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Long Term Evaluation of Insulated Roads & Airfields in Alaska

Prepared by: David C. Esch
Research Engineer
Alaska Department of Transportation & Public Facilities
3132 Channel Drive
Juneau, Alaska 99810

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David C. Esch

Research Engineer
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ABSTRACT

The use of expanded plastic foam insulations in Alaska to reduce freezing and thawing of soils beneath road and airfield embankments began in 1968, with the installation of polystyrene and polyurethane foam products for frost heave control. This was followed, in 1969, by the first insulated roadway section over permafrost in North America at Chitina, and the first insulated airfield runway at Kotzebue. Since then, many roadway sections, totalling over 45 lane-km have been insulated by the Alaska DOT, along with four additional airports. Materials used have been primarily extruded-expanded polystyrene foam with one installation of foam-in-place polyurethane and three of molded polystyrene "beadboard." Evaluations of the long-term performance of these installations have included periodic sampling and testing of the insulations. Based on these observations, foamed-in-place polyurethane insulation was rejected for subgrade insulation uses, while extruded polystyrene is preferred based on it's superior performance and longevity. Molded polystyrene beadboard has given acceptable performance, but must be installed at a thickness 30 to 50% greater than the extruded polystyrenes to provide comparable thermal performance.

Comparisons are given between insulated and non-insulated embankment behavior on permafrost and between measured and calculated late summer thaw depths using the "Modified Berggren" calculation method, which provided reasonable one-year thaw estimates.

INTRODUCTION

The Alaska Department of Highways constructed its first experimental installation of expanded plastic foams for frost heave control in 1967 , at a site 18 km 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 (1). Since that time, many additional roadway sections on permafrost have been insulated by the Alaska Department of Transportation, along with six airport runways. 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-35, HI-40 or HI-60, and UCI Foamular 400) with several installation of polyurethane foam and six of molded polystyrene "beadboard". Note that for these products the final number designation indicates compressive strength in psi for Styrofoam and in psi x 10 for Foamular. The mention of brand names herein is only done to indicate the actual products installed and evaluated. The manufacturing processes for foamed insulation products of the molded and extruded types may differ between manufacturers. It is not known whether the performance of competing products having similar compressive strengths and dry densities will be similar to those evaluated in this study. Current AASHTO specifications for polystyrene foam insulations do not require conductivity testing, and lack procedures for evaluating the long term resistance of these materials to moisture absorption.

To evaluate the long-term thermal performance of these installations, extensive air and ground temperature monitoring instrumentation, consisting of thermocouples, thermistors, and chart recorders were installed at six sites (2). Temperatures have been monitored monthly or semi-annually at the different sites, the longest period being 25 years at the Chitina permafrost site. In Septembers of 1984 and 1994, 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 airfield 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 (DOT) to control frost heaving or permafrost thaw settlements are listed in Tables 1 & 2.

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

Year Built	Site or Route	Specific Location	Insulation Type	Thick-ness cm	Cover Depth cm	Length Lanes km
1968	Seward Hwy	Potter	FIP Urethane	5	46	0.058
1968	Seward Hwy	Potter	Styrofoam HI	7.5	46	0.068
1970	Parks Hwy	MP 75.0	Styrofoam HI	10	46	0.089
1970	Parks Hwy	MP 84.2	Styrofoam HI	10	46	0.156
1971	New Seward	Tudor-East	Styrofoam HI	7.5	61	1.464
1971	Talketna Spur	MP 9.3	Styrofoam HI	7.5	46	0.274
1971	Parks Hwy	MP 117.0	Styrofoam HI	10	46	1.249
1975	Minnesota Drive	15 ST. Jct.	Styrofoam HI	10	68	0.122
1975	New Seward	Tudor-East	Styrofoam SM	7.5	61	2.109
1978	Parks Hwy	MP 36.7	Styrofoam HI	10	152	0.177
1981	Minnesota Dr.	At Dimond	Sty. Beadboard	10	61	1.224
1983	Northern Lights	Goose Lake	Styrofoam, HI	10	112	1.341
1984	Minnesota Ext.	At Dimond	Sty. Beadboard	10	91	3.767
1985	A-Street	@ 23 St.	Styrofoam HI	10	119	0.488
1985	A-Street	@ 15 St.	Styrofoam HI	10	119	0.853
1984	Parks Hwy	Panguingue	Styrofoam HI	10	61	0.061
1986	Parks Hwy	MP 293-297	Foamular 400	5&10	107	4.266

