

# Tire shreds as lightweight fill for construction on weak marine clay

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**ABSTRACT:** Tire shreds were used as lightweight fill to improve slope stability for two highway projects constructed on weak marine clay. Tire shreds, which are scrap tires that have been cut into 50 to 300 mm pieces, were chosen because they have an in-place density of 0.80 to 0.93 Mg/m<sup>3</sup>, which is less than half the density of conventional soil fill. In the first project, a 4.3-m thick zone of tire shreds was used as lightweight fill to improve global stability of a bridge approach fill founded on weak marine clay. In addition, the tire shreds reduced horizontal pressure on the bridge abutment. Some 400,000 tires were used in the project. In the second project, two layers of tire shreds, each up to 3.05 m thick, were used as lightweight fill for a highway embankment founded on 9 m of weak marine clay. This project used about 1.2 million tires.

## 1 INTRODUCTION

Tire shreds are scrap tires that have been cut into pieces with a maximum size ranging from 50 to 300 mm (ASTM 1998). This material is lightweight, free draining, and compressible. Moreover they have a thermal resistivity that is about seven times higher than soil and they produce low earth pressure. Because of their special properties tire shreds are increasingly being used as lightweight fill for embankments constructed on weak foundation soils (Humphrey et al. 1998; Whetten et al. 1997), lightweight backfill for retaining walls and bridge abutments (Tweedie et al. 1997, 1998a,b; Humphrey et al. 1998), compressible inclusions behind integral abutment and rigid frame bridges (Humphrey et al. 1998; Reid & Soupier 1998), thermal insulation to limit frost penetration beneath roads (Humphrey & Eaton 1995; Lawrence et al. 1999), and drainage layers for road (Lawrence et al. 1999) and landfill applications (Jesionek et al. 1998). In 1998 approximately 18 million tires were used in these applications in the United States.

Civil engineering applications of tire shreds had a significant setback in 1995 and early 1996 when three thick tire shred fills (each greater than 8 m thick) experienced a serious self-heating reaction, however, guidelines to limit self-heating are now available (Ad Hoc Civil Engineering Committee 1997; ASTM 1998). Key features of the guidelines are to use larger size tire shreds, limit the amount of fine material in the shreds, limit layer thicknesses to 3 m, and limit the access of the fill to water and air.

The full guidelines are contained in ASTM D6270-98, *Standard Practice for Use of Scrap Tires in Civil Engineering Applications* (ASTM 1998). Field studies have shown that tire shreds have a negligible effect on water quality (Downs et al. 1997; Humphrey et al. 1997, 1999a,b; Humphrey & Katz, 2000).

This paper presents two case histories using tire shreds as lightweight fill for highway embankments constructed on weak marine clay foundations. In the first project tire shreds were used as lightweight fill and bridge abutment backfill for the approach embankment for the North Abutment of the Merry-meeting Bridge in Topsham, Maine. In the second project tire shreds were used for two approach embankments for a new bridge over the Maine Turnpike in Portland, Maine. From the information presented below, it will be clear that tire shreds are a viable material for use as lightweight fill for highway construction on weak marine clays and similar applications.

## 2 NORTH ABUTMENT APPROACH FILL

The key element of the Topsham Brunswick Bypass Project was the 300-m long Merry-meeting Bridge over the Androscoggin River. The subsurface profile at the location of the North Abutment consisted of 3 to 6 m of marine silty sand overlying 14 to 15 m of marine silty clay. The clay is underlain by glacial till and then bedrock. The existing riverbank had a factor of safety against a deep seated slope failure

that was near one. Moreover, the design called for an approach fill leading up to the bridge abutment that would have further lowered the factor of safety. Thus, it was necessary to devise a strategy to both improve the existing factor of safety and allow construction of the approach fill. The best solution was to excavate some of the existing riverbank and replace it with a 4.3-m thick layer of tire shreds. Tire shreds had the added advantage of reducing lateral pressures against the abutment wall. Other types of lightweight fill were considered including geofom and expanded shale aggregate. However, tire shreds proved to be the lowest cost solution. The project used some 400,000 scrap tires (Whetten et al. 1997).

