RECYCLING OF SHREDDED RUBBER TIRES AS ROAD BASE IN MANITOBA: A CASE STUDY

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ABSTRACT

Civil engineering applications of scrap tires benefit from their lightweight, thermal insulation properties, and hydraulic conductivity. In Manitoba, over one million tires are scraped annually. This paper discusses a project that involved the construction of a gravel road on a very soft subgrade near Winnipeg, Manitoba. The 300 m road provides access to a gravel pit and is expected to carry heavy loads during the Spring and Summer seasons. The design incorporated 1500 mm thick shredded scrap tires in the base layer. An estimated 300,000 passenger car tire equivalents are used in this section or almost one third of the annual supply of scrap tires in the province.

An extensive monitoring program was undertaken by the University of Manitoba to monitor the road and environmental conditions during construction and service. The monitoring program included installing thermocouple probes up to a depth of 3m and a data acquisition system to permit year-round temperature monitoring. The compressibility of the tire layer is monitored with settlement plates. The effect of tires on the ground water quality is monitored through periodical analysis of water samples from ground water.

RÉSUMÉ

L'utilisation de vieux pneus en génie civil est avantageuse à cause de leur légèreté, de leur propriété d'isolant thermique et de leur conductibilité hydraulique. Au Manitoba, plus d'un million de pneus sont jetés à chaque année. La présente rédaction discute d'un projet de construction d'un chemin en gravier sur un sous-base très mou près de la ville de Winnipeg au Manitoba. Le chemin, long de 300m, fournit accès à une mine de gravier. Cette rue doit supporter des charges très lourdes pendant le printemps et l'été. Le plan de construction a incorporé une épaisseur de 1500mm de pneus déchiquetés dans la sous-couche. On estime qu'un équivalent de 300 000 pneus d'automobiles ont été utilisés dans cette section de chemin; un tiers des pneus jetés annuellement dans la province.

Un programme intensif de surveillance a été entrepris par l'Université du Manitoba pour surveiller le chemin et les conditions écologiques durant la construction du chemin ainsi que durant son utilisation. Le programme de surveillance a inclus l'installation de sondes thermiques à une profondeur de 3m et un système de recueil de données qui permet la surveillance des températures pendant toute l'année. Des plaques de tassement sont utilisées pour surveiller la compression de la couche composée de pneus. L'effet des pneus sur la qualité de l'eau souterraine est surveillé périodiquement par des échantillons d'eau.

1. INTRODUCTION

Shredded tires have several uses in civil engineering construction including retaining wall and bridge abutment backfill, drainage layers in landfills, and pavement frost barriers. Lightweight fill, used to replace granular fill on weak subgrade, is of particular interest to highway construction. It provides a means of disposing the tires and helps reduce the instability of construction over soft and frost susceptible soils.

Several studies have been completed using shredded tires as a lightweight fill in highway construction (Edil et al., 1992, Humphrey et al., 1993, Eaton et al., 1994, Bosscher et al., 1995, Hager et al., 1998, Dickson et al., 2001). Tire shreds reduce the overburden pressure on the soft subgrade, thereby reducing the settlement

2. SITE DESCRIPTION

The project site is located 5 Km North-East of Winnipeg, near the intersection of PR 213 and PR 206. The new access road is to provide an alternative route into an active gravel pit. The site is mostly a swampy area with an influx of surface water flowing from an adjacent golf course. The subgrade in this area is very soft and excessive settlement is expected if conventional fill materials are used.

3. GEOTECHNICAL INVESTIGATION

The University of Manitoba carried out a soil investigation. Four boreholes were augured with a 50 mm diameter bit to depths of 2.4 m and 3.0 m. The boreholes were drilled from the existing ground surface. A borehole was drilled every 60 m along the construction of the road. Due to partial construction of the road, boreholes 1 and 2 were drilled in the ditch beside the road. Boreholes 3 and 4 were drilled on the centreline of the proposed road. Samples were obtained directly off the auger for laboratory testing. The tests were performed in the Geotechnical Laboratories of University of Manitoba. The tests performed in this soil investigation included the natural moisture content, grain size analysis, Atterberg limits, soil classification, and direct shear test. The topsoil was moist and sandy with some soft gray clay intermixed. The remaining soil was primarily gray-brown clay with fine sand, silt lenses and silt nodules. The high plastic clay ranged from soft near the surface to firm at depths of 3.0 m.

