Using Mobile Rock-Crushing Equipment to Rehabilitate Unpaved Forest Road Surfaces: Recent Developments in Canada

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New equipment is being developed in Canada to rehabilitate worn surfaces on unpaved low-volume forest roads. The Forest Engineering Research Institute of Canada has monitored trials of three road-rehabilitation options in recent years. The McNolty dual-rotor mobile windrow crusher, first introduced in British Columbia in 1989, has reached the operational stage in its development. It crushes oversize rock that has accumulated on roadsides and produces an ideal resurfacing aggregate. More recently, the single-rotor mobile windrow crusher (F.A.H.R. Industries, Edmunston, New Brunswick) has been adapted to rehabilitation work on forest roads in eastern Canada. Also, in British Columbia an excavator-mounted rock grinder has been tested to assess its ability to remove rock protruding from a worn road surface. With planning and preparation, these systems offer cost-effective alternatives for improving road surface conditions.

Improving techniques and reducing costs related to maintaining unpaved forest roads is a priority for the forest industry and government agencies throughout North America. Forest road surfaces deteriorate because fines are gradually lost through runoff, dustfall, grading, and snow ploughing. Poor road surfaces can increase vehicle maintenance costs and log truck cycle times. Oversize cobbles on road running surfaces, on shoulders, and in ditches lower grading productivity because more time is required to sort the material. In some situations, simply sidecasting oversize road rock is not environmentally acceptable.

The traditional alternative for rehabilitating worn road surfaces is to replace lost material with pit-run gravel, blasted rock, or crushed material. However, this often involves costly transportation and is not compatible with efforts to reduce, for environmental and aesthetic reasons, the size and frequency of borrow pits.

Converting accumulations of oversize roadside rock into usable resurfacing aggregate is a concept that has intrigued road maintenance managers and road contractors for decades. Equipment developed to address this need has met with varying degrees of success (*1*–*3*). Trials in Canada of recently developed equipment have been encouraging. The current status of three equipment alternatives is summarized and their potential for improving road surface conditions is evaluated: the McNolty dual-rotor mobile windrow rock crusher in British Columbia, the F.A.H.R. Industries single-rotor mobile windrow crusher in eastern Canada, and an excavator-mounted rock grinder in British Columbia.

McNolty Mobile Windrow Crusher

Background

A mobile windrow crusher has been under development by McNolty Contracting Limited of Fort Fraser, British Columbia, since 1989. The unit has undergone extensive tests and modifications and is now in use. The machine has worked for many forest-related companies throughout interior and coastal British Columbia.

In 1990 the Forest Engineering Research Institute of Cananda (FERIC) conducted a detailed performance evaluation of the prototype, monitoring crushing programs at five forest operations on Vancouver Island (*4*). Improvements have since been made to the machine's design and to the planning and support phases of the rehabilitation work. In 1993 FERIC observed another crushing program at the same forest operations to assess the effects of these improvements on the crusher's performance and utilization.

System Description

The McNolty mobile windrow crusher is designed to rehabilitate worn road surfaces by crushing oversize material that has accumulated along roadsides and in ditches. The oversize material is retrieved with a grader and formed into a windrow for processing by the crusher. The crusher is towed by a log skidder over the windrow and deposits the crushed material on the road surface as shown in Figure 1. To complete the process, the crushed material is spread with a grader.

The McNolty crusher unit utilizes an impact-type crushing system that acts on the material in the windrow, not on the road surface. In this operation the crusher and motor grader do not cut into the existing stabilized base course. Two horizontal shafts or rotors are mounted within the chassis of the unit perpendicular to the direction of travel. Each rotor has nine rigidly mounted rectangular hammers positioned in three equidistant rows about the shaft. Worn hammers can be replaced by removing a single locking bolt, which retains the hammer in the rotor. Material in the windrow is thrown upward by the rotors against steel bars welded in the middle of the unit and against a set of horizontal grizzly bars mounted at the rear of the machine. The grizzly bars are spaced 38 mm apart and provide final sizing of the rock as the material flows through them onto the road surface.

