Use of Shredded Tires for Lightweight Fill

RICHARD J. UPTON AND GEORGE MACHAN

Shredded waste tires were used as lightweight fill to repair a landslide in a highway improvement project in southwest Oregon. Approximately 580,000 shredded waste tires were trucked to the site from four different sources 240 to 440 km (150 to 275 mi) away. The tires were placed and compacted with a dozer, then capped with 0.9 m (3 ft) of soil and a pavement section with 20 cm (8 in.) of asphalt pavement over 58 cm (23 in.) of aggregate base course. The in-place shredded tire fill cost \$16.82/m^3 (\$12.87/yd^3), which included a significant rebate from the Department of Environmental Quality. Without the rebate, the cost would have been \$35.16/m^3 (\$26.91/yd^3). The shredded tire fill was instrumented and monitored for 1 year following installation. Instrumentation included inclinometers, piezometers, settlement plates, and survey hubs. Falling weight deflectometer tests were also performed. The shredded tire fill compressed linearly in relation to surcharge load as the soil cap and pavement section were placed. Compression appears to be related to shredded tire fill thickness. Creep or compression under traffic loading occurred during the monitoring period. The compacted density of the shredded tires varied from 730 to 845 kg/m^3 (45 to 53 pcf) at various stages of compaction and surcharging. A standard asphalt pavement with aggregate base was adequate over the shredded tire fill. The shredded tire embankment represents a softer subgrade condition than do surrounding soil embankments. However, pavement deflections were considered within acceptable limits after 20.3 cm (8 in.) of asphalt pavement was in place.

A landslide associated with highway embankment construction was repaired with lightweight fill constructed of shredded tires. This use of waste tires was experimental, and a program was established to monitor installation and performance of the shredded tire fill.

This paper presents the results of the monitoring program and discussions of background information, remedial design, construction, monitoring, and performance of the shredded tire fill.

BACKGROUND

In the United States each year 240 million tires are discarded. Federal regulations limit disposal, and waste tires accumulate throughout the country, with the current stockpile estimated at 2 billion. Beneficial uses for the stockpile are continually being sought.

In 1986 the Minnesota Department of Forestry demonstrated the feasibility of using shredded waste tires as lightweight fill in roadway embankment construction (*1*). The application at the Minnesota installation was intended to limit embankment settlement over soft foundation soils.

Reducing embankment loads by using lightweight materials is also an accepted landslide repair technique. Lightweight embankments constructed of shredded tires represent a beneficial use for waste tires.

LANDSLIDE REPAIR

Design

As part of an improvement project on U.S. Highway 42 in southern Oregon (Figure 1) an existing highway embankment 3.3 m (11 ft) deep was widened 6.1 m (20 ft) and raised 1.2 m (4 ft). The additional embankment load remobilized an old landslide that moved progressively downslope perpendicular to the highway. The approximate extent of the slide is given in a plan view of the site in Figure 2.

A geotechnical investigation showed that slide movement could be arrested by reducing embankment load and adding a downslope counterbalance (*2*). The specific design was to replace embankment soils with lightweight fill and use the excess soils to construct the counterbalance. Sawdust and shredded tires were considered for the lightweight fill. Shredded tires were selected because there was concern about deterioration of sawdust. Shredded tire material costs were favorable because there is a state rebate for beneficial use.

The repair design also included a rock blanket and french drain system to maintain the groundwater level below the shredded tires. A cross section of the proposed repair design is given in Figure 3.

Environmental Considerations

The shredded tire fill was considered a solid waste disposal site by the Oregon Department of Environmental Quality (DEQ). A formal authorization process was required.

DEQ referred to a Minnesota Pollution Control Agency study (*2*) to review disposal plans. DEQ cited a potential for contamination of the groundwater in contact with the tire chips. DEQ approved the disposal plan, which included the rock blanket and french drain system to isolate the shredded tires from groundwater.

For several years, DEQ has had a program in place to collect a \$1 per tire fee upon disposal. This fee was used for programs to encourage beneficial use of waste tires. At the time of shredded tire fill construction, DEQ had in place a program to reimburse beneficial users \$22/Mg (\$20/ton). This reimbursement program made the cost of shredded tires competitive and resulted in the use of shredded tires in the landslide repair.

R. J. Upton, Oregon Department of Transportation, 2925 State Street, Salem, Oreg. 97310. G. Machan, Oregon Department of Transportation, 9002 S.E. McLaughlin Boulevard, Milwaukie, Oreg. 97222.

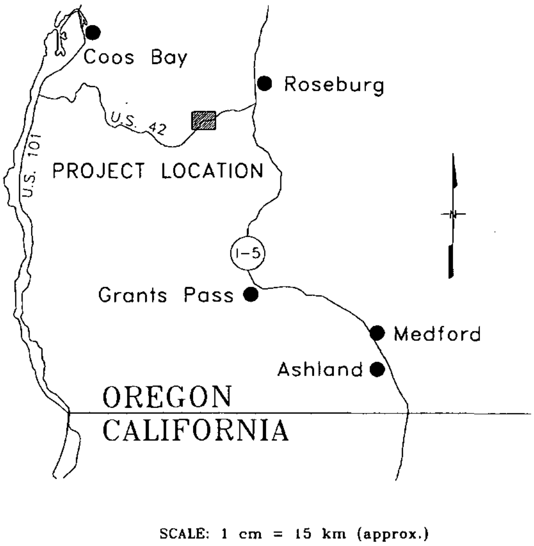


FIGURE 1 Vicinity map.

SHREDDED TIRE CONSTRUCTION

Scheduling

The landslide repair was part of the ongoing highway improvement project. Completion of the repair by fall 1990 was required to support overall project scheduling. Shredded tire fill construction took place in two phases to allow continuous highway traffic. Earthwork began on the landslide repair in June 1990. Shredded tire fill construction milestones are given on the time line in Figure 4.

