Lightweight Fill Materials for Road Construction

In cooperation with the Local Road Research Board "Sponsoring research for county and municipal roads and streets"
Acknowledgment

This project was funded by the Minnesota Local Road Research Board (LRRB). Legislation creating the Board was passed in 1959. The board appointments are made by the Commissioner of the Minnesota Department of Transportation (Mn/DOT). It includes four county and two city engineers whose terms are set at a maximum of two 3-year positions. Persons serving from Mn/DOT include the Director of the Research Administration Office, the State Aid Engineer, and the Research Administration Engineer, who also serves as secretary. A representative from the University of Minnesota serves as the tenth member.

Monies for LRRB projects come from municipal and county state aid funds (up to 1/4 of one percent). This money is put into a research account and is used for:

- Conducting research for improving the design, construction, maintenance and environmental compatibility of state aid highways.

- Constructing research elements and reconstructing or replacing research elements that fail.

- Conducting a program for the monitoring and implementation of research results.

The program is approved on a calendar year basis by the LRRB Board.
The use of lightweight fill is increasing in the state of Minnesota. This material is used to replace a heavier insitu soil so as to reduce the load burden on the subgrade.

There may be several alternative materials to consider for any construction project; however, design engineers might not consider them because of a limited knowledge or unfamiliarity with them. Various materials have been used, but specific design guidelines are not available because this type of construction is still considered experimental.

The current selection is generally based on local knowledge. Additional research is required to determine more specific design guidelines for each lightweight fill material. The Local Road Research Board (LRRB) has therefore requested this synthesis to determine what technology and materials are available for the appropriate use of lightweight fill material in road construction.

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   a. Descriptors
      - Lightweight fill
      - Elastizell
      - Rubber tires
      - Wood chips
      - Expanded polystyrene

   b. Identifiers/Open-Ended Terms

   c. COSATI Field/Group

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Lightweight Fill Materials
for Road Construction

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The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Minnesota Local Road Research Board or the Minnesota Department of Transportation.
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1. Executive Summary

A lightweight fill is any material used to replace a heavier in situ soil for the purpose of reducing the load burden on subgrade soils. The use of lightweight fills is increasing in the state of Minnesota. Various materials have been used; however because of their experimental nature there are no formal design guidelines specific to each material. Additional research is required to determine more specific design guidelines for each available lightweight fill material. The current selection of a lightweight fill is generally based on local knowledge of each fill material.

For any construction project requiring a lightweight fill there may be several alternative materials to consider. However because of cost, a limited knowledge or unfamiliarity with these materials, design engineers might not consider them as an alternative. The Local Road Research Board (LRRB) has therefore requested this synthesis to determine what technology and materials are available for the use of road construction in areas where a lightweight fill material may be appropriate.

The synthesis includes information from the following sources:

- literature searches
- vendor information
- interviews
- site visits

This synthesis will focus on the following areas:

- material characteristics
- material availability
- costs analysis
- performance
- restrictions

The information was evaluated with respect to Minnesota conditions and, where reasonable, transformed to Minnesota terminology. This report describes the findings of several studies along with their subsequent conclusions.

The Minnesota Department of Transportation currently does not list design guidelines for the use of lightweight fills in areas where the in situ soils do not have sufficient bearing capacity.

1. The most commonly used lightweight fill in low volume road construction is wood chips. Wood chips are a very good fill material, although in all but special cases, they must be kept in a saturated state (below water table) to prevent biodegradation.

2. The lightest of all available fills is Expanded Polystyrene (EPS); however, the high cost of this material has delayed its use in Minnesota. The low density of EPS requires the least amount of soil replacement to achieve the required load reduction on the existing subgrade; therefore because less excavation and material is required a cost analysis may indicate a lower end cost.
3. Shredded waste tires are a readily available and inexpensive lightweight fill material. The use of tire waste products would work well under many conditions. However, the Minnesota Pollution Control Agency (MPCA) currently has several restrictions with respect to the use of tires as a fill material. Tires may not be placed below the water table and any potential use of waste tires as a fill material must be submitted to and approved by the MPCA prior to placement.

4. Lightweight foamed concrete is another lightweight fill material. Because of its high application cost, foamed concrete is most cost effective where high strength is required and minimal horizontal forces are tolerable. Although Minnesota has some experience in the use of foamed concrete, the Michigan Department of State Highways and Transportation (MDSHT) has conducted extensive research with its use.

Following is a quick reference summary table highlighting some of the key features of each lightweight fill material. Included are compacted densities which may be expected of each fill.

