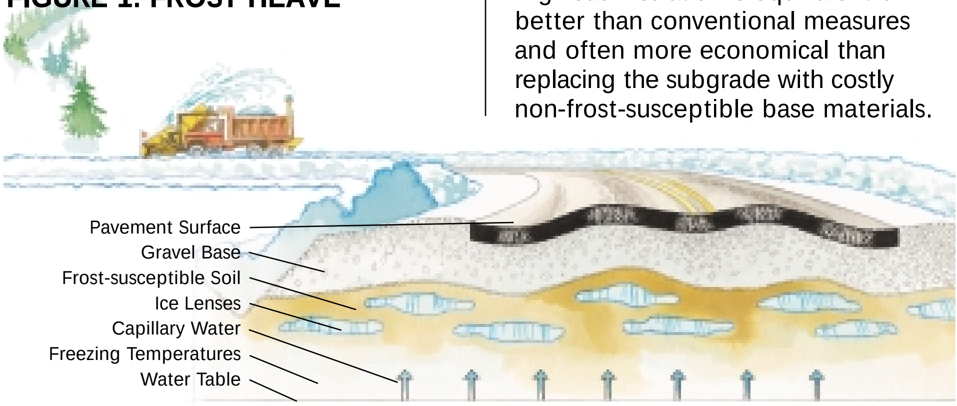
COMMERCIAL

# HIGHWAY INSULATION

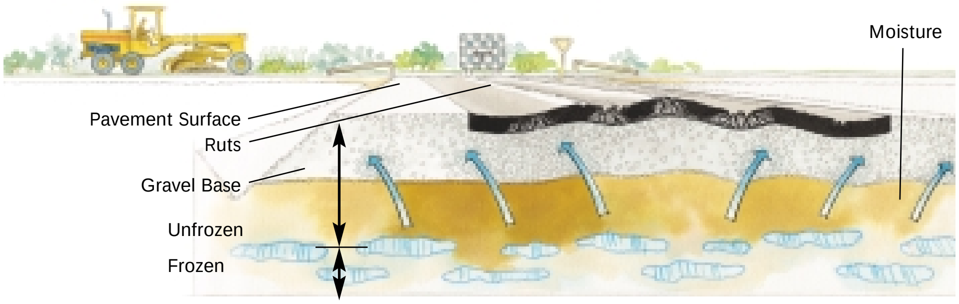
Styrofoam Building Materials

# STYROFOAM Brand Highload Insulation One of man's best laid plans.

## FIGURE 1: FROST HEAVE




## FIGURE 2: SPRING BREAK-UP




Wherever underlying soils are susceptible to frost, roadways will suffer frost heaving and spring break-up. The damaging effects of this frost action play havoc with traffic on major arteries as well as pose a monumental cash outlay to repair year in, year out.

To combat this recurring engineering nightmare, Dow Chemical Canada Inc. introduced the concept of highway insulation in 1959, with the first Canadian installation appearing in 1962.

Essentially this concept required Dow to draw on its resources and develop a rigid board insulation with a combination of properties which would prevent sub-soil frost action. With that, they manufactured STYROFOAM* Brand Highload Insulation, a TYPE 4 extruded polystyrene rigid foam board. When properly installed between the sub-soil and gravel base, STYROFOAM Brand Highload Insulation reduces heat loss from the frost-susceptible subgrade so that frost heaving and spring break-up are held at bay. Since its inception, STYROFOAM Brand Highload Insulation has been successfully reducing frost and thaw damage on countless roadways in Canada, the U.S.A., Japan and throughout Europe. These widescale field applications have also demonstrated that STYROFOAM Brand Highload Insulation is equivalent or better than conventional measures and often more economical than replacing the subgrade with costly non-frost-susceptible base materials.

## HIGHWAY INSULATION IN SEASONAL AREAS

Frost action on roadways is inevitable. This frost action includes "frost heave" and "spring break-up".

"Frost heave" is the upward movement of pavement as a direct result of ice lenses forming in the frost-susceptible subgrade. As freezing starts in the subgrade, a suction force develops and draws water up through the soil to the freezing face. This moisture expands as it freezes, creating more suction. As the process continues and ice lenses are formed, the upward pressure causes heaving in the surface of the pavement.

"Spring break-up" occurs when warm spring temperatures start to thaw the ice lenses from the surface downward. Since the lower soil zones are still frozen, drainage is restricted and super-saturated soil conditions result. The soil's bearing capacity is greatly reduced, forming a very weak foundation that can result in alligator cracking and rutting in flexible pavements. In rigid pavement, cracking develops in the slabs.

## SOLUTIONS TO THE PROBLEM

Three factors are responsible for frost action.

