Field Performance of Tire Chips as Subgrade Insulation for Rural Roads

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This paper describes a field trial that uses tire chips as an insulating layer to limit frost penetration beneath a gravel-surfaced road. Tire chips are an attractive alternative to conventional insulation boards because they have a high thermal resistivity and are durable, free draining, and low-cost. The primary goals were to determine the thickness of tire chips needed to provide effective insulation and the minimum thickness of overlying soil cover needed to produce a stable riding surface. The project is 230 m (750 ft) long and consists of five sections with either a 152-mm (6-in.) or a 305-mm (12-in.) tire chip layer overlain by 305 mm (12 in.), 457 mm (18 in.), or 610 mm (24 in.) of granular soil. In addition, there are three control sections. The project is instrumented with thermocouples, resistivity gauges, and groundwater monitoring wells. Based on an analysis of the first two winters in service, a 152-mm-thick tire chip layer overlain by 305 mm (12 in.) of gravel reduced the depth of frost penetration by 22 to 28 percent compared with an adjacent control section. Likewise, a 305-mm (12-in.) tire chip layer overlain by either 457 mm (18 in.) or 610 mm (24 in.) of gravel resulted in a 15 to 37 percent reduction. Furthermore, the two sections with 305 mm (12 in.) of tire chips experienced a heave of between 10 mm (0.4 in.) and 40 mm (1.6 in.), whereas a nearby control section heaved 55 mm (2.3 in.) to 91 mm (3.6 in.).

Maintaining gravel-surfaced roads in northern climates during the spring thaw is a perennial problem. Ice lenses form in the underlying soil if the soil is frost susceptible and the groundwater table is near the road surface. As temperatures warm, these ice lenses melt, releasing significant quantities of excess water. Melting proceeds downward from the road surface. The water cannot drain down because the underlying soil is still frozen. Moreover, the ditches at the side of the road are often still filled with snow and ice, so the water cannot drain laterally through the granular surface course. The water is forced up to the road surface, which saturates and weakens the granular surface course. Traffic ruts the surface, which ruins the cross drainage and traps more water on the road surface. Regrettably, this is a common occurrence since the soil types found in northern climates, such as glacial tills, poorly sorted outwash sands and gravels, and marine and lacustrine clays, are often very frost susceptible. Moreover, most northern climates are relatively wet and produce a high groundwater table.

Three remedies to reduce the rutting of the road surface during the spring melt are (*a*) to increase the thickness of the granular surface course; (*b*) to improve the drainage to lower the groundwater table; or (*c*) to use insulation to prevent the underlying frost-susceptible soil from freezing. The first two remedies are the most common. However, the granular surface course must be thick to completely solve the problem. Roads with a 457-mm (18-in.) granular surface course have experienced significant rutting during the spring melt. Improving drainage by increasing the depth of the ditches along the side of the road is a low-cost solution, but local topography and the possibility that vehicles may slide into the ditch may make it impossible to provide ditches deep enough to solve the problem. The third remedy, insulation, is rarely used on rural roads because of the high cost of extruded polystyrene insulation boards.

This paper presents results of a field trial using a new insulating material, tire chips, to limit the depth of frost penetration beneath a gravel-surfaced road. Tire chips are waste tires that have been cut into 51-mm (2-in.) pieces or smaller. Tire chips are an effective insulator because rubber has a much lower thermal conductivity than soil does (*1,2*). Moreover, tire chips have a very high permeability (*3,4*) and provide excellent drainage to remove excess water from the road substructure.

Using tire chips as an insulating layer has important implications for waste disposal since every cubic meter of tire chip fill contains 100 tires (75 tires/yd^3). A kilometer of two-lane road underlain by a 305-mm (12-in.) layer of tire chips would require about 200,000 tires (300,000 tires/mile). Tire chips are produced by portable shredding machines, so it would be possible to produce tire chips at local solid waste disposal facilities and leave behind a pile of road building material instead of a solid waste disposal problem. In addition, this application could use some of the more than 2 billion scrap tires that have been discarded in huge open piles across the United States (*5*).

The field trial was designed to answer three primary concerns: (*a*) the thickness of tire chips needed to provide adequate insulation; (*b*) the thickness of granular soil cover needed over the tire chips to provide a stable riding surface; and (*c*) the effect of tire chips on groundwater quality. Several thicknesses of the tire chip layer and overlying granular soil cover were tested. An extensive instrumentation and monitoring program was established that included using thermocouples and resistivity gauges to monitor thermal behavior, measuring surface deflections of the road with a heavy weight deflectometer; and monitoring groundwater quality in several monitoring wells. This paper will concentrate on the thermal behavior of the field trial using data from the first two winters. A companion paper focuses on the support characteristics of the tire chips (*6*). The groundwater quality study is ongoing, but laboratory tests suggest that there is little likelihood that tire chips will release contaminants in sufficient quantities to be of concern (*7–9*) as long as chips are placed above the groundwater table. Other field studies are under way at the University of Maine to gather more data on the effect of tire chips on water quality when they are placed below the groundwater table. Construction of the test section and data from the first winter were discussed in detail in previous papers (*10,11*).