## 2.1 Project Layout and Construction

The surficial marine sand was excavated to elevation 5.2 m and then the H-pile supported abutment wall was constructed. A 4.3-m thick zone of tire shreds was placed from station 53+50.6 m to the face of the abutment wall at station 53+72.0 m. The fill tapers from a thickness of 4.3 m at station 53+50.6 m to zero thickness at station 53+35.4 m thus providing a gradual transition between the tire shred layer and the conventional fill. It was estimated that the tire shred layer would compress 460 mm due to the weight of overlying soil layers. As a result, the layer was built up an additional 460 mm so that the final compressed thickness would be 4.3 m. The tire shred layer was enclosed in a woven geotextile (Nylon Mirafi 500X) to prevent infiltration of surrounding soil. The tire shreds were spread with front end loaders and bulldozers and then compacted by six passes of a smooth drum vibratory roller with a static weight of 9.4 metric tons. The thickness of a compacted lift was limited to 305 mm. Tire shred

placement began on September 25, 1996 and was completed on October 3, 1996. A longitudinal section of the completed abutment and embankment is shown in Figure 1.

This project was designed and built prior to development of the guidelines to limit self-heating of tire shred fills. However, the project did include some design features to limit self-heating. The first was to use larger size shreds (called Type B shreds) in the lower portion of the fill from elevation 5.2 m to elevation 8.2 m. The Type B shreds were specified to have a maximum dimension, measured in any direction, of 305 mm; a minimum of 75% (by weight) passing the 203-mm square mesh sieve, a maximum of 25% (by weight) passing the 38-mm square mesh sieve, and a maximum of 5% (by weight) passing the No. 4 (4.75-mm) sieve. Gradation tests showed that the shreds generally had a maximum dimension smaller than 150 mm. Type A shreds, with a maximum size of 75 mm, were placed from elevation 8.2 m to the top of the tire shred fill. It would have been preferable to use the larger Type B shreds for the entire thickness, however, a significant quantity of Type A shreds had already been stockpiled near the project prior to the decision to use larger shreds. It was judged that it would be acceptable to use the smaller Type A shreds in the upper portion of the fill. Moreover, it would have been preferable to limit the total thickness of the tire shred layer to 3 m as recommended by the guidelines to limit self-heating.

As an additional step to reduce the possibility of self-heating, the tire shreds are overlain by a layer of compacted clayey soil with a minimum of 30% passing the No. 200 (0.075 mm) sieve. The purpose of the clay layer is to minimize the flow of water and air through the tire shreds. The clay layer is ap-

