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Measured Soil Thermal Conductivities and Modified Design Curves for Predicting Frost Penetration Adjacent to Insulated Foundations

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RÉSUMÉ

Pour éviter les problèmes découlant du soulèvement du sol dû au gel, il faut disposer de méthodes de prévision de la pénétration du gel lorsque les fondations reposent sur des sols gélifs. Il existe des méthodes graphiques permettant de prévoir la pénétration du gel dans le cas des fondations non chauffées mais pour ce qui est des fondations chauffées, les données de calcul sont très limitées. Le degré d'isolation des fondations chauffées influe sur la perte de chaleur au profit du sol environnant, et donc sur la profondeur de pénétration du gel.

Ce document fait état de données sur la pénétration du gel et la conductivité du sol, mesurées sur une longue période, pour quatre fondations d'habitation chauffées typiques. On y présente les rapports graphiques (courbes de calcul modifiées) entre les profondeurs et les indices de gel et on fait la comparaison avec les conditions (absence de chauffage) en terrain découvert.

Measured Soil Thermal Conductivities and Modified Design Curves for Predicting Frost Penetration Adjacent to Insulated Foundations*

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ABSTRACT

Methods for predicting frost penetrations are necessary when foundations are placed on frost susceptible soils if problems with frost heave are to be avoided. Graphical methods exist for predicting frost penetration for unheated foundations, however, design information for heated foundations is very limited. Insulation levels on heated foundations will affect the heat loss to the surrounding soil and hence the depth of frost penetration.

The paper presents long term measured frost penetration and soil conductivity data for four typical heated residential foundations. Graphical relationships (modified design curves) between frost depths and freezing indices are presented and compared with open field (unheated) conditions.

KEY WORDS

Frost, frost depth, soil, soil conductivity, foundation insulation, design curve.

INTRODUCTION

THE PROBLEMS ASSOCIATED with frozen soils around foundations are of concern to building designers. When soils freeze to structures and then

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undergo dimensional changes, substantial structural stresses can be imposed. This situation, known as adfreezing [1], can (in principle) be aggravated when insulation is added to below grade heated structures. The reduction of the heat flow into the ground will cause a corresponding reduction in the temperature of the surrounding soil. A second situation (frost heave) can also develop if the frost depth increases to the point where freezing occurs under the foundation. If the soil expands upon freezing (frost susceptible soil) large uplifting forces can be applied to the foundation system [2].

If foundation designers are to avoid these problems, they require information about frost in soils surrounding foundations. When unheated foundations are involved, design curves can be used to predict the depth of frost penetration. These curves relate the depth of frost penetration to the air freezing index (cumulative °C days below freezing). The U.S. Corps of Engineers produced one curve for predicting frost penetration based on soil temperature data from snow cleared airport runways [3] and this curve was later modified by Brown [4] to incorporate additional data. Louie [5] has also reported design curves which account for various soil types and 0.3 m of snow cover. These methods do not take into account specific soil properties or site conditions but may represent the "worst case" situation for unheated soils.

Foundations for heated structures pose additional problems for designers since the depth of frost penetration will be further influenced by the amount of heat gained by the soil from the foundation. Heated foundations with various insulation configurations are common components of modern buildings. In particular, basement insulation has been adopted as a method for reducing heating energy requirements for residences. As insulation levels are increased, the surrounding soil temperatures will fall and frost penetration depths will increase. In the case of very high insulation levels, frost penetration will approach the design curve presented by Brown.

The selection of the insulation system for a basement is governed by two basic criteria:

1) Determine the optimal thermal resistance based on comfort and economic considerations.
2) Ensure that the installation of this insulation will not cause subsequent problems with adfreezing or frