Case Study of Insulated Pavement in Jackman, Maine

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Traditionally, detrimental effects of frost action are reduced by thick fills or by excavation and removal of large quantities of frost-susceptible material and replacement with a thick layer of non–frost-susceptible material. However, incorporating an insulating layer within the pavement structure can often provide a cost-effective alternative for protecting the subgrade from frost penetration. In 1986 the runway, taxiway, and parking apron at Newton Field, a small airport in Jackman, Maine, were reconstructed using a layer of extruded polystyrene insulation 51 mm (2 in.) thick as part of the pavement structure. Because test results from the first winter of observation showed substantial frost penetration beneath the runway insulation, four additional test sections of various combinations of insulation and sand subbase thickness were constructed adjacent to the parking apron in 1987. The insulated test sections, which were constructed under tighter controls, on a firm working platform, and in a slightly drier location than the runway, experienced very little frost penetration into the subgrade. The good performance of the insulated test sections as well as runway observations, methods used to investigate insulation integrity, and theories considered to explain the relatively poor performance of some sections of the insulated runway pavement are discussed.

Newton Field, which includes an 18- × 884-m (60- × 2900-ft) insulated runway, taxiway, apron, and four adjacent insulated pavement test sections, is in the town of Jackman, Maine (45°38′N, 70°15′W). The runway at Newton Field was reconstructed in 1986 to replace an old, smaller runway that exhibited severe differential frost heaving and excessive cracking. Jackman has an average annual air temperature of 3°C (38°F) and a design air freezing index of approximately 1428°C-days (2570°F-days). The runway elevation is approximately 358 m (1175 ft) above mean sea level; the 100-year flood level of nearby Moose River is approximately 357 m (1170 ft). Figure 1 shows an aerial view of Newton Field and the town of Jackman.

DESIGN AND CONSTRUCTION OF TEST SITES

According to U.S. Army Corps of Engineers and Maine Department of Environmental Protection criteria, the entire airfield is classified as a wetlands zone. Deep frost penetration and highly frost-susceptible materials in the immediate vicinity are reported (*1*).

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Runway construction contracts for insulated and noninsulated pavements were sent out for bid. The insulated-pavement alternative was selected because the bid was less than 4 percent higher than the bid for a conventional pavement.

Construction began during the summer of 1986. The entire area of the 18- × 884-m (60- × 2900-ft) runway, the 9- × 75-m (30- × 245-ft) taxiway, and the 38- × 91-m (125- × 300-ft) parking apron was underlaid by a layer of extruded polystyrene insulation panels 51 mm (2 in.) thick. A total of one-half million board feet of insulation was used. A typical insulated pavement cross section is shown in Figure 2*a*. A geotextile separated a sand leveling course of varying thickness [25 mm (1 in.) minimum specified] from the underlying wet silty subgrade.

The final design was for total frost protection of the subgrade. Minimum compressive strength of the insulation was 276 kPa (40 psi), and the design load was for a 134-kN (30,000-lb) single-wheel load. The high water table at the site presented challenges to both design and construction personnel.

Also in 1986, the first 46 m (150 ft) of nearby Nichols Road were reconstructed to a cross section similar to that of the noninsulated conventional pavement specified for the runway at Newton Field. Figure 2*b* shows the typical cross section.

Because test results from the first winter of observation (1986–1987) showed substantial frost penetration beneath the insulation on the runway, four test sections consisting of various combinations of insulation and sand subbase thickness were constructed adjacent to the aircraft parking apron in July 1987. The test section site was wet but not quite so swampy as much of the runway site. Figure 2*c* shows a longitudinal section of the test sections. Test section 1 most closely approximates the design used for the insulated runway. In contrast to placement of single-thickness insulation panels in the runway, test section insulation panels were placed in multiple layers with joints staggered. The original soil profile was the same as that of the runway.

INSTRUMENTATION

Instrument installation in 1986 and 1987 is discussed in detail in works by Kestler and Berg (*2,3*) and by Allen (*4*). Initial instrumentation included thermocouples and thermistors to monitor subsurface temperatures above, within, and beneath the insulation; tensiometers to measure soil moisture; and electrical resistivity gauges to indicate frozen/nonfrozen conditions beneath the insulating layer. The water table was monitored by water wells, frost heave was measured by conducting periodic pavement surface elevation surveys with an engineer's level and rod, and pavement stiffness was measured nondestructively with the U.S. Army Cold Regions Research and Engineering Laboratory's (CRREL) falling weight