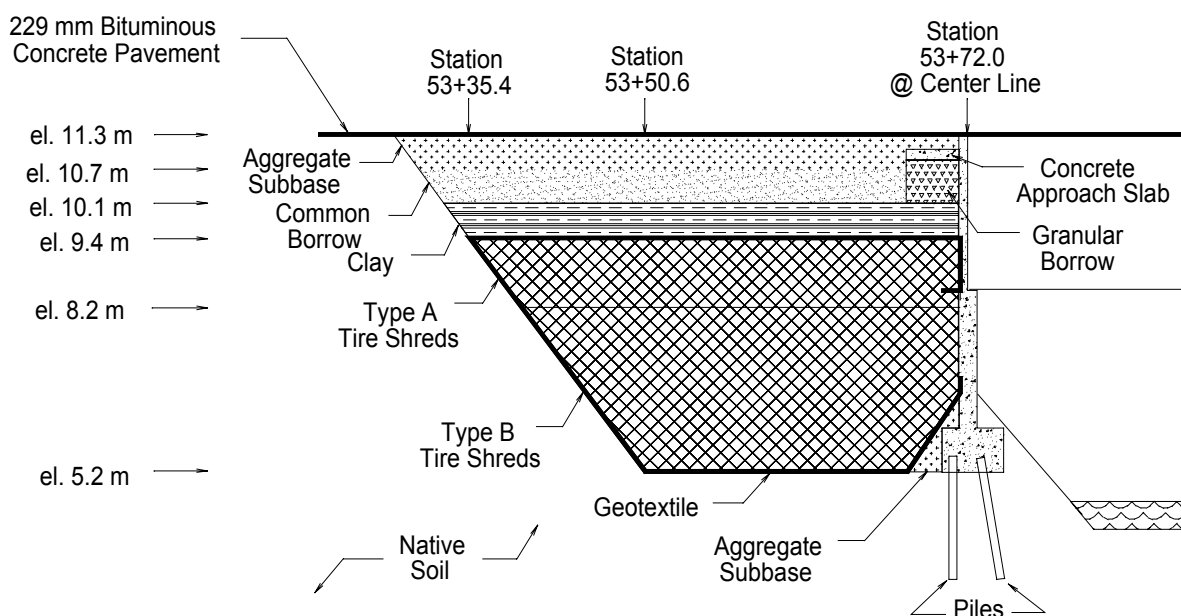


Figure 1. Cross section through North Abutment tire shred fill.

proximately 0.6 m thick and is built up in the center to promote drainage toward the side slopes. A 0.6-m thick layer of common borrow was placed over the clay layer. Overlying the common borrow is 0.76 m of aggregate subbase.

Tire shreds undergo a small amount of time dependent settlement. For this project a thick tire shred fill adjoined a pile supported bridge abutment. This led to concerns that there could be differential settlement at the junction with the abutment. However, Tweedie et al. (1997) showed that most of the time dependent settlement occurs within the first 60 days. To accommodate the time dependant settlement prior to paving, the contractor was required to place an additional 0.3 m of subbase aggregate as a surcharge to be left in place for a minimum of 60 days. In fact, the overall construction schedule allowed the contractor to leave the surcharge in place from October, 1996 through October, 1997. The surcharge was removed in October, 1997 and the roadway was topped with 229 mm of bituminous pavement. The highway was opened to traffic on November 11, 1997. Additional construction information is given in Cosgrove and Humphrey (1999).

## 2.2 Instrumentation

Four types of instruments were installed: vibrating wire settlement gauges, settlement plates and temperature sensors placed in the tire shred fill; and pressure cells cast into the back face of the abutment wall. The vibrating wire settlement gages gave no useful readings and will not be discussed. Six settlement plates were installed. SP1-1 and SP2-1 were at the base of the tire shred layer. SP1-2 and SP2-2 were at the mid-height of the tire shred layer. SP1-3 and SP2-3 were at the top of tire shred layer. Vibrating wire pressure cells were installed to monitor lateral earth pressure against the abutment wall. Three Roctest model TPC pressure cells (PC1-1, PC1-2, PC1-3) were installed on the face of the abutment wall 4 m right of centerline at elevations 6.7, 7.8, and 8.8 m. Three Roctest model EPC pressure cells (PC2-1, PC2-2, PC2-3) were installed 4 m left of centerline at the same elevations. Tire shreds were placed against all the cells.

## 2.3 Measured Horizontal Pressure and Settlement

The lateral pressure at the completion of tire shred placement (10/3/96) and completion of soil cover and surcharge placement (10/9/96) is summarized in Table 1. Lateral pressures on 10/31/96 are also shown. It is seen that at completion of tire shred placement, the pressures increased with depth. However, at completion of soil cover and surcharge