Site Description

The test site is located on Dingley Road in the town of Richmond, Maine. The dead-end, gravel-surfaced road serves 29 residences and two farms. The predominant traffic is cars, light trucks, and school buses. However, one day a month, 10 to 40 fully loaded double- and triple-axle dump trucks haul sewage sludge to farms located at the end of the road. Residents report that the road surface becomes severely rutted during the annual spring melt.

The road follows the northeast shoulder of a broad, flat ridge that trends northwest to southeast. During the summer and fall, no standing water or wet areas are evident near the test site. However, during the spring melt, the generally flat topography leads to poor drainage and areas of standing water.

In most areas, the existing road was surfaced with more than 457 mm (18 in.) of clean sandy gravel and gravely sand. The underlying native soils ranged from gray silty clay to gray-brown silty gravely sand. These soil types are highly frost susceptible. Probes were conducted with a 127-mm (5-in.) diameter power auger. Refusal occurred at depths ranging from 2.7 to 5.6 m (9 to 18 ft). The general geology of the area suggests that refusal was glacial till with boulders or bedrock. The water table in the summer and fall is 1 to 3 m (3.3 to 9.8 ft) below the ground surface.

Test Site Configuration

The test site is 290 m (950 ft) long and is broken up into five tire chip test sections, each with a length of 23 m (75 ft) or 46 m (150 ft). The tire chip test sections are designated Sections A through E. In addition, there is one 46-m (150-ft) long control section and two 30-m (100-ft) long transition sections. Two sections of the existing road are also used as controls. The location of the sections is shown in Figure 1. Two different thicknesses of tire chips, 152 and 305 mm (6 and 12 in.), were used to investigate the thickness required to provide adequate insulation, and three different thicknesses of granular soil, 305, 457, and 610 mm (12, 18, and 24 in.), were placed over the tire chips to investigate the thickness necessary to provide a stable riding surface. The granular soil cover includes a 102-mm (4-in.) thick

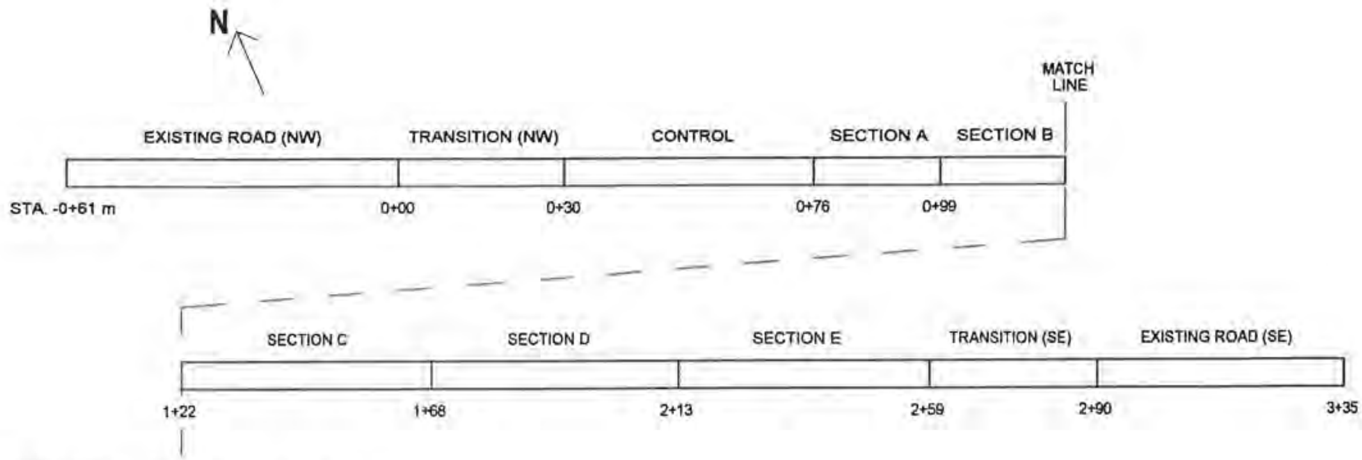

FIGURE 1 Plan view of test site.

granular surface course with a maximum particle size of 25 mm (1 in.). This provides a smooth, low-maintenance riding surface. A typical cross section is shown in Figure 2. Before the tire chips were placed, the existing road surface was excavated to between 152 and 457 mm (6 and 18 in.) to keep the final grade of the road surface from being too far above the surrounding terrain. The bottom of the excavation was sloped toward the ditch to enhance drainage. A minimum of 610 mm (2 ft) of gravel cover was maintained between the edge of the tire chip course and the 3:1 side slopes.