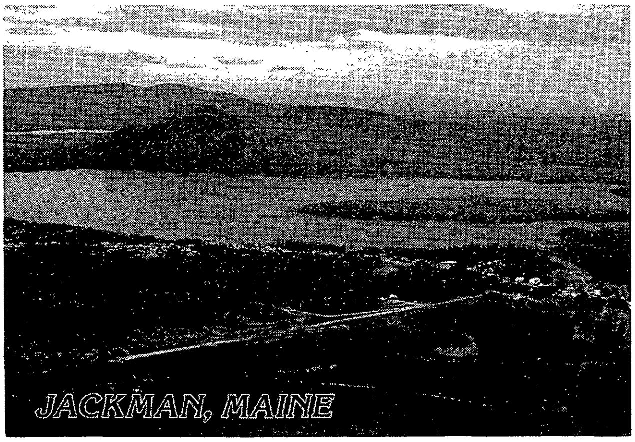

FIGURE 1 Newton Field, Jackman, Maine (photographed by S. Coleman of Dave Walker Cards).

deflectometer. During later years of observation linear-motion potentiometers were installed across selected transverse cracks to monitor diurnal and seasonal asphalt concrete (AC) expansion and contraction and to determine AC shrinkage associated with aging. In addition, vibrating-wire piezometers and pressure transducers were installed in water wells (located on a line perpendicular to the lateral edge drain) to define changes in phreatic surface throughout the year.

DESIGN METHODS

For a design air-freezing index of 1428°C-days (2570°F-days), the Army and Air Force (*5*) require an insulation thickness of approximately 76 mm (3 in.). Several other charts and rule-of-thumb design methods yield a desired insulation thickness of approximately 64 mm (2.5 in.). Each method ensures designs that prevent frost penetration into the subgrade. During the winters of observation at the test sections the 0°C (32°F) isotherm penetrated through the bottom of the insulation 51 mm (2 in.) thick in Test Section 1 but not into the subgrade. From these data it appears that the test section field results conformed well to design thicknesses. During a design winter, frost is expected to penetrate the 51-mm (2-in.) insulation but not the 76-mm (3-in.) insulation. Although the winters in Jackman during the observation period ranged from average to colder than average, the design freezing index was never attained.

The test sections, which were constructed under tighter controls, on a firm working platform, and in a slightly drier location than the runway's, performed quite well and as expected. In comparison, some areas of the insulated runway did not perform particularly well. The following sections briefly discuss the good performance of the insulated test sections but concentrate on runway observations, methods used to investigate insulation integrity, and theories considered to explain the relatively poor performance of some insulated runway pavement sections.

FROST PENETRATION

Although the insulated test sections experienced little frost penetration into the subgrade, the runway experienced appreciable frost penetration into the subgrade where our instruments were located. Figure 3 shows a general trend of increasing temperatures with increasing depth beneath the surface of the pavement for noninsulated Nichols Road. Figure 4 shows the same trend but also demonstrates the efficiency of the insulating layer in the test sections. Figure 5, however, shows a distinct temperature discontinuity immediately beneath the insulating layer in the runway. A probable explanation of the temperature discontinuity and resulting frost penetration follows.

Two vertical thermocouple assemblies, one located in and above the insulation and the second located entirely below the insulation, are separated horizontally by approximately 1.5 m (5 ft). It is believed that the temperature discontinuity between thermocouple assemblies is caused either by damage to the insulation or by horizontal separation of the insulation panels. The problem probably occurred during construction. Evidence of this problem was encountered during construction in areas 9 to 5 m (30 to 50 ft) square near Stations 4+50 and 8+00. At both locations trucks, bulldozers, and other construction traffic caused a large subgrade flow that in turn raised the insulation. Under direction of the resident engineer, insulation was removed in the problem areas; subgrade was removed to the desired depth; and the geotextile, insulation, and base course were all replaced.

INSULATION DISCONTINUITIES

In July 1987, a 3- × 9-m (10- × 31-ft) section of pavement near station 30+00 was removed because of excessive local settlement. Figure 6 shows the overlapping and damaged insulation that was removed and replaced.

During the years following removal of the pavement section at Station 30+00 a variety of nondestructive methods were used to confirm the suspicion that damaged or separated panels, or both, were not limited to Station 30+00. Methods included infrared photography, ground-penetrating radar, and hand excavation of the base course alongside the runway.

The infrared camera showed considerable variation in surface temperatures. However, it could not identify insulation discontinuities.

Ground-penetrating radar provided more information than did infrared photography. Investigations yielded profiles such as those shown in Figure 7 (*6*). Assuming a uniform water content between the AC and the insulation, approximate depths from AC to insulation panels can be determined from these radar records. The uppermost set of dark bands represents the antenna direct coupling. The next series of bands represents the interface between insulation panels and the subbase (i.e., the bottom of the insulation). The third, less distinct set is caused by multiple reflection of the radar pulse between the various layers. Depths to insulation panels appear to range from 127 mm (5 in.) to 610 mm (24 in.) beneath the runway pavement surface. Although individual panels 610 mm (2 ft) wide can be identified in Figure 7 (bottom), the resolution of the ground-penetrating radar was not sufficient to permit estimation of gap sizes between individual panels. It should be noted that, in contrast to the nonuniform depth of insulation panels beneath the runway, the depth of insulation panels beneath the test sections was uniform. As stated previously, the primary differences between the test sections and the runway were that the test section site was not so wet as the runway site and that the test sections were constructed under tighter controls. The test sections also had a deeper subbase than the runway.

