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Shallow Insulated Foundation at Galena, Alaska

A Case Study

Lawrence S. Danyluk

March 1997

Abstract: A 2000-ft^2 addition to an aircraft control tower was constructed at Galena, Alaska, during the summer of 1990. Because of limited resources, a shallow insulated foundation (SIF) was specified instead of a traditional foundation (one in which the bottom of the footing is placed lower than the anticipated depth of frost penetration). An SIF design allows the footing to be placed at a much shallower depth by incorporating the use of strategically placed insulation around the foundation. The insulation utilizes heat from the building and surrounding soil, redirects it to the area around the foundation, and thus reduces the frost penetration.

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Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

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PREFACE

This report was prepared by Lawrence S. Danyluk, Research Civil Engineer, Civil Engineering Research Division, Research and Engineering Directorate, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire.

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Shallow Insulated Foundation at Galena, Alaska
A Case Study

LAWRENCE S. DANYLUK

INTRODUCTION

A 2000-ft^2 addition to an aircraft control tower was constructed at Galena, Alaska, during the summer of 1990. Because of limited resources, a shallow insulated foundation (SIF) was specified instead of a traditional foundation (one in which the bottom of the footing is placed lower than the anticipated depth of frost penetration). In this case, a 20-in.-deep foundation was constructed instead of one at 12 ft. An SIF design allows the footing to be placed at a much shallower depth by incorporating the use of strategically placed insulation around the foundation. The insulation utilizes heat from the building and surrounding soil, redirects it to the area around the foundation, and thus reduces the frost penetration.

The Scandinavian countries routinely use insulation around shallow foundations to protect them from frost damage (Farouki 1992); however, the use of the SIF system in this country is still new and somewhat limited. Most buildings codes require footings to be placed below the expected depth of frost. There is currently an effort to change the codes to allow for the use and implementation of SIFs.

This report will first describe the design and construction of an SIF in an extremely remote and harsh environment. It will then describe the performance of the foundation during the following three winters.

SITE CHARACTERIZATIONS

Galena is a small village located in west central Alaska. It is approximately 350 miles northwest of Anchorage and 275 miles west of Fairbanks along the banks of the Yukon River (Fig. 1). Adjacent to the village is an airfield and associated support buildings used by the Air Force for aircraft out of Elmendorf AFB. The Air Force is responsible for the operation and maintenance of the airport and associated facilities. The only

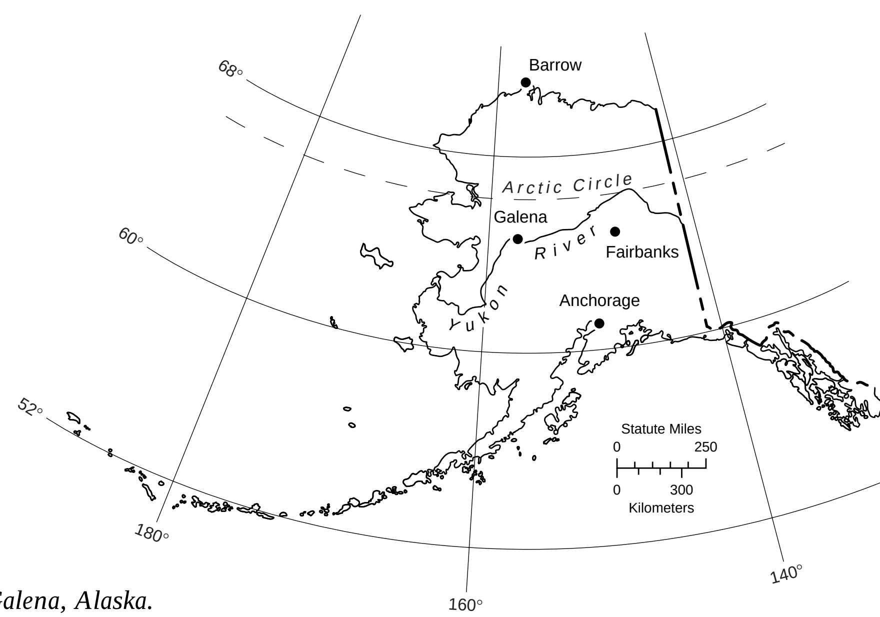


Figure 1. Location map, Galena, Alaska.

practical year-round access to the area is by air transport. River boats or barges may be used when the river is ice-free.

Galena is located on the flood plain in a broad basin more than 30 miles wide bordered by hills and mountains up to 2000 ft high. The basin is crossed by the Yukon River, whose elevation is approximately 100 ft (mean sea level) at low water at Galena, and by the Yukon's large north tributary, the Koyukuk River. Both rivers are bordered by a flood plain that is up to 10 miles wide and covered by many elongated channel lakes, sloughs, and swamps. The rest of the basin between the flood plain and the bordering bedrock consists of alluvial terraces.

Galena is within the discontinuous permafrost zone although there is no known permafrost on the base. The water table varies with the elevation of the Yukon River, but generally is 8–10 ft below the ground surface. There have been times during spring breakup when the elevation of the river actually has become higher than that of the airport. However, the water table at the base seems to rise no more than 2–4 ft below the surface. Figure 2 shows how the base is surrounded by a system of levees.

The soils at the site are generally river deposits of sands and gravels. A typical profile obtained from soil borings in the immediate area is shown below:

0.0–2.5 ft	Sandy gravel;
2.5–7.0 ft	Gravelly sand, 2–4% fines;
7.0–9.0 ft	Silt;
9.0–22.0 ft	Silty gravelly sand, 3–15% fines;
22.0–47.5 ft	Sand.

The weather at Galena is typical of the sheltered continental interior of Alaska. This type of climate is characterized by quite cold winters with relatively little precipitation and summers that are considered relatively warm for Alaska. Winter temperatures fall well below zero, at times reaching –60°F for periods of weeks. There are usually several thaw periods of one to two days each per winter. Temperatures rise to 80°F for approximately two weeks during the summer. The mean annual temperature is approximately 25°F. The design and average air freezing indexes (FI) are 6000 and 5500 °F-days, respectively.

