlying pumice/sand or clay material may be as cost effective as a larger machine, particularly if the job is small and transportation costs are high. However once the profile angle increases or the material type becomes difficult the productivity, ripping ability of larger D8 size machines may come into their own.

TABLE 3 : MACHINE FACTOR

Machine power	Description	Factor
< 150 KW	D6/D65 size	1.5
150 - 200	D7/D85 size	1.25
> 200 KW	D8/D155 size	1.0
> 225 KW	Int TD25E	0.9

If an excavator is used for road construction then the machine power factor will be different and the factor needs to be carefully evaluated and based on previous costing data. At this time there is little reliable data available with which to give some guidance.

Experience in the Nelson area with excavators shows that a well managed multiple machine crew (excavator and dozers) can achieve formation cost savings of up to 30%.

In easy ground conditions this saving will be less but increasing as ground conditions (such as water, hard rock) get more difficult for construction.

Some savings can be achieved by using an excavator on its own (as compared to a dozer) but conditions need to be difficult, wet, or hard rock to make any significant saving. In easy material a dozer alone will out perform an excavator on its own.

As already mentioned, a team approach using both excavator and dozer is the best and most cost effective method.

OTHER FACTORS

Although weather and operator ability do affect the cost of formation it is difficult to put a factor on them and they have been ignored. Short term weather delays are unlikely to greatly increase the cost of construction and below average operators should not be tolerated for long. In this respect an experienced roading overseer is invaluable. Winter road formation costs in clay or difficult country are not easy to estimate since the weather plays a major part and this cannot be readily allowed for in the variety of conditions likely to be encountered. A few field examples however show that increases of 100% in construction cost for roads built in winter or wet weather are common.

When heavy rainfall affects a roading operation the result is often slumped batter slopes, blocked or washed out culverts, drop-outs, and slumped fills. The cost of reinstatement and the inevitable delays in restarting operations may easily double the cost of constructing a formation section of road. For winter road construction in clay soils the use of low ground pressure machines such as wide tracked excavators is essential if costs are to be contained and delays minimised. It is much better to schedule roading operation in periods of suitable weather.

The length of road to be constructed also has an effect on the total cost. For a short length of road the cost of transporting a heavy machine to the site may outweigh the cost of lower productivity from a smaller but more easily transported machine.

Example : How factors are used to get approximate road construction cost.

Average side slope angle of 30 degrees, in clay soils with formation by Liebherr 741 (147 KW)

Base formation rate hours per km	*50.0*
Enter slope profile factor	*1.25*
Enter material type factor	*1.0*
Enter machine power factor	*1.5*
Enter cost per machine hour	*$ 105.0*
Formation cost per km	*$9,844*

(50 x 1.25 x 1.0 x 1.5 x $105)

COMPACTION

Although it has been traditional to construct most forest roads without compaction this fact should not detract from considering the advantages of adequate compaction and ensuring that it is carried out on both subbase and road basecourse materials.

In almost every case the cost of compaction will be recovered in the short term in savings in road surfacing and basecourse.

Compaction can be defined as the densification of a soil by mechanical manipulation.

The behaviour of an engineering soil in a compacted state is often different from that when in a loose state. Compaction does not improve the qualities of all soils to the same degree but by reducing the volume of voids in a soil sample the following desirable characteristics can be achieved:

(a) Reduction in porosity
(b) Increase in internal friction (ie strength)
(c) Volumetric stability, ie resistant to compression or swelling.

The stress induced in a road by a passing wheel can be classified as either compressive or shear. Of these two shear is the most important and fortunately for the road builder the following states of:

(a) maximum density

(b) maximum shear strength
(c) minimum porosity and hence best water shedding ability.

all tend to occur at the one optimum point.

Water content controls how easily and effectively any given compactive effort will compact a soil. For further information in this area refer to:

COMPACTION DATA Handbook distributed by LIRA - no cost to members (p 17-18).

Higher than optimum water content will always mean less than optimum compaction. The correct moisture content will allow best compaction because slip between soil particles aids the mechanical densification.

In the final analysis, ease and quality of compaction depends on:

(a) layer thickness (250mm maximum suggested)

(b) the soil type (moisture content, uniformity etc.)

(c) compactive effort

(d) the stiffness of the foundation.

Compaction achievement is difficult and laborious to measure in a quantitive manner but experience or simple Clegg Hammer type equipment will be of considerable benefit.

COMPACTION COST

Because there is no background of compaction in the forest industry any estimate will have to be based on manufacturers' data for the roller being used.

The Compaction Data Handbook gives some guide to production rates on p 53-60 and further assistance is available in various roading books.

Any compaction with any roller will be a major advance on doing none at all. Track rolling with dozers (which is considered compaction by some) is not! Tracked machines are designed for relatively low ground pressure and the effort available from these machines cannot be considered adequate. Scraper tyres and even construction truck tyres can give good compaction if carefully controlled.

Calculation Guide

Take the width of the roller = WR (metres)
Take the length of compaction area = LC (metres)
Take the width of the compaction area = WC (metres)
Take the speed of compactor = S metres/min

Then time to compact one lift (with no allowance for any stoppages) can be calculated by finding how many runs are needed to cover the area allowing for overlap of 50%.