Table 2: Permafrost Highway Insulation Sites in Alaska

Insulated Roadways on Permafrost for Thaw Control

Year Built	Site or Route	Specific Location	Insulation Brand & Type	Thick-ness cm	Cover Depth cm	Length Lanes km
1969	Chitina N.	MP 27	Styrofoam HI	10	152	0.113
1973	Parks Hwy	MP 231.8	Styrofoam HI	10	137	0.274
1974	Parks Hwy	Alder Ck. S.	Styrofoam HI	10	137	0.201
1974	Parks Hwy	Alder Ck. N.	Styrofoam HI	10	305	0.116
1979	Farmer's Loop	Fairhill Rd.	Insulfoam BB	10	122	0.124
1985	Canyon Creek	Rich. MP 299	Styrofoam HI	7.6	84	1.708
1986	Edgerton Hwy	MP 1.3-7.0	Styrofoam HI	5	107	3.349
1989	Alaska Hwy	Dot Lake	Insulfoam 2 BB	10	102	1.708
1990	Alaska Hwy	MP 1285-1303	Styrofoam HI	10	102	14.39
1991	Rich. Hwy	MP 80.2	Styrofoam HI	10	91	0.111
1991	Davis Road	Fairbanks	UCI Foamular	10	102	1.010
1993	Tok Cutoff	MP 59	Insulfoam 2 BB	10	473	1.915
1994	Alaska Hwy	Mp 1380 N.	Insulfoam 2 BB	10	102	2.027

Insulated Airfield Runways on Permafrost

Year Built	Site or Route	Specific Location	Insulation Brand & Type	Thick-ness cm	Cover Depth cm	Length Lanes km
1969	Kotzebue Airport		Styrofoam HI-35	10	107	.580
1981	Buckland Airport		Styrofoam HI-35	15	91	.732
1981	Deering Airport		Styrofoam HI-35	5	76	.824
1985	Nunapitchuk Airport		Styrofoam HI-60	15	76	.839
1985	Deadhorse Taxiway B		Styrofoam HI-60	10	142	.110
1988	Golovin Airport		Styrofoam HI-40	10	91	.701
1990	Selawik Airport		Styrofoam HI-40	10	91	1.333

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 (3). 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 top and bottom with a thick layer of hot asphalt. In fact the polyurethane absorbed up to 70% water by volume in some test applications. Therefore, it was not allowed in future 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 45 cm 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 the depth of cover over the insulation. As shown by Table 1, the depth of cover over frost heave insulation has varied from 45 cm to 1.2 m. Surface frost forms more quickly on bridge decks and above insulated areas than on normal road structures. The resulting decreases in traction have been treated by installing Plus-Ride (TM) process 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 and reported by Esch (4).

Permafrost Sites

The Chitina insulated road site, constructed in 1969 over relatively warm (-1 C) permafrost, has performed reasonably well, with almost total annual refreezing of the summer thaw zones beneath the roadway and a long term sub-roadway permafrost temperature of -0.1 to -0.3 C. 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; the increases in thaw depth averaging about 8 cm per year into the permafrost beneath the slopes. This has resulted in progressive slope sloughing and cracking in the shoulder areas (5). By comparison, the adjacent uninsulated roadway areas have continued to settle annually at a rate of 3 to 6 cm per year. The surface of this experimental roadway section was left as gravel for the first two years. It was then topped with a cold road mixed pavement in 1971 to evaluate the effects of the darker asphalt surfacing on thaw into the underlying permafrost. It was returned to gravel surfacing between 1975 and 1987, and finally paved with hot-mixed asphalt in 1988. Settlements of the embankment continued throughout these periods, and measured settlements of the outer edges of the travel lanes are reported in Figure 1. These measurements demonstrate the relatively improved performance of the insulated sections, but the lack of overall stability even after 20 years. 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.