Hand excavation of trenches and random holes alongside the runway yielded the most definitive evidence of damaged and separated

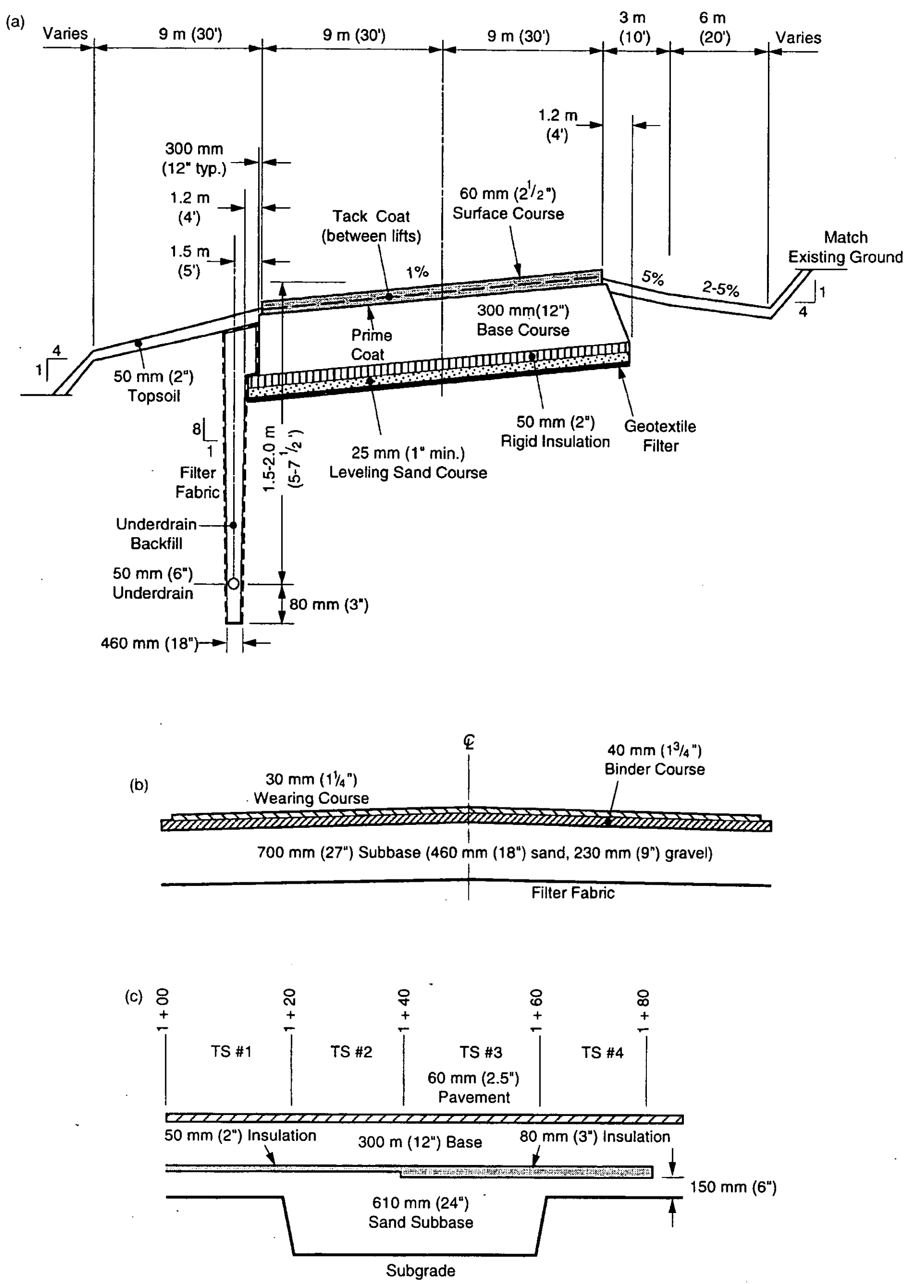

FIGURE 2 Typical cross section of (*a*) Newton Field runway and (*b*) Nichols Road and (*c*) longitudinal section of insulated test sections.

panels. A 64-mm (2.5-in.) gap was uncovered in the second 610- × 1520-mm (2- × 5-ft) trench alongside the runway at Station 7+75 in 1988. Further excavation yielded several gaps of approximately 51 mm (2 in.). During summer 1991 small holes alongside the runway at or near the ends of transverse cracks were excavated down to the insulation. Figure 8 shows cracked insulation at Station 22+80, which was representative of most test holes. It appears that cracking that occurred during periods of freezing conditions propagated down through the insulating layer and broke the insulation panels. The figure also shows a gap between insulation panels, which was typical.