Example

No. of runs required:

$$\text{No. of runs} = WC - \frac{WR}{2}$$

for example if WC = 7 metres and WR = 2 metres

$$\text{then no. of runs} = 7 - \frac{2}{2} = 7 \text{ runs}$$

No. of runs possible per hour:
If length of compaction LC = 1000 km
and speed of compactor = 5 km/h

$$\text{then no. of runs per hour} = \frac{5000}{1000} = 5$$

As 5 runs can be achieved per hour and 7 are required for the area, about 7/5 = 1.4 hours will be required for compactor coverage at the specified rate.

By allowing for turn time, operator breaks etc. and multiplying by the hourly rate of the compactor a cost of compaction can be arrived at.

Specific information on the particular roller capabilities speed etc. can often only be determined by reading the manufacturers technical specifications or manuals.

CULVERT COSTS

Forest roads are located in a wide range of topography types but for culvert costing purposes roads will be classified according to three categories. These are :

1. **Ridge top roads**
   (minimum number of culverts).

2. **Side slope roads**
   (average number of culverts with the occasional large one).

3. **Valley bottom roads**
   (maximum number of culverts with a high proportion of large diameter culverts).

The cost of culverts depends on topography and road gradient, the type of culvert (e.g. concrete, corrugated steel, plastic, or timber stave), soil type, number and length of large culverts, length of fluming and number of inlet boxes is required. The long term cost of culverting also dependant on the quality of installation.

The purpose of culverts is to pass surface water from the slopes above the road under the road formation and to provide rapid drainage of the road surface into permanent water courses. Regularly spaced 300mm or 375mm diameter culverts are used to drain the road surface, and 450mm diameter culverts for draining road surface water plus seeps, swamps, and small water catchments above the road. Larger diameter culverts would normally carry a permanent flow and may be any size from 600 mm diameter upward, depending on the soil type and catchment area, shape and vegetative cover.

Practical experience shows that 300 mm water table culverts should only be used on ridge top roads. Even then care is required with maintenance to ensure that they do not block with debris. Generally 375 mm is the smallest culvert diameter that should be used. This is determined by ease of maintenance and improved flow rather than by any volume requirement.

TOPOGRAPHY CONSIDERATIONS

The road gradient has a major effect on the number of watertable culverts required. For an 8% to 10% gradient, culvert spacing should be of the order of 60 to 120m apart. When gradient flattens to 5% this spacing can increase to 150m or so.

On steep gradients scour of the road surface can cause expensive problems in resurfacing costs and downtime because the road is not available for use. Control of water on steep gradient roads is therefore a major concern and frequent culverts with good inlet characteristics go a long way toward avoiding problems.

For wet or unstable ground, a higher than normal number of watertable culverts will be required at somewhere between 70m to 100m culvert spacing.

A variety of other factors will affect the number, size and cost of culverts but for the purposes of this program, two major types of culvert are considered :

(a) watertable culverts

(b) larger culverts

Both are costed out in detail by size, length and number, keeping in mind the guidelines mentioned. Any other method has too many inherent problems with accuracy.

For culverts of 300mm and 375mm, the basic culvert pipe cost is increased by a factor of 2 by the time it is installed. This is allowed for in the spreadsheet program but can easily be modified by the user if required. Installation costs factors for other culvert sizes are shown in Table 4.

TABLE 4 : TABLE OF INSTALLATION COST FACTORS

Culvert Pipe Factors	
Diameter, mm	*Factor*
300	*2.0*
375	*2.0*
450	*1.8*
600	*1.7*
750	*1.6*
900	*1.5*
1200	*1.4*
1200 - by individual estimation	

Note: These factors are used in the spreadsheet model. They may be modified by an experienced user.

MATERIAL FACTOR

Pumice and sand are highly erodible materials and these occur extensively on the central plateau area or in dune forests on the west coast of the North Island. Fortunately these soils are highly permeable and are able to absorb large quantities of runoff before saturation. Protection of watertables and fill embankments from scour require the use of berms and fluming and careful placement of cut-outs. Provided appropriate measures are taken to protect exposed slopes and watertables the culvert density will often be less than for clay materials. The Table of material factors below is only a guide to the relative ease of installation. It is used to alter the installation cost.

TABLE 5 : MATERIAL FACTOR
(affects installation costs)

Material type	Description	Factor
Pumice/sand	easy	0.9
Clay	average	1.0
Soft rock	difficult	1.5
Hard rock	v. difficult	2.0

CULVERT MATERIAL TYPE

Culvert pipes are generally made of either concrete or corrugated galvanised steel. Concrete pipes are generally more expensive than steel pipes and require careful handling and placement but they do have advantages in certain areas where water contains a high bedload or acidic content. Due to the nature of deals that may be offered to forestry companies by manufacturers, it is difficult to allow more than a 10% advantage to steel pipe over concrete. Differing prices for culvert pipes are allowed for by altering the cost per pipe.

WATERCOURSE CULVERTS

Any culvert should, ideally, be sited on a topographic plan, inspected in the field and designed before being installed. In forest roading many consider this unrealistic but for other than watertable culverts this is not just the ideal - it is essential.