Cross-section plots of one side of this road embankment after 20 years of monitoring of settlements and thaw depths are shown by Figures 1 through 4, covering the four different embankment types at the Chitina site. These figures demonstrate the continually deepening thaw zones which result from the warming influence of the road embankment.

The performance of most other insulated permafrost roadway sites has been similar to that at Chitina. Embankments do not reach full annual refreezing of soils beneath the insulated roadway areas and progressively faster and deeper annual thawing and related movements of the side-slope areas. The insulated road sections typically are in climates with mean annual air temperatures of -3 to -5 C, where the permafrost is best described as "discontinuous". All roadway sections monitored have continued to exhibit annually increasing settlements over time, and are still deforming after as long as 25 years. The use of insulation has typically reduced settlements to half of those of the uninsulated adjacent road segments. By comparison, airfield insulation sites typically are in areas with lower air temperatures and full annual refreezing of the seasonal thaw zones is more common. For these sites the insulated embankment performance has been better than that of the roadways, due primarily to the colder local climates.

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. As such they have proven very successful.

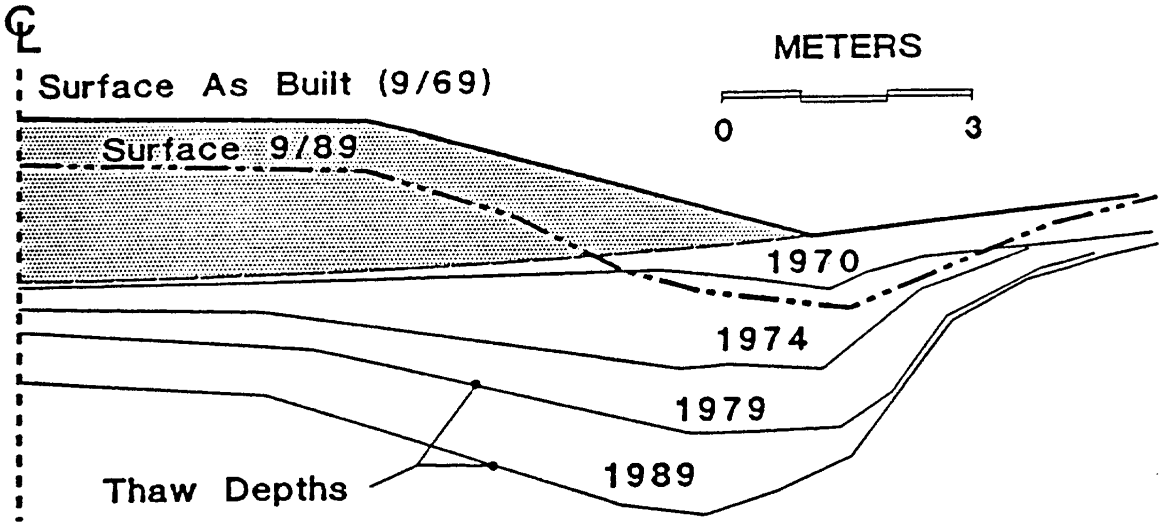

Figure 1. Cross-Section of Normal non-insulated Embankment build over surface vegetation and brush layers. Maximum Thaw Depths after 1,5,10 and 20 Years and Settlements after 20 years.

