

INSULATION PERFORMANCE BENEATH ROADS AND
AIRFIELDS IN ALASKA

December 1986

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ABSTRACT

In 1968 the Alaska Department of Highways constructed its first experimental installation of expanded plastic foam for frost heave control at a site 11 miles south of Anchorage. This was followed, in 1969, by construction of both the first insulated roadway section over permafrost in North America at a site near Chitina, and the first insulated airfield runway at Kotzebue. Since that time, six additional roadway sections on permafrost, totalling 3.6 lane-miles, have been insulated by the Alaska Department of Transportation, along with four additional airport installations. Applications of insulation for frost heave control have been numerous, totalling 11 lane-miles. Materials used for subgrade insulations have been primarily extruded-expanded polystyrene foam (Dow's Styrofoam HI and UCI Foamular) with one installation of polyurethane foam and three of molded polystyrene "beadboard."

Evaluations of the long-term thermal performance of these installations have included sampling and testing of the insulations to determine the retained thickness, thermal conductivity, and compressive strength properties. Based on these observations, foamed-in-place polyurethane insulation is not accepted for use as a subgrade insulation by the Department of Transportation, while extruded polystyrene insulation has demonstrated superior performance and longevity. Molded polystyrene beadboard insulation layers have given acceptable performance, but must be installed at a thickness 30 to 50% greater than the extruded polystyrenes to provide comparable thermal performance.

Comparisons were made between measured late summer permafrost thaw depths for insulated airfields, and calculated thaw depths using the "Modified Berggren" calculation method and actual site soil and insulation properties. These comparisons demonstrated that this method of calculation results in calculated thaw depths slightly greater than the actual values, but provides reasonable values for a conservative design.

INTRODUCTION

In 1967 the Alaska Department of Highways constructed its first experimental installation of expanded plastic foams for frost heave control, at a site 11 miles south of Anchorage. This was followed, in 1969, by construction of both the first insulated roadway section over

permafrost in North America at a site near Chitina, and the first insulated airfield runway at Kotzebue. Since that time, six additional roadway sections on permafrost have been insulated by the Alaska Department of Transportation, along with three airport runways and one taxiway. Applications of insulation for frost heave control have been numerous, particularly in the Anchorage-Wasilla area where varying glacial deposits can result in severe differential frost heaving. Insulation layers are also frequently used beneath roadway crossings of buried water and sewer lines and subdrain systems. Materials used for subgrade insulations have been primarily extruded-expanded polystyrene foam (Styrofoam HI and UCI Foamular 400) with one installation of polyurethane foam and three of molded polystyrene "beadboard".

To evaluate the long-term thermal performance of these installations, air and gravel temperature monitoring instrumentation, consisting of thermocouples, thermistors, and chart recorders were installed at five sites. Temperatures have been monitored on a monthly basis for various periods at the different sites, the longest period being 16 years at the Chitina permafrost site. In September of 1984 insulation samples were taken from selected road and airfield sites and tested for thermal conductivity and moisture absorption to analyze their long-term performance. At the permafrost insulation sites, soil moisture contents and thaw depths were also measured. Thaw depth calculations were then made by the Modified-Berggren calculation method to compare predicted versus actual thaw depths.

Insulated Embankment Sites

Roadway and airfield insulation sites constructed by the Alaska Department of Highways/Transportation to control frost heaving or permafrost thaw settlements are listed in Tables 1 & 2 and locations are shown by Figure 1.