<table>
<thead>
<tr>
<th>Material</th>
<th>Expected Compacted Density (lbs/ft³)</th>
<th>Summary Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Chips</td>
<td>24-36</td>
<td>Readily available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Easily placed with standard construction equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Burdened by the need to remain saturated at all times</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Considered a by-product and therefore relatively inexpensive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No formal design parameters, based on field experiments</td>
</tr>
<tr>
<td>EPS</td>
<td>3</td>
<td>With respect to other materials has the lowest available density for the strength it supplies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Easily placed, no need for additional equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Little effect from environmental conditions such as submersion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Requires the least amount of soil replacement for given load reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Has formal design parameters</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High unit cost</td>
</tr>
<tr>
<td>Shredded Tires</td>
<td>20-45</td>
<td>Readily available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Considered a by-product, relatively inexpensive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Easily placed by standard construction equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Design parameters are based on field experiments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use restricted by MPCA regulations</td>
</tr>
<tr>
<td>Foamed Concrete</td>
<td>24-80</td>
<td>Limited number of suppliers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Specifically designed and manufactured for each case; therefore high unit cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Must be placed by producer using their equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High compressive strength</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exerts very little horizontal pressure on adjacent structures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Has known design parameters</td>
</tr>
</tbody>
</table>

Table 1. Material Characteristics
2. Introduction

Minnesota is known as the Land of 10,000 lakes; however, there are just as many, if not more, swamps and bogs. Generally the soils near these swamps and bogs restrict the type of road construction applicable to these areas. These construction restrictions can cause city, county and state engineers a wide variety of design problems. Sometimes traversing these areas can be costly and time consuming. Because of this, construction of new roads may not follow the most desirable routes, and existing routes may continue to have high maintenance costs for the agency responsible for upkeep.

The use of wetlands for construction purposes is regulated and it is therefore difficult to obtain permits for its use. These regulations make the use of wetlands very complicated and beyond the scope of this report.

In Minnesota, soils of concern are generally organic or clay materials and involve a relatively high water table near the surface. When encountering areas of organic materials or other poor soils, the first alternative is to find an acceptable route around the area. In some instances this may not be feasible and the poor soils must be traversed. When constructing over an area of poor soils there are several alternatives:

1. The soils of concern can be removed to a depth where stronger soils are found and backfilled with a granular material.

2. A small amount of the poor soil may be removed and replaced with a light weight material of lower density. This creates a floating platform.

3. If the insitu soils are only a concern while saturated, the area may be permanently drained to a suitable depth.

4. Stage construction and surcharge the soils.

5. A geotextile may be placed over the existing vegetation and covered with a granular material.

6. Bridging the area with a suspended structure.

These options are all viable alternatives and each one should be evaluated to determine its feasibility and cost effectiveness. This report will focus on the second alternative - construction with lightweight materials.
3. Lightweight Fills

Various lightweight fill materials have been in use for many years throughout Minnesota. The materials most commonly used are saw dust and wood chips. These materials are a light and inexpensive by-product and are often readily available. Although many of their qualities are desirable for a fill material in road construction, wood products also possess some undesirable qualities. In many cases, wood products placed above the permanent water tables are highly biodegradable. Additionally toxins may leach from the wood products and enter the ground water system. A danger of fire with wood products also exists, more so during than after construction.

Shredded waste tires are another readily available and inexpensive product that may be used as a lightweight fill material. The use of tires below the water level has been found to be a concern for toxic leachates when exposed to certain chemicals. This is currently a concern of the MPCA and further independent research is welcome.

Expanded polystyrene (EPS) is a form of heavy duty Styrofoam™ which has a density lower than any other lightweight fill currently in use. EPS is non-biodegradable and is easily placed with the use of little or no machinery. The deterrent of EPS is its high cost. Although widely used and relatively inexpensive in Norway, there is limited documented use in the United States. One documented use is in Pickford, Michigan near a Dow Chemical Plant. The costs of the EPS in Pickford are unique in that the Dow Plant had an unused stockpile of EPS at the time it was needed.

3.1. BARK AND SAWDUST

Bark and sawdust are lightweight fill materials that will greatly reduce the static load of a pavement structure.

Wood products have been used for many years by the timber companies as a lightweight fill material for the reclamation of peat and swamplands. Many states and counties have also used these products as a lightweight fill material for swamps as well as areas where excessive soil loads may cause slope shear failures.

3.1.1. CASE STUDY: Cosmopolis, Washington (1)

The use of sawdust was researched by the Federal Highway Administration (FHWA) in 1974 on a sight near Cosmopolis, Washington (1). This was a site in which excessive rain fall led to a slope failure. Although these soils were not below the water table, sawdust was selected as a lightweight fill. This created a problem in that when placed above the water table (an aerobic condition) sawdust is biodegradable and will decay and break down. To reduce the biodegradation process an emulsified asphalt sealer was mixed with the sawdust on the slopes creating an impermeable shell to help achieve a near aerobic condition. Three varieties of sawdust were used: Hog fuel, planer chips, and bark chips. The uncompacted and compacted densities were 23.7 lb/ft³ and 36.3 lb/ft³, respectively. The FHWA report states the following conclusions:
1. Sawdust is a very workable and easily placed fill material.

2. Sawdust can reduce the driving weight of a potential slide area by as much as 71 percent, thereby reducing the chance of slope shear failure.

