

Expanded Polystyrene Concrete Subbases

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An investigation was conducted to determine the potential use of expanded polystyrene concrete as a subbase material for pavements, particularly in areas where severe winter conditions prevail. The work included experimental and analytical evaluations. Measurements taken on pavement sections in an outdoor test installation indicated that expanded polystyrene concrete is effective in reducing or even eliminating subgrade frost penetration under rigid and flexible pavements. In addition, expanded polystyrene concrete subbases reduce pavement deflections. The results of an analytical investigation indicated that expanded polystyrene concrete subbases effectively reduce or eliminate subgrade freezing under pavements. Expanded polystyrene subbases also reduce pavement and subgrade stresses, thereby increasing the load-carrying capacity of pavements.

Pavement damage caused by frost action is a recognized problem in the United States and Canada. Current practices to reduce problems caused by frost action include the removal of frost-susceptible soils and replacement with a thick granular base course. However, the use of a subbase material that provides both insulation and improved strength is a better solution to these problems. Expanded polystyrene concrete—a form of lightweight concrete made of expanded polystyrene beads, cement, sand, water, and admixtures—has this potential.

An investigation was conducted to determine the potential use of expanded polystyrene concrete as subbase material for pavements, particularly in areas where severe winter conditions prevail (1). This paper reports the results of (a) deflection and frost penetration measurements made on outdoor pavement test sections that incorporated expanded polystyrene concrete subbases and (b) an analytical investigation to determine the contribution of expanded polystyrene concrete subbases to subgrade frost protection and the load-carrying capacity of pavements.

OUTDOOR TESTS

The objective of outdoor testing was to evaluate the performance of pavement sections that incorporate expanded polystyrene concrete subbases. For this purpose, six pavement sections were built and instrumented with thermocouples to determine the extent of frost penetration under the pavement. In addition, pavement deflections were measured for representative truck loads.

Details of Test Sections

Test sections consisted of six pavement panels constructed with different subbase layers and surfaces. Pavement thicknesses represented general practice for both rigid and flexible pavements.

Three test sections—designated C1, C2, and C3—were built with a 203-mm (8-in) thick portland cement concrete (PCC) surface. The other three test sections—designated A1, A2, and A3—were built with a 127-mm (5-in) thick asphaltic concrete surface. The type and thickness of the subbase for each test section are given below (1 mm = 0.039 in):

| Section | Surface | Subbase |
|---------|------------|--------------------------------------|
| C1 | 203-mm PCC | 152-mm crushed stone |
| C2 | 203-mm PCC | 152-mm expanded polystyrene concrete |
| C3 | 203-mm PCC | 305-mm expanded polystyrene concrete |

| Section | Surface | Subbase |
|---------|---------------------------|--------------------------------------|
| A1 | 127-mm asphaltic concrete | 254-mm crushed stone |
| A2 | 127-mm asphaltic concrete | 152-mm expanded polystyrene concrete |
| A3 | 127-mm asphaltic concrete | 305-mm expanded polystyrene concrete |

The pavement sections measured 3.048 x 3.048 m (10 x 10 ft), and the subbases measured 3.658 x 3.048 m (12 x 10 ft), which provided a 0.610-m (2-ft) wide crushed stone shoulder beyond the pavement edge.

The granular subbase consisted of crushed limestone, which met requirements of grade CA6 of the state of Illinois (2). The subbase was placed in lifts and compacted with a vibrating sled to standard density conditions as determined by AASHTO T 99.

Expanded polystyrene concrete made with a density of 625 kg/m³ (39.0 lb/ft³) was used. The expanded polystyrene concrete was mixed in a ready-mix truck and placed without compaction or vibration.

A general view of the test sections is shown in Figure 1.

