Construction and Performance of a Shredded Waste Tire Test Embankment

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The construction and performance of a test embankment designed to evaluate the use of shredded waste tires as soil replacement in highway construction are described. The shredded tires offer the advantage of low unit weight and durability. The test embankment was designed and built to test key variables including chip size, confining overburden pressure, and use of chip-soil mixtures or chip-soil layering. The embankment consisted of sections, each 20 ft long, containing differing chip-soil compositions. The embankment was constructed parallel to the access road of a sanitary landfill and exposed to the heavy incoming truck traffic. Field data were collected to assess the stability and deformation of the road surface, compaction of tire chips, and quality of tire chips leachate. Observations were made to assess the potential difficulty of depositing and compacting layers of tire chips. Normal construction machinery can be used successfully with tire chips, though rubber tires can be punctured by the exposed wires at the edge of the chips. Vibratory or static compaction does not significantly induce compaction in tire chips. After an initial adjustment period, the overall road performance was similar to most gravel roads. Tire chips used as a replacement for fill under a road perform better when covered by 3-ft-thick soil caps compared with chips covered by only 1 ft of soil. Furthermore, the void ratio of the pure tire chips affects its stiffness. The leachate quality data indicate that shredded automobile tires show no likelihood of having adverse effects on groundwater quality. The findings support the use of properly confined tire chips as a lightweight fill in highway applications.

With the banning of whole tires in sanitary landfills, stockpiles of waste tires are growing in the country. For example, it is estimated that there are 20 million waste tires in Wisconsin, with an additional 4 million generated each year. Whole tires are not easily disposed of for several reasons, including their poor compressibility and their potential combustibility and associated toxic fumes. Recycling is also difficult due to the composite structure of tires: integrally combined rubber, synthetic fibers, and steel wire. Shredding is one common means of modifying waste tires to ease disposal. Finding large-volume uses of shredded tires is desirable to increase the lifetime of sanitary landfills.

The findings from an experimental test embankment designed and constructed to provide information regarding the behavior of waste tire chips as a fill material are summarized. The research specifically examined the difficulty of constructing a fill made of tire chips, the stability and deformability of tire chips used below a road surface, and the environmental acceptability of the leachate that passed through the tire chip fill (*1*).

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CHARACTERIZATION AND CLASSIFICATION OF TIRE CHIPS

To characterize and classify the range in size and shape of shredded tires, an inventory of the waste tire stockpiles and shredders in Wisconsin was developed by visiting most of the tire-shredding operation sites. The shredding process was videotaped at the sites visited, representative bag samples were taken, and the owners/operators were interviewed. Data were collected regarding shredding operations, type of machinery used, product cost, and product types and characteristics. Most processors use fairly small mobile shredding equipment of 30 to 100 HP. These shredders use a shearing process in contrast to the tearing process in the older versions. The shearing process produces more uniform products, makes cleaner cuts, and eliminates the partial pulling of the reinforcing wires out of the tire chips. The production rate ranged from 100 to 400 tires per hour depending on the machinery type and desired chip size. The cost of shredding ranged from $30 to $65 per ton, 1 ton equaling approximately 100 tires.

The size of the tire chips is dictated primarily by the design of a particular machine and the setting of its cutting mechanism. Small chips are produced by processing the material through more than one shredder, each set to produce finer cuts than its predecessor. Classifiers can also be used to separate the finer sizes from coarser ones. Usually the chips are shaped irregularly, with the smaller dimension being the size specified by the manufacturer and the larger dimension two to four times as much. Samples collected from sites visited range from 1 × 2 in. to 4 × 18 in., with the most common size chip being 2 × 3 in. Classifiers are not typically used on these sites. Figure 1 shows information concerning the minimum tire chip sizes of samples collected from four shredding sites. The names of the tire chips were assigned on the basis of the location of the shredding process.

After reviewing the tire chip samples collected, three distinct size groups were recognized. The Edgar chips were the smallest and were produced by a tearing action resulting in significant amounts of loose metal fibers. At the other extreme, the Verona chips (not plotted in Figure 1 because of size extremes) had passed through only one cycle of shredding and consisted of large striplike pieces up to a length of 12 in. Between these two extremes were the Franklin and the Rodefeld tire chips. These chips had an intermediate size, the Rodefeld chips being somewhat coarser than the Franklin chips. Because of the availability of the Rodefeld chips at the construction site, it was decided to use the Edgar, Verona, and Rodefeld tire chips with the Rodefeld the main tire chips to be investigated. The large chips, referred to as the Verona

