

# CRREL FULL-DEPTH TEST SECTIONS: PERFORMANCE DURING FIRST THREE WINTERS

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Four highway pavement test sections were built in July 1971 at the U. S. Army Cold Regions Research and Engineering Laboratory. Two sections were designed by using the Asphalt Institute full-depth criteria, and the other two were based on similar traffic volumes by using the U. S. Army Corps of Engineers reduced subgrade strength criteria to compare their performance under freeze-thaw conditions. The first 3 years' observations show that (a) the maximum frost penetrations of 35 to 40 in. (89 to 101.6 cm) were essentially the same beneath all four sections, (b) the thawing condition in the subgrade as compared with that in the full-depth sections existed a fraction of the time beneath the crushed-stone base course sections (2 or 3 days versus 11 to 20 days), (c) the subgrades beneath the full-depth sections were subjected to two times as many freeze-thaw cycles as the subgrades under the crushed-stone bases because of the thinner pavement structure (8 cycles versus 4 cycles), (d) moisture increases of 8 to 12 percent occurred each year in the top foot (0.3 meter) of subgrade directly beneath the full-depth sections and caused high Benkelman beam deflections of up to 0.12 in. (3 mm) in the thinnest [5-in. (12.7-mm)] section and visible transitory rutting, and (e) uniform frost heaves of at least 2½ in. (6.4 cm) were measured on both full-depth sections and of 1½ and ½ in. (3.8 and 1.3 cm) on the crushed-stone base sections each year. From September 1971 to May 1974, a total of 49,000 vehicles had traversed the sections. Of this total, there were over 12,000 equivalent 18-kip (80-kN) axle loads, and the bulk of the truck traffic traversed the sections during the frost-melting period. Observations are continuing for a more comprehensive evaluation.

•IN July 1971, four highway pavement test sections were constructed at the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire. The test sections include thin asphalt pavements over unbound bases as conventionally used by the U. S. Army Corps of Engineers and full-depth asphalt pavements placed directly on the subgrade for comparative evaluations, specifically during the spring-thaw period. Emphasis was placed on observations that would allow comparison of frost depth, frost heave, and behavior during spring thaw. Observations include air temperatures, subsurface temperatures, surface elevations, moisture contents in the base and subgrade, and pavement deflections under a loaded truck as measured with the Benkelman beam. Although accelerated traffic testing was not planned, the test sections were intentionally located on an access road to a gravel pit where heavy trucks would make use of the test sections during the frost-melting season.

## SITE CONDITIONS AND TEST SECTIONS

The natural subgrade soil in the test area adjacent to the north side of the CRREL facility is a clean nonplastic, frost-susceptible silt classified as ML under the Unified Soil Classification System (USCS) (8) and as F-4 under the Corps of Engineers frost

group classification (6). The normal period California bearing ratio (CBR) (summer strength) value is 8. The in situ moisture content of the silt on the dry unit weight basis ranged from 25 to 35 percent before construction. The optimum moisture content of the material is 15 percent.

Each section, shown in Figures 1 and 2, measures 24 ft (7.3 m) wide by 50 ft (15 m) long. The top 18 in. (45.7 cm) of the subgrade was scarified and mixed to ensure uniformity. Sections 1 and 3 were designed on the basis of an assumed average daily traffic (ADT) of 4,000 vehicles (total for both directions) on a two-lane rural highway. A design life of 20 years with zero traffic growth was chosen. Sections 2 and 4 were designed on the basis of an assumed ADT of 100 vehicles (total for both directions) on a two-lane rural highway. Again, a design life of 20 years with zero traffic growth was chosen. Sections 1 and 2 were designed by using the Corps of Engineers design criteria for reduced subgrade strength (6), which resulted in combined thicknesses of pavement and base of 30 and 22 in. (76.2 and 55.8 cm) for sections 1 and 2 respectively. Sections 3 and 4 were designed by using full-depth pavement design criteria (2) and a subgrade CBR value of 8, which resulted in thicknesses of 9 and 5 in. (22.8 and 12.7 cm) respectively.

The design freezing index for Hanover, New Hampshire, is 1,820 F-days (993 C-days); this index is based on the average of the 3 coldest years in 30. The mean freezing index is 1,060 F-days (571 C-days) (10). The freezing index during the 1971-72 winter was 1,430 F-days (776 C-days); in the 1972-73 winter, 1,143 F-days (617 C-days); and in the 1973-74 winter, 1,021 F-days (549 C-days).

## INSTRUMENTATION

Copper-constantan thermocouples were installed at the center of each section to monitor subsurface temperatures. Figure 1 shows the plan view locations of the instrumentation. A cross-sectional view giving thermocouple depths beneath the surface is shown in Figure 2. From September 1971 to May 1973, a strip chart recorder was used for recording the temperatures. In May 1973, a digital data collection system was installed. Initially, hourly readings were taken on strip chart paper, but when the data system was used automatic hourly readings were recorded on punched paper tape.