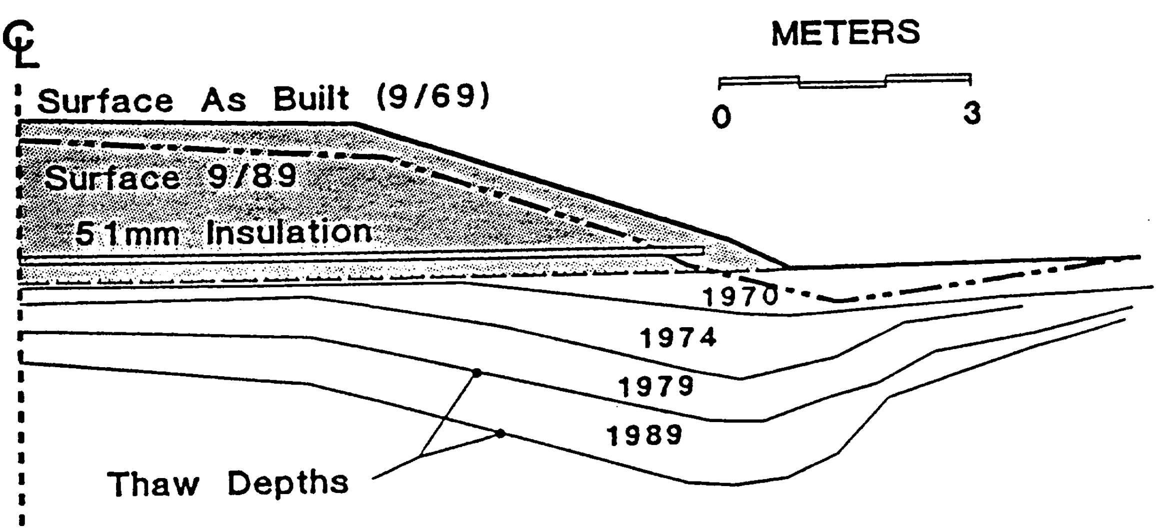

Figure 2. Embankment constructed as above except for addition of 51 mm insulation layer at 0.4 m above original ground surface. Maximum thaw depths and 20 year surface settlements.

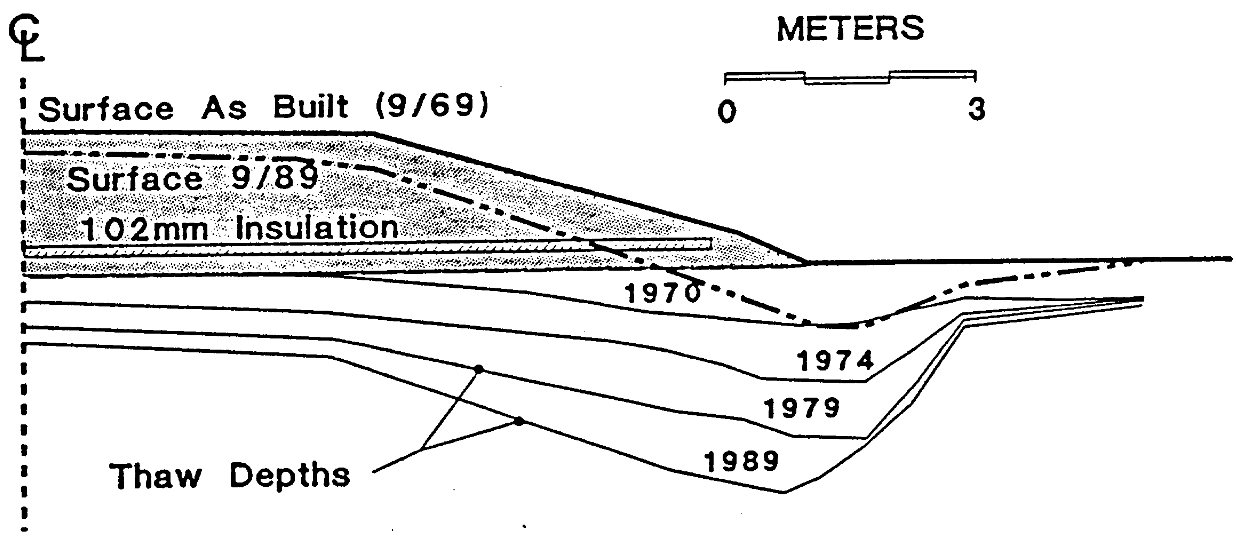

Figure 3. Embankment constructed with 102 mm insulation layer at 0.4 m above original ground surface. Maximum thaw depths and 20 year surface settlements.