placement, the pressures recorded by cells PC1-1, PC1-2, and PC1-3 were nearly constant with depth and ranged between 17.1 and 19.6 kPa. These findings are consistent with at-rest conditions measured on an earlier project (Tweedie et al. 1997; 1998a). Cells PC2-1, PC2-2, and PC2-3 showed different behavior. On 10/9/96, cell PC2-2 showed a pressure of 30.2 kPa while cell PC2-1, located only 1.07 m lower, was 20.0 kPa and cell PC2-3, located 1.07 m above PC2-2, was 12.31 kPa. These cells were the less stiff EPC cells. Large scatter has been observed with EPC cells on an earlier tire shred project (Tweedie et al. 1997, 1998a,b). This is thought to be due, at least in part, to large tire shreds creating a nonuniform stress distribution on the face of the pressure cell. The average pressure recorded by the three PC2 cells was 20.9 kPa, which is slightly higher than the PC1 cells. Between 10/9/96 and 10/31/96 the lateral pressure increased by 1 to 2 kPa. The pressures have been approximately constant since that time.

Table 1. Summary of lateral pressures on abutment wall.

	PC1-1	PC2-1	PC1-2	PC2-2	PC1-3	PC2-3
Date	Cell el.=6.70m	Cell el.=7.77m	Cell el.=8.84m			
10/3/96 <sup>2</sup>	7.84 <sup>1</sup>	7.41	6.04	7.27	2.62	1.41
10/9/96 <sup>3</sup>	17.04	20.04	19.61	30.22	17.05	10.91
10/31/96	18.27	21.05	20.98	32.84	20.24	12.31

<sup>1</sup>Horizontal pressure in kPa.

<sup>2</sup>Date tire shred placement completed.

<sup>3</sup>Date soil cover and surcharge placement completed.

Settlement during construction is shown in Figure 2. By the end of fill placement the tire shred fill compressed about 370 mm as indicated by plates SP1-3 and SP2-3. Post construction settlement is shown in Figure 3. In the first 60 days after the end of fill placement, the top of the tire shred layer settled an additional 135 mm. Between December 15, 1996 and December 31, 1997 the fill underwent an additional 15 mm of time dependent settlement. By late 1997, the settlement of the plates at the mid-height of the tire shred layer (SP1-2 and SP2-2) and top of the tire shred layer (SP1-3 and SP2-3) had essentially stopped

The total compression of the tire shred fill was 520 mm, which was 13% greater than the 460 mm that was anticipated based on laboratory compression tests. The difference is due, at least in part, to time dependent settlement that is not accounted for in the short term laboratory tests. The final compressed density of the tire shreds was about 0.9 Mg/m<sup>3</sup>.

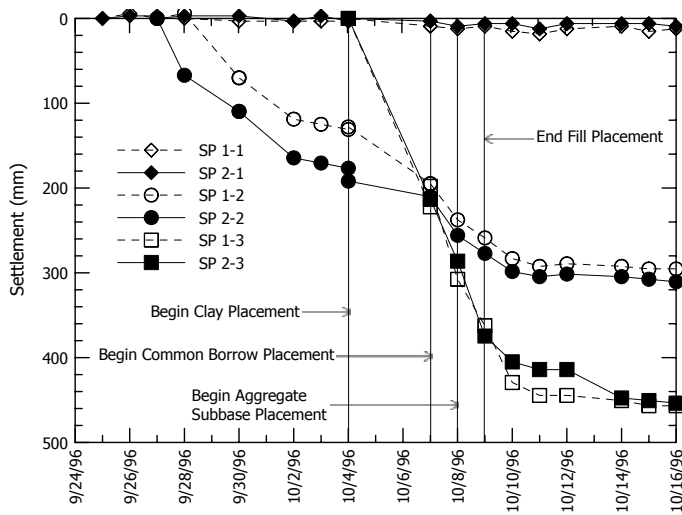


Figure 2. Settlement of the North Abutment fill during construction.