Instrumentation

Subbase, subgrade, and concrete temperature measurements were monitored by thermocouples made by soldering the ends of copper-constantan wire. The thermocouples were attached to a 25-mm (1-in) diameter lath and placed into augered holes before the construction of the subbase. Lead wires were carried to the edge of the pavement in a trench. For concrete test sections, thermocouples were placed 13 mm (0.5 in) below the concrete surface, at the concrete-subbase interface, at the subbase-subgrade interface, and in the subgrade 152, 457, and 762 mm (6, 18, and 30 in) below the subbase-subgrade interface. For asphalt test sections, thermocouples were placed 13 mm (0.5 in) below the asphalt-subbase interface, at the subbase-subgrade interface, and in the subgrade 152, 457, and 762 mm (6, 18, and 30 in) below the subbase-subgrade interface.

Temperatures were recorded periodically by connecting wire ends to thermocouple plug-ins of a System 3000 temperature recorder manufactured by Kaye Instruments of Bedford, Massachusetts. Automatic temperature printout was obtained at preselected time intervals.

Figure 1. General view of pavement test sections.



Edge and corner deflections of test sections were measured under a three-axle truck that had a gross weight of 205 kN (46 000 lb). Deflections were measured for the rear axle of a standing truck by using a Benkelman beam (3), as shown in Figure 2.

Temperature Distribution

Temperature distribution in pavement surface, subbase, and subgrade was recorded periodically to determine the extent of frost penetration. Examples of temperature distribution in pavement, subbase, and subgrade at selected times are shown in Figure 3 for rigid-pavement test sections and in Figure 4 for flexible-pavement test sections.

The deepest subgrade frost penetrations of the six sections recorded during the 1974-1975 or 1975-1976 winters are given below (1 mm = 0.039 in):

| Section | Frost Penetration (mm) | |
|---------|----------------------------|---|
| | 1974-1975 and 1975-1976 | January 1977 |
| C1 | 38 | 533 |
| C2 | 51 | 127 |
| C3 | 0 | 25 |
| A1 | 279 | Not recorded because of malfunction of thermocouples |
| A2 | 254 | 330 |
| A3 | 0 | 102 |

However, because of persistent cold weather during the 1976-1977 winter, subgrade frost penetration measured in January 1977, as given above, was deeper than that measured during the first two winters of the investigation.

These data indicate that, for the climatic conditions encountered during the first two winters of the investigation, a 152-mm (6-in) thick expanded polystyrene concrete subbase was almost sufficient to prevent subgrade freezing under a 203-mm (8-in) thick PCC pavement. However, neither a 254-mm (10-in) thick crushed stone subbase nor a 152-mm (6-in) thick expanded polystyrene concrete subbase was sufficient to

Figure 2. Deflection measurement using a Benkelman beam.



prevent subgrade freezing under a 127-mm (5-in) thick asphaltic concrete pavement. A 305-mm (12-in) thick expanded polystyrene concrete subbase was sufficient to prevent subgrade freezing.

Temperature measurements indicated that, under continued freezing air temperatures, rigid and flexible pavements with expanded polystyrene concrete subbases show higher subgrade temperatures than those with crushed stone subbase of the same thickness. In addition, surface temperatures of concrete pavements with crushed stone subbase were generally higher than air temperatures. In contrast, surface temperatures of pavements with expanded polystyrene concrete subbases were lower than air temperatures.

Pavement Deflections

Edge and corner deflections of test sections were measured at two different times under the rear axle of a three-axle truck that had a gross weight of 205 kN (46 000 lb).

Deflection data for rigid-pavement test sections indicated that deflections of the sections with expanded polystyrene concrete subbases were less than those for the section with a granular subbase. Reductions in edge deflections averaged 5 and 17 percent for sections C2 and C3 respectively. Reductions in corner deflections averaged 7 and 34 percent for sections C2 and C3 respectively.

Deflection data for flexible-pavement test sections indicated that deflections of the sections with expanded polystyrene concrete subbases were less than those for the section with a granular subbase. Reductions in edge deflections averaged 15 and 28 percent for sections A2 and A3 respectively. Reductions in corner deflections averaged 2 and 35 percent for sections A2 and A3 respectively.