1) Frost-susceptible soil
2) Freezing soil temperatures
3) Water supply at or near the freezing front

To reduce frost action, one or more of these factors must be reduced or removed. Over the years, several different techniques have been found useful in minimizing or alleviating the problem to some degree:

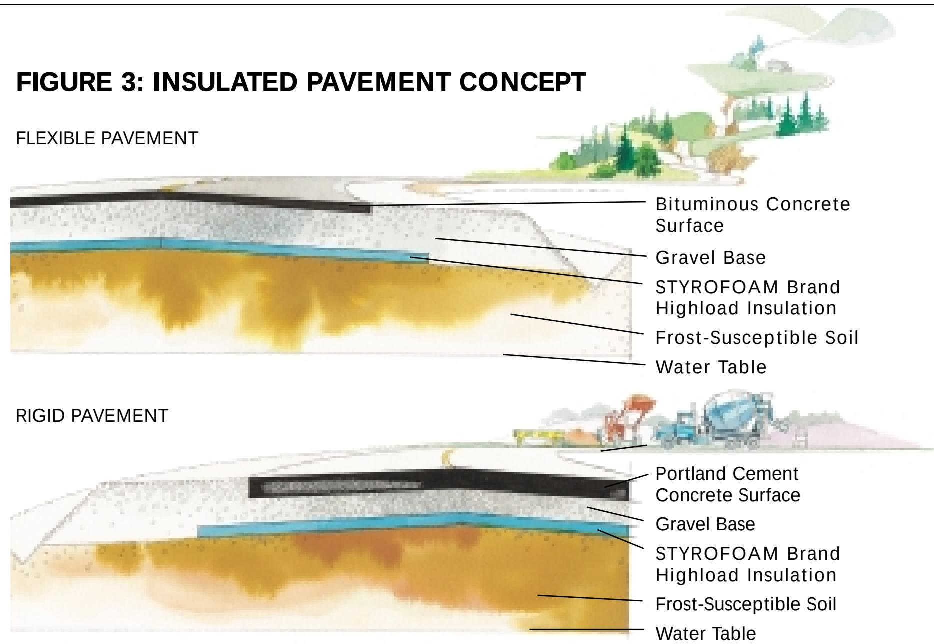
1) Removing pockets of frost-susceptible soil and using extra-thick base courses to spread the load during spring thaw. This can be expensive and may not provide complete protection.
2) Providing adequate drainage for free water through ditching.
3) Placing a layer of insulation in the embankment section to keep subgrade soil temperatures above freezing.



*Trademark licensed from The Dow Chemical Company

The third concept calls for an insulation material, which combines an important range of properties unique to STYROFOAM Brand Highload Insulation. Installed between the sub-soil and gravel base, STYROFOAM Brand Highload Insulation prevents heat loss from the frost-susceptible subgrade so that ice lenses are not formed. Thus, frost heaving and spring break-up are held at bay.

**FIGURE 3: INSULATED PAVEMENT CONCEPT**




## TABLE 1: SPECIFICATIONS

| PROPERTY | METRIC | IMPERIAL |
|---|---|---|
| †Thermal resistance. Minimum R-value or RSI[1] ASTM C-518-91, C-177-85 | 0.87 $(m^{2\circ}C)/w$ | 5.0 $ft^2$ hr°F/BTU |
| Linear thermal coefficient of expansion ASTM D696-79 | 6.3 x $10^{-2}$ mm/m/°C | 3.5 x $10^{-5}$ in/in/°F |
| Capillarity | NONE | NONE |
| Water vapour permeance[1] (max) ASTM E96-90 | 35 ng/Pa•s•$m^2$ | 0.6 perms |
| Water absorption (% by volume) (max)•ASTM D2842-90 | less than 0.7 | less than 0.7 |
| Maximum operating temperature | 74°C | 165°F |

**NOTE:** (1) For 25mm or 1 inch thickness.

## TABLE 2: SPECIFICATIONS

| PROPERTY | Highload 40 | Highload 60 | Highload 100 |
|---|---|---|---|
| Compressive Strength[1] (min) ASTM D1621-73 | 275kPa (40psi) | 415kPa (60psi) | 690kPa (100psi) |
| Tensile Strength (Typical) ASTM D1623-78 (Method A) | 480kPa (70psi) | 590kPa (85psi) | 860kPa (125psi) |
| Shear Strength (Typical) ASTM C273-61 | 275kPa (40psi) | 310kPa (45psi) | 350kPa (50psi) |
| CAN/ULC Classification | CAN/ULC S-701-97 – (Type 4) | | |
| Flexural Strength[2] (Typical) ASTM C203-91 | 480kPa (70psi) | 585kPa (85psi) | 690kPa (100psi) |
| Compressive Modulus (Typical) ASTM D1621-73 | 9650kPa (1400psi) | 15170kPa (2200psi) | 25510kPa (3700psi) |

**NOTE:** (1) At 5% deformation or yield, whichever comes first. Suitable safety factors must be employed to limit long-term creep and fatigue deformation.
(2) For 25mm or 1 inch thickness.

**PRECAUTIONS:** This product is combustible and should be properly installed. For specific instructions, see Dow literature available from your supplier or from Dow.