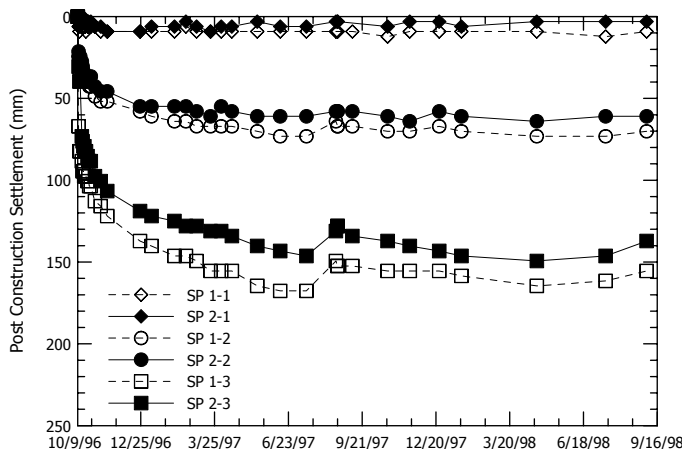


Figure 3. Post-construction settlement of the North Abutment fill.

#### 2.4 Temperature of Tire Shred Layer

A small amount of self heating of the tire shreds occurred. Five out of the 12 thermistors in Type A shreds experienced a peak temperature of between 30 and 40°C. In contrast, only two of the 18 thermistors in the larger Type B shreds experienced a peak in this range and these two sensors may have been influenced by warmer overlying Type A shreds. This suggests that larger shreds are less susceptible to heating. In any case, the peak temperatures were too low to be of concern. Since early 1997, the overall trend has been one of decreasing temperature, however, the temperature of the shreds do appear to be slightly influenced by seasonal temperature changes.

### 3 PORTLAND JETPORT INTERCHANGE

Tire shreds were used as lightweight fill for construction of two 9.8-m high highway embankments in Portland, Maine (Humphrey et al. 1998). These embankments were the approach fills to a new bridge over the Maine Turnpike. The bridge is part

of a new interchange that will provide better access to the Portland Jetport and Congress Street. This site was underlain by about 12 m of weak marine clay. Test results indicated that the clay is an over-consolidated, moderately sensitive, inorganic clay of low plasticity. Undrained shear strength varied from approximately 72 kPa near the top to 19 kPa near the center of the layer.

The designers for the project (the Maine offices of HNTB, Inc. and Haley and Aldrich, Inc. and the University of Maine) found that embankments built of conventional soil were too heavy resulting in an unacceptably low factor of safety against slope instability. They looked at several ways to strengthen the foundation soils but these were too costly. Constructing the embankments of lightweight fill was chosen as the lowest cost alternative. They considered several types of lightweight fill including tire shreds, expanded polystyrene insulation boards, and expanded shale. Tire shreds were chosen because they were \$300,000 (US) cheaper than the other alternatives. Moreover, the project would put some 1.2 million tires to a beneficial end use. Wick drains were also used to accelerate consolidation of the foundation soils.

#### 3.1 Project Layout and Construction

Several steps were taken to comply with the guidelines to limit heating of thick tire shred fills (Ad Hoc Civil Engineering Committee 1997; ASTM 1998). The guidelines required that a single tire shred layer be no thicker than 3 m, so the tire shred layer was broken up into two layers, each up to 3 m thick, separated by 0.9 m of soil as shown in Figure 4. Low-permeability soil with a minimum of 30% passing the No. 200 (0.075 mm) sieve was placed on the outside and top of the fill to limit inflow of air and water. The final precaution to limit heating was to use large shreds with a minimum of fines. The shreds had less than 25% passing the 38-mm sieve and less than 1% passing the No. 4 sieve (4.75-mm). The shreds had a maximum size measured in any direction of 300 mm to ensure that they could be easily placed with conventional construction equipment. The embankment was topped with 1.22 m of granular soil plus 1.22 m of temporary surcharge. The purpose of the surcharge was to increase the rate of consolidation of the soft clay foundation soils and was unrelated to the tire shred fill.

The tire shreds were placed with conventional construction techniques. First geotextile was placed on the prepared base. Then the shreds were spread in 300-mm lifts using a Caterpillar D-4. Each lift was compacted with six passes of a vibratory roller with a minimum 9.1-metric ton operating weight. After placing the shreds, the contractor placed a geotextile separator on the sides and top of the tire shred zone and then the surrounding soil cover.