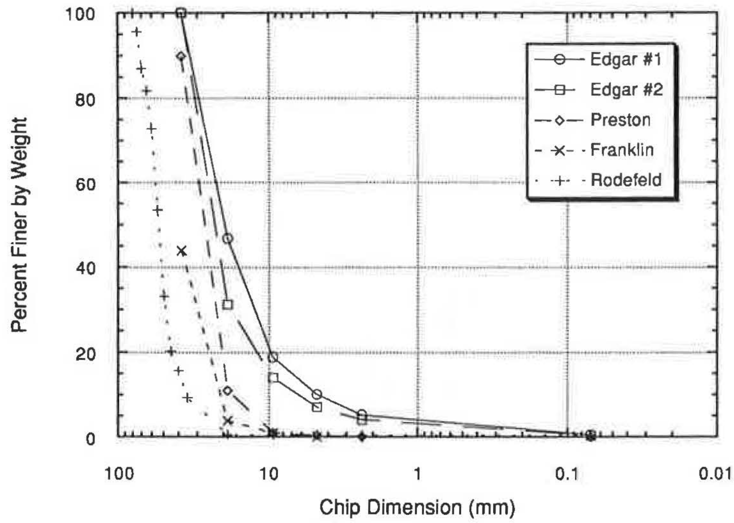

FIGURE 1 Size distribution data of tire chips.

chips, were originally sampled at the Dane County Verona Landfill. However, the first cycle of shredding at the Rodefeld site produced a product similar to the Verona chips. Therefore, in the construction of the test embankment, the coarse Rodefeld material was used. However, the name "Verona" was retained for ease of identification.

TEST EMBANKMENT DESIGN AND CONSTRUCTION

The test embankment was constructed in Dane County Landfill No. 2 (Rodefeld Landfill) near Madison, Wisconsin. This site offered a sufficient supply of the main chip size to be tested and an abundant soil source. The test embankment was constructed parallel to the access road near the landfill entrance, allowing the diversion of a known quantity of heavy traffic (incoming refuse trucks) onto the test embankment as desired. The trucks were individually weighed as they brought their refuse to the landfill, providing a record of the traffic. Regular weather monitoring and ground and surface water monitoring at the landfill site provided environmental data.

Test Embankment Design

In designing the test embankment, the following factors were considered:

1. Tire chip size and type,
2. Soil type and chip-to-soil ratio for chip-soil mixture, and
3. Placement conditions (pure chips, mixed with soil, or layered).

An available soil at the landfill site (a glacial outwash gravelly sand) was chosen to be mixed with the chips. The grain size curve of this sand is given in Figure 2. It is a well-graded, predominantly coarse-grained material with some fines in it. It is classified as an A-1-b(0) granular material in the AASHTO system and an SW well-graded sand with gravel in the USCS.

Three soil-chip compositions were adopted for study: pure tire chips, tire chips mixed with soil, and tire chips layered with soil. For the chip-soil mixture, a ratio of 50 percent tire chips and 50 percent sand by volume was chosen. The mixing was achieved in the field by a relatively simple operation using a backhoe. The layered tire chip and soil section was built by placing alternating 1-ft lifts of tire chips and sand. In this section, an overall ratio of tire chips to sand was targeted to be the same as used in the mixture.

In two of the sections a thicker soil cap was designed to assess its effect in reducing the deformation of the chips under traffic loading. In addition to testing tire chips, it was decided to include a fiber-reinforced soil in the construction of the test embankment. Reinforcement fibers obtained from Synthetics Industries were mixed into the sand at two different ratios and placed in two separate sections in the test embankment. This paper will focus only on the behavior of the tire chip sections of the embankment. However, reference is made to these fiber-reinforced sections for the purpose of comparison.

On the basis of site geometry and number of variables, the test embankment has eight sections, each 20 ft long as shown in Figure 3. The six tire chip–soil cross sections are shown in Figures 4a and 4b. Along with the approaches built of sand, the test embankment included a total of 10 sections to be monitored and compared. The test embankment has a nominal height of 6 ft with side slopes of 1V:2H. The crest width is 16 ft wide to permit safe passage of large trucks.

Field Compaction

After scraping off the surface organic soils, an elevation survey was made of the foundation base. A geotextile was then placed to separate the foundation soils from the embankment materials. A geotextile was also placed between the tire chips and the soil cap in Section 4 as well as over the whole embankment before placing the gravel wear coarse and the organic soils on the slopes. The embankment was constructed in six lifts of approximately 1 ft each. During the compaction

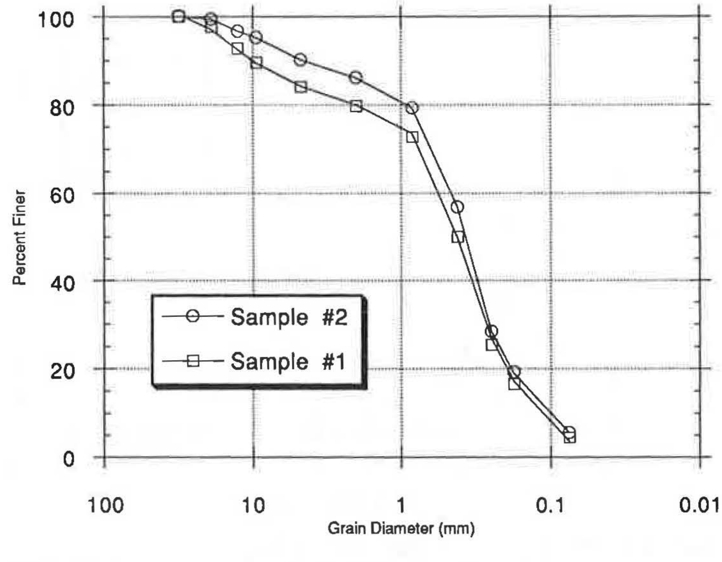

FIGURE 2 Grain size distribution of outwash sand.