# DESIGN TECHNOLOGY

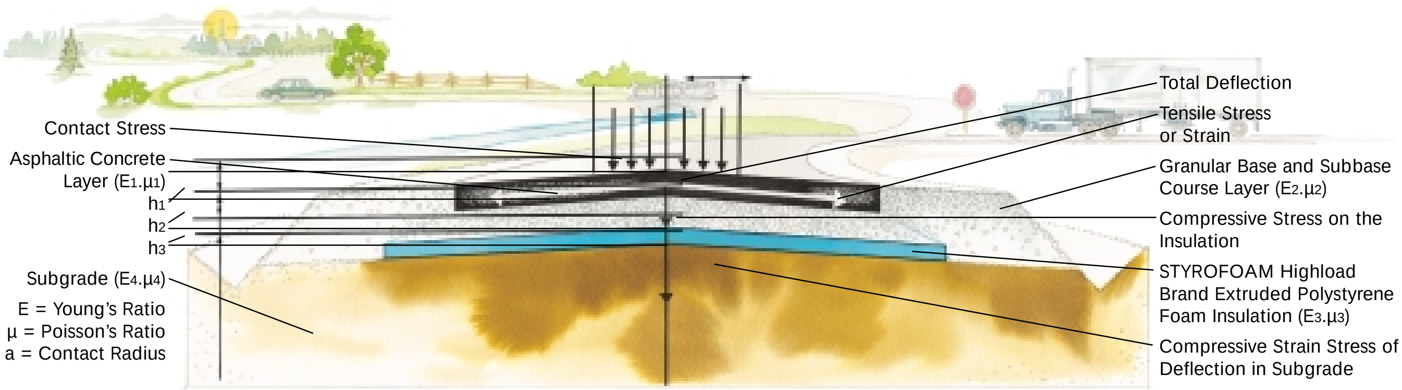
To bring the concept of the insulated pavement to life, Dow developed a structural computer program based on the Elastic Layer Theory, to be used with standard rigid and flexible pavement design methods. The investigation method assigned values of elastic modulus and Poisson's ratio to each pavement layer and subgrade class. Stresses, strains and deflections in the layers were then calculated for a circularly distributed wheel load.

A pavement section was then designed using conventional practices based on loading and soil conditions. By applying the Elastic Layer Theory to the simulation, the resultant stresses, strains and deflections were determined. An insulation layer was then added. By comparing results, along with known fatigue properties of the system, insulated pavement designs were selected which limited stress on the insulation within a reasonable safety factor. It's important to note that where insulation is installed according to a correct design, it eliminates frost action in the subgrade. This excludes the extra material normally used to combat frost action in conventional designs, and the structurally designed section stands as the required pavement thickness.

To determine the thickness and width of insulation required in a section to prevent subgrade freezing, a thermal analysis of the system was necessary. To do this, Dow developed a thermal computer program based on a numerical technique known as the Finite Difference Method. Soil and climatological data were also introduced to determine the insulation thickness. In addition, the Two Dimensional Finite Element thermal program was used in design sections where frost penetration through the embankment sides was critical.

The results of the programs compared favourably with field data gathered from instrumentation of several test sites.

**FIGURE 4: STRESSES AND STRAINS ANALYZED IN A LAYERED STRUCTURE**




As a guide, the computer analyses that have been performed were based on the following data:

## CLIMATOLOGICAL DATA

1) Mean annual air temperature for the site (assumed to be average value for all past years available).
2) Design air thawing index for the site (assumed to be average for all past years available).
3) Design air freezing index for the site (assumed to be the maximum value for any given 10-year period, or assumed to be average of 3 highest values for any 30-year period, if available).

## GEOTECHNICAL DATA

1) Characteristic soil profiles from ground surface to depth of at least 3 metres (10 ft.) – preferably to a depth of 6 metres (20 ft.) where available – below subgrade elevation. Profiles were representative of foundation soil conditions along the route.

   Each profile included strata depths described according to symbols, soil description, terminology and field identification procedures of the United Soil Classification System of the AASHTO System.
2) Measured and recommended best values assumed as bearing capacity indices at subgrade elevation for each soil profile.
3) The range and recommended best values for the in situ dry density and moisture content (expressed as % of dry density) for each subgrade soil stratum.
4) Predicted in-place dry densities and moisture contents of the highway embankment materials.

## HIGHWAY DESIGN DATA

1) Type, thickness, width and description of pavement, base course and sub-base.
2) Design maximum single-axle load limit and tire pressure.
3) Estimated number of heavy trucks per year on design lane and average gross weight of heavy trucks.
4) Design life of highway.

## COST OPTIMIZATION DATA

Comparative non-insulated frost action free design with estimated unit prices for construction.

## HELPFUL BUT NONESSENTIAL DATA

1) Mean annual ground temperature at 0 to 9 metres (0-30 ft.) – depth below ground surface, or best approximation.
2) Depth of frost penetration for a particular soil profile at the site with the mean annual air temperature, air thawing index and air freezing index for the year or years that the depth was determined.

## CONSTRUCTION METHODS

Insulated pavement construction can utilize conventional road-building equipment and techniques.

The subgrade should be shaped and compacted in accordance with normal specifications prior to placement of insulation. On this surface, insulation boards 600mm x 2400mm (24 inches x 96 inches) thickness are placed in staggered fashion with long axis parallel to the centre line and pinned to underlying soil with wooden skewers approximately 150mm x 6mm (6 inches x 1/4 inch) diameter. When placing the first row of board down the highway centre, a stringline is the most convenient way to ensure straight alignment. Placement of boards progresses from the centre out and extends 1.2m (4 ft.) into the shoulder. Care should be taken to obtain tight joints and to stagger all transverse joints.

When going from an insulated to an uninsulated pavement section, a transition zone is required to provide a gradual change in embankment thermal properties. This zone consists of a step-down pattern of insulation thicknesses to allow greater subgrade heat loss at each end of the insulated section. The insulation thickness step-down (or reduction) in these zones is 25mm (1 inch) and each step-down is carried for 4.9m (16 ft.). For example, an insulated pavement employing a 75mm (3 inch) thick STYROFOAM Brand Highload Insulation layer would have two insulation step-downs in each of its transition zones. The insulation would first be reduced to a 50mm (2 inch) thickness for 4.9m (16 ft.) and then reduced to a 25mm (1 inch) thickness for another 4.9m (16 ft.).