3. The fibrous intertwining of sawdust particles tends to create an interconnected web thereby distributing the loads in a more lateral direction.

4. Sawdust does not require mechanical compaction. The compaction obtained from the construction equipment is adequate.

5. Indications are sawdust fill materials can sustain roadway sections for 15 years or longer before the decomposition of the fill requires reconstruction.

6. The use of sawdust material above the water table should be based on economics, availability and environmental concerns.

Mn/DOT currently does not have written design guidelines for the use of wood products in road construction. The Mn/DOT Office of Materials and Research did sponsor a research study in 1976, conducted by Erland O. Lukanen, entitled "Design and Evaluation of Roadway Widening Sections Through Swamps" Investigation No. 199.(2).

This project consisted of six methods of floating roadway widening sections over a peat swamp. The six various methods are:

1. Corduroy - A method of placing tied logs perpendicular to the road in order to create a solid working platform for further construction.

2. Wood chip working platform - A modification of the corduroy method in order to create a working platform with 2 feet of wood chips. The chips are then capped with a minimum of 6 inches of clay to reduce their exposure to air.

3. Wood chip embankment - Used in areas of high fill in order to reduce the total fill weight. Capped with 2 feet of clay to reduce exposure to air.

4. Full width fabric section - Fabric is placed transversely across the road and into the ditches. The fabric should limit horizontal movement and transfer some of the load of the widening to the existing roadbed.

5. Ditch fabric section - Fabric is placed 17 feet from centerline and extended out into the ditch area. The fabric adds tensile strength allowing a thinner layer of fill for equipment to work on.

6. Weakened plane section - A 3 foot deep, 6 inch wide trench is dug 15 feet from centerline. This allows the widened section to settle without causing distress within the original road section.
The construction and observation of these six methods yielded the following findings and conclusions:

"Wood chips provide a good working platform upon which fill can be placed and light machinery can operate. They did not displace in front of machinery or fill and had sufficient stability to withstand submersion in water. Running water, however, may easily displace wood chips."

"Any kind of disturbance of the existing vegetation mat appears to cause problems. A drainage ditch was cut into the root mat and longitudinal cracking appeared in the lane adjacent to the ditch. A judicial ditch was cut adjacent to the widening over a shallow swamp, and longitudinal cracking appeared in the pavement for several hundred feet along the ditch. Later borings showed the fill to be setting on 3 to 5 feet of peat in this area."

"The construction costs of floated widenings are much less than the keying method. Floating widenings are also much quicker to construct than keyed widenings."

"Any drainage ditches that have to be constructed in conjunction with widening on future projects should be placed a sufficient distance away from the road to prevent transverse movement and the formation of longitudinal cracks in the pavement."

When utilizing sawmill residue or timber corduroy as a road embankment, the bio-deterioration of the ligno-cellulosic material has to be controlled. Wood is made up of more than 50 percent cellulose and 10 percent to 35 percent lignin. Lignin is a more complex carbohydrate than cellulose, however both will break down under aerobic conditions. Various methods to control bio-deterioration are:

- ensure the wood product remains below the groundwater table
- chemical treatments such as an emulsified asphalt or other type of sealer. The chemicals may be expensive and difficult to distribute evenly.
- use of a geotextile fabric to restrict aeration to the sawmill residue. (3)
- cap wood product with a layer of plastic soil to reduce exposure to air.

3.2. POLYSTYRENE FOAM

Expanded polystyrene (EPS) has had limited use in the United States as a lightweight fill. (One documented case was in Pickford, Michigan). However, Norway and Finland, with their numerous wetlands and peat bogs, have extensive experience with EPS as a lightweight fill. For many years Norway has been using EPS as insulation boards for a frost protectant. In 1972 they began using polystyrene in greater thicknesses for the purpose of reducing excessive settlements in areas where soils were unable to support the static load of a pavement structure.

The cost of EPS is dependent on the strength required, amount needed, and various other factors. For this reason, it is not possible to accurately estimate product cost. The unit cost of EPS may be high although an analysis of the cost of load reduction per square foot must be conducted. Total load reduction is the weight of the soil removed minus the weight of the fill used. The cost of load reduction takes into account the cost of the soil excavation plus the cost of the required fill material. Although a material of lower density may be more expensive it will not require as much excavation thereby decreasing the cost of excavation and the amount of fill material required.
3.2.1. CASE STUDY: Pickford, Michigan (4)

Engineers within the United States have done little experimentation with polystyrene as a lightweight fill. One application of EPS is near Pickford, Michigan on the Big Munuscong River. This is a case where the soft dense soils, approximately 125 lb/ft³, of a bridge approach were sliding toward the river, moving the piers and abutments. Since increasing the length of the bridge or complete removal of the unstable soils were determined to be too costly, various lightweight fills were considered.

Lightweight expanded aggregate would have required excavation below the pier and river bottom. This option was eliminated because of instability problems and the transportation cost of hauling the aggregate (nearest source was 250 miles away).