FROST HEAVE

Maximum vertical displacement was similar each winter throughout the 4 years of observation. The maximum frost heave in test sections 1 to 4 and the conventional pavement at Nichols Road was approximately 25 mm (1 in.). Maximum frost heave along most of the runway was slightly greater than that observed at the test sections. However, the two ends of the runway exhibited 76 mm (3 in.) and 102 mm (4 in.) of frost heave, with localized areas of differential heaving. Areas of substantial frost heave correspond to areas that were excavated to a lesser depth during construction. In addition,

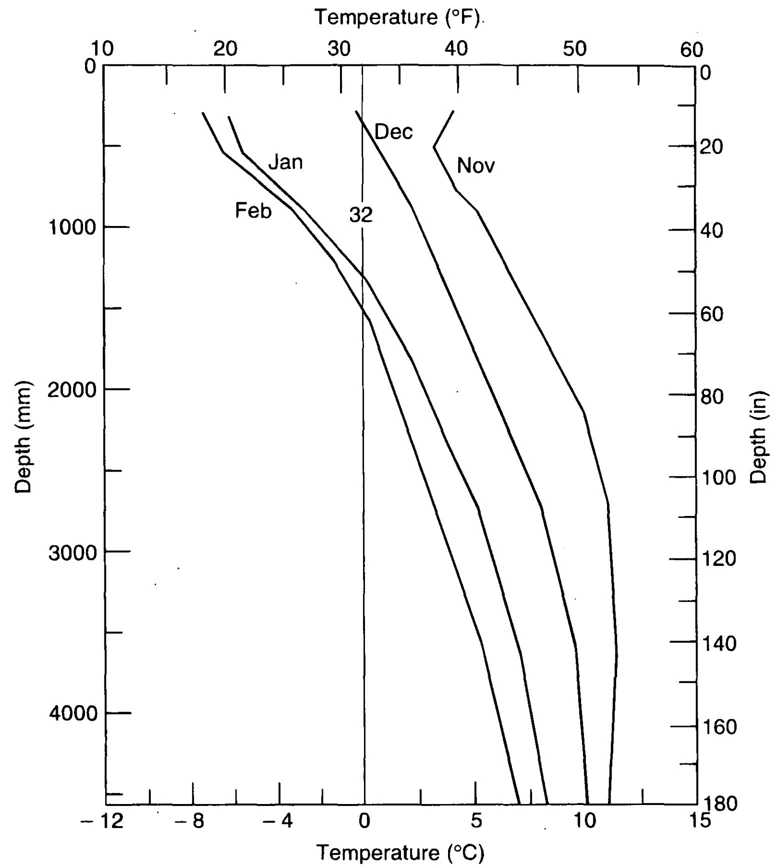

FIGURE 3 Nichols Road temperature profiles, winter 1987–1988.

both ends of the runway were particularly spongy during construction. Maximum differential movement within a length of 1.5 m (5 ft.) was approximately 152 mm (6 in.). Because of its absence from the test sections, differential frost heave on the runway was used as an indicator of damage to the underlying insulation. As discussed earlier, gaps in the insulating layer beneath the runway probably occurred during construction. The resulting nonuniform frost penetration into the subgrade undoubtedly caused most of the differential frost heaving. Differential frost heaving may, in turn, contribute to further cracking of insulation panels, thus perpetuating the cycle.

CRACKS

General

By far the most serious distress exhibited by the 8-year-old pavement is cracking. Crack types include small longitudinal cracks that typically occur in localized groups and individual transverse cracks ranging in width from hairline to several inches. The severity of the transverse cracks has been a cause for concern. Generally, (a) one or two more develop each winter, (b) no one year has been more conducive to crack production than another, and (c) they continue to increase in size.

In December 1992 several cracks were measured, of which the maximum width was approximately 127 mm (5 in.). By June 1994 the maximum width had increased to 229 mm (9 in.). Figure 9 shows one of the more severe cracks. Cracks have been sealed with a rubberized crack sealer several times. Nevertheless, the AC is exhibiting signs of secondary cracking and some crack settlement. One possible reason for this is that the base course may have eroded from beneath some of the larger cracks. During several heavy rains, granular material was observed in motion atop the AC at unsealed cracks, where the sealer has been removed by snowplows.

Of concern is the ever-increasing width of the cracks. It is recognized that insulated pavements experience greater temperature fluctuations than do conventional pavements because of the reduced effective thermal mass of insulated pavements. Greater temperature extremes cause the insulated pavement to undergo slightly greater thermal expansion and contraction than would a conventional pavement. Increased thermal stresses caused by these lower temperatures are discussed in the section entitled Laboratory AC Testing.