Subsurface moisture measurements were taken in tubes at a 3-ft (0.9-m) offset from the centerline of each section (Figure 1). A Nuclear-Chicago Model 5810 subsurface moisture probe and Nuclear-Chicago Model 5920 d/m-gauge scaler were used to measure the moisture content variations around the access pipes.

There were two Benkelman beam test points per section for a total of eight points (Figure 1) to measure pavement strength characteristics.

Level surveys were conducted on 139 elevation check points. The level surveys monitor frost heave, permanent set, and failure. A 15-ft-deep (4.6-m) manhole was used as the frost-free benchmark.

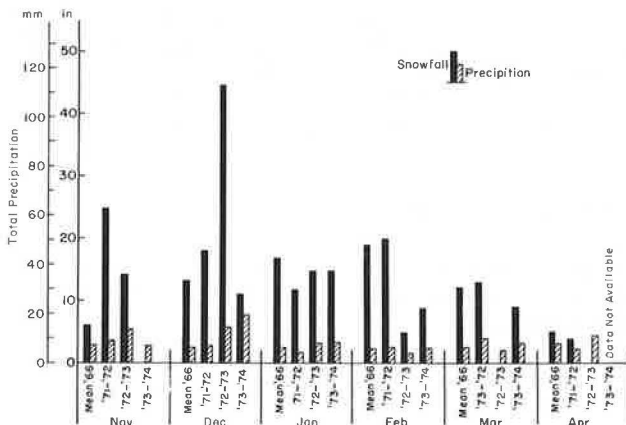
Air temperatures and other weather observations were made at a field site located on CRREL property approximately 1,000 ft (304.8 m) west of the road at an elevation approximately 20 ft (6.1 m) lower.

## TEST RESULTS FOR FIRST 3 YEARS

Since construction of the test sections, each winter has been milder than the previous one, and the 1973-74 freezing index was slightly lower than the mean for this area. Figure 3 shows average daily air temperatures for the 1973-74 winter. Also shown are the long-term mean values of maximum, minimum, and average daily temperatures (3) for the Hanover meteorological station.

Figure 4 shows the monthly quantities of snowfall and total precipitation for each winter season and the mean values for the Hanover meteorological station. Monthly precipitation for the 1971-72 winter was above the mean during 4 of the 6 monitored months, and the snowfall was greater than the mean for only 4 months. In the 1972-

- Δ Benkleman Beam test point
- Thermocouples
- Steel access tubes



73 winter, the snowfall was greater than the mean for only 2 months. The water equivalent precipitation average, however, was 6 in. (15.2 cm) higher than the mean for the entire winter [22.6 versus 16.2 in. (57.4 versus 41.1 cm)]. Rain was more prevalent in the 1973-74 winter because the measured precipitation was greater than the mean every month from November 1973 through March 1974. The measured water equivalent precipitation for the period (November through March) was 19.57 in. (49.7 cm) versus a mean of 13 in. (32 cm).

### Frost Penetration

During the latter part of the freezing seasons and the entire spring-thaw periods, sub-surface temperatures were examined in detail. Thermocouples indicated maximum frost penetration in the first year (1971-72) of about 36 to 40 in. (91.4 to 101.6 cm) in sections 1, 2, and 4 and about 40 to 44 in. (101.6 to 111.8 cm) in section 3.

In 1972-73, the maximum frost penetration was 30 to 36 in. (76.3 to 91.4 cm) in all four sections. The 1973-74 maximum frost penetration readings were 38 in. (96.5 cm) in section 1, 35 in. (89 cm) in section 2, 37 in. (94 cm) in section 3, and 36 in. (91.4 cm) in section 4 [Figure 5 shows 32 F (0 C) isotherm penetrations for 1973-74]. An average curve, which ignores the spikes, was used for determining the maximum frost depths given above for each section. The CRREL test sections were kept essentially free of ice and snow throughout the winter seasons.

Temperature fluctuations, both diurnal changes and those caused by changing weather systems, subjected the upper 18 in. (45.7 cm) of the pavement structures to numerous freeze-thaw cycles. When freezing temperatures had penetrated to depths where daily variations were attenuated, the material at that depth generally remained in a frozen state until it completely thawed in the spring. The first year, the subgrades in sections 1 and 2 experienced only one freeze-thaw cycle as the daily cycles were contained within the granular base courses. By comparison, the subgrades in the full-depth sections experienced at least seven freeze-thaw cycles (because the subgrades were closer to the surface). The second year, sections 1 and 2 had no freeze-thaw cycles in the subgrade, but both full-depth sections had 3 cycles. In 1973-74, there were three and four freeze-thaw cycles in the subgrades of sections 1 and 2 respectively and six and eight cycles for sections 3 and 4 subgrades. A subgrade freeze-thaw cycle is defined as the time between initial freeze of a part [top 1 in. (2.5 cm)] of the subgrade until it has thawed completely. The cyclic freeze-thaw causes distress in the pavement because of vertical movements and affects the subgrade support capability. The duration of the subgrade thawing period for sections 1 and 2 was considerably shorter than that for the full-depth sections 3 and 4. During the first year, the thawing period was 2 days for subgrade of the 30-in. (76.3-cm) pavement and base, section 1, compared with 13 days for the 9-in. (23-cm) full-depth pavement, section 3. The subgrade of the 22-in. (56-cm) pavement and base, section 2, was in a subgrade thawing period for 4 days; the period for the 5-in. (12.7-cm) full-depth pavement, section 4, was 25 days. Freezing temperatures no longer existed in section 1 after March 18, 1972; in section 2 after March 30, 1972; and in sections 3 and 4 after April 10, 1972. In 1972-73, there was no subgrade thawing period for sections 1 and 2, as it had not frozen, but there were a 12-day period in section 3 and a 22-day period in section 4. The soil temperature in the 1973-74 winter was above 32 F (0 C) by March 5, 1974, in section 1; by March 7, 1974, in section 2; by March 29, 1974, in section 3; and by March 26, 1974, in section 4 (Figure 5). After the spring thawing is complete, subgrade strength begins to increase toward normal summer values.

