Application of New Rock Drilling Technology to Forest Road Construction in Coastal British Columbia

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In 1988, the Forest Engineering Research Institute of Canada initiated a series of studies to evaluate the effect of state-of-the-art drills on the techniques and costs of constructing low-volume forest roads in coastal British Columbia. The fact that rubber-tired units are more mobile than conventional pneumatic tank drills has changed many aspects of constructing coastal logging roads. Total ownership and operating costs for the rock drills studied varied from $127 to $182 per hour (in Canadian dollars). Average productivity varied from 97 to 128 m drilled per shift, and cost per meter drilled ranged from $9.15 to $14.43. Rock drill utilization levels ranged from 31 to 46 percent. The relatively low utilization levels result from lengthy nonmechanical delays associated with the overall forest road construction process; planning, work procedures, and the organization of crews and equipment can influence these figures.

The western Canadian province of British Columbia contains an extensive network of low-volume roads that have been constructed for timber extraction, and hundreds of millions of dollars are spent annually to construct new roads. Complete data are not available, but the Forest Engineering Research Institute of Canada (FERIC) estimates that in 1988 the province's forest companies, and to a lesser extent the provincial Forest Service, built approximately 2500 km of unpaved forest roads in the coastal region of British Columbia. In addition, several thousand kilometers of existing road are maintained on a regular or sporadic basis.

The most difficult conditions for forest road construction are found in the coastal region. Timber harvesting systems on the coast use off-highway logging equipment that requires forest roads to be constructed to a 165-tonne load rating. The terrain is mountainous, annual rainfall often exceeds 4500 mm, and rock excavation by drilling and blasting is continually required. As a result, average forest road construction costs range from $50 000 to $150 000 per kilometer (in Canadian dollars).

Because of escalating costs of drilling and blasting, there has been a resurgence in development of new rock drilling equipment for constructing low-volume forest roads in coastal British Columbia. Rubber-tired hydraulic rock drills were successfully introduced to the forest industry in 1984. New equipment configurations include pneumatic or hydraulic drifters mounted on tracked or rubber-tired carriers. However, little information is available to guide forest road builders in selecting the most cost-effective equipment complement for a particular set of road-building conditions. In order to assist the forest industry, FERIC initiated a series of case studies in 1988 to evaluate the performance and utilization of state-of-the-art drilling equipment in British Columbia and to provide quantitative information on related productivity and costs (*1–4*). Current road-building practices in British Columbia are reviewed and results of these case studies are described. Rock drill productivity, utilization levels, and mobility are related to the goal of achieving the best overall cost per meter drilled.

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CURRENT FOREST ROAD CONSTRUCTION PRACTICES IN COASTAL BRITISH COLUMBIA

Coastal British Columbia is dominated by glaciated valleys and steep, rugged mountains mantled with thin soils (<1 m deep) over hard and massive bedrock. On Vancouver Island, where the rock-drill studies took place (Figure 1), bedrock formations consist mainly of thick volcanic flows (usually basaltic), and intrusive igneous rocks that are typically granodiorites, with lesser amounts of sedimentary formations such as limestone. The adjacent mainland coast is dominated by massive intrusive igneous rocks, which are principally granodiorites.

Drilling and blasting is an integral part of coastal forest road construction, so a typical road construction team usually consists of a primary subgrade machine (usually a hydraulic excavator), a rock drill, and sometimes a crawler tractor. For many years, the excavator has been the primary subgrade machine used in coastal British Columbia. When used efficiently, the excavator produces high-quality subgrade and substantially reduces, or eliminates, the need for expensive ballasting (road surfacing) that may be required to meet load-carrying specifications. It performs several functions in the construction process, which can be described in three distinct phases. In the first phase, the excavator "pioneers" ahead on the right-of-way, establishing the road centerline, moving the felled and bucked timber to the side for later retrieval, and removing tree stumps. During the second phase, the excavator strips the overburden from the underlying mineral soil and deposits it well away from the road to ensure that the organic overburden is completely separated from the mineral soil. In the final phase, the machine excavates and shapes the road prism to the required specifications, creates a ditch, and installs drainage structures.

