Session 4
Paper (b)

EXCAVATORS for ROAD and TRACK FORMATION

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INTRODUCTION

The Hydraulic Excavator (backhoe) has many advantages over the more traditional tractor or dozer, when used for the construction of forest roads and tracks. This paper sets out some of those advantages and highlights the benefits of using backhoes for road and track formation. The use of dozers as a construction tool is acknowledged where it is more suitable than a backhoe.

The hydraulic backhoe has been commonly used in forest road construction since the mid 1970's. I personally utilised backhoes for forest road construction in 1975 and have been an advocate for the sensible use of these versatile machines ever since. In some areas of New Zealand the backhoe has largely replaced the dozer as a primary construction machine and in others it is used in conjunction with a dozer to form an effective and economic roadbuilding unit. In other areas however it is still largely ignored in a roadbuilding role for reasons which are not immediately obvious.

Traditionally tractor methods of road construction have predominated in the forest industry. The reason for this lies largely with the historical use of tractors in forests for a multitude of tasks, and the need for versatile machines able to perform many tasks ranging from road construction and maintenance through to hauling logs. This single unit versatility was further reinforced because the dozer was often owned by the forest owner and the need to keep this workhorse busy and "paying" was paramount even at the expense of newer or more efficient construction methods. As the industry developed and emphasised plantation crops, the economics of operations has come under increasing scrutiny. Machinery ownership by the forest owner is nowhere near as prevalent as it was and managers are increasingly looking to achieve their results with what ever they see as the best (and most economic) method.

Hydraulic backhoe development began in post-war USA and by the mid sixties, hydraulic technology was advanced to the stage where all functions of the backhoe including track drive were able to be performed with hydraulics. In New Zealand the hydraulic backhoe machines that were available at this time were largely looked upon as replacements for older rope operated excavators working in traditional areas such as drainage, although in some areas contractors, in particular, were quick to recognise the advantages of the new machines and to exploit these advantages to their benefit. The first roading area (1971) in which I saw these hydraulic machines extensively used was in city road reconstructions where excavation of old failed subbase and replacement with clean graded roading aggregate was enhanced by the easy,

versatile action of the hydraulic backhoe. Considerable savings were possible over the old grader ripping, and front end loading of trucks, in what was a limited workspace.
Stjernberg (1) gives some good comments on the use of backhoes in forest road construction.

ROAD and TRACK FORMATION

Forest Road and Track construction is almost invariably done in order to facilitate planting, tending, thinning or harvesting a plantation crop of trees. Increasingly, these trees are regarded as a crop whose main purpose is to generate revenue. To achieve this purpose the manager must place great emphasis on ensuring that road construction is planned, economic and suitable to the task at hand.

Road construction methods within forestry can be considered as one of, or a combination of, the following three methods.

1. "Over top" construction.
Over top construction of roads is usually only used where the organic matter and/or topsoil are too deep to be removed or are to wet to handle. Typical areas are swamp, peat or high rainfall areas. The construction method consists of tree removal; excess material such as branches and small limbs used as matting; stumps lifted, and turned over if useable as a mat; ditch both sides of road and use excavated material (if suitable) in the roadway; let formation drain; aggregate is applied as required (or available) to make a roadway.

2. "Side slope" construction.
Side slope construction of roads where the road is formed by benching the hill slope, with excess soil side cast to waste is common in all hill country forests. Various dangers are evident in this construction method. Some of the dangers are ameliorated by adopting a multiple pass approach and the particular advantages will be expanded later in the paper.

3. "End Haul" construction.
End haul construction, in which all excavated material is removed from the work face and deposited in designated "waste" areas or used as fill in the road formation, has, fortunately, not been common in New Zealand. There are however, times when this approach would be sensible, although one should be very aware of the considerable cost increases which this form of construction will force upon the forest.

In all these construction methods there are some over-riding concerns or important points.

1. The mixing of overburden, organic soil or vegetation with the mineral soil used to provide road strength must be avoided - almost at any cost.

2. The quantity of construction in a given unit of time maybe of less importance than the quality (within some reasonable limits).

3. "Cut and fill" type construction using compaction equipment to stabilise the fill material can be used in conjunction with any of the three methods mentioned.

The hydraulic excavator can be used in all these construction methods. It can perform as well as, or better than, a dozer working alone - but the best results are likely to be obtained from a judicious use of both machines, preferably working in close co-operation.

FEATURES of ROAD and TRACK CONSTRUCTION by BACKHOE.