Acquisition

The proposed design required approximately 580,000 waste tires to generate the 6400 Mg (5,800 tons) of lightweight fill material. No single source in the region had this quantity, so shredded tires were bought from four different vendors 240 to 440 km (150 to 275 mi) from the site. The tires were shredded at the vendor locations and trucked to the site in 76 m^3 (100 yd^3) trucks. Transport of the shredded tires to the site from the remote vendors was a critical scheduling item. Shredded tire transport began at the same time as site preparation. The tire chips were stockpiled near the landslide repair.

Manufacturing

The waste tire shredding process involves feeding tires through a series of rotating blades that compress and slice the tires into smaller pieces or chips. The chips are screened and sorted by size. Chips are fed through the shredder several times and screened to approximately 5 cm (2 in.) to provide a uniform product. Wire can be removed from smaller chips frequently used as low-grade fuel.

The shredded tire chip specification for the project was taken from work done in Minnesota (*1*). The specification dealt primarily with chip size and wire encasement. The size specification required 80 percent to be smaller than 20 cm (8 in.) and 50 percent to be larger than 10 cm (4 in.). The maximum size was 61 cm (24 in.).

To meet the chip specification, tires were passed through the shredder once. This process produced chips that substantially met the specification, but excursions in maximum size and exposed wire were common. Dull shredder blades of one

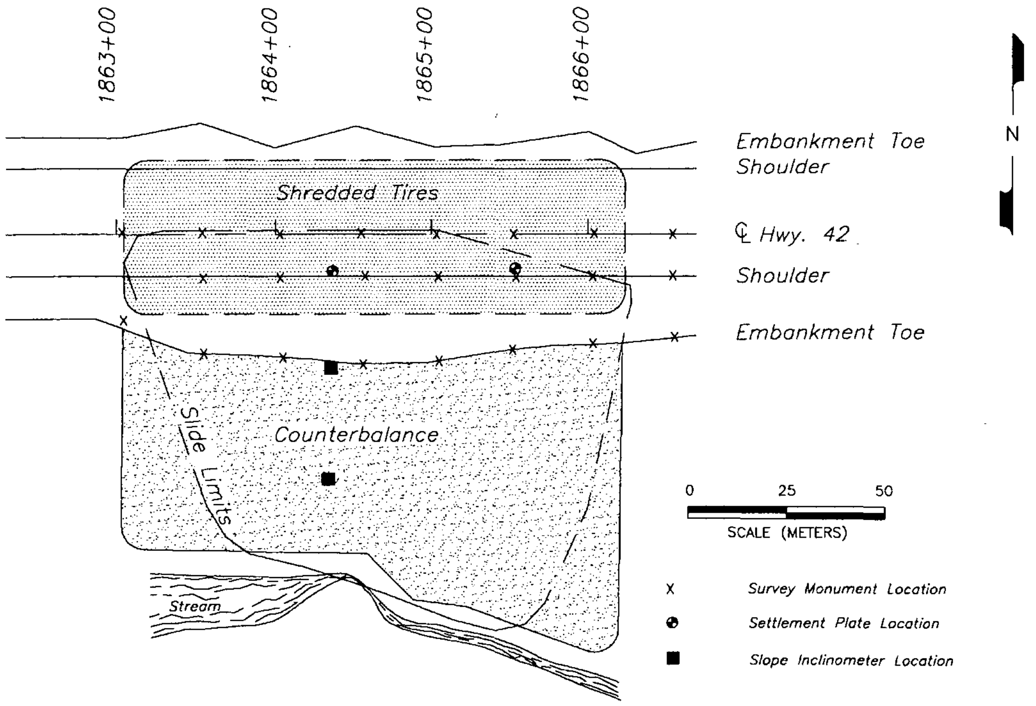


FIGURE 2 Site plan view.

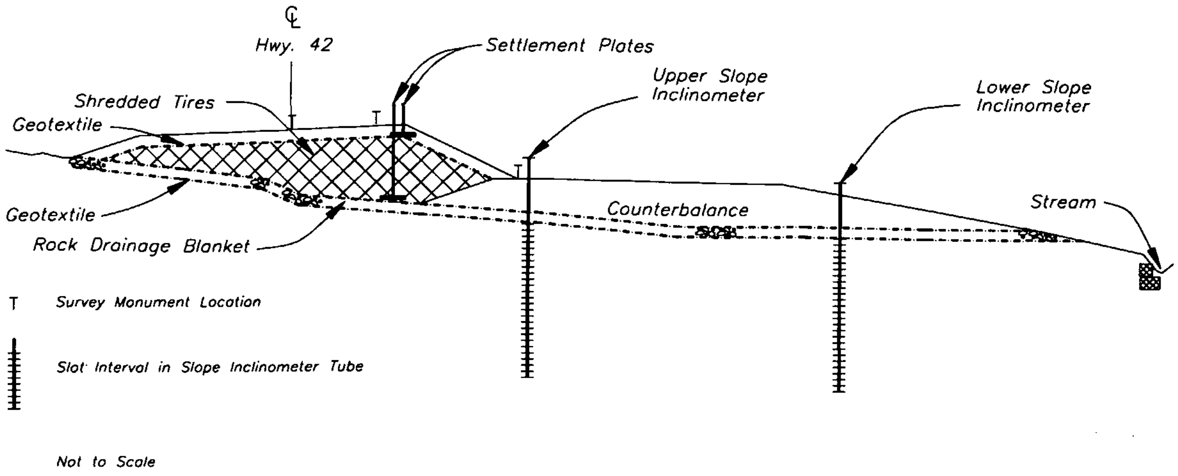


FIGURE 3 Typical cross section.

of the vendors increased excursion rate. Further processing of the chips could have resulted in tighter adherence to the specification. This was considered but not pursued because it would have added to the cost. The excursions were not considered detrimental to shredded tire fill performance.