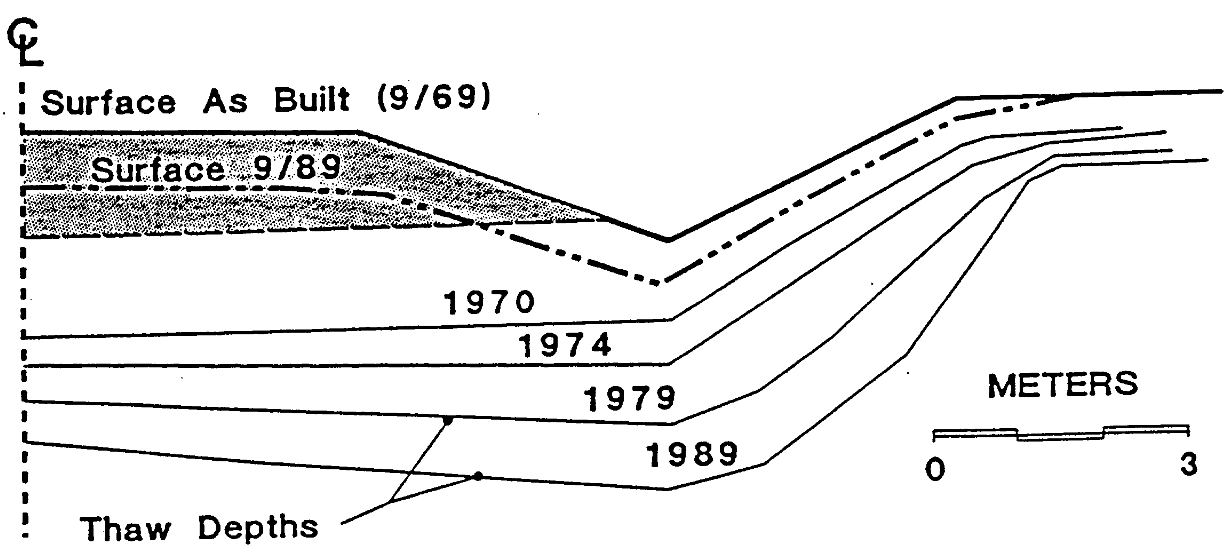

Figure 4. Embankment constructed in "cut" section where all surface vegetation is first removed. Maximum thaw depths and 20 year settlements.

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. Results are discussed below by insulation type.

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 (3).

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) five cm insulation area, and an average thickness of approximately 2.3 cm was noted. No foam thicker than 3 cm 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 2.5 cm. Many areas of thickness as low as 12 mm were noted, and foam in these areas was generally nearly saturated. This foamed-in-place urethane had an average compressive strength of 217 Kpa 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 32 and 34 kg/m , absorbed water contents of 1.3 and 1.0% by volume, and average compressive strengths of 194 and 181 Kpa 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. Repeat sampling was again done in 1994 at three roadway sites. Samples were typically taken from hand-dug test pits located at the edge of the asphalt pavement or near the toe of the embankment slope. 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 (6) (1983) in the 1984 sampling program, and the more accepted "guarded hot plate" method in 1994.

In the thermistor method a single thermistor bead, approximately 1.0 mm 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 the study sites; the Fairbanks area "Fairhill Access Road", constructed in 1979, and Anchorage's "Minnesota Extension - Phase I", constructed in 1981, contain white molded polystyrene, with a compressive strength greater than 200 Kpa. This product is molded into boards of the desired thickness in a 2-step process starting with the pre-expansion of foam beads, and is commonly called "polystyrene beadboard". The remaining sites all were insulated with polystyrene insulation of the type foamed and formed in a single extrusion process in the desired thicknesses, and is termed "extruded polystyrene". Results of all testing of the recovered insulation samples are included in Table 3 and averages for each site are plotted on Figure 5 to show relationships between moisture absorbed and thermal conductivity measured on wet insulations. Initial test results on new, dry polystyrene foam products at 22 C average about .029 and .032 W/m C for the extruded (type E) and molded beadboard (type BB) insulation products.