ANALYTICAL INVESTIGATION

In this investigation, analytical methods were used to evaluate the effect of expanded polystyrene concrete subbases on subgrade freezing and pavement stresses. Both rigid and flexible pavements that incorporated expanded polystyrene concrete and compacted granular subbases were investigated.

Frost Penetration

To evaluate the effect of expanded polystyrene concrete subbases on subgrade frost penetration, the thickness of granular material or expanded polystyrene concrete subbase required to provide complete subgrade frost protection was calculated for three selected climatic conditions. This was accomplished by using the modified Berggren formula (4) for a layered system. The assumed material properties for pavement, subbase, and subgrade that were used in the calculations are given in Table 1.

Thicknesses of granular material or expanded polystyrene concrete subbase required to prevent subgrade freezing under a 203-mm (8-in) thick portland cement or a 127-mm (5-in) thick asphaltic concrete pavement were calculated for minor, moderate, and severe frost levels. Freezing index, mean annual temperature, and duration of freezing index for the three conditions are given below [degree day C = 1.8 degree days F and $t^{\circ}\text{C} = (t^{\circ}\text{F} - 32)/1.8$]:

| Frost Level | Freezing Index (degree days C) | Mean Annual Temperature (C) | Duration of Freezing Index (d) |
|-------------|-----------------------------------|--------------------------------|--------------------------------------|
| Minor | 333 | 10.0 | 90 |
| Moderate | 889 | 5.5 | 125 |
| Severe | 1167 | 4.4 | 140 |

These climatic conditions are similar to those normally encountered in Chicago, Minneapolis, and Bismarck, North Dakota, respectively.

Results of this analysis, given in the table below, indicate that subgrade freezing under the pavement can be prevented by using an expanded polystyrene concrete subbase whose thickness is approximately one-third that of a compacted granular subbase (1 cm = 0.39 in and 1 mm = 0.039 in):

| Climatic Condition | Subbase Thickness (cm) | | | |
|--------------------|---------------------------------|-------------------------------|--|-------------------------------|
| | Under 203-mm-thick PCC pavement | | Under 127-mm-thick asphaltic concrete pavement | |
| | Granular Material | Expanded Polystyrene Concrete | Granular Material | Expanded Polystyrene Concrete |
| Minor frost | 83.8 | 30.5 | 91.4 | 30.5 |
| Moderate frost | 198.1 | 71.1 | 205.7 | 71.1 |
| Severe frost | 243.8 | 91.4 | 251.5 | 91.4 |

Pavement Stresses

The purpose of this analysis was to compare critical stresses in pavements that incorporate expanded polystyrene concrete subbases with those in pavements that use compacted granular subbases. Both rigid and flexible pavements were considered. For this evaluation, the wheel load was assumed to be distributed uniformly over a 305-mm (12-in) diameter circular area.

Calculations of stress for both rigid and flexible pavements were based on the theory developed by Burmister (5) for a layered system. To simplify calculations, tables prepared by Jones (6) were used. Stresses were calculated for pavements that consisted of 203-mm (8-in) thick PCC or 127-mm (5-in) thick asphaltic concrete and various thicknesses of expanded polystyrene concrete or granular subbases. Different subgrade conditions were also considered.

For stress calculations, the following values for modulus of elasticity for the surface, subbase, and

Figure 3. Temperature distribution in PCC test sections.