Because of site specific factors, transport cost of larger pipes, and the installation cost it is impossible to give a generalised breakdown for culvert cost estimation. Instead the approach should be one of rational consideration of the factors to arrive at a cost. Culverts larger than 900mm diameter should be designed by a suitably qualified engineer as they are a high cost component in the roading estimate and the consequences of underdesign are the serious risk of premature failure. The consequence of overdesign is the considerable added expense.

CONCRETE CULVERT PIPE COSTS

Typical 1990 costs for concrete culvert pipes are approximately:

375mm ϕ x 2.44m	*($125/2.4m long pipe)*
450mm ϕ x 2.44m	*$165*
600mm ϕ x 2.44m	*$240*
750mm ϕ x 2.44m	*$310*
900mm ϕ x 2.44m	*$440*
1200mm ϕ x 2.44m	*$710*
1800mm ϕ x 2.44m	*$1320*

Waterway approval from the Catchment Authority is invariably required for culverts larger than 900mm diameter and a condition of this approval is likely to be a check on the design calculations.

FLUMING AND INLET BOXES

In some areas culvert inlet boxes may be required. These are particularly useful in erodible soils and where unstable batter slopes may cover the inlet. Where required an allowance at $150 each should be made.

Fluming is a culverting cost. It is often required particularly where a culvert outlet discharges onto an erodible soil such as a fill slope or sand. Fluming may be constructed from timber but a better material is steel half pipe to suit the diameter of the culvert. A rate of $30 per metre installed should be allowed.

WATERTABLE CULVERT COSTS

The length of watertable culverts is determined by the roadway width, depth of cover, angle to the road, and fill slopes as shown in the Figures 3 and 4.

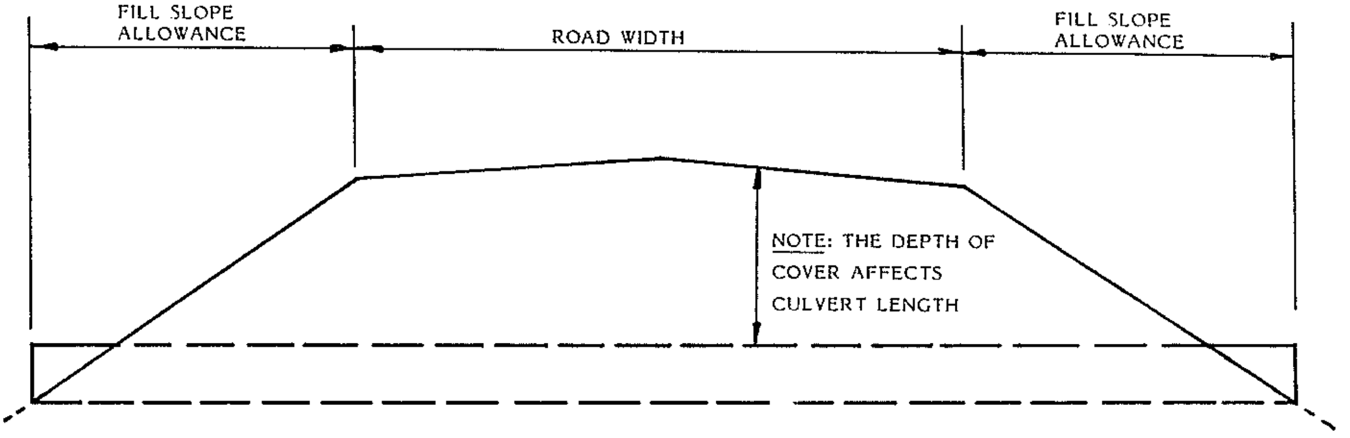


Figure 3 - To assist in determining length of culverts

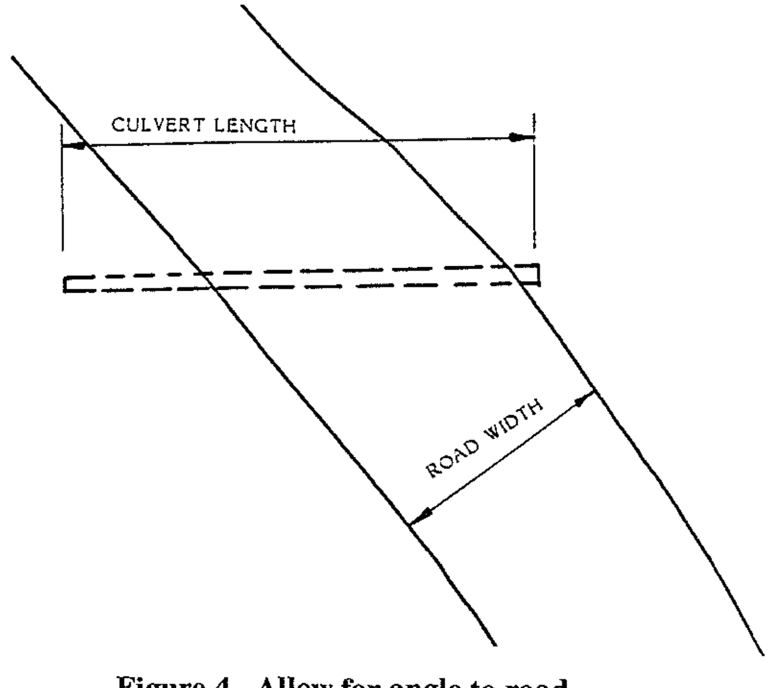


Figure 4 - Allow for angle to road

SURFACING COSTS

The total cost of metalling is the sum of the purchase, cartage and spreading costs.

