TIRE SHRED EMBANKMENTS: DESIGN AND CONSTRUCTION CONSIDERATIONS VERIFICATION THROUGH MONITORING

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ABSTRACT: The New York State Department of Transportation (NYSDOT) constructed a pilot project using tire shreds as embankment fill. The prototype section, measuring 200 meters in length, utilized approximately 2,500 metric tons of tire shreds (265,000 tires) as the core of the embankment section. The tire shred zone had a maximum thickness of 3 m. The tire shreds were covered with 1.5 and 1.0 m of embankment fill on the top and sides respectively. The entire section was then surcharged with an additional 1.25 to 2.5 m of fill. After four months, the surcharge was removed to subgrade elevation, the granular base was placed and the section was paved. The tire shreds were produced by a hook and shear shredder, were placed in the fill with a front end loader and compacted with a smooth drum roller. Instrumentation of the prototype section was monitored both during and after construction. In all, 10 settlement platforms, 15 temperature sensors, 2 ground water collection systems and a ground water observation well were installed and monitored. Settlements were as expected, based on previous projects and temperature measurements showed that there was no internal heating of the tires shreds.

1 INTRODUCTION AND HISTORY

Waste tire stockpiles in the US contained over 500 million tires in 1999 with 270 million more entering the waste stream every year, representing serious potential health and environmental problems. NYSDOT has historically been very proactive when it comes to using recycled materials in transportation projects but had no knowledge or experience in using tire shreds. It was therefore decided to establish a pilot project that would allow NYSDOT to properly design, develop specifications, construct and evaluate (via instrumentation and monitoring) the use of tire shreds for infrastructure applications. Prior experience using tire shreds gained by the Maine DOT and described by Humphrey (1997) was valuable in developing the pilot study.

2 PROJECT DEVELOPMENT

Criteria were developed for the selection of an appropriate site and it was determined that the prototype embankment site should be a new fill section on a new alignment with low traffic volume, away from structures, heavily populated areas and drinking water resources. Efforts should be made so that the height of the prototype embankment is minimized, yet still allow a 1.5 m minimum cover over the top of tire shreds to avoid differential icing and minimize internal heating. The bottom of tire shreds should be above the groundwater table.

As per Upton (1993), Humphrey (1997), Humphrey (1998), ASTM (1998) engineering properties of tire shreds have lent themselves to several excellent and successful engineering uses, primary among these being as lightweight fill and drainage media. NYSDOT wanted to gain experience with the tire shred design process, development of tire shred construction specifications, processing and supplying of the tire shreds, contractors handling of the tire shred material and construction monitoring without taking any risk of negatively impacting the surrounding area.

The project that closely met all of the criteria was the reconstruction of Route 17 in the towns of Windsor and Kirkwood, east of Binghamton, NY. It involved eliminating at-grade crossing by constructing new service roads on both sides of Route 17 and connecting them with new bridges via several new fill sections for on and off ramps.

3 DESIGN

The actual design of the prototype embankment is no different than any other roadway embankment. In addition to there being adequate factors of safety against base sliding, bearing capacity and slope failure while the settlements are being checked, there must also be sufficient sliding stability between the geotextile-tire shred and geotextile-embankment fill interfaces.

The plan and a typical section for the prototype embankment are shown in Figures 1 and 2. In plan, the embankment is approximately 200 m long, runs in the east-west direction and was constructed on an existing side slope with an approximate grade of 5%. In cross-section, a layer of geotextile was placed on the natural ground to act as a separator between the tire shreds and the natural ground as well as between the tire shreds and the embankment fill/cover. The tire shred core of the prototype embankment, had a thickness up to 3 m and was completely covered with 1.0 to 1.5 m of embankment fill and then surcharged with an additional 1.25 to 2.5 m of fill. The purpose of the surcharge was to minimize long term settlement of the tire shreds, however, it should be noted that negligible long term settlement has been obtained for projects with no surcharge, as per Upton (1993) or minimal (0.3 m) surcharge as per Humphrey (1998). After two months surcharge period, the surcharge was removed to subgrade elevation, a 0.3 m granular base course was placed and the section was paved.

