

The Use of Paper Mill Sludge To Stabilize Sand Roads

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A method of stabilizing loose-sand road surfaces with paper mill sludge in aggregate-deficient areas has been developed. Select roads in the Chequamegon National Forest have been treated with paper mill sludge from the James River Corporation (formerly American Can Company) since 1977. These roads were constructed in vast areas of glacial outwash sands that consisted mostly of one-sized particles. Aggregate is greatly needed in these large areas and must be imported at a high cost. The sludge is a waste product of a paper recycling process, is available free of charge, and is an effective stabilizing agent. The clays and wood fibers in the sludge give the sand cohesive properties and fill the voids that result from the sand's uniform gradation. The characteristics of the sand-sludge mixture, its application and incorporation, the performance of roads treated, and its use in conjunction with gravel are discussed in this paper. When the sludge is mixed with sand, it forms a stable all-weather road, reduces substantial erosion problems, and lessens the amount of sludge that needs to be landfilled.

INTRODUCTION

A method of stabilizing loose-sand road surfaces with paper mill sludge has been found to be more cost-effective than aggregate in areas of low-volume, low-standard roads. It has been demonstrated, through an extensive monitoring program, that this is an environmentally acceptable method of using waste material instead of gravel.

Select roads in the Washburn Ranger District of the Chequamegon National Forest have been treated since 1977 with sludge from a paper recycling mill in Ashland, Wisconsin. These roads were constructed in vast areas of glacial outwash sands that consisted mostly of one-sized particles; the remaining particles were fine. The aggregate that is used to stabilize surfaces is not readily available and must be imported at a high cost. The sludge is a waste product of the paper recycling process, is available free of charge, and is an effective stabilizing agent. The wood fibers and clays contained in the sludge fill the voids in the uniformly graded sand and allow the sand particles to maintain grain-to-grain contact. With a proper sand-sludge mixture, these loose-sand road surfaces could become reasonably stable running surfaces under both wet and dry conditions.

BACKGROUND

In the paper recycling process, food-grade board that is misstamped, miscut, misprinted, or is otherwise unsuitable is

hauled to the mill in large bales called broke. The broke is ground up and mixed with hot water and caustic agents to form a slurry that is passed through a series of sieves to separate the polyethylene coating and the long wood fibers that are used for pulp in the paper-making process. The sludge waste product consists of short wood fibers, mineral filler (clay), dyes, inks, and other coatings.

Before 1977, low-volume roads in glacial outwash sand areas were stabilized by pulling as much leaf litter and topsoil as possible onto the road and mixing it with the sand. The running surface eventually became a stable all-weather surface that created little dust and required less maintenance than normal on lightly travelled roads. However, problems were created by the use of this method of stabilization. Topsoil and leaf litter were frequently not within reach of road graders because of the large cut and fill slopes that existed along these roads. Stabilization was further hindered by the presence of brush and trees along the roadside. The greatest problems were the erosion that the removal of vegetation caused and the heavy logging traffic that rendered this treatment ineffective. The removal of vegetation exposed bare sand that quickly eroded and led to washouts in the road, unsightly trenches in the cut and fill slopes, sand-filled ditches, and some wide, unsightly road sections. Furthermore, it can take more than 20 years to grow vegetation in the nutrient-deficient sand.

The replacement of leaf litter and topsoil with paper mill sludge in the road stabilization technique just described has proven to be effective.

PROPERTIES OF MATERIALS

Laboratory tests of the sludge material as a road stabilizer were performed by the University of Minnesota and Lakehead Testing Laboratory of Duluth, Minnesota. The University of Minnesota commenced a study on October 25, 1976, to investigate the use of paper mill sludge as a stabilizer on many miles of low-standard, low-volume, loose-sand road surfaces (1). The purpose of the study by Lakehead Testing Laboratory was to determine the lasting effect of the sludge after a few years and compare it to its initial application (2).

One of the first tests performed by both laboratories was a mechanical sieve analysis. The gradation results showed that this outwashed sand was uniformly graded, which can be seen on the grain distribution graph shown in Figure 1. The six "raw sand" samples tested had a uniformity coefficient (C_u) of around 2.6. Soils with uniformity coefficients of less than 4 are classified as uniform, which is indicated by the steepness of the grain distribution curve (3). Uniformly graded sand has few fine particles that can fill the voids between larger particles, which results in a loose, unstable surface. The dry sand behaves like a surface made of ball bearings instead of a well-consolidated, interlocking material. The sludge was used to fill the void

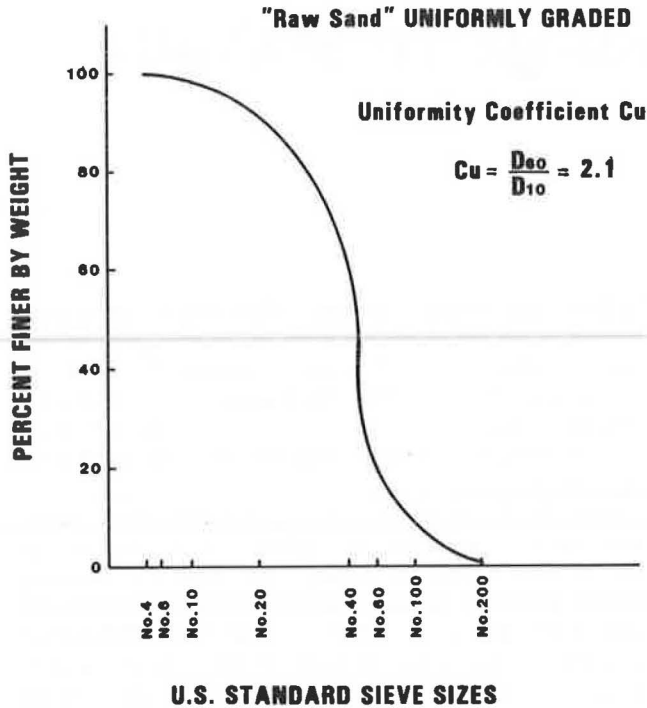


FIGURE 1 Typical grain size distribution.

between sand particles with wood fibers and clays, which allowed the sand particles to maintain grain-to-grain contact. The sludge also added cohesion to the sand and gave it some elasticity. Normally, under wet conditions, sand assumes some cohesive properties from the water's surface tension. Water and air bond the particles together and make the sand more stable.

Dry density versus moisture content relationships were plotted according to ASTM specifications D1557-78, Method B, and D1557-64T (T-180 tests) (1, 2). The optimum moisture content and density were determined from these curves. For a mixture of 5 percent dry matter by weight, which was recommended by both laboratories for the sand-sludge mixture, the density was 113.5 pcf and the optimum moisture content was 14.5 percent. The dry density of the mixture, which was at 119.0 pcf, was slightly lower than that of raw sand, and the moisture content, 14.9 percent, was slightly higher. The slightly lower density of the sand-sludge mixture has had little effect on the performance of the road.

The California Bearing Ratio (CBR) test was also conducted on the sand-sludge mixture by both laboratories (1, 2). The CBR test measures the load required for a standard-size plunger to penetrate a soil sample at a specified rate, which is expressed as a percentage of the load required to penetrate a standard material. The CBR test was done to provide the relative bearing value of base, subbase, and subgrade materials. The Wisconsin Department of Natural Resources (WDNR) also asked that CBR tests of the surface material be performed (4).

CBR tests were performed by both laboratories, without soaking the material, to approximate road conditions in summer, when roads are most unstable. Both the University of Minnesota and Lakehead Testing Laboratory found a general increase in CBR with small application rates of sludge (1, 2), which may have resulted from small increases in shear resistance or increases in the cohesion of the soil.

Lakehead Testing Laboratory performed CBR tests on four

samples at three molding densities approaching 90, 95, and 100 percent (2). Each sample had a different amount of organic matter content, ranging from 0 percent for raw sand, and 1.2 percent, 4 percent, and 17 percent for the other samples. The first three of these samples are plotted as CBR versus penetration, as shown in Figures 2, 3, and 4. Raw sand with no organic material or sludge added to it is shown in Figure 2. When sand is penetrated more than .2 in, the CBR rapidly drops off due to failure. However, when organic matter, or sludge, is added, the CBR increases at a penetration greater than .2 in, as shown in the graphs of Figures 3 and 4. This indicates that after failure the sand will break away whereas the sludge will still give support. This can be related directly to the case of a vehicle tire passing over the two materials. When the sand fails, the tire sinks and loses traction and control. When the sludge fails, it will still support the tire and allow it to pass over. The CBR

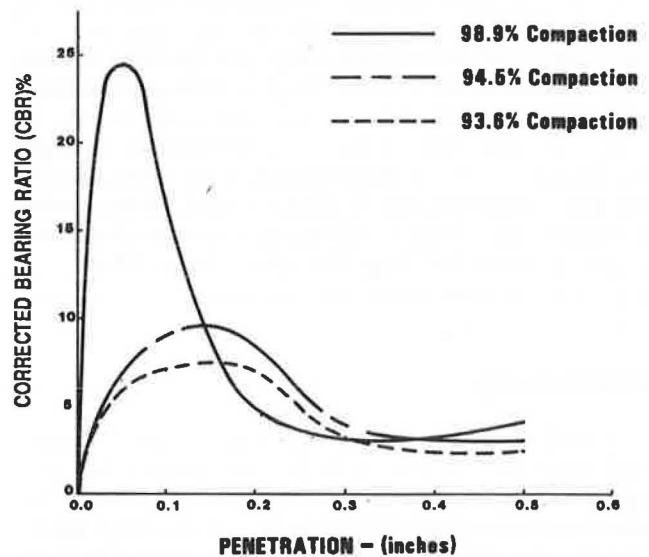


FIGURE 2 CBR penetration curve of sand with no organic matter.

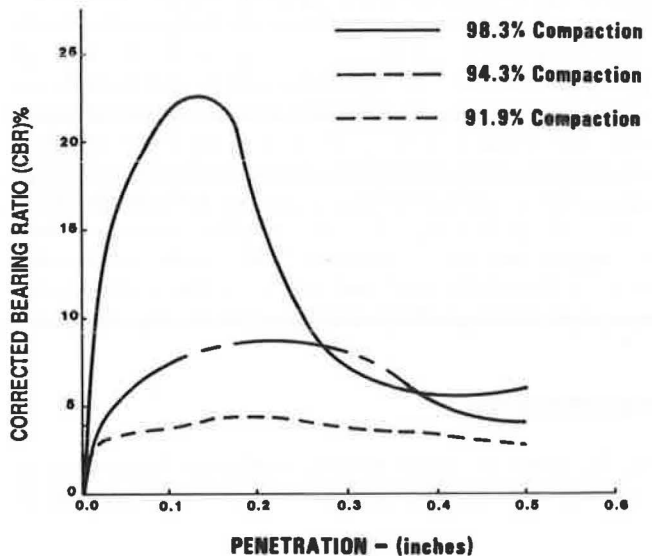


FIGURE 3 CBR penetration curve of sand with 1.2 percent organic matter.

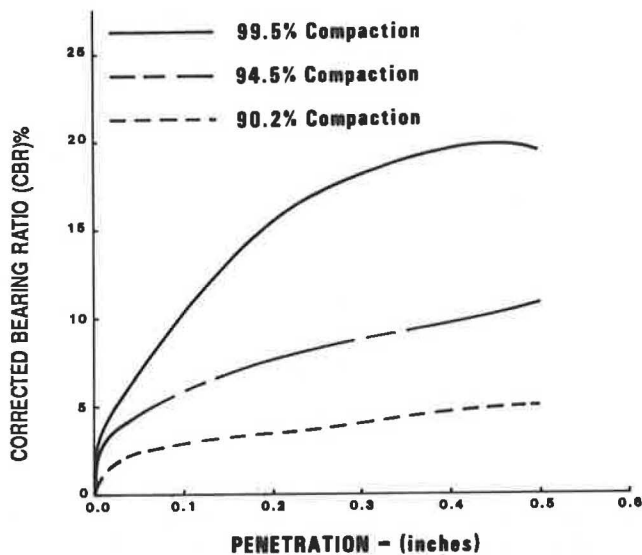


FIGURE 4 CBR penetration curve of sand with 4 percent organic matter.

increases tremendously with increased compaction, as shown in the graphs in Figures 3 and 4. The greater the compaction, the greater the surface strength of the road. The level of compaction is limited to the compaction equipment available.

APPLICATION AND INCORPORATION OF CONSTRUCTION PROCEDURES

Forest Road 241

Forest Road (FR) 241 was the first site in which the use of sludge to stabilize sand pockets was tested. Experiments were performed on different sand-sludge mixtures and two different application and incorporation procedures were tested.

The first procedure required the use of a bulldozer, grader, and rubber-tired roller. The sand and sludge were mixed as well as possible with a blade and the mixture was then windrowed along the side of the road. A portion of the windrow was spread across the roadway in a thin layer and compacted with the rubber-tired roller. This thin layer was then moved to the other side of the road and the procedure was repeated until the windrow was gone. The entire windrow was spread across the roadway, shaped, and compacted.

The second procedure required the use of a bulldozer, grader, rubber-tired roller, and rotary mixer. The sand and sludge were mixed by blading as well as possible and windrowed down the center of the road. A pass was made with the rotary mixer and the mixture was rewindrowed. This procedure was repeated three more times. The windrow was then spread across the roadway, and shaped and compacted with the rubber-tired roller.

Forest Roads 245, 434, 431, and 251

The sludge was hauled directly from the mill to the national forest road, where it was applied. The average 1-day accumulation of sludge at the plant was between 85 and 100 yd³.

The sludge was dumped in piles between predetermined points, depending on the road width and depth of mixture. A D-5 bulldozer was used to spread the piles as evenly as possible over the entire width of road. After the sludge was spread between the predetermined points, it was mixed with the sand by a 10-ft Rhino agricultural disk. The disk was pulled back and forth over the road surface about 12 times to evenly spread the sand-sludge mixture across the road. The surface was then compacted by a rubber-tired roller that was filled with 1.5 yds of sand and pulled by the bulldozer over the surface in the same pattern as the disk to compact the surface as much as possible. After the mixture dried, a grader was run over it, which lightly turned the material over, exposed it to air, and crowned the surface to ensure good drainage. All of the equipment work was accomplished with one bulldozer and one operator.

Forest Road 419

The installation of a new sludge press at the plant increased the average 1-day accumulation of sludge to between 75 and 100 yd³.

The sludge was once again dumped in piles between predetermined points to obtain the required mixture. A JD 740A skidder was used to spread the piles evenly over the entire width of road. The 10-ft Rhino agricultural disk mixed the sludge and pulled it up and down the road surface about eight times to obtain a good sand-sludge mixture. A Champion 715R grader shaped and crowned the road surface before it was compacted. Instead of pulling the rubber-tired roller to compact the road surface, the skidder and grader ran up and down the section approximately 10 times, and compacted the sludge with their tires. The road was passed over one final time with the grader just before the project was finished to ensure proper drainage. See Table 1 for information on application rates and sludge characteristics.

PERFORMANCE EVALUATION OF PROJECTS

Forest Road 241

Forest Road 241 is a collector road with a fair amount of heavy logging traffic. In 1977 it was selected to be the first road to be treated with sludge because of its numerous sand pockets and erosion problems. The road was divided into six test sites, each 1,000 ft long. The three dry matter percentages and the two incorporation procedures are as follows:

3, 5, and 7 percent dry matter—blade and roller mixed, and
3, 5, and 7 percent dry matter—rotary mixed (5).

The spread rate was figured for a 3-in depth on a wet unit weight basis. The optimum moisture content and maximum dry density were calculated for each percentage of dry matter and found to be as follows (5):

3 percent dry matter: 14.5 percent—116 pcf,
5 percent dry matter: 14.0 percent—113.5 pcf, and
7 percent dry matter: 13.5 percent—115 pcf.

After the material was mixed, it was compacted with a rubber-tired roller with high tire pressures. Compactions close

TABLE 1 SLUDGE APPLICATION CHARACTERISTICS

	Roadway	
	14 ft	20 ft
Layer depth of sludge	6 in	6 in
Dry weight per linear ft of sludge	41.1 lbs	58.2 lbs
Rate of spread	7.5 ft/yd ³	10.6 ft/yd ³
Moisture content	230%	230%
Wet unit weight of sludge	53.7 pcf	53.7 pcf
Dry unit weight of sludge	16.27 pcf	16.37 pcf
Sand-sludge mixture dry matter (weight)	5.0%	5.0%
Maximum density of mixture (T-180)	113.5 pcf	113.5 pcf
5 percent dry matter	5.675 pcf	5.675 pcf

to 100 percent (AASHTO-T180) resulted (5). Observations did not indicate a noticeable difference between the three mixtures; they all performed well.

A sample from FR 241 was tested by Lakehead Testing Laboratory and found to have a CBR at 100 percent compaction of 28 compared to 19 for the raw sand, and between 30 and 50 for crushed aggregate. The density of the sand-sludge mixture was also higher at 114.6 pcf than the sand, which was at a level of 108.0 pcf. The optimum moisture content of the mixture was 9.7 percent, compared to 11.6 for the raw sand (5). This indicated that the material had a high density and a low moisture content, and would perform better than normal surfaces in dry weather, when sand pockets would normally occur.

The sludge mixture appears to have decomposed somewhat since 1977, which has actually benefitted the road because the finer organic material that resulted during decomposition filled the sand voids and bound the sand particles much the same way as the clay and leaf litter did. The surface is still well compacted in these areas.

Maintenance operations on these sandy roads used to consist mainly of blading them two or three times a year. Since sludge was added to the roads, blading has been reduced to one or two times a year. Forest Road 241 has held up well since 1977. Sand pockets occasionally reappear, and are repaired by adding more sludge mixture.

In addition to stabilizing the road surface, the sand-sludge mixture considerably reduced erosion of the ditches and the amount of sand that collects at the bases of hills along the road.

Forest Road 419

Forest Road 419, which was treated in 1985, was the first road to use the drier sludge from the sludge press installed in 1983 by James River Corporation. The moisture content was reduced almost by half from 400 percent to approximately 230 percent. Trucks can now haul both ways over the freshly treated road and it will be open to through traffic as soon as the project is completed.

The road held up well until about 7 to 10 in of rain fell on the road in one day in September of 1986. From then through late fall, the road was saturated and rutted. This may have been a result of the way the road was compacted. A rubber-tired roller was formerly used to compact the sand-sludge mixture. The road material was so dry in 1986 that it was compacted with the grader and skidder tires instead. As a result, the crown may not

have shed the water as it had in the past and the level of compaction needed may not have been obtained.

During the spring of 1986, the road was soft until the middle of May. It appeared that further compaction by the rubber-tired roller and further decomposition of the sludge particles would improve the running surface of the road.

Forest Road 245

Forest Road 245 is a collector road with medium to heavy traffic, depending on the number of active timber sales in the area. The stretch between FR 236 and FR 431 was chosen to be treated because it had many sand pockets. Erosion was also a problem because of the road's many curves and steep slopes.

In 1983, FR 245 was treated with approximately 2,400 yds³ of sludge. The application and incorporation were done between the last 2 weeks of June and the first 2 weeks in July, unlike past applications, which were done in the late fall. This period was chosen in order to speed the set-up time during the dry months of July and August. An 8-mi stretch of FR 245 had intermittent treatments on surface distances that totalled about 2.7 mi. The road was opened to light summer traffic about 2 weeks after the treatment. The fall rains saturated the treated sections, which became extremely rutted by four-wheel-drive vehicles during hunting season. In the spring of 1984, the road was graded and opened to all traffic. The sand-sludge mixture has since become a stable running surface.

A couple of problem areas have developed since the treatment. The first problem is at the bottom of the hills, where drainage is poor. The clay in the sludge seals off the surface, which causes standing water and rutted areas. These areas now are either avoided or drainage ditches are constructed to move the standing water away from the road. The other problem occurs during the breakup period when the frost comes out of the ground. During the spring of 1986, two timber sales were hauled out the west 2 mi of FR 245. Timber continued to be hauled over the road right through spring breakup. There were many areas where ruts were 2 ft deep and the tractor trailer had to be pulled through with a skidder. These sections were bladed and set up again by the middle of June. Just like any gravel and heavy soil roads, the sand-sludge roads must be posted for light traffic only during spring breakup.

In the fall of 1984, about 2 in of crushed aggregate was applied to a number of sites on FR 245 that were treated with sludge the year before. The sites that were treated were in some of the worst sand pocket areas to give the combination of

sand-sludge and aggregate a worst-case test. Areas with steep slopes and poor drainage were also prime sites for the test. The sludge-aggregate combination was used to separate the aggregate from the sand, to add support, and to bind the aggregate onto the surface. This procedure has proved to create a stronger running surface that holds together better, and reduces washboard and rutted areas. The aggregate alone tends to be pounded into the sand. Use of the sludge-aggregate mixture reduced the costs of using aggregate alone and increased the life of the road and further reduced maintenance costs. This procedure could prove to be an effective method of stabilizing heavily travelled loose-sand roads.

The aggregate surface worked well in lower areas that had water problems.

Forest Road 434

Forest Road 434 is a collector road that experiences intermittent heavy traffic when sales are being made in the immediate area. The sludge mixture was applied to FR 434 during a rainy period in October 1982; the road surface was so saturated that traffic was detoured until the following spring. That next spring, the sludge dried out and set up with the result that FR 434, which had been impossible to drive on before the sludge was applied, became the main haul road for logging trucks in that area. This particular road had sand pockets up an 8-percent grade for about 500 ft. During heavy rains, this hill eroded considerably, which left trenches down the road and large deposits of sand at the base of the hill. Before the sludge was applied, a four-wheel-drive truck was the only vehicle that could make the grade. After the sludge set up, semi-trucks loaded with logs drove up the hill with no problems. The roads treated with sludge have taken about 6 months to a year to set up before heavy trucks and traffic could travel them easily. Traffic would have been allowed before this time, but some rutting would have occurred during wet periods.

After FR 434 was treated in the fall of 1982, a sample of it was tested by Lakehead Testing Laboratory. The CBR was quite low because of the abnormally high concentration of sludge. The sludge sample was taken from the intersection of Forest Roads 252 and 434, where two extra loads were dumped because of a miscommunication between the Forest Service and the truck driver. An attempt was made to spread it out, which resulted in abnormally high concentrations of sludge of around 17.8 percent. This problem was later resolved by staking predetermined dumping points at the treatment sites ahead of time. Recent observations have shown no difference in performance as a result of the higher concentrations of old sludge; however, during wet periods, this area is greasy.

The sludge has held up well on this road. The long grade is firm and the substantial erosion problems encountered before the treatment have been eliminated.

Forest Roads 431 and 251

A few areas in these two roads were stabilized with sludge and have since performed well. Water has been trapped in a number of low spots on FR 431 in the past; however, most of these areas have been drained by removing the berm on the shoulder of the road. A few sand pockets have reappeared, but they have been repaired by blading them every year.

ECONOMIC ANALYSIS

Seventy-six percent of the main roads in the Washburn Ranger District are unsurfaced, compared to 45 percent of the roads in the other districts. These unsurfaced roads are mainly loose-sand roads that have very unstable surfaces. The reason such a high percentage of sand-surfaced roads exists is that aggregate is seriously lacking in this glacially outwashed area. The nearest aggregate sources are between 14 and 45 miles away, which increases the cost to haul aggregate to between \$5 and \$12 per yd^3 , which does not include the crushing, loading, or application costs. In this area, crushed aggregate roads 3 inches in depth cost an average of \$13,400 per mile to surface because of the long haul distance (about 30 miles).

1985 Project

In 1985, 1.3 mi of FR 419 was stabilized with sludge for a cost of \$2,000. The cost per mile was roughly \$1,500, compared to \$4,500 for previous years and \$13,400 for crushed aggregate. The reduction in cost was due to the fact that the total haul cost was paid by the paper mill; a 50 percent reduction in the road surface's moisture content, which allowed the net truckload to increase; and new incorporation and compaction procedures and equipment.

In 1985, the sludge was available free of charge, as it was in the past. However, the mill paid for the total haul cost, which saved the Chequamegon National Forest between \$2 and \$5 per yd^3 .

The maneuverability of the equipment has improved tremendously because of the reduction in moisture content. Dump trucks could not haul over the sludge at all in the past. Now, trucks can drive over the sludge before it is incorporated into the road surface. The grader is also able to help spread and shape the sludge, whereas in the past it could not get near the site until it had a week or two to set up. The incorporation and compaction procedures and equipment have also been changed.

In previous years, a D-5 bulldozer was used to pull the disk. The bulldozer has since been replaced by a JD-704A skidder, which is easier to maneuver and much faster. In the past, the bulldozer pulled a 14-tire roller loaded with sand to compact the road surface. In 1986, the road was compacted by running the tires of the skidder and grader up and down the road. The reduction in compaction has affected the running surface, which has necessitated that it be compacted once again with the 14-tire roller. This will slightly increase the cost.

SUMMARY AND CONCLUSION

The method of stabilizing sand roads with paper mill sludge has proven to be a substantial development in the improvement of road surfaces in these aggregate-deficient areas. It uses a waste product that had been previously disposed of in a landfill as a beneficial stabilizing agent in loose-sand roads.

When the sand is stabilized with sludge, it assumes cohesive properties and performs better during summer weather conditions. In addition to stabilizing the road surface for vehicle traffic, the sludge has nearly eliminated the many erosion problems that plagued the area.

However, there are some limitations to this approach. As with other surfacing materials, certain areas should be avoided

and use should be limited to certain times. Use of sludge should be avoided in low areas with poor drainage. Road use should also be limited to light traffic only during the fall after application, during heavy rains, and during spring breakup when the frost is coming out of the ground.

Over the past 10 years, an effort has been made to improve the application and incorporation process, and also reduce costs. The costs of using the sludge have since been reduced from \$4,500 per mile to between \$1,500 and \$2,000 per mile. This is a substantial savings when compared to the cost of using crushed aggregate at \$13,400 per mile.

Aggregate will continue to be used on heavily travelled arterial and collector roads because it gives more support and has a stronger wearing surface than that of the sludge. The sludge will be used primarily on lower-volume collector and local roads with the exception of use of the sludge-aggregate combination on some higher-volume collector and arterial roads. The combination could prove to work well on heavily travelled arterial and collector roads by reducing costs through the use of less aggregate, increasing the life of the road, and reducing maintenance.

RECOMMENDATIONS

Stabilization of sand roads with paper mill sludge under the conditions just mentioned is cost-effective, but its use is not meant to replace that of aggregate totally. Aggregate is the

preferred surface material and would be used almost exclusively, with exceptions, if the aggregate was within an economic hauling distance. However, because of budget reductions, limited aggregate sources, and long haul distances, the use of the sludge mixture is a viable stabilization technique.

Sludge is used on lower-standard collector and local roads, and aggregate is used on the heavily travelled arterial and collector roads. A decision has to be made on whether to use sludge or aggregate on the collector roads, which depends on the amount of traffic and the funds available.

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