Hydraulic backhoes are available in a large range of sizes up to 450 tonnes and with bucket sizes up to 22m3. They are manufactured by a large number of different companies many of whom also produce dozers. The useful sizes for forestry roading use lie between 15 and 40 tonnes. The larger sizes are more difficult to transport and generally the most useful size seems to be around 30 tonnes. There are few physical limitations on the use of backhoes in forest roading and, although many managers unfamiliar with backhoes find it difficult to believe, the steeper, and/or harder, the material being worked the more useful and economical the backhoe becomes.

Some features of the backhoe when used in road and track construction are very important.

Backhoe road construction maximises the effective "dirt moving" capacity because the movement of earth is minimised. For instance it is most unlikely that soil will be moved solely to enable positioning of the machine as is the case with a dozer. As the backhoe requires no ramps or manoeuvring space the finished road invariably looks tidier and less soil is moved for the same effective roadway width. As soil from road and track construction is recognised as a major contributor to sedimentation problems, the substantial reduction in water transportable soil is important. The backhoe is particularly good at "inside" corners on sideslope construction, around culverts and in stream areas. Much of the sediment production from roads is in these areas.

The backhoe has the ability to reach in depth, height and forward to enable it to move material which a dozer would not be able to reach. The finish achievable from a backhoe on batter slopes is better than from a dozer. This is not just a matter of aesthetics, as reduced overhangs, the solid finished surface and minimum soil removal all lead to decreased soil available for transport as sediment. The decreased ongoing maintenance required on neatly finished earthworks is also important.

The backhoe has the ability to excavate material and to then load direct to transporters (trucks or scoops) without an intermediate loader. This point becomes very important in "end haul" construction. It also has the ability to sort relatively small pockets of suitable material in order to use these in the construction of the road. This material would be effectively unavailable to a dozer.

The backhoe does not move on its tracks in order to excavate material. The work loading on the tracks is therefore considerably reduced. Dozers however depend on moving on tracks in order to excavate even small quantities of material. This reduction in track use not only reduces the track wear on the machine (reducing maintenance costs), but also ensures that minimum reworking of the road surface takes place. This in turn gives water less opportunity to penetrate the surface and weaken the important road formation layer. The importance of this is hard to emphasise enough. Forest roads always use a minimum of aggregate pavement in order to reduce construction cost. Anything which maintains maximum strength in the layers immediately below the applied roading aggregate is worth pursuing.

The backhoe has more breakout force in its bucket tips than a larger dozer has in its blade tip. The breakout force is dependant on machine weight/size, horsepower and bucket/arm geometry, but it is largely independent of the uphill or downhill working pattern. This ambivalence as to work direction (uphill or downhill) becomes very important when

access to the road under construction is limited. Access is almost always limited in steep country forest roading.

If travel speed is important, backhoes are available on wheels and travel speed exceeds that of a dozer. The wheeled backhoe has no limitations on its use on sealed road surfaces, other than normal licensing requirements.

Material is confined to the bucket during movement and placement anywhere within the working zone of the digger is possible. This confinement means that mud and high water content materials can be handled with accuracy and surety. This advantage is not available to the dozer.

The backhoe has the ability to handle trees, or at least reasonable size logs, with accuracy. Its ability to lift stumps and accurately place them is a major point in its favour. It is far superior to a dozer at dealing with standing trees and the degree of control over the tree felling particularly in smaller size trees should lead to better volume recovery while at the same time providing a safer working environment for "first cut" roading. This ability to handle trees should not be used where it is clearly better to fell them first. Sensible planning is the only process to determine whether motor manual felling, or backhoe felling, by pushing over trees, is the best option.

Backhoes generally have lower ground pressure than dozers which can be a definite advantage when working in wet or swampy areas.

In wet conditions backhoes with their boom - bucket combination have a built in "de-bogging" mechanism whereas a dozer would have to rely on assistance or winching. The boom and bucket can be used, even at maximum reach, to provide tractive assistance when the tracks are unable to provide any motive power.

Backhoes are unmatched at culverting and forming stream crossings as they can accurately excavate and place material, fully contained within the bucket, causing little damage to the stream.

The fuel consumption is less than for a dozer of comparable power.

The above reasons should not, however, be construed to mean that dozers have no place in road construction. The dozer has some features unable to be matched by a backhoe such as:-

The ability to finish road surfaces - although this advantage is not as great as it may seem. The best finish to road or track surfaces is obtained from a grader. This grader finish is invariably cheaper and better than any other method although one must have enough work to justify what could be large positioning or transport costs.