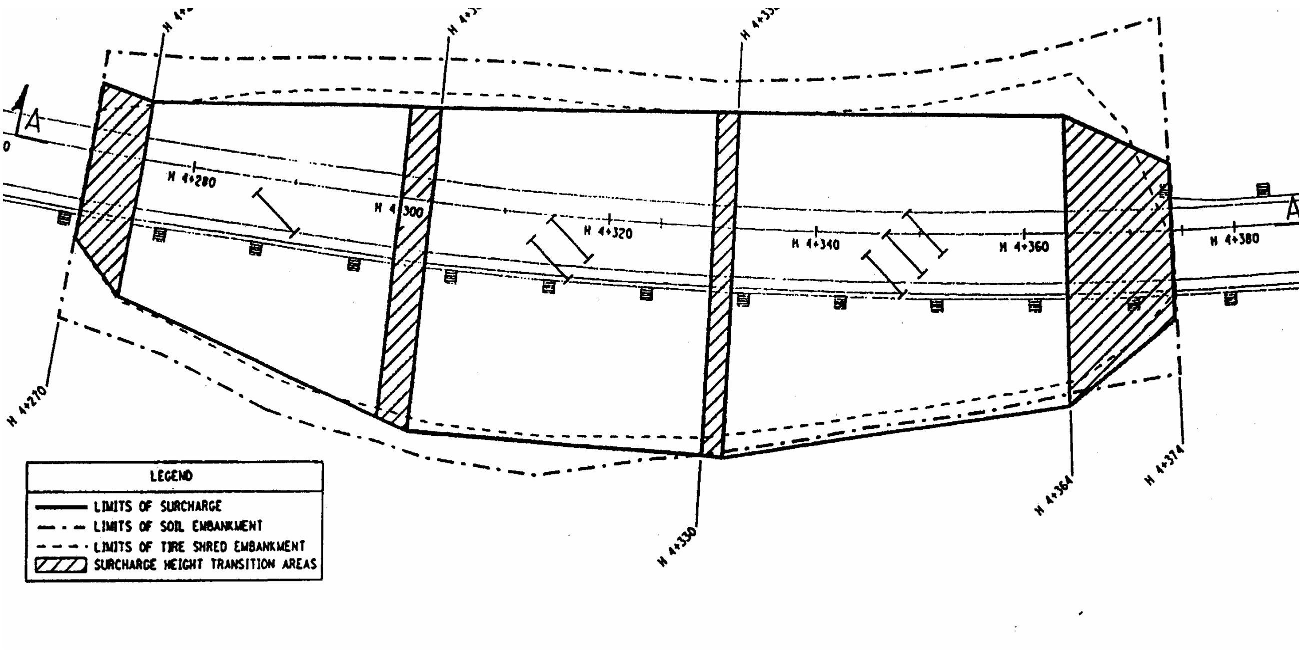

Figure 1 Prototype Embankment Plan

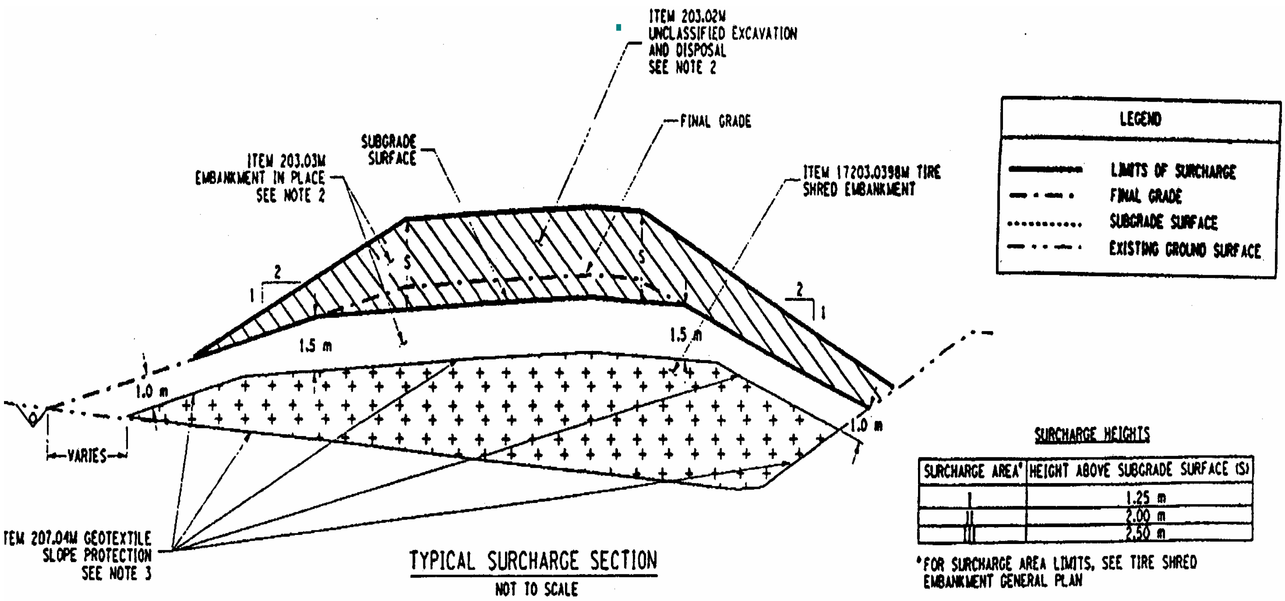

Figure 2 Typical Section of the Tire Shred Embankment

The biggest concern NYSDOT had during the design of the prototype embankment section was to minimize the possibility of internal heating of the tire shred fill. This concern stemmed from three tire shred fills completed in 1995 that experienced a disastrous self-heating reaction as per Humphrey (1996). As a result of these problems, the ASTM DE6270-98 guidelines to minimize internal heating of tire have been developed as per ASTM (1998). Among others, the guidelines recommend that the maximum thickness of a tire shred layer be 3 m while they give less stringent requirements for tire shred layers less than 1 m thick. NYSDOT incorporated ASTM guidelines into the project specifications. In addition, trench drains were designed and carried along the entire length of the section to prevent buildup of water in the bottom of the tire shred fill.

Instrumentation of the prototype embankment section was included as part of the design and construction. In all, 10 settlement platforms, 15 thermistors, 3 water observation wells and 2 water sampling collection points were installed. These results will be discussed in a subsequent section.

4 SPECIFICATIONS

Specifications modeled after the Maine DOT's and Nickels (1995) were written for the tire shred embankment, water sampling collection points and thermistors. In addition to the recommended guidelines, they included the following:

- Have one sidewall severed from each tire shred.
- Have less than 10% of individual tire shreds with a maximum dimension greater than 0.3 m.
- Meet the following shred gradation requirements

Sieve Size (mm)	% Passing by Weight
300	100
200	75-100
38	0-25
4.75	0-1

- Maximum loose lift thickness of the tire shreds could not exceed 300 mm.

5 SHRED PRODUCTION AND DELIVERY

Tire shreds were produced and supplied to the project using a hook and shear shredder with a 50 to 75 mm knife. Undersize material was removed with a 50 mm classifier. This method for removing the undersize material was very effective and the tire shreds easily met the specified gradation requirements. Oversize material exiting the shredding machine on a conveyor belt was removed by hand, and rerouted back on another conveyor belt into the shredder.

6 EMBANKMENT CONSTRUCTION