FIGURE 1 McNolty windrow crusher operating on Vancouver Island, British Columbia.

Evaluation

FERIC concluded in 1991 that compared with alternative methods, the mobile windrow crusher was a cost-effective solution for rehabilitating many unpaved forest road surfaces (*4*). The crushed material it produces is an ideal aggregate for resurfacing (Figure 2). Since the trials, improvements in the material recovery and windrow preparation phases, design changes to the machine itself, and an increased parts inventory have led to improvements in the productive time of the machine and increased efficiency for this road-rehabilitation system. The machine's estimated time distribution, based on

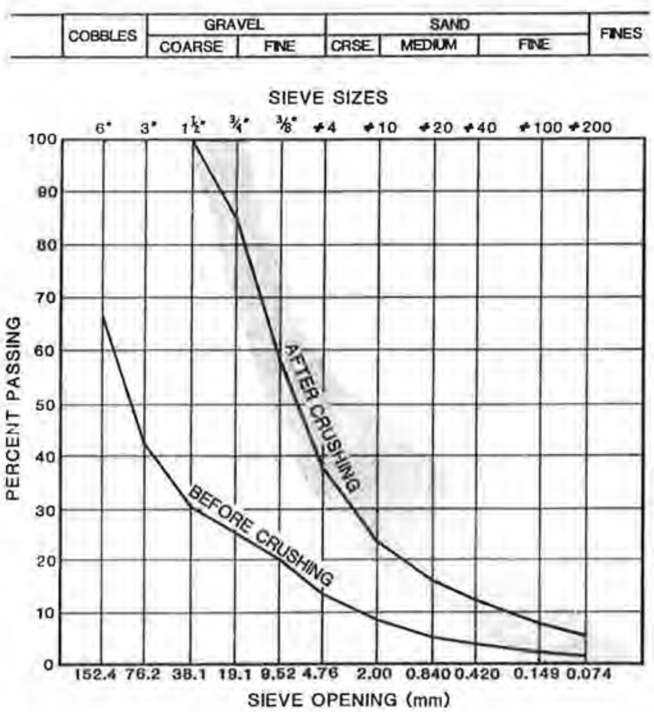

FIGURE 2 Aggregate gradation before and after processing with the McNolty windrow crusher.

follow-up observations in 1993, is approximately 45 percent for crushing time; 45 percent for welding, hammer changes, and other maintenance; and 10 percent for nonmechanical delays. This compares with 25, 30, and 45 percent for crushing, maintenance, and nonmechanical delays, respectively, for the first prototype. Primary and secondary rock crushing done in one pass with a mobile machine is a demanding task and thus a large proportion of maintenance time must be expected.

Costs for the crushing phase are approximately \$1,000 (Canadian)/km of windrow processed, and often two to four windrows are processed to complete a section of road. When work by a motor grader to prepare the windrow and spread the crushed aggregate is included, the total cost is approximately \$1,300 to \$1,400/km of windrow processed. The unit cost for the volume of windrowed rock and gravel processed by the crusher is approximately \$11.26 /m^3.

Rock conditions at the study sites were variable with some locations proving to be very challenging for the McNolty crusher. Lithological classification of windrowed rock showed that basalt, granodiorite, and quartz diorite were the predominant types processed. The maximum diameter of boulders processed varied from 25 to 45 cm, depending on the contractor's assessment of rock strength.

Weather conditions affect crushing performance. Operations are usually curtailed in heavy rain because the machine's sizing grate can become plugged if the aggregate contains a large proportion of wet fines.

Engineering personnel and grader operators for several of the operations noted that grading costs have been significantly reduced on the roads that were treated by the McNolty crusher in 1990. They have reported increased grading productivity because the crushed aggregate is reworked continuously without the retrieving of additional material beyond the road shoulders. Motor graders incur less wear because it is easier to cut into the resurfaced road, and fewer hang-ups occur on rock protrusions. The stabilized road surfaces are also less susceptible to pothole formation.

Project planning, preparation of the windrow, and spreading of the new aggregate are important phases in the resurfacing operation. Experienced personnel have identified two key factors in a successful operation. First, the grader should stockpile a large windrow of oversize rock well in advance of the crushing phase. Some sorting of the boulders that are too large to be processed can be done at this time. When the crusher is on site, successive suitably sized windrows can be quickly retrieved for processing. Second, grader operators, should be made to realize the importance of preserving the crushed aggregate. The crushed material should be spread only on the running surface and not mixed with unprocessed rock along roadsides.

Other equipment combinations can be incorporated into the system and may prove cost-effective on a site-specific basis. For example, experiments have been done with the use of excavators to retrieve oversize rock that is out of reach of a motor grader. Also, in the British Columbia interior, graders equipped with sloping attachments have been used to retrieve additional material.

In some cases not enough rock may be available to adequately resurface a road section. In coastal British Columbia, abandoned rock quarries found adjacent to many forest roads have been used as a source of additional rock. This may be feasible for short-haul distances, but a key objective of mobile windrow crushing is to eliminate the costly transportation phase associated with conventional resurfacing operations.

If the life of the crusher's hammers can be extended, the cost of replacing hammers would be reduced and crusher productivity would increase. Currently, hammers are cast form ASTM A128 grade C austenitic manganese steel. Much of the hammer wear is attributed to low-stress abrasion rather than high-stress indentation (failure from impact) (D. J. Brown, unpublished data, MacMillan Bloedel Research, MacMillan Bloedel Limited, Burnaby, British Columbia, 1992). The abrasive nature of the crushing process prevents the manganese steel from developing its characteristic work-hardened surface. The contractor has found that welding hard surfacing material onto the hammers up to four times during the life of a hammer provides satisfactory hammer life.

F.A.H.R. Mobile Windrow Crusher

Background

FERIC evaluated a single-rotor rock crusher, imported from France by F.A.H.R. Industries of Edmunston, New Brunswick, in August 1993 (5). The largest model in a line of mobile windrow crushers manufactured for agricultural use was tested on forest roads. FERIC determined that the crushing unit can be operated reliably and is cost-effective for rehabilitating forest road surfaces. In the study, the F.A.H.R. crusher was towed by a farm tractor. To improve the machine's function in the forest road application, modifications have since been made to adapt the crusher for operation with a front-end loader (Figure 3).

System Description

The rock crusher is simply designed, containing one 2.13-m-wide rotor fitted with eight hammers. The rotor

FIGURE 3 F.A.H.R. single-rotor crusher retrofitted to a front-end loader.

is driven by 10 belts connected to a driveshaft powered by the power-takeoff (PTO) of the towing tractor. The unit's frame acts as a rock guard by enclosing the crushing process. The crusher weighs 4000 kg and has an overall width of 2.5 m.

Like the McNolty crusher, the F.A.H.R. crusher processes a windrow prepared by a motor grader. The hammers, rotating in a direction opposite to the tractor's travel, propel the oversize rock upward against an overhead anvil. The spacing between the anvil and the hammers determines the maximum size of the fragments produced. The fragments are thrown to the rear of the enclosure and fall onto the road surface as they are reduced in size and able to pass between the anvil and the hammers.

Evaluation

Crushing trials using the towed unit were carried out over a 12-day period at two different sites. In both cases, oversize material was drawn from ditches and formed into windrows 50 cm high and 120 cm wide. Two windrows were required to produce a sufficient quantity of crushed aggregate for the 6-m-wide road surface.

The F.A.H.R. crusher processed an average of 300 m of windrow per hour and an average volume of 350 m^3 of crushed material per kilometer of windrow. The cost of resurfacing the road, including preparation and spreading by the motor grader, was $2,950 (Canadian)/km for two windrows.