The starting point for surfacing costs is the cost of basecourse loaded on truck at the pit or quarry. It is necessary to obtain or calculate the cost of producing the basecourse and loading it on truck. All the costing information required to do this should be readily available particularly for a contract operation. The material may be ex-stockpile, crushed or uncrushed, screened or all-in river-run. Typical costs would vary from $2 to $20 per loose cubic metre.

The truck carrying capacity is required. If the trucks are new or have not been hired before then the truck capacity must be measured and calculated. It is important that loads are periodically levelled and checked for volume. A slight underloading per truck will rapidly add up to a significant cost if allowed to continue unchecked.

The hourly rate for the truck is required. This can be the hire rate or a company calculated rate. For a typical 6 cubic m truck rates may vary from $45 to $60/hour.

Estimate the average time per round trip per truck from metal source to job and return. The distance from metal source to job may be obtained from previous direct measurement or from maps using a digitiser, plainmeter or other distance measuring device. In the absence of better information the time may be estimated from the of average times in Table 6.

TABLE 6

Description of cartage road profile	*Speed*
Sealed highway/county road	*60 kph*
Flat grade/open alignment	*45 kph*
Flat grade/winding alignment	*30 kph*
Moderate grade/open alignment	*25 kph*
Moderate grade/winding alignment	*20 kph*
Steep grade/winding road	*15 kph*

The amount of basecourse to be spread per kilometre is required. For logging roads the metal depth depends principally upon the strength of the subgrade, gradeout, curvature and the volume of heavy traffic over the road. 500 m^3/km will generally be a minimum amount for a logging road on a good hard subgrade and standard width. For very soft subgrades it may be necessary to apply up to 2000 m^3/km. For low strength subgrades it is worthwhile investigating the cost and suitability of lime stabilisation or mechanical compaction, as these may be cheaper options if basecourse costs are high. In any event compaction of the subgrade and of the basecourse is considered as essential in any job.

The compaction factor is a value, which when multiplied by the compacted volume will give the loose (truck) volume measure. Common figures are 1.2 - 1.4. For example a 100mm depth of compacted basecourse over a 4m width (400m^3/km) may require 400 x 1.2 = 480 m^3 loose volume, depending on the type of material used.

Allowance for the loss in stockpile (about 10% maximum) and feathering at the edges of the surfaced roadway should be made also.

Example

Roadway width = 6m
Metal depth = 100mm
feathering = 500mm each side of road
Therefore: additional surfacing aggregate for feathering
= 1m x .100 - 2 = .05 m^3/m
in a 1 km length 50m^3 extra compacted metal is required.

50m^3 x 1.1 (to allow for stockpile losses) = 55m^3

55m^3 x 1.3 (compaction factor) = 71.5m^3

This represents an increase of 43% over compacted bare volume.

This small calculation highlights the need for sensible thinking in surfacing quantity calculations.

Pumice is a low density material commonly used as a subbase material on the volcanic plateau. A factor based on actual measurement and observation should be used. If unknown use a 1.5 to 2.0 factor.

Example :

Cost of metal at source	*$5.00/m^3*
Capacity of truck	*6 m^3*
Hourly hire rate of truck	*$60/hr*
Average time per round trip	*0.8 hr*
Compacted volume per km	*600 m^3/km*
Compaction factor	*1.3*
Cost per cubic metre supplied and spread	*15.0*
Grading cost (no data in this report)	
Total cost per km	*$11,700*

COST ESTIMATION PROGRAM

With the information presented so far, the reader can do manual calculations to determine costs. A suggested layout is given in Appendix A.

It is however easier, more accurate and easier to change if this typical costing format is produced and stored on a personal computer spreadsheet.

LIRA has developed a spreadsheet model to do this costing.

It will run on two common spreadsheets:

(i) SUPERCALC5
(ii) LOTUS 123

The program is available from LIRA at a cost of:

$ 12.00	for members
$170.00	for non-members

OPERATION OF SPREADSHEET MODEL

To run this model requires that you:

(i) Have an IBM style PC

(ii) Have the spreadsheet program Supercalc or LOTUS 123

(iii) Have the spreadsheet model available from LIRA

A printer is required for easy output of the finished costing.

Operation of the model is simple but requires a basic understanding of spreadsheet operation.

Entries which require alteration for specific projects such as:

Segment lengths }
Days } in Planning and
Cost/day } Design section

and

Length }
Slope angle }
Slope factor } in Formation Cost
Material factor } Estimate section
Machine factor }
Machine hourly rate }

are not protected and can easily be altered by overtyping.

Other entries are protected. These entries contain formulas to calculate costs. If you try to change any of these entries you will get a message on the screen telling you they are protected.

It is advisable to work through an example manually before running the same example in the spreadsheet.

MODIFICATION OF SPREADSHEET MODEL

If your spreadsheet program is not Supercalc or Lotus compatible it may still be possible to run the model. Specific changes will have to be made by the user as LIRA cannot undertake modifications to this model for other spreadsheets.

The model does however use standard procedures throughout and any competent computer user could adapt the ideas to almost any commonly available spreadsheet.