A semi-nested series of corrugated metal pipes in a sand fill was considered. This procedure would have required 16 feet of excavation and 1000 lineal feet of various culvert sizes. Because of the cost of the corrugated pipe this option was not chosen.

Another option, cedar logs would have provided a load reduction of 70 lb/ft² for each 1 foot of fill. Since this option would require 5,000 yd³ of cedar logs, it was rejected because the logs could not be obtained within a reasonable time. Additionally their long-term durability was questionable.

Polystyrene was examined and found to weigh much less than sand or very soft clay (3 lb/ft³ vs. 120 lb/ft³). The tremendous weight reduction per depth of excavation would be a great advantage reducing the required excavation substantially. EPS has long-term durability and is only slightly effected by the surrounding moisture. Approximately 1285 yd³ of EPS would be required.

The Michigan Department of State Highways and Transportation (MDSHT) discovered that due to an ordering error Dow Chemical Company (Midland, Michigan) possessed a large amount of EPS from a previous order and provided the material at a lower than normal unit cost. To obtain a product cost for future projects, a producer would have to be contacted and given the amount and required strength of the needed EPS.

The unit cost of the EPS for this project is not a representative cost for future projects. Polystyrene fill was selected because of its low density, minimum required excavation, durability, ease of placement, immediate availability, and comparatively low cost. The foam came in 8 ft. x 2 ft. x 1.5 in. boards. These boards were taped together in bundles of eight forming a billet 8 x 2 x 1 ft. weighing 50 lbs. As shown in Figure 1 these billets were placed, staggering joints, at a total thickness of 5 ft. near the bridge where the most load reduction was needed to one billet of 1.5 in., 150 ft. from the abutment. It was important to cover the polystyrene with enough fill material to resist the buoyant forces of the foam when the Big Munuscong River rises in the spring. Prior to covering with soil, the foam was covered with a 4 mil thick polystyrene sheeting. This sheeting was placed to protect the foam from possible spillage of petroleum-based liquids that could seep through the granular cover and dissolve the polystyrene.
3.2.2. CASE STUDY: Norway

Numerous projects have been conducted throughout Norway using expanded polystyrene as a lightweight fill. Norway, like Minnesota, experiences numerous freeze-thaw periods and extended periods with temperatures below freezing. Minnesota may be able to utilize some of Norway's experience with EPS.

In a publication of VEGLABORATORIET (5) produced by the Norwegian Road Research Laboratory, the following experiences with expanded polystyrene as a lightweight fill are discussed:

**Compressive Strength**
The compressive strength of the EPS was tested from four construction sites using excavated samples. These construction sites in Solbotmoan, Flom, Langhus, and Lenken have been in place from one to five years. The study concluded that the compressive strength of the expanded polystyrene has not measurably decreased over time. In fact, in some cases the compressive strength had increased, possibly due to the increase of the moisture content of the fill material.

**Moisture Resistance**
In the most extreme case, a polystyrene fill was permanently submerged below the ground water level for nine years at Solbotmoan to evaluate EPS resistance to moisture. An increase of 9 percent absorption was observed. Above the groundwater level the moisture content decreased to 1 percent by volume. In areas of periodic submersal, a moisture content of 4 percent was observed. Due to these moisture contents a density of 28 lbs/cu yd is recommended for dry conditions and 56 lbs/cu yd for submerged conditions.

**Settlements**
Only slight settlements have been noticed at a few sights throughout Norway. Most settlements can be attributed to slipping of the underlying embankment materials. Settlement within the polystyrene blocks can be expected to be between 0.5 percent and 2.0 percent of the thickness of the blocks.

**Flammability**
Similar to sawdust and barkchips, polystyrene is flammable. Two sites in Norway, a fill and a stockpile, accidently burned and were destroyed. The fill was a 1960 cu yds polystyrene embankment
leading up to Knatten Bridge in the district of Akefhus. The fire was caused by welding being conducted too close to the bridge abutment. It is recommended that extreme care be taken when conducting any high temperature work near polystyrene.

A self-extinguishing polystyrene can be obtained at a higher cost; however, statistics show it would be cheaper to remain with the standard polystyrene and accept the occasional loss.

Chemical Resistance
Petroleum based products will react with and dissolve polystyrene foam. Therefore it is necessary to cover the material with a concrete slab or a petroleum resistant geotextile. In the event of an accident or spill, the chemical products would be prevented from reaching the EPS.

Pavement Bearing Capacity
Through analysis conducted at the Norwegian Road Research Laboratory the stresses and strains in the pavement and subgrade were calculated using a Modified Chevron Program. The research concluded that varying the depth of the polystyrene fill had no significant influence on the pavement design.

A 4 inch concrete slab is recommended below the bituminous surface. If the concrete slab is omitted the bituminous would have to be increased by 12 to 16 inches in order to keep stresses and deflections at the same level. This is a substantial structure and the increase cost would have to be considered in a cost comparison study.