### Pavement Freezing Indexes

Surface freezing indexes based on pavement temperatures and the air freezing index for the 1973-74 winter are shown in Figure 6. The data for the 1971-72 and 1972-73 winters are not available.

The modified Berggren equation is used to calculate frost penetration into the ground.

Figure 5. Frost penetration for 1973-74.

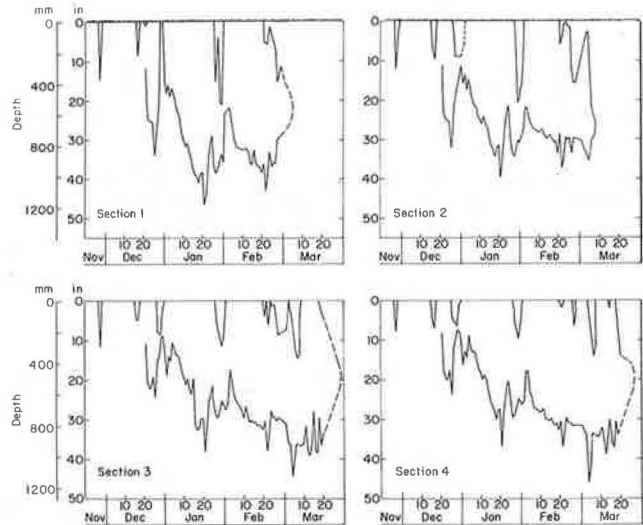


Figure 6. Air and pavement surface freezing indexes.

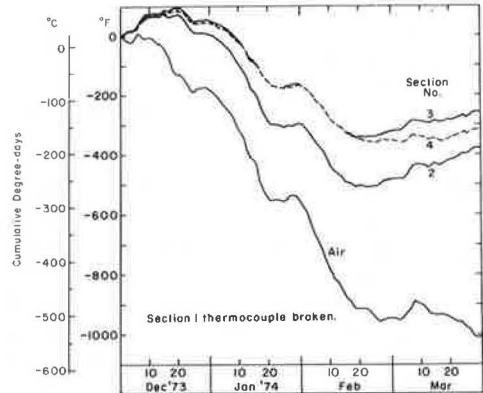
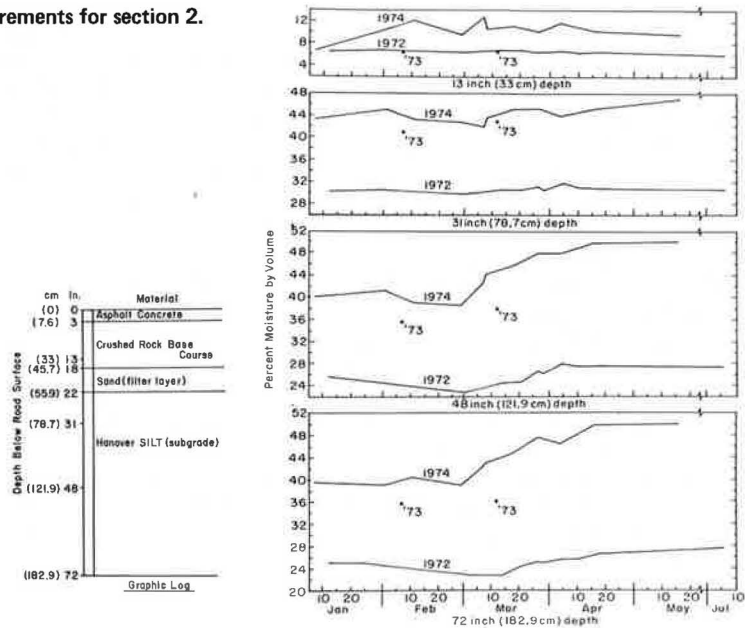


Figure 7. Nuclear moisture measurements for section 2.





When the air freezing index values are used in the equation to calculate frost penetration, an *n*-factor (surface transfer coefficient) is used to provide the surface freezing index. The *n*-factor is the ratio of surface index to air index. The *n*-factor recommended by the Department of the Army is 0.9 for pavements free of ice and snow (5).