of the first lift, surface elevation measurements were made after each pass of the compactor. Since the surface was irregular due to the large tire chips, these measurements were made from a 2 × 2 ft steel plate placed at the center of each section. The compactor used was a Case 1102 PD 12-ton sheepsfoot roller with vibratory capability (26 ft-tons). The north half of the first lift was compacted with vibration on, whereas the south half was subjected to no vibratory action. The corresponding lift thicknesses were computed from the surface elevations.

Examination of the data indicated that vibratory action improved compaction of the tire chips somewhat (25 measurements out of 40 showed more compaction for the vibrated side), but not enough to support use of vibratory rollers. A comparison of the first pass with the fifth pass indicated no additional compaction in the tire chip sections. In general, tire chips showed little plastic deformation due to compaction, unlike the soil sections.

The density achieved during construction was monitored by computing unit weights from a record of the weights of the soils and chips used and the embankment dimensions. Figure 5 shows the calculated unit weights of each material as they were encountered in each section (e.g., S1 = Section 1). Densities of the Rodefeld and Edgar tire chips (medium and finest size) were comparable at 25 to 35 lb/ft^3 range, but the density of the Verona chips (coarser chips) was decidedly lower at 19.3 lb/ft^3 even though the Verona chips were confined with an additional foot of sand because of their large initial compression during the placement of the soil cap (*1*). Sand used in interlayering with the Rodefeld chips in Section 1 was not compacted as well as the top cap sand layer in Sections 3 and 4 (60 lb/ft^3 versus 105 to 111 lb/ft^3). In Section 1 this may be due to the lack of inertial mass of soil to compact against, whereas in Sections 3 and 4 the soil mass is two or three times thicker. The Rodefeld/Sand mixture used in Section 6 had an average unit weight of 75 lb/ft^3.

Embankment Instrumentation

The instrumentation of the embankment was designed to evaluate the compressibility of the embankment. Slope stability was not deemed to be a problem because of the high friction angle of tire chips; the angle of repose of the piles of tire chips was more than 50 degrees. The compressibility behavior of the test embankment was monitored by regular surveys of surface markers and settlement plates located in the embankment. For surface surveys, target markers were placed at seven locations in the center of each section, as shown in Figure 6. The marker consists of a 2-in. square, ¼-in.-thick plate with a 10-in.-long #4 rebar anchor welded in its center. There are 70 markers on the embankment and the two approaches. Periodic surveys of these markers provide the *x*, *y*, and *z* coordinates of these points and the changes thereof.

In addition, 10 settlement plates were placed in the embankment. The settlement plates are standard Wisconsin DOT plates, consisting of a 2-ft-square plate with a rod and a friction pipe. They were placed roughly in the midheight of the embankment (on the third compacted lift from the base) in each test section. An additional plate was placed on the foundation base in Section 4 to measure foundation settlement (see Figure 4b).

Two leachate collection lysimeters used for obtaining leachate samples were constructed by cutting a 1-ft-deep, 10-ft by 12-ft hole in the sand base (see Figure 3). The collection lysimeters were placed in the base of Sections 2 and 5 because these sections contained pure tire chips and were thought to be the sections in which the leachate would be the most affected by the tire chips. The lysimeters consisted of a 10- × 12-ft square, 30-mil-thick PVC liner with 1-ft-high sidewalls. It was filled with gravel and fitted with a 4-in. pipe boot. A nonwoven geotextile covered the collection system. The base of the hole was sloped to the center and in the direction of the 4-in. pipe. The pipe conducts the collected leachate to