Dynamic Loads
If the total dynamic and static loads are limited to 80 percent or less of the compressive strength of the polystyrene, EPS can theoretically service an unlimited number of loads. Therefore, for all practical purposes of a twenty year design period, dynamic loads do not affect an expanded polystyrene fill. It is likely the pavement surface will reach the end of its design life long before the EPS fill material. EPS is available in wide range of compressive strengths, these strengths must be known for each loading condition.

Icing Problems
EPS has high insulative properties. During a frost cycle, a pavement structure with EPS does not experience the warming effects of the soil below causing differential icing with respect to the surrounding road surface. This may cause traffic hazards, therefore deicing procedures must be established.

3.3. SHREDDED TIRES

Automotive waste tires are discarded at a rate of 3 million tires (110,000 cu yds of rubber) annually in the state of Minnesota. (6) This is a large volume of waste with little applicable reuse. In 1985 a recycling firm and a logging contractor contacted the Minnesota Pollution Control Agency (MPCA) regarding the use of waste tires to construct forest roads. In 1986 the Hedbom Forest Road in Floodwood, MN was constructed using waste tires. The tires were placed below the base material using nine different placement strategies (6). These placements ranged from whole tires tied together to spreading shredded tires as a base material. As of 1989 all of the test sections were performing exceptionally well. This study caused the MPCA to do testing in order to establish some guidelines involving the use of waste tires as a fill material. These guidelines have led to some controversy. Many individuals wish to further investigate the use of waste tires as a lightweight fill as opposed to stockpiling which may have equal or greater hazards.
3.3.1. MPCA Guidelines

The use of shredded tires as a lightweight fill may be efficient and effective, however there is an environmental concern. A study published by the Minnesota Pollution Control Agency (10) discusses many of the possible negative aspects of the use of shredded tires as a fill material. Laboratory tests were conducted over a range of pH levels from 3.5 to 8.0 in order to simulate potential worst case scenarios. These laboratory tests were extreme and may or may not represent actual field conditions. Soils in the northeast portion of Minnesota tend to be acidic while the soils in the southwest are primarily alkaline. Soil sampling was also conducted around two existing waste tire stockpiles. The laboratory tests conducted and soil samples tested yielded the following conclusions:

1. Toxic metals are leached, in the highest concentrations, from the tires under acidic conditions. The materials of concern are barium, cadmium, chromium, lead, selenium, and zinc.

2. Polynuclear Aromatic Hydrocarbons (PAHs) and Total Petroleum Hydrocarbons are leached from tire materials in the highest concentration under alkaline conditions.

3. Asphalt materials may leach higher concentrations of contaminants of concern than tire materials under some conditions.

4. Drinking water Recommended Allowable Limits (RALs) set by the Minnesota Department of Health may be exceeded under "worst-case" conditions for arsenic barium, cadmium, chromium, lead, selenium, and carcinogenic and non-carcinogenic PAHs. "Worst-case" case conditions for metals appear to occur at low pH (acid) conditions. "worst-case" conditions for organics appear to occur at high pH (basic) conditions.

5. A biological field survey did not identify significant differences between waste tire areas and control areas with respect to soil samples.

6. Potential environmental impacts from the use of waste tires can be minimized by placement of tire materials only in the unsaturated zone (above the water table) of the roadway subgrade. This can be accomplished by placing alternative materials, such as wood chips or soil, below the water table.

7. The metals leached from waste tire stockpiles are similar in concentrations to those leached in areas where tires are used for fill.

From this study the MPCA has set forth guidelines with respect to using shredded tires as a lightweight fill material in construction. Following are the MPCA Guidelines as quoted from an MPCA Technical Fact Sheet (11).

Road Repair and Construction

- Shredded waste tires can be used in road construction or repair if the tire shreds will be above the water table and not in contact with ground water. Tire shreds cannot be used below the water table.

- Roads and road slopes must be designed and constructed to reduce water infiltration and to promote surface water drainage away from the road bed, to minimize the amount of surface water seeping through the shredded tires.
General Construction (Applies to all construction projects)

- A synthetic geotextile fabric is recommended above and below the areas where shredded waste tires are used. The fabric will prevent movement of soil into the tire shreds, and will hold the tire shreds in place.

- Tire shreds must be covered by a low-permeability surface to reduce seepage of surface water.

If a proposed construction project meets these criteria, the MPCA should be contacted to determine what type of information or monitoring is required. If subsequent monitoring indicates unacceptable types and levels of leachates, it is likely the MPCA will require the removal of the fill material.

3.3.2. CASE STUDY: Municipal 9-Ton Roadway, Eden Prairie, MN (6)

A roadway was to be constructed over a depth of more than 40 feet of soft organic soil. During construction the alignment was inadvertently overfilled, resulting in a depth of 30 feet of fill material. The fill material punched through the soft soils and resulted in substantial settlements. Over a three year period settlement averaged 1 foot per year. This area was under commercial development, the roadway construction had to be completed to accommodate the public. The choice was made to use shredded tires as a lightweight fill material. The top 10 to 14 feet of existing fill was removed and replaced with 4,800 cu yds of shredded tires. The rubber tires were covered with a geotextile fabric and 4 feet of common borrow.