Average daily pavement surface temperatures recorded in sections 2, 3, and 4 from December 1973 to February 1974 were used to calculate actual surface freezing indexes, and resultant *n*-factors are 0.57, 0.43, and 0.43 respectively. (The section 1 surface thermocouple did not function properly in this period and no data are shown.) These results are approximately half of the recommended value of 0.9 cited earlier. As stated previously, the 1973-74 winter was mild.

Lengths of freezing seasons and freezing indexes were taken from maximum to minimum points on a plot of cumulative degree-days [based on 32 F (0 C)].

### Variation in Subsurface Moisture

The nuclear moisture probe measures water content by volume in a sphere about 2 ft (0.6 m) in diameter, depending on soil density, organic content, and water content. Steel access tubes 10 ft (3.0 m) long are installed in each section.

The nuclear probe source became defective in August 1972 and had to be repaired. The probe was returned in February 1973, and higher readings taken February 7 and March 12 were due to the new source. Difficulties with access to the tubes and lack of technical help prevented a more thorough test program in the spring of 1973.

All readings shown in Figures 7 and 8 are relative. Both sources were not calibrated for absolute values. Our concern was to measure moisture changes, not absolute moisture contents.

In the first year (1971-72) the pavement structure of each section began to thaw about March 1, 1972. The precipitation during March 1972 was 40 percent above normal, and the air temperature cycled through freeze-thaw 20 times. The moisture measurements in section 2 (Figure 7) show that the base course moisture content remained essentially constant throughout the period of observation. On the other hand, in section 4 the moisture content at the 13-in. (33-cm) depth increased from a fairly constant 26 to 34 percent between March 1 and 30, 1972 (Figure 8). The increase in moisture can possibly be attributed to the fact that thaw was taking place and that the thaw water was gravitating to a zone of deeper thaw in the central portion of the roadway. The above-normal precipitation during March also would contribute to this increase in water content.

The moisture content at the 31-in. (78.7-cm) depth in section 2 remained fairly constant in 1971-72, and increased by about 2 percent during spring thaw from 30 to 32 percent. At the 24-in. (61-cm) depth in section 4, the moisture content increased steadily from 34 to 38 percent between January 12 and March 29, 1972. Between April 5 and 10, 1972, the moisture content decreased to about its early winter level of 34 percent. As noted previously, section 4 had completely thawed by April 10, 1972.

Sections 2 and 4 exhibited decreases in moisture at the 48-in. (122-cm) depth between early January and the end of March 1972 and thereafter increased by about 6 percent in section 2 and by 2 percent in section 4. At the 72-in. (182.8-cm) depth, both sections had a similar moisture content ranging between 24 and 27 percent. Sections 1 and 3 experienced similar moisture variations at all levels during 1971-72.

In July 1973, the CRREL wastewater management team (11) calibrated the new source, and a new percentage-by-volume curve resulted.

Figure 7 shows section 2, at the 13-in. (33-cm) depth, increasing from 6.7 percent in January 1974 to 12.0 percent in February, where it fluctuated between 10 and 12 percent until April and then leveled out at 10 percent. Section 4 at the 13-in. (33-cm) depth fluctuated from 45.2 to 40.8 percent and then increased dramatically to a maximum of 54.9 percent on March 8, 1974. From March 8 to 22, 1974, the moisture decreased again to 42 percent. This feature of full-depth pavements in frost areas is believed most critical.

At the 24-in. (61-cm) depth of section 4, the moisture decreased from 54.0 percent

on February 11, 1974, to 47.0 percent in April. In the same period, the 31-in. (78.7-cm) depth of section 2 fluctuated from 45.0 percent on February 11 to 41.9 percent on March 7, and then rose to 45.3 percent on April 16. The readings remained within the range of 42 to 47 percent. All of section 2, at the 48, 72, and 96-in. (122, 183, and 244-cm) depths increased approximately 10 percent in moisture content by volume during 1973-74; however, the 10-ft (3-m) depth remained fairly constant.

Section 4 at the 48, 72, and 96-in. (122, 183, and 244-cm) depths decreased in moisture content from February to March at which time it began to increase again. The thaw from February 27 to March 7 resulted in an apparent redistribution of subsurface moisture as shown by the v-shaped increase at the 13-in. (33-cm) depth and by the drop for the other depths on March 7 (Figure 8). The 10-ft (3-m) depth of section 4 closely follows that of section 2 by fluctuating within a 2 percent range but at a 9 percent higher level.

### Frost Heave

The materials and gradations used in the construction of the test sections are given in Table 1. The USCS designation (8), Corps of Engineers frost classification (6), and the percentage finer than the 0.02-mm size are given in Table 2.

Pavement surface elevations to measure frost heave were obtained by level survey a minimum of once a month, with weekly or daily surveys conducted when deemed necessary during the spring thaw-weakening period.

On the surface of the test sections, 139 points were monitored. The average maximum frost heaves for each section for the first 3 years are given in Table 3.