The crawler tractor has taken on a secondary role and is often not needed to produce a finished road. It can move

FIGURE 1 FERIC's rock drill study sites.

excess material from the cut to fill areas and grade the road surface, but often an excavator and rock drill can produce a finished road at a lower cost per kilometer without the crawler tractor.

When the excavator encounters an impassable section of rock in the road right-of-way, the rock drill moves to the site and drills enough rock to allow the excavator to resume work. In situations where the excavator bypasses rock outcrops and continues with the initial phase of subgrade construction, the rock drill works concurrently to widen the subgrade and drill rock for ditch excavation.

Blasting methods typically involve some form of controlled blasting in which individual boreholes or rows of holes are initiated in a sequence that controls rock movement and achieves a finer fragmentation. The purpose of controlled blasting is to minimize hazardous flyrock and reduce the waste of suitable construction material. The most widely accepted detonation system uses nonelectric (NONEL) blasting caps and detonating relays in conjunction with cast primers and detonating cord. An ammonium nitrate and fuel oil (ANFO) blasting agent is the most common explosive used because its cost is approximately 25 percent of the cost of packaged dynamites. The wet conditions on the West Coast often require the use of water-resistant ANFO products, borehole dewatering techniques, and borehole liners. ANFO prills can be poured into downholes or loaded into horizontal (lifter) holes with a pneumatic blasthole charger.

Road construction costs for most coastal forest companies decreased significantly between the late 1970s and the mid-1980s. This cost reduction was influenced by several factors, mainly:

- Increased use of ANFO rather than expensive packaged dynamite products;
- Improved overburden stripping techniques and greater use of local materials; and
- Reduced overhead costs necessitated by restraint measures during an economic recession in 1981–83.

CURRENT ROCK DRILLING EQUIPMENT

The pneumatic tank drill has long been the standard rock drill used in the forest industry, but now hydraulic tank drills, hydraulic crawler drills, and hydraulic rock drills mounted on rubber-tired carriers are gaining acceptance. The pneumatic tank drill has evolved through several models. More than 200 units are in use today, mainly in the Pacific Northwest. The most recent version is the Finning M32FA, which uses a Gardner-Denver PR66 valveless pneumatic drifter, a 380-L/sec (800-ft^3/min) compressor, and a tracked carrier built with military-type components.

Ten to 15 years ago, hydraulic tank drills were used (to a limited extent) for forest road construction, but they did not gain widespread acceptance. However, a manufacturer in British Columbia recently developed a new version that uses Tamrock hydraulic drilling components mounted on a hydrostatically driven tracked carrier. Four of these units are in use, all in British Columbia.

Hydraulic crawler drills are widely used in the construction and mining industries but have limited application in the forest industry because the carriers are not designed to negotiate the rugged subgrade conditions typical of logging roads. Some contractors prefer them because the capital cost is lower than the purpose-built rock drills. However, the crawler units may require modifications to meet local operational and safety standards.

Between 1969 and 1983, Atlas Copco Canada Inc. manufactured 36 pneumatic rock drills mounted on rubber-tired carriers. Some are still being used for building forest roads in coastal British Columbia and for secondary drilling in open pit mines in eastern Canada.

The rubber-tired hydraulic rock drill was developed with input from major British Columbia forest companies and has become increasingly popular in the last 5 years. Many major companies and some contract road construction firms have purchased these units. These machines represent state-of-the-art drilling technology. Three British Columbia manufacturers produce rubber-tired hydraulic rock drills, and 47 units are currently working in the province's forest industry. The carriers are similar to skidders used for timber harvesting in that they can easily negotiate rough subgrades and broken terrain. All manufacturers use maneuverable boom arrangements that enable the feed beam to be rotated 360 degrees in both the vertical and horizontal planes. The more maneuverable booms have increased the amount of downhole (vertical borehole) drilling in comparison to horizontal (lifter) hole drilling. This process in turn has introduced other efficiencies in blasting methods. It is generally agreed that downholes permit better control of blasts. Also, operations can use a higher percentage of ANFO because the blasting agent is easier to load into vertical boreholes.