BACKGROUND

Engineers at the Air Force's 5099th Civil Engineering Operations Squadron were tasked to provide a new structure for the weather station at Galena. It was decided that the most logical place would be at the airport, adjacent to the aircraft control tower (Fig. 2). Because of budget constraints and the remoteness of the site, the building had to be designed such that it required shipping the minimal amount of material and equipment. For example, cement had to be airlifted to the site in 94-lb bags; the concrete was then made on site using a small motorized mixer. By minimizing the amount of concrete needed for the project, the shipping, labor, and construction costs, as well as the time required to make the concrete, were reduced.

The designers were particularly concerned about the foundation's stability. Because the addition was to be attached to the control tower, there could be no differential movement between the two. This would have required a conventional foundation depth of 12 ft (estimated frost depth in the area), similar to the control tower. At the same time it would have required large machinery to dig the excavation, additional material to shore up the sides of the excavation, and large quantities of concrete for the footings, none of

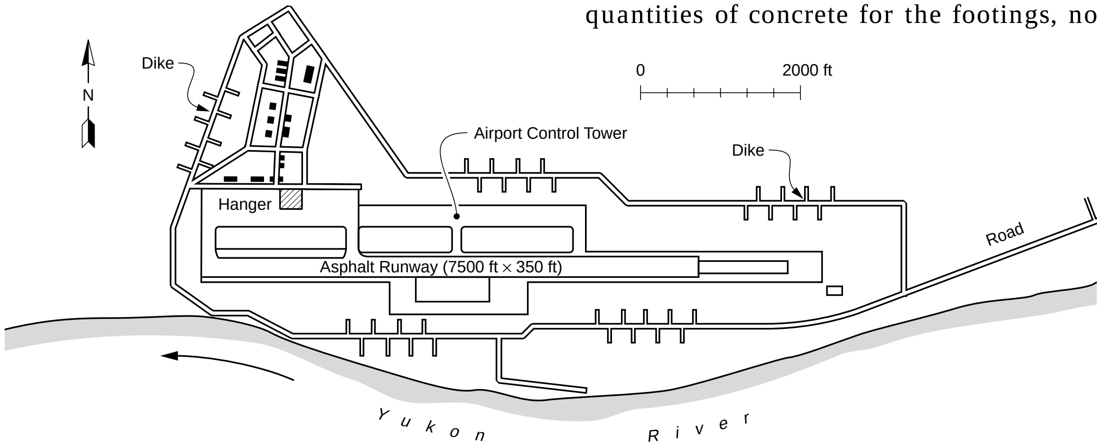


Figure 2. Galena Airport, general vicinity plan.

which were available or affordable to the project. The designers decided the concept of an SIF would be the most practical solution to this unique project.

DESIGN CONSIDERATIONS

For a typical SIF structure with slab-on-grade construction, about 10% of the heat loss from inside the building is through the floor (Torgersen 1976). The actual amount varies according to the effectiveness of the insulation in the rest of the structure. The heat loss through the floor passes through the ground below and rises toward the outside air by means of an approximately semicircular path. The effect is to reduce the frost depth near the foundation compared with the frost depth in undisturbed ground. The heat flow from a floor will take the path with the least amount of thermal resistance, whether it be the connection between the floor and foundation wall (where a cold bridge could form), through the foundation wall, or through the soil under the floor and foundation.

In an SIF structure, the insulation must be placed so that the majority of the heat loss through the floor is guided to the underside of the foundation. This can be done with floor, wall, and ground insulation, as shown in Figure 3. The type of insulation to use, how much, and where to place it depend on many variables, including (but not limited to) climate, soil type, moisture conditions, building type and use, snow conditions, and exposure.

The starting point in an SIF design is to select the necessary floor insulation. If the insulation has a low thermal resistance, the heat loss across

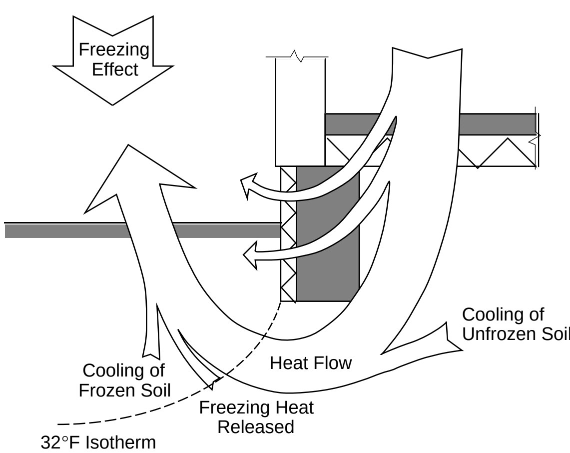


Figure 3. Heat flow lines around a shallow insulated foundation.

it is large. The floor's temperature is reduced, but the frost boundary does not advance very deeply at the foundation wall because of the large heat flow contribution from the floor. On the other hand, if the floor insulation has a high thermal resistance, heat loss is restricted and thereby maintains higher floor surface temperatures. As a result, the frost boundary advances deeper down the foundation wall and thus the foundation depth must increase. A balance must be established that results in both a comfortable floor surface temperature and acceptable frost penetration depth.

The next step is to determine the requirements for foundation wall insulation. Great care should be taken to ensure interruption of all possible cold bridges at the junction of the floor, the foundation wall, and the outer wall. Insulation placed on the outside of the foundation wall requires protection above grade from physical and ultraviolet radiation damage. Insulation installed on the inside of the foundation wall does not require this protection; however, with inside insulation there have been cases of the outside foundation wall becoming cold enough for the soil to adfreeze to it. If this outside soil then heaves, the foundation can be lifted or jacked. Furthermore, walls with inside insulation are more susceptible to cold bridges and in some cases are subject to loads from the floor or foundation, and thus require an insulation with a higher compressive strength.