Figure 9 shows heave versus time for each section each year. Section 4 heaved from 2 to 3 in. (5.1 to 7.6 cm) each year, section 2 heaved from  $\frac{3}{4}$  to  $1\frac{3}{4}$  in. (1.9 to 4.4 cm) each year, and section 1 heaved from  $\frac{1}{4}$  to  $\frac{3}{4}$  in. (0.6 to 1.9 cm) each year. Section 3 heaved  $2\frac{1}{2}$  in. (6.4 cm) the first 2 years, but in March 1974 an average heave of 4 in. (10.2 cm) was measured. All heaves were fairly uniform across each section.

The readings for vertical displacement were referenced to base levels determined in a July 1972 survey (considered normal summer elevations).

### Pavement Deflection Measurements

The Benkelman beam test is used as an indicator of strength of the pavement structure at any time. However, pavement temperatures influence the test results by causing changes in the pavement stiffness. A common standard temperature that is used for correcting readings is +70 F (21.1 C). Various agencies have their own methods (e. g., curves and factors) of modifying the readings to the standard temperature.

The Canadian Good Roads Association Benkelman beam rebound procedure currently in use has a temperature correction factor of 0.002 in./10 F (0.05 mm/5.5 C) within a range of rebound values from 0.02 to 0.07 in. (0.5 to 1.8 mm). However, it is known that the correction factor increases when the magnitude of the deflection increases. The U. K. Transport and Road Research Laboratory has reported on this, but not a sufficient amount of work has been carried out in Ontario to arrive at specific relationships (13).

To date, we have been unable to find a method for modifying results at temperatures below +35 F (+1.7 C). Therefore, our data have not been modified. Results obtained from these test sections show that different types and thicknesses of pavement, base course, and subgrade influence the deflections as well as frozen or unfrozen base courses and subgrades. A frozen pavement structure will deflect only a fraction of the amount an identical partially thawed section will.

The locations and results of the Benkelman beam static pavement rebound deflection tests (1), which are conducted year round, are shown in Figures 1 and 10 respectively. These deflections are influenced by temperature, subsurface moisture conditions, and traffic volume.

Figure 8. Nuclear moisture measurements for section 4.

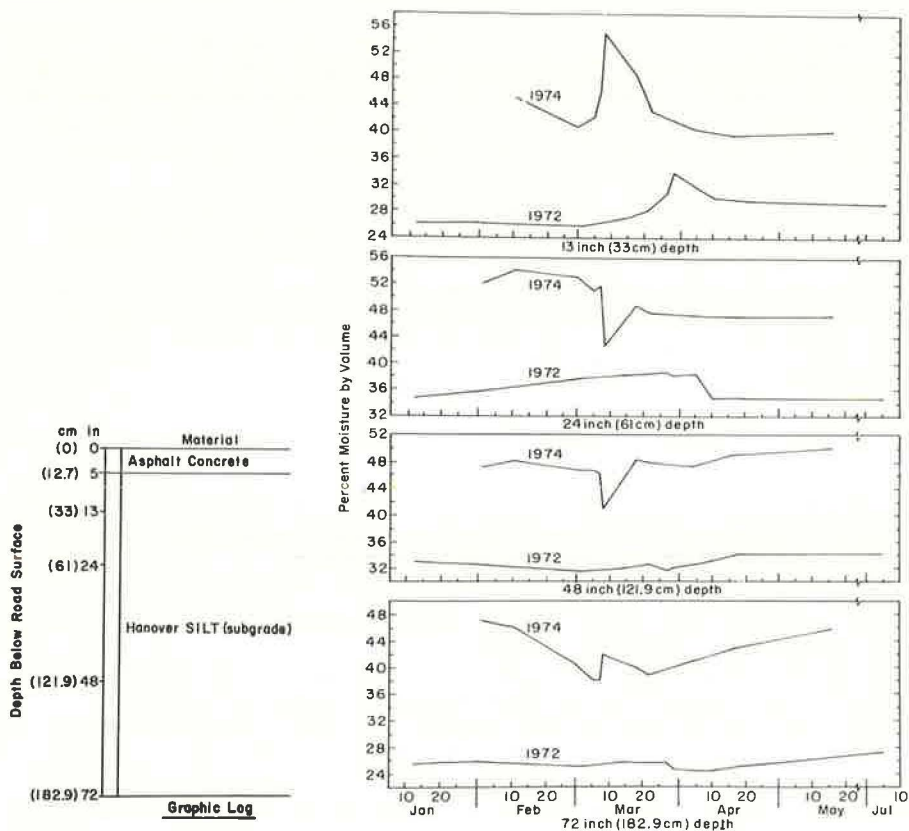


Table 1. Gradation of materials.