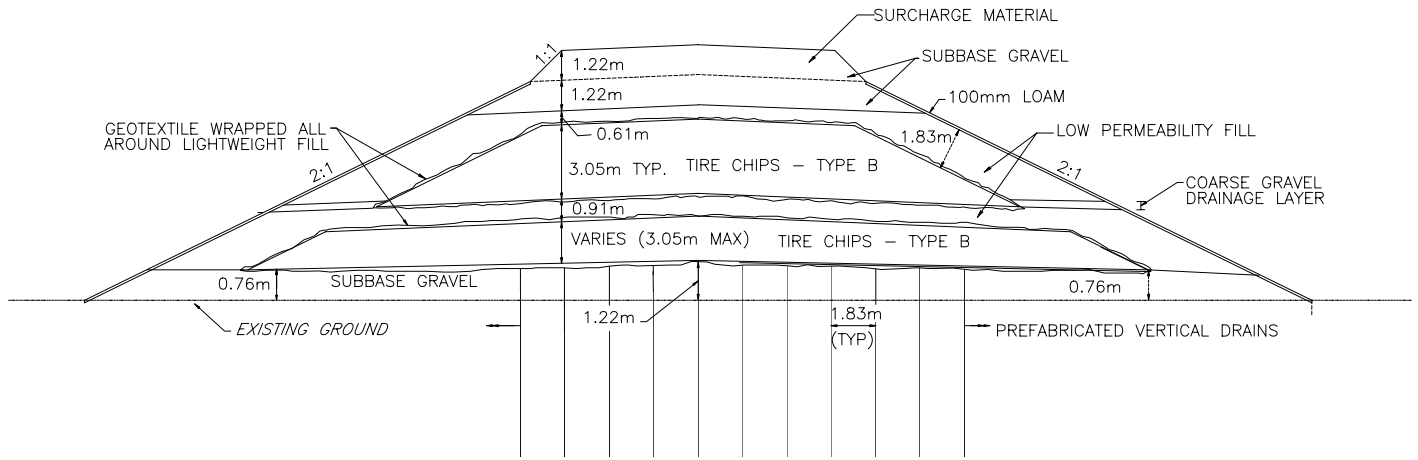


Figure 4. Cross section through embankment for the Portland Jetport Interchange (Humphrey et al. 1998).

### 3.2 Construction Settlement and Unit Weight

Settlement plates were installed at the top and bottom of each tire shred layer to monitor settlement. Compression of each tire shred layer at the end of fill placement is summarized in Table 2. The compression predicted based on laboratory compression tests on 75-mm maximum size tire shreds is also shown. It is seen that the predicted compression is significantly greater than the measured value. Thus, the compressibility of shreds with a 300-mm maximum size appears to be less than for 75-mm maximum size shreds. This was one factor that led to overprediction of the final in-place unit weight. The final in-place unit weight was predicted to be  $0.93 \text{ Mg/m}^3$  compared to an actual value of  $0.79 \text{ Mg/m}^3$ , a difference of 18%. This difference cannot be entirely accounted for by the difference in compressibility. Thus, it is likely that the initial (uncompressed) unit weight of these larger shreds is less than for 75-mm maximum size shreds.

Table 2. Measured compressibility on centerline of tire shred layer for Portland Jetport Interchange project.

Plate	Station	Lower layer		Upper layer	
		Measured	Predicted	Measured	Predicted
SW1	7+62	12.6%	22%	8.3%	14%
SW4	7+92	13.4%	21%	11.2%	14%
SE1	9+14	19.1%	22%	10.9%	14%
SE4	9+45	17.3%	23%	9.3%	14%
Average		15.6%	22%	9.9%	14%

### 3.3 Temperature Measurements

Monitoring the temperatures of the tire shred fill was of great interest because of past problems with heating of thick tire shred fills (Humphrey 1996). The warmest temperatures were measured at the time of placement when the black tire shreds were heated by exposure to direct sunlight. Initial temperatures ranged from 24 to  $38^\circ\text{C}$ . After being covered with the first few lifts of fill, the temperatures began

dropping with time. Temperatures had stabilized between 11 and  $15^\circ\text{C}$  when monitoring was discontinued in July 1999. Typical temperature measurements are shown on Figures 5 and 6.