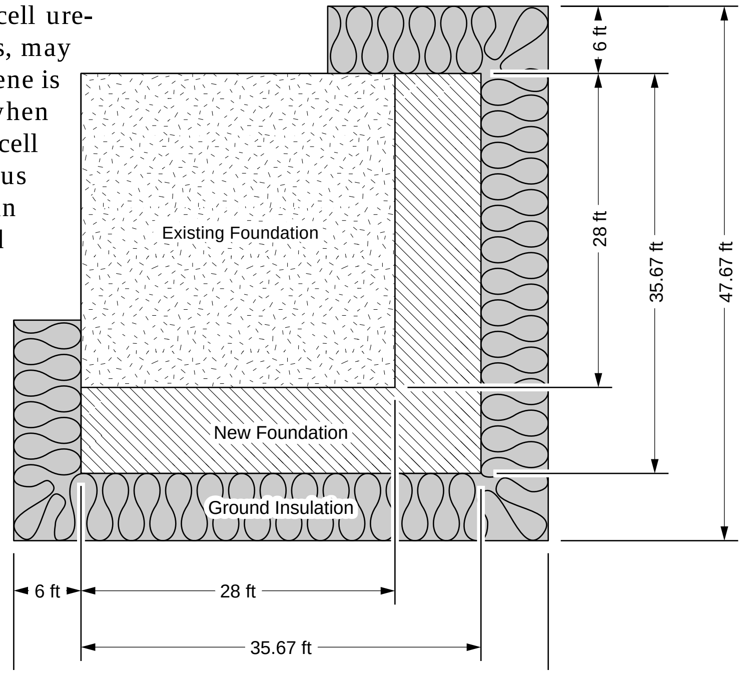
Insulation placed horizontally outside the foundation is called ground or wing insulation and is usually used only in colder climates with a freezing index greater than 2250 °F-days (NBI 1986). The horizontal insulation inhibits the release of the soil heat, which is stored in the soil during the summer half of the year and is available to retard the downward advance of frost. For maximum thermal efficiency, ground insulation should be placed as near the ground surface as possible (Farouki 1992). Because of the three-dimensional heat-loss effect at corners, additional ground insulation is usually required. However, this could result in damage by inadvertent digging or vegetation. Care must be taken to protect the insulation from physical and moisture-related damage. In areas where the insulation may experience loading, an insulation with sufficient compressive strength must be specified.

The three most common types of insulations used in SIFs are mineral wool, expanded or molded polystyrene (EPS), and extruded polystyrene

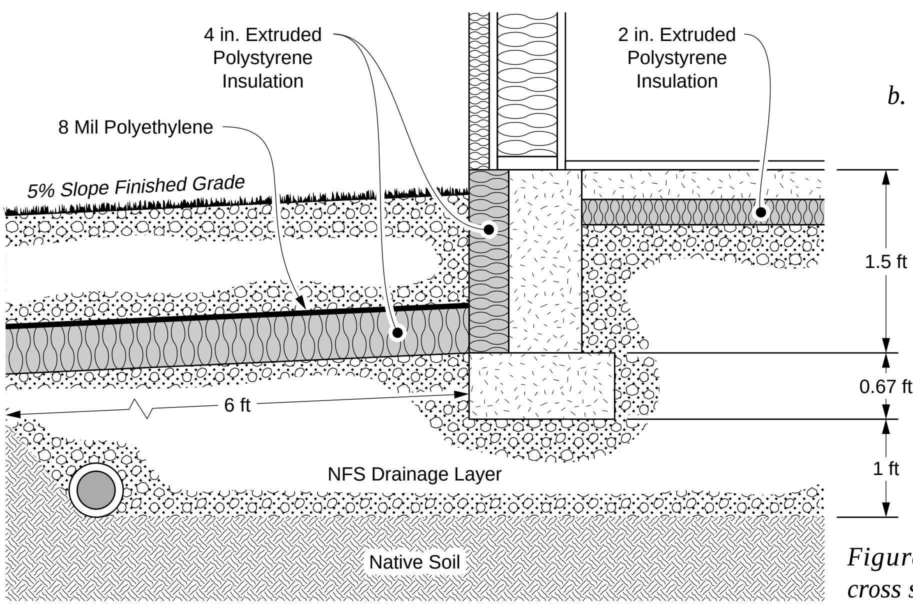
(XEPS). Other materials, such as closed-cell urethane, lightweight clinker, or wood chips, may be used as insulators. Extruded polystyrene is usually recommended in this country when the insulation is to be buried. Its closed-cell design inhibits moisture absorption, thus enabling its thermal resistance to remain high. Expanded polystyrene may be used if precautions are taken to limit its exposure to moisture.

FOUNDATION DESIGN

At the time of the weather station's design, there were no publications available in this country to assist in an SIF design. The designers resorted to using the Norwegian Building Research Institute's (NBI 1986) charts, graphs, and building details as a guide to assist in the design. It was found, however, that the NBI publications addressed climates only as severe as 4500 °F-days. NBI's figures were projected out to meet the conditions expected at Galena by using a simple least-squares regression analysis.



a. Foundation plan.



b. Foundation cross section.

Figure 4. Foundation plan and cross section.

The final foundation plan is shown in Figure 4a and the cross section in Figure 4b. The bottom of the footing is approximately 20 in. below grade. The insulation chosen was an extruded polystyrene with a density of 2.0 pcf, a vertical compressive strength of 30 psi, a thermal resistivity (R-value) of 4.9 ft^2-hr-°F / Btu-in., and a thermal conductivity (k-value) of 0.204 Btu / hr-in.-°F. The wall and ground insulations are 4-in.-thick XEPS. It was determined that the ground insulation had to extend 48 in. along the side of the building and 72 in. at the corners. For ease of construction and added safety, all of the ground insulation was installed out 72 in. from the building. Design calculations required that the floor insulation be 2 in. thick throughout the structure, except for a 3-ft strip along the outer wall that required a 4-in.-thick layer. However, the floor was constructed using only 2 in. of insulation throughout.

Although the floor's surface temperature would be slightly lower at the outer edge, the design strategy was to use the additional heat lost to the subgrade to keep the footing frost-free.

Also note in Figure 4b the non-frost-susceptible (NFS) drainage layer, perforated drain tile, and 8-mil plastic film. These are specified to minimize any moisture from coming in contact with the insulation or foundation.