Construction of the prototype embankment began in early October, 1999, after stripping and removing topsoil and other unsuitable material from the prototype embankment site. About 300 tons of tire shred were delivered and stockpiled at the west end of the embankment site and a water sampling collection point was installed. NYSDOT drill crews also installed the first of three water observation wells on the uphill side of the prototype embankment section. Geotextile was then placed on the ground by unrolling the geotextile down the natural slope from the east end of the project to the west end, observing a minimum 0.45 m overlap as the work progressed. Geotextile was then held in place by placing bucket loads of tire shreds from a small front end loader along the edges. The loader was capable of driving directly on to the geotextile with no adverse affects to the geotextile or disruption to the overlaps. Once the geotextile was placed, five settlement platforms were installed on the foundation soil. The contractor then placed and spread the remainder of the 300 metric tons of tire shreds with a front end loader onto the geotextile. Compaction was achieved with eight passes of a smooth steel drum roller (9 tons min weight).

The contractor had little trouble constructing with tire shreds once he started the work. Minor problems related to the existence of soil material mixed with the shreds (as the contractor was scooping shreds close to the bottom of the stock pile) were eliminated by unloading all tire shreds directly onto the shred fill. The irregular delivery schedule (25 to 150 metric tons of tire shred per day) was the only thing that kept the contractor from constructing the prototype embankment faster. In early November 1999, approximately half of the tire shreds were in place and compacted. No significant problems other than infrequent delivery were encountered. By the end of November 1999, the tire shred core had been completely placed and compacted. The contractor pulled the remaining geotextile outside of the embankment area up and over the sides of the completed tire shred section. Once this was done, the side slope cover of embankment fill and the required surcharges were constructed. Although the placement of the side slope cover after the construction of the tire shred was effective, compaction was difficult near the edges of the tire shred because they were so compressible and not confined. It would have been better to place the embankment side slope fill in conjunction with the tire shreds to make the compaction process easier. Embankment construction was completed by the end of December 1999 and was then allowed to sit and settle over the winter. In April 2000, the surcharge was removed to subgrade elevation and in May 2000, the ramp was paved.