Pavement temperatures were recorded approximately biweekly during the 1986–1987 through 1990–1991 winters. Average base course temperatures in the insulated pavements were generally a few degrees lower than in the conventional pavement at Nichols Road throughout the freezing season, a few degrees higher during the summer season (but sometimes lower), and sometimes higher in fall and spring. Figure 10 shows base course temperatures just

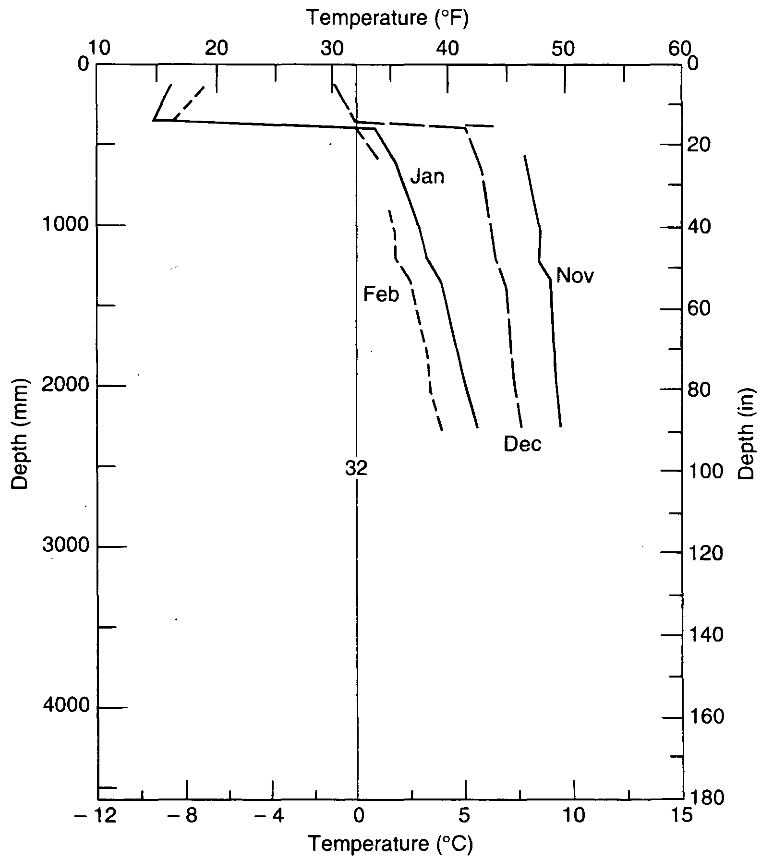

FIGURE 4 Test section temperature profiles, winter 1987–1988.

above the insulating layer in Test Section 1 and at a comparable depth in Nichols Road during the 1988–1989 observation season. Even if the lower temperatures contributed to additional cracking, they should not be responsible for the 229-mm (9-in.) crack observed during June 1994.

It is suspected that abnormally wide cracks are initiated by something other than the insulation but may be made worse by the insulation. During construction the asphalt mixture was hauled several hours from the asphalt plant to the project site. It is quite possible that the asphalt was overheated at the plant or placed at the site at a temperature below that desired. This could accelerate oxidation, making the AC brittle and susceptible to shrinkage and fracture (*7*).

Linear Motion Potentiometers

To differentiate diurnal thermal contraction and expansion, seasonal thermal contraction and expansion, and shrinkage of AC caused by aging, linear-motion potentiometers (LMPs) were installed across a transverse crack at Stations 16+15 and 18+00 (Figure 11). Figure 12 shows diurnal crack movement at Station 16+15 and corresponding temperatures recorded by temperature sensors embedded in the AC. Neither LMP functioned continuously for an entire year, so shrinkage because of asphalt aging could not be determined by this means. It is, however, believed that an LMP picked up a cracking event. Figure 12 shows appreciable damping in diurnal crack width variation starting February 3, 1991. During the first visit following February 3 a new crack between Station 16+15 and what had been the next closest crack was observed Clearly, the reduced slab length on one side of the monitored crack would cause some or all of the observed LMP attenuation.

Manual Measurements

The runway asphalt has shrunken considerably during the monitoring period, which began almost 6 years after the runway was built. A manual method was also used to measure this shrinkage. Nails were installed in the AC at 30-m (100-ft) intervals and on either side of each transverse crack. Distances between nails were measured with a 30-m (100-ft) steel surveyor's chain pulled taut with 67 N (15 lb) of tension. Temperature corrections were applied to the measurements of the AC and the steel chain. Total slab shrinkage from June 1992 to June 1994 was nearly 127 mm (5 in.). It should be noted that this method underestimates total runway shrinkage because new cracks occurred between old cracks during the monitoring period. Also, total runway length (from the center of the first AC slab to the center of the last) remained constant. This serves as a check of manual measurement accuracy, and reductions in slab