LIRA distributes this program in the interests of providing the logging industry ideas on how well costing can be adapted to modern personal computers. While LIRA and its staff have taken all reasonable precautions to ensure the functionality of this spreadsheet model neither LIRA, it's employees, staff or contractors can take any responsibility for any event or action as a result of using this spreadsheet model.

REFERENCES

Goldsack, R W (1988) : "Log truck gradeability on corners and grades". LIRA Project Report No 38.

Taylor, P (1989) : "Log truck axle layouts - 1989 (An economic comparison of layouts under the new Weights and Dimensions Legislation)". LIRA Report Vol 14 No 4.

Compaction Data Handbook (1982), Ingersoll-Rand Co.

APPENDIX A

CONSTRUCTION COST ESTIMATION FOR FOREST ROADS

Forest	:	Someones
Project Name	:	Joes Road
Project Length	:	2730 m
Date	:	10 Feb 1989
Calculated By	:	Don Robinson

PLANNING AND DESIGN

Segment Number	1	2	3	4
Length (kilometres)	.30	.76	1.42	.25
Days	.30	.76	1.42	.25
Cost / day	350.00	350.00	350.00	350.00
Planning cost	105.00	266.00	497.00	87.50
Planning Total	955.50			
Length	2.73			

FORMATION COST ESTIMATE

Estimate is based on a standard rate of 50 hours/km in moderate topography, clay soils, and a 200/220 KW bulldozer. The project road may be split into segments differentiated by side slope angle.

Segment Number	1	2	3	4
Length (kilometres)	.30	.76	1.42	.25
Slope Angle (degrees)	18.50	10.00	14.00	29.00
Slope Factor	1.00	.90	1.00	1.30
Material Factor	1.25	1.00	1.20	1.50
Machine Factor	1.00	1.00	1.00	1.00
Machine Hourly Rate ($)	160.00	160.00	160.00	160.00
<u>Compaction</u>				
Cost per Kilometre ($)	10000.00	7200.00	9600.00	15600.00
Cost/Segment ($)	3000.00	5472.00	13632.00	3900.00
Total Formation Cost ($)	26004.00			
Average Cost/km ($)	9525.27			

CULVERT COST ESTIMATE

Segment Number			1	2	3	4
Material Factor			1.00	1.10	1.20	1.50
No of	375mm culverts		3	4	10	3
Av. length	375mm culverts		9.00	9.00	10.00	9.00
No of	450mm culverts		.00	1.00	2.00	.00
Av. length	450mm culverts		.00	9.00	10.00	8.00
No of	600mm culverts		.00	.00	.00	.00
Av. length	600mm culverts					
No of	750mm culverts					
Av. length	750mm culverts					
No of	900mm culverts					
Av. length	900mm culverts					
No of	1200mm culverts					
Av. length	1200mm culverts					
No of	large culverts		.00	.00	.00	.00
Av. length	large culverts		.00	.00	.00	.00
CULVERT cost/pipe install						
375	125	125	2812.50	3937.50	11458.33	3515.63
450	165	149	.00	1231.31	2860.00	.00
600	240	168	.00	.00	.00	.00
750	310	186	.00	.00	.00	.00
900	440	220	.00	.00	.00	.00
1200	710	284	.00	.00	.00	.00
Large	1320		.00	.00	.00	.00
Large install		1100	.00	.00	.00	.00
Length of fluming			10	30	60	10
No. of inlet boxes			.00	2.00	4.00	1.00
Cost of fluming			300.00	900.00	1800.00	300.00
Cost of inlet boxes			.00	300.00	600.00	150.00
Cost/segment ($)			3112.50	6368.81	16718.33	3965.63

Total Culvert Cost ($)	30165.27
Average Cost/km ($)	11049.55

METALLING COST ESTIMATE

Segment Number	1	2	3	4
Cost of Metal at Source	5.00	5.00	5.00	5.00
Capacity of Truck (m3)	6.00	6.00	13.00	6.00
Hourly Rate of Truck	60.00	60.00	110.00	60.00
Dist - Source to Job	17.50	17.90	19.10	20.00
Av. Time Per Trip (hr)	.80	.80	.78	.90
Compacted Vol. per Km	600.00	500.00	600.00	800.00
Compaction Factor	1.30	1.30	1.30	1.30
Grading cost/km	.00	.00	.00	.00
On-road Cost Per m3	13.00	13.00	11.60	14.00
Cost per Kilometre ($)	10140.00	8450.00	9048.00	14560.00
Total Cost/Segment ($)	3042.00	6422.00	12848.16	3640.00

Total Metalling Cost ($)	25952.16
Average Cost/km ($)	9506.29

PROJECT COST SUMMARY

		Total
Planning and Design		955.50
Formation		26004.00
Culverts		18227.50
Metalling		25952.16
Total Project Cost		71139.16
Average cost/km	:	30431.11

APPENDIX B

TABLES OF FACTORS

FORMATION COST

PROFILE FACTOR

Slope (degrees)	Description	Profile Factor
< 10 deg	easy	0.75
10 - 25	moderate	1.0 (normal case)
> 25	steep	1.25 - 1.75
> 40	v. steep	2.0

MATERIAL FACTOR

Material Type	Description	Factor
Pumice/sand	easy	0.75
Clay	average	1.0
Soft rock	difficult	1.5
Hard rock	v. difficult	2.0 - 2.5

MACHINE FACTOR

Machine power	Description	Factor
< 150 KW	D6/D65 size	1.5
150 - 200	D7/D85 size	1.25
> 200 KW	D8/D155 size	1.0
> 225 KW	Int TD25E	0.9

<u>CULVERT COST</u>

MATERIAL FACTOR

Material type	Description	Factor
Pumice/sand	easy	0.9
Clay	average	1.0
Soft rock	difficult	1.5
Hard rock	v. difficult	2.0

APPENDIX C

ROAD SURFACING MATERIALS

GRANULAR MATERIALS

The two most important characteristics of granular materials used for road surfacing are:

(a) gradation of the gravel/sand particles, and

(b) plasticity properties of the fine or silt/clay sized particles.