Table 3: Polystyrene Insulation Test Results at 22°C

Site	Layer	Thickness	Dry Foam Density	Insulation Type	Water by Volume	K avg.	Year Placed
		(cm)	(kg/m³)		(%)	(W/m°K)	
1984 Samples and Test Data:							
Kotzebue	Top	5	38.2	E	2.38	.031	1969
Kotzebue	Bottom	5	34.2	E	0.89	.028	1969
Buckland	Top	7.5	36.2	E	0.41	.029	1981
Buckland	Bottom	7.5	33.6	E	0.23	.030	1981
Deering	Single	5	34.6	E	1.37	.029	1981
Chitina	Top	5	40.9	E	0.71	.034	1969
Chitina	Bottom	5	42.1	E	0.88	.037	1969
Chitina	Single	5	42.1	E	1.54	.031	1969
Bonanza Creek	Single	5	35.8	E	1.48	.036	1974
Bonanza Creek	Single	5	45.3	E	2.38	.036	1974
Fairhill	Single	10	39.0	BB	1.18	.040	1979
Fairhill	Top	5	34.7	E	0.50	.032	1979
Fairhill	Bottom	5	36.3	E	0.20	.031	1979
Fairhill	Single	10	47.7	B	1.48	.042	1979
Minnesota Dr.	Top	5	39.4	BB	5.88	.052	1981
Minnesota Dr.	Bottom	5	43.4	BB	2.90	.038	1981
Geneva Woods	Single	7.5	---	E	0.64	---	1970
Geneva Woods	Single	7.5	---	E	0.53	---	1970
1994 Samples and Test Data:							
Chitina	Top	5	43.8	E	1.36	.034	1969
Chitina	Bottom	5	43.0	E	1.72	.035	1969
Fairhill	Single	10	39.2	BB	5.15	.046	1979
Bonanza Creek	Single	5	47.4	E	3.10	.038	1974

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

As shown by Figure 5, the relationships between moisture content and thermal conductivity for both extruded and molded foam boards were found to be in excellent agreement with other reported data from laboratory tests at higher moisture contents (7,8). All samples were within 5% of the original nominal thickness, indicating that compression and creep with time has not been a problem. The extruded Styrofoam insulation board, sampled in 1984 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-Factors or k) of these samples averaged 0.032 W/m°C at 22°F. Maximums were a moisture of 2.4% and a k of 0.036. By comparison the molded beadboard samples, from sites three and five years old, had an average moisture of 2.9% and an average Kfactor of 0.043. Maximum values for the beadboard were 8.7% moisture and a k of 0.60. When analyzed by a standard statistical approach, the long-term minimum k-factors expected at the 95% confidence level, are .037 for extruded polystyrene foam and .055 for high-strength molded polystyrene beadboard. This results in a thickness ratio for equivalent performance of 1.5 cm of molded polystyrene foam to 1.0 cm of extruded polystyrene foam. If this ratio is based on average rather than minimum insulation 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.