The ability to economically move quantities of spoil a limited distance - say up to 200 m. Remember that a dozer and backhoe in combination are generally more effective in this area, if it involves "breaking out", than a dozer alone. A dozer is particularly effective at moving large quantities of blasted rock or dry rotten rock over distance up to 200 m.

The ability to have a winch fitted and it is therefore useful in "skidding" logs.

Faster "walking" speed than tracked excavator.

It **may** be a better stand-alone machine than a backhoe if its special features are essential.

Although the dozer is often quoted as achieving a better road compaction than a backhoe, this point should not be given

any weight. Compaction by rollers is the only sensible way to achieve an useful degree of compaction. It is always more cost effective than track rolling by machines such as a dozer and backhoe which are designed specifically to have low ground pressure.

CONSTRUCTION TECHNIQUE.

"Over top" construction.

As mentioned above this technique involves the overlaying of existing ground and vegetation with a mat of branches, slash or root material. It can also consist of a geotextile layer on top of existing ground and overlaid with suitable road formation material. The backhoe is ideally suited to this type of construction which depends on minimal ground disturbance for its effectiveness. The ability of the backhoe to move and accurately place material of all compositions and the low ground pressure of the machine make it unmatched in this situation. Dozers cannot work well in this type of construction and it is probably one of the reasons that this construction method has not been widely used in New Zealand.
One problem with this type of construction is the almost inevitable decomposition of the vegetation mat. This leads to local sinking in the road and consequent loss of shape. In the swampy or wet situations where this technique is mostly used, this is a minor cost to pay for the provision of a road. If the vegetation mat remains wet at all times the decomposition process takes many years.

Sidecast

This technique has been, and still is, widely used in New Zealand forest roading. It involves the "pioneering" or "pilot track" formation of a benched track of sufficient width to carry the construction machine. Material surplus to the track formation is pushed off the bench to form a fill, in the more gently sloped country, or a spill in steeper terrain. Subsequent formation to full roadway width is achieved by working on the preliminary bench to widen and align the road formation as required. Again, surplus material is usually pushed off the bench, to waste, but in some cases the material can be, and is, used as fill to form part of the road formation. Various techniques are used to minimise the amount of material pushed off the bench in an uncontrolled way. Benching the toe area of the fill slope is one common method of minimising large spill slopes. The spill is contained within limits defined by the benching and the ability of the backhoe to work in safety on steep side slopes while forming minimal width benches is a distinct advantage.
Other techniques depend on the compaction of excess material to make it suitable for use as a part of the road formation but this is not common in forest roading. If the material is unsuitable for use in the formation it is simply treated as waste and is often simply sidecast without any containment.
The time required by a backhoe for this type of construction is of the same order as that required by a comparable dozer. The most important features to look for when considering the use of a backhoe in sidecast construction are slew speed and the operators ability to work efficiently in this type of work. Kemp (2) reports that savings of 20% on prime earthworks costs are possible using a backhoe for sidecast road construction.

Pioneering or Pilot Tracking.

These tracks generally form an essential part of the road construction process. In my experience it is always cheaper and

quicker to construct these tracks using an excavator. Balcom (4) reports similar results.

Clearing and topsoil removal.

Balcom (4) shows that backhoes are more cost effective in this role than dozers in all but the most favourable conditions.

Stumping and Roadline Logging

Backhoe stumping has some definite advantages over stumping by dozer. The backhoe ability to lift stumps with considerable force, rather than just push them, is the key to its use in this role. It also has an ability to dig and render parts of the tree root system ineffective, enhancing the ease with the stumping operation can be carried out.
Roadline logging is often carried out under difficult conditions and the backhoe is ideally suited to felling and placing trees. Skidding logs however is more suited to the dozer. Roadline logging by excavator is currently under study by LIRO.

Ditches, drains, watertables and batters.

Backhoes are ideally suited to work on ditches drains and watertables. Most forest managers will be familiar with, and need little convincing of, the backhoes superiority in this role. The reason for the backhoes superiority in road batter work is its ability to reach upward and cut and shape the soil with precision.