Placement

The embankment foundation area was prepared by dozing and placing the rock blanket. Tire chips were moved from the stockpile to the fill in 7.6-m^3 (10-yd^3) dump trucks and dropped at one end of the prepared area. Dump trucks were not routed over the in-place shredded tires to avoid tire puncture from exposed wires in the shredded tire chips.

Compaction

The tire chips were spread in 0.9-m (3-ft) lifts and compacted with a D-8 dozer. The dozer was routed back and forth longitudinally on the shredded tires until at least one track pass had been accomplished everywhere. The dozer was then routed back and forth transversely until one track pass was again

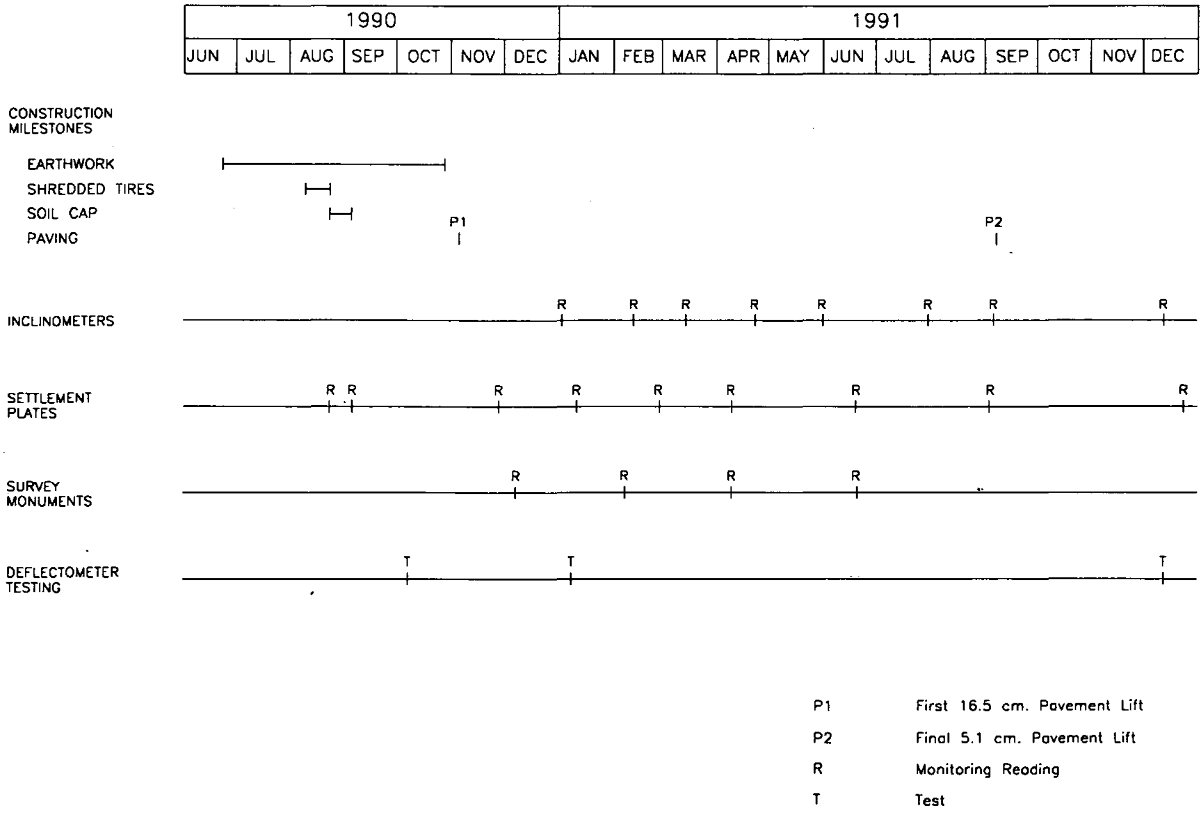


FIGURE 4 Time line.

accomplished everywhere. Full coverage in either direction was considered to be one compaction pass. At least three compaction passes were completed for each lift.

A test lift was compacted with a D-6 dozer in a similar routine. The lift compacted with the lighter dozer was visibly looser and could be compacted further with the heavier D-8 dozer. The lighter D-6 dozer was not used for compaction.

Compaction was also attempted by a series of in-place turning maneuvers or squirming with the D-8 dozer. This tended to loosen already compacted shredded tires and was discontinued.

Slope Trimming

Final trimming of the shredded tire side slopes was attempted with a dozer, but this resulted in a rough, uncompacted surface. Final trimming was successfully achieved by overbuilding the slope approximately 0.3 m (1 ft) and trimming with a hoe-type excavator situated at the top of the tire embankment. The excavator was equipped with a "thumb" bucket used in a grabbing motion. The resulting surface was relatively smooth and compact.

Geotextile Placement

The geotextile (Figure 3) was placed on top of the tires to separate the chips and soil cap. Field joints were attempted by lapping the geotextile 0.9 m (3 ft), but the joints tended to separate as soil was placed and compacted. To overcome this tendency, brass "hog-ring" clips were used to pin the joints together. The panel edges were overlapped 0.3 m (1 ft), and the clips were placed at 1.8-m (6-ft) intervals along the joints. The clips successfully prevented field joint separation.