The mobility of rubber-tired drills is considered important in forest road construction because they travel more quickly than tracked drills, thus facilitating movements between work sites. This can translate into more available drilling time. In some situations, one rubber-tired drill can do the work of two tank drills because the high travel speeds permit it to service neighboring work sites without delaying or idling other road-building equipment. The extra time and cost of moving tracked drills between work sites on lowbed truck trailers is also eliminated.

FERIC'S ROCK DRILL STUDIES

Machine and Site Descriptions

Four case studies have been completed on four state-of-the-art rock drills working in the logging operations of major forest companies on Vancouver Island (Figure 1). Most phases of road construction and logging in these operations used company-owned equipment and company-employed crews. All the operators were experienced and knowledgeable drillers and blasters.

Three hydraulic rock drills mounted on rubber-tired carriers were monitored: a Tamrock Logmatic at the Kelsey Bay Division of MacMillan Bloedel Limited (MB) (Figure 2); a Cypress Roc-Champ at MB's Eve River Division (Figure 3); and a Finning RTD528 Rock Master drill at the Englewood Division of Canadian Forest Products Limited (Figure 4). The fourth drill, a Finning M32FA pneumatic rock drill mounted on a conventional tank-type carrier, was monitored at MB's Cameron Division (Figure 5).

Study Method

The method developed by FERIC for studying the drills involved working closely with each operator for a period of 3 to 4 months. A DSR Servis Recorder mounted in the cab produced detailed charts of drilling activities and machine travel for each shift. The driller documented all nonmechanical delays and breakdowns, daily production, and an estimate of rock conditions for each shift worked. In order to collect more-detailed information about the drilling cycle and penetration rates, a detailed timing study using stopwatches was conducted on each machine for a period of 1 week.

FIGURE 2 Tamrock Logmatic at Kelsey Bay.

RESULTS AND DISCUSSION

Operating Conditions

In all case studies, the drills were used mainly for drilling grade rock (i.e., the rock within the road prism that must be excavated to produce the finished subgrade) during the course of normal subgrade road construction (Table 1). In the Kelsey Bay study, other occasional work duties included drilling quarries for road surfacing material, drilling ditch lines, and widening existing roads.

A three-person crew was employed at the Eve River study site to perform drilling and blasting activities, whereas two-person crews (driller-blaster and assistant) were used at the other study sites. The three-person crew consisted of a full-time drill operator and assistant as well as a full-time blaster. The blaster transported explosives, loaded explosives into boreholes, and fired the blasts. The goal was to increase drilling production by reducing the amount of nonmechanical delay time incurred by having the drill operator load explosives and fire blasts, as is the case with two-person crews.

The size of drill bits used varied (Table 1). In the Cameron and Eve River studies, 76-mm button bits were used exclu-

FIGURE 3 Cypress Roc-Champ at Eve River.

FIGURE 4 Finning RTD528 at Englewood.

sively, but a mix of 64- and 76-mm bits was used at the Kelsey Bay and Englewood sites.

Time Distribution

Figures 6–9 show time distributions for each drill studied. In the Kelsey Bay study, drilling accounted for 38 percent of total time, mechanical delays (repair time plus waiting time for mechanics and parts) made up 10 percent, and nonmechanical delays accounted for 52 percent of the total time studied. For the Cameron case study, 31 percent of the total time was spent drilling, 18 percent was for mechanical delays, and 51 percent was for nonmechanical delays. The breakdown for the Eve River study was 46 percent for drilling, 19 percent for mechanical delays, and 35 percent for nonmechanical delays. The experience during the Englewood study was 32 percent of total time for drilling, 10 percent for mechanical delays, and 58 percent for nonmechanical delay time. (During the latter half of 1989, when the Englewood case study was conducted, road construction conditions were good. The drill was idle for a number of shifts because no rock was available for drilling. If these atypical shifts are not included in the utilization calculations, drilling time would be approximately 40 percent, mechanical delays 13 percent, and nonmechanical delays 47 percent of the total time studied.)