Table 1: Anchorage Area and Parks Highway - Frost Heave Control Sites

Year Built	Site or Route	Specific Location	Insulation Type	Thick-ness Inches	Cover Depth Inches	Length Lane Miles
1968	Seward Hwy	MP 114.9	FIP Urethane	2	18	0.036
1968	Seward Hwy	MP 115.1	Styrofoam HI	3	18	0.042
1970	Parks Hwy	MP 75.0	Styrofoam HI	4	18	0.055
1970	Parks Hwy	MP 84.2	Styrofoam HI	4	18	0.097
1971	New Seward	Tudor-East	Styrofoam HI	3	24	0.909
1971	Talkeetna Spur	MP 9.3	Styrofoam HI	3	18	0.170
1971	Parks Hwy	MP 117.0	Styrofoam HI	4	18	0.776
1975	Minnesota Drive	15 ST. Jct.	Styrofoam HI	4	27	0.076
1975	New Seward	Tudor-East	Styrofoam SM	3	24	1.310
1978	Parks Hwy	MP 36.7	Styrofoam HI	4	60	0.110
1981	Minnesota Dr.	At Dimond	Sty. Beadboard	4	24	0.760
1983	Northern Lights	Goose Lake	Styrofoam, HI	4	44	0.833
1984	Minnesota Ext.	At Dimond	Sty. Beadboard	4	36	2.340
1985	A-Street	@ 23 St.	Styrofoam HI	4	47	0.303
1985	A-Street	@ 15 St.	Styrofoam HI	4	47	0.530
1984	Parks Hwy	Panguingue	Styrofoam HI	4	24	0.038
1986	Parks Hwy	293.4-297	Foamular 400	2&4	42	2.650