From the laboratory test results, as shown in Figure 1, it is evident that this soil is not a suitable subgrade for conventional construction. The California Bearing Ratio for this soil will not exceed 2%. A thick layer of sub base material would be required to adequately reduce the stresses and settlements of the subgrade under traffic conditions. However, the loading from a thick sub base layer would itself produce significant and probably irregular settlements in the subgrade soil.

There were three possible alternatives to improve the subgrade soil prior to construction of a road embankment. These were: (1) replacing the existing subgrade with a compacted borrow that is better suited for use as a subgrade; (2) stabilizing the soft subgrade; and (3) constructing a lightweight road embankment. Each of the three alternatives would limit the progressive settlement of the soft subgrade and provide the strength required to adequately distribute the load.

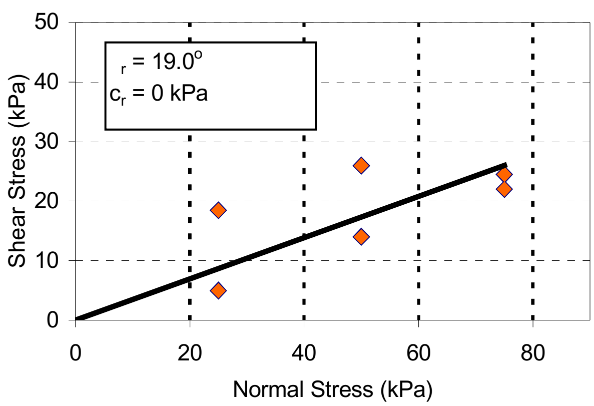

Figure 1. Shear strength of subgrade soil

4. CONSTRUCTION

The 300 m long road embankment was constructed in 2000. Initially five layers of tire sidewalls were manually placed on the subgrade in an overlapping pattern. Then 300 mm tire shreds were hauled to the site and were unloaded directly over the sidewalls, Fig 2. The tire shreds were spread to the desired thickness with the backhoe and then gravel was placed on top of the embankment, Fig 3. Approximately 300,000 passenger car tire equivalents were used in the construction, or one-third of the annual supply of scrap tires in Manitoba. Cross section of the road embankment is shown in Fig 4.

Fig 2. Delivery of shredded tires to construction site

Fig 3. Tire road embankment during construction

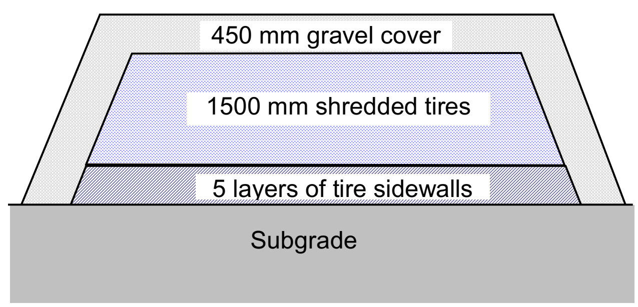

Fig 4. Cross section of tire road

5. INSTRUMENTATION

Long-term field-monitoring program was carried out by the University of Manitoba to monitor the performance of the road embankment. For this purpose, instrumentation of the embankment was designed to evaluate thermal behavior and compressibility of the tire shreds. Slope stability was not deemed to be a problem because of the high friction angle of tires chips (Bosscher et al., 1995).

5.1 Automated Temperature Measurement

A temperature-monitoring program was started in November 2000 for the evaluation of thermal behavior of shredded tires. Ground temperature was measured by means of thermocouple sensors connected to a computer and Data Acquisition System (DAQ) located on site. The system has 16 bit analog inputs, signal amplification and cold junction compensation to provide accurate temperature measurement up to 0.1^{0}C.