INSTRUMENTATION

Temperature sensors were installed along the east side of the addition because it was thought that the coldest ground temperatures would occur there. The building profile is narrow along this side and thus the heat loss from the building to the ground is minimal. Also, the east side of the addition is kept free of snow for vehicle parking.

During the spring of 1990, 64 temperature sensors were installed to get a temperature profile of the SIF. After a winter's worth of data, it was obvious that additional sensors would be needed because the frost line was penetrating deeper than anticipated and more detailed temperature information was needed under the ground insulation. Sixteen additional sensors were installed during the summer of 1991. The location of all sensors can be seen in Figure 5.

Because of scheduling conflicts, temperature sensors were not installed above the slab insulation or within the floor itself. This would have been useful in determining the comfort level of the floor. Comments on comfort were verbally provided by the weather technicians using the facility.

The temperature sensors used at the addition were type-T, copper-constantan thermocouples. The sensor wires were crimped together at the end and coated with an epoxy. A cap was then heat-shrunk around the sensor to make it completely waterproof. The thermocouples were connected to low-resistance switches located inside the addition and read using a digital thermometer. The overall accuracy with the type-T sensors is approximately ±0.8°F.

The temperature strings were read once a week by the weather technicians. Because it is a first-order weather station, meteorological data were available.

FOUNDATION CONSTRUCTION

Construction on the foundation began in June 1990 and the project was completed in December 1990. No precise length of time can be attributed to the foundation construction phase because the crew was continually pulled from the site to work on other projects. However, conversations with the site foreman revealed that a substantial amount of time was saved: he estimated the SIF took 1–2 weeks to complete whereas a conventional foundation would have taken 3–4 weeks.

Construction of the SIF is similar to a conventional foundation and is very straightforward. Figure 6 depicts the excavation along the east side of the addition. The laborers are leveling the bottom of the excavation; the footings will be placed at this elevation. In Figure 7 the footing and stem wall have been poured and the excavation has been backfilled to the top of the footing. (The man

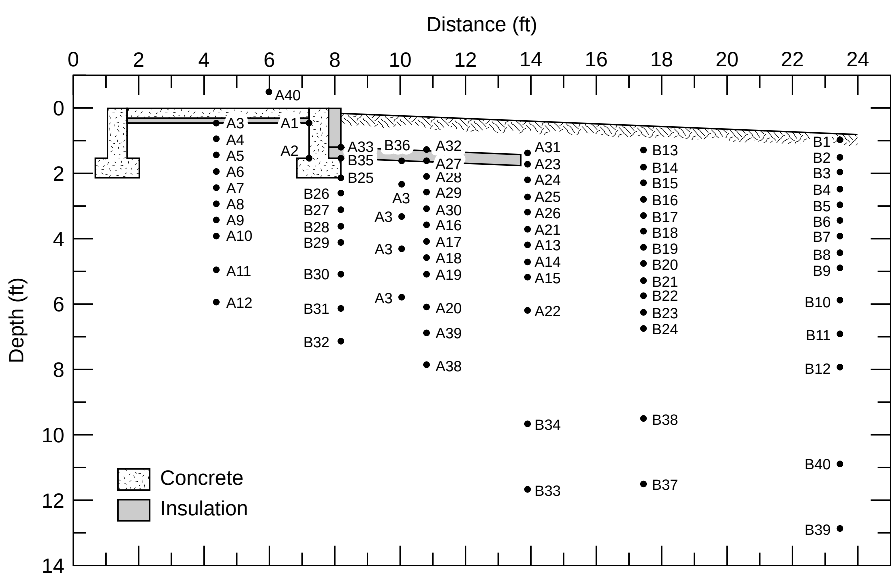


Figure 5. Location of temperature sensors.

on the outside of the wall is standing on top of the footing.) The laborer inside the foundation is placing the floor insulation. Note that the surface was prepared so the insulation lies flat and thus is less vulnerable to breakage. A plastic 8-mil film was placed over the insulation prior to the floor being poured. Figures 8 and 9 show the installation of the ground insulation. In Figure 8 the ground insulation is being placed horizontally on top of the footing and the plastic film placed over it. The wire that the laborer is holding is a temperature sensor that will be installed below the insulation. Figure 9 shows the stem wall insulation in place and backfill placed over the ground insulation. Figure 10 is the existing control tower and the complete addition.

RESULTS AND DISCUSSION

Temperatures were recorded for the winters of 1990–91, 1991–92, and 1992–93. During the early part of the first winter the addition was still under construction; it was only occasionally heated until the addition was completed and occupied in December. The second winter there were numerous personnel changes at the weather station and thus thermocouple readings were

Figure 6. Excavation of foundation.

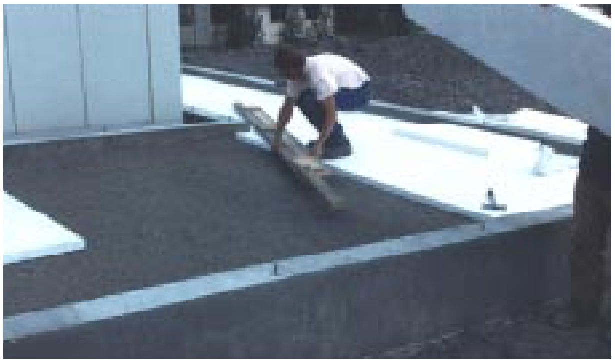


Figure 7. Floor insulation.

Figure 8. Ground insulation, temperature sensor.

Figure 9. Ground and stem wall insulation.

Figure 10. Existing control tower and complete addition.