## FLEXIBLE PAVEMENT SECTION

In constructing flexible pavements, the insulation is covered by end dumping, spreading, and compacting a granular-material lift to a compacted thickness of 0.15 meters (6 inches) minimum. Coarse aggregate causes no appreciable damage to the insulation surface. Once this layer is compacted to the required density, the strength of STYROFOAM Brand Highload Insulation extruded polystyrene foam allows subsequent lifts of granular material and asphalt concrete to be placed in the normal manner.

NOTE: Care should be taken to prevent vehicles, heavy equipment, etc., from bearing directly on the insulation since damage can result.

## RIGID PAVEMENT SECTION

From the structural aspect of design, concrete slabs can be poured directly on the insulation. However, since the probability of surface icing occurring increases with proximity of insulation to road surface, a base course is often placed on top of insulation before the slab is poured. The phenomenon of surface icing is covered in detail in the "Differential Icing" section of this brochure.

## OVERLAYS

In some cases, instead of building an entirely new pavement, it's more economical to construct an insulated flexible or rigid overlay. In these applications, the appropriate thickness of insulation is placed directly onto the existing pavement and kept in place by bonding it to the pavement with an adhesive, or by placing small piles of granular material on the insulation boards immediately after installation. The properly designed overlay can then be placed on top of the insulation in the same manner described in previous paragraphs.

# DESIGN CHARTS

**FIGURE 5: AVERAGE PENETRATION OF FROST BENEATH STYROFOAM BRAND HIGHLOAD INSULATION IN PAVED HIGHWAYS**

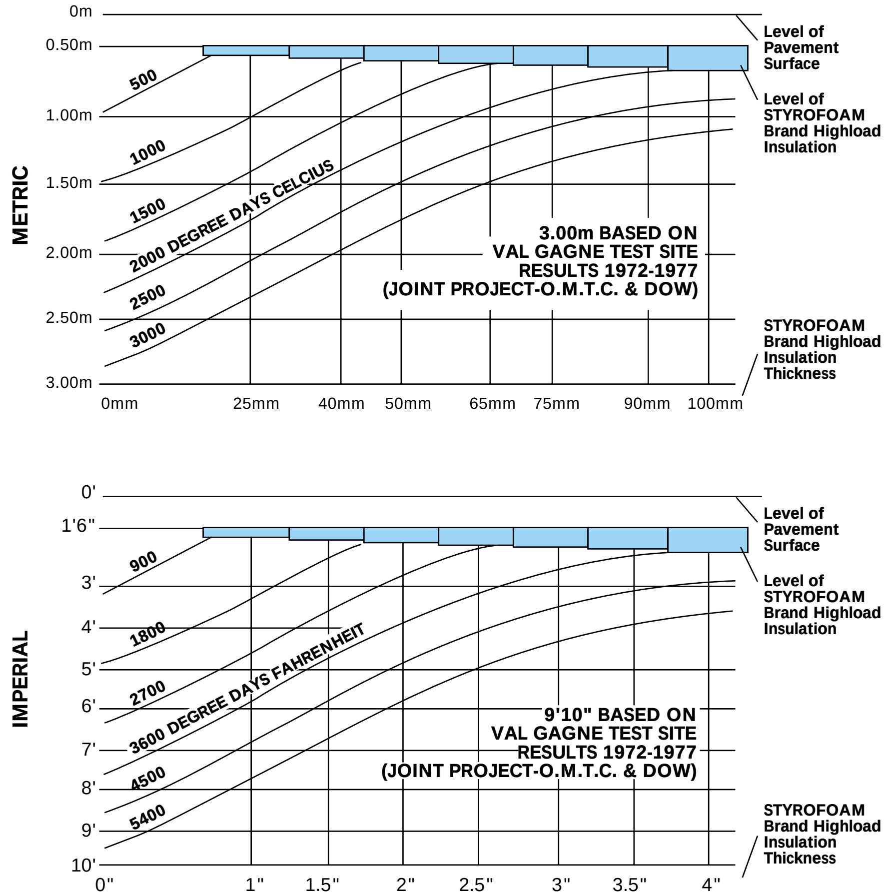
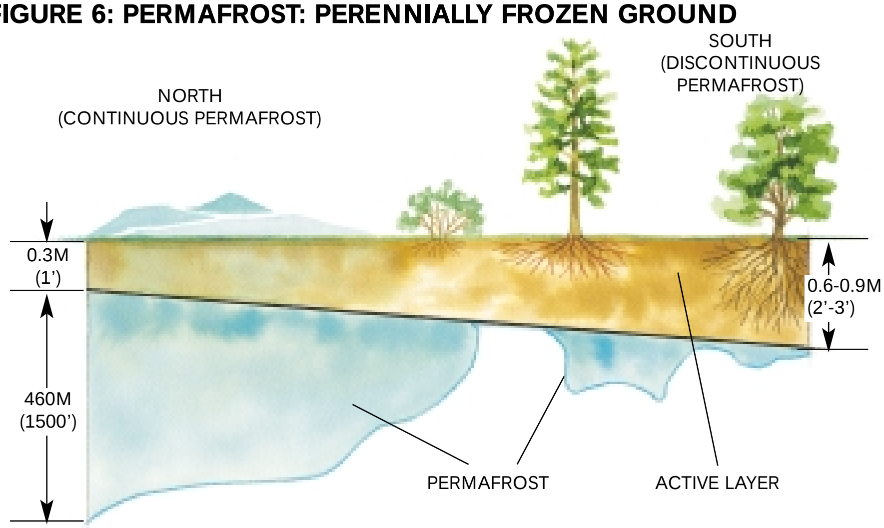



**FIGURE 6: PERMAFROST: PERENNIALLY FROZEN GROUND**




## HIGHWAY INSULATION IN PERMAFROST AREAS

Permafrost is a perennially frozen ground condition, and it can encompass all soil types, from coarse ice to free gravel to clays to silts containing large volumes of ice. When constructing pavements in permafrost areas, engineering problems are thermal problems.