Strings of thermocouples were attached to 50 mm PVC pipe casings. The thermocouple strings were 3 m long. The gaps between the thermocouples and top and bottom of the pipes were sealed using high quality sealing compound. Nine thermocouples @ 343 mm c/c and seven thermocouples @ 457 mm c/c spacing were placed in the tire road and in the ground adjacent to the tire road respectively, as shown in Fig 5. The thirty-two thermocouples were connected to the DAQ system as shown in Figure 6. The box was completely insulated using Styrofoam insulating sheets. An electric heater was placed to maintain a temperature in the range of (10-25) ^{0}C inside the box.

The average depth of frost penetration is summarized in Fig 7. It is seen that depth of frost penetration beneath the tire road ranged from 1050 mm to 1525 mm. In contrast, in natural ground, the depth of frost penetration ranged from 450 mm to 850 mm. One reason for greater depth of frost penetration in tire road compared to the natural ground is the presence of more thicker blanket of snow on top of the natural ground compared to the tire road as the effectiveness of insulation of soil increases as thickness of overlying snow cover increases (Highway Research Board, 1952). Other reason is the presence of large voids in the tire road embankment.

Fig 5. Installation of Thermocouple strings

Figure 6. DAQ system

Figure 8 shows the thermal gradient of soil and tires for Winter and Spring seasons. The surface temperatures in the tire road is lower than the natural ground while the base temperature is essentially the same at both sections indicating a rapid resistance to the frost within the tire shreds fill. Hence the thermal gradient of tires is more compared to the natural ground.