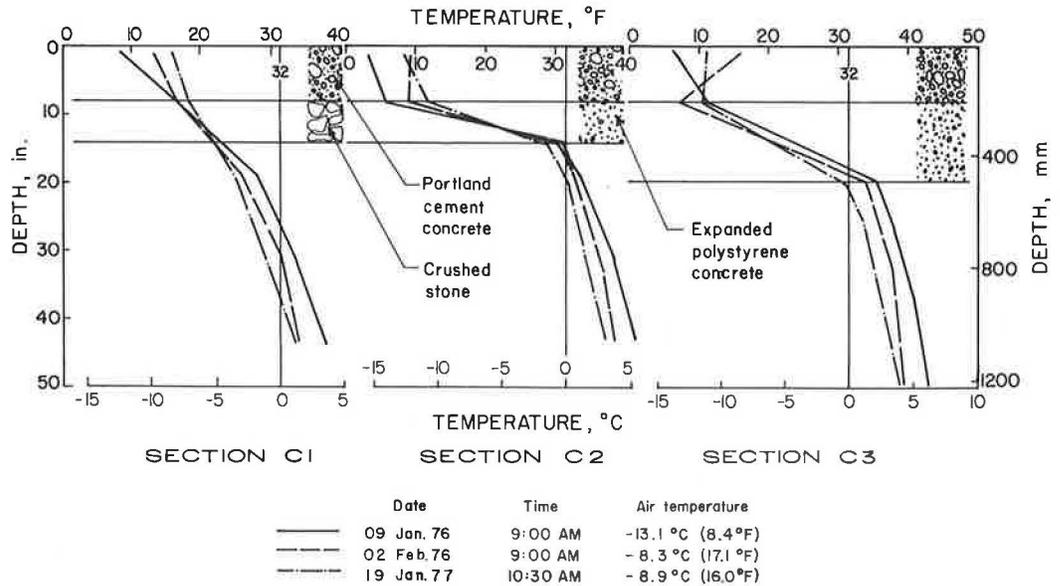
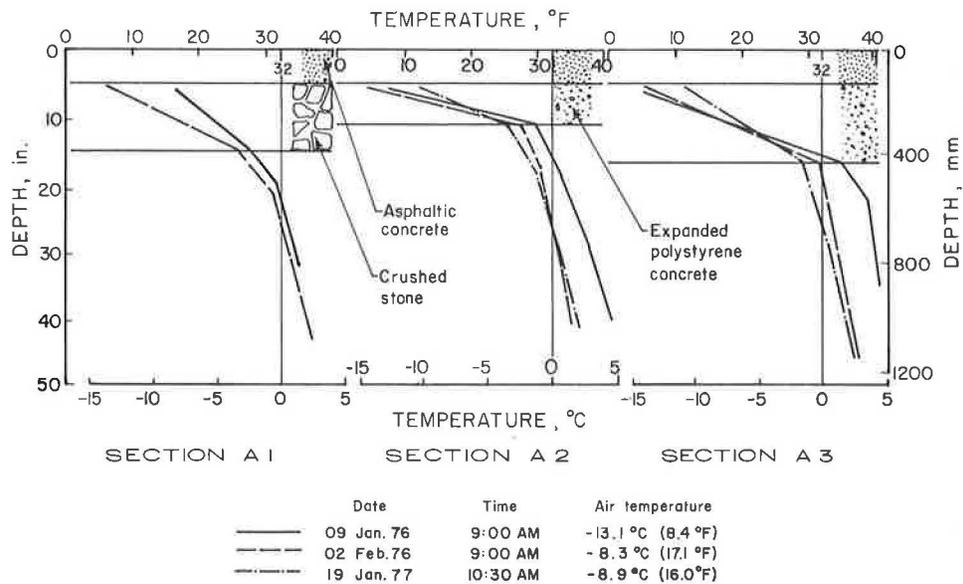


Figure 4. Temperature distribution in asphaltic concrete test sections.



subgrade pavement layers were assumed (1 MPa = 145 lbf/in²):

| Material | Modulus of Elasticity (MPa) |
|-------------------------------|-----------------------------|
| PCC | 31 000 |
| Asphaltic concrete | |
| Spring | 10 000 |
| Summer | 1 034 |
| Granular subbase material | 207 |
| Expanded polystyrene concrete | 1 034 |
| Subgrade | 21-103 |

Rigid Pavements

For rigid concrete pavements, radial bending stress in the concrete and vertical stress at the subbase-subgrade interface are most critical. The effect of the type and thickness of the subbase on these stresses was determined for different subgrades.