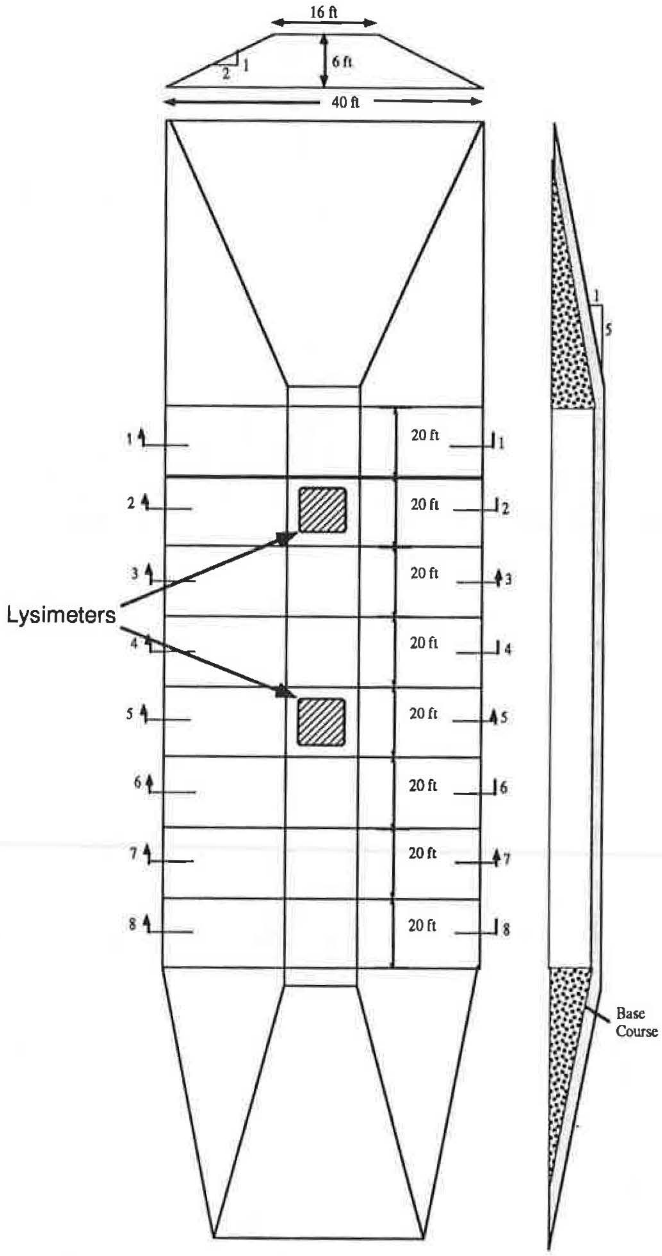

FIGURE 3 Plan view of test embankment design.

the south side of the slope into a 66-in.-deep cylindrical container of inside diameter 6 in. The container is fitted with a cap and allows retrieval of leachate samples. The pipes and the container were all built using PVC.

Construction Observations

The following observations were made during the construction process:

1. The handling and placement of the tire chips were not problems. The backhoe seemed more capable of spreading the material evenly for each section than the front-end loader or grader.
2. Tracked equipment had no trouble maneuvering over the shredded tire fill, but trucks occasionally became stuck and had to be pulled out when the lifts of pure tire chips were more than 2 ft thick. Flat tires on dump trucks also occurred from driving over tire chips.
3. Vibratory compaction did not have an advantage over nonvibratory compaction because of the low inertial mass of the tire chips and their tendency to rebound.
4. Although the chips compressed with each pass of the roller, rebound of the chips was visible behind the compactor. Only the first pass appears to induce a small amount of per-