7 INSTRUMENTATION – MONITORING

7.1 *Temperature Data*

Nine temperature sensors were placed in the tire shred fill and an additional six sensors were placed in the adjoining control sections constructed with conventional earth fill material. Typical temperature data is plotted in Figures 3 and 4.

Temperatures in the tire shred fill during construction (November 1999) ranged from 0.0° to 16.7 °C (32.0° to 62.0° F). The higher readings occurred in the upper part of the tire shred fill and were probably caused by warm daytime air temperatures and solar radiation heating of the exposed shreds. The sensors in the control sections were installed after construction was completed.

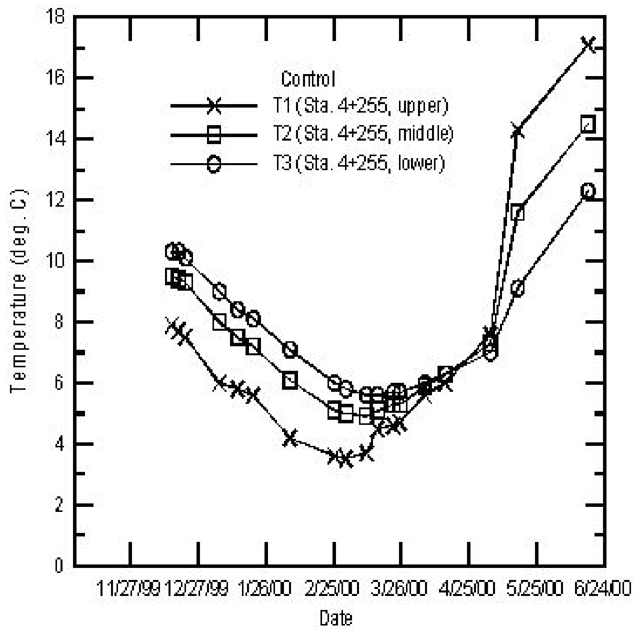

Figure 3 Temperature sensors in control section at station 4+255, on C/L

Temperatures in the period since fill placement was completed (mid December 1999) have ranged from 3.0° to 17.0° C (37.5° to 63.0° F) in the control section and 3.5° to 11.5° C (38.5° to 52.5° F) in the tire shred fill. During the winter, all instrumented stations showed the warmest temperature in the lower while the coolest in the upper portion of the fill respectively. Possibly this is due to the upper portion of the fill being closest to the cold winter air temperatures. During the summer (06/15/00) the trend is reversed with the warmest temperatures occurring in the upper portion of the fill. Thus, both in the control and the tire shred sections, the temperatures near the surface are increasing in response to warmer summer air temperatures. The similar response of the temperature sensors in the tire shred fill and control stations indicate that there is little or no self-heating occurring in the tire shred fill.