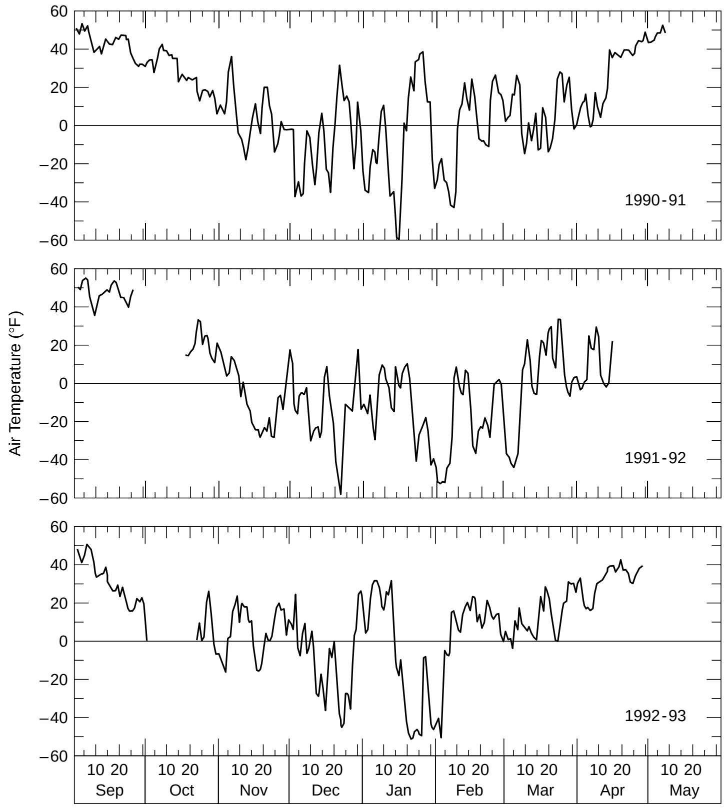


Figure 11. Average daily air temperatures.

sporadic. During the final year the readings were recorded regularly on an established schedule. Freezing indices for the three winters were 5600, 6100, and 5500 °F-days, respectively.

All three winters were at least as cold as the average of 5500 °F-days, with two being 2% and 11% colder than average. The 1991–92 winter was 2% colder than the design index of 6000 °F-days. Average daily air temperatures for the three winters are shown in Figure 11.

Figures 12–14 illustrate the 32°F isotherms for various dates throughout the winter. The isotherms in Figure 12 are truncated because the frost penetrated deeper than the sensors that were installed at that time. Additional sensors were placed deeper the following winter, and sensors were also installed to provide a more detailed temperature regime under the insulation. It is apparent from the figures that at no time during the monitoring period did the 32°F isotherm threaten the bottom of the footing. As expected, the depth of frost on the far right side of the figures (areas assumed not to be influenced by heat loss from the foundation, i.e., control area) were deeper during the colder 1991–92 winter than the others. However, it seems that the freezing front never gets closer than approximately 6–12 in. out from the bottom corner of the footing regardless of the frost load. It is also interesting to note that the maximum frost penetration next to the footing occurs in early to mid February, whereas in the control area this occurs in the more traditional time frame of mid to late March.

Figure 15 shows the temperature difference above and below the horizontal insulation approximately 3 ft out from the footing. The figure illustrates the effectiveness of the insulation to retard heat loss from the foundation and surrounding ground. Even with winter temperatures of –10°F above the insulation, the temperature under the insulation seems to hover around 30°F, with periods where it may vary by a couple of degrees, but never falls lower than 24°F.

There are two areas where temperatures are critical around an SIF: the first is under the toe of the footing (sensor B25) and the second is under the floor slab (sensors A1 and A3). Figure 16 shows that the temperature never gets lower than 34°F at the toe of the footing. It also shows that the temperature below the floor insulation gets below 37°F for only a short period of time. As expected, temperatures under the floor insulation at the outside edge of the slab (sensor A1) are lower than those at the center (sensor A3). Unfor-

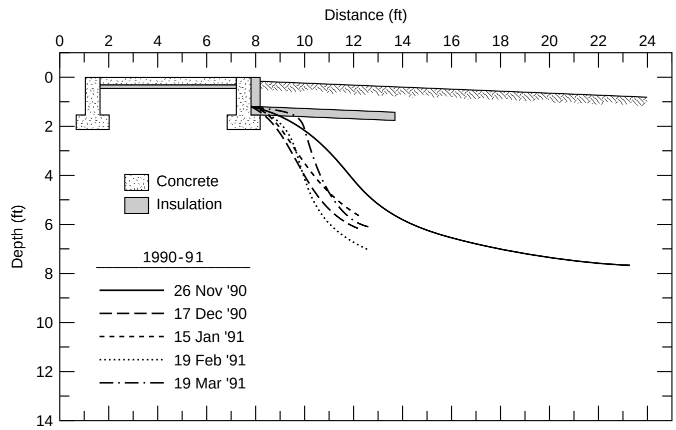


Figure 12. Isotherm (32°F) for the winter of 1990–91.

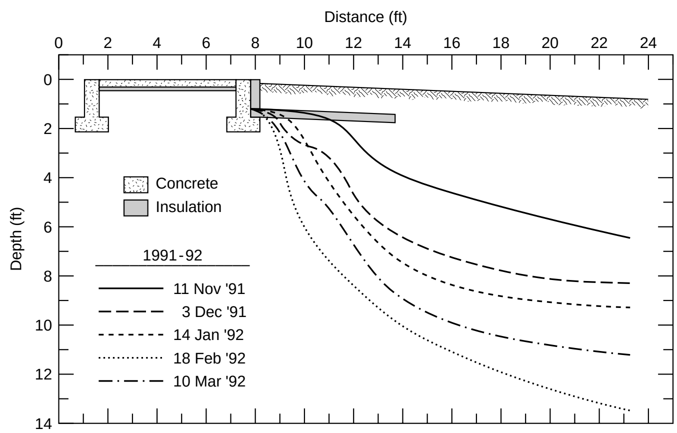


Figure 13. Isotherm (32°F) for the winter of 1991–92.