The high proportion of nonmechanical delay time is characteristic of rock drill use in logging road construction. Loading boreholes and blasting was the largest single reason for drilling delay in all the studies, accounting for 26 percent of total shift hours at Kelsey Bay, 24 percent at Cameron, 10 percent at Eve River, and 22 percent at Englewood. The use of the three-person crew at Eve River is reflected in the relatively low proportion of loading and blasting delay time recorded at this site.

FIGURE 5 Finning M32FA at Cameron.

Waiting for the subgrade machine to prepare more rock for drilling was the second largest cause of nonmechanical delay time in the Kelsey Bay, Cameron, and Eve River studies. In the case of the Englewood study, the second largest cause was the machine being idle because of a lack of rock (16 percent). The Other category shown in Figures 6–9 includes delays such as machine travel between road headings (work sites), drill operators' blasting dangerous trees (e.g., snags) during the timber-felling phase of the logging operation, marking of borehole locations on the ground, and waiting for more right-of-way timber to be felled.

Utilization and availability are presented for each machine in Table 2. Rock drill utilization, which is the time spent on the drilling function, includes drifter percussion time and the time spent positioning for each borehole. Machine availability excludes waiting time for parts and mechanics, as well as repair time.

The drilling time, or production machine hours (PMH), identified on the Service Recorder charts also included minor delays to position the boom and the machine for drilling the next borehole. During the detailed-timing period, this drilling time was further subdivided into actual drifter percussion time and positioning time, which are the two main elements, and other miscellaneous activities. The results of the detailed timing period are presented in Table 3 for the four study sites. The ratios of percussion time to positioning time, when applied to the shift-level data, suggest that the drifter operated for about 24 percent of total shift hours in the Kelsey Bay study, 20 percent in the Cameron study, 34 percent in the Eve River study, and 18 percent in the Englewood study.

Machine Travel Between Road Headings

When evaluating rock drill utilization, considering the number of road headings under concurrent construction is important. In favorable situations, where distances between road headings are short, a highly mobile rock drill may be able to service two or more road headings efficiently without idling the

TABLE 1 CONDITIONS DURING STUDIES

	Study sites			
	Kelsey Bay	Cameron	Eve River	Englewood
No. of operating shifts	60	68	47	71
Total shift hours (TSH)	467.9	468.2	354.5	556.3
Bit type [a]				
64-mm button	73%	0%	0%	45%
76-mm button	27%	100%	100%	55%
Activity [a]				
Grade rock	87%	100%	100%	100%
Quarry	3%	0%	0%	0%
Road maintenance	10%	0%	0%	0%

[a] Expressed as a percentage of total metres drilled.

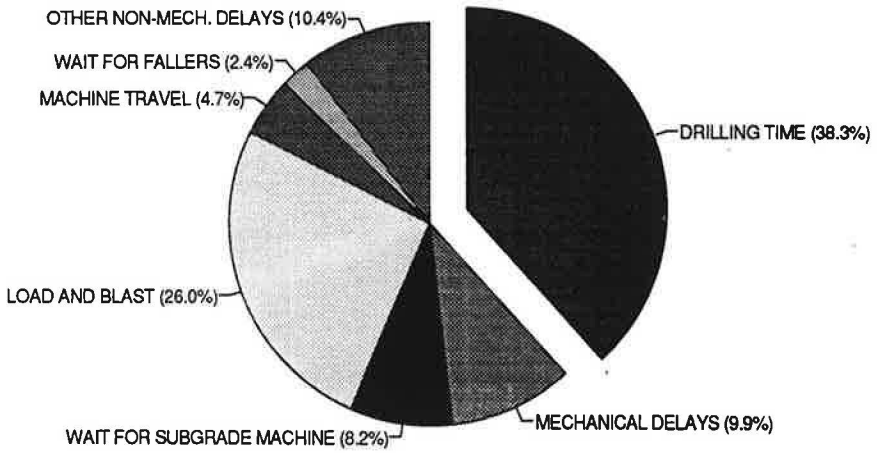

FIGURE 6 Time distribution for the Kelsey Bay study.

