The Use of Wood Chips in Low-Volume Road Construction in the Great Lake States

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Wood chip fills are an effective means of constructing roadway embankments across swamps. The cost of materials is about the same as that of soil fills, but the fact that the fill has a much lower unit weight is a significant factor in the reduction of future maintenance costs and environmental damage caused by excessive settlements. A supply of low-value timber near the area to be crossed is necessary. In 1984, construction of a wood chip fill across a wetland on the Chequamegon National Forest in northwestern Wisconsin was started. Documentation of the construction, including its procedures, structural characteristics, maintenance observations, and economic analyses are discussed in this paper. Observations of the effects that the water flow and chip fill have on each other are also discussed. Another wood chip embankment was constructed in 1983 on the Superior National Forest in northeastern Minnesota. The report of this construction includes the preliminary engineering data, the design rationale, a description of the construction methods, and general comments on the project.

The Great Lake States of Minnesota, Michigan, and Wisconsin are located in the north central part of the United States adjacent to Lake Superior. The national forests of the Great Lake States mostly consist of land that has been logged and mined, and sometimes farmed. Most of the land, which was acquired by the Federal Government between 1928 and 1942, had little value because of past abuse and exploitation. Many thousands of acres were rehabilitated by the Civilian Conservation Corps from 1933 to 1942, when the Corps was terminated because of World War II. Despite this tremendous effort to rehabilitate national forest lands, many thousands of acres were not put back into a productive state so that combinations of wood, water, wildlife, recreation, and forage could be made available. The unrehabilitated land often contained naturally occurring pioneer stands of low-value, low-quality decadent vegetation. The high cost of removing the less productive vegetation has been a significant deterrent to conversion of these stands to much more productive material.

The energy crisis forced a closer examination of readily available, conventional energy sources such as wood chips. In 1984 a pulp mill in Park Falls, Wisconsin, installed a steam-generating plant fueled by wood chips, which produced a market for the low-quality, storm-damaged timber stands of the national forests. There are now several whole-tree chipping operations in the vicinity.

A highly efficient, well-managed logging-chipping operation is necessary to make the production of low-value wood chips possible. Most of these operations are highly mechanized when compared to other logging operations in the Great Lake States. A typical operation has two feller-bunchers and three skidders. The skidders are large, 90 to 130 hp, articulated four-wheel drive tractors with large grappels to hold log bunches while skidded to a chipper unit. The chipper has a smaller grappel on a hydraulically operated boom that feeds the logs into the machine. The chips are blown into large vans for transport to the boiler, where they are unloaded using a hydraulically operated tilt platform. A typical chipping operation will load four 80-cubic-yard vans per hour. A maximum transport distance of about 45 miles is currently needed to make the production of wood chips competitive with low-grade coal. This tends to limit the availability of low-cost wood chips to the vicinity of the boilers.

Wood chips have also been used as low-weight embankments for roads built on landslides or in areas of high failure potential in the northwestern United States. Some fairly large embankments were constructed with such compacted wood residues as sawdust, shavings, chips, and hog fuel. The compacted woody residue was covered with several feet of soil to keep air from reaching the wood in order to minimize rot.

Logging railroads used log corduroy (logs laid perpendicular) in many bog crossings between 1880 and 1940. Many of the logs that were in contact with water are still fairly sound. It is anticipated from these observations that if the chips can be kept in contact with the bog, and the contact with air can be minimized by a soil cover, the life of the wood chip fills should be at least 30 years. This may sound somewhat optimistic, but only time will tell. The old railroad fills across bogs usually disrupted the water flow, which greatly altered the ecology of the bog. The water level on one side of the fill would be high enough to usually kill the large trees many hundreds of feet from the roadway. The other side of the fill would be drier, which resulted in the growth of trees larger than would naturally occur. Usually about 5 to 10 times as much bog had higher water level than the area that was helped by a lower water level.

Most peat bog crossings on the forests have settled into the bogs, which requires costly maintenance. The crossings that were constructed from 1930 to 1978 were made by placing logs perpendicular to the center line of the road and covering them with limbs and brush, when available. The logs were then covered with 2 to 6 ft of soil and base rock. These crossings often settled several feet into the peat within a year. In some cases, they settled so much that the water level of the bog was above the road surface, which required that additional fill be hauled in to bring the road grade above the water level. The additional weight of the fill caused more settling. Small culverts 8 and 12 inches in diameter were used in early bog fills. These pipes would sink with the heavy fill, become clogged, and have to be replaced. Sometimes sections of the fill would wash out before the pipe could be replaced. Eighteen and 24-in pipes are now

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used. When these larger pipes sink, they continue to function. In areas where the fill did not sink, the logs tended to be frost-heaved out of the ground during spring thaw. The temperature often gets colder than -30°F in the Great Lake States. If the road is snow-plowed during the winter, frost will penetrate the road to at least 6 ft. When the road thaws, the ice directly under the log will thaw last because of the insulating characteristics of wood. This tends to lift the logs up through the road surface. Starting in the late 1970s, non-woven construction geotextile, or fabric mat, was used to cover the logs and brush before the fill was placed. The use of fabric mat has solved the problem of the logs frost-heaving up through the fill. It has not solved the problem of road sinkage caused by the weight of the fill.

However, because of the availability of wood chip logging operations in the area, it was decided to try the idea of using wood fills in the peat bogs of the Great Lake States.

Although there is some variability among peat bogs, most have similar characteristics. Small trees are usually on the top of the bog. They are often blown down because the support for their roots is weak, and they are eventually incorporated into the mass of roots, peat moss, and older wood in varying stages of decay. The intertwined roots tend to lie in the first top foot of the bog. The mass of rotted material is usually 6 to 15 ft deep, depending on the depth of the bog. Most bogs are between 3 and 30 ft deep. Fairly solid logs are usually found in the upper 6 ft of woody peat material of bogs. Often below this layer is a layer of very weak, poorly consolidated organic silts that extend to the bottom of the bog.

TEST SITES FOR WOOD CHIP CONSTRUCTION MATERIAL

Forest Road 648C

A bog crossing on Forest Road 648C, located 6 mi east of Park Falls, Wisconsin, was the first test site on the Chequamegon National Forest using wood chips as fill material. This project started in November of 1984 and was completed in June of 1985. The relatively shallow bog had a maximum depth of 8 ft. Trees were felled, placed at right angles to the center line, and covered with brush. Layers of non-woven geotextile and "Geogrid," a polymer reinforcement, were placed on top of the trees and brush layer (Figure 1). A layer of wood chips 4 ft deep was placed on the geogrid using a loader with an oversized bucket designed for snow removal. Each trip the loader would off track to obtain compaction. A mixture of sand and chips was used around the culverts. It was believed the additional weight of the sand would have made it easier to hold the culvert in place during construction and would add strength to the fill. Two culverts 24 inches in diameter were placed in the fill to maintain slow water flow through the peat bog.

After the chips were placed and machine-compacted five or six times by the loader, a layer of sand-gravel material 6 to 12 in deep was placed over the entire fill. The cover material was spread and compacted by a small bulldozer. It was believed this material would help distribute the wheel loads, keep oxygen away from the chips, and maintain a high moisture content. Much of the timber used had been damaged by insects and was somewhat rotted, which should not have affected the performance of the fill.

Cost Estimate

It was estimated that 600 yds^3 of chips were needed for the fill. Past experience in wood chip logging operations indicated that 10 cords of wood were needed to produce a van load of chips. A van has a capacity of 80 yds^3; therefore, 75 cords of wood were needed to produce 7.5 van loads of chips.

$$\frac{600 \text{ yds}^3 \text{ needed}}{80 \text{ yds}^3/\text{van load}} = 7.5 \text{ van loads needed, and}$$

7.5 van loads at 10 cords/van load = 75 cords of wood.

Timber density in the area of the fill was estimated at 13 cords per acre.

$$\frac{75 \text{ cords needed}}{13 \text{ cords per acre}} = \text{About 6 acres of low-volume timber.}$$

The costs were as follows:

1. *Preparation*

Hydro-AX, Model 311, feller-buncher — 13 hrs at $35/hr =	$455.00
Skidder, John Deere 440B — 9 hrs at $35/hr =	$315.00

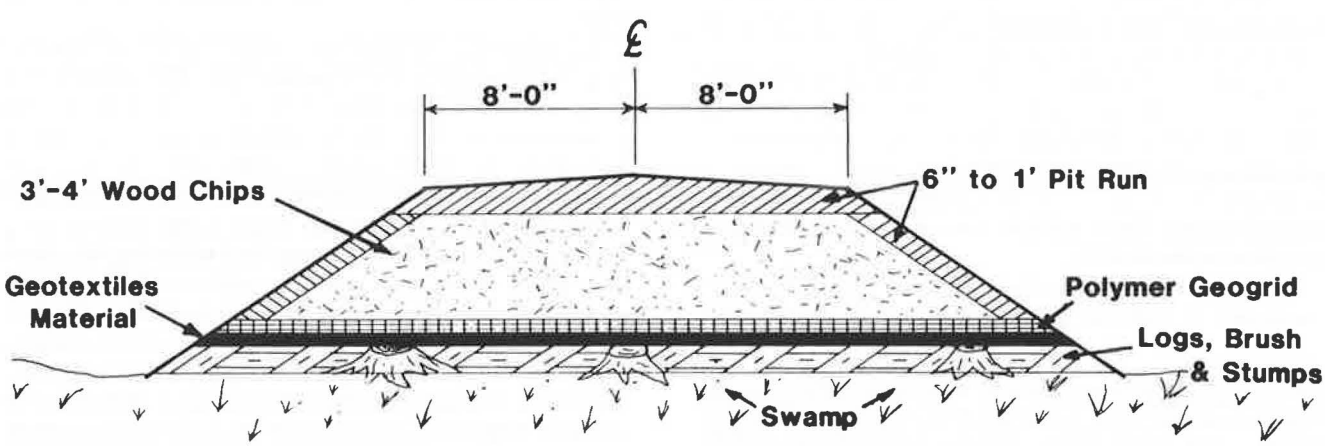

FIGURE 1 Typical section —swamp crossing.

2. *Chipping*

Mobark chipper and	
John Deere 540A Grapple skidder —	
9.5 hrs at $125/hr =	$1,187.50
Total cost =	$1,957.50

All equipment was rented with an operator. About 600 yds^3 of chips were produced.

$$\frac{\$1{,}957.50}{600\ \text{yds}^3} = \$3.26/\text{yd}^3$$

3. *Placement*

John Deere 544B loader with snow bucket —	
9.5 hrs at $40/hr =	$380.00

About 600 yds^3 of chips were placed.

$$\frac{\$380}{600\ \text{yds}^3} = \$0.63/\text{yd}^3$$

	$3.26
	$0.63
Total cost/yd^3 =	$3.89

The loose weight of wood chips is 10.4 lbs/ft^3. Using AASHTO T99 to determine the moisture-density relationship, the dry weight is 16.6 lbs/ft^3. The actual dry weight in the fill is probably less than the T99 compacted weight, but more than the loose weight. Common fill materials weigh about 110 lbs/ft^3. The moisture content is about 11 percent for a gross weight of about 122 lbs/ft^3. Assuming a moisture content of 100 percent in the wood chip fill, the in-place density is about 33 lbs/ft^3. These figures indicate that the weight of the chips in place is approximately one-fourth the weight of the soil fill.

The first 400 ft of the road was over rather weak, silty soil that developed 12 to 16 ft ruts from pickup truck use. As a further test, it was decided to surface this section of road with an 8-in layer of chips. Chips have been used as a surface to prevent dust and abrasion (*1*). Because we had quite a few extra yards of chips, this appeared to be a good use for them. The chip surface has consequently prevented the development of deep ruts, but has a high-rolling resistance because the chips do not compact well. An unexpected benefit of using wood chips for surfacing has been the elimination of vegetation growing in the roadway of low-use roads. Vegetation growing in the roadway is a significant maintenance problem in parts of the Great Lake States. After nearly 3 yrs of low use, no vegetation has grown in the roadway. The chips appear to work in the same way as mulch to keep light and heat away from the soil so that vegetation does not easily start to grow.

It will be interesting to see how long this wood chip surface lasts and what effect the rotting of the chips will have on the road. The chip surface has not needed blading to date and appears that it will not need maintenance for at least 3 more years. It is anticipated that the chip surface will last for 7 to 10 years, which is longer than the road will be needed.

The following are the results of several sieve analyses of the chips:

Sieve Size	*Percent Passing Sample 1*	*Percent Passing Sample 2*
1 in.	100.0	100.0
3/4 in.	98.0	98.8
3/8 in.	68.5	64.4
No. 4	35.5	32.7
No. 8	21.0	17.1
No. 30	11.0	6.0
No. 100	2.0	1.7

The moisture content of Sample 1, which was taken after a long dry spell, was 41 percent. Sample 2 was taken several days after a typical summer shower and had a 61.8 percent moisture content.

Forest Road 472

In June of 1985, while Forest Road 648C was being constructed, a tornado devastated 10,000 acres of the Chequamegon National Forest in Wisconsin from Park Falls to 22 mi southeast of Park Falls. Fifty million board feet of timber had been badly damaged, but about 30,000,000 board feet of the damaged timber was salvageable. Most of the roads needed to salvage the timber had good sources of pit run surfacing nearby. Forest Road 472, which is 13 mi southeast of Park Falls, had some very wet, weak soils and crossed two bogs. Because of the availability of low-quality wood, and a chipper working nearby, it was decided to use wood chips for the fill material.

A 2-ft layer of chips was placed over a geotextile in the two bog areas, which were each 400 ft long. A 1-ft layer of chips was spread over wet soils on an 800-ft section of the road. The last 800 feet of the road was very boggy; a layer of geotextile was placed on it before a 1-ft layer of chips was spread. One 50-ft-long section that had geotextile and 2 ft of chips showed repeated deep rutting. This section never completely failed, but each loading drove the geotextile and chips down into the peat (Figure 2). Water collected about 2 in deep in the 14-in-deep ruts. Smaller vehicles had difficulty negotiating this area, even when off-tracking to avoid getting stuck in the truck ruts. The smaller vehicles would leave 6- to 8-in-deep ruts in the chips. It appeared that the trucks would sink until the geotextile was under tension and spread the weight across the peat bog.

Cost Estimate

A cost estimate indicated that if a chipping operation could be rented for 9 hrs, 1,440 yds^3 of chips could be produced. The rented equipment included a chipper, a feller-buncher, and a skidder. Another feller-buncher and skidder were employed on log production. Most saw logs were saved; only tops and low-quality wood were chipped. Because the large trees were not chipped, only 630 yds^3 of chips were produced in 9 hrs.

The actual costs were as follows:

Chipping

Move in, 1 hr at $150/hr =	$ 150.00
Chipping, 9 hrs at $150/hr =	1,350.00
	$1,500.00

$$\frac{\$1{,}350}{630\ \text{yds}^3} = \$2.14/\text{yd}^3$$

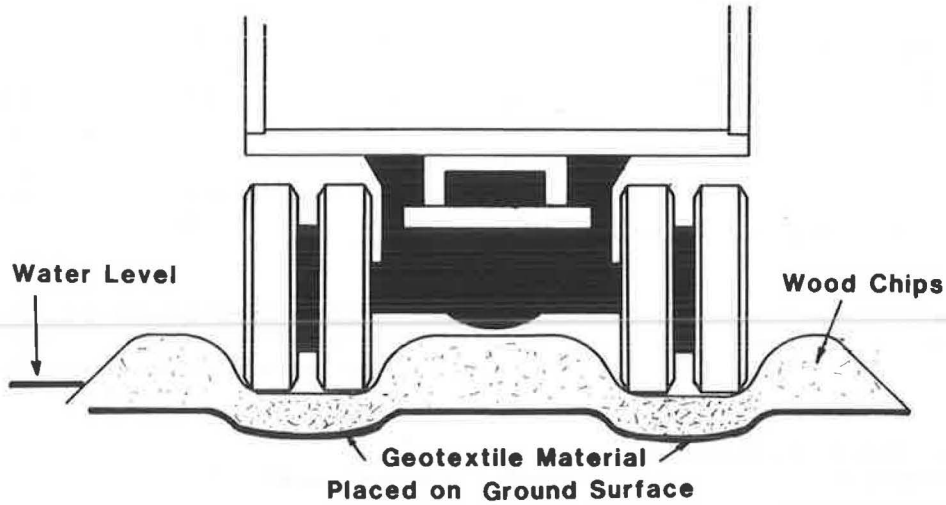

FIGURE 2 Apparent behavior of chip fill near failure.

Hauling and Placing Labor (Includes Laying Fabric)	
Supervision — 20 hrs at $16.54/hr =	$330.80
Truck driver — 20 hrs at $11.65/hr =	233.00
Truck driver — 20 hrs at $11.58/hr =	231.60
Loader operator — 20 hrs at $8.00/hr =	160.0
Hourly costs include all benefits including retirement.	$955.40
Equipment	
Dump truck — 90 mi at $0.60/hr =	$ 54.00
Dump truck — 70 mi at $0.60/hr =	$ 42.00
Loader — 17 hr at $10/hr =	$170.00
	$266.00

Almost half of the time was spent working with the wood chips. The rest of the time was spent with the sand/gravel cover material. The cost for the chips is:

$$\frac{\$955.40 \text{ labor} + \$266.00 \text{ haul and place}}{2} = \$610.70$$

$$\frac{\$610.70}{630 \text{ yds}^3} = \$0.97/\text{yd}^3$$

Cost of haul and placement/yd^3 =	$0.97
Cost of chipping/yd^3 =	2.14
Total cost/yd^3 =	$3.11

The summer of 1985 was very wet and cool. This further complicated construction, because the soils did not dry out. Although the subgrade was very wet, the chips worked well. Another significant factor that complicated construction, and tested the wood chips nearly to the limit of performance, was the fact that an energy wood chipping operation was using the road during construction. As a result of this operation, four 80-yd^3 loaded vans and associated service vehicles hauled over the road each hour.

The entire fill would deflect about 6 in under the larger trucks. The truck tires would sink into the chips about 4 to 6 in, but the chips would rebound after the load passed (Figure 2). Six in of sandy soil was placed on top of the chips as a finish surface. This layer of soil appeared to substantially increase the strength of the road. The heavy loads would depress the surface less than 2 in directly under the wheels and the road would rebound after the load moved. About 900 cords of wood were moved over this road. The road is satisfactory and shows no distress from the heavy hauling.

It was expected that the wood chips would let some water percolate through the fills. Because the fills did not compress the peat, a more natural water flow than was experienced with soil fills was maintained. The apparent reduced environmental impact of the wood chips is a factor that will be considered for future applications.

If self-dumping vans were available, the use of wood chips on low-volume roads would have been even more economical. If they were available in the Great Lake States, the cost of chips would have been as follows:

Production	
80-yd^3 van load x $2.14	= $171.20
Haul	
10-mi average	
$0.05/yd x 80 yd^3 x 10 mi	= $ 40.00
Overhead (Profit and Risk)	= $ 65.00
Total	$276.20

$$\frac{\$276.20}{80 \text{ yd}^3} = \$3.45/\text{yd}^3$$

Superior National Forest Project

In 1983, a roadway embankment was constructed in the Superior National Forest in Cook County, Minnesota, across a deep, weak peat deposit. This embankment was designed to preclude structural failure of the peat subgrade. The desired factor of safety against such failure was a minimum of two. A

safety factor of two is appropriate when one considers the inadequacy of evaluating the peat strength with a field vane and, basing the design on the equilibrium of a circular sliding mass, the possibility of poor construction inspection, the severe consequences of failure such as the possible loss of life, the permanent loss of an expensive piece of equipment, and the substitution of a relatively inexpensive method of crossing the peat deposit with a much more expensive method.

Direct sampling of the peat deposit was performed, and the data are presented on the Boring Log sheet (Figure 3).

A strength evaluation of the peat was also performed using a 4-in rectangular vane apparatus. A description of the vane and test procedures is presented in ASTM D2573. Shear strength profiles of the peat deposit are presented in the Shear Strength Profile sheets (Figures 4 to 13).

The problem of embankment stability was approached in the same way as a slope stability problem. The method of solution involved the equilibrium of a free body rotating on an assumed circular failure surface. The analysis involved finding the circular surface that produced the lowest factor of safety, an example of which is presented in the Stability Analysis sheet (Figure 14).

Evaluations of many different road cross sections were made to find those that had factors of safety of two or more. These were further evaluated for cost of construction, and the least expensive cross section was selected as the design for the embankment across this peat deposit. Station 63+30 was found to be the most critical location in the peat deposit. The design cross section is shown in Figure 15.

The 10-ft layer of weak peat (150 in/lb) at the bottom of the peat deposit at Station 63+30 would have allowed deep failure to occur. The log corduroy functioned as an extremely strong layer and forced the failure circle to occur outside of the corduroy, which consequently increased the failure circle arc and the total shearing resistance of the peat. The wood chip fill functioned as a space filler; the desired profile grade could therefore be obtained with minimum dead load. The layers of geotextile over the corduroy and wood chips acted as separators only. The earth fill functioned as an envelope over the degradable wood chips and log corduroy to keep air from reaching these materials. The earth fill berms on each side of the major roadway embankment also functioned as counter weights and lent a great deal of stability to the entire embankment. The grade was surfaced with 6 in of good quality crushed gravel.

Construction specifications for this project were detailed and required the use of method type specifications. This was necessary to ensure that construction techniques, sequences, and equipment sizes were all consistent with the design and the minimum factor of safety. Construction of embankments on peat subgrades typically produce the most severe loadings the peat will ever experience during the life of the project. The construction equipment is extremely heavy and sometimes operates only on thin lifts above the peat surface. The peat itself is at its weakest state because of its high water content and unconsolidated state. It should be noted that a good construction inspection is necessary to ensure compliance with the specifications.

The contractor proposed a method of construction that was not outlined in the construction specifications. This proposal was checked for consistency with the design, and it was determined that the minimum factor of safety could be maintained.

The contractor constructed the entire cross section, except for the surfacing, as work progressed across the swamp. A Cat 235 excavator located at the end of the fill, with an extended boom attachment, placed corduroy about 20 ft ahead of the

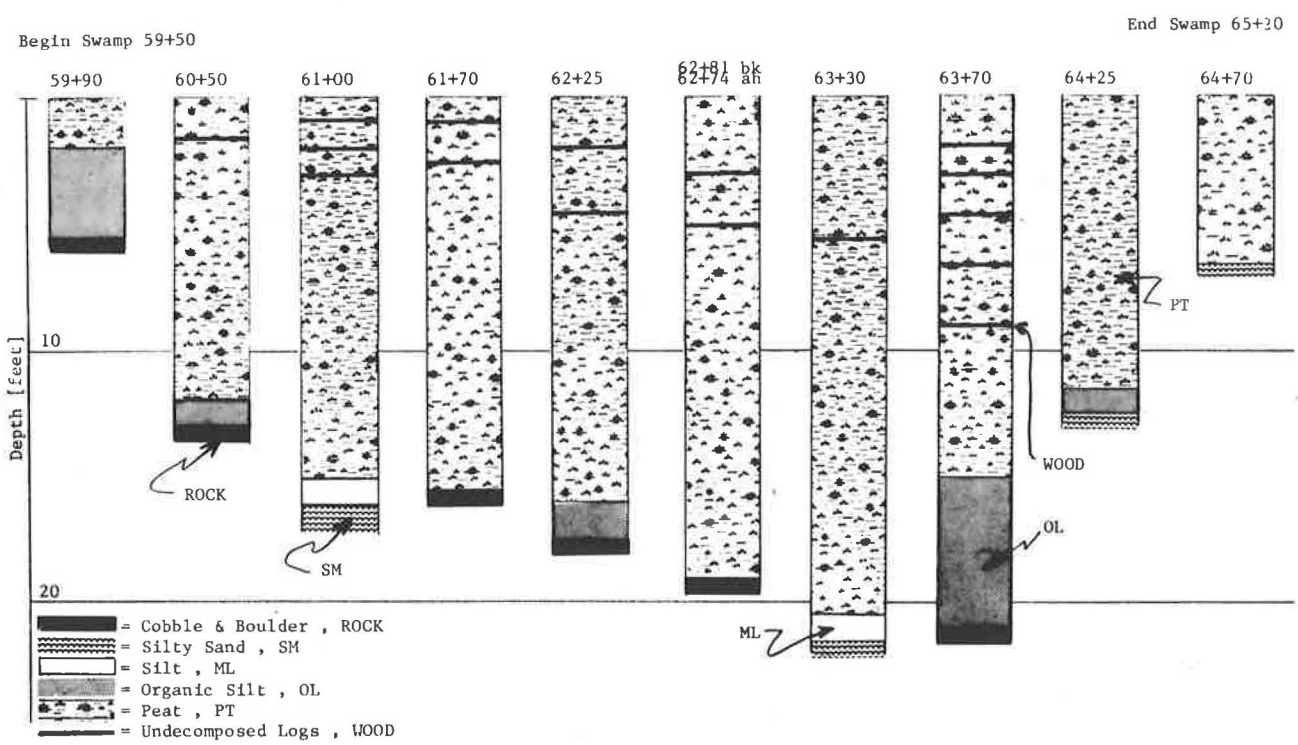

FIGURE 3 Shoe lake road FR313, Section A (boring logs).

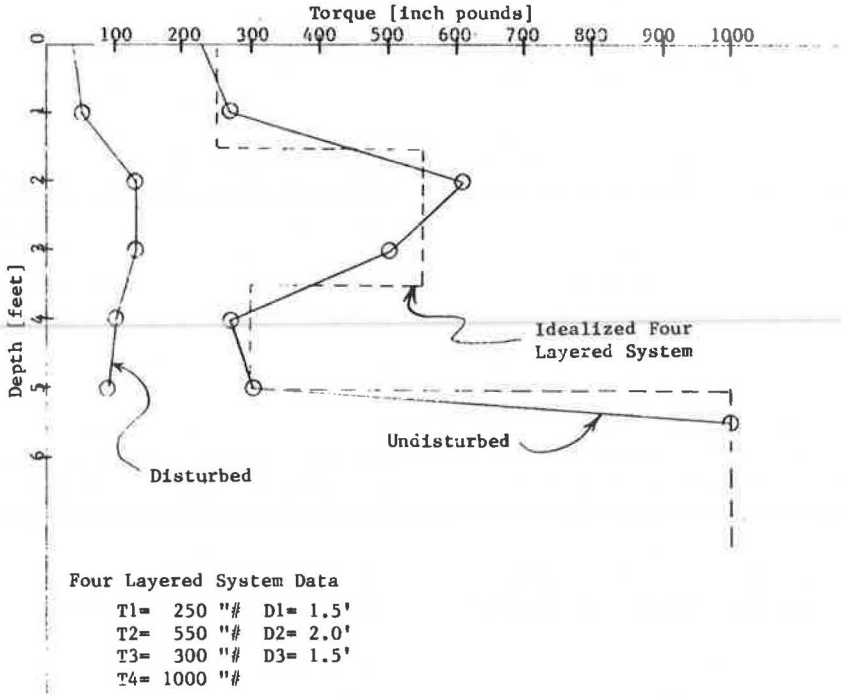

FIGURE 4 Shear strength profile, 50 + 90.

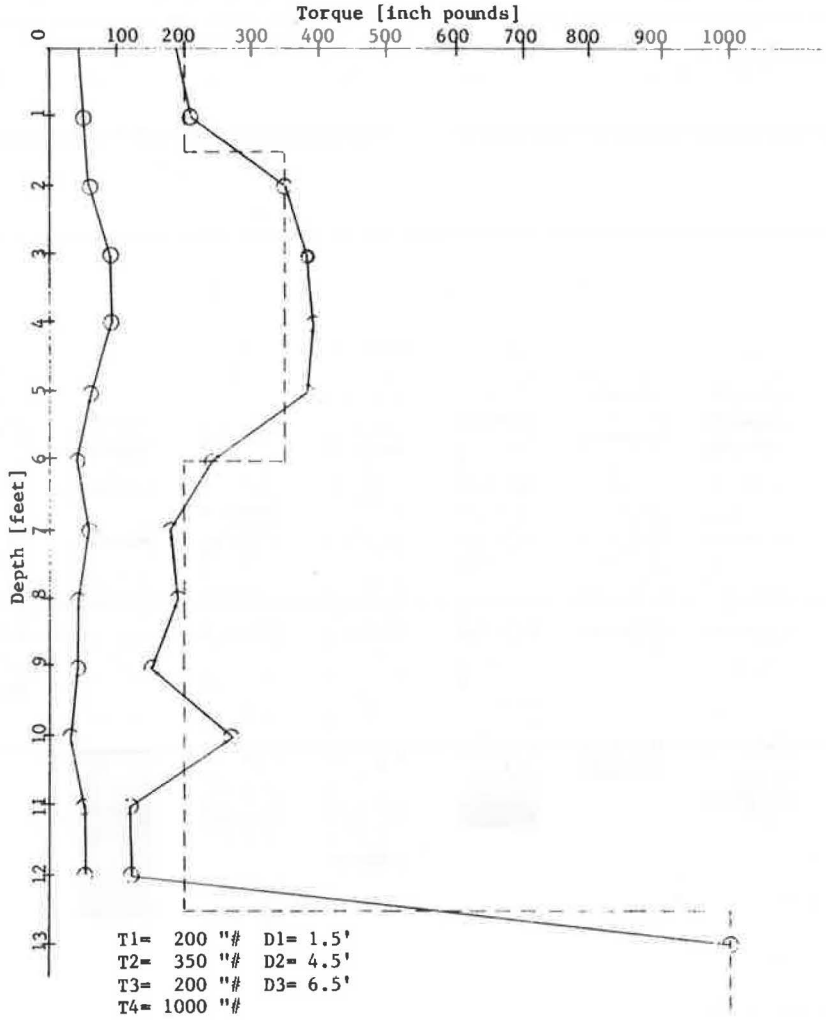

FIGURE 5 Shear strength profile, 60 + 50.

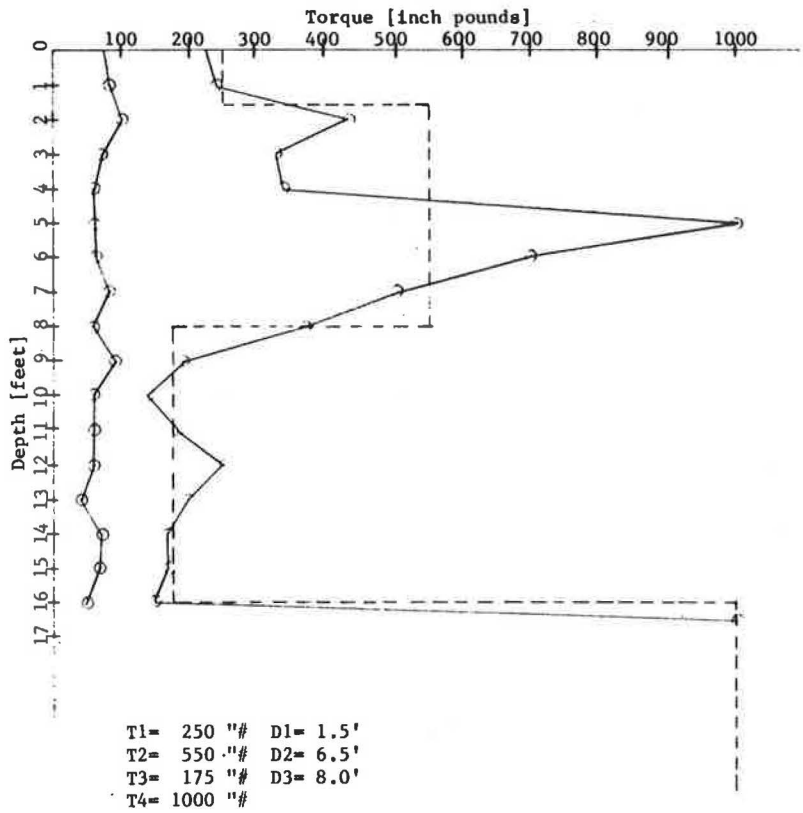

FIGURE 6 Shear strength profile, 61 + 00.

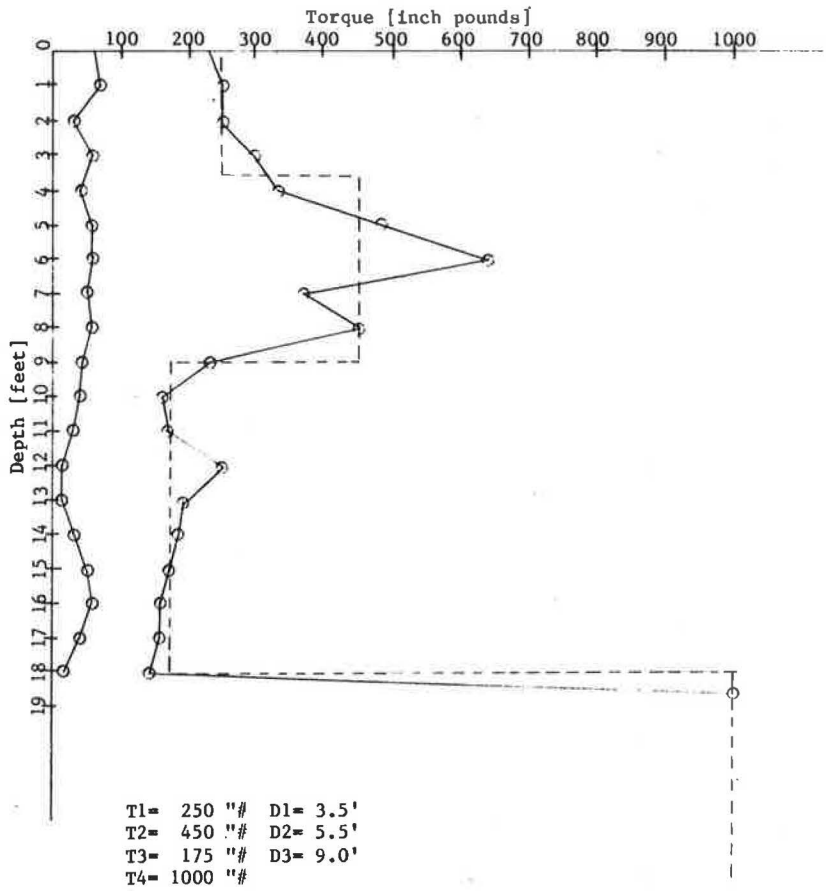

FIGURE 7 Shear strength profile, 61 + 70.

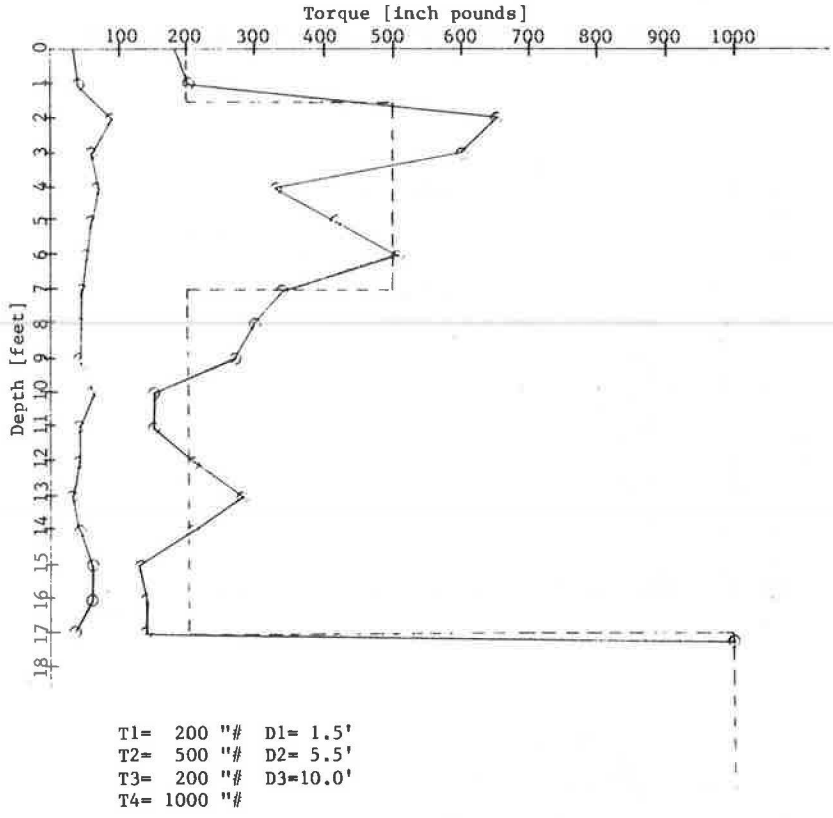

FIGURE 8 Shear strength profile, 62 + 25.

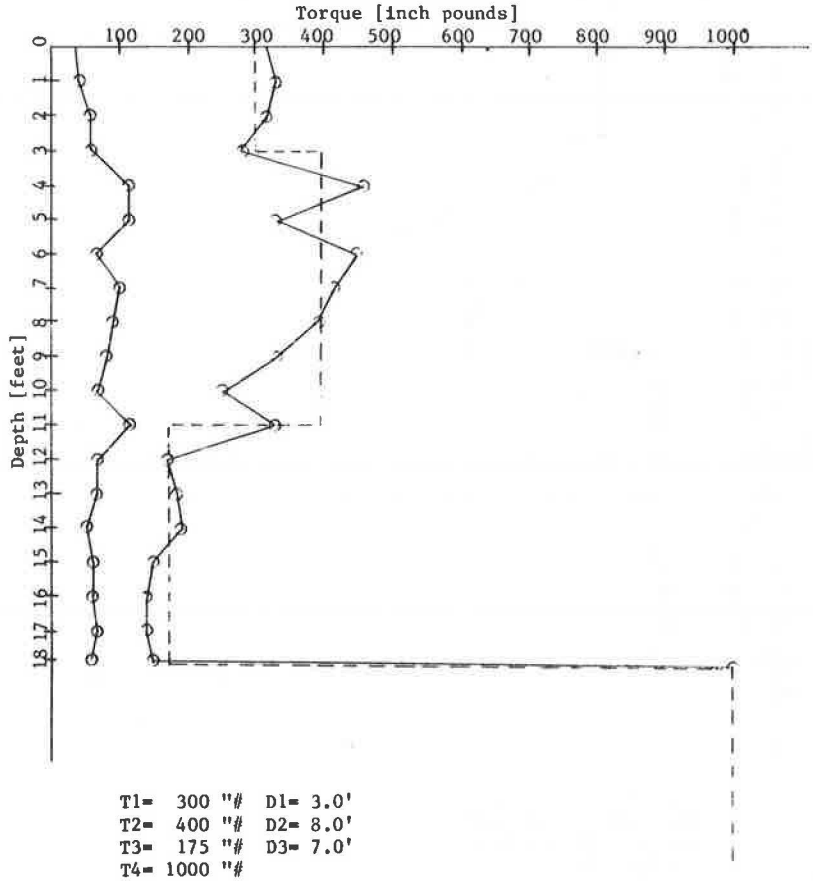

FIGURE 9 Shear strength profile, 62 + 82 bk = 62 + 74 ah.

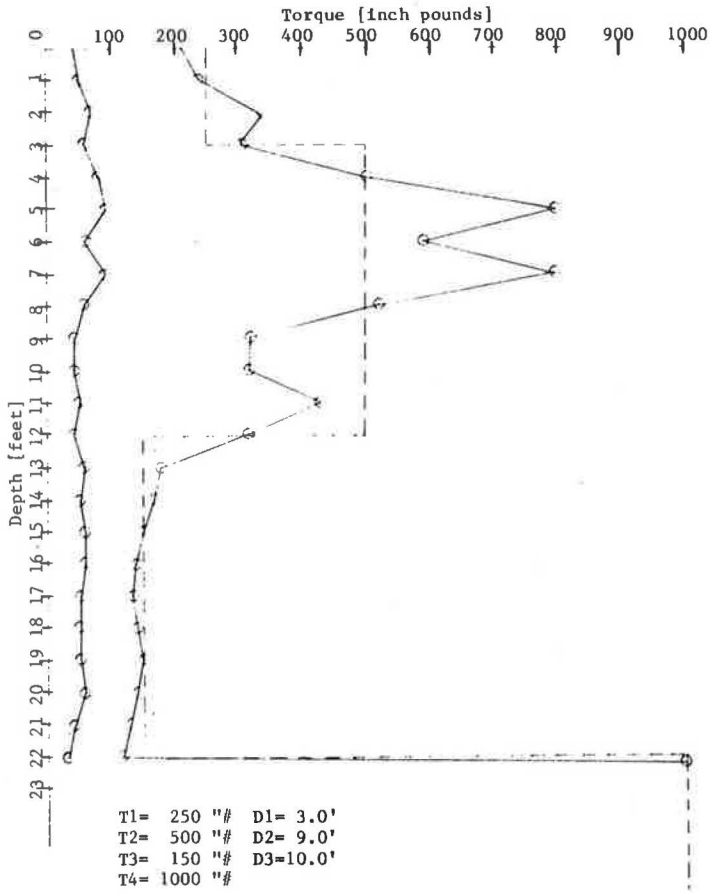

FIGURE 10 Shear strength profile, 63 + 30.

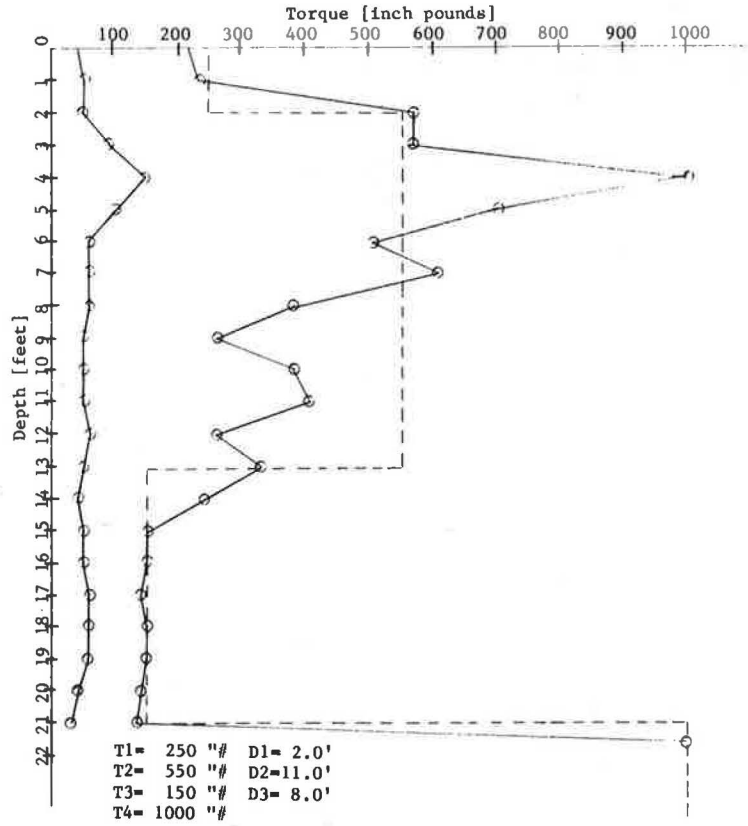

FIGURE 11 Shear strength profile, 63 + 70.

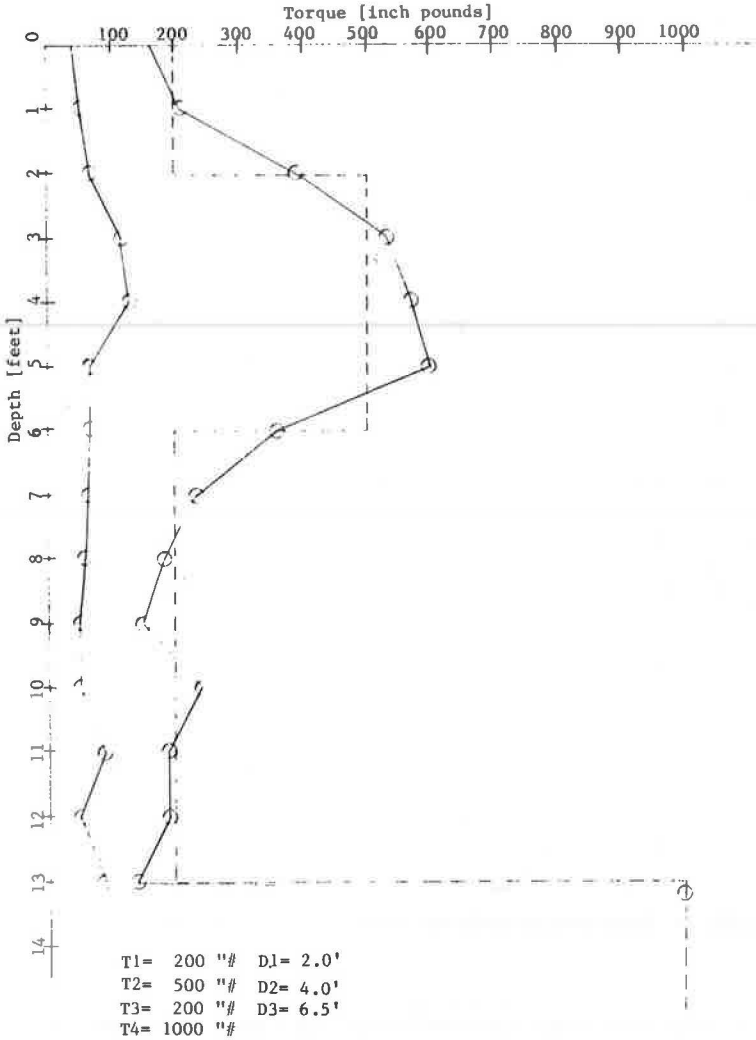

FIGURE 12 Shear strength profile, 64 + 25.

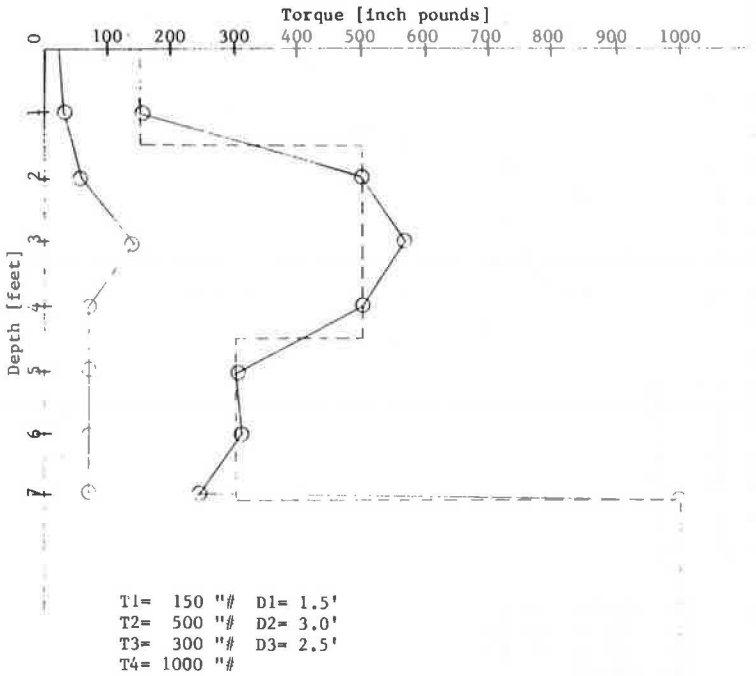

FIGURE 13 Shear strength profile, 64 + 70.

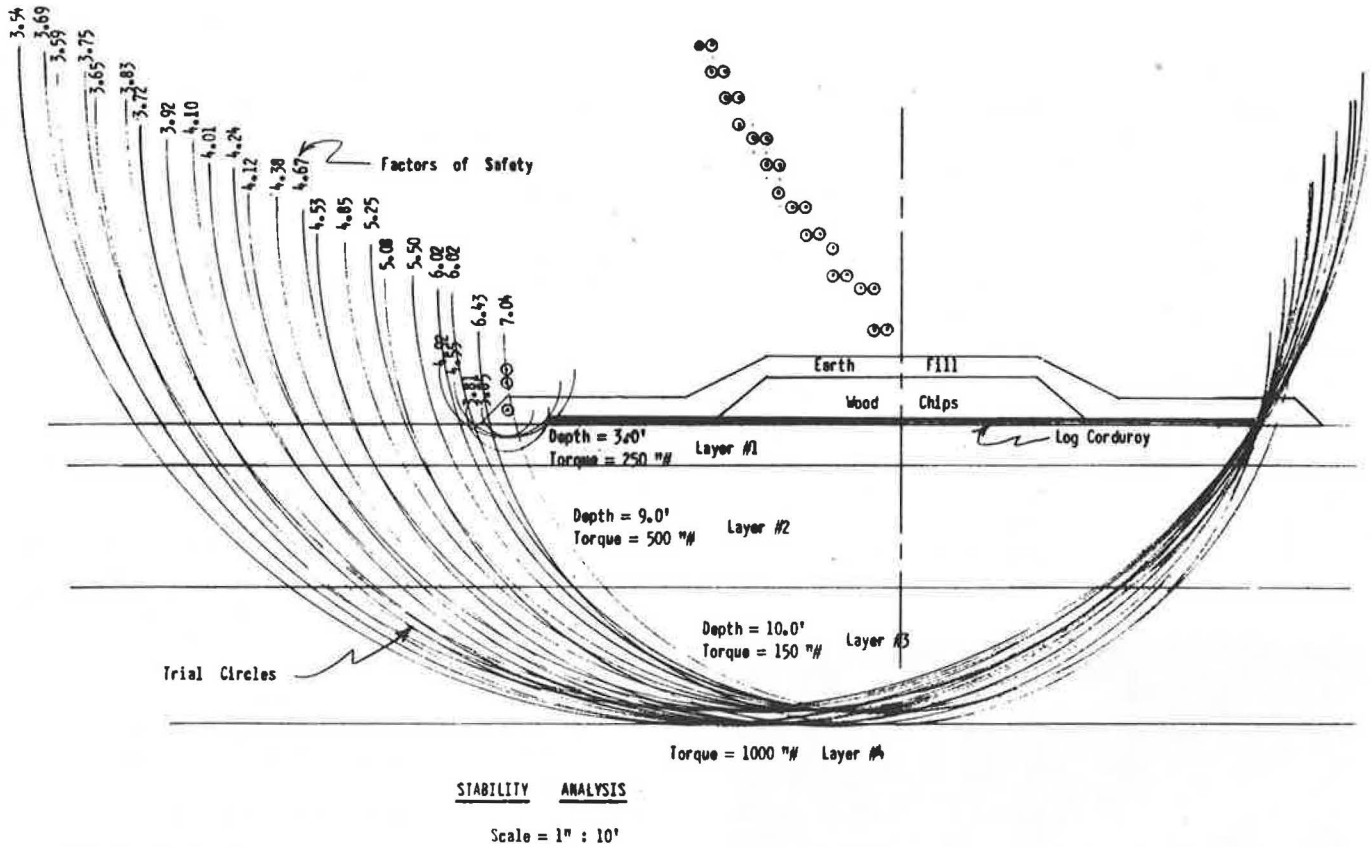

FIGURE 14 Station 63 + 30.

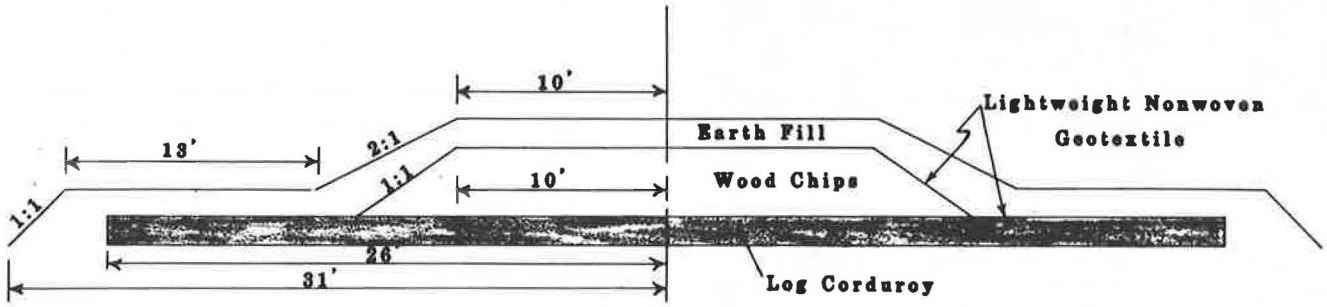

FIGURE 15 Station 63 + 30.

work. A layer of 4-oz./sq yd, non-woven geotextile was placed over the corduroy. The excavator backed off the fill so tandem axle 15 CY dump trucks could back onto the fill and dump the wood chips. The wood chips were spread and shaped with a Cat D3 bulldozer and covered with the same geotextile. The earth fill was then spread and shaped by the small bulldozer. After this 20-ft length of embankment was completed, the excavator returned to place another 20 ft of corduroy.

Settlements of this embankment were not monitored; however, points outside of the construction limits were monitored for elevation changes during and shortly after construction. Increases in elevation of these points would have been interpreted as indicating displacement of peat resulting from structural failure. Large fluctuating elevations (bouncing) of these points were noted as the excavator moved past on the newly constructed embankment. This phenomenon completely stopped in a day, and no net elevation changes were noted at these monitoring points.

The construction profile grade was determined by an estimation of embankment settlement added to the desired final profile grade. This estimate was made from observations of measured settlements of similar construction projects. In this case, the settlements were estimated to be 5 percent of the peat depth. The actual amount of settlement a year after construction was 10 percent of the peat depth.

This embankment has carried over 10,000 10-ton axle loads over the 3-yr period it has been in place, and is functioning as intended. Because the design precluded displacement of the peat, there was no uplift of the swamp surface and, consequently, no water buildup or associated environmental changes.

Further Research

Researchers at the North Central Forest Experimental Station's Forest Engineering Project in Houghton, Michigan, recently developed prototype machinery that reduces whole trees into particles substantially larger than those from whole-tree chippers. The resulting particles have been coined "chunkwood" and the machine a "whole-tree chunker." Figure 16 is a photograph of chunkwood on a pile of wood chips. Chunkwood is made in a great range of sizes; some particles are highly irregular in shape and have sharp, angular edges. The main potential market for chunkwood produced from small trees and residues is as an industrial fuel. However, there is a high degree of certainty from very limited tests that chunkwood could prove to be an acceptable, readily available material for a range of situations in low-volume road construction. Because of the range of shapes and particle sizes of chunkwood compared to chips, and because of its lower production costs, it is believed that chunkwood could be a superior road-building material.

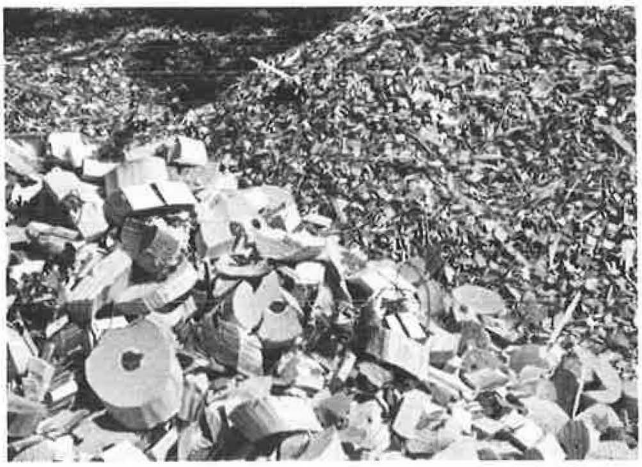

FIGURE 16 Chunkwood on woodchips.

A combined research and demonstration program is being performed using chunkwood as a road-building material to construct sections of low-volume roads in three different National Forest problem areas, including roads through sugar sands, muskegs, and low-strength wet silts. The cooperators are the Chequamegon National Forest, Park Falls, Wisconsin; the Superior National Forest, Duluth, Minnesota; Michigan Technological University, Department of Civil Engineering, Houghton, Michigan; and the North Central Forest Experimental Station, Forest Engineering Project in Houghton, Michigan. The roads will serve as field research and demonstration sites. The chunkwood will be tested in the laboratory at Michigan Tech for various mechanical properties important to road building, including permeability. The "woodchunker" used was built by the Forest Service Missoula Equipment Development Center in Missoula, Montana, for the Colville National Forest in Colville, Washington.

Should chunkwood prove to be a suitable road-building material, it would provide the national forests with an excellent use for a forest resource for which there are limited or no existing markets. In fact, use of this product would eliminate a costly disposal problem. In the ultimate scenario, the National Forest could plan future low-volume roads concurrently with future harvesting operations. For example, low-value northern hardwood poletimber stands could be thinned for road building materials. Use of renewable, above-the-ground forest biomass for low-volume roads would ensure the availability of material and would, more importantly, conserve quality borrow-pit materials for higher-standard roads.

Wood preservatives will be examined at a later date to see if the chips or the chunks can be preserved at a reasonable cost. If the wood materials can be preserved at a fairly low cost, and with little environmental damage, the number of potential applications for surfacing would be substantially increased.

CONCLUSIONS

Wood chip fills are an effective means of constructing roadway embankments across swamps and bogs. The cost is about the same as using soil fill material, but the fact that wood chip fills have a much lower unit weight is a significant factor in reducing future maintenance costs and environmental damage. However, a supply of low-value timber near the area to be crossed is essential.

REFERENCES

1. G. P. Williams, Jr. *Wood Chips for Dust Control on Surface-Mine Haul Roads.* Forest Service Research Note NE-277. U.S. Department of Agriculture, Forest Service, Broomall, Pa., 1979, pp. 1-16.