The compacted volume of the shredded tires was reduced to 2,300 cu yds with an estimated density of 40-45 pounds per cu ft. The tires were shredded to a dimension of 6-8 inches wide by 12-24 inches long and placed in 2-3 foot lifts. A D-8 dozer was used to compact the shredded tire fill. Following the geotextile and granular borrow cover, the section was paved with 12 inches of crushed limestone base, 3-1/2 inches bituminous base, and 1-1/2 inches bituminous wear. This road has been in place for three years and has performed well with negligible settlement.

3.3.3. CASE STUDY: CSAH 21, Rice, MN (8)

A portion of CSAH 21 in Benton County, north of Rice, Minnesota crosses a swamp. Increases in the level of the swamp caused the need to increase the roads elevation. Conventional methods of additional granular fill attempted to raise this roadway above the water level. During extended periods of dry conditions the underlying peat material decreased in strength and failed. A decision was made to use a lightweight fill rather than remove the soft underlying soils. In an experiment to reduce a waste problem while solving a construction problem, shredded tires obtained from a tire land fill which the MPCA had designated for early clean-up were selected as a lightweight fill material.

The existing embankment was excavated to a level 6 inches above the surrounding marsh. A layer of shredded tires, approximately 4 feet in depth, was sandwiched between a geotextile fabric and covered with 3.5 feet of clean granular backfill. The geofabric was used to prevent the intrusion of soils into the tire fill. The section was paved with gravel base, subbase and bituminous as normal and is performing well with no apparent visual problems.
The intersection of Duluth Avenue and Tower Avenue in the city of Prior Lake required reconstruction in 1991. In order to obtain state funding the city was required to change the alignment of the two roadways. The new alignment crossed a wetland with organic deposits of approximately 30 feet in depth.

Three options were considered:

1. Excavate to adequate load bearing strata and refill with granular material.
2. Stage construction and surcharge to compress the underlying organics.
3. Replace subgrade with a lightweight fill.

Because of relatively higher costs and time constraints of options 1 and 2 the City decided to use option 3, construction with a lightweight fill. Wood chips were placed to a depth of 1 foot above the anticipated groundwater level on top of a Geotextile fabric, Mn/DOT Type 3. Wood chips were placed in order to conform with the MPCA regulation restricting the use of shredded tires below the groundwater level. To reduce the risk of biodegradation, wood chips were not used for the entire fill. Approximately 3 feet of shredded recycled tires were placed directly on the wood chips and covered with a geotextile Mn/DOT Type 5. A 6 inch sand layer and 24 inches of Class 5 were used to cover the entire section prior to paving. A cross section of the existing soils and the final design may be found in Figures 2 and 3.

During placement of the 2 1/2 feet of sand and class 5 materials, the tire chips settled 6 inches resulting in the need for an additional 6 inches of granular base. Although this settlement was unexpected, the additional 6 inches of compaction increased the modulus of the tire chips; however the actual increase in modulus is unknown. Based on this project it is the city engineer’s opinion that pavement design using shredded tire subgrades should assume an R-value of 5 for the tire material (9).

This section was constructed in 1991 and it is too early to determine if any problems or irregularities will develop. The section appears to be in good condition and the city engineers expected it to perform adequately.
3.3.5. Interim Design Guidelines

This interim report was conducted to determine some of the characteristics of a shredded tire fill and was generated from data gathered from a private access road constructed with shredded tires at thicknesses of 3 and 6 feet. Some of the conclusions found in this interim report are as follows:

1. The rate and effectiveness of compaction are similar to sawdust fills.
2. Approximately 99 percent of maximum compaction can be achieved with about 24 passes of a D7 caterpillar.
3. The maximum bulk unit weight of tire shreds with an average particle area of 1 sq ft is approximately 20 to 23 lb/ft³.

Currently the primary cost of using waste tires is the transportation and placement of the material. Many stockpilers are willing to shred and give the tires away in order to reduce their accumulating piles. As the use of waste tires increases the cost from the suppliers may increase, however it will likely remain one of the least expensive materials.

3.4. FOAMED CONCRETE

Foamed lightweight concrete has been widely used in building construction for floors, roof decks and insulation. Recently foamed concrete has been used as a lightweight fill in highway construction, primarily in the area of bridge abutments. These areas may contain poor soils and require a lightweight fill which does not exhibit horizontal pressures on the adjoining structure. Foamed concrete has been used for many roadway projects simply because a lightweight fill material with high strength is required.

Foamed concrete is generally mixed on site with a portable mixing unit by the supplier. The cost of this fill may be too costly, at $40-45 per cubic yard, for small county and city projects in remote areas, although for special cases, such as bridge abutments, it may be an economical alternative.