The crusher's travel speed was little affected by the volume of material in the unprocessed windrow, but was strongly affected by the type of unprocessed material. The crusher tended to become clogged if the aggregate contained a high proportion of fines. Stones up to 40 cm in diameter were crushed without difficulty. The grain size distribution of the material produced by the crusher was influenced by the travel speed of the crusher along the windrow and the amount of wear on the hammers and the anvil. Trials performed at 500 m/hr produced fewer fines and allowed more stones to escape uncrushed. Conversely, at a travel speed of 250 m/hr the amount of fines produced exceeded preferred levels for resurfacing aggregate. As the hammers reached the end of their useful life, the crusher began to produce material containing stones 5 to 10 cm in size.

During the trials, the performance and mechanical availability of the F.A.H.R. rock crusher were encouraging. The only nonproductive periods were attributable to the towing tractor and to replacement of worn hammers. The useful life of a set of hammers was approximately 7 hr. Hammers were replaced in 45 min.

Headed by FERIC, a committee of forest industry representatives formed to examine developments in mobile rock-crushing technology. It recommended that mobile crushers should be easy to transport and compatible with equipment commonly found in forest operations. Also, efforts should be directed toward reducing maintenance time; thus, extending the life of the crusher's hammers is a priority. Hammer costs account for approximately 50 percent of the F.A.H.R. crusher's total hourly ownership and operating cost of $425/hr. Opportunities to lengthen hammer life and reduce costs are possible if hammer metallurgy is improved and abrasive fines are removed from the windrow before crushing. Modifications to the crusher were completed in the summer of 1994 in response to FERIC's recommendations.

Excavator-Mounted Rock Grinder

Background

As the surface of an unpaved road deteriorates over time, bedrock outcrops and boulders embedded in the road subgrade become exposed. Protruding rock can damage vehicle suspensions and tires, decrease road grading productivity, and increase travel time and driver discomfort. Rock protrusions are usually treated by drilling and blasting the exposed rock before resurfacing the road with crushed gravel or rock. A mobile windrow crusher, which is not designed to treat these protrusions, simply rides over them.

In 1992 Alpine Road Maintenance Ltd. of Vancouver, British Columbia, began development of a prototype rock-grinding attachment for excavators as an alternative to traditional drilling and blasting. The machine has been used to remove rock from forest road surfaces and ditch-lines and from walls and ditch-lines of railway tunnels. In 1993 FERIC monitored a 1-day trial on a forest road to obtain preliminary information about the grinder's productivity and its potential to reduce forest road maintenance costs (6).

Machine Description

The rock grinder with a quick-change coupling arrangement was mounted on a Komatsu PW210 rubber-tired excavator. Hydraulic power for the grinding attachment is supplied by the excavator's hydraulic system. The cutting head (Figure 4) is fitted with 100 replaceable teeth, similar to those used in asphalt milling planers and some motor grader cutting edges. Cylindrical tungsten-carbide inserts are seated in the shanks of the teeth. As the cutting head rotates, each tooth contacts the exposed rock at an angle of approximately 45 degrees to the road surface. The grinder is positioned by controlling the excavator's boom and stick functions.

Evaluation

Protruding rock was ground down to a level approximately 5 to 10 cm below the road surface. Eighty-six percent of the rocks required less than 2 min for processing, and 74 percent of the rocks sampled had treated surface areas of less than 1000 cm^2. Thus a large proportion of time was spent grinding relatively small boulders and cobbles. Procedures were modified in subsequent trials to reduce grinding of small obstacles. Before the grinding operation, smaller, easily removed boulders were pried out with the excavator's bucket. The grinder's time was then spent more effectively on difficult-to-remove rock.

FIGURE 4 Excavator-mounted rock grinder.

Rock-strength measurements confirmed that the test site's rock was challenging for grinding and crushing equipment. The predominant rock type processed was granodiorite. Samples tested for uniaxial compressive strength ranged from 150 to 255 MPa. Although it was not possible to quantify productivity in terms of the volume removed, the brief trial demonstrated the grinder's ability to treat this difficult rock type.