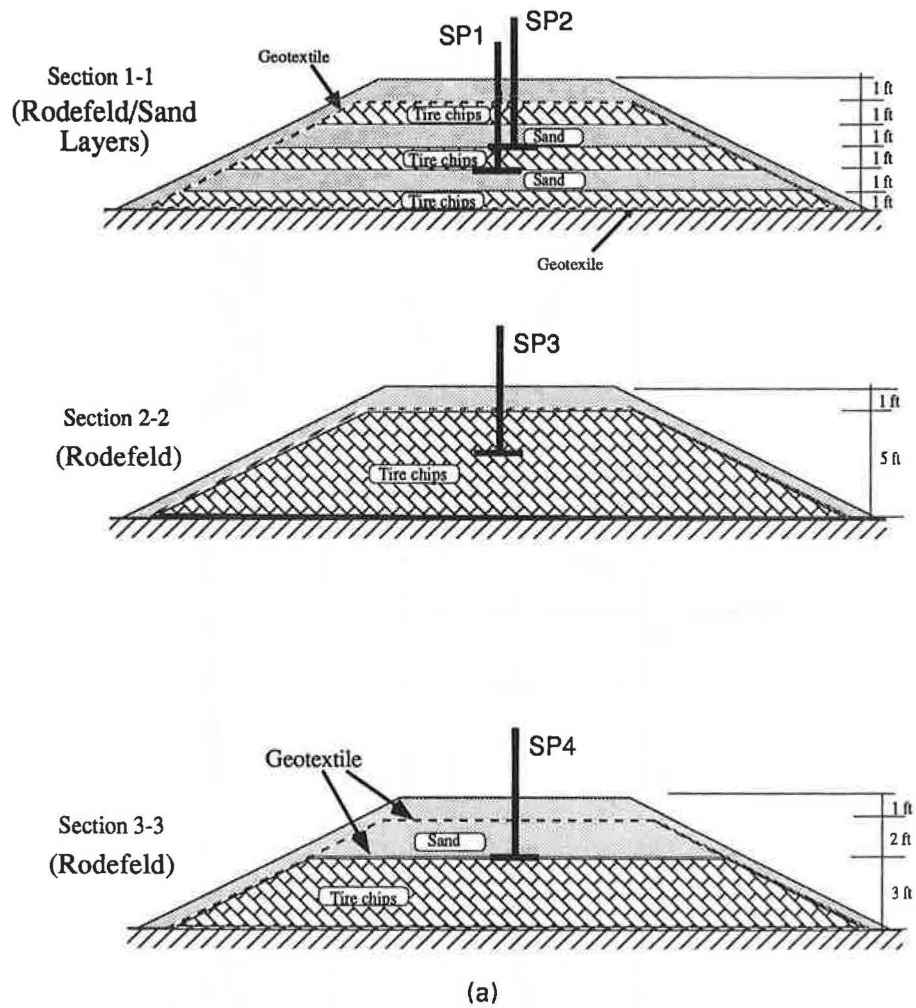

FIGURE 4 Elevation view of test embankment sections as designed: (*a*), Sections 1, 2, and 3; (*b*), Sections 4, 5, and 6. ***(continued on next page)***

manent compaction, with the other passes being totally ineffective.

TEST EMBANKMENT PERFORMANCE

Traffic and Maintenance

The embankment was constructed parallel to the access road of a sanitary landfill and exposed to the heavy incoming truck traffic, which is weighed before entering the landfill. Approximately 60 to 100 trucks per day weighing an average of 21.6 tons per vehicle pass over this embankment. The standard deviation of truck weight is approximately 10 tons; the weight of some trucks is more than 45 tons. On June 4, 1990, the test embankment was opened to traffic. On June 8, 1990, the embankment required regrading because of immediate rutting under the traffic load. This was accomplished by adding 32 tons of crushed rock (base course) over the whole test embankment. From June through August the embankment went through several cycles of regrading, opening to traffic, rutting and pothole formation, closing to traffic, and back to regrading. The west approach of the embankment was particularly affected even though it was built using soil without any tire chips. Furthermore, dust due to traffic was threatening the air quality near the landfill. On October 3, 1990, the west approach was regraded using 31 tons of base course. In addition, minor work was performed on the east approach. Later a calcium chloride treatment for dust control was applied, and the embankment was reopened to traffic on October 26, 1990. On December 3, 1990, the test embankment was closed to traffic for the winter after a record snowfall (17 in.). On April 10, 1991, potholes that developed in the east approach, especially at the contact with the asphalt pavement, were repaired, and the embankment was again opened to traffic. Traffic has been routed over the embankment throughout spring, summer, and fall 1991 with virtually no closures. At the present time, an asphalt concrete pavement is being placed on the embankment to permit traffic throughout the coming winter months and to investigate the performance of asphalt concrete pavement founded on a tire chip fill.