Because the thermal state of the ground can be significantly altered by only minor variations in site conditions, thawing of high-ice-content soils may result, leading to a super saturated soil condition that greatly reduces the load-carrying capacity of the soil. Since the top soil in these cold areas is composed of organic materials, it has extremely poor engineering properties in its thawed state.

## SOLUTIONS TO THE PROBLEM

To overcome these difficulties, the ice-rich soil can either be eliminated during construction or preserved in its frozen state. Eliminating permafrost and replacing it with non-frost susceptible material may be economical in discontinuous zones where there are permafrost pockets of limited size and number. In most cases, however, it's not economical. This is especially true in continuous zones where permafrost is much deeper and widespread. Here, a common procedure is to build an embankment with a sufficient amount of granular material to preserve the permafrost and provide a structurally sound base in order to support summer traffic.

Conventional methods of roadway construction across permafrost only provide a sufficient overlay to support vehicle loadings during the most critical climactic period. This minimum is usually much less than the thickness of granular overlay necessary to prevent degradation of the permafrost. This means that a considerable amount of differential road settling will occur as indicated in Figure 7.

Two current factors increase the potential for using STYROFOAM Brand Highload Insulation for permafrost areas. First, the costs for obtaining non-frost susceptible fill for embankments are increasing. Second, the increasing number of gravel highways being paved with asphalt concrete poses problems of great depth of thaw into permafrost due to the asphalt's heat-absorption properties.

STYROFOAM Brand Highload Insulation is an economical alternative to conventional embankment insulation methods. When placed in the correct location within the embankment, it can prevent the thawing of permafrost during the summer months. This protection enables the frost-susceptible soil to retain the structural properties needed to support traffic as shown in Figure 8.

## CONSTRUCTION METHODS

As in the seasonal areas, construction of an insulated pavement section in permafrost areas can be accomplished with conventional road-building equipment and techniques.

In preparing the subgrade for installation of STYROFOAM Brand Highload Insulation, site clearance should be done by hand to keep disturbance of the ground cover to a minimum. The required sub-base material should then be spread on top of the subgrade with a light crawler-type tractor and compacted to the satisfaction of the engineer.

Installation of boards of STYROFOAM Brand Highload Insulation on this surface follows the same procedure described for seasonal areas. In cases where wooden skewers cannot penetrate to pin the insulation to the underlying frozen sub-base, steel spikes of the same length can be used. The thermal short created by the spikes will cause no appreciable thawing in the sub-base.

**FIGURE 7: CONVENTIONAL EMBANKMENT**

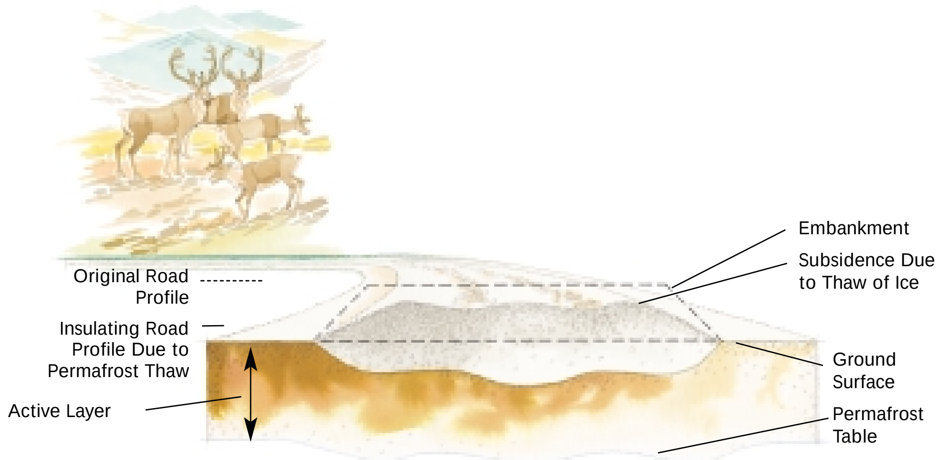
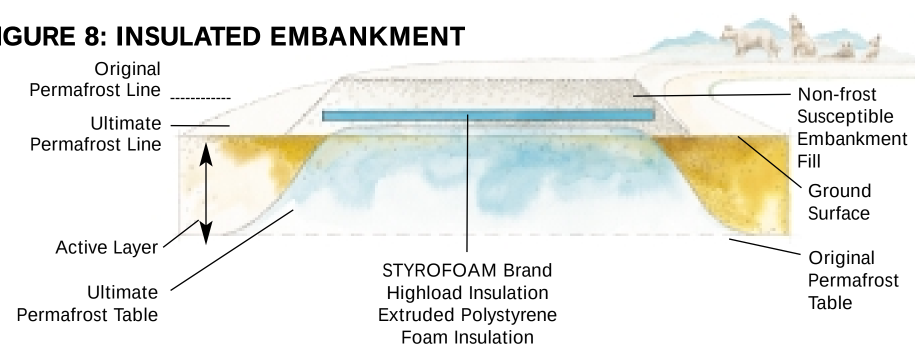



**FIGURE 8: INSULATED EMBANKMENT**



# HISTORY AND DEVELOPMENT

Early in 1959, The Dow Chemical Company and Purdue University undertook a joint investigation of insulated pavements. The University's School of Civil Engineering had considerable basic knowledge on frost penetration in soils. This information was used to further develop a mathematical technique for predicting rate and depth of frost penetration in pavement systems.