The configuration of the test sections is summarized in Table 1. The thicknesses of the soil and tire chip layers in Sections A and B were identical. However, the tire chips in Section A were completely enveloped in a woven geotextile (Amoco 2000-2) to evaluate the need for a geotextile to act as a filter to minimize infiltration of the underlying and overlying soils into the tire chip layer.

MATERIALS

The tire chips were uniformly graded and had a nominal maximum size of 51 mm (2 in.). Almost all the tire chips were retained on the No. 4 (4.75-mm or 0.187-in.) U.S.-standard sieve. The chips were made from a mixture of steel and glass-belted tires and were irregular

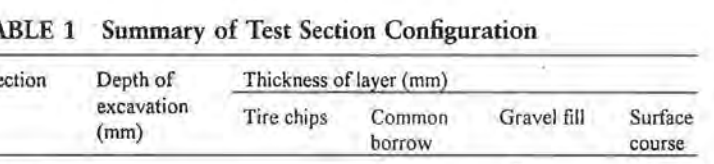

FIGURE 2 Typical cross section.

TABLE 1 Summary of Test Section Configuration

Section	Depth of excavation (mm)	Thickness of layer (mm)			
		Tire chips	Common borrow	Gravel fill	Surface course
Control	----	----	----	203	102
A	152	152	----	203	102
B	152	152	----	203	102
C	152	152	----	356	102
D	305	305	----	356	102
E	457	305	305	203	102

25.4 mm = 1 in.

in shape; many had steel belts protruding from the cut edge. They were donated by Pine State Recycling of Nobleboro, Maine. Approximately 20,000 tires were used in this small project. There is great potential for this application to use large quantities of waste tires.

The gravel fill used over the tire chips was a well-graded mixture of sand and gravel, with less than 5 percent passing the No. 200 (0.075 mm; 0.00295 in.) U.S.-standard sieve and a maximum particle size of 152 mm (6 in.). The surface course was obtained from the same source as the gravel fill; however, it had a maximum particle size of 25 mm (1 in.) and about 7 percent passing the No. 200 sieve. Common borrow was used as part of the soil cover over the tire chips in Section E to reduce the quantity of imported granular fill. The common borrow was salvaged from granular soil excavated from the existing road surface. It was a gravely sand with about 3 percent passing the No. 200 sieve.

Construction

The test section was constructed from August 24 through September 2, 1992. The first step was to excavate the northwestbound lane of the existing road down to the desired starting grade. This was done with a wheel-mounted hydraulic excavator. Excavated soil was hauled away with 11-m^3 (14-yd^3) capacity dual-rear-axle dump trucks. Some of the soil was stockpiled near the site for later use as common borrow; the remainder was disposed of off-site. The grade was smoothed with a small bulldozer and given the specified 4 percent slope toward the ditch. The exposed grade was then compacted with four passes of a vibratory smooth drum roller with a static weight of 9 metric tons (10 U.S. short tons).

The tire chips were hauled to the site in a 12-m (40-ft) long self-unloading semitrailer. About 20 metric tons (22 U.S. short tons) was hauled in a single load. The tire chips were unloaded directly on the prepared subgrade and then spread to the desired thickness with a small bulldozer. The bulldozer could easily achieve the specified grade within ± 12 mm (0.5 in.).

The tire chips were compacted with six passes of a smooth drum vibratory roller with a static weight of 9 metric tons (10 U.S. short tons). From visual observation, the first pass caused a 305-mm (12-in.) thick layer of tire chips to be compacted by 10 to 25 mm (0.45 to 1.0 in.). Compaction on subsequent passes was too minor to be observed.

After the tire chips were placed, they were covered with the specified thickness of gravel fill or, in Section E, by common borrow followed by gravel fill. The specified thicknesses are summarized in Table 2. The gravel cover and common borrow were hauled to the site in 11-m^3 (14-yd^3) capacity dump trucks, spread in a 305-mm (12-in.) maximum thickness lift with a small bulldozer, and then compacted with six passes of a smooth drum vibratory roller with a static weight of 9 metric tons (10 U.S. short tons).

During construction, three in-place density tests were performed on the gravel fill, and one was performed on the common borrow. Compared with the results of modified Proctor compaction tests, the water contents were 2 to 3 percentage points dry of optimum and the percent compactions were 78 to 88 percent (*10,11*). The low water contents were undoubtedly a contributing factor in the low compacted densities. The difficulty of compacting granular soil placed on the compressible tire chips may also be important.

Finally, the 102-mm (4-in.) thick surface course was placed on the gravel fill. It was hauled, spread, and compacted in a manner similar to the gravel fill process except that only four passes were made with the roller. Final shaping was performed with a small road grader. The completed surface was treated with flake calcium chloride. The complete construction specifications for the project are given by Humphrey (*12*).