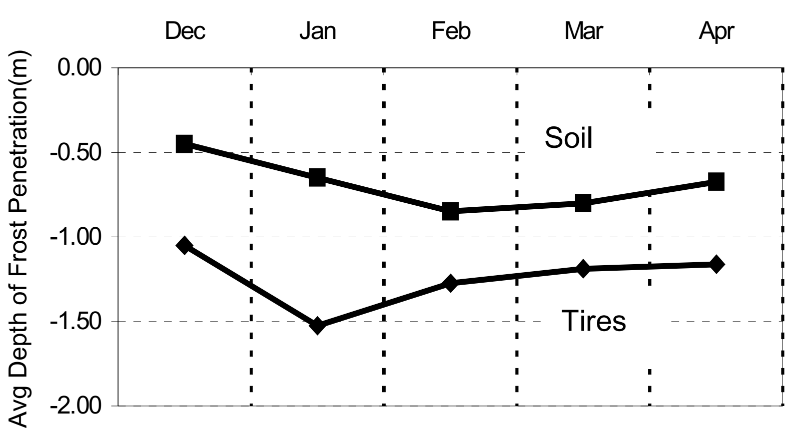

Figure 7. Average Depth of Frost Penetration during 2000-2001

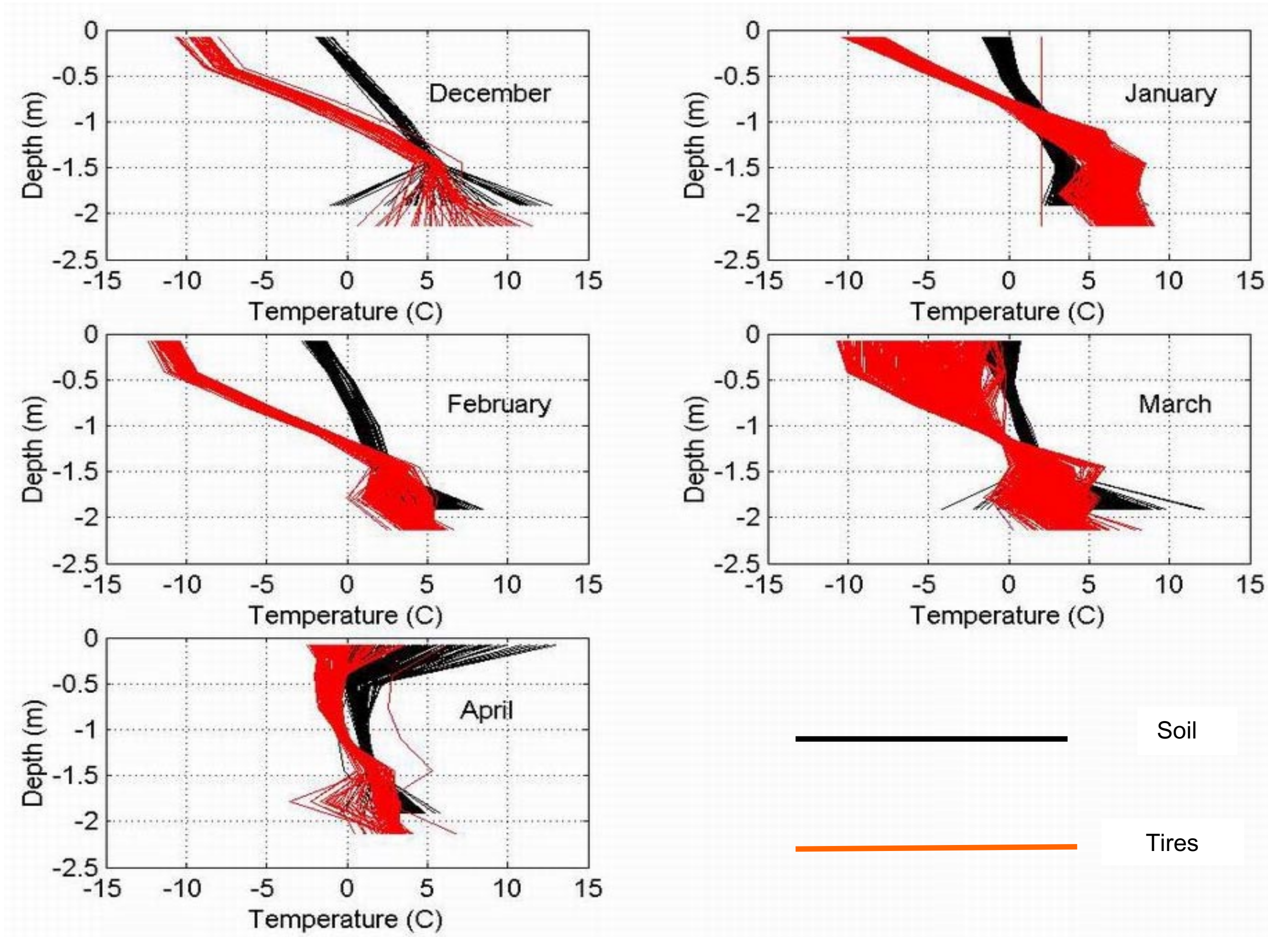

Figure 8. Thermal gradient in soil and tires

5.2 Deflection Measurement

Metal settlement plates (500x500 mm) were placed at several locations on the surface of the tire road to evaluate its compressibility. Rod and level survey was performed for this purpose in May 2001. Initially the as built elevations of the settlement plates SP1, SP2, SP3 and SP4 were recorded. Then the settlement plates were loaded by 21000 Kg dual-tandem axle load and again the elevations were recorded as shown in Fig 9. The compressibility of the road was obtained from the difference of initial and final readings. Two loading and unloading passes were performed to evaluate the compressibility of the tire road, Fig 10, which indicates an average of 15 mm and maximum of 25 mm deflections, after one year of fill placement. An average instantaneous rebound of 11 mm and an average deformation of 7 mm were also recorded after two passes of the loaded truck.

6. GROUND WATER QUALITY

Scrap tires are the source of the metals as shown in table 1, (NCHRP, 2001). Inorganic and organic water quality testing were performed for the shredded tire road on 15/03/001 and 20/04/001.