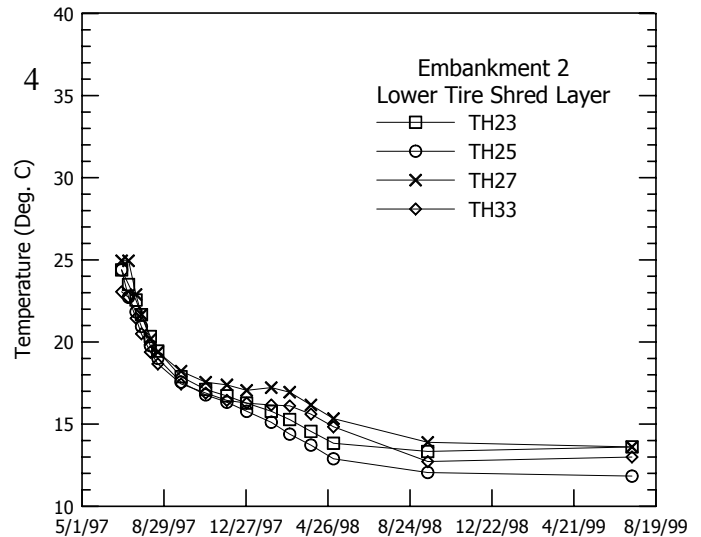


Figure 5. Temperatures in lower tire shred layer of light-weight embankment fill at Portland Jetport Interchange.

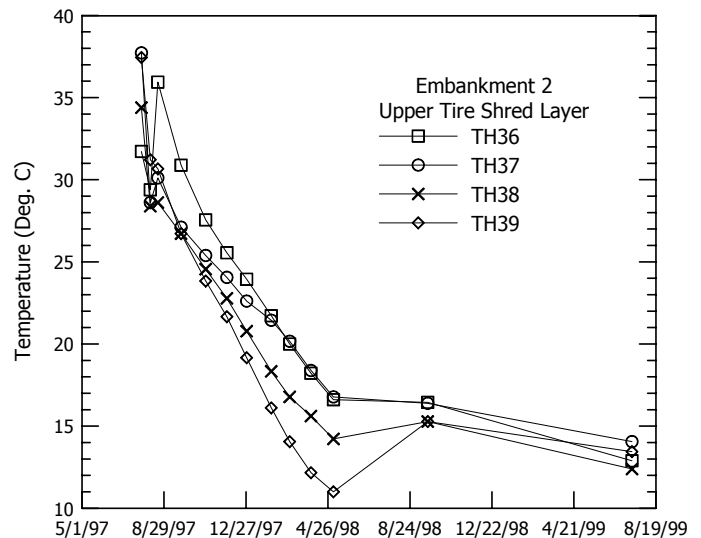


Figure 6. Temperatures in upper tire shred layer of light-weight embankment fill at Portland Jetport Interchange.

## 4 SUMMARY

The low unit weight, widespread availability, and low cost of tire shreds has led to their being used as lightweight fill for embankments constructed on weak foundation soils. The engineering properties of tire shreds are known including gradation, unit weight, compressibility and shear strength. When the special properties of tire shreds are needed for a project they are often the lowest cost alternative. Thus, civil engineers are choosing tire shreds because they offer both the properties needed to solve special problems and lower costs to satisfy the demands of their clients for the most economical project possible. In the next few years, major increases in the number of scrap tires used for civil engineering applications is possible because of their growing record of successful performance combined with guidelines to limit self-heating of thick fills, recently published ASTM guideline specifications, and groundwater data showing that they have a negligible environmental impact.

## ACKNOWLEDGEMENTS

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