Monitoring Program

An extensive monitoring system was put in place to evaluate the thermal behavior, road surface support characteristics, and groundwater quality of the project. Installed instrumentation includes vertical strings of

TABLE 2 Depth to Groundwater Table

Well no.	Station (m)	Section	Depth from road surface to ground water table (m)	
			11/24/92	12/23/93
1	0+21.0	Transition (NW)	2.84	1.05
2	0+91.5	A	2.50	0.89
3	1+04.3	B	2.15	0.59
4	1+88.7	D	2.36	1.08
5	2+06.4	D	1.44	0.80
6	2+53.7	E	1.66	1.37

1 m = 3.28 ft

thermocouples installed at two locations in each of the five tire chip test sections, the control section, and a section of the existing road; resistivity gauges to monitor the location of the freezing front in each test section, the control section, and the existing road; six groundwater monitoring wells; and two frost-free bench marks. The thermocouples and resistivity gauges were connected to a system that allowed them to be read by telephone from the Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. The instrumentation plan and cross section are shown in Figure 3. Details of the monitoring program follow.

Thermocouples and Resistivity Gauges

Two vertical strings of thermocouples were installed in each test section, the control section, and the existing road. Each string consisted of twelve 20-gauge copper constantan thermocouples. The vertical spacing between thermocouples varied from 76 mm (3 in.) near the road surface to 305 mm (12 in.) at greater depths. The deepest thermocouple was typically about 2 m (6.5 ft) below the road surface. The installation in a typical section (Section C) is shown in Figure 4. To maintain the desired spacing, the thermocouples were mounted in a 25-mm (1-in.) diameter wooden dowel. The thermocouple strings were installed in a 127-mm (5-in.) diameter hole drilled with a trailer-mounted power auger. After the string was placed, the hole was backfilled with native soil tamped in place with a hand tamper.

The thermal resistivity gauges consisted of 25-mm (1-in.) diameter copper rings spaced 51 mm (2 in.) apart on an epoxy-filled core. The electrical resistivity of the soil between adjacent rings was measured to determine if the soil was thawed or frozen. The resistivity of frozen soil was much lower than that of thawed soil. This allowed the location of the freezing front to be monitored during the winter; the thawing front was also monitored during the spring. The resistivity gauges were 1.2 m (4 ft) long. The top of the gauge was typically even with the bottom of the tire chip layer. The installation technique was the same as that for the thermocouples. A typical installation is shown in Figure 4.

Groundwater Wells

Groundwater monitoring wells were installed at six locations so that water quality samples could be taken and the elevation of the groundwater table could be measured. The wells consisted of 51-mm (2-in.) diameter Sch. 40 polyvinyl chloride (PVC) pipe. A cap was glued to the bottom of the pipe and a hacksaw was used to cut slots in the cap and the bottom 0.6 m (2 ft) of the pipe. The pipe was placed in a 127-mm (5-in.) diameter hole drilled with a trailer-mounted power auger. The slotted lower portion was then surrounded with concrete sand. A 0.5-m (1.5-ft) thickness of bentonite balls was then placed to form an impermeable seal to prevent surface water from reaching the slotted tip. The remainder of the hole was backfilled with native soil.

One well was located next to the control section to provide background readings of water quality. The remaining five wells were located next to the tire chip test sections. Water quality samples will be taken on a quarterly basis and monitored for metals such as iron and manganese that could potentially leach from the tire chips. Results from groundwater quality monitoring are not yet available.

Heave Survey

The heave of the road surface was measured several times during the winter with a level survey. Two frost-

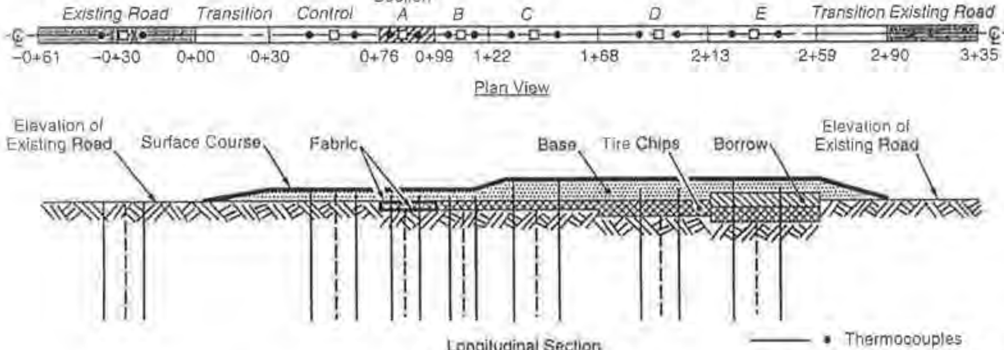

FIGURE 3 Location of instrumentation.