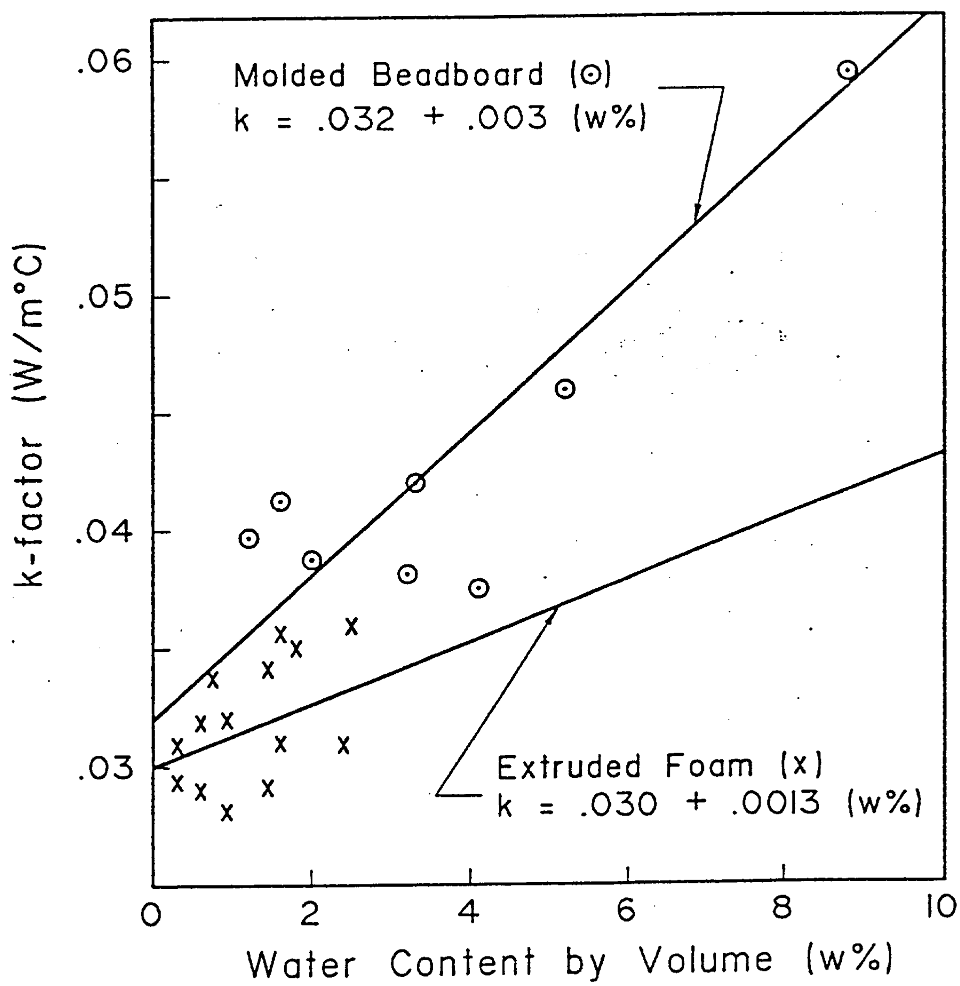

Figure 5: Moisture Contents and Thermal Conductivities at 22°C of In-Service Polystyrene Insulation Samples from Roads and Airfields in Alaska

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 of depth to permit comparisons between thaw depth calculation 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, (9), the recorded Kotzebue air thawing index of +820°C-days, and surface n-factors (ratios of surface to air thawing indices) of 1.70 for Kotzebue (paved) and 1.30 for the other (unpaved) sites. These calculations over-predicted the thaw depths by 6 to 15 cm, as shown by Table 4, indicating that this calculation method is slightly conservative for designing insulation layers on cold ($T<-1°C$) permafrost.

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

Site	Thawing Index (°C-Days)	Surface n-Factor	Insulation Depth (m)	Insulation Thickness (cm)	Thaw Depths Measured (m)	Thaw Depths Predicted (m)
Kotzebue	820	1.70	1.07	10	1.43	1.50
Buckland	820	1.30	1.01	15	1.16	1.31
Deering	820	1.30	0.70	5	0.85	0.98

SUMMARY

Since 1967, the Alaska Department of Transportation has insulated more than 20 lane-kilometers of roadways and 2,970 meters 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 boards. 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 25 years in service. In fact, all of the extruded samples taken in 1994 were removed from locations below the water table and had been immersed for periods as long as 10 years, yet showed excellent resistance to moisture absorption. Molded Polystyrene beadboard products, evaluated after 3 to 15 years of service, were somewhat less resistant to moisture absorption in the sub-roadway environment, although they had not been similarly immersed. To provide equivalent long-term thermal performance under soil burial conditions, beadboard insulation thicknesses should be 30 to 50% greater than extruded foam thicknesses. It should be noted that the insulation sampling locations used were not located beneath the pavement or in areas exposed to cyclic pressures from from wheel loadings. Information from Norway suggests that in some instances moisture content increases in insulations may be higher beneath paved surfaces than beneath unpaved shoulders, and that moisture levels in insulations may vary seasonally to some extent. Data on moisture contents in polystyrene roof insulations shows that when temperatures are high, temperature differences between the top and bottom of an insulation layer are very high, and moisture is present; the moisture gain over time is greatly increased. When insulation layers are buried in soil at depths great enough to avoid cyclic tire pressure effects and high temperature gradients across the insulation layer, moisture pickup will be very slow, even if the insulation layer is submerged.

Based on the data obtained over the course of this study, the functional design life of extruded foams installed beneath roads and airfields is projected to be much greater than 25 years. Increases in thermal conductivity of insulations due to moisture absorption after 15 to 25 years of field exposure, averaged only 10 to 22% for extruded polystyrenes and 34 to 44% for molded polystyrene beadboard products.

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