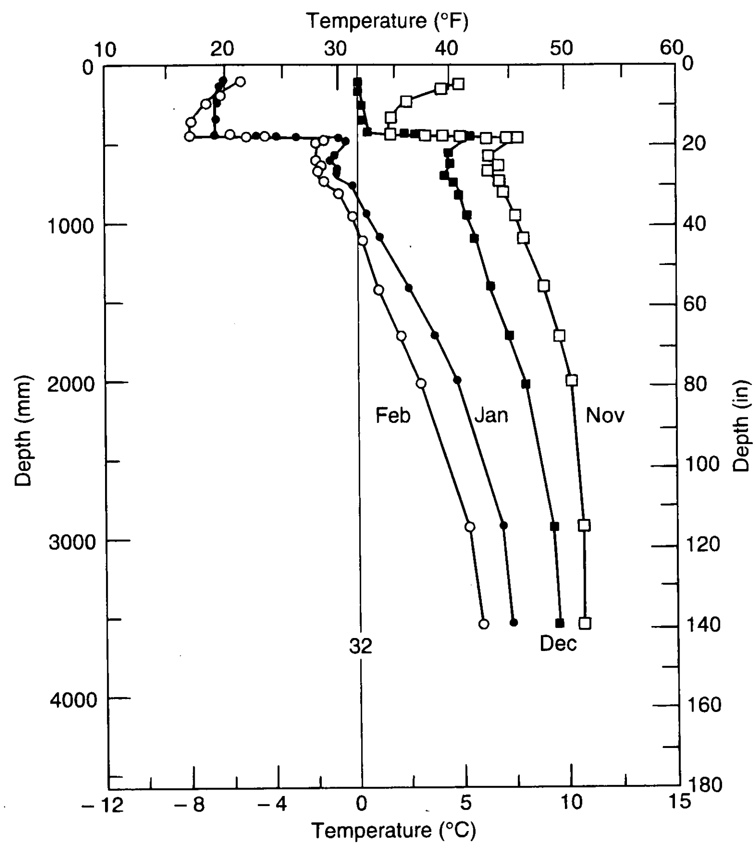

FIGURE 5 Newton Field temperature profiles, Station 4+50, winter 1987–1988.

lengths attributed to shrinkage far exceed manual measuring tolerances. Additional crack width is probably the result of secondary cracking and spalling.

Laboratory AC Testing

Laboratory tests to determine both a coefficient of thermal contraction and the temperature necessary for thermal cracking under an applied load were conducted on AC samples obtained from the Newton Field runway in 1992.

The coefficient of thermal contraction was determined to be approximately 20×10^{-6} mm/mm/°C (11×10^{-6} in./in./°F), which is typical. In contrast, thermal stress test results were not typical. Results help support the belief that excessive cracking could be as attributable to the asphalt as to the insulation. An AC sample 254 mm (10 in.) long was subjected to decreasing temperatures in accordance with the procedure discussed elsewhere (*8*). The sample broke at −20°C (−4°F), which is well outside the expected range of −25° to −30°C (−13° to −22°F) for this type of AC.

Again, it is possible that overheating for the lengthy plant-to-site haul could have caused a loss of higher-end volatiles, which effectively altered the AC to a higher-grade AC that is more susceptible to low-temperature cracking. Compounding the situation, temperatures experienced by the insulated pavement were lower than those for a conventional pavement.

FIGURE 6 Damaged and overlapping insulation panels, Station 30+00, Newton Field runway.

NONDESTRUCTIVE TESTING

Falling weight deflectometer tests were conducted periodically to assess stiffness of the conventional and insulated pavements. Backcalculated moduli [using WESDEF (*9*) and MODCOMP (*10*)] and deflection basin areas were used as indicators of pavement stiffness.

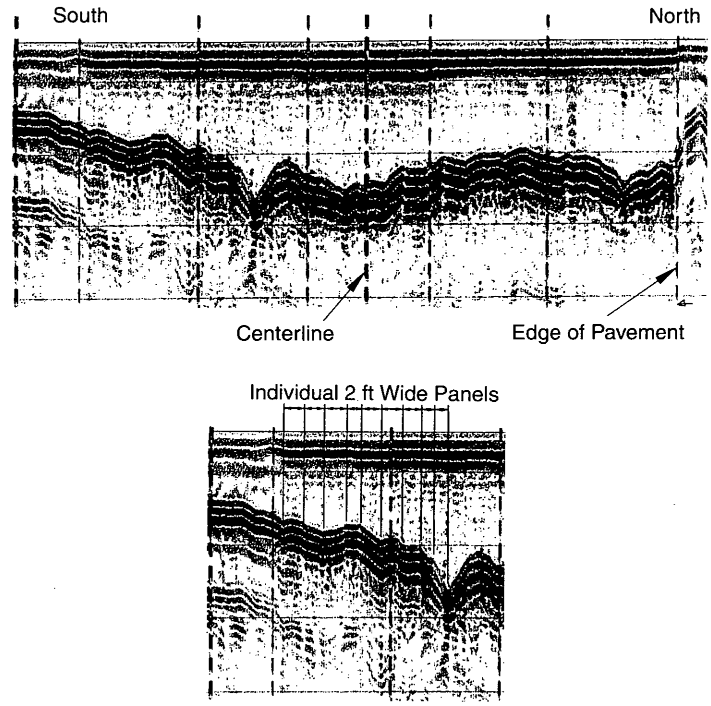

FIGURE 7 Ground-penetrating radar profile, *top,* and enlargement of south end of profile showing insulation panels 610 mm (2 ft) wide, *bottom.*

FIGURE 8 Insulation panels alongside runway, showing crack and gap between panels.