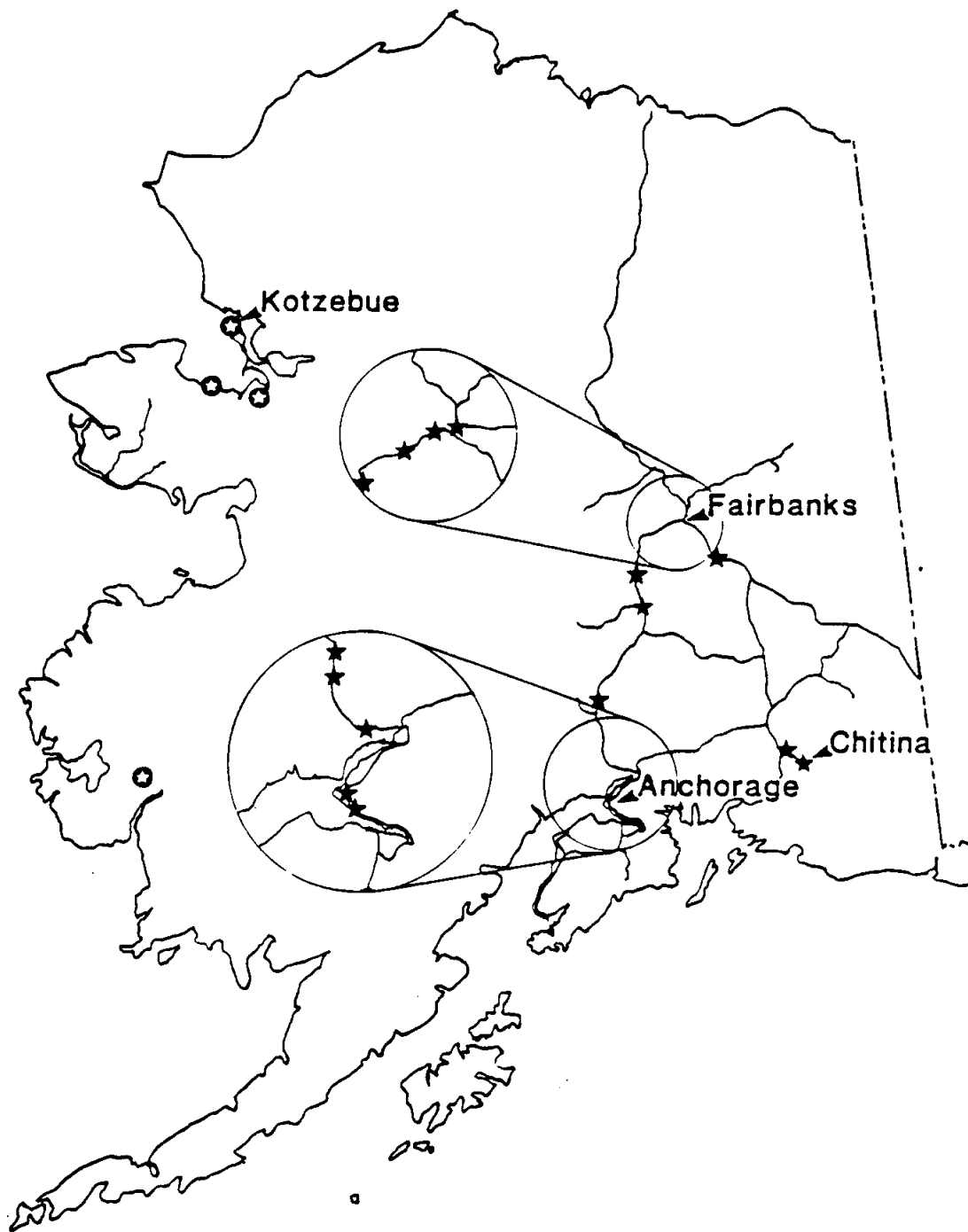


Figure 1: Locations of Insulated Roadways (★) and Airfields (⊙) Constructed by Alaska Department of Highways and Department of Transportation

Table 2: Permafrost Insulation Sites

Roadway Permafrost Thaw Control Sites

Year Built	Site or Route	Specific Location	Insulation Type	Thickness Inches	Cover Depth Inches	Length Lane Miles
1969	Chitina N.	MP 27	Styrofoam HI	2&4	60	0.070
1973	Parks Hwy	MP 231.8	Styrofoam HI	4	54	0.170
1974	Parks Hwy	Alder Ck. S.	Styrofoam HI	4	54	0.125
1974	Parks Hwy	Alder Ck. N.	Styrofoam HI	4	120	0.072
1979	Farmer's Loop	Fairhill Rd.	Poly. Beadboard	4	48	0.077
1985	Canyon Creek	Rich. MP 299	Styrofoam HI	3	33	1.061
1986	Edgerton Hwy	MP 1.3-7.0	Styrofoam HI	2	42	2.080

Insulated Airfield Runways on Permafrost

1969	Kotzebue Airport	Styrofoam HI-35	4	42	1900'
1981	Buckland Airport	Styrofoam HI-35	6	36	2400'
1981	Deering Airport	Styrofoam HI-35	2	30	2700'
1985	Nunapitchuk Airport	Styrofoam HI-60	6	30	2750'
1985	Deadhorse Taxiway B	Styrofoam HI-60	2	56	360'

GENERAL SITE PERFORMANCE OBSERVATIONS

Frost Heave Sites

The first sites insulated in 1967 for frost-heave control were monitored for 3 years and their performance was documented (Esch, 1968, 1970). The basic conclusions of this work were that the foamed-in-place polyurethane insulation used was not adequately resistant to water absorption, even when coated with asphalt, and it was not recommended for further roadway insulation applications. The extruded polystyrene, however, performed very well and was recommended for future frost heave control applications. For these instrumented sites, the Modified Berggren calculation method predicted freeze depths beneath the insulation with reasonable accuracy with a tendency to slightly overpredict these depths for thick insulation layers. This study also demonstrated that the full extent of the frost heave problem area must be known prior to designing the length of the insulation section, to avoid creating heave bumps at the ends of the insulation. Based on data from these sites, a composite thermal design approach is recommended, with specified thicknesses of non-frost susceptible gravels or sands placed above and below the insulation layer. By allowing freezing to penetrate into gravel fill placed beneath the insulation, the most economical design can be achieved. A depth of cover of at least 18

inches of gravel and pavement above the insulation is recommended to provide tolerable wheel load stresses on the insulation. The problem of differential frost formation on the road surface in insulated areas is lessened by increased depths of burial.

As shown by Table 1, the depth of cover over frost heave insulation has varied from 1½ to 5 feet. Surface frost forms more quickly on bridge decks and above insulated areas than on normal road structures. The resulting decreases in traction have recently (1985) been treated by installing rubber-modified asphalt pavement surfacing above the insulated areas at the A-Street, New Seward at Tudor, and Canyon Creek sites. The benefits of this pavement type have been investigated by Esch (1982). If this treatment proves successful in eliminating icing problems, it may permit cover depths above the insulation to be reduced to the 18 inch minimum required by stress considerations.