| Item  | Sieve Size | Percent Passing | Item  | Sieve Size | Percent Passing |
|---|------------|-----------------|---|------------|-----------------|
| Mortar sand filter                                      | 3 in.      | 100             | Percentage of asphalt concrete                  | 1/8 in.    | 70 to 80        |
|   | No. 4      | 93 to 100       |   | No. 4      | 44 to 54        |
|   | No. 10     | 78 to 100       |   | No. 10     | 32 to 40        |
|   | No. 40     | 45 to 75        |   | No. 40     | 18 to 26        |
| Crushed-rock base course                                | 2 in.      | 100             |   | No. 80     | 8 to 16         |
|   | 1 1/2 in.  | 70 to 100       |   | No. 200    | 3 to 6          |
|   | 1 in.      | 45 to 80        | 1/2-in.-maximum asphalt concrete surface course | 1/2 in.    | 100             |
|   | 1/2 in.    | 30 to 60        |   | 3/8 in.    | 83 to 93        |
|   | No. 4      | 20 to 50        |   | No. 4      | 60 to 70        |
|   | No. 10     | 15 to 40        |   | No. 10     | 41 to 49        |
|   | No. 40     | 5 to 25         |   | No. 40     | 20 to 28        |
| 3/4-in.-maximum asphalt concrete binder and base course | No. 200    | 0 to 10         |   | No. 80     | 11 to 19        |
|   | 1 in.      | 100             |   | No. 200    | 4 to 8          |
|   | 3/4 in.    | 94 to 100       | Percentage of asphalt concrete                  |            |                 |
|   | 1/2 in.    | 77 to 87        |   |            | 5.0 to 8.0      |

Note: 1 in. = 2.54 cm.

Table 2. Frost classification of soils.

| Material          | USCS | Percentage Finer Than 0.02 mm | Frost Group      |
|-------------------|------|-------------------------------|------------------|
| Crushed limestone | GW   | <3                            | NFS <sup>a</sup> |
| Concrete sand     | SP   | 0                             | NFS <sup>a</sup> |
| CRREL sandy silt  | ML   | 14                            | F-4              |

<sup>a</sup>Non-frost-susceptible material.

Table 3. Average maximum frost heave.

| Section | Avg. Maximum Frost Heave (in.) |                       |                       |
|---------|--------------------------------|-----------------------|-----------------------|
|         | 1971-72, 1,430 F-Days          | 1972-73, 1,143 F-Days | 1973-74, 1,021 F-Days |
| 1       | 0.66                           | 0.44                  | 0.48                  |
| 2       | 1.23                           | 0.80                  | 1.80                  |
| 3       | 2.50                           | 2.50                  | 4.00                  |
| 4       | 2.71                           | 2.52                  | 2.88                  |

Note: 1 in. = 2.54 cm. 1 F = 1.8 (C) + 32.



Figure 9. Average frost heave.

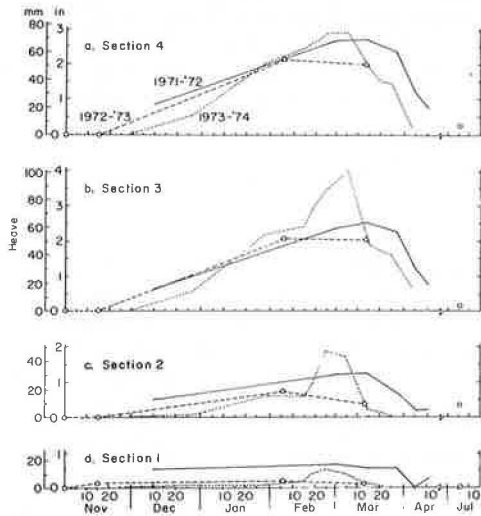


Figure 10. Benkelman beam deflections.

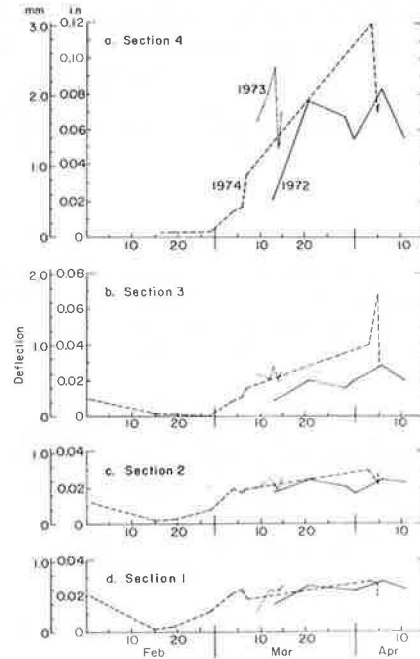


Table 4. Total equivalent 18-kip (80-kN) axle loads traversing test sections.

| Vehicle Type               | Equivalency Factor | Number of Vehicles      |                   |                  | Total  | Total               |
|----------------------------|--------------------|-------------------------|-------------------|------------------|--------|---------------------|
|                            |                    | Sept. 1971 to Dec. 1972 | Jan. to Dec. 1973 | Jan. to May 1974 |        |                     |
| Loaded single-axle truck   | 2.4                | 2,150                   | 1,750             | 1,100            | 5,000  | 12,000 <sup>a</sup> |
| Unloaded single-axle truck | 0.04               | 2,150                   | 1,750             | 1,100            | 5,000  | 200 <sup>b</sup>    |
| Car                        | 0.002              | 21,000                  | 15,200            | 3,600            | 39,800 | 80 <sup>c</sup>     |
| Total                      |                    | 25,300                  | 18,700            | 5,800            | 49,800 | 12,280              |

<sup>a</sup>2.4 (5,000). <sup>b</sup>0.04 (5,000). <sup>c</sup>0.02 (39,800).