Purdue also produced a structural analysis procedure for insulated pavement systems. Dow later developed a thermal analysis method. The combination of these two analytical methods into the computer design programs is described in greater detail in the "Design and Technology" section.

Extensive laboratory evaluations of many insulation materials and their findings led researchers to select STYROFOAM Brand extruded polystyrene foam as uniquely qualified to meet all requirements. From that base, STYROFOAM Brand Highload Insulation was specially developed for highway insulation. This extruded foam has a dense, tough surface skin. It possesses very high compressive strength and very high thermal resistance. It has low water absorption, it will not sustain mould growth or decay, and it has no food value for plant or animal life. These permanent properties together with ease of handling and installation make STYROFOAM Brand Highload Insulation ideally suited for use in a soil environment beneath a highway.

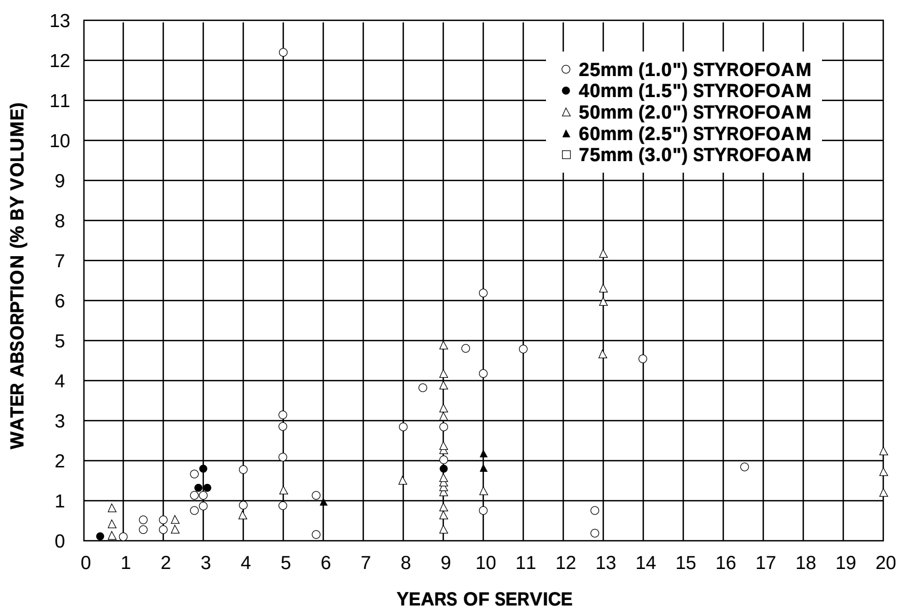
Since inception in 1962, a number of test sites have been continuously monitored. This data is used in studies for refining the procedure and techniques of highway insulation.

## PERFORMANCE

In order to measure how the properties of STYROFOAM Brand Highload Insulation react to prolonged periods of use, comprehensive testing has been done in the field and in laboratory simulations.

Two basic types of laboratory tests were performed to project the long-term thermal performance of STYROFOAM Brand Highload Insulation. The first was a simple soaking test. Samples of the insulation were submerged for varying time periods and then removed to monitor their properties. Test results showed very little water pickup and very little reduction in thermal resistance. Next came an accelerated freeze/thaw test which showed very little increase in water pickup and reduction in thermal resistance after extensive freezing and thawing.

**FIGURE 9: WATER ABSORPTION VS YEARS OF SERVICE FOR CANADIAN AND U.S. HIGHWAY FIELD INSTALLATIONS**



Moisture absorption performance was also examined under field conditions. Samples of STYROFOAM Brand Highload Insulation were taken from various highways after several years service. Again, very little moisture pickup was recorded. These test results are displayed in Figure 9 where the insulation's water pickup is shown as a function of the years of service.

The results in Figure 9 are excellent for the type of STYROFOAM Brand Highload Insulation used in the past. However, current grades of STYROFOAM Brand Highload Insulation have improved properties, including lower water absorption and a thermal resistance value of: RSI = 0.87 (R=5.0).

STYROFOAM Brand Highload Insulation has also been subjected to continuous and repeated load application tests to simulate dead and live loading conditions found in the field. From these tests and others, the creep (long term deformations due to dead loads) and fatigue (long term deformations due to live loads) lives of STYROFOAM Brand Highload Insulation were established. Dead loads on STYROFOAM Brand Highload Insulation should be limited to one third of the rated compressive strength of the insulation product. Allowable live load stresses on STYROFOAM Brand Highload Insulation depend on the number of repeated loads expected. For less than $10^3$ loadings, design so that the stress on the STYROFOAM Brand Highload Insulation does not exceed one half the rated compressive strength of the insulation. For $10^6$ load cycles, design to one eighth of the rated compressive strength; for $10^8$ load cycles, use one tenth of the rated compressive strength to limit fatigue deformation. More information on the creep and fatigue properties of STYROFOAM Brand Highload Insulation can be obtained from your Dow Sales Representative.