Permafrost Sites

The Chitina insulated road site, constructed in 1969 over relatively warm (+30°F) permafrost, has generally performed very well, with full annual refreezing of the soils beneath the roadway and a long term sub-roadway permafrost temperature of 31.0 to 31.5°F. However, the gravel side-slopes of the embankment, which are insulated by snow in winter and exposed to direct sunlight in summer, have caused progressively deeper annual thawing, averaging about three inches per year into the permafrost beneath the slopes. This has resulted in progressive slope sloughing and cracking in the shoulder areas (Esch, 1973). By comparison, the adjacent uninsulated roadway areas have continued to settle annually at a rate of 0.1 to 0.2 feet per year. Side-slope thawing movements have been similar in insulated and uninsulated areas, and some settlements related to stress-related creep of the warm permafrost foundation soils continue to be noted in all areas of this roadway.

The performance of most other insulated permafrost roadway sites has been similar to that at Chitina, with full annual refreezing occurring beneath the insulated, travelled roadway area, but progressively deeper annual thawing and related movements of the side-slope areas.

Cover depths used over permafrost insulation layers tend to be greater than for frost heave control, primarily because of construction traffic considerations. Permafrost insulation has generally been designed based on borings and installed during embankment construction. The heavy construction equipment used requires care to avoid crushing. By contrast, frost heave insulation sections have nearly always been designed as corrective measures for heaves on existing roads, where minimizing the depth of excavation is of major concern.

FIELD SAMPLING AND INSULATION TESTING PROGRAMS

Insulation sampling and testing to measure moisture absorption and compression under field conditions has been done at various times and locations to verify the field performance of the buried insulation layers.

Polyurethane Foams

The most extensive testing of polyurethane road insulation samples was in September of 1972 at an Arco Chemical road test site near Prudhoe Bay. At that location, urethane foam board samples taken from beneath a permafrost area roadway, after 2 years of exposure on a wet tundra foundation, demonstrated moisture contents as high as 30% by volume or 1000% by weight of the dry foam. Unfortunately, data from this polyurethane field test and sampling program were never published because of the unexpectedly poor insulation performance. This investigation was followed in March of 1979 by a foamed-in-place urethane insulation sampling program at the Potter frost heave insulation test site located near Anchorage (Esch, 1971).

At Potter, several samples were obtained from the wheelpath areas after twelve years of insulation exposure to traffic and environment. In addition, two samples were obtained from an extension of the urethane insulated area, placed in 1974. Six representative samples of the 1967 insulation were tested for absorbed moisture and had total moisture contents, calculated as percent water by volume, ranging from 3.1 to 72.0%.

Thickness measurements were made in many locations which were believed to be within the original (1968) two-inch insulation area; and an average thickness of approximately 0.9 inches was noted. No foam thicker than 1.2 inches could be found. Exact thickness comparisons are not possible because of the somewhat random thickness obtained from in-place foaming of urethanes, but measurements at the time of placement indicated an average thickness very close to two inches. Many areas of thickness as low as $\frac{1}{2}$ inch were noted, and foam in these areas was generally nearly saturated. This foamed-in-place urethane had an average compressive strength of 31.5 psi when placed in 1967. All data indicate that this foam insulation failed by moisture absorption and compression under field service.

By contrast to the generally compressed and relatively wet state of the 1968 urethane foam, the samples from the 1974 extension appeared to be in excellent condition, maintaining some hope that polyurethane foams may perform reasonably well under direct soil burial conditions. Two samples of this insulation had dry densities of 2.0 and 2.1 pcf, absorbed water contents of 1.3 and 1.0% by volume, and average compressive strengths of 28.1 and 26.3 psi at 5% strain. The strength and moisture properties of this product appeared satisfactory for acceptable performance in direct burial. Unfortunately, this entire test site was excavated in 1979 so the long-term performance of this material could not be followed. The reasons could not be determined for the good performance of this foam as compared to the failures of the two urethanes previously mentioned.

Polystyrene Foams

Field samples of in-service polystyrene subgrade insulations were taken in September of 1984 from various road and airfield sites in Alaska. Samples were typically taken from hand-dug test pits located at the edge of the asphalt pavement. All samples were sealed in ziplock bags and subsequently tested for moisture absorption and wet thermal

conductivity, using the thermistor bead technique detailed by Atkins (1983).