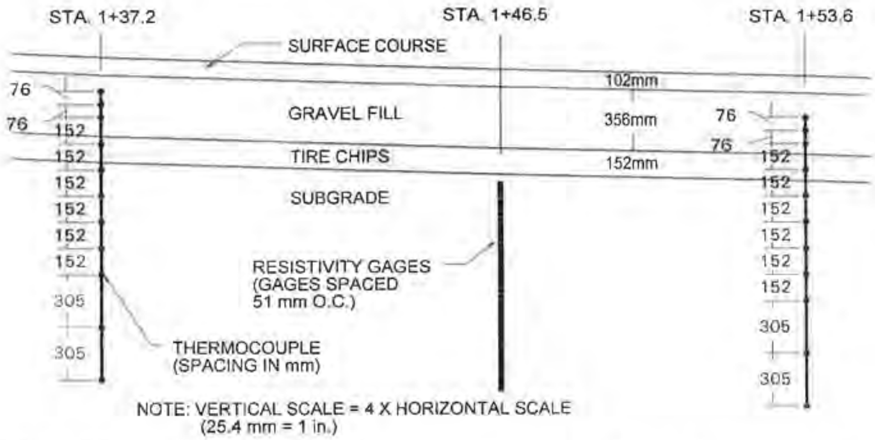

FIGURE 4 Cross section showing thermocouples and resistivity gauges in Section C.

free benchmarks were installed to provide stable reference points for this survey.

Performance

The test sections were in place for the winters of 1992 to 1993 and 1993 to 1994. The freezing index for 1992 to 1993 ws 626°C-days (1128°F-days); for 1993 to 1994, it was about 707°C-days (1273°F-days). Both winters were somewhat colder than the reported average for the area of 470°C-days (850°F-days) (*13,14*). The following summary concentrates mostly on the data from the 1993 to 1994 winter. A more complete presentation of data from the winter of 1992 to 1993 is given by Humphrey and Eaton (*10,11*).

Thermal Behavior

The maximum depth of frost penetration for the winters of 1992 to 1993 and 1993 to 1994 is summarized in Figure 5. The depth of frost penetration beneath the existing road and control sections ranged from 1170 mm (46 in.) to 1600 mm (63 in.). In contrast, in tire chip Sections A, B, D, and E, the depth of frost penetration ranged from 910 mm (36 in.) to 1021 mm (40 in.). The tire chips reduced the depth of frost penetration by between 22 and 28 percent compared with the control section. In Section C the depth of frost penetration was 1040 mm (41 in.) during the winter of 1992 to 1993 and 1205 mm (47 in.) during the winter of 1993 to 1994. This indicates that the thicknesses of soil cover and tire chips in Section C are not as effective in reducing the depth of frost penetration as the tire chips in the other sections. One reason that frost penetration depth was greater in Section C than in Sections A and B, which have 152 mm (6 in.) of tire chips, is that the effectiveness of insulation decreases as thickness of the overlying soil cover increases, as indicated by design charts presented by Berg and Johnson (*15*). In Sections C and D, which both have 457 mm (18 in.) of soil cover, increasing the thickness of the tire chip layer from 152 mm (6 in.) to 305 mm (12 in.) reduced the depth of frost penetration by 70 mm (3 in.) in the 1992 to 1993 season and 307 mm (12 in.) in the 1993 to 1994 season. In Section E, the frost penetrated 45 to 76 mm (2 to 3 in.) below the bottom of the tire chip layer.

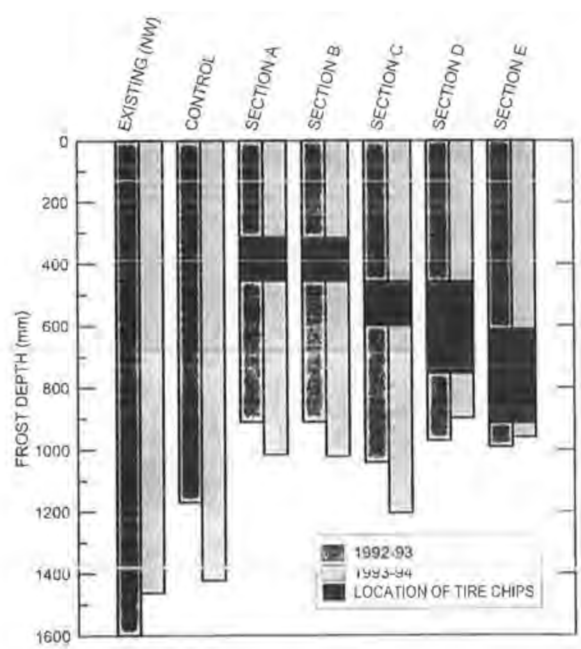

FIGURE 5 Maximum depth of frost penetration.