The effect of the type and thickness of the subbase on radial bending stress in the concrete is shown in Figure 5. These data indicate that radial stresses in pavements with expanded polystyrene concrete subbases were smaller than those for pavements with gran-

Table 1. Properties of pavement materials.

| Material | Density (kg/m ³) | Thermal Conductivity (W/m·K) | Specific Heat (J/kg·K) | Water Content (percent by weight) | Volumetric Heat (MJ/m ³ ·K) | Latent Heat (MJ/m ³) |
|--------------------------------|------------------------------|------------------------------|------------------------|-----------------------------------|--|----------------------------------|
| Portland cement concrete | 2323 | 2.08 | 921 | 2 | 2.3 | 15.5 |
| Bituminous concrete | 2291 | 1.45 | 837 | 1 | 2.0 | 7.6 |
| Expanded polystyrene concrete | 641 | 0.16 | 1256 | 10 | 1.0 | 21.4 |
| Granular base course (subbase) | 2003 | 2.25 | 628 | 6 | 1.6 | 40.1 |
| Subgrade | 1762 | 2.94 | 419 | 20 | 1.8 | 117.5 |

Note: 1 kg/m³ = 0.062 lb/ft³; 1 W/m·K = 0.578 Btu·ft/h·ft²·°F; 1 J/kg·K = 0.000 24 Btu/lb·°F; 1 MJ/m³·K = 14.8 Btu/ft³·°F; and 1 MJ/m³ = 26.8 Btu/ft³.

Figure 5. Effect of type and thickness of subbase on concrete stress in rigid pavements.

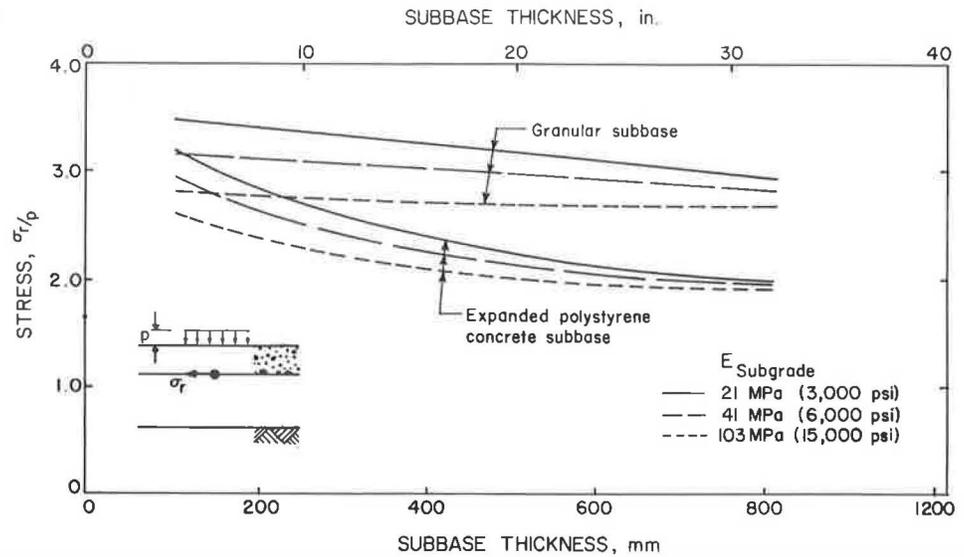


Figure 6. Effect of type and thickness of subbase on subgrade stress in rigid pavements.