In this method a single thermistor bead, approximately .04 inches in diameter, is inserted into the insulation board and a controlled electrical current is applied to cause resistance heating of the thermistor. Periodic readings are taken of temperature rise versus time, from which the thermal conductivity can be calculated. Multiple readings at various depths within a foam sample are used to obtain a profile of conductivity versus depth, from which an average value is calculated. Results are consistent and agree well with the more precise laboratory "guarded hot plate" method.

Two of these sites, the Fairbanks area "Fairhill Access Road", constructed in 1979, and Anchorage's "Minnesota Extension - Phase I", constructed in 1981, contain white polystyrene beadboard, with a compressive strength greater than 30 psi. This product is molded in blocks from pre-expanded foam beads. The remaining sites all were insulated with blue "Styrofoam HI" insulation which is foamed in an extrusion process. Results of all testing are included in Table 3 and averages for each site are shown on Figure 2.

Table 3: Polystyrene Insulation Test Results

Site	Layer	Thickness	Foam Insulation			Kavg.	Year Placed
			Density (pcf)	Type	% Water/Vol		
Kotzebue	Top	2"	2.39	E	2.38	0.214	1969
Kotzebue	Bottom	2"	2.14	E	0.89	0.194	1969
Buckland	Top	3"	2.26	E	0.41	0.204	1981
Buckland	Bottom	3"	2.10	E	0.23	0.208	1981
Deering	Single	2"	2.16	E	1.37	0.204	1981
Chitina	Top	2"	2.56	E	0.71	0.237	1969
Chitina	Bottom	2"	2.63	E	0.88	0.225	1969
Chitina	Single	2"	2.63	E	1.54	0.216	1969
Bonanza Creek	Single	2"	2.24	E	1.48	0.247	1974
Bonanza Creek	Single	2"	2.83	E	2.38	0.248	1974
Fairhill	Single	4"	2.44	BB	1.18	0.278	1979
Fairhill	Top	2"	2.17	E	0.50	0.222	1979
Fairhill	Bottom	2"	2.27	E	0.20	0.213	1979
Fairhill	Single	4"	2.98	BB	1.48	0.289	1979
Minnesota Dr.	Top	2"	2.46	BB	5.88	0.358	1981
Minnesota Dr.	Bottom	2"	2.71	BB	2.90	0.266	1981
Geneva Woods	Single	3"	---	E	0.64	---	1970
Geneva Woods	Single	3"	---	E	0.53	---	1970

Type E = Extruded Expanded Foam
 Type BB = Molded and Cut Beadboard Foam

The "best-fit" trend lines (Figure 2) showing the relationships between moisture content and thermal conductivity for both extruded and molded foam boards were found to be in excellent agreement with other data from laboratory tests at higher moisture contents. All samples were within 5% of the nominal thickness, indicating that compression and creep with time is not a problem.

The extruded Styrofoam insulation board, sampled from six sites with a maximum age of 15 years and averaging 9.5 years of service, had an average moisture content of 1.16% by volume. Thermal conductivities (K) of these samples average 0.22 Btu-in/hr-ft²-°F at 72°F. Maximums were a moisture of 2.38% and a K of 0.248. By comparison the molded beadboard samples, from sites three and five years old, had an average

moisture of 2.9% and an average K-factor of 0.30. Maximum values for the beadboard were 8.7% moisture and a K of 0.42. When analyzed by a standard statistical approach, the long-term minimum R-values per inch expected at the 95% confidence level, are 3.9 for extruded polystyrene foam and 2.6 for high-strength molded polystyrene beadboard. This results in a thickness ratio for equivalent performance of 1.5 inches of molded to 1.0 inches of extruded foam. If this ratio is based on average rather than minimum R-values, a thickness ratio of 1.36 to 1 is indicated; however, a ratio this low would be unfair to extruded foams, which are more consistent and better able to resist moisture gains and R-value losses with time in service.