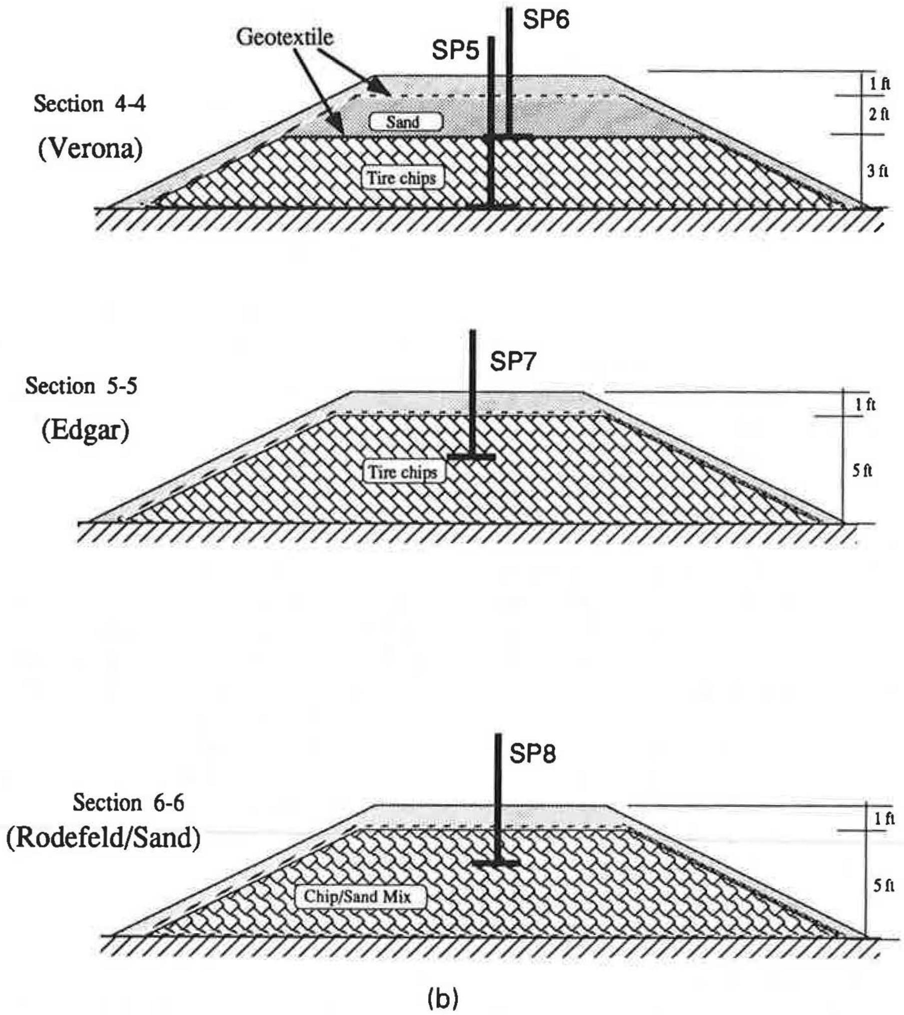

FIGURE 4 ***(continued)***

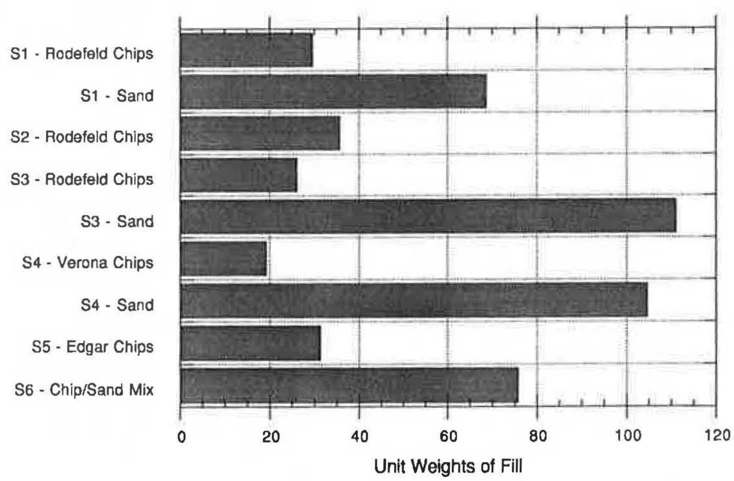

FIGURE 5 Calculated unit weights of fill components.

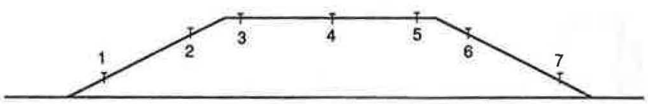

FIGURE 6 Settlement marker locations.

Roadway Rating

Gravel roads provide service to agricultural, forestry, and recreational areas with fairly high traffic volumes. Surface evaluation and rating of such roads are needed for planning their maintenance and overall management. A system for evaluating and rating gravel roads was developed by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in 1987 (*2*). A simplified visual method for gravel road evaluation based on the work at CRREL was prepared as a PASER manual by the Transportation Information Center of the University of Wisconsin-Madison (UW) in 1989 (*3*). The evaluation is based on major factors such as the road cross section, drainage, and adequacy of the gravel layer. Five road conditions are used to evaluate and rate gravel roads: crown, drainage, gravel layer, surface deformation, and surface defects.

Using the PASER system, the test embankment surface conditions were inspected and evaluated after the first year of service on April 5, 1991, by the Wisconsin DOT District 1 maintenance supervisor and UW personnel. The overall condition of the road surface was excellent (a score of 10) for drainage, good to excellent (a score of 8 to 10) for crown, and somewhat variable (a score of 6 to 10) for potholes. This over condition after the initial period of adjustment and repairs puts the test embankment among the better gravel roads. However, there were notable variations in the ratings of each section. For instance, the crown rating was 10 for all sections constructed using earth and for three of the six sections constructed using various tire chip products (Sections 3, 5, and 6). Pothole ratings showed more variation between the various sections constructed of earth or tire chips. Just about every section and the two approaches (built entirely of earth) developed potholes under the heavy garbage truck traffic.

The embankment surface was regraded one final time on April 10, 1991, rendering the rating of all sections excellent (a score of 10). After 7 months of continuous traffic, the embankment surface conditions were again assessed. The ratings were similar to those found on April 5, 1991.

Surface Settlement

To date, five surveys have been run on (*a*) the ground surface elevation; (*b*) the surface markers placed just after the construction was completed, which became buried after additional gravel was applied; and (*c*) the settlement plates buried in the test embankment.

Three of these surveys were carried out with total stations permitting the collection of three-dimensional data, whereas the other two surveys obtained only the elevation of the surveyed points. The results from these surveys permit a quantitative evaluation of the performance of the embankment.

A review of the lateral movement of the individual markers indicated that there was no apparent bulging of the slopes of any sections or any noticeable longitudinal stretching. The measured lateral movements of the markers placed on the embankment crest (Markers 3, 4, and 5) also indicated relatively small movements (less than 1 to 2 in.) between the initial and final surveys. Consequently, the measured elevations of the embankment crest markers can be used in studying the overall settlement of the embankment section free of local surficial disturbances. The markers were not removed throughout the observation period, and actually the base coarse overlay was excavated to reach the markers during the surveys.