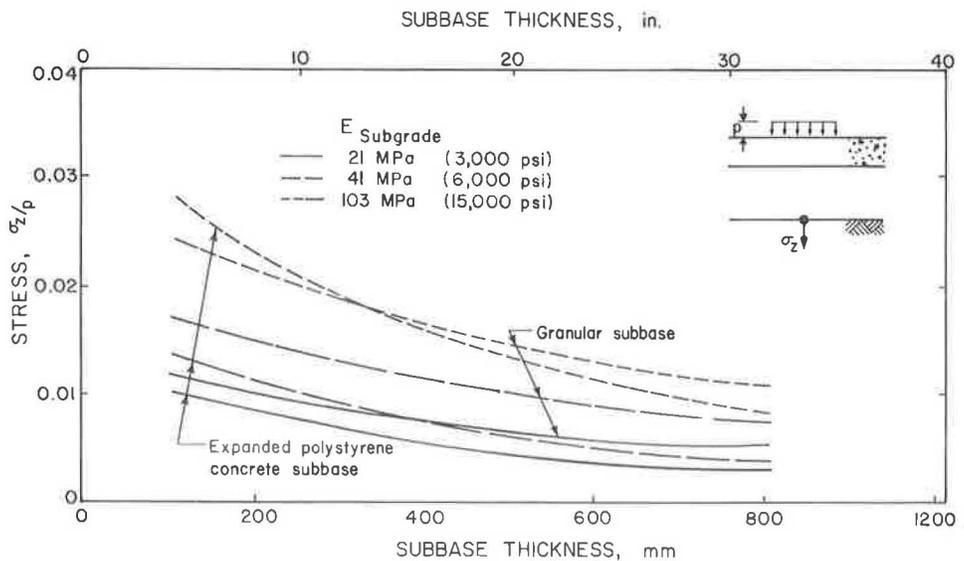


Figure 7. Effect of type and thickness of subbase on radial stress in flexible pavements.

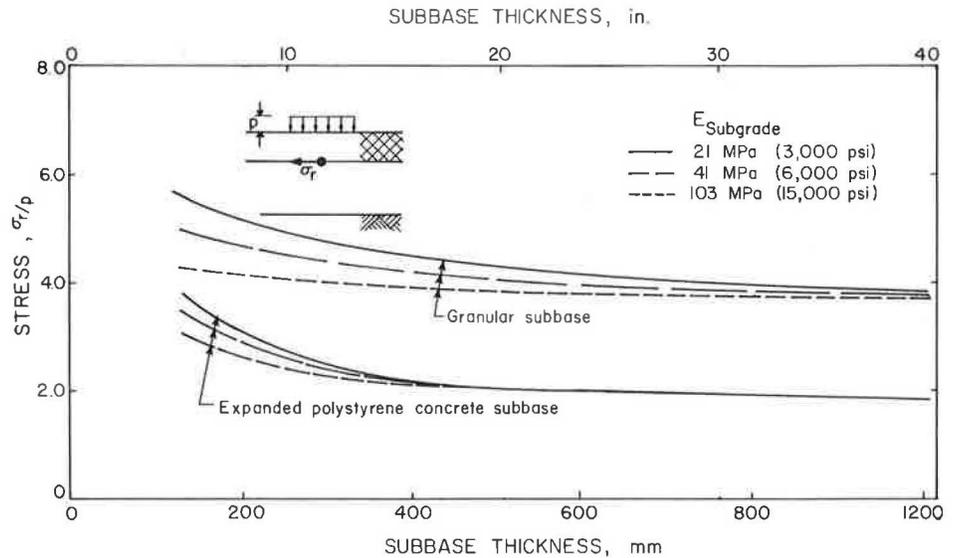
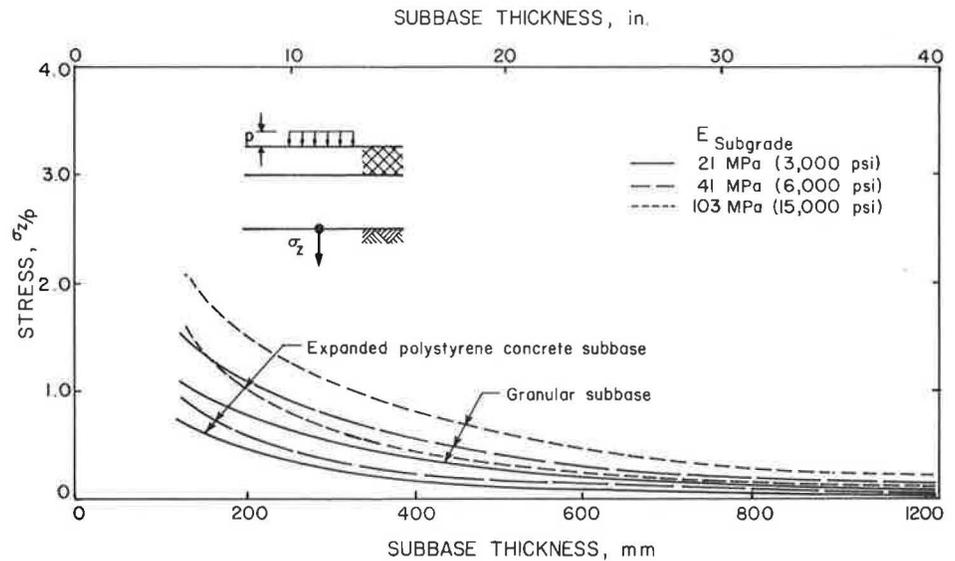