## PERFORMANCE OF INSULATED HIGHWAYS

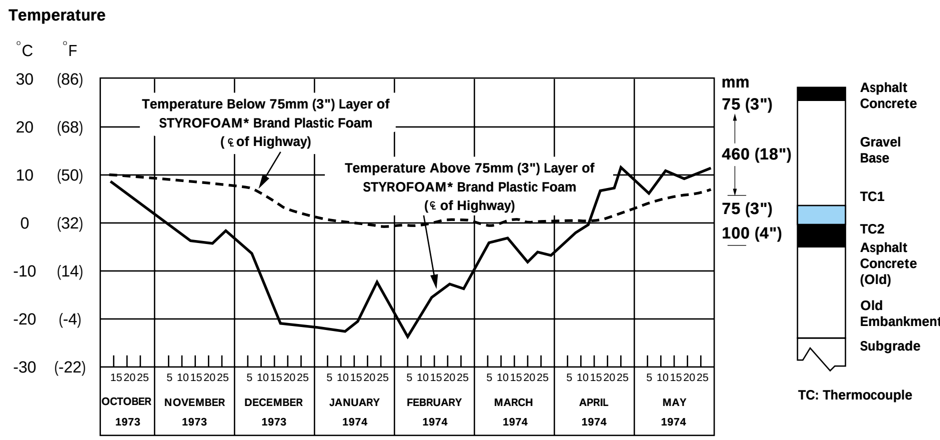
To show the type of overall performance that can be expected of insulated roadways, data from one seasonal and one permafrost test section typify the success of STYROFOAM Brand Highload Insulation.

The seasonal region test for a highway in Val Gagne, Ontario, is demonstrated in Figure 10. As the graph shows, very little freezing took place below the STYROFOAM Brand Highload Insulation. In this case, no frost action occurred in the frost-susceptible subgrade.

These results typify the performance of foam-insulated highways in seasonal areas.

### FIGURE 10: THERMAL PERFORMANCE OF AN INSULATED PAVEMENT IN A SEASONAL AREA[1]

**VAL GAGNE, ONTARIO, 1973-1974 AIR INDEX = 2100 DEGREE-DAYS C. (3780 DEGREE-DAYS F.)**



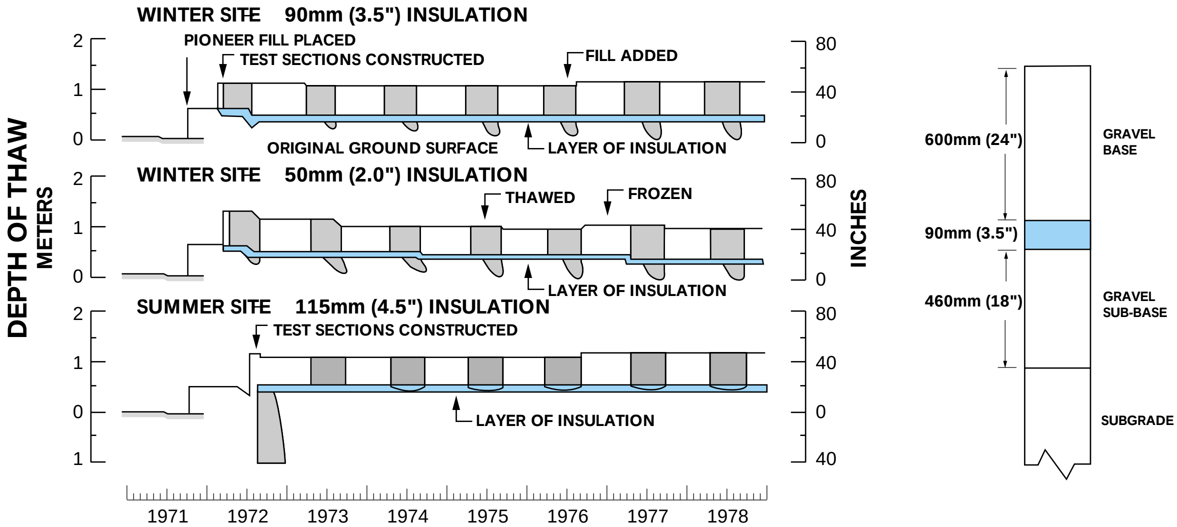
To demonstrate the thermal performance of an insulated highway embankment in the permafrost region, a test site was installed near Inuvik, N.W.T. Figure 11 shows that results from this site compare favourably with early predictions and calculations. They indicate that, in properly designed insulated pavement sections, the sub-grade will remain frozen throughout the warm summer months.

The structural performance of a highway insulated with STYROFOAM Brand Highload Insulation in a seasonal area was studied using Benkelman beam deflection tests.

An examination of the data acquired from these tests shows the fall deflection of the pavement is slightly greater in the insulated section than in the control. However, deflections in the control increased significantly during the spring thaw indicating a loss of subgrade support. During this same period, deflections in the insulated sections remained well below those in the control and showed only a slight increase over the fall values.