The static pavement rebound deflections shown in Figure 10 represent measurements taken in the outer vehicular wheel paths (i.e., points 2, 3, 6, and 8 in Figure 1). The measured deflections at the inner and outer wheel paths follow the same trends and ranges of deflection. The vehicle used for testing purposes is a two-axle truck equipped with rear dual-tired wheels each loaded to  $9 \pm 0.1$  kips ( $40 \pm 0.4$  kN) for a total rear axle load of  $18 \pm 0.2$  kips ( $80 \pm 0.8$  kN).

As seen in Figure 10, sections 1, 2, and 3 have generally the same response each spring [0 to 0.035 in. (0 to 0.89 mm)] except for section 3 in April 1974 when it deflected 0.068 in. (1.7 mm). A heavy rain and warming trend caused subgrade thawing, and the full-depth structure deflected accordingly.

Section 3 maximum deflections were 0.028 in. (0.71 mm) in 1971-72 and 1972-73, and 0.068 in. (1.73 mm) in 1973-74 during the frost-melting period. This is in close agreement with a  $9\frac{1}{2}$ -in. (24.1-cm) full-depth pavement performance during 1966-69 on the Brampton Test Road, which had maximum deflections of 0.028 in. (0.71 mm) in 1966 and 0.033 in. (0.84 mm) in 1969 (12). A  $5\frac{1}{2}$ -in. (14-cm) full-depth section on the same Brampton Test Road had a maximum deflection of 0.043 in. (1.09 mm) in 1966 and 0.073 in. (1.85 mm) in 1969. We measured maximum deflections of 0.082 in. (2.08 mm) in 1971-72, 0.096 in. (2.44 mm) in 1972-73, and 0.12 in. (3.05 mm) in 1973-

74 on our 5-in. (12.7-cm) full-depth section. Sections 1 and 2 could not be compared with the Brampton Road sections because of differences in construction.

Section 4 has had high deflections each year and deflected up to 0.12 in. (3.05 mm) in April 1974. No pavement cracking or other signs of distress have been evident, other than a  $\frac{1}{2}$  to  $\frac{3}{4}$ -in. (12.7 to 19.1-mm) depressed basin at station 0+38, 3 ft (0.9 m) south of the centerline in section 4 in April 1974. The basin has since returned to normal grade and currently is not visible.

### Traffic

Passenger cars of CRREL employees were routed over the test sections 1 to 2 weeks each month during the first year after construction because it was expected that the pavement would deteriorate with no traffic throughout the first winter. The sections also serve as an access road to a gravel pit, thus obtaining natural truck trafficking during the thawing period, even though the traffic intensity assumed for design was not expected to be reached. On March 20, 1972, trucks began hauling gravel out of the pit, and by April 6, 2,000 vehicles had traversed the sections (approximately 47 percent were loaded gravel trucks). The heaviest traffic occurred on April 3 and consisted of 75 loaded gravel trucks, 75 unloaded trucks, and one automobile. Two loaded trucks were stopped and weighed on portable weighing scales on April 4, and the following results were measured (1 lb = 0.45 kg):

| <u>Vehicle</u> | <u>Gross Weight (lb)</u> | <u>Rear-Axle Weight (lb)</u> |
|----------------|--------------------------|------------------------------|
| 1              | 30,275                   | 22,000                       |
| 2              | 29,150                   | 21,275                       |

The two trucks weighed were typical of the type and load capacity of all trucks traversing the test sections. Based on the traffic count, sections 2 and 4 were subjected to daily load repetitions exceeding the design premise [three equivalent 18-kip (80-kN) axle loads per day], but the total number of passes of loaded trucks during the thawing period was only a small fraction of the product of the daily loadings assumed for design and the number of critical days of subgrade thawing that might be expected in the 20-year design period. On sections 1 and 3, the truck traffic experienced in the spring of 1972 was insignificant compared with the design premise [100 equivalent 18-kip (80-kN) axle loads per day]. During this period of heavy traffic, the subgrade of each section was thawing.

Slight rutting was visible in the wheel tracks in sections 3 and 4 during the heavy traffic period, and depressions were particularly noticeable in section 4. After the loading stopped (April 6, 1972), the depressions disappeared.

During the first year (September 1971 to December 1972), 25,000 vehicles passed over the sections. From January 1973 to February 1974, more than 20,000 vehicle passes were made, and more than 4,000 passes were made from February to May 1974. To date, over 49,000 vehicle passes have been experienced; the traffic mix is discussed below.

A summary of the number of total equivalent 18-kip (80-kN) single-axle load repetitions (for 20-year life) for various Corps of Engineers pavement design indexes (4) is as follows (1 kip = 4.4 N):

| <u>Design Index</u> | <u>Load Repetitions</u> | <u>Design Index</u> | <u>Load Repetitions</u> |
|---------------------|-------------------------|---------------------|-------------------------|
| 1                   | 3,100                   | 3                   | 59,000                  |
| 2                   | 13,500                  | 4                   | 260,000                 |

Equivalent operations factors (7) are 2.4 for 22-kip (98-kN) single-axle trucks (loaded gravel trucks), 0.04 for 15-kip (67-kN) single-axle trucks (empty gravel trucks), and 0.002 for cars. Table 4 gives the total equivalent 18-kip (80-kN) axle loads that have crossed the test sections from September 1971 to May 1974, based on equivalent operations factors. This calculation indicates that 12,280 equivalent 18-kip (80-kN) axle loads have traversed the sections. When 12,280 total equivalent 18-kip (80-kN) axle loads are used and compared with data from the table above, it is seen that a design index of 2 has almost been attained by the test sections.