Soil Cap Placement

The 0.9-m (3-ft) soil cap over the shredded tire fill was placed using standard 20.3-cm (8-in.) maximum lift thickness. Compaction requirements were 95 percent of maximum density as determined by standard Proctor except for the first lift, which was 90 percent. Compaction was achieved with an Ingersoll-Rand LD 150 compactor. During compaction of the first lift the earth cap deflected significantly, but 90 percent compaction was achieved with normal compactive effort. With each additional lift of capping soil, aggregate base, or asphalt, the deflections became progressively smaller.

The south slope of the shredded tires (right side, Figure 3) had a rise of approximately 3 m (10 ft). On this slope, the soil cap was placed and compacted in standard lifts approximately 3 m (10 ft) wide. The resulting vertical soil cover thickness was approximately 1.5 m (5 ft).

The north slope (left side, Figure 3) had a rise of less than 0.9 m (3 ft). The slope angle was designed flat enough to allow the soil cap to be constructed as part of the cap on the top of the tire fill.

Vertical Cut Performance

The shredded tire fill was constructed in two phases to accommodate highway traffic during construction. When the first phase of the fill was complete, the soil cap and aggregate base were placed to facilitate highway traffic. A 2.4-m (8-ft) vertical face was cut along the first phase of in-place tire chips to prepare for the second phase of tire chip placement. Highway traffic was routed over the first phase fill for 28 days. The pavement and shredded tires visibly deflected under truck traffic; however, no permanent deflection or distress was observed.

Costs

The shredded tires delivered to the site cost $33/Mg ($30/ton). The $22/Mg ($20/ton) DEQ reimbursement resulted in a net cost of $11/Mg ($10/ton) for shredded tires. The cost of placing and compacting the shredded tires was $9.18/Mg ($8.33/ton). Consequently, the net cost of the in-place shredded tire fill was $20.18/Mg ($18.33/ton), which equals $16.82/m^3 ($12.87/yd^3).

The DEQ reimbursement program was a significant factor in selecting shredded tires for the lightweight fill in this installation. The cost of the installation without the reimbursement would have been $42.18/Mg ($38.33/ton) or $35.16/m^3 ($26.91/yd^3). At this higher cost, other lightweight materials, such as sawdust, had a cost advantage. With the reimbursement program, the cost of the in-place shredded tire embankment was competitive with rock-fill embankment construction.

Construction Challenges

A major construction challenge was the impact of wire strands exposed on the shredded tire chips. These frequently punctured tires on construction equipment and prevented haul trucks from being routed over the fill. The placement sequence required an additional step to spread the chips, resulting in lost efficiency and extra cost. Shredded tire chips were also scattered throughout the stockpile area and dropped along the haul route, creating a continual puncture hazard.

Tighter adherence to the encasement requirement at the shredding plant might have reduced, or eliminated, this problem. This might have been achieved with sharper shredder blades. Communication about shredded tire chip quality was difficult without an inspector at the vendor plants. If the excursions from the specifications had been more severe, an inspector at the plant would have been necessary.

PAVEMENT SECTION CONSTRUCTION

Pavement design was based on the structural requirements of the natural subgrade materials surrounding the shredded tire embankment. The design section was 20.3 cm (8 in.) of asphalt pavement over 53.3 cm (21 in.) of aggregate base. The pavement section was constructed in phases, allowing several opportunities for observations and testing.

The full depth of aggregate base course was placed at the same time as the soil cap to facilitate highway traffic staging. Fill compression resulted in placement of approximately 58.4 cm (23 in.) of aggregate base to achieve design grade. An asphalt surface coat was sprayed on the aggregate base and performed well during 2 months of highway traffic.

The first lift of asphalt pavement was placed in January 1991. Lift thickness was 15.2 cm (6 in.). Shortly after placement, cracks were seen in a wheelpath over the shredded tire fill. The cracks propagated along the wheelpath and rutting also began. Drainage improvement failed to stem the deterioration. By late summer the rutting and cracking had affected the entire width of the lane for approximately 15.2 m (50 ft) over the shredded tire fill. The area was excavated to the top of the shredded tires. The soil cap in this area was only 0.5 to 0.6 m (1.5 to 2 ft) thick. The shredded tires were then excavated down to accommodate the full 0.9-m (3-ft) soil cover, and the pavement section was restored. After the repair, the final 5.1 cm (2 in.) of asphalt pavement was placed.