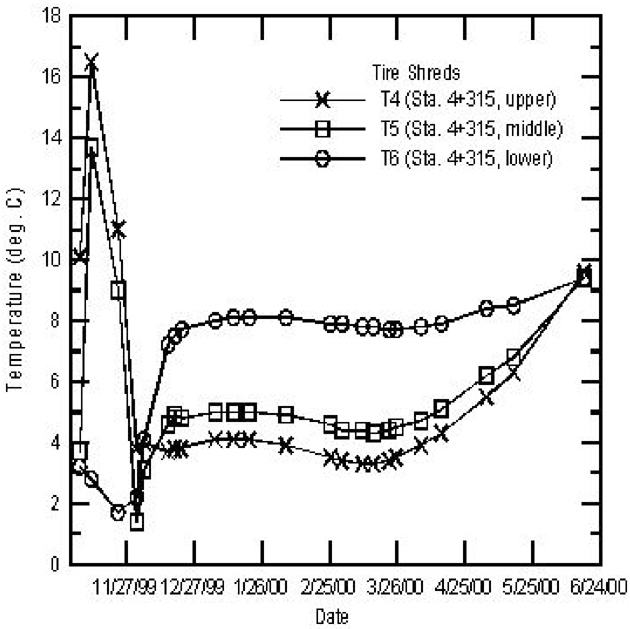

Figure 4 Temperature sensors in the tire shred fill at station 4+315, 8 m right

7.2 *Settlement Plates*

Ten settlement plates were installed-five on the underlying foundation soil and five on top of the tire shred layer. Readings for plates on the foundation soil were deemed unusable because of the tilt of the riser pipes during compaction. However, the foundation soils at this site are very firm and little settlement would be expected. Thus, in subsequent analyses it was assumed that the foundation settlement was negligible. However, two aspects of the settlement data from the plates on top of the tire shreds are of interest, compression during construction and time dependent post construction settlement.

The tire shred fill is compressed due to the weight of the overlying fill. The settlement was converted to strain by dividing the settlement by the initial thickness of the tire shred layer, which was assumed to be the design thickness of 3.0 m. The resulting plot is shown in Figure 5. The relationship was nearly linear and data from the five plates plotted within a narrow band. The latter in fact indicates that there was very little spatial variability in the compressibility of the tire shreds. To compare the compressibility of the tire shreds on this project with results from other projects, it is useful to compute the vertical strain of the tire shreds.

The computed strain was compared with the strain at the end of fill placement of the tire shred fills at the Portland Jetport Interchange in Portland, Maine as per Humphrey (1998) and (2000), which had shreds smaller than those used on the Binghamton project (300 mm max for the Jetport vs. approximately 450 mm max for Binghamton) and the north abutment of the Merrymeeting Bridge in Topsham, Maine as per Humphrey (1998) and (2000), which had even smaller shreds (75 to 150 mm). For the Portland Jetport Interchange, the strain at the end of fill placement was 9.9% and the overlying fill thickness was 2.9 m. At the same overlying fill thickness, the Binghamton project had 9.0% strain. For the Merrymeeting Bridge the strain at the end of the fill placement was 8.7% with an overlying fill thickness of 2.1 m. At the same overlying thickness, the Binghamton project had 6.5% strain. This suggests that larger shreds are less compressible than smaller shreds.

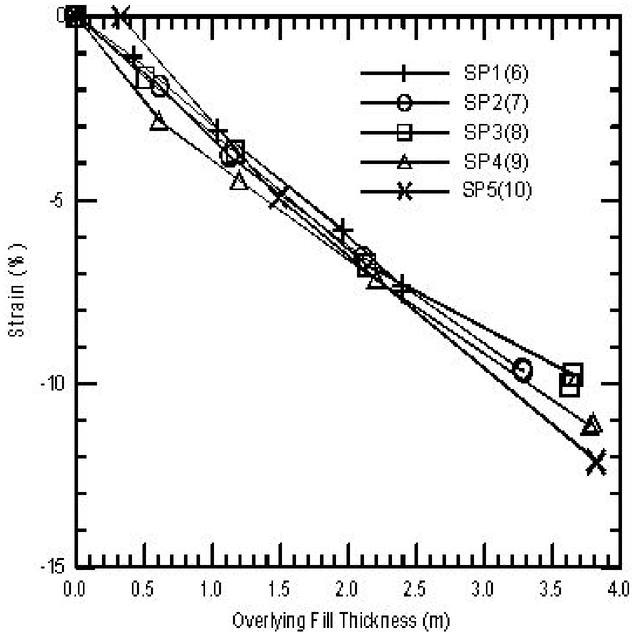

Figure 5 Strain versus Overlying Fill Thickness

Some time dependent settlement occurred after fill placement was completed. From 11/30/99 through 02/04/00 an additional 0.010 to 0.025 m of settlement occurred (Figure6).