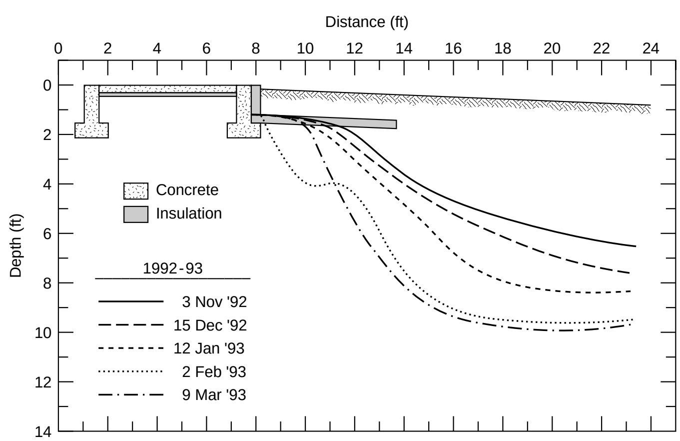
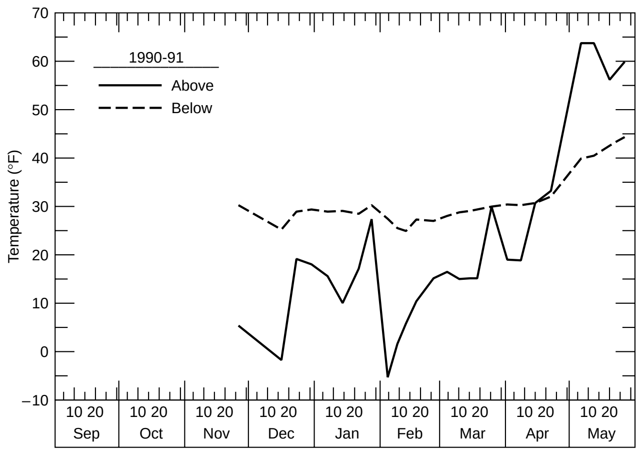


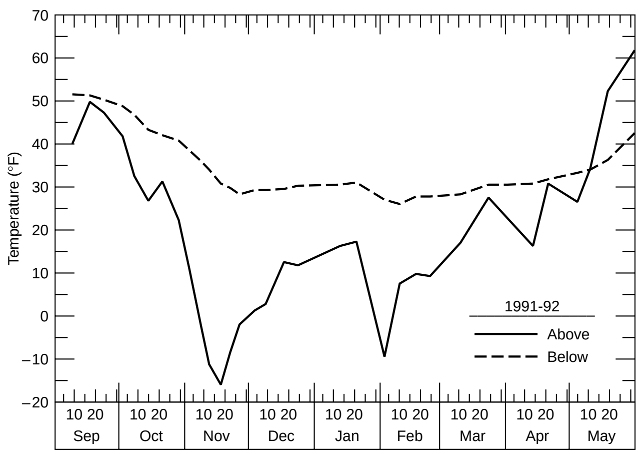
Figure 14. Isotherm (32°F) for the winter of 1992–93.

tunately, a temperature sensor was not placed above the floor insulation. This would have given an indication of the comfort level of the floor; however, technicians working in the addition have commented that the floor never felt cold even when the outside temperature was –60°F.

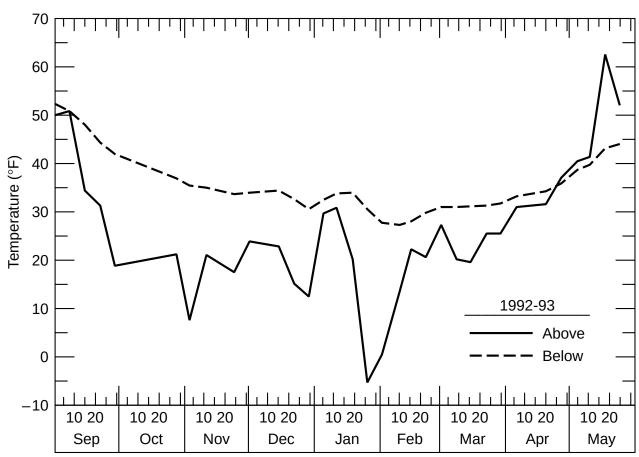
Temperatures at the toe of the footing (B25) and midway under the horizontal ground insulation (A27) are shown in Figures 17 and 18 for the three years of the study. Temperatures for the 1991–92 year are generally lower than the other two years. This coincides with the magnitudes of the freezing



a. 1990–91.

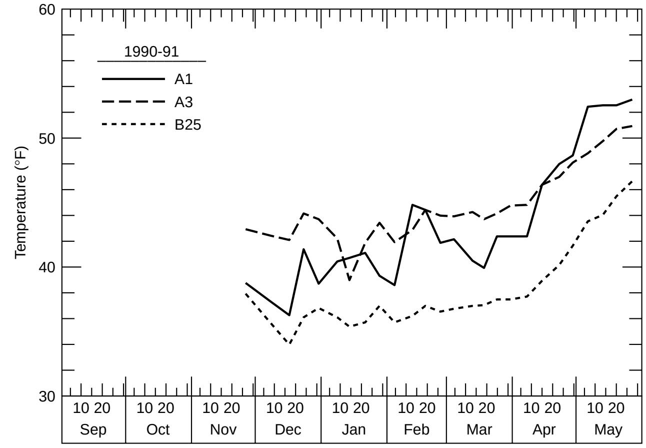


b. 1991–92.

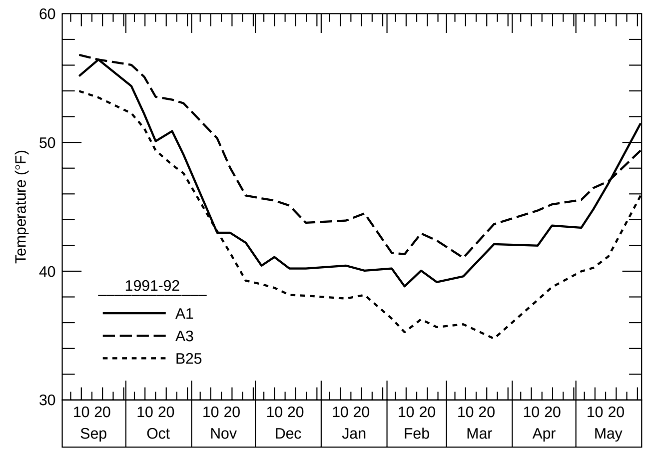


c. 1992–93.