SHREDDED TIRE FILL MONITORING AND TESTING

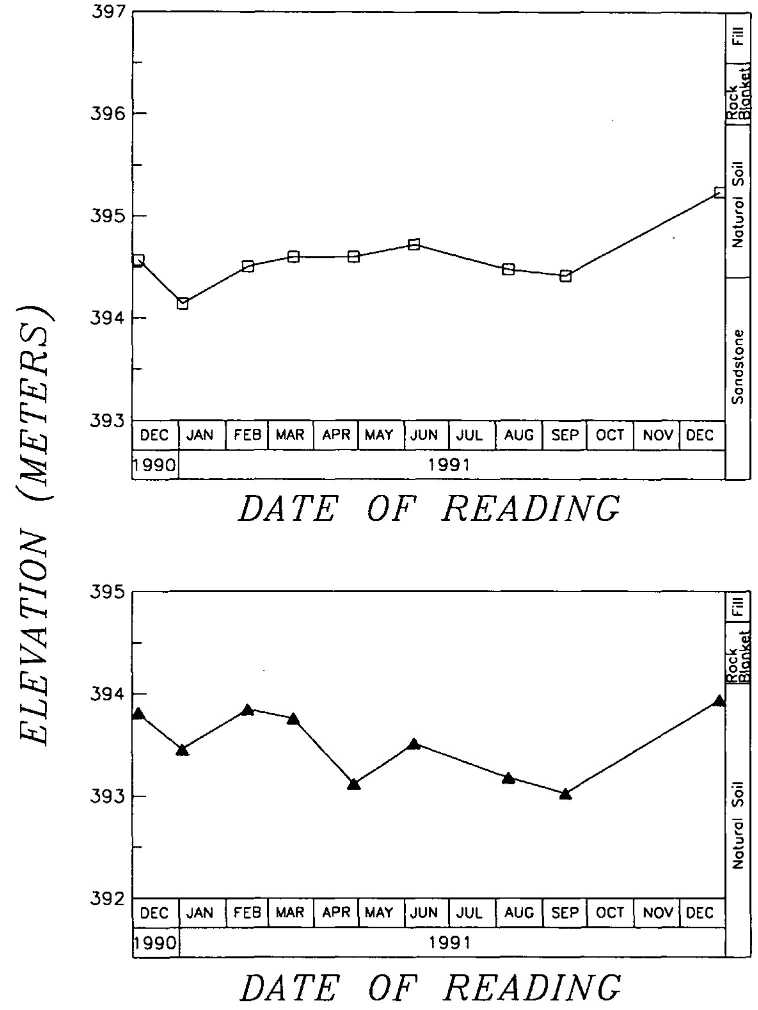
During and after construction, the shredded tire fill was instrumented to aid in assessing performance (*3*). Monitoring devices included two inclinometers, two settlement plate installations, and three rows of survey monuments. The inclinometer casings were slotted and used for piezometers. Monitoring device locations are given in Figure 2. A typical cross-section view of monitoring devices is given in Figure 3. Pavement testing was performed with falling weight deflectometers. The various instruments were installed and monitored on different schedules. A summary of the timing of monitoring activities is given in Figure 4.

Inclinometer Installations

Inclinometer installations consisted of commercially prepared casing, which was also slotted to act as a piezometer. The distance from ground surface to the top of the groundwater table was measured and plotted versus time (Figure 5).

Settlement Plate Installations

Settlement plate installations consisted of one plate at the bottom of the shredded tire layer and one at the top. Settle-



1 Meter = 3.28 Feet

FIGURE 5 Water level data: *top*, upper slope inclinometer; *bottom*, lower slope inclinometer.

ment plate data were reduced to yield plots of shredded tire fill thickness versus time (Figure 6). The data were further analyzed to yield shredded tire compression versus surcharge load (Figure 7).

Settlement plate data and measurements taken during construction facilitated computation of shredded tire densities in several different conditions. The conditions were loose in haul vehicles before and after hauling, compacted by dozer, surcharged by soil cap and pavement section, and final after 1 year of traffic. The computed densities are given in Table 1.

Loose Density

Average loose densities were calculated using weights and dimensions taken from one long-haul truck load from three different vendors. Two trucks were measured immediately after loading, and one truck was measured after a 64-km (40-mi) haul.

The loose density of the shredded tire material depended on chip size. Larger chips resulted in lower densities. The material weighing 485 kg/m^3 (30 pcf) at loading is most repre-