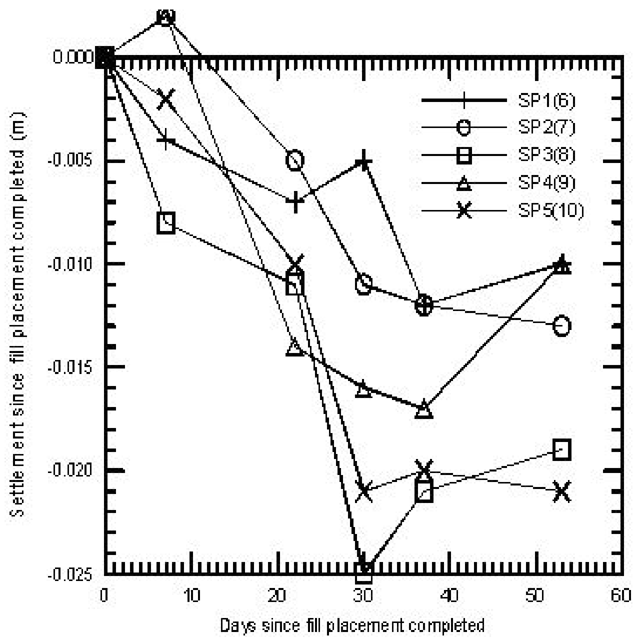

Figure 6 Settlement since completion of fill placement

In terms of vertical strain, an additional 0.3 to 0.9% strain occurred during this period. It appears that most of this settlement occurred within the first 30 days after fill placement and that by 02/04/00 time dependent settlement had largely stopped. Due to some scattering in the data, it has not been possible to draw absolute conclusions on time dependent settlement from this project. However, data from other projects shows that most of the time dependent settlement occurs within 30 to 60 days after construction, as per Tweedie (1998).

Using the settlement data, it is possible to estimate the final in-place density of the tire shred fill. Approximately 2,500 metric tons of shreds were placed on the project and the volume of the fill was 4,500 m^3. The vertical strain measurements indicated that the fill was compressed about 9%, so that final volume of the fill would be 4,100 m^3. Thus, the estimated final in-place unit weight was 0.61 Mg/m^3. This is much lower than has been measured in other projects. The Portland Jetport Interchange had a final in-place density of 0.79 Mg/m^3 while the fill behind the north abutment of the Merrymeeting Bridge had a density of 0.91 Mg/m^3 as per Humphrey (1998) and (2000). This suggests that final in-place density decreases as shred size increases.

8 QUANTITY & COST ESTIMATES

The estimated and actual construction costs for this project were about $118,000 and $84,000 respectively. In addition, the contractor was paid $235,000 or the equivalent of $94 per metric ton under the incentive program. This program prompted the contractor to use tires from abandoned stockpiles rather than the current flow of scrap tires. In all, 2,500 metric tons equating to 265,000 shredded tires were used. It is important to note that even though this prototype embankment was a very small section of a much larger embankment section for one ramp on the total project, a huge quantity of waste tires were consumed.

9 CONCLUSIONS

- Placement and compaction of tire shreds can be performed with typical construction equipment.
- The tire shred embankment design based on FHWA guidelines was effective in preventing internal heating problems.
- The immediate compression of tire shreds under the weight of overlying soil appears to decrease as the shred size increases. Likewise, the final in-place density of tire shreds appears to decrease as shred size increases.
- There is no water quality data collected to date. However, there is no reason to expect that primary water quality will be affected.
- Providing sufficient trucking capacity to transport the tire shreds from the production facility to the construction site in a timely fashion speeds up the construction process.
- Construct the shred fill and the soil cover simultaneously. This makes it easier and safer to compact the shreds.

10 PRACTICAL RECOMMENDATIONS

- When cleaning waste tire stockpiles, be aware that these piles may contain hidden “surprises” that can cause unexpected delays and increased costs. The contractual agreements should state who is responsible for this added cost.
- Do not specify any particular tire piles to clean up unless access to these sites has been granted.
- Be sure to consider shred production time in the contract documents, to avoid construction delays. In some cases, it may be wise to provide shreds under a separate contract, so as not to delay shred placement.
- Be sure to provide sufficient trucking capacity to transport the tire shreds from the production facility to the construction site in a timely manner.
- The scrap tire processor should either use a trammel screen or a disk screen (disk classifier) to remove oversize pieces and return them to the shredder for reprocessing. This will minimize the number of oversize pieces and enhance the desired degree of compaction. Using a laborer to visually examine the shreds and manually remove the oversize pieces is generally unacceptable.
- For other countries considering using tires from the current flow rather than abandoned stockpiles it should be noted that in the US, tire processing contractors are paid a tipping fee by tire dealers to pick up their scrap tires. In Central New York State the tipping fee is approximately $70 per metric ton. This covers a significant portion of the cost to process and deliver tire shreds and makes it possible to economically use the current flow of scrap tires for highway construction projects without state financial incentives.

11 ACKNOWEDGEMENTS

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