The only foamed concrete considered to be a "lightweight" fill for this report is a product called "Elastizell", produced and patented by the Elastizell Corporation of America. They are based out of Ann Arbor, Michigan. The material mix plants are truck mounted and are therefore available to us in Minnesota. Various classes of the material are produced with different strength and densities. The maximum cast densities can be found in the table below.

<table>
<thead>
<tr>
<th>CLASS</th>
<th>MAXIMUM CAST DENSITY pcf</th>
<th>MINIMUM COMPRESSIVE STRENGTH psi</th>
<th>ULTIMATE BEARING CAPACITY Tons/sf</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>24</td>
<td>10</td>
<td>0.7</td>
</tr>
<tr>
<td>II</td>
<td>30</td>
<td>40</td>
<td>2.9</td>
</tr>
<tr>
<td>III</td>
<td>36</td>
<td>80</td>
<td>5.8</td>
</tr>
<tr>
<td>IV</td>
<td>42</td>
<td>120</td>
<td>8.6</td>
</tr>
<tr>
<td>V</td>
<td>50</td>
<td>160</td>
<td>11.5</td>
</tr>
<tr>
<td>VI</td>
<td>80</td>
<td>300</td>
<td>21.6</td>
</tr>
</tbody>
</table>
3.4.1. CASE STUDY: 7th and Lyndale, Minneapolis, MN

In Minnesota a large project, the intersection of Lyndale Avenue and 7th Street near I-94, was constructed using "Elastizell". (A detailed report of this project is not available). This was a project in which a new bridge over I-94 required high approach fills (see Figure 4). Normally this would not have been a problem, however the approach was located over poor soils and was to cross over the Basset Creek storm sewer tunnel. Future settlement of the high fill was a concern. A fill, light enough to minimize settlement and strong enough to support the high approach with minimal horizontal stress, was needed. "Elastizell" was selected and various classes with different compressive strengths were used. A cross section of the various materials is shown in Figure 5. This project has performed well for ten years and no future problems are anticipated.

3.4.2. CASE STUDY: Waiska River, M 28 Crossing (13)

During the replacement of bridge superstructure crossing the Waiska River 6 miles west of I-75 in Michigan (1976), it was discovered that the east approach had settled 1.5 feet and would require replacement. Because of the soft alluvial clay sub-soils, either the bridge structure would have to be lengthened or the soils in the "approach area" would have to be removed and replaced with a lightweight fill material. The relatively high cost of lengthening the bridge structure was prohibitive and a lightweight fill option was selected. "Elastizell" was used to keep horizontal stresses against the bridge abutment to a minimum. The Michigan department of State Highways and Transportation covered the foamed concrete with approximately 4 ft of sand subbase to reduce the number of freeze-thaw cycles to which the concrete might be exposed.

The construction report for this project concluded:

1. Placement of the foamed concrete by the producer and their equipment was easy with relatively few construction problems. Due to the low viscosity, it was recommended that any transverse slopes be step tapered using basic concrete forming procedures.
2. Specifications must be developed in order to enable acceptance on the basis of two or three day compressive strength and dry density.

3. Due to material property characteristics (low compressive strength, non-homogeneity, water sorption characteristics, and equilibrium wet density) "Elastizell" concrete cannot be recommended for general use as a lightweight fill material without qualifications.

A follow-up study had not been conducted at the time this report was written.

3.4.3. CASE STUDY: Pine River Bridge, St. Clair (12)

Another construction site in Michigan is the Pine River Bridge, St. Clair project (1976). The original bridge had been rebuilt in 1933 but had become increasingly difficult and costly to maintain. The area consisted of deep, soft alluvial clays. This resulted in extensive settlement that required structural repairs. A new bridge was designed which included a 3-1/2 ft raise in grade.

Because of the soft clay subgrade, two design alternatives were considered to prevent future settlement; the construction of additional approach spans, or the use of a lightweight fill material. It was estimated the use of a lightweight fill material could save as much as $200,000 for this project.

The technical report for this project has similar conclusions with respect to the Waitska River project in that the "Elastizell" was easily placed although specifications and qualifications must be further developed.

3.4.4. Performance of Foamed Concrete (14)

In a later report, concerning the two Michigan projects mentioned previously, titled "Condition of 'Elastizell' Lightweight Concrete Backfills After One Year in Place" dated 1978 (14) the Michigan DSHT concludes:

1. In general, "Elastizell" concrete appears to be a satisfactory lightweight fill material. The material has adequate strength, remains lighter than the design unit weight, does not absorb water, and settlements are negligible.

2. Although structurally sound, the "Elastizell" fills contain a large number of soft, powdery areas which have little or no support value. To date, these areas have not appeared to be damaging, but they should certainly be eliminated or minimized by better batch mixing control.

3. No conclusions concerning the long-term performance of "Elastizell" were made at this time. Sampling and testing of the fills continue to monitor any changes in settlement, in-place density, or moisture content that may take place with continued exposure.
4. Findings

General

The current level of technology being applied to the design of roadways using lightweight fills, is based on either experience or the adaptations of other design guidelines.