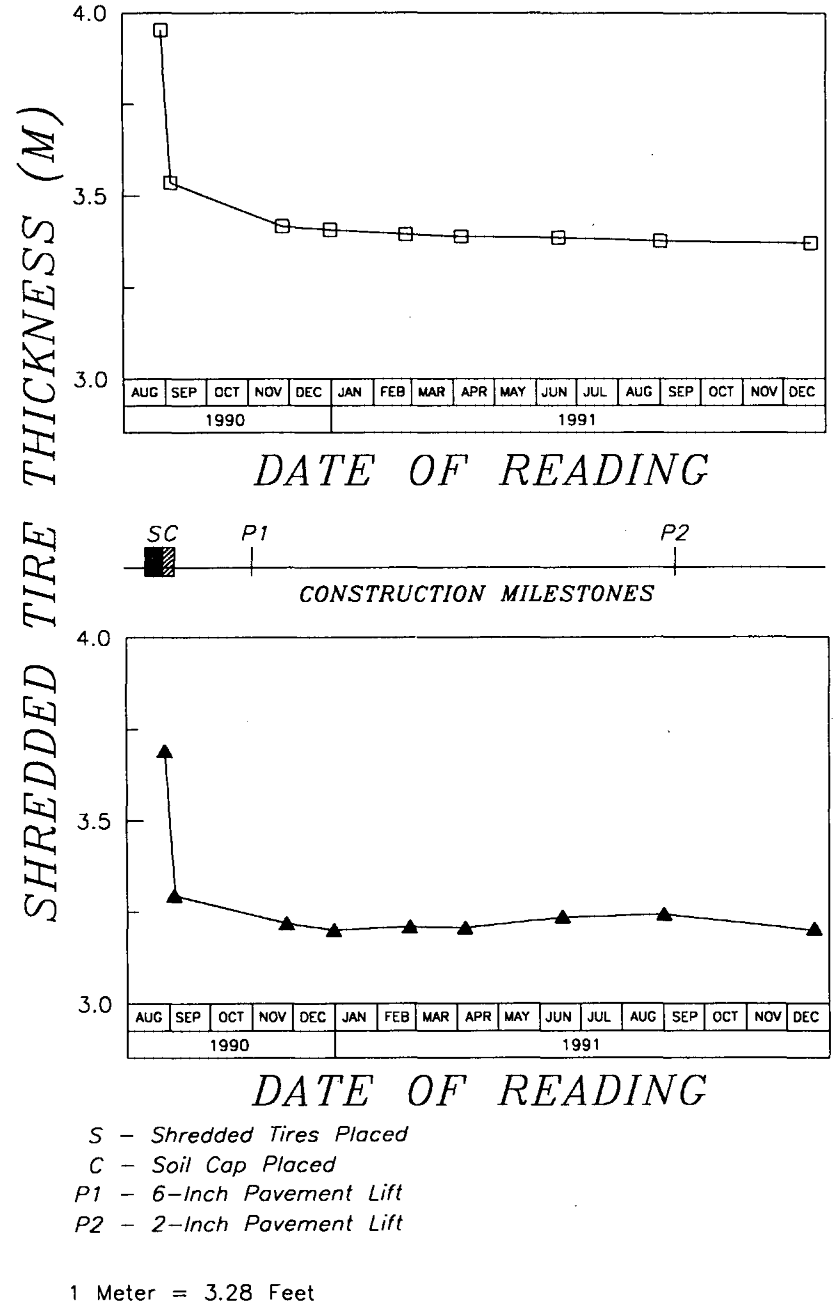


FIGURE 6 Settlement plate data: *top*, Station 1864 + 33.5; *bottom*, Station 1865 + 50.

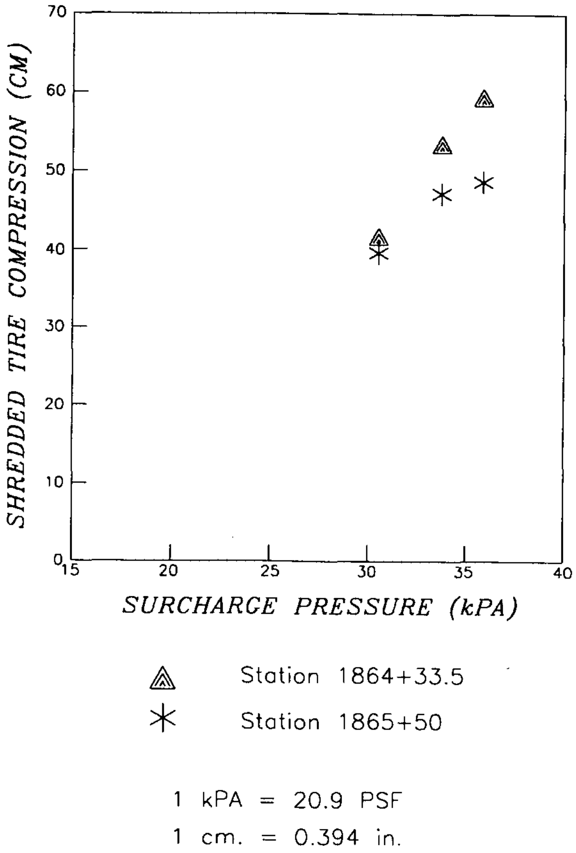


FIGURE 7 Shredded tire compression versus surcharge.

sentative of that intended by the specifications. This density is consistent with 470 kg/m^3 (29 pcf) loose density estimated from the data for the Minnesota project (*1*). The computed 390 kg/m^3 (24 pcf) density appeared to be the result of oversize material and should not be considered typical.

Density increased approximately 10 percent after hauling 64 km (40 mi). Density was not estimated after the full haul distances of 240 to 400 km (150 to 250 mi). Density appeared to increase with greater haul distances.

Compacted Density

The average compacted density was estimated by dividing the weight of shredded tires incorporated in the embankment by the volume occupied by the tires at the end of compaction. Weight was estimated from quantities delivered minus the reject and excess. Volume was estimated from cross sections on 15.2-m (50-ft) centers before placement and after compaction.

Surcharged Density

The average surcharged density was estimated following loading with 0.9 m (3 ft) of soil, 58.4 cm (23 in.) of aggregate base, 15.2 cm (6 in.) of asphalt pavement, and 3 months of highway traffic. This density was determined by adjusting the volume of compacted tires to compensate for the compression of the tire fill. Compression was measured at settlement plate locations and extrapolated to the rest of the fill by assuming that settlement was directly proportional to shredded tire thickness.

Final Density

Compression associated with the final 5.1-cm (2-in.) pavement lift and 1 year of creep settlement was also estimated by adjusting previous estimates for settlement.

Survey Monuments

Survey monuments consisted of driven pins spaced at 15.2-m (50-ft) intervals long three lines (Figure 2). Survey monument data were reduced to yield plots of deflection versus station for each of the three lines (Figure 8). The deflection shown in the plots is the total deflection measured from December 1990 to June 1991. After June, no additional measurements were taken before the hubs were paved over in September 1991.

TABLE 1 Shredded Tire Densities

Condition	Density
Loose Density (as loaded in trucks)	390 - 485 kg/m^3 (24 - 30 pcf)
Loose Density (after 64 km haul in trucks)	535 kg/m^3 (33 pcf)
Compacted Density (after three dozer passes)	730 kg/m^3 (45 pcf)
Surcharged Density (after final pavement lift)	845 kg/m^3 (52 pcf)
Final Density (after 1 year of compression)	860 kg/m^3 (53 pcf)