The inorganic water quality results, as shown in table 2, are compared with the maximum values obtained during spring of 5 years field study conducted in Maine, USA (Humphrey et al., 2000) and Canadian Council of Ministers of the Environment (CCME) Environmental Quality Guidelines (EQGs), (CCME, 1999). These results show that concentrations of Aluminum, Iron and Manganese are higher than the recommended values but are of less concern, as these are secondary parameters in the EQGs.

The organic water testing was performed for total extractable and purgeable hydrocarbons including Benzene, Toluene, Ethyl benzene, Xylenes (BTEX). These results showed that the level of organics is below the test method detection limits as shown in table 3.

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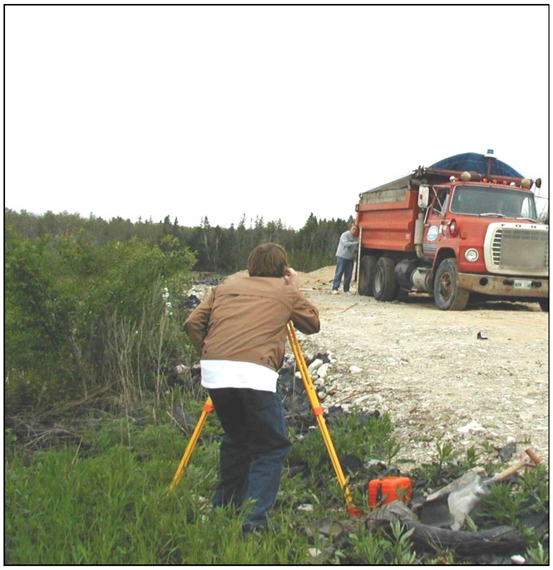

Figure 9. Deflection survey

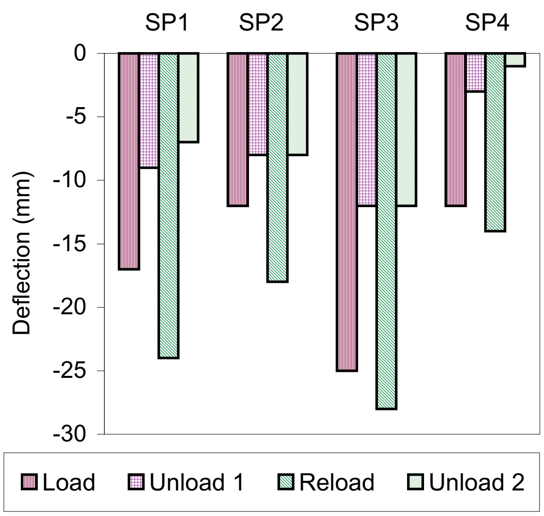

Figure 10. Surface deflections at four locations

7. CONCLUSION

A program for the long-term field monitoring of a shredded tire road embankment near Winnipeg, Manitoba has been carried out. The following observations are made.

1. The thermal gradient in tires is approximately 10 ^{0}C/m while in soil the gradient is 2 ^{0}C/m.
2. Frost penetration in the tire road is larger than in the natural ground because of the difference in thermal conductivity, the presence of large voids in the tire road embankment and the difference in snow cover.
3. The observed deflection of the tire road embankment is 15 to 25 mm, under 21000 Kg dual-tandem axle load. An average rebound of 11 mm and a permanent deformation of 7 mm were recorded after two passes.
4. The levels of Aluminum, Iron and Manganese for the ground water below the tire road embankment are above the recommended values but are of less concern, as these are secondary drinking water quality parameters.

8. ACKNOWLEDGEMENT

The authors are grateful to the Manitoba Tire Stewardship Board for providing funding for this research.

9. REFERENCES

Bosscher, P., Edil, T., 1995. Design of Highway Embankments Using Tire Chips, Environmental Geo-technics Report No.95-2, University of Wisconsin, Madison.