At temperatures above freezing, typical modulus values for all the insulated pavements were appreciably lower than those for non-insulated Nichols Road. This was probably because of the near-surface water table at Newton Field compounded by the low modulus of extruded polystyrene.

Although conventional pavements typically experience appreciable strength loss during spring thaw and recover with time, the strength of the insulated test sections remained relatively constant through spring and summer, with fluctuations caused primarily by AC temperatures. If insulation prevents frost from penetrating into the subgrade, the subgrade never undergoes thaw weakening. However, the high water table again complicates the issue because it may cause the subgrade to remain weak during what would otherwise be a recovery period.

FIGURE 9 Transverse runway crack.

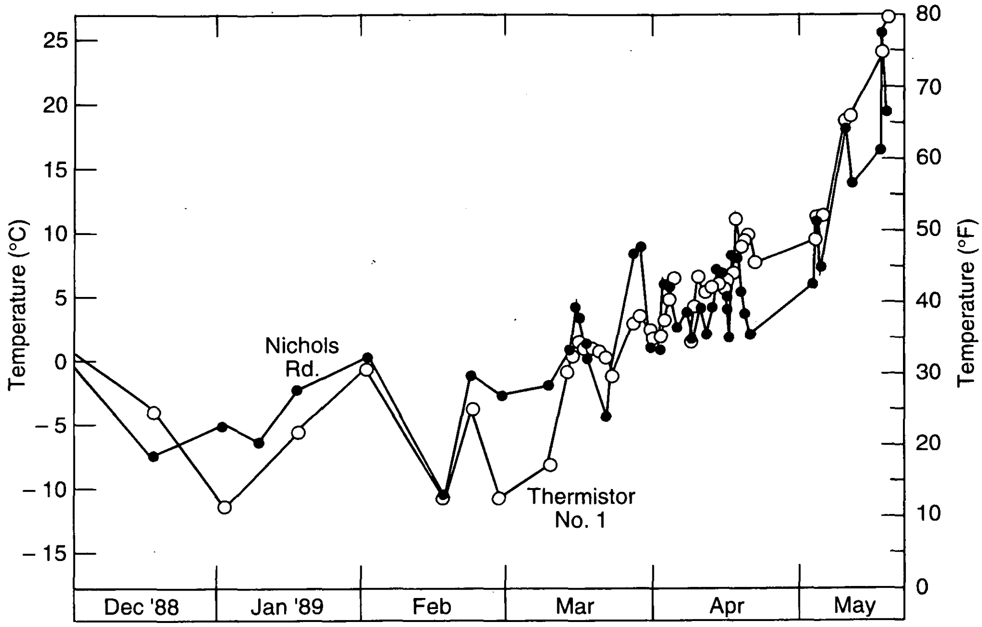

FIGURE 10 Base course temperatures for insulated and noninsulated pavements.

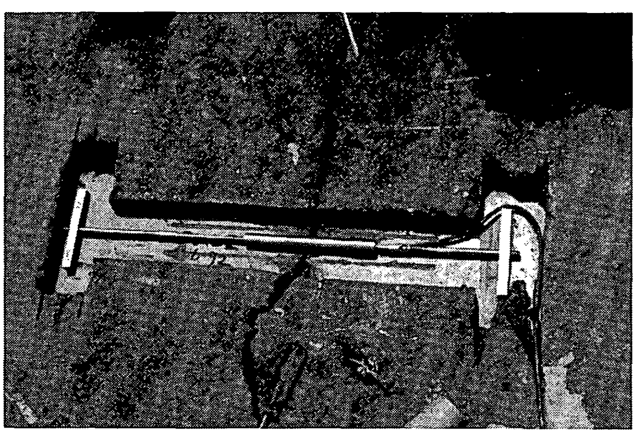

FIGURE 11 Linear-motion potentiometer installed across crack.

The two ends of the runway were noticeably weaker than the middle and test sections. Furthermore, they exhibit more variation in pavement strength during spring thaw. These two nondestructive testing observations agree with the previously discussed runway performance observations. The ends of the runway were particularly wet during construction. All other factors being equal, this typically indicates a weaker pavement. In addition, the middle of the runway was undercut deeper and, as a consequence, has a thicker subbase than do the ends. Finally, as discussed earlier, the ends of the runway exhibit substantial absolute and differential frost heave, possibly because of insulation damage and discontinuities. This heaving indicates frost penetration into the subgrade (observed), which in turn implies subgrade weakening during spring thaw.