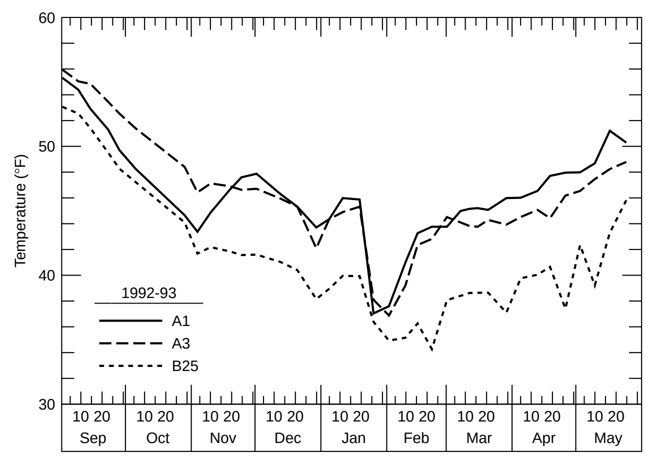
Figure 15. Temperatures above and below horizontal ground insulation.



a. 1990–91.



b. 1991–92.



c. 1992–93.

Figure 16. Temperatures under floor insulation and at toe of footing.

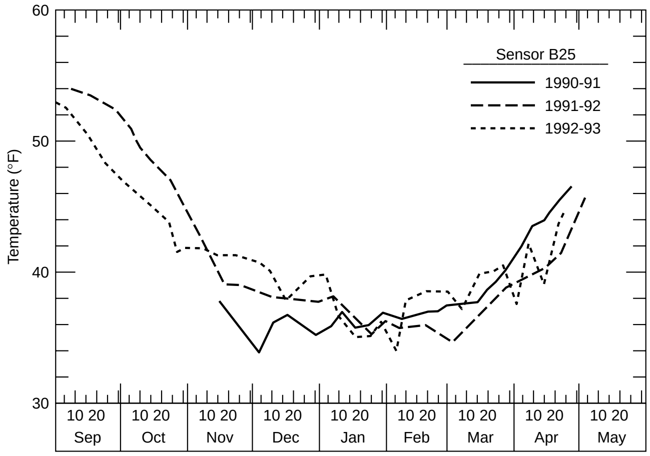


Figure 17. Yearly temperatures at toe of footing.

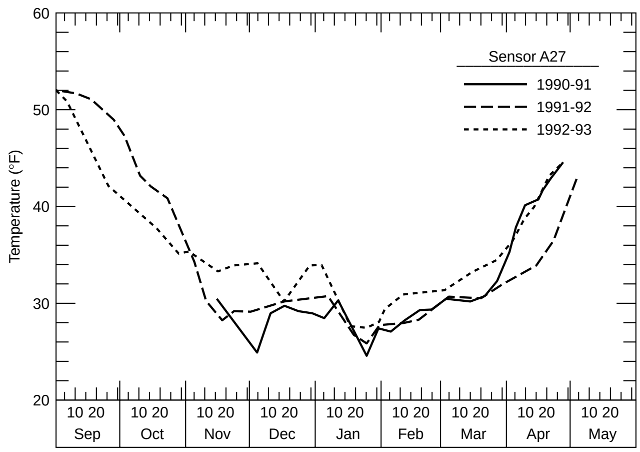


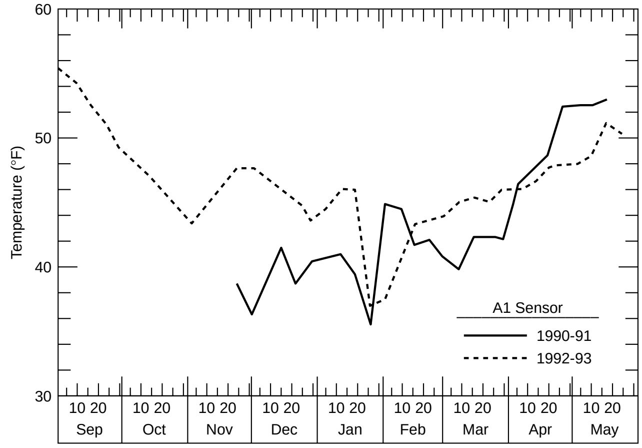
Figure 18. Yearly temperatures under horizontal ground insulation.

indices, with the 1991–92 winter being the most severe and the 1990–91 and 1992–93 winters being less severe and approximately equal. This holds true for the end of the freezing season; however, it becomes evident in the figures that at the beginning of the 1990–91 season the temperatures are uncharacteristically cold. This was the winter when the addition was still under construction and was heated only occasionally until the first of December. Figure 19 further illustrates the importance of using the heat loss from the building in an SIF design. Given that the 1990–91 and the 1992–93 winters had approximately the same indices, the temperatures at the sensors are clearly lower for the 1990–91 winter than for the 1992–93 winter. Assuming the heat was on consistently from December 1, 1990, it took almost two months for the temperatures to return to values similar to the 1992–93 winter values.

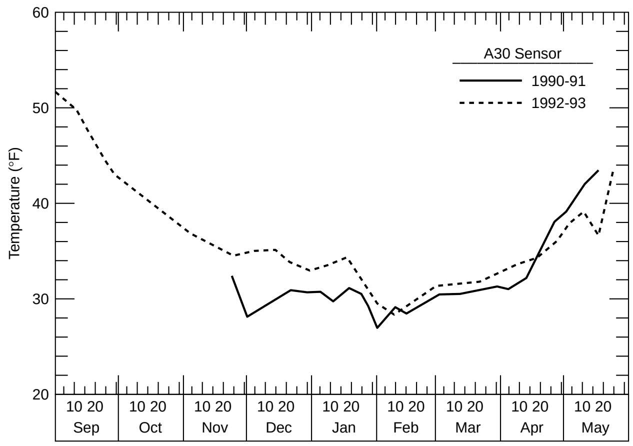
Figure 20 shows how temperatures decrease as the distance from the heated foundation increases. All the measurements were taken 2 ft below grade. Sensor A6 is located under the center of the addition, B25 at the toe of the footing, A28 under the center of the horizontal ground insulation, and B4 in the control area. The figure also shows how the soil temperatures under the foundation (i.e., A6 and B25) change very little from winter to winter even though the freezing indices are quite different.