Canadian Council of Ministers of the Environment, CCME, 1999. Summary of existing Canadian Environmental Quality Guidelines (EQGs). CCME Publications, Winnipeg, Manitoba. http://www.mbnet.mb.ca/ccme/pdfs/ceqg_rcqe/summary_table_e.pdf. Accessed May 24, 2001.

Dickson, T., Dwyer, D., Humphrey, D., 2001. Prototype Tire road embankment Construction by the New York State Department of Transportation, Transportation Research Board, 80th Annual Meeting, Washington D.C.

Eaton, R., Roberts, R., Humphrey D., 1994. Gravel Road Test Sections Insulated with Scrap Tire Chips, US Army Cold Regions Research Laboratory, Hanover, N.H.

Edil, T., Bosscher ,P., 1992. Development of Engineering Criteria for Shredded Waste Tires in Highway Applications, Wisconsin Department of Transportation.

Hager, G., James, M., Bret B., 1998. Construction and Instrumentation of a Shredded Tire Fill at the Double Nickel Landslide, Wyoming Department of Transportation, Cheyenne.

Highway Research Board, Frost Actions in Soil, 1952. A Symposium, Special Report No. 2, Washington, D.C.

Humphrey, D., Sandford, T., 1993. Tire Chips as Lightweight Subgrade Fill and Retaining Wall backfill, Symposium Proceedings, Recovery and Effective Reuse of Discarded Materials and By-Products for Construction of Highway Facilities, Denver, Colorado.

Humphrey, D., Katz L., 2000. Five-year Field Study of the Water Quality Effects of Tire Shreds Placed Above the Water Table, Transportation Research Board, 79th Annual Meeting, Washington D.C.

NCHRP, 2001. Appropriate Use of Waste and Recycled Materials in Transportation Industry, Project 4-21, Transportation Research Board.

Table 1. Trace Metals Concentration in Rubber Tires

Trace Metal	Concentration (mg/kg)	Trace Metal	Concentration (mg/kg)
Aluminum	280	Mercury	0.1
Arsenic	4.1	Magnesium	< 500
Barium	< 20	Manganese	28
Beryllium	< 0.5	Molybdenum	1
Boron	< 500	Sodium	< 500
Calcium	1160	Nickel	3.3
Cadmium	3.6	Selenium	< 5
Cobalt	107	Strontium	< 100
Chromium	3.3	Titanium	48
Copper	30	Vanadium	< 1
Iron	4480	Zinc	15500

Table 2. Inorganic Water Quality Analysis

Analyte	Detection Limit [1] (mg/L)	Humphrey [2] (mg/L)	Canadian Limit [3] (mg/L)	As tested on 15/03/01 (mg/L)	As tested on 20/04/01 (mg/L)
Aluminum	0.009	0.50	0.2	1.53	0.055
Barium	0.0002	0.23	1	0.0780	0.0454
Calcium	0.2	500	1000	120	83.2
Chromium	0.0009	0.75	0.05	0.0024	< .0009
Iron	0.003	28	0.3	5.75	0.159
Magnesium	0.06	160	No Limit	54.7	31.3
Manganese	0.0002	19	0.05	0.714	0.033
Sodium	0.4	800	200	11.5	5.5
Zinc	0.0007	1.25	5	0.0868	0.0098

1. APHA Standard Methods for Examination of Water and Wastewater, 2. Humphrey et al. (2000)
3. CCME Environmental Quality Guidelines, (1999).

Table 3. Organic Water Quality Analysis

Analyte	Detection Limit [1] (mg/L)	Canadian Limit [2] (mg/L)	As tested on 20/04/2001 (mg/L)
Benzene	0.001	0.005	< 0.001
Toluene	0.001	0.024	< 0.001
Ethyl benzene	0.001	0.0024	< 0.001
Total Xylenes	0.001	0.3	< 0.001
Total purgeable	0.01		< 0.01
Total Extractable	0.1		< 0.1

1. US EPA Method 8020/8015, 2. CCME Environmental Quality Guidelines, (1999)