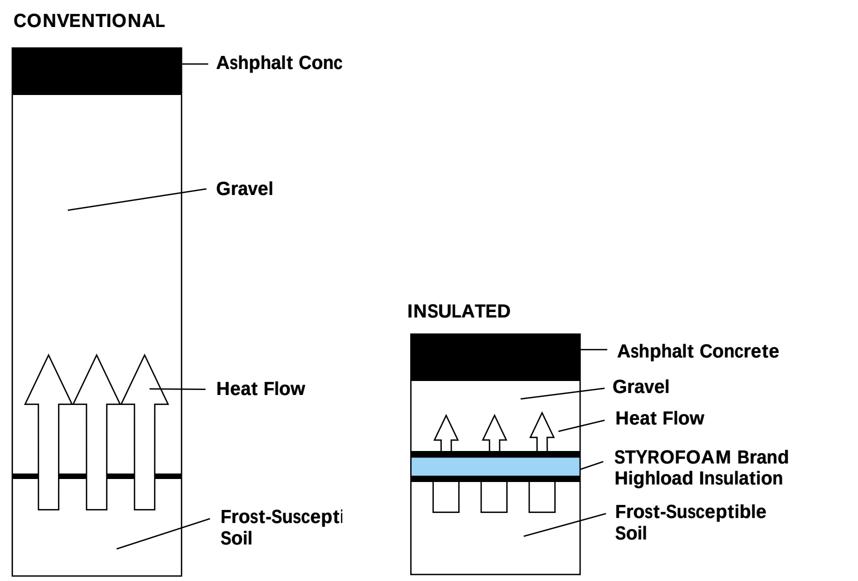
## FIGURE 11: THERMAL PERFORMANCE OF AN INSULATED EMBANKMENT IN A PERMAFROST AREA[1]

INUVIK N.W.T. 1971-1978 AIR FREEZING INDEX = 4690 DEGREE-DAYS C. (8442 DEGREE-DAYS F.)




(1) DATA PROVIDED BY INTERDEPARTMENTAL COMMITTEE ON HIGHWAY INSULATION.

## FIGURE 12: WINTER HEAT FLOW IN CONVENTIONAL AND INSULATED PAVEMENT SECTIONS



# DIFFERENTIAL ICING

Introducing insulation into the design of a highway embankment has the effect of controlling the sub-soil thermal regime as shown in Figure 12. However, this insulating layer also alters temperature distribution in the embankment section above the insulation. This can result in warmer or colder pavement surface temperatures in an insulated highway section, compared to those on adjacent non-insulated sections. This temperature difference between insulated and non-insulated pavement sections allows one surface to support formation of ice while the adjacent surface does not.

This discontinuous or "differential" icing phenomenon also occurs over conventional non-insulated highways in practically all areas subject to freezing and thawing conditions. Its frequency largely depends on meteorological conditions and the thermal properties of the highway section. As yet, no practical basis has been established so quantitative frequency predictions can be made in insulated or non-insulated sections.

## SUGGESTED WAYS OF REDUCING DIFFERENTIAL ICING

1) Lowering the insulated foam in the pavement section to allow for a thicker cover to act as a heat sink over the foam.
2) Putting in thinner sections of insulation to allow more heat to pass through the insulation during critical times.

## SUGGESTED PRECAUTIONS

It is suggested that an insulated section should not be started in the following locations:

1) The middle of a curved portion of the road.
2) At the top of a hill.
3) Near a major intersection.
4) Near a railroad crossing.

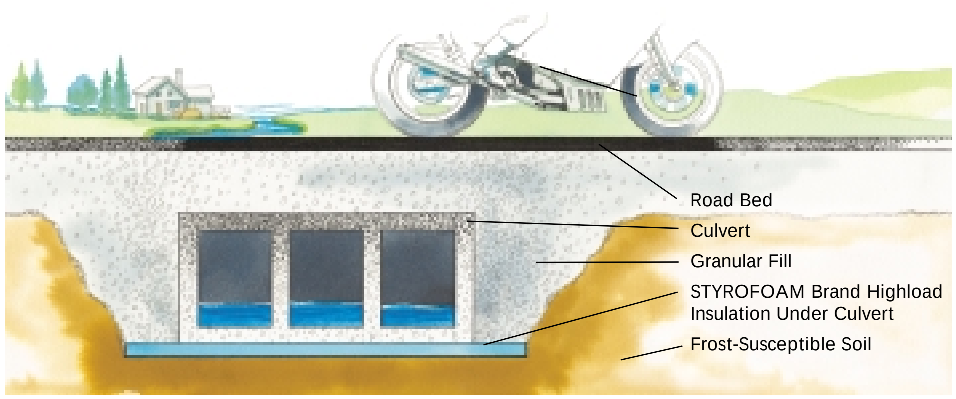
Differential icing is not confined solely to intermittently insulated highways. It can occur on bridges, overpasses, shaded areas, areas of severe wind exposure, and where abrupt changes in soil and ground-water conditions occur.

## OTHER APPLICATIONS

STYROFOAM Brand Highload Insulation has been field tested and found effective for numerous other applications. One is the insulation of culverts. Cold air blowing through the culvert in the winter can freeze the soil, severely damage the culvert, and create a bump in the pavement surface above. Differential heaving at a culvert or any other drainage structure crossing the roadway pavement can be minimized or alleviated by the use of STYROFOAM Brand Highload Insulation as shown in Figure 13.

Other insulation applications include: airport pavements, railroad beds, embankment lightweight fill, shallow buried utility lines, foundations, and transmission line towers.

**FIGURE 13: TYPICAL INSULATED CULVERT**



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