Figure 7 shows the settlement data collected from several surface markers (shown in Figure 6). The data in Figure 7 are the average settlement of Markers 3 and 5, the two surface markers located near the track made by the truck tires as a function of number of days of traffic. The data indicate that the settlement increased rapidly during the first 20 days after truck traffic was first allowed on the embankment, corresponding to the time of major pothole and rut formation. After the surface was regraded and a crushed gravel layer added, the settlement rate tapers off (20 to 60 days). After 60 days, the settlement remains relatively constant. This is further supported by Figure 8, which gives the settlement rates for each of the sections in these time intervals of traffic load.

Using the maximum values of settlement (at 152 days of traffic on Figure 7) as the measure of performance, comparisons of the sections support grouping of the sections as follows:

1. Best performance—Sections EA (east approach), 7, and 8 (Sections 7 and 8 are not shown—they are the fiber-reinforced soils);
2. Higher performance—Sections 3, 4, and 6;
3. Lower performance—Sections WA [west approach (also not shown)], 2, and 5; and
4. Poorest performance—Section 1.

Examination of these groups indicates that the best performance is found in sections composed entirely of soil or fiber-reinforced soil. The exception to this is in the west approach; however, this approach was built initially with frozen soil, which is thought to have contributed to its lower performance. On October 3, 1991, this soil was removed and the west approach was reconstructed. Since then, its performance has been similar to other earthen sections. The next-best-performing group is composed of sections having thick soil caps (Sections 3 and 4) and a section made with a mixture of chips and soil (Section 6). The presence of a thick soil cap is important to reduce the amount of plastic deformation of the chips. The mixture of soil and chips provides performance similar to the pure chip sections with a thicker soil cap; however, the amount of chips recycled in either Sections 3 or 4 is larger than that recycled in Section 6. In addition, the extra operation of soil mixing could be avoided by constructing roads similarly to Sections 3 or 4. The sections made of pure chips that did not have the thicker soil cap did not perform as well, most likely because of the lack of confinement of the surface tire chips. The worst-performing section was the layered section. The performance can be traced back to the lack

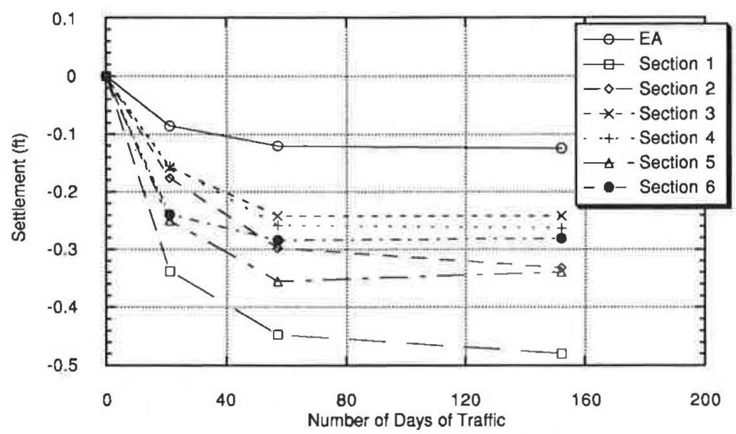

FIGURE 7 Tire track settlement versus days of traffic.

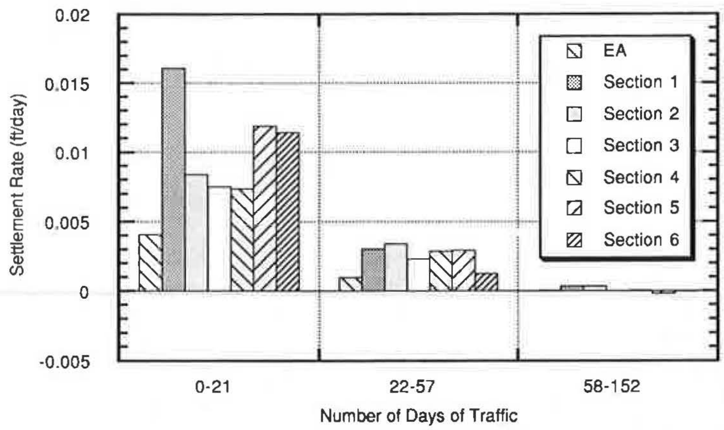

FIGURE 8 Tire track settlement rate versus days of traffic.

of compaction imparted to the soils (see Figure 5) in that section as well as the near-surface tire chips without adequate confinement.