The depth of frost penetration compared with time for the 1993 to 1994 season shows even more clearly the effect of tire chips (Figure 6). In the existing road and control section, the frost penetrated to a depth of about 750 mm (30 in.) within about 1 week of the onset of the freezing season. After this, the frost continued to penetrate at an approximately constant rate for the remainder of the freezing season. In the tire chip sections, there was also a rapid initial penetration of the frost; however, after this, the rate of frost penetration was considerably lower than that beneath the existing road and control section. In Sections A and B, the rate of frost penetration decreased to almost zero after February 1, 1994. From February 1, 1994, through February 24, 1994, the frost penetrated an additional 18 mm (0.7 in.) in Section A. In contrast, the depth of additional frost penetration in the adjacent control section over the same period was 122 mm (4.8 in.). In Section D, there

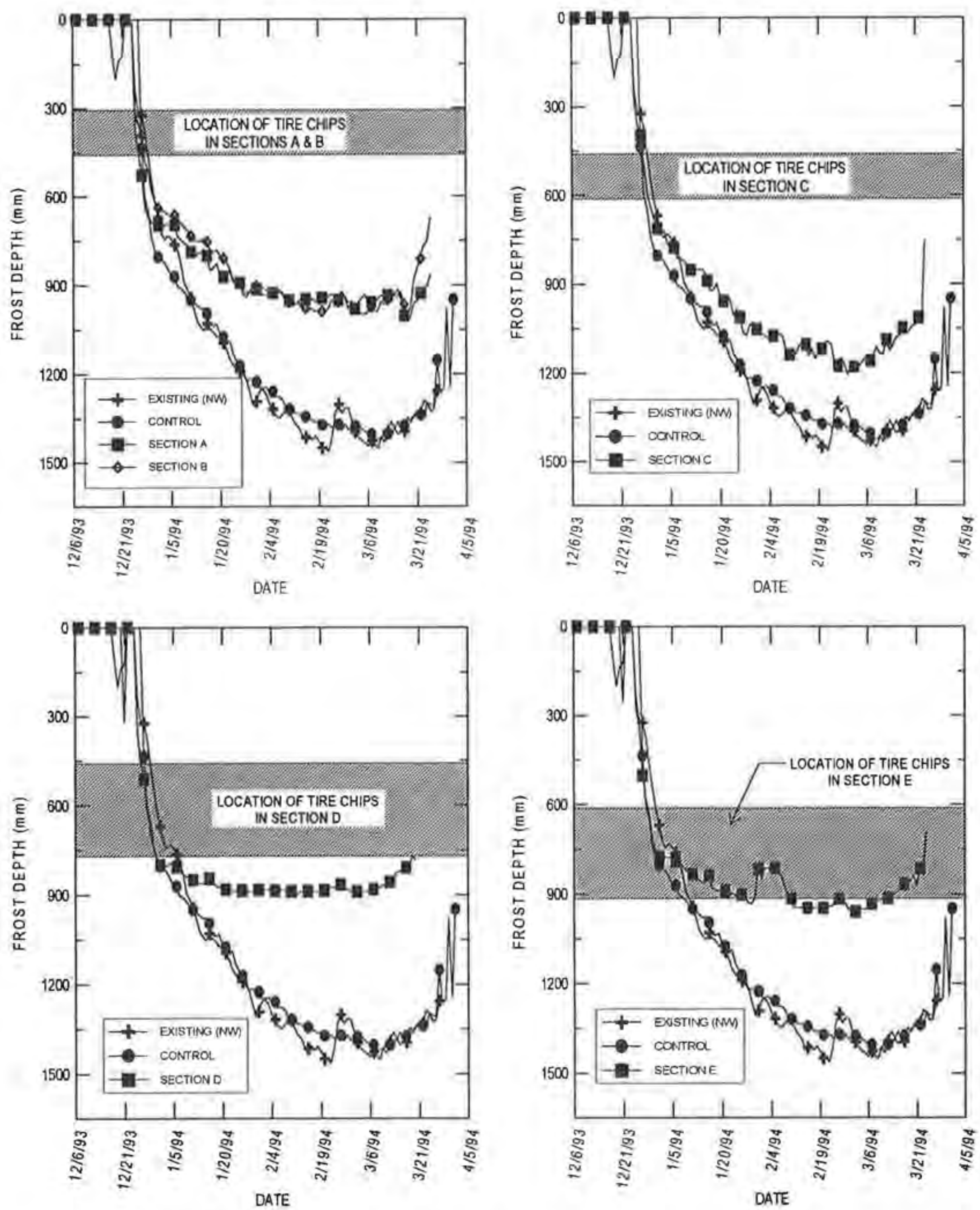

FIGURE 6 Depth of frost penetration versus date.

was little additional frost penetration after the frost penetrated the tire chip layer; in Section E, the frost remained within the lower portion of the tire chip layer for most of the freezing season, as shown in Figure 6. Similar results were found for the 1992 to 1993 season, as discussed by Humphrey and Eaton (*10,11*).