CONCLUSIONS

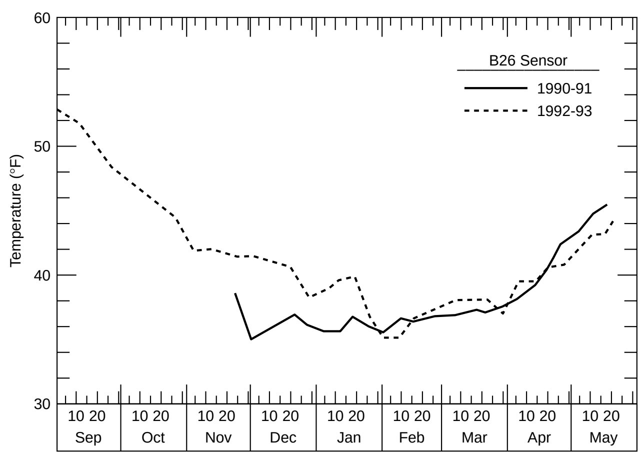
The shallow insulated foundation used at the addition for the Galena, Alaska, aircraft control tower was a cost-effective alternative to a more conventional footing design. Placed at only 20 in. below grade where the expected frost depth may reach 12 ft, the shallow foundation was protected from potential frost damage by extruded polystyrene insulation. Because the site is unique (i.e., remote), an accurate estimate of economic



a. A1 sensor.

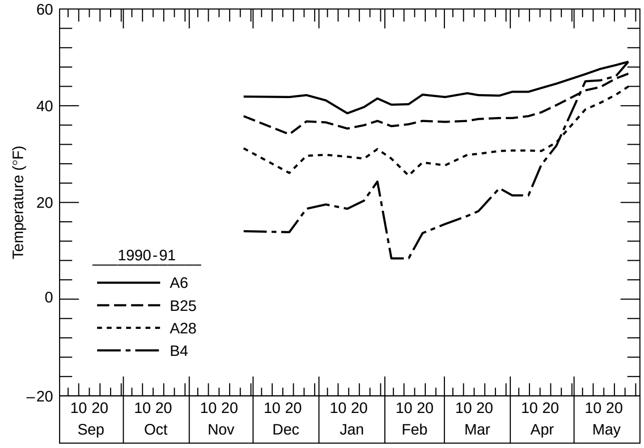


b. A30 sensor.

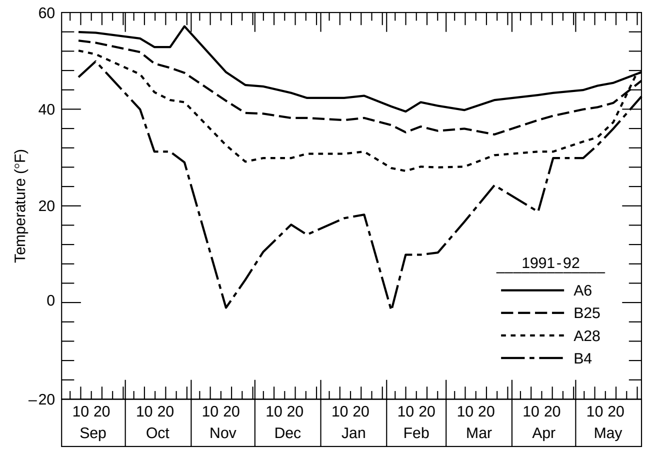


c. B26 sensor.

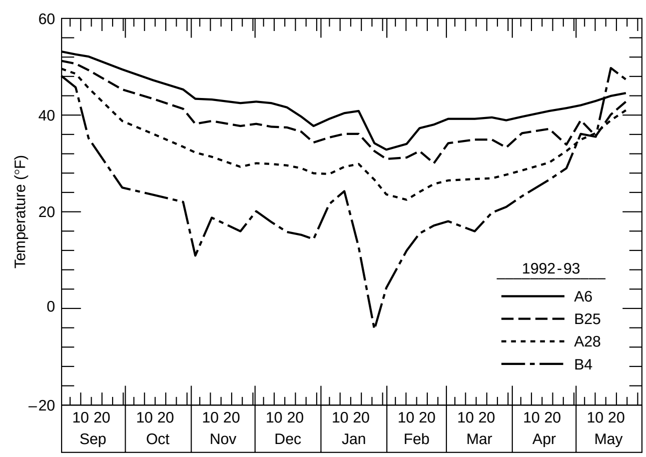
Figure 19. Temperatures 1990–91 vs. 1992–93.



a. 1990–91.



b. 1991–92.



c. 1992–93.

Figure 20. Temperatures taken 2 ft below grade.

savings could not be made; however, based upon the site foreman's assessment, it saved considerable time and materials over a conventional foundation. This was not only a case of how much the SIF saved in dollars, but also a case of whether the project could have been built at all given the availability of funds, manpower, equipment, building supplies, and construction timetable.

Observations made during the three winters of this study showed the freezing front never threatened the bottom of the footing, even during the very cold winter of 1991–92, a design freezing year that had an associated frost depth of approximately 13.5 ft in the control area. Soil temperatures around the foundation varied according to the outside temperatures: the higher the freezing index, the lower the soil temperatures. As expected, the soil temperatures decreased the farther they were from the foundation. During the first year of observations, the soil temperatures around the foundation were significantly lower than in other similarly severe winters. This can be attributed to the fact that the building was only partially heated during the construction phase, thus reducing the amount of heat loss to the underlying soil and resulting in lower soil temperatures. It was obvious that the heat loss from the foundation plays a critical role in the SIF design.

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Lawrence S. Danyluk

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U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road
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A 2000-ft^2 addition to an aircraft control tower was constructed at Galena, Alaska, during the summer of 1990. Because of limited resources, a shallow insulated foundation (SIF) was specified instead of a traditional foundation (one in which the bottom of the footing is placed lower than the anticipated depth of frost penetration). An SIF design allows the footing to be placed at a much shallower depth by incorporating the use of strategically placed insulation around the foundation. The insulation utilizes heat from the building and surrounding soil, redirects it to the area around the foundation, and thus reduces the frost penetration.

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