## CONCLUSIONS

The freezing index as experienced ranged from 1,430 F-days (776 C-days) in 1971-72 to 1,021 F-days (549 C-days) in 1973-74; the design index was 1,820 F-days (993 C-days), and the mean was 1,060 F-days (571 C-days).

Average maximum frost penetrations (ignoring the spikes that are considered to be anomalous) were approximately the same each year with section 1 [30-in. (76.2-cm) crushed-stone base course] where they were the deepest; section 2 [22-in. (55.9-cm) crushed-stone base course] had the least amount of frost penetration. The maximum frost penetrations of sections 3 and 4 [9 and 5 in. (22.9 and 12.7 cm) full-depth respectively] were between those of sections 1 and 2. The sections with crushed-stone bases thawed before the full-depth sections every year, and the subgrade thaw-weakened condition existed a fraction of the time in the crushed-stone base course sections compared with the time in the full-depth sections. The subgrades beneath the full-depth sections were subjected to two to three times as many freeze-thaw cycles as the ones with the crushed-stone bases because of the thinner pavement structure. This tentatively proves the beneficial aspects of granular base courses.

The pavement *n*-factors were less for the full-depth sections than for the conventional sections, indicating higher pavement surface temperature.

Moisture increases beneath the full-depth sections each spring cause high Benkelman beam deflections and visible transitory rutting in the wheel tracks because of heavy truck loading. Moisture increases of 10 to 15 percent occurred each year in the 2 ft (0.6 m) of subgrade directly beneath the full-depth sections. The moisture in the thawed portion of the subgrade was trapped between the pavement and the underlying frozen subgrade, causing structural weakness. To date, no surficial distress has been evidenced other than the transitory rutting.

Frost heave was fairly uniform; the full-depth sections heaved approximately  $2\frac{1}{2}$  in. (6.4 cm) each year. However, the 9-in. (22.9-cm) full-depth section heaved 4 in. (10.2 cm) in the last year. Sections 1 and 2 with crushed-stone base courses heaved less than  $\frac{3}{4}$  and 2 in. (1.9 and 5.1 cm) respectively. Although the heaves were greater in the full-depth sections, they were uniform and did not produce noticeable roughness. This uniformity is attributed to the subgrade preparation that involved the scarifying, blending, and recompacting of the top 18 in. (45.7 cm) of the in situ silt subgrade soil. No distress due to frost heave was observed on any section.

Traffic was light; a total of 49,000 vehicles passed over the sections from September 1971 to May 1974. Of this total there were over 12,000 equivalent 18-kip (80-kN) axle loads. Of the 18-kip (80-kN) axle loads, 90 percent traversed the sections during the spring thaw-weakened period.

Observations should be continued for a few years for a more thorough and comprehensive evaluation.

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#### REFERENCES

1. Special Procedures for Testing Soil and Rock for Engineering Purposes. ASTM STP 479, 5th ed., Method A, 1970, pp. 568-576.
2. Thickness Design—Full-Depth Pavement Structures for Highways and Streets. Asphalt Institute, Manual Series, No. 1, 8th ed., Dec. 1969.
3. M. Bilello. Publishing of Climate Data for Hanover, N. H. USACRREL Bulletin, Jan. 17, 1966.
4. W. N. Brabson. Development of Thickness Design Criteria for Asphaltic Concrete Pavements for Military Roads. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss., 1974.
5. Calculation Methods for Determination of Depths of Freeze and Thaw in Soils. Department of the Army, TM5-852-6, 1966.
6. Pavement Design for Frost Conditions. Department of the Army, TM5-818-2, July 1965.
7. Planning, Site Selection, and Design of Roads, Airfields, and Heliports in the Theater of Operations. Department of the Army, TM5-330/AFM 86-3, Vol. 2, Sept. 1968.
8. Unified Soil Classification System for Roads, Airfields, Embankments, and Foundations. Department of Defense, Military Standard 619B, June 1968.
9. R. A. Eaton and D. W. Van Pernis. USACRREL Highway Pavement Test Sections, First Year Analysis, 1971-72 Winter. Symposium on Frost Action on Roads, Oslo, Norway, Oct. 1973.
10. G. Gilman. The Freezing Index in New England. CRREL Special Rept. 63, June 1964.
11. H. McKim et al. Physical, Chemical, and Soil Water Relationships in Soils Used in USACRREL's Wastewater Management Program. CRREL Technical Rept., 1974.
12. W. A. Phang. Four Years Experience at the Brampton Test Road. Ontario Department of Highways, Rept. RR 153, Oct. 1969.