Comparisons of temperature and depth show the beneficial effects of tire chips. February 16, 1994, marked the end of a 45-day cold period in which the average daily temperature typically ranged between −5°C and −20°C (23°F to −4°F). The temperature beneath the existing road and control sections increased roughly linearly with depth, as shown in Figure 7. However, in the tire chip sections, there was a marked increase in temperature from the top to the bottom of the tire chip layer. The temperature increased 3°C to 4°C (5°F to 7°F) for the sections with 152 mm (6 in.) of tire chips and 8°C for sections with 305 mm (12 in.) of tire chips. This indicates that the tire chips have a higher thermal resistivity than that of the soil. Figure 7 also shows that in Sections D and E, the temperature of the soil immediately above the tire chip layer was 2°C to

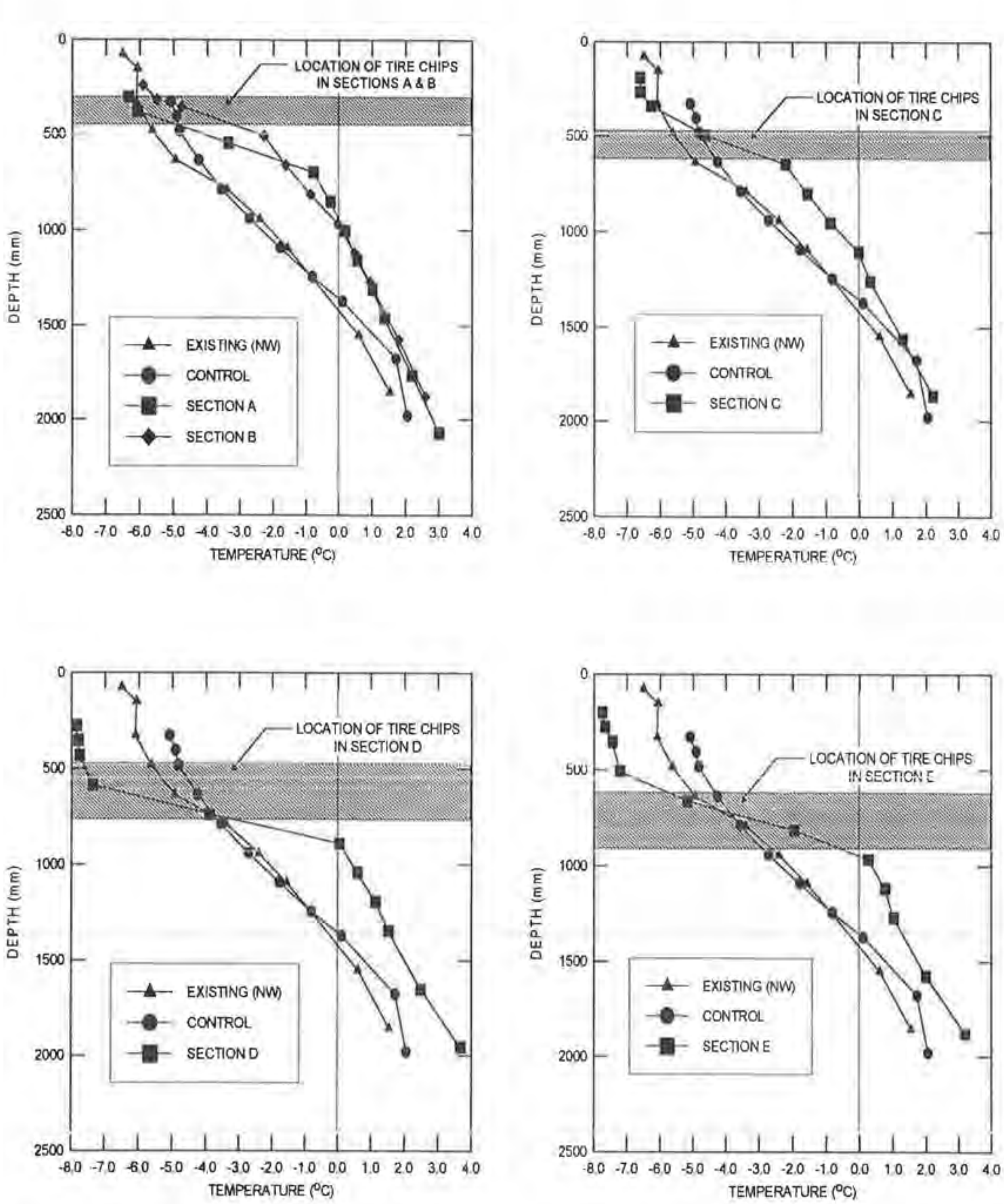

FIGURE 7 Temperature profile on February 16, 1994.

3°C (4°F to 5°F) colder than the same depth in the existing road and control section. This was because the higher thermal resistivity of the tire chips reduced upward flow of heat from the underlying warmer soil. Results for the 1992 to 1993 season were similar (*10,11*).