FERIC observed that the teeth at the base of the cutting head maintained greater contact with the rock and wore at a faster rate. During the trial, 12 of the cutting-head teeth were replaced at a cost of approximately $7.00 each. No teeth inserts or shanks broke during the trial. Good tooth performance can be credited to the effective design of the attachment. The teeth rotate freely within their sockets, thus distributing wear evenly over the tungsten-carbide inserts and ensuring maximum tooth life. They are quickly and easily replaced.

Since FERIC made its observations, the grinder has been used successfully to remove rock on roads where conventional drilling and blasting were not an option. Good results were achieved at one site where a natural gas pipeline was buried within the road's ditch-line. Similar restrictions would apply to roads in the vicinity of overhead electrical lines and other structures such as buildings and bridges.

For the rock grinder to be cost-effective, FERIC believes that it should be incorporated into a well-planned and controlled program of road rehabilitation and resurfacing. The grinder is a tool that can be used in conjunction with other procedures to upgrade a road before resurfacing. The excavator can perform other tasks, such as ditching, brushing, culvert replacement, shaping and crowning the road base, and removing small loose boulders. The grinding attachment can then be used on difficult-to remove boulders and high spots or grade breaks in the road caused by exposed bedrock. Also, the shape of the unit is well suited to removing high points of rock within a ditch that can divert water onto the road surface during heavy rain.

A complete package of road-upgrading work, incorporating a variety of rehabilitation tasks, is perhaps best suited to a site-specific, negotiated contract price per unit length of road. Tangible cost benefits should be expected from such work because a well-prepared base course can reduce the volume of resurfacing material required and extend the life of the new road surface.

Conclusions

Cost-effective rehabilitation of forest road surfaces requires methods that are tailored to the attributes of low-volume roads. The examples discussed here are innovations developed by Canadian contractors to address needs in their respective regions. FERIC believes that the systems described are also applicable to unpaved low-volume roads in other geographic regions.

Development of the McNolty windrow crusher has progressed to the stage at which it is being used in actual operation. The contractor has concentrated on improving the crushing system for a towed unit rather than developing a more costly and complex self-propelled machine, and FERIC believes this has been a prudent strategy. In eastern Canada, adaptation of the F.A.H.R. single-rotor windrow crusher to forest road situations also appears promising. The excavator-mounted grinder in British Columbia has also demonstrated its ability to reduce exposed road rock. It is a tool that can expand an excavator's capability for rehabilitation work and is especially useful at locations where drilling and blasting are restricted.

These equipment options should be considered as one component of a road-surface rehabilitation system that is integrated with other phases such as project planning, windrow preparation, and motor-grader finishing work. To successfully introduce these new technologies into an operation, adequate attention must be given to all phases.

REFERENCES

1. Fisher, P. H. *Mobile Hammermill for Inplace Processing of Oversize Rock.* Equipment Development and Test Report 7700-13. USDA Forest Service, Equipment Development Center, San Dimas, Calif., 1979, 10 pp.
2. Gallup, R. M. and C. S. Airall. *Treatment of Oversized Rock on Non-Surfaced Roads.* USDA Forest Service, Equipment Development Center, San Dimas, Calif., 1974, 54 pp.
3. Provencher, Y. and J. D. Chalifoux. Mobile Rock Crushers and Dust Control Agents: Two Options to Improve Road Surface Quality. *Proc., of 71st Annual Meeting, Woodlands Section, Canadian Pulp and Paper Association,* Montreal, Quebec, Canada, 1990, pp. E107–E112.
4. Bennett, D. M. *Evaluation of the McNolty Mobile Windrow Rock Crusher.* Technical Note TN-161, Forest Engineering Research Institute of Canada, Vancouver, British Columbia, 1991, 8 pp.
5. Provencher, Y. *"OBLX" Rock Crusher.* Field Note: Roads and Bridges-37. Forest Engineering Research Institute of Canada, Quebec, 1993, 2 pp.
6. Bennett, D. M. *Using a Prototype Rock Grinder to Rehabilitate Forest Road Surfaces.* Field Note: Roads and Bridges-36. Forest Engineeering Research Institute of Canada, Vancouver, British Columbia, 1993, 2 pp.