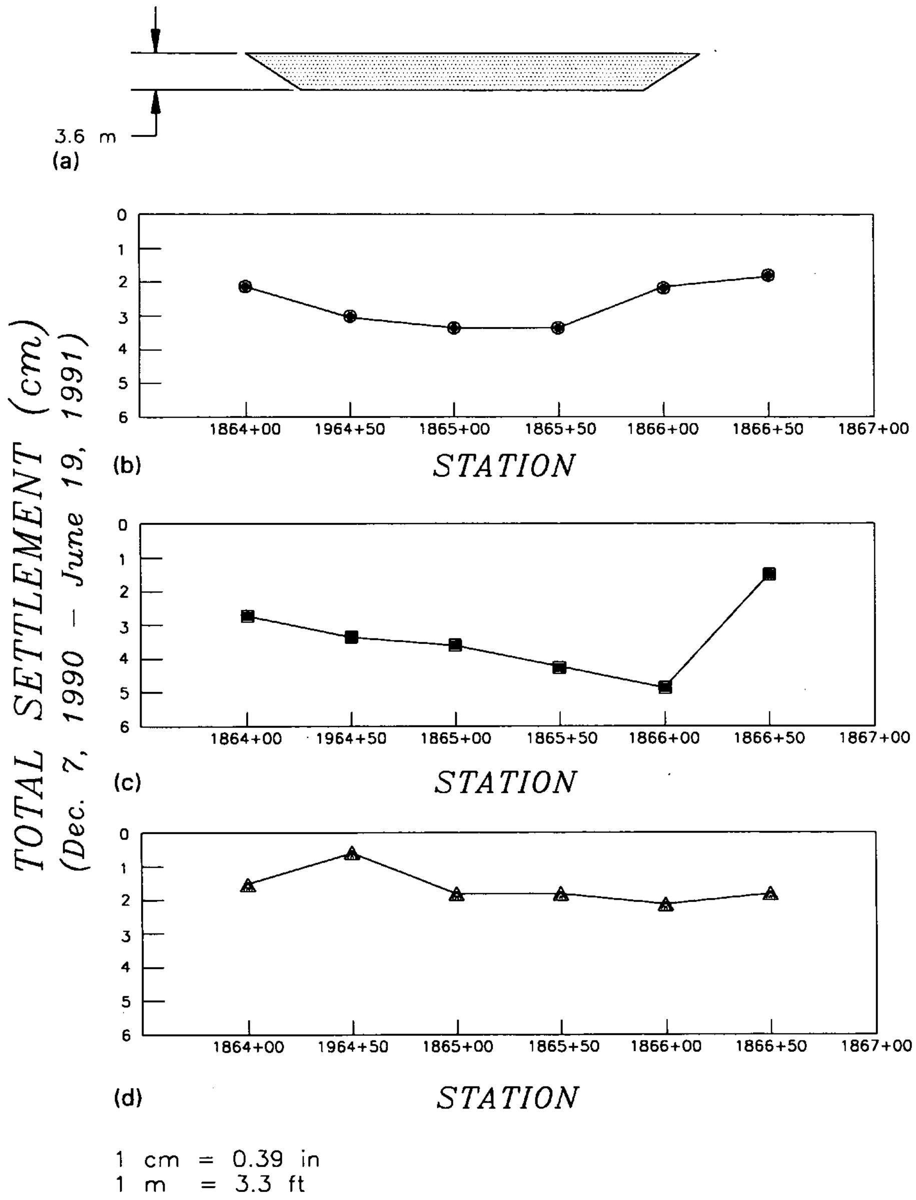


FIGURE 8 **Survey monument data: (*a*) approximate compacted shredded tire thickness at shoulder, (*b*) centerline, (*c*) shoulder, (*d*) embankment toe.**

Deflectometer Tests

Falling weight deflectometer tests, commonly used to estimate overlay thickness in road surface rehabilitation projects, consist of dropping a weight equivalent to 40 kN (9,000 lb) onto the highway surface and measuring deflection near the impact point. The tests were conducted at the landslide repair site at approximately 15.2-m (50-ft) intervals along the eastbound lane over the shredded tire fill and beyond each end. Deflection test results for each of three test dates were plotted versus highway station (Figure 9).

OBSERVATIONS

The project engineer made periodic site visits to inspect the installation. The embankment over the shredded tire fill section consistently appeared to be performing well, with no signs of settlement, sloughing, or erosion. Embankment slopes retained their shape. No ground surface movement or cracks were observed that would suggest landslide activity. Inclinometer data also confirm that the landslide at the shredded tire fill is no longer moving.

During site visits at the various stages of pavement section construction, vibrations associated with truck traffic could also be felt. When the aggregate base course was in place, heavy commercial trucks would cause vibrations of the fill felt while each truck was over the shredded tires. After placement of the first lift of asphalt pavement the vibrations were less perceptible but could still be felt. After placement of the final asphalt pavement lift, heavy trucks could only be felt as their wheel passed within 6 m (20 ft) of the observer.