Fines are considered as those particles that pass through the .075mm (#200) screen, even though the plastic index test is performed on all particles passing a .425mm screen.

GRADATION OF GRAVEL/SAND PARTICLES

There are three types of gradation.

1. Lean or open grade;
2. Dense grade;
3. Dirty or rich grade.

In lean or open graded mixes, the strength is controlled by the frictional component of shear strength. This depends on aggregate-to-aggregate contact. The angularity of the granular particle has a marked effect on the strength. Well rounded gravel particles impart little strength, whereas highly angular (crushed aggregate) particles possess higher strength capabilities. Because lean or open graded mixes have a high voids volume, the permeability of the aggregate is high.

As the fines percentage increases the fine material begins to fill up the void spaces but not to the extent that larger sized particles are dislodged from each other. The increase in fines accomplishes several important functions:

1. more void particles are placed within the same total volume, the density of the material is increased;
2. the shear strength is increased;
3. the ability for water to flow through to permeate the material is drastically reduced.

As fines are increased still more, the fines displace the coarser particles from one another. Eventually a point is reached where the granular particles float in a matrix of fine material and at this point the granular material is said to have a dirty or rich gradation.

Although a dirty or rich gradation leads to only a minor decrease in density, there is a significant decrease in strength caused by the loss of the frictional component (compact between the coarse particles). As a result, the strength of the material is that of the fine soils, rather than that of the granular particles. The permeability is of course low because the voids are filled with fine particles.

From this it can be seen that the distribution of sizes within a granular material plays an important role in the density, strength and permeability properties of the material. The size distribution also plays an important part in the material workability, and what is important for our use, in unsealed forest roads is that the the aggregate gradation plays an important part in the ability to form a waterproof protective skin on the metalled road.

The influence of the percentage fines on the optimum density and CBR strength of an aggregate pavement is such that generally both the greatest density and strength will occur with 7 to 10 percent passing a .075mm (#200) sieve.

For any compaction effort the greatest strength occurs when the percentage of fines corresponds to the greatest density. Always remember that the strength of a compacted basecourse is influenced significantly by the level of compaction.

The significance of extra compaction is highlighted by the fact that the average strength of a basecourse compacted to modified compactive effort levels is at least two times that obtainable at standard compactive effort levels. Although this compactive effort results in very little density increase, significant strength increases can be achieved.

Compaction and aggregate gradation are important factors in the assessment of materials for use in basecourse construction.

INTRUSION OF FINE GRAINED SUBSOILS

Intrusion of fine grained subsoil into the granular layers can effect the performance by causing a decrease in the strength under wet conditions and by allowing granular base material to be pushed into the subgrade.

Intrusion can be prevented by using sand-type filter layers (50-100mm thick) or geotextiles.

SOUNDNESS

Another factor to be considered in assessing a basecourse material is its soundness or weatherability which is usually checked by either Los Angeles abrasion tests, an accelerated weather test or a 10% fines crushing test.

GRADATION REQUIREMENTS

Figure C(i) shows typical grading envelope requirements for granular materials to be used as surface layers. Figure C(ii) illustrates a typical grading envelope for base or subbase use.

For wearing surfaces the maximum aggregate size is about 19 to 25mm with the smaller size being preferred. This is in contrast to the larger sizes used for base or subbase.

It is noticeable from the figures enclosed that general recommendations for base and surfacing aggregate are considerably different from those used for NRB M4 (Figure C(iii)).

Unlike NRB M4, some plasticity is desirable and because of this allowable values of plastic index and liquid limit are greater for these types of material than the National Roads Board specification would allow. For these reasons M4 specification is not desirable on unsealed roads.

Further information on this subject is available from :

FERRY, Alan G (1986) : "Unsealed Roads : A Manual of Repair and Maintenance for Pavements",RRU Technical Recommendation TR8, National Roads Board, Road Research Unit, Wellington.

National Academy of Sciences (U.S) : (1982) "Structural Design of Low-Volume Roads", Transportation Technology Suppot for Developing Countries, Synthesis 4, Washington, DC.