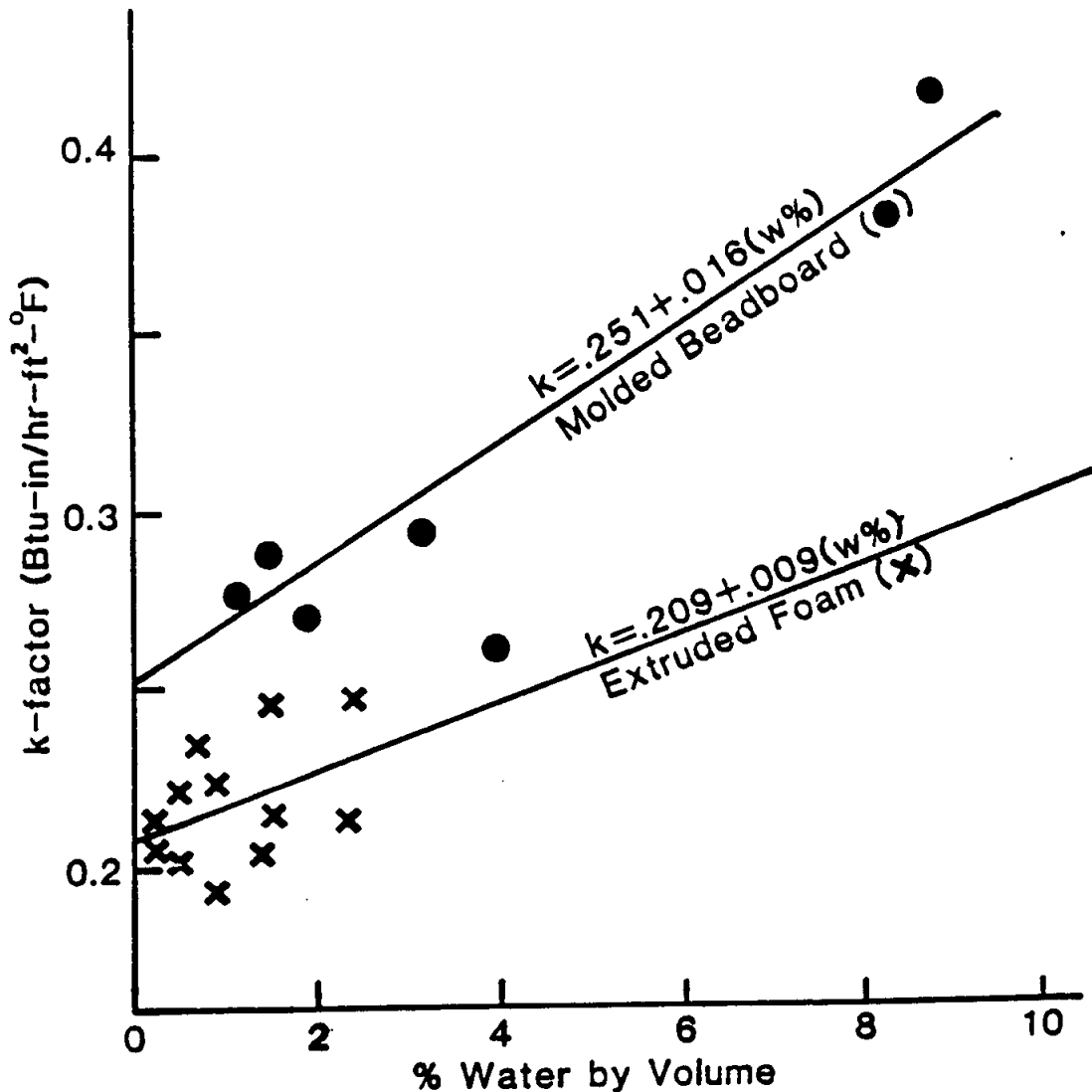


Figure 2: Moisture Contents and Thermal Conductivities at 72°F of In-Service Polystyrene Insulation Samples from Roads and Airfields in Alaska

THAW DEPTHS - INSULATED AIRFIELDS ON PERMAFROST

Observations of the thaw depths were made between September 4 and 6 of 1984 at the three insulated airfields investigated in this study, and soil moisture contents were measured at intervals to permit comparisons between thaw depth prediction methods and actual field values.