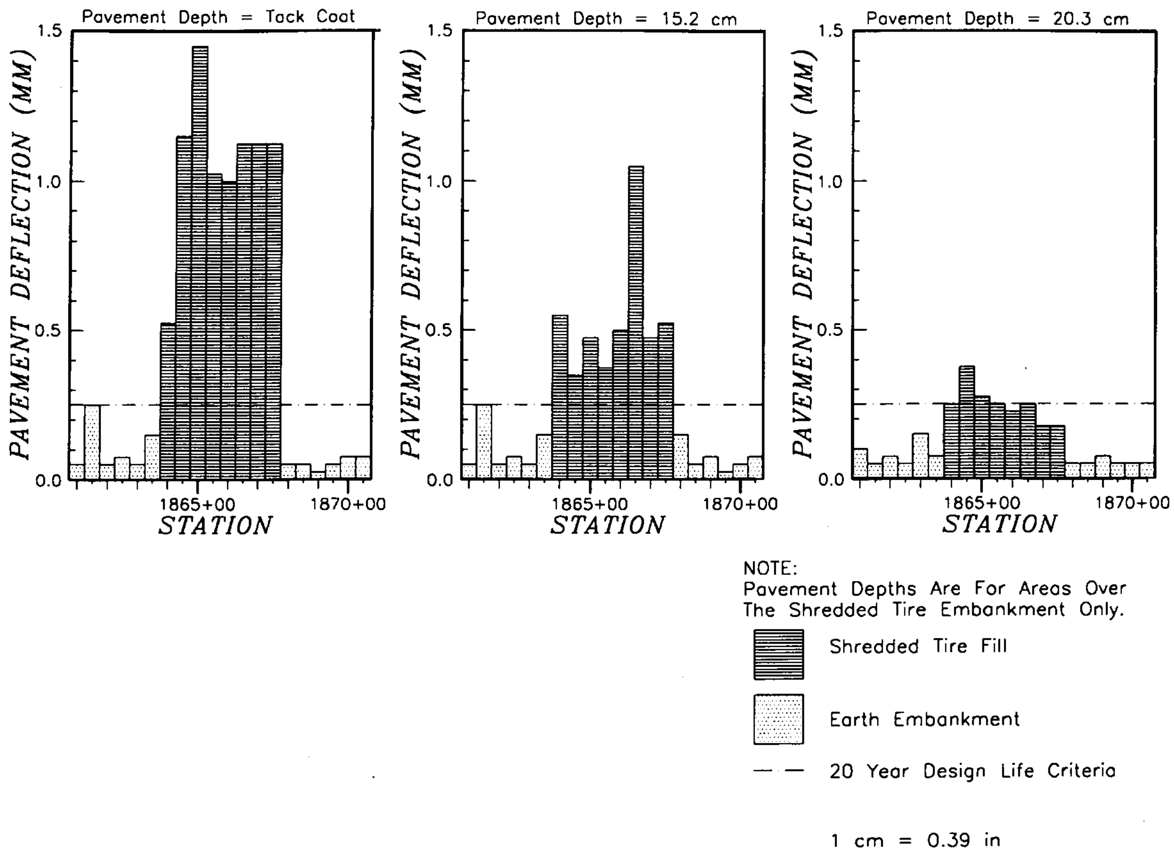


FIGURE 9 Deflectometer test data: *left*, October 30, 1990; *middle*, January 7, 1991; *right*, December 12, 1991.

DISCUSSION OF RESULTS

Shredded Tire Fill Compression

Shredded tire fill compression under surcharge loading was anticipated from experience at the Minnesota installation (*4*) where 2.7 m (9 ft) of shredded tires compressed approximately 10 percent under a 1.2-m (4-ft) soil cap.

At the landslide repair site, settlement plate data indicate that the 3.6-m (12-ft) shredded tire fill compressed 15 percent under the soil and pavement surcharge. A plot of shredded tire fill thickness versus time (Figure 6) shows compression in response to various stages of surcharge loading. A plot of shredded tire fill compression versus surcharge load is given in Figure 7.

The settlement plate data reflected compression of 1.3 and 3.1 (0.5 and 1.2 in.) under constant surcharge between January and September 1991. This indicates some type of creep compression or compression associated with traffic loading occurred in the shredded tires.

The survey monument data (Figure 8) indicate greater settlement near the center of the shredded tire fill and less toward the ends. The shredded tire fill is thicker near the center and thinner toward the ends, indicating a correlation between shredded tire thickness and compression.

Density Comparison

Table 2 gives a comparison of compacted and surcharged densities measured in this investigation and reported in other investigations.

The Minnesota installation (*1*) consisted of 2.8 m (9 ft) of shredded tires capped with 1.2 m (4 ft) of soil and aggregate. Chips size and compactive effort were similar to this investigation.

The laboratory test samples were 25.4 cm (10 in.) in diameter and 25.4 cm (10 in.) high. The chips used in the laboratory testing were 5 cm (2 in.) and smaller. Compactive effort simulated standard and modified Proctor tests (ASTM D698 and D1557).

Pavement Deflection

The first falling weight deflectometer test sequence was performed over the aggregate base course. It confirmed that an asphalt pavement section could be constructed over the shredded tire fill. Deflections were on the order of 1 m (0.04 in.).

The second test sequence was performed on the first lift of asphalt pavement and used as a design aid in selecting the

TABLE 2 Comparison of Compacted and Surcharged Densities

Installation	Compacted Density	Surcharged Density
This Investigation	730 kg/m^3 (45 pcf)	845 kg/m^3 (52 pcf)
Minnesota Installation (1)	550 kg/m^3 (34 pcf)	615 kg/m^3 (38 pcf)
Laboratory Testing (4)	650 - 665 kg/m^3 (40 - 41 pcf)	-[a]

[a] No data

final pavement lift thickness. It was decided to add 5.1 cm (2 in.) more pavement in the final lift. The third test sequence was used to confirm performance of the completed pavement section.

Results from the second and third test sequences displayed a greater deflection over the shredded tire fill relative to the surrounding earth fill. On the basis of these deflection measurements, the shredded tire fill appears to represent a softer subgrade than does the surrounding earth embankment. The deflection magnitudes measured in the third test sequence meet Oregon Department of Transportation (ODOT) criteria for a 20-year pavement design life.

Groundwater Levels

The groundwater levels were monitored in the slotted inclinometer casing. A plot of groundwater levels for the monitoring period is given in Figure 5. Groundwater levels were consistently 0.6 to 1.8 m (2 to 6 ft) below the bottom of the rock blanket at the inclinometer installations. This indicates that the rock blanket and french drain system were successful in maintaining the groundwater level below the shredded tires.

SUMMARY

As part of a landslide repair project on a highway in southern Oregon, a lightweight fill was constructed of shredded tires. The embankment was instrumented and monitored for 1 year after construction.

Deflectometer tests indicate that the pavement section over the shredded tire fill meets 20-year design life criteria; however, it deflects more than a similar pavement section over earth embankment.

ACKNOWLEDGMENTS

The authors thank FHWA for funding this project as part of the Experimental Projects program. The authors also thank Tim Dodson of ODOT for designing the shredded tire fill and initiating the monitoring program. Joe Thomas (ODOT) also contributed to the field work as construction inspector.

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