Compressibility of Deep Materials

The settlement of the surface markers depicts the plastic deformation associated primarily with the surface materials (crushed stone, gravel, and some tire chips), where the stress increase due to the traffic loading is the largest. The movement of the deep settlement plates describes the response of the deeper materials (chips, chip-soil mixture, or layered chips-soils) to smaller stress increases from traffic loads. A comparison of the observed surface marker settlement with the movement of the deep settlement plates indicates a much-reduced response of the deep settlement plates, though the trends are similar: higher initial movement compared with the period after 60 days. Table 1 summarizes an analysis of the stiffness of the deeper materials as measured by the movement of the deep settlement plates. The stiffness index is defined as the ratio of the overburden stress to the plastic strain. A comparison of the stiffness differences between the sections supports the previous performance grouping based on surface settlement. The settlement plate data is useful for further differentiation within each of these performance groups. In addition to the influence of thick soil caps, the data indicate effects of the tire chip void ratio. In Table 1, the bulk unit weight gives a measure of the void ratio of tire chips except for Section 6, where the bulk unit weight is that of the chip-soil mixture. A comparison of SP4 and SP6 indicates that the Verona chips do not perform as well as the Rodefeld chips even though they were subject to a higher cap overburden stress.

Test Embankment Environmental Testing

Waste tires are essentially a solid waste, and the recycling of tires in highway applications will probably require a permit from state or federal environmental regulatory agencies. To obtain an early evaluation of potential environmental problems before construction, duplicate EP toxicity and AFS leaching tests were performed on tire chip samples by the State Laboratory of Hygiene (*1*). The test results indicate that the shredded automobile tire samples show no likelihood of

TABLE 1 DEEP LAYER COMPRESSION DATA FROM SETTLEMENT PLATES FOR 58 TO 152 DAYS OF TRAFFIC

Section-Settlement Plate	Description	Bulk Unit Weight	Settlement	Layer Thickness	Overburden Stress	Plastic Strain	Stiffness Index
		pcf	feet	feet	psf	%	psf
1-SP1	Layered	29.6	0.156	0.98	294	15.9	1846
1-SP2	Layered	29.6	0.205	1.45	278	14.1	1965
2-SP3	Rodefeld	35.7	0.069	1.92	273	3.6	7594
5-SP7	Edgar	31.4	0.075	1.85	328	4.1	8093
6-SP8	Rodefeld/ Sand Mixture	75.7	0.080	2.27	373	3.5	10588
4-SP6	Verona + Cap	19.3	0.098	1.86	565	5.3	10724
3-SP4	Rodefeld + Cap	26.2	0.032	2.02	481	1.6	30375

TABLE 2 WATER QUALITY ANALYSIS OF LEACHATE—EAST LYSIMETER

SAMPLE	Units	5/9/90	3/28/91
pH	su	7.7	7.7
Alkalinity	mg/L	533	705
Barium	µg/L	210	350
BOD	mg/L	14	70
Calcium	mg/L	170	340
Chloride	mg/L	460	1400
COD	mg/L	170	560
Conductivity	µmhos/cm		5150
Iron	mg/L	0.05	0.7
Lead	µg/L	<3	22
Magnesium	mg/L	150	390
Manganese	µg/L	270	3200
Sodium	mg/L	220	200
Sulfate	mg/L	140	450
Total solids	mg/L	2000	4630
Zinc	µg/L	46	560
Hardness	mg/L	1100	2500

being a hazardous waste. Table 2 provides the results of the water quality analyses performed on two samples taken from the east lysimeter established under the tire chip test embankment. Samples were retrieved initially on a monthly basis, quarterly since April 1990, and are retrieved semiannually now. The data given in Table 2 are typical of the changes observed in the water quality samples obtained.

A review of the data to date support our expectations based on earlier leach tests. The pH is stable around 7.5. Consistent with that pH, most of the parameters stay within acceptable limits. As indicated by the leach tests, there is an elevated manganese concentration in the field samples too, especially in the last samples.

To clarify the possible source of higher manganese concentration in the samples, ground and surface water data from the vicinity of the test embankment were obtained from the Dane County Public Works Department. It is believed that the geological formations here cause the higher-than-usual manganese concentration. The test embankment is located at the foot of the landfill. The volume of water pumped out of the two lysimeters and the elevations of the lysimeters indicate that surface and groundwaters are entering the lysimeters laterally through the slope cover soil. The general characteristics of the water quality at the site are reflected to a certain extent in the measured quality of the lysimeter leachate samples (*1*).

CONCLUSIONS

On the basis of the results of the research program, the following can be concluded:

1. Normal construction machinery can be used successfully with tire chips, though rubber tires can be punctured by the exposed wires at the edge of the chips. Vibratory or static compaction does not significantly induce compaction in tire chips.
2. After an initial period of adjustment, the overall performance of a gravel road founded on tire chips appears similar to that of most gravel roads.
3. Tire chips used as a replacement for fill under a road perform better when covered by 3-ft-thick soil caps compared with chips covered by only 1 ft of soil.
4. The void ratio of the pure tire chips affects its stiffness. The void ratio is affected by the size of the tire chip and by the presence of soil within the tire chip voids.
5. Shredded automobile tires do not show any likelihood of being a hazardous waste. Compared with other wastes for which leach test and environmental monitoring data are available, the tire leach data indicate little or no likelihood of shredded tires having adverse effects on groundwater quality.
6. The preceding conclusions support the use of tire chips as a lightweight fill in highway applications if properly confined.

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