Figure c (i) - Typical Grading Envelope Requirements for Granular Materials to be used as Surface Layers

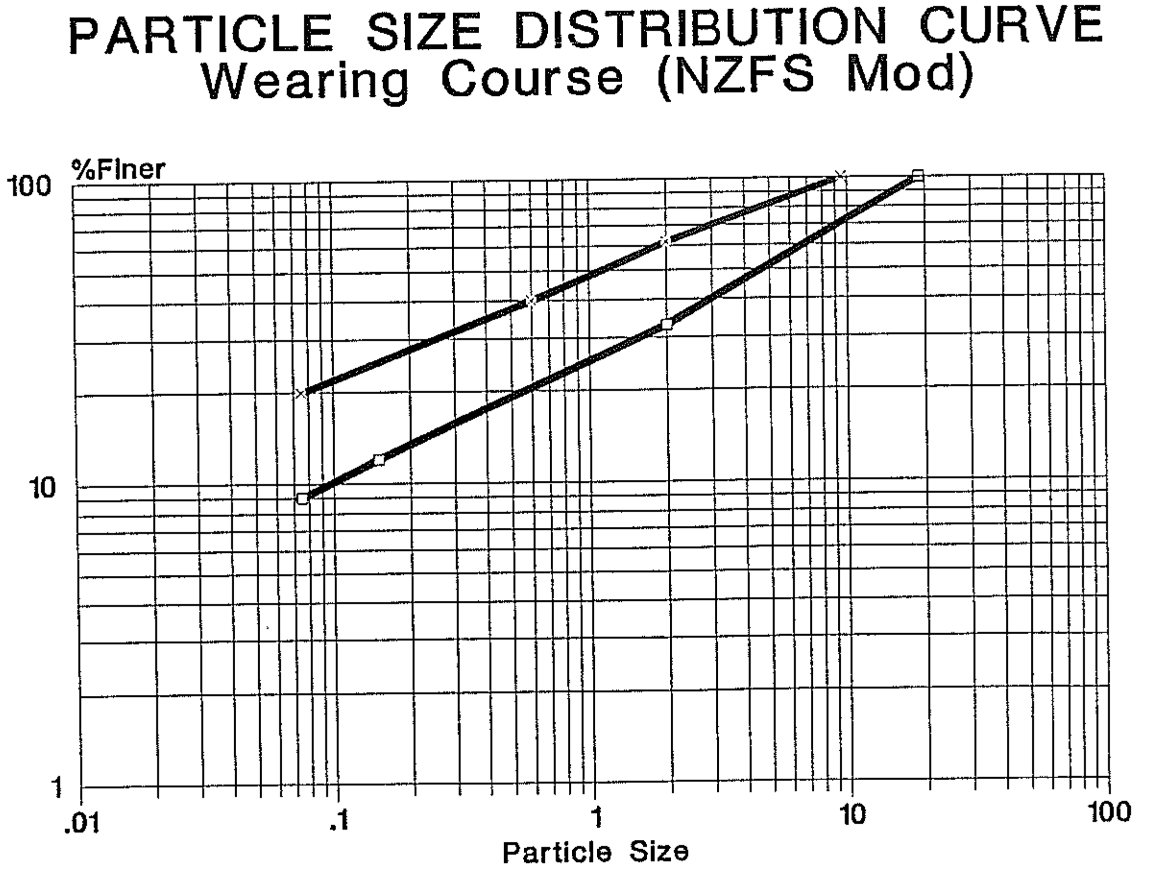


Figure C (ii) - Typical Grading Envelope for Base or Subbase Use

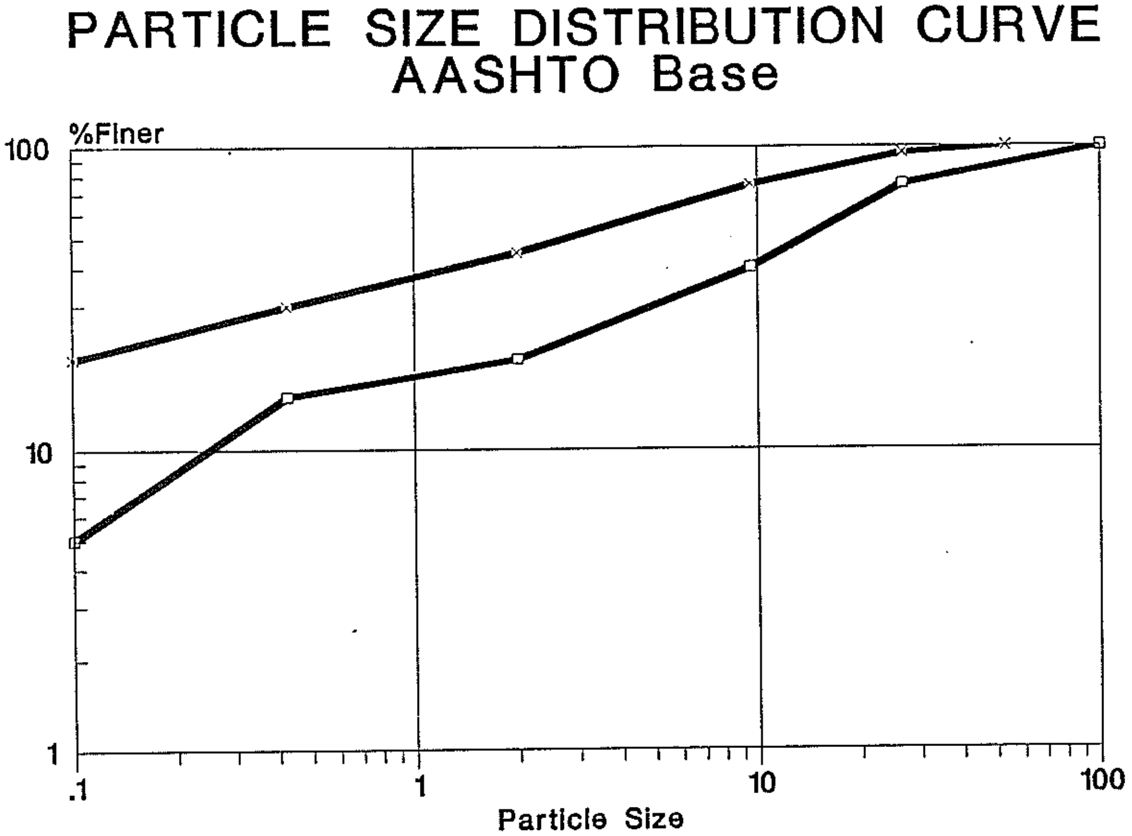
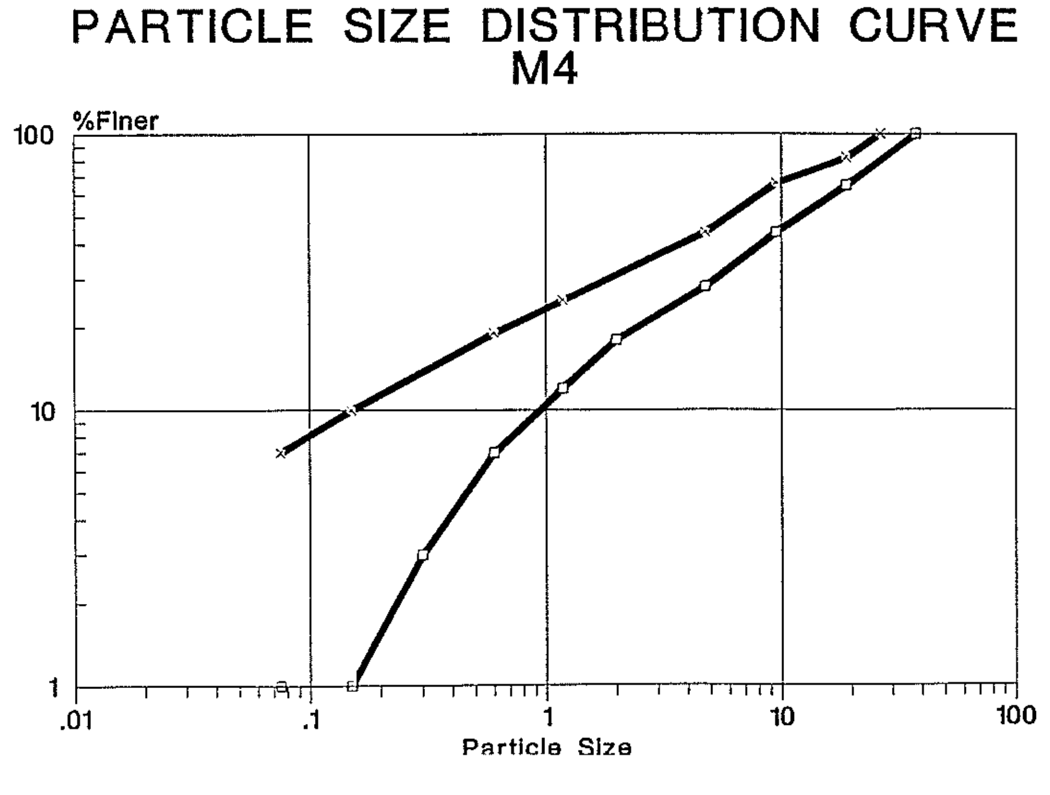


Figure C (iii) - Typical M4 Basecourse Grading Limits



APPENDIX D

USING PACE TO COST MACHINE HOURLY RATE

PACE is a programme which originated with John Sessions of Oregon State University.

It can be used to cost machines of almost any type and an example print out is shown below.

```
----------------------------------- Summary --------------------------------

          *** Demo Costing for Joes Road Someones Forest ***

Ownership
    Depreciable value:                              $   250,000.00
    Equipment depreciation:                         $    31,250.00 / Year
    Interest expense:                               $    19,687.50 / Year
    Taxes, license, insurance and storage:          $     7,031.25 / Year
    Annual ownership cost:                          $    57,968.75 / Year
    Ownership cost (Subtotal):                      $        27.87 / Hour
Machine operating
    Repairs and maintenance:                        $        15.02 / Hour
    Fuel and oil:                                   $        21.63 / Hour
    Lines and rigging:                              $         0.00 / Hour
    Tires or tracks:                                $        20.00 / Hour
    Equipment operating cost  (Subtotal):           $        56.65 / Hour
Labor
    Direct labor cost:                              $        17.64 / Hour
    Supervision and overhead:                       $         2.65 / Hour
    Labor cost (Subtotal):                          $        20.29 / Hour

OWNERSHIP COST                                      $        27.87 / Hour
OPERATING COST                                      $        56.65 / Hour
LABOR COST                                          $        20.29 / Hour
Machine rate (Ownership + Operating + Labor)        $       104.80 / Hour
                  *** Press [RETURN] for the menu ***
```

PACE is available with a Users Manual from LIRA.