Groundwater Levels

Groundwater levels were measured in six monitoring wells. Readings taken near the beginning of the freezing season are shown in Table 2. For the readings before the 1993 to 1994 season, the groundwater table was 0.59 m (1.9 ft) to 1.37 m (4.5 ft) below the road surface. Comparison with Table 1 shows that the groundwater table is 0.04 m (0.1 ft) to 0.5 m (1.6 ft) below the bottom of the tire chip layer. The control section is located between Wells 1 and 2, so the depth to the groundwater table is about 1.0 m (3.3 ft). Figure 5 shows that the frost penetrated at least 0.4 m (1.3 ft) below the groundwater table. It appears that the location of the groundwater table did not have a significant effect on the depth of frost penetration.

Frost Heave

Frost heave was measured for the winters of 1992 to 1993 and 1993 to 1994. For the 1992 to 1993 season, frost heave was computed as the increase in the elevation of the road surface between December 14, 1992, and February 24, 1993. For the 1993 to 1994 season, computations were made between December 6, 1993, and March 9, 1994. The results are summarized in Figure 8. The sections correspond to those shown in Figure 1. Interpretation of Figure 8 is complicated by the many factors that affect frost heave, including depth to groundwater table, depth to bedrock, and soil type. However, the low heave of the northwest existing road section was probably due to a greater depth to the groundwater table and shallow depth to bedrock. Heave of the northwest transition and the control section was higher because of greater depths to bedrock and shallower depths to the groundwater table. The highest heave was recorded in the southeast transition and southeast existing road section because the groundwater table is very shallow, probably in the range of 1 to 2 m (3 to 6 ft) below the road surface.

The heave was lower in the tire chip sections. This was because of a reduction in the depth of frost penetration by the tire chips. Additionally, the existing road surface was excavated to a level between 152 mm (6 in.) and 475 mm (18 in.) and replaced with tire chips and clean granular fill, as summarized in Table 1. In Sections D and E, the heave was reduced by a factor of between 2 and 5 compared with the control section.

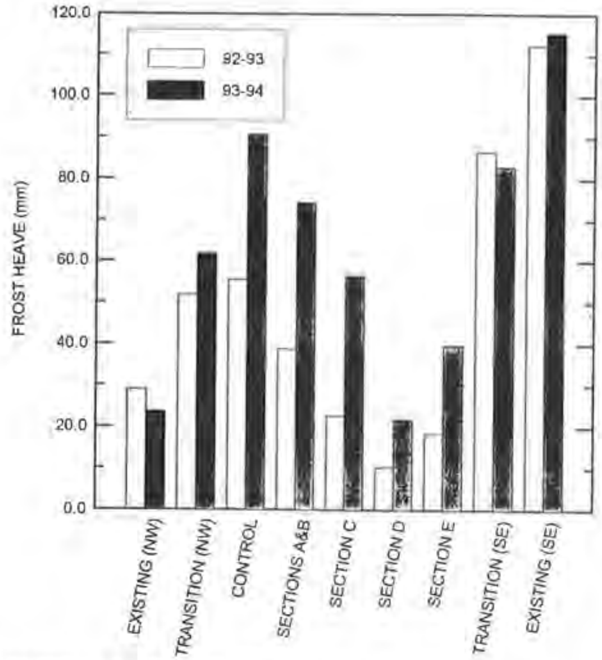

FIGURE 8 Frost heave.

Conclusion

A full-scale field trial using tire chips as an insulating layer beneath a gravel-surfaced road showed that tire chips effectively limit the depth of frost penetration. On the basis of tests conducted during the first two winters in service, a 152-mm (6 in.) thick tire chip layer overlain by 305 mm (12 in.) of gravel reduced the depth of frost penetration by 22 to 28 percent. Likewise, a 305-mm (12-in.) thick tire chip layer overlain by either 457 mm (18 in.) or 610 mm (24 in.) of gravel resulted in a 15 to 17 percent reduction in the 1992 to 1993 season and a 33 to 37 percent reduction in the 1993 to 1994 season. In the section with a 305-mm (12-in.) thick tire chip layer covered by 457 mm (18 in.) of gravel, the frost penetrated a maximum of 208 mm (8 in.) into the underlying subgrade soil; in the section with 305 mm (12 in.) of tire chips covered by 610 mm (24 in.) of gravel, the maximum penetration into the underlying subgrade soil was 76 mm (3 in.) Furthermore, the two sections with 305 mm (12 in.) of tire chips experienced a heave of between 10 mm (0.4 in.) and 40 mm (1.6 in.), whereas a nearby control section heaved 55 mm (2.3 in.) to 91 mm (3.6 in.). Clearly, the tire chips significantly reduced the depth of frost penetration and the amount of frost heave.

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