Although a material may have a high cost, an economic study should be conducted to determine the cost per pound load reduction per sq. ft. to determine the total cost. A cost study may show that the more expensive material may require less excavation and therefore require less fill material compared to the less expensive lightweight fill material.

Example:
A construction area located over soft alluvial clays requires a load reduction of the subgrade materials, 500 lbs/ft², in order to minimize future settlement. Assuming an in-place wet density of the surface materials to be 125 lb/ft³ the following excavations and fill depths would be required:

<table>
<thead>
<tr>
<th>Lightweight Fill</th>
<th>Average Fill Density (lb/ft³)</th>
<th>Required Excavation and Fill Replacement (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shredded Tires</td>
<td>33</td>
<td>5.4</td>
</tr>
<tr>
<td>Wood Chips</td>
<td>27</td>
<td>5.1</td>
</tr>
<tr>
<td>Polystyrene Foam</td>
<td>5</td>
<td>4.2</td>
</tr>
</tbody>
</table>

A cost analysis would include the cost of the excavation, lightweight fill, and fill placement.

$\text{(excavation)} + \text{(fill material)} + \text{(fill placement)} = \text{comparable fill cost}$

Although shredded tires may be cheaper, polystyrene foam requires less excavation and is placed easily without the need of heavy equipment.

Sawdust, Wood Chips and Corduroy

Wood material is a viable material for a lightweight fill, however it is biodegradable. Design parameters are known and many agencies have experimented with wood materials. Wood materials are considered a by-product and therefore are generally inexpensive.

Expanded Polystyrene

Although EPS has had limited use in Michigan and even less use in the rest of the United States, it has been used extensively in Norway and Finland. EPS is performing well in these countries. Further use of EPS in the U.S. may prove to be beneficial and cost effective.
Waste Tires

Shredded tires are an effective lightweight material which may currently be used above the water table. It provides adequate strength and load transfer while reducing the static load on the underlying soils.

Currently the MPCA restricts the use of tires within a saturated zone. A composite alternative using waste tires has been to place wood chips to a depth of 1 ft above the water table, taking care to prevent biodegradation, and continue the fill with waste tires. However the use of one fill that is non-biodegradable and inexpensive, in comparison to using numerous fills, could cut the cost of expanding our roads across load restrictive soils.

Many people would like to see the use of waste products, such as tires, expanded. For this reason further research into the area of waste tires as a lightweight fill has been suggested by many engineers.

Foamed Concrete

Foamed concrete is a high strength, low density material that would work well in many areas. The cost of foamed concrete is high, therefore it may only be justified in special cases where high strength and limited horizontal forces are required.

Table 2 on the following page summarizes some of the advantages and disadvantages of various lightweight fill materials.
### PROS / CONS AND USES OF SOME LIGHTWEIGHT FILLS

<table>
<thead>
<tr>
<th>Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Practice Areas of Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Products</td>
<td>Inexpensive</td>
<td>Biodegradable when not saturated unless special measures are taken.</td>
<td>Bogs and wetlands with water table near surface.</td>
</tr>
<tr>
<td></td>
<td>Easily placed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expanded Polystyrene</td>
<td>Lightest fill available</td>
<td>High cost</td>
<td>Near bridges and other structures requiring minimal lateral forces.</td>
</tr>
<tr>
<td></td>
<td>Does not exert lateral forces</td>
<td>Not readily available</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Easily placed with minimal equipment</td>
<td>Insulates subgrade which may lead to surface icing</td>
<td></td>
</tr>
<tr>
<td>Waste Tires</td>
<td>Inexpensive</td>
<td>Must be kept above water table</td>
<td>Bogs and wetlands with water table not near surface</td>
</tr>
<tr>
<td></td>
<td>Easily placed</td>
<td>May leach toxins</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-biodegradable</td>
<td>Minimal design parameter available</td>
<td></td>
</tr>
<tr>
<td>Foamed Concrete</td>
<td>Does not exert lateral forces</td>
<td>High cost</td>
<td>Near bridges and other structures requiring high strength minimal lateral forces</td>
</tr>
<tr>
<td></td>
<td>High strength</td>
<td>Only one producer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-biodegradable</td>
<td>Must be placed by producer</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2**
5. References


3 Smith, R.S., Coulter, T.S., "Use of Lightweight Sawmill Residue in Highway Embankments" RTAC Forum Vol. 3, No. 1, Pg. 84-89.


5 Aabøe, R. "13 Years of Experience with Expanded Polystyrene As a Lightweight Fill Material In Road Embankments" Veglaboratoriet, Norwegian Road Research Laboratory, ISSN 0376-7280.


9 Rudd, J.C., Loney, B. "The Use of Shredded Tires as a Lightweight Subgrade on 9-Ton Road," City of Prior Lake In-house Report, Fall 1991.

10 Ronchak, A. "Waste Tires in Sub-Grade Road Beds" Minnesota Pollution Control Agency, February 19, 1990.


