FOREST SERVICE EXPERIENCE WITH IN-PLACE REDUCTION OF OVERSIZED ROCKS IN UNSURFACED ROADS

Martin C. Everitt and Ernest L. Hoffman, U. S. Department of Agriculture, Forest Service

The Rocky Mountain Region of the USDA, Forest Service has about 11,100 km (6,900 mi.) of unsurfaced roads in a system totaling 37,400 km (23,225 mi.). Surface maintenance of unsurfaced roads in rocky soils is difficult, yet gravel surfaces or pavements often are not economically justified. A Browning RB-4 traveling hammermill crusher has been evaluated to reduce oversize rocks in place. In several trials in 1976 and 1977, the cost averaged $1,708 per km or $2,750 per mile. Different applications were tried and the most efficient determined. Results were generally satisfactory, but a sizable crew and fleet of supporting equipment are essential. This is not a routine maintenance tool, but rather a heavy maintenance tool approaching reconstruction. Some equipment modifications are suggested.

The Rocky Mountain Region of the USDA, Forest Service includes the States of Colorado, South Dakota, Nebraska, Kansas, and Wyoming east of the Continental Divide. In this area, there are 15 National Forests and 3 National Grasslands.

The Regional road system includes about 37,400 km (23,225 mi.) of roads of various standards. About 716 km (445 mi.) are paved, and these are primarily in recreation areas. The remainder includes about 4,280 km (2,660 mi.) of aggregate surfaced roads, 11,100 km (6,900 mi.) of unsurfaced roads, and about 21,300 km (13,230 mi.) of primitive roads. Unsurfaced roads may handle from as few as two or three vehicles per day to more than a hundred vehicles on peak days in some recreation areas. Most of the unsurfaced roads are old, but some are still built where the soils will support the expected traffic without undue environmental damage. Forest Service roads primarily serve timber harvest, recreation uses, and land management activities. The system does not include Federal, State, and local roads with which it is connected.

Construction specifications have changed over the years, but typically it has been required that all rocks larger than 10 cm (4 in.) in size be removed from the top 15 cm (6 in.) of the subgrade. Below that level, rocks up to 61 cm (24 in.) in diameter may be placed in embankments. However, surface degradation, frost action, abrasion, erosion, or poor quality maintenance eventually bring large rocks to the road surface. The road becomes rough, unpleasant to drive, hard on vehicles, and sometimes unsafe. Users properly criticize the owning agency.

The standard technique for handling the problem is to remove the rocks a few at a time as they are pulled out of the road in normal maintenance. In time, this removes a substantial volume of material and results in the profile grade being lowered, sometimes by more than 30 cm (1 ft.). The boulders accumulate along the roadside. In relatively flat terrain, they sometimes make an unsightly row of rocks beside the road.

Where a road is located on terrain such as a glacial moraine where a large number of boulders are present, the problem is very difficult. There are too many rocks to remove without replacing the lost volume, the cost is very high, and the resulting road is usually poor. On an old road, it is difficult to place an aggregate surface over an uneven, rocky subgrade, and even more difficult to keep the aggregate in place. The roads usually do not justify a bituminous pavement system due to low traffic volumes.

In-place treatment of such rocky surfaces was a logical idea and was not new. It was widely practiced in the past by counties, but has largely been abandoned as county systems were upgraded to pavements. The Forest Service decided to try the technique and in research reported in 1974 (1), the San Dimas Equipment Development Center examined two systems. One, a traveling jaw crusher, would have required the material to be dug up, lifted into the crusher, and spread behind the crusher. The mobile jaw crusher available at that time would handle rocks up to 30 cm (12 in.) in diameter. Moist or cohesive materials would have caused problems. According to the San Dimas research prediction, the cost was about 10 percent greater than that of the mobile hammermill system.

Machine

The traveling hammermill type machine was selected by San Dimas for further evaluation, and their 1974 report gave a favorable recommendation

Figures 1 and 2. Browning RB-4 parked without towing unit. Hammer chamber is under sloping cover on front view. Note many hand-operated adjustment cranks, turnbuckles, levers, etc., which have been eliminated in newer equipment. Rubber skirts control flying fragments.

Front view.

Rear view.

on the basis of controlled tests and computer models. Tests, however, are not the same as experience in day-to-day production work. The Rocky Mountain Region decided to buy a machine and evaluate it in routine use. A used Browning Model RB-4 "Rock Buster" was purchased from an area contractor and overhauled before being placed in service. It was somewhat smaller than the Pettibone Model P-500 used in the San Dimas test, but otherwise similar (Figures 1 and 2).

The machine obtained is quite old and does not represent current equipment technology. It was built in about 1952. It is 2.44 m (8 ft.) wide, 5.00 m (16 ft. 5 in.) long, 2.75 m (9 ft.) high, and weighs 5,443 kg (12,000 lbs.). The engine is an International Model UD-14 diesel rated at 180 hp. The engine drives the hammers through a multiple V-belt. The machine rides on two wheels which are adjustable for height, and is towed by a tractor. The only controls are the clutch and throttle, which are operated by ropes to the tractor. All other adjustments are manual. The arrangement is awkward but workable. There are some problems with parts availability resulting from the age of the machine.

Manufacturer's literature indicated that a D-4 class tractor could pull the crusher. However, both San Dimas and Regional crews found that such a small tractor was marginal in power and lacked underclearance to straddle the windrow. A D-6 class tractor with power shift transmission was preferable. Underclearance was satisfactory, and the power shift transmission provided smooth operation at very slow forward speeds. A side benefit was noted in that the larger tractor crushes some rocks under its tracks, assisting the operation.

Crushing is done by 18 free-swinging hammers which are mounted on four pivot pins arranged parallel to a central driveshaft (Figures 3, 4, and 5). The hammer speed is 1,000 rpm, and with new hammers the total assembly has a diameter of 96 cm (38 in.). The rated capacity is 115 to 153 m^3 (150 to 200 cu. yds.) per hour. The width of the impact area is 1.22 m (4 ft.), and the loose depth of the processed material behind the machine is 20 cm (8 in.). This is a maximum capacity of 0.07 m^3 (2.67 cu. ft.) per 30 cm (lineal foot) of travel, or about 0.76 m^3 (1 cu. yd.) per 3 m (10 ft.) of travel.

Objectives

In the uses described here, performed in 1976 and 1977, the following objectives were considered:

1. Find the most efficient application technique.
2. Determine the optimum crew and support equipment arrangements.
3. Determine costs of routine production operations.
4. Determine lives and costs of several different hammer alloys and compare, if possible, with rock type being processed.
5. Suggest equipment modifications if any are indicated.
6. Determine crew training needs and see if the machine can be effective with minimal training.

Trials

The first trial, while getting the crew acquainted with the equipment, was simply to eliminate loose rocks pulled out of a road by previous normal blading operations. Rocks were pulled out of the ditches, etc., and brought onto the road surface, which was not disturbed. A single pass of the machine crushed and scattered them. A layer of gravel about one pebble thick was produced over the road width, and within a week or two most of this had been whipped off by traffic (Figure 6). Rock that might otherwise have been loaded and trucked to a dump site was

Figure 3. Inside hammer chamber of Browning RB-4. In operation, hammers swing free on shafts. Note different wear patterns depending on position. These hammers have a few hours of life remaining. Replacement hammers will be placed where blank spaces occur in this set, enabling two sets of hammers to be used on one set of pins.

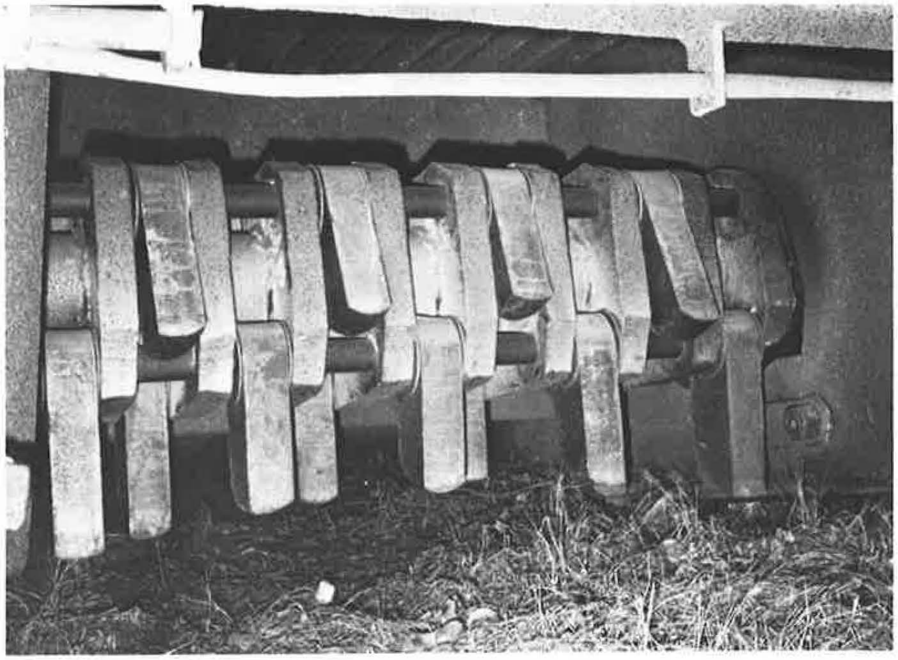
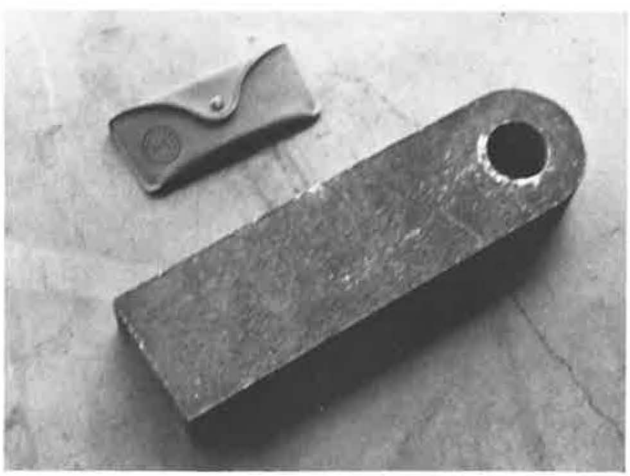


Figure 4. New hammer for the Browning RB-4. Dimensions 40 cm (16 in.) long, 11.1 cm (4-3/8 in.) wide, 6.3 cm (2-1/2 in.) thick; Weight 24.5 kg (54 lbs.).



eliminated. However, there was no lasting benefit to the road. It was a convenient way to get rid of these rocks, but was judged to be an inefficient use of the equipment.

The next experiment was to scarify the road surface to a depth of 15 cm (6 in.) to 30 cm (1 ft.), windrow and crush the material, and relay it without compaction. Equipment included a D-7 tractor with three ripper teeth, one grader, and a water truck. Total progress was about 0.8 km (1/2 mi.) per day, and the cost was about $1,875 per km

Figure 5. Worn hammers from Browning RB-4. Hammer on left is about 25 cm (10 in.) long.

($3,000 per mi.). The material was weathered granitic rock and residual soil.

The road was in very good condition when completed, but potholes began to develop within 3 months. This potholing may have been due to the nature of the soils, but other roads where compaction was used have not developed much potholing. Thorough compaction after processing was highly beneficial.

The equipment array was not efficient with respect to the crusher. The ripper, blade, and other equipment worked steadily for the full day to prepare and respread the surface, but the crusher was in operation only a little more than 2 hours. Also, it was observed that the three-tooth ripper was not as effective as a five-tooth, short-shank ripper

Figure 6. Windrow before and after processing by the RB-4 and the same spot about 3 weeks later. This windrow is smaller than the maximum which can be handled, but is otherwise typical. This section was not ripped.

a.

b.

c.

would have been, because the ripper teeth were too widely spaced.

Optimum Equipment Array

The most efficient operation and equipment array was developed by trial and error and includes:

1 Crusher with towing tractor.
1 Bulldozer, D-7 class, with multitooth, short-shank ripper.
2 Motor graders, Caterpillar No. 12 class.
1 Water truck, 19 m^3 (5,000 gal.) capacity.
1 Rock rake.
1 Dump truck.
1 Wheel type tractor-backhoe with loader and hydraulic rock splitter attachments.
1 Mechanic's truck, well equipped.
1 Welder.
1 Compactor, usually pneumatic tired.
1 Rock drill, either air- or gasoline-driven.
2 Pickups or personnel transports.
1 Brush chipper (optional).

The crew included six operators, eight laborers, one mechanic-welder, and two flagmen, if needed.

Optimum Technique

The bulldozer-ripper and one grader prepare the road by ripping the surface. Several passes with the ripper are necessary to fully loosen the surface, and a single-lane road usually must be totally closed during operations. The blade makes a few trips to work the rock to the surface and makes a windrow.

Windrow construction is an important step. The windrow must be of the proper volume for the machine. Rocks larger than 35 cm to 41 cm (14 to 16 in.) must be removed from the windrow. There must be some fine soil for efficient crushing and to confine flying rocks, but too much fine soil slows the process. The operation depends heavily on the blademan's judgment and skill.

One to three passes by the crusher are usually necessary to crush the rock in the windrow. The blade then reworks the windrow and brings out any rocks missed in the first passes. A new windrow is built and processed, and the operation is continued until the entire volume is processed. For the usual one-lane road, this requires about three full windrows. In a dry climate, almost continuous watering is required to control dust. During crushing, the bulldozer-ripper and one grader are starting the next section.

After crushing, the second grader, rock rake, compactor, and water truck work to spread, shape, and compact the surface. If this operation exposes any uncrushed rock, a final pass with the crusher may be worthwhile before final compaction.

The tractor-backhoe is an auxiliary machine used for digging out boulders which the ripper cannot handle, as well as clearing culverts and other incidental work. The hydraulic rock splitter reduces large boulders or rock outcrops. Blasting is inefficient for this kind of work. The air compressor and rock drill are required with some types of hydraulic splitters.

The dump truck, brush chipper, and other small equipment is used for incidental work.

The mechanic-welder and his equipment are indispensable with this amount of equipment operating at considerable distance from town.

The overall operation can be speeded by the use of two crushers. Windrow processing is faster, and lost time due to crusher breakdowns and hammer changes is greatly reduced.

It is obvious that this process is a heavy maintenance operation approaching reconstruction. It was originally hoped that the crusher could be used in routine surface maintenance, but such is not the case.

Materials

The Browning machine has been used in many different soil and rock types, including fresh and weathered granite, glacial moraine, volcanic extrusives of several types, limestone, quartzite, etc. It has performed about equally well with all.

Initially, an attempt was started to relate rock type to hammer life and cost. A number of samples were taken before and after one, two, and sometimes three passes of the machine. Gradation tests were run, and Los Angeles abrasion tests and some visual rock classifications by particle counts were made, but this effort was eventually dropped because of lack of time and funds to pursue it.

Some observations based on very limited data are as follows:

1. The crusher effectively reduces rocks up to about 41 cm (16 in.) in size to the 5 cm (2 in.) sieve size and smaller. Contract specifications could be based on this performance.
2. There was conflicting data on the material passing the No. 4 sieve. In some tests there was no significant change, but other tests indicated changes even in the material passing the No. 200 sieve and in the Plasticity Index. Accurate comparison sampling was almost impossible, and this may be the reason for conflicting data. The question was not pursued to a solution. No important changes in the fine soil were expected.
3. There appears to be some correlation between crusher performance, hammer wear, and the Los Angeles abrasion characteristics of the principal rock type present, but no correlation with the sulfate soundness loss. Tests included rocks having L. A. losses from 21 to 70 percent. Visual identification of the rock type and weathering condition might be as informative as the L. A. abrasion test. Rock toughness and abrasiveness are important.
4. The manufacturer states that rocks up to 61 cm (24 in.) can be crushed. Experience shows that 41 cm (16 in.) is the practical limit without risking damage to the machine. The pivot pins which carry the hammers are very difficult to remove if they are bent.

Equipment Life and Modifications

Several different alloy steels were tried for the hammers with the following life spans reported:

1. Mild steel, grade 1020, average life 19 hours. These cost about $16 each.
2. Mild steel, grade 1020, faced with welding rods, Eutectrode No. 4 and Chromecarb N600G, average life less than 24 hours in weathered granite and metamorphic rocks. The cost and life of these vary with the amount of hardfacing used.
3. Cast manganese steel, life 24 to 65 hours. This was the best, though the hammers cost $31 each in 1977. The reduction in time lost to hammer changes more than compensated for the initial cost. A full set of hammers and pins cost about $1,000 in 1978.

Several different steels for the hammer support pins were also tried. Cold rolled steel was unsatisfactory. The best to date has been grade C1144 steel, which usually lasted through two sets of hammers by staggering the hammer location (Figure 3).

A number of modifications were made in the machine. Many corrected peculiarities of the rig, and fell in the general category of strengthening or toughening it to cope with the strong vibrations and very severe operating conditions. The most important was to weld heavy reinforcement to the underside of the crushing chamber to absorb the impact of rocks thrown up by the hammer. The material used was buildup bar for crawler track shoes, which worked very well.

A second major category of modifications was related to speeding the change of hammers and pins. When the Browning machine was first received, it took in excess of 4 hours for two men to replace the hammers. With some modifications, it is possible to do it in less than 2 hours unless something is bent or broken.

Most of the mechanical problems appear to have been solved in the newer Pettibone machine.

Operating Problems

The most serious problems are not usually directly concerned with operation. They involve coordination and control of the work.

1. Traffic control. During this operation it is very hard to keep a two-lane road open to traffic, even intermittently, and on a one-lane road, total closure during the workday is highly desirable. On a system of one-lane roads, detours are often difficult to find, and work must be scheduled during minimum traffic seasons.

2. Coordination. Only one or two of the Forests in this Region have either the men or equipment to handle the full operation. It is often necessary to combine crews from two or more Forests with counties or other agencies. This is very difficult to coordinate, especially since crews and funds must be diverted from other work which may be equally important. One project in 1978 involved crews and equipment from the Forest Service, a county, and a contractor. Management has been extremely difficult, and this kind of arrangement should be avoided.

3. Crew and equipment. Since the machine is moved from one Forest to another, a new crew must be broken in every time. This always results in some lost time, inefficiency, and excessive wear on the machine until the new crew gets accustomed to it. A full-time crew chief traveling with the rig helps, but a permanent crew with its own supporting equipment would be the best arrangement. Separate funding would also help avoid many of the problems and permit more efficient scheduling.

Costs

The precise operating cost of the Browning RB-4 was difficult to isolate because a number of variables such as crew size, hammer type, soil and rock type, etc., were being tested. It was intended that the entire trial be handled as nearly as possible in a "real world" environment. Thus, all personnel were regular construction and maintenance foremen, operators, and laborers. Cost accounting was no more elaborate than in routine operations.

A total of about 59 one-lane km (36.8 one-lane mi.) of road were processed in 1976 and 1977. These included many rock conditions and soil types. Several crews were used, and the work was geographically scattered throughout the Region.

The costs ranged from a high of $2,086 per km ($3,338 per mi.) to a low of $1,580 per km ($2,462 per mi.). The overall average for all work was $1,708 per km ($2,750 per mi.). In general, the more costly projects were those where a small crew and minimum outfit of supporting equipment were used.

By comparison, the cost of 10.2 cm (4 in.) of crushed aggregate, in place, would average between $1,875 and $3,125 per km ($3,000 to $5,000 per mi.). The additional cost of preparing an old subgrade to receive the gravel would average more than $625 per km ($1,000 per mi.). There may be rare situations where gravel would compete with the Browning machine.

Other Trial Applications

One other minor test was conducted on a section of old bituminous pavement that was so badly deteriorated that it was no longer maintainable. It was decided that the road would be more economical with a gravel surface. The pavement was scarified, windrowed, and processed with the Browning machine in the manner previously described. The product was a very satisfactory gravel surface. The alternative would have been to remove the old pavement and replace it with new crushed aggregate.

In this case the old asphalt was very brittle. While some relatively fresh patches crushed satisfactorily, it is not known whether the process would work with bituminous material which is not generally brittle.

The machine might also be useful in new construction to finish the top of a rocky subgrade in lieu of removing all rock greater than that allowed by specification. This idea has not been tested.

Summary and Conclusion

The original objectives were generally fulfilled, and the findings can be summarized as follows:

1. This is a useful technique, though not inexpensive. It is not a routine maintenance tool, but rather a tool for heavy maintenance approaching complete reconstruction. It requires a considerable support force and trained manpower for efficient operation. The overall average of costs in 1976 and 1977 was $1,708 per one-lane km or $2,750 per one-lane mile. A more efficient machine might be much cheaper to operate. Crushed gravel surfacing may occasionally be competitive.

2. The most effective hammers are high alloy types which have higher first costs but last longer, reducing time lost in changes. There appears to be some correlation between soil or rock type and equipment behavior, but this work was not conclusive.

3. Improvements can be made to any available machine, generally toward strengthening it and simplifying maintenance and hammer replacement.

4. Trained crews are essential to smooth operation. It takes about 2 weeks for a crew to "shake out" and begin to work well together.

5. The major problems are with coordination between agencies, financing, etc., rather than in operation, which is fairly straightforward once crews are well trained.

6. Other practical uses for the equipment probably will appear.
7. The trial was successful. The technique will continue to be used by the Region.

In 1978, the Pettibone P-500 machine originally used in the San Dimas research was obtained and used in place of the Browning RB-4, which was sidelined due to parts shortages. Early indications suggested a major reduction in costs due to greater speed and easier hammer changes, but full information was not available at this writing.

Reference

1. R. M. Gallup and C. S. Airall. Treatment of Oversized Rock on Non-Surfaced Roads. USDA, Forest Service, San Dimas Equipment Development Center, 1974, 54 pp.