SURFACE ICING

The Army and Air Force (*5*) require insulation to be placed at a minimum depth of 457 mm (18 in.) beneath the pavement surface to minimize surface icing. Differential icing is not an uncommon phenomenon at transitions between insulated and noninsulated pavements. However, there are no such transitions in the AC surfaced pavements at Newton Field. (Paved insulated test sections transition into a noninsulated gravel road.) The range in depth to the insulating layer could promote differential icing on the runway surface under certain environmental conditions. Visual observations were limited to those made by CRREL personnel, the town snowplow operator, and local pilots. Although surface icing was observed by CRREL personnel on several occasions, differential surface icing was not observed. Surface temperature sensors showed that the insulated pavement was generally colder than the noninsulated pavement throughout the freezing season.

CONCLUSIONS

The four insulated pavement test sections performed well. Frost penetration into the subgrade beneath insulation panels 51 mm (2 in.) and 76 mm (3 in.) thick was minimal, and frost heave was similar to that of a conventional (control section) pavement at Nichols Road. Field results for the insulated pavement test sections conformed well to those predicted by the design thickness.

Why did the insulated runway pavement perform so poorly when the insulated pavement test sections (one of which was nearly identical in design to the runway) performed so well? A variety of investigative methods was used to confirm suspicions that frost penetration and localized frost heave could be at least partially attributed to

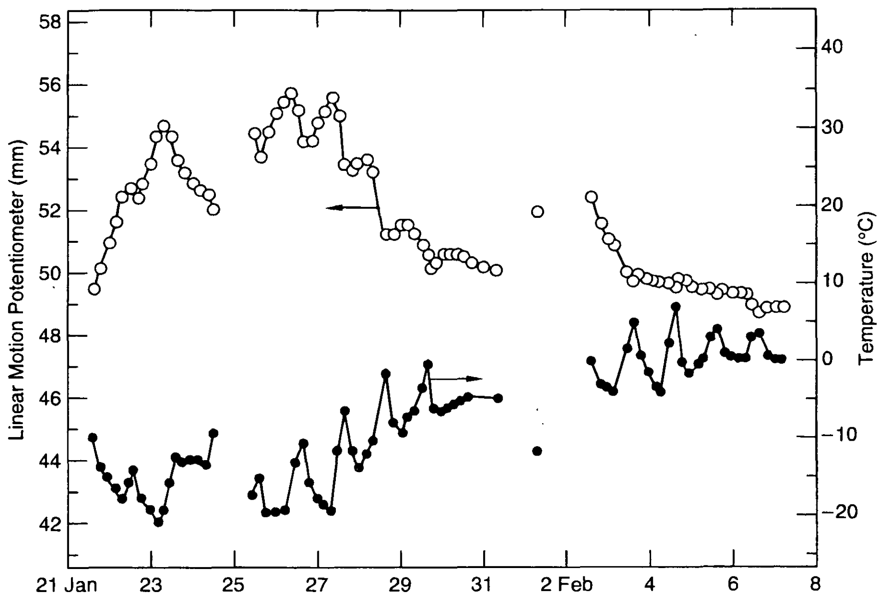

FIGURE 12 Linear-motion potentiometer data.

insulation irregularities at the ends of the runway: (a) hand-excavated trenches and holes alongside the runway revealed cracked insulation panels and gaps of up to 64 mm (2.5 in.) between panels, (b) mechanical excavation during runway repair exposed damaged and overlapping insulation panels, (c) infrared photography showed irregularities in pavement surface temperatures, and (d) ground-penetrating radar investigations revealed that the depth to the insulation/subbase interface ranged from 127 to 610 mm (5 to 24 in.).

The insulated pavements did not exhibit the strength of noninsulated pavements. In contrast, however, the insulated pavement test sections did not exhibit significant strength loss because frost never penetrated into the subgrade and, as a consequence, the subgrade did not undergo thaw weakening. The ends of the runway, however, did exhibit thaw weakening. This is probably because damaged insulation and insulation discontinuities allowed deeper subgrade frost penetration, as was shown by frost heaving.

As indicated by differences in performance between the ends of the runway and the center, the thickness of the granular subbase appears to be a critical component contributing to pavement performance. The granular base, particularly in wet areas, provides a firm working platform for panel placement and subsequent construction.

The runway pavement exhibits several severe transverse cracks up to 229 mm (9 in.) wide. Periodic measurements of the asphalt slabs between adjacent cracks show excessive asphalt shrinkage with aging. In addition, thermal stress tests showed that the asphalt was susceptible to thermal cracking at a considerably higher temperature than is typical for asphalt mixtures of that grade. It is suspected that cracking is primarily the fault of the AC but is perhaps compounded by the insulation. Because insulated pavements undergo greater temperature fluctuations than do noninsulated pavements, it is possible that the slightly lower temperatures could induce cracking. However, no other instances of extensive cracking in thermally insulated pavements were found in the literature.

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