Figure 8. Effect of type and thickness of subbase on subgrade stress in flexible pavements.



ular subbases of identical thickness. In addition, depending on subgrade properties, 100-mm (3.94-in) thick expanded polystyrene concrete subbase had the same effect on pavement radial stress at a 450- to 1000-mm (17.72- to 39.37-in) thick granular subbase.

The effect of the type and thickness of the subbase on vertical subgrade stress is shown in Figure 6. These data indicate that vertical subgrade stresses under pavements with expanded polystyrene concrete subbases were generally smaller than those under pavements with granular subbases of identical thickness. The only exception occurred when subgrades with a high modulus of elasticity were used in combination with thin subbases. In these cases, stresses under an expanded polystyrene concrete subbase exceeded those for pavements with granular subbases of the same thickness. However, because of the normally low subgrade stresses under concrete pavements and the greater permissible subgrade stress, such an increase in stress under an expanded polystyrene concrete subbase is insignificant.

Flexible Pavements

In asphaltic concrete pavements, the critical stresses are radial bending stress at the concrete-subbase

interface and vertical stress at the subbase-subgrade interface.

Since temperature variations affect the modulus of elasticity of asphaltic concrete, radial bending stress in the asphaltic layer is greater during the spring because of the high asphaltic modulus of elasticity concurrent with a lower subgrade modulus. Similarly, vertical stress at the subbase-subgrade interface is greater in the summer because of the low modulus of elasticity.

The effect of the type and thickness of the subbase on radial bending stress in the asphaltic layer is shown in Figure 7. These data indicate that radial stresses in flexible pavements with expanded polystyrene concrete subbases were significantly smaller than stresses for pavements with granular subbases with the same thickness. For example, the radial stress in a flexible pavement with a 127-mm (5-in) thick expanded polystyrene concrete subbase was smaller than that in a pavement with a 1.016-m (40-in) thick granular subbase.

The effect of the type and thickness of the subbase on vertical subgrade stress is shown in Figure 8. These data indicate that vertical subgrade stresses under flexible pavements with expanded polystyrene

concrete subbases were smaller than those under pavements with granular subbases of identical thickness. The data indicate that, depending on subgrade properties, a 100- to 150-mm (3.94- to 5.91-in) thick expanded polystyrene concrete subbase had the same effect on subgrade stress as a 250-mm (9.84-in) thick granular subbase.

SUMMARY AND CONCLUSIONS

Tests were conducted on outdoor slabs to evaluate the performance of pavement sections that incorporate expanded polystyrene concrete subbases. An analytical investigation was made to determine the contribution of expanded polystyrene subbases to subgrade frost protection and pavement load-carrying capacity.