End haul

The use of the backhoe to load trucks or spoil haul vehicles is the preferred option when end haul construction is required. The backhoes ability to swing material through 360 degrees and place it with precision is unmatched by any other machine. Balcom(4) reports that end haul construction can be 4.1 to 17.5 times as expensive as conventional sidecast construction. A New Zealand example which I have been working on, shows a doubling of cost over sidecast techniques. This was a short section of 200 meters with an ideal dump site nearby. This doubling of cost is likely to represent the lower limit of cost increase by chosing end haul construction.

Sidecast pullback.
This technique is little used in New Zealand but has recently found some favour in the West Coast of the USA. A backhoe moves along an existing road or landing and removes any excess burden (soil and debris) placed on the original ground slope during construction. Stumps and debris are scattered downhill while the truck carrying the removed spoil travels to and from the dump site. Backhoe spare time is used to smooth the final side slope. Balcom(4) describes a small operation using this technique. No cost information is known but it is likely to be cheaper than full end haul construction.

Culverts

This area is one in which the backhoe shines. It is undoubtedly the best machine for work in and near streams, when installing culverts, crossings and even bridges. In many instances the backhoe will only need to cross a stream once to prepare both sides of the stream bank for installation of culverts or small bridges. Its ability to lift the culverts into place with minimal machine movement is a major benefit. In the case of small culverts up to 750 mm in diameter the backhoe can often fully install the culvert without ever crossing the unculverted stream.

Log handling

Hydraulic excavators are well suited for handling logs and trees. The ability to pick up logs in a "tight"grip between bucket and boom is very useful but this ability is extended even more with special purpose fittings and bucket attachments to enhance this log handling ability.

Rock work

Backhoe road construction in rock is more productive and cost effective than dozer construction. The greater effective breakout power of the backhoe and the accuracy of positioning and long reach in any direction pays large dividends in rock. At some stage drilling becomes necessary and here again the backhoe can assist greatly by constructing drill platforms and working areas which are impossible with a dozer.

Safety.

The backhoe has some benefits from a safety point such as:-

Drilling - When rock drilling the ability of the backhoe to reach and accurately work loose rock minimises risk during subsequent drilling operations.

Overhangs - Batter overhangs are a feature of dozer constructed forestry roading particularly when working uphill. The ability of the backhoe to reach and deal with dozer overhangs (or totally prevent them occurring if it is the prime earthmover) is beneficial.

Logs - a backhoe can move logs from the high side of the road construction and minimise risk associated with these logs rolling down onto the construction area.

Earthworks on side slope - Backhoes minimise the necessity to have "tracks in air" when constructing side slope roads (or preparing quarries for operation by removing overburden).

ECONOMICS

Cost savings in the use of backhoes for road construction are not easy to quantify since most of the situations are site specific. Savings should be looked for in the following areas.

1. Less establishment cost to get equipment on site because machinery is lighter and more manouverable.

2. In wet areas production is much increased.

3. Because sorting of materials and the use of the more suitable materials is easier the resulting road formation before aggregate is applied is stronger and cleaner. Less mixing of the expensive road aggregate with soil results in a better pavement or a similar pavement with less aggregate. In wet areas expected saving can amount to 50% of the aggregate cost.

4. Road maintenance, particularly with regard to ditches, drainage and batters is much more cost effective with a backhoe than with most other methods.

5. Environmentally sensitive areas are particularly favoured by the backhoe. Almost absolute control within the work zone and containment of the material being handled within the confines of the bucket make this an area in which the backhoe can shine. While not specifically a cost saving in construction terms, work in environmentally sensitive areas handled with care lessen any potential conflict with outside interest groups and may prevent construction or logging operations being curtailed.

Nagy (3) concluded that backhoes produced roads cheaper than dozers but

that machine productivity was dependant to a significant degree on operator skill. Many operators were self trained and had developed some poor construction techniques. This is in accordance with my own observations made over a number of years. The best and most productive backhoe operator I have experienced was also an excellent dozer driver who was enthusiastic about the backhoe advantages in forest road construction.

CONCLUSIONS

The backhoe is a versatile machine with many advantages that can lead to cost savings in forest roading. The machine is not however invincible and it can be used improperly. It is important for supervisors of roading work to consider the use of the backhoe carefully and ensure that it is being used effectively and economically. Operators vary markedly in their abilities on these machines particularly on forest roading work. Some who have graduated from dozers are excellent and some are mediocre. As in all machine operations, good operators will always make a difficult job look easy. Under these circumstances it is easy to be mislead into thinking the operator is not "working". A check on production for the time spent will always mean more than casual visual observations. The use of backhoes in various New Zealand Forest Operations is being studied by LIRO and will be reported on in the future.