Thaw depth calculations were made for each of these runways using the actual measured soil and insulation properties, the Modified-Berggren calculation method as programmed by Braley, (1984), the recorded Kotzebue air thawing index of +1480°F-days, and surface n-factors of 1.70 for Kotzebue (paved) and 1.30 for the other (unpaved) sites. These calculations over-predicted the thaw depths by 0.2 to 0.5 ft, as shown by Table 4, indicating that this calculation method is conservative for designing insulation layers on cold (T > 30°F) permafrost.

Table 4: Measured and Predicted Total Thaw Depths for 1984 for Insulated Airfields on Permafrost. Predictions based on "Modified Berggren" Calculation Method Using Measured Soil Moistures and Insulation Thermal Properties

Site	Thawing Index (F-Days)	Surface N-Factor	Insulation Depth	Measured Thaw Depth (ft)	Predicted Thaw Depth (ft)
Kotzebue	1480	1.70	3.5'	4.7'	4.9'
Buckland	1480	1.30	3.3'	3.8'	4.3'
Deering	1480	1.30	2.3'	2.8'	3.2'

Summary

Since 1967, the Alaska Department of Transportation has insulated a total of 9.9 lane-miles of roadways and 9,750 feet of airfield runway, to control frost heaving and permafrost thawing. Insulation materials used have included foamed-in-place polyurethanes, molded polystyrene "beadboard", and extruded-expanded polystyrene foam.

Polyurethane foams have varied greatly in field performance, with high moisture absorption and compression failure noted at two of three sample locations. For this reason Polyurethane foams are not presently accepted by the Alaska Department of Transportation for use beneath roads or airfields.

Based on observations from field sampling of the insulations after various exposure periods, the superiority of extruded-expanded polystyrene foam is evident after as much as 15 years in service. Molded Polystyrene beadboard products, evaluated after 3 to 5 years of service, were somewhat less resistant to moisture absorption in the sub-roadway environment. To provide equivalent long-term thermal performance under soil burial conditions, beadboard insulation thicknesses should be 30 to 50% greater than extruded foam thicknesses. When installed beneath roads and airfields, the functional design life of extruded foams is projected to be much greater than 20 years.

References and Bibliography

- Atkins, R.T. (1983). "In-Situ Thermal Conductivity Measurements", Alaska DOT&PF Report FHWA-AK-RD-84-06.
- Braley, W.A., (1984). "A Personal Computer Solution to the Modified Berggren Equation", Alaska DOT&PF Report AK-RD-85-19.
- Dechow, F.J. & Epstein, K.A. (1982). "Laboratory and Field Investigations of Moisture Absorption and its Effect on Thermal Performance of Various Insulations", STP 660, ASTM, pp. 234-260.
- Esch, D.C. (1982). "Construction and Benefits of Rubber-Modified Asphalt Pavements", Transportation Research Record 860, pp. 5-13.
- Esch, D.C. and Jurick, R. (1980). "Construction History of Permafrost Insulation with Polystyrene Beadboard - Fairhill Frontage Road", Alaska DOT&PF Interim Report.
- Esch, D.C. and Rhode, J.J. (1977). "Kotzebue Airport Runway, Insulation over Permafrost", Proc. 2nd International Symposium on Cold Regions Engineering, University of Alaska, pp. 44-61.
- Esch, D.C. (1973). "Control of Permafrost Degradation Beneath a Roadway by Subgrade Insulation", Proceedings, Permafrost - Second International Conference, pp. 608-622.
- Esch, D.C. (1971). "Subgrade Insulation for Frost Heave Control", Alaska DOT&PF Research Report.
- Kaplar, C.W. (1978). "Effects of Moisture and Freeze-Thaw on Rigid Thermal Insulations; A Laboratory Investigation", Proc., ASCE Cold Regions Specialty Conference - Applied Techniques for Cold Environments, pp. 403-417.
- McFadden, T. (1986). "Effects of Moisture on Extruded Polystyrene Insulation" Proc. ASCE Cold Regions Specialty Conference, Anchorage, Alaska.
- Tobiasson, W. and Ricard, J. (1979). "Moisture Gain and its Thermal Consequences for Common Roof Insulations", Proc. 5th Conference on Roofing Technology", U.S.A.-CRREL.