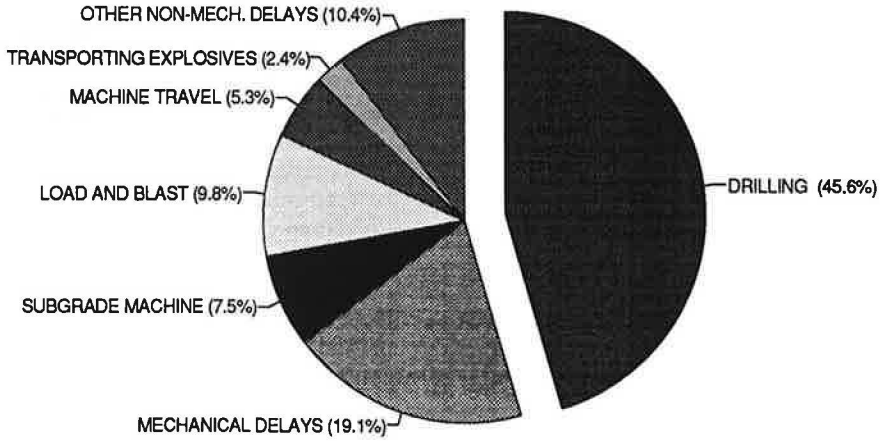

FIGURE 7 Time distribution for the Eve River study.

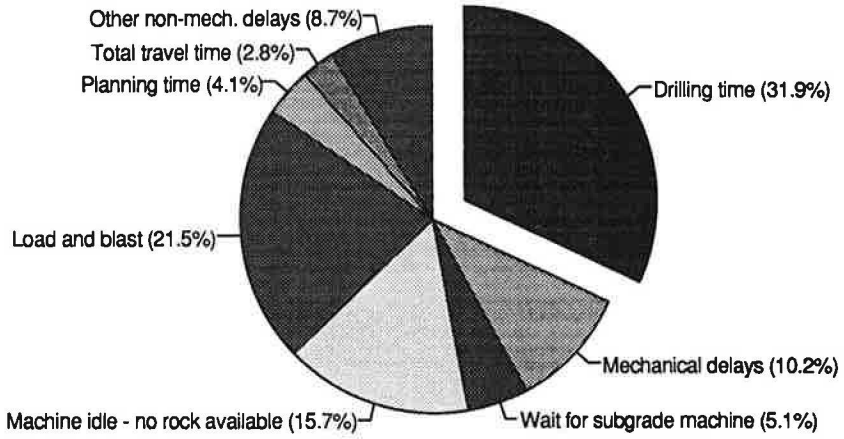

FIGURE 8 Time distribution for the Englewood study.

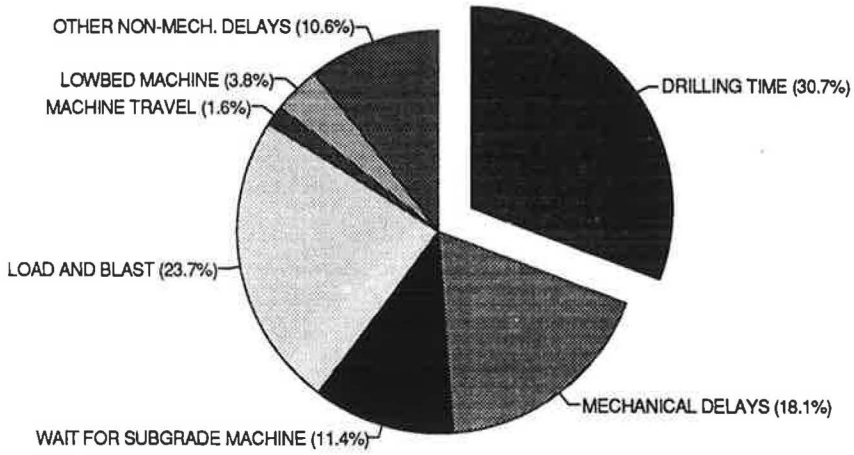

FIGURE 9 Time distribution for the Cameron study.

subgrade machines. However, the amount of time the drill spends traveling must be weighed against lost productivity (drilling time) when determining the most efficient use of equipment and labour.

Machine travel time (Figures 6–9) accounted for 5 percent of total shift hours for the Kelsey Bay, Cameron, and Eve River studies, and 3 percent of total shift hours for the Englewood study. These hours include travel time between road headings plus short moves within the work area. The Cameron results include the time that the tracked rock drill spent waiting for, and being transported on, a lowbed truck trailer. The rubber-tired units, however, traveled between headings under their own power.

Table 4 presents machine moves between road headings for each case study. The machine-move ratio (the number of moves per 100 shifts worked) indicates that machine mobility was an important element in the road-building strategies of the Kelsey Bay and Eve River operations. In both cases, the drills were utilized effectively without incurring excessive delay time for machine travel.

Productivity and Costs

For all the studies, 3-m downholes were the most popular method of drilling. The four measures of productivity presented in Table 5 are averages for the entire study period. Boreholes per shift and production per shift are conventional units used by the forest industry. Average number of meters drilled per shift ranged from 97.2 for the Cameron study to 128.0 at the Englewood location.

On a daily basis, production can fluctuate over a wide range. In the Englewood study, for example, the crew often drilled steadily for a few days before stopping the drill for a full shift, or more, to load and blast boreholes. As a result, there were 10 shifts in which more than 100 boreholes and more than 300 m were drilled.

Boreholes per PMH and production per PMH indicate the amount of drilling done when the machine was involved only in the drilling function. These figures exclude nonmechanical and mechanical delay time. Boreholes per shift and production per shift are strongly affected by machine utilization rates, whereas boreholes per PMH and production per PMH reflect factors such as the type and condition of the rock, the size of the drill bit used, the length and orientation of the boreholes, and the type and condition of the drifter itself.

Production per PMH ranges from 31.6 m per PMH at Eve River to 51.3 m per PMH at Englewood. The following factors probably contributed to this range:

- The Cypress Roc-Champ drill at Eve River encountered harder rock than the drills at the other study sites, and it drilled several long horizontal boreholes, which take more time to drill.
- The Finning Rock Master RTD528 drill at Englewod drilled short downholes exclusively.
- A larger 76-mm bit was used throughout the entire study period at Eve River, whereas a 64-mm bit was used during much of the Englewood study.

TABLE 2 ROCK DRILL UTILIZATION AND MACHINE AVAILABILITY

	Study sites			
	Kelsey Bay (%)	Cameron (%)	Eve River (%)	Englewood (%)
Rock-drill utilization	38	31	46	32
Machine availability	90	82	81	90

TABLE 3 ELEMENTS OF PRODUCTIVE MACHINE HOURS[a]

	Study sites			
	Kelsey Bay (%)	Cameron (%)	Eve River (%)	Englewood (%)
Percussion time[b]	63	66	76	58
Position for drilling	31	26	21	25
Other activities (e.g. (drill-rod changes, etc.)	6	8	3	17

[a] Productive machine hours (PMH) = Drilling time.

[b] As a percentage of productive machine hours (PMH).

TABLE 4 SUMMARY OF MACHINE MOVES BETWEEN ROAD HEADINGS

	Study sites			
	Kelsey Bay	Cameron	Eve River	Englewood
Total number of moves	16	6	12	5
Number of different road headings worked	8	3	8	4
Average distance travelled per move (kilometres)	8.8	21.5	19.6	15.6
Average time per move (hours)	1.0	2.1	1.2	1.2
Machine-move ratio $\frac{\text{(Total no. moves} \cdot 100)}{\text{Total shifts worked}}$	26.7	8.8	25.5	7.5

The pneumatic rock drill, at the Cameron study site, compared favorably to the rubber-tired hydraulic machines in terms of production per PMH and boreholes per PMH.

Hourly machine costs (Table 6) and unit drilling costs (Table 5) were calculated for all case studies using one standard method and may not represent the actual costs experienced by the users. All costs are based on figures available as of July 1990, and they include the labor rates in effect at that time. Additional information on costing is presented in the individual case study reports.

Two basic unit costs for each case-study period are presented in Table 5: Unit cost (Canadian dollars per borehole) and Unit cost (Canadian dollars per meter/drilled). Machine cost per hour was multiplied by total shift hours and then divided by the total number of boreholes or meters drilled to yield these costs. In the case of the Eve River study, the extra cost of the full-time blaster was also added to the hourly machine cost. For the Cameron study, the extra cost of transporting the tracked drill with a lowbed truck trailer was included in the unit cost calculations. The lowest costs per borehole were recorded by the Kelsey Bay and Cameron case studies. The average borehole length was greater at the Cameron study site, resulting in the lowest overall cost per meter drilled ($9.15 per meter). The highest cost per meter drilled was recorded in the Eve River study ($14.43 per meter). However, the Roc-Champ drill performed most of the rock drilling duties in an operation that used three excavators to build 26 km of road during the year in which the study was conducted. The three-person crew used at Eve River contributed to higher rock drill utilization, as shown in the time distribution results, but it also added to the drilling costs.

TABLE 5 SUMMARY OF ROCK DRILL PRODUCTIVITY AND COSTS FOR SHIFT-LEVEL STUDIES

	Study sites			
	Kelsey Bay	Cameron	Eve River	Englewood
No. of boreholes drilled	3 025	2 163	2 077	3 368
Boreholes per shift	50.4	31.8	44.2	47.4
Boreholes per PMH [a]	16.9	15.1	12.9	19.0
Unit cost (C$ per borehole)	26.43	27.95	35.47	30.07
Production (metres)	7 582	6 607	5 105	9 091
Production per shift (metres)	126.4	97.2	108.6	128.0
Production per PMH (metres)	42.3	46.0	31.6	51.3
Unit cost (C$ per metre drilled)	10.54	9.15	14.43	11.14

[a] Boreholes/PMH (productive machine hours) = Average number of boreholes drilled for every hour the machine was actually employed on the drilling function.

Other Observations

The rubber-tired hydraulic rock drills are more technologically and ergonomically advanced than the traditional pneumatic tank drill. Cleaner, quieter, dust-free cabs; air conditioning; better control systems; and improved visibility make these machines more popular with operators. The more maneuverable booms and boom heads improve the operator's ability to position the feed beam for drilling. Of the operators who have worked steadily on a rubber-tired hydraulic machine, few state a preference for going back to a pneumatic tank drill.

The importance of the operator to rock drill utilization and performance cannot be overstressed. Proper training of operators and mechanics is especially important with the more complicated rubber-tired hydraulic drills. The organization and coordination of other road crews and equipment, the number of road headings available, and the amount of rock encountered on those headings are also important to rock drill productivity and should be considered when evaluating machine performance.

The superior mechanical efficiency of hydraulic drifters results in faster penetration rates than could be achieved by the pneumatic drills that were common to the industry 15 to 20 years ago. However, the difference is not as great when compared to advanced pneumatic drifters coupled with compressors in the 380-L/sec class. Hydraulic drifters are powerful and relatively quiet, but state-of-the-art pneumatics can produce at an acceptable rate in the forest road construction application. Detailed timing results showed that rock conditions alone can have a greater effect on penetration rates than the type of drifter.

At Eve River, a three-person crew was employed in an effort to increase utilization. This study recorded the highest utilization level but not the lowest overall cost per meter drilled. The reasons for the latter include ownership and operating costs of the particular machine, difficult rock conditions, and the extra cost of employing the full-time blaster. It would appear that the anticipated benefits of a larger crew may often be less than the extra costs incurred. If extra care is taken to assign a knowledgeable and qualified assistant to a driller/blaster, then significant gains in utilization may be possible

TABLE 6 MACHINE COSTS

	Study sites			
	Kelsey Bay	Cameron	Eve River	Englewood
Machine				
Model	Tamrock Logmatic	Finning M32FA	Cypress Roc-Champ	Finning RTD528
Carrier	Rubber-tired	Tank-type	Rubber-tired	Rubber-tired
Drifter	Hydraulic	Pneumatic	Hydraulic	Hydraulic
	Tamrock HLR 438L	Gardner-Denver PR66	Atlas Copco 1238 ME	Gardner-Denver HPR1HA
Purchase price [a]				
(C$)	350 000	278 000	394 000	403 000
Hourly ownership and				
operating cost (C$)	170.87	126.52	180.61	182.05

[a] Price as of July 1990.

without resorting to a three-person crew. A well-trained assistant can reduce nonmechanical delay time by occasionally operating the drill and relieving the regular operator, or by loading explosives into previously drilled boreholes while the driller continues to operate the machine.

Thorough planning of road construction activities and coordinating them with other phases of the logging operation is essential for reducing nonmechanical delay time. Drilling operations that are forced to restrict blasting times because of the proximity of logging crews and equipment have lower productivity. It is also important to ensure that enough right-of-way timber is felled in advance of construction.

The results of these case studies suggest that the conventional pneumatic tank drill yields the lowest overall cost per meter of borehole. However, the primary objective in forest road construction is to achieve the lowest possible cost per kilometer for an entire road-building operation. This is a vital point. A high cost per meter of borehole does not necessarily produce a high cost per kilometer of finished road. However, an analysis of productivity and unit costs is needed to compare rock drills and to determine the correct rock drill complement for a particular set of operating conditions.

For a logging operation with one road-building team and requiring one rock drill, a state-of-the-art pneumatic tank drill can drill effectively and give a lower cost per meter than rubber-tired hydraulic machines. It is more difficult to estimate the long-term drilling requirements in a larger operation with multiple work sites. Long-range road-building plans must be studied to determine whether one rubber-tired unit can replace two or three tracked machines on a consistent basis. If multiple nearby road headings can be continually serviced by one rubber-tired drill, then obviously the cost per meter drilled will be lower than if two tank drills are used. A combination of one, or perhaps two, rubber-tired hydraulic drills and one or more tank drills is possibly the best drill complement in a large operation. The rubber-tired hydraulic drills could work in areas of multiple road headings containing isolated or discontinuous rock, and the pneumatic tank drills could work in areas of heavy rock requiring continuous drill-and-blast sequences. Other alternatives, such as the new hydraulic tank drills and hydraulic crawler rigs, may be cost-effective as well.

CONCLUSIONS

Rock drilling technology for forest road construction is constantly evolving and it appears that no one type of rock drill is the most cost-effective in all situations. The utilization, productivity, and cost information determined in FERIC's studies will help forest road builders choose the correct rock drilling arrangement for a particular application.

The studies indicate that the most significant gains in rock drill productivity and costs can be made by improving rock drill utilization, that is, increasing the amount of drilling time relative to idle time. When actual percussion time for drifters is in the range of 18 to 34 percent of total shift time, the effects of factors such as penetration rate and rock type are not as significant as the gains possible from small increases in utilization. In FERIC's studies, rock drill utilization ranged from 31 to 46 percent. It is not easy for forest road builders to make significant improvements in rock drill utilization because other phases of the logging operation strongly influence road-building operations. However, a goal of 50 percent for rock drill utilization would be a reasonable target for operators and supervisors to work toward.

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