REFERENCES

1. Stjernberg, Ernst, I. (1982) "The use of hydraulic excavators in Forest Road Construction: Central and Eastern Canada". FERIC Special Report No SR-20.

2. Kemp, Peter.(1984) "Excavators in Forest Roading Operations". LIRA Technical Release Vol 6 No 4 1984.

3. Nagy, M. M. (1978) "Productivity and Cost of four Subgrade Construction Machines". FERIC Technical Report No TR-28.

4. Balcom, John. (1988) "Construction costs for Forest Roads" Forest Research Laboratory, Oregon State University, Corvallis. Research Bulletin 64 21p.

APPENDIX 1

Typical operating costs for 30 tonne hydraulic excavator.
From PACE program (developed by J Sessions distributed by LIRO)

Equipment Ownership Costs

->Delivered equipment cost	$	300,000.00
Minus line and rigging cost	$	0.00
Minus tyre or track replacement cost	$	40,000.00
Minus residual (salvage) value	$	75,000.00
Life of equipment (Years)	#	5.00
Number of days worked per year	#	235.00
Number of hours worked per day	#	8.00
Interest Expense	%	12.00
Percent of average annual investment for:		
Taxes, License, Insurance, and Storage	%	3.00
Depreciable value:	$	185,000.00
Equipment depreciation:	$	37,000.00
Average annual investment:	$	210,000.00
Interest expense:	$	25,200.00
Taxes, license, insurance and storage:	$	6,300.00
Annual ownership cost:	$	68,500.00
Annual utilization (Hours per year):	#	1,880.00
Ownership cost (Dollars per hour):	$	36.44

Equipment Operating Costs

->Percent of equipment depreciation for repairs	%	80.00
Fuel amount (Litres per hour)	#	25.00
Fuel cost (Per litre)	$	0.50
Percent of fuel consumption for lubricants	%	5.00
Cost of oil and lubricants (Per litre)	$	3.00
Cost of lines	$	0.00
Estimated life of lines (Hours)	#	0.00
Cost of rigging	$	0.00
Estimated life of rigging (Hours)	#	0.00
Cost of tyres or tracks	$	40,000.00
Estimated life of tyres or tracks (Hours)	#	4,000.00
Repairs and maintenance:	$	15.74
Fuel:	$	12.50
Oil and lubricants:	$	3.75
Lines:	$	0.00
Rigging:	$	0.00
Tyres or tracks:	$	10.00
Equipment operating cost (Subtotal):	$	41.99

Labour Costs

->Base wage for 1st crew position (Per hour)	$	18.00
Base wage for 2nd crew position (Per hour)	$	0.00
Base wage for 3rd crew position (Per hour)	$	0.00
Base wage for 4th crew position (Per hour)	$	0.00
Base wage for 5th crew position (Per hour)	$	0.00
Base wage for 6th crew position (Per hour)	$	0.00
Fringe benefits	%	15.00
Travel time per day (Hours)	#	1.00
Operating time per day (Hours)	#	8.00
Percent of direct labour cost for supervision	%	25.00
Total number of workers:	#	1.00
Total crew wage (Per hour):	$	18.00
Direct labour cost:	$	23.29
Supervision and overhead:	$	5.82
Labour cost (Subtotal):	$	29.11
Total operating cost (Operating+Labour):	$	71.10

Summary

*** Typical 30 tonne road construction hydraulic excavator (backhoe) ***

Ownership		
Depreciable value:	$	185,000.00
Equipment depreciation:	$	37,000.00 / Year
Interest expense:	$	25,200.00 / Year
Taxes, license, insurance and storage:	$	6,300.00 / Year
Annual ownership cost:	$	68,500.00 / Year
Ownership cost (Subtotal):	$	36.44 / Hour
Machine operating		
Repairs and maintenance:	$	15.74 / Hour
Fuel and oil:	$	16.25 / Hour
Lines and rigging:	$	0.00 / Hour
Tires or tracks:	$	10.00 / Hour
Equipment operating cost (Subtotal):	$	41.99 / Hour
Labour		
Direct labour cost:	$	23.29 / Hour
Supervision and overhead:	$	5.82 / Hour
Labour cost (Subtotal):	$	29.11 / Hour
OWNERSHIP COST	$	36.44 / Hour
OPERATING COST	$	41.99 / Hour
LABOUR COST	$	29.11 / Hour
Machine rate (Ownership + Operating + Labour)	$	107.54 / Hour