The following are the principal conclusions that were made based on this investigation:

1. Expanded polystyrene concrete subbases effectively reduce or eliminate frost penetration into subgrades under rigid and flexible pavements. A 10-mm (0.39-in) expanded polystyrene concrete subbase is as effective as a 30-mm (1.18-in) granular subbase.

2. Expanded polystyrene concrete subbases reduce pavement deflections and stresses and thereby increase pavement load-carrying capacity. In addition, the effect of an expanded polystyrene concrete subbase on pavement stresses is similar to that of a relatively thicker granular subbase.

From the results of this investigation, it is evident that expanded polystyrene concrete subbases have the potential of reducing pavement damage caused by frost action in those areas where severe winter conditions prevail.

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REFERENCES

1. A. N. Hanna. Properties of Expanded Polystyrene Concrete and Application for Pavement Subbases. Portland Cement Association, Skokie, IL, RD057.01P, 1978.
2. Standard Specifications for Road and Bridge Construction. Department of Public Works and Buildings, Illinois Division of Highways, Springfield, 1971.
3. W. J. Nowlen. Techniques and Equipment for Field Testing of Pavements. Journal of PCA Research and Development Laboratories, Vol. 6, No. 3, 1964, pp. 43-52; Portland Cement Association, Bulletin D83, Skokie, IL.
4. H. P. Aldrich, Jr. Frost Penetration Below Highway and Airfield Pavements. HRB, Bulletin 135, 1956, pp. 145-149.
5. D. M. Burmister. Theory of Stresses and Displacements in Layered Systems and Applications to Design of Airport Runways. Proc., HRB, Vol. 23, 1943, pp. 126-148.
6. A. Jones. Tables of Stresses in Three-Layered Elastic Systems. HRB, Bulletin 342, 1962, pp. 156-214.

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Some Factors That Affect Thaw Strain

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Factors that affect the thaw strain of a remolded clay were studied by using conventional isotropic and anisotropic consolidation techniques. A test sequence was developed to simulate a temperature history experienced by soils in many parts of the continental United States. The test sequence was divided into 24-h increments and included isothermal consolidation, undrained freezing, undrained thaw, and isothermal recompression. For all test sequences, the loading applied before the consolidation phase was held constant throughout the test period. The effect of various factors on thaw strain was determined by comparison of results obtained from isotropically and anisotropically loaded samples subjected to confining pressures of 103, 207, and 414 kPa (15, 30, and 60 lbf/in²). In addition, the effect of repeated freeze-thaw was obtained from tests where the undrained freeze and undrained thaw phase of the test sequence was repeated up to four times. Results from the test indicate that thaw strain increases with increasing principal stress ratio and also increases as the confining pressure decreases. It was also observed that excess pore pressures developed during the undrained freezing and undrained thaw phase of the test and that these pore pressures are closely related to the development of thaw strain.

It is generally maintained that most strains that occur in soils are related to the application of bound-

ary stresses. However, other factors are also capable of causing strain, and in some cases they may be more significant than boundary stresses. Typical examples are strains caused by changes in the physicochemical environment and pore water chemistry. More specifically, some researchers (1, 2) have documented the effect of temperature change on soil compressibility and pore pressure, and others (3, 4, 5) have investigated the strain that occurs when freezing is followed by thawing.

The purpose of the experimental tests described in this paper was to assess the effect of principal stress ratio, confining pressure, and freeze-thaw cycling on the magnitude of thaw strain. This information was then used to develop a mechanistic picture to describe thaw strain.

The general experimental approach involved triaxial consolidation of a test soil under anisotropic or isotropic stress conditions. Each test involved at least a single drained consolidation, undrained freeze, undrained thaw, and drained recompression phase. Various confining pressures and principal stress ratios were used, and some of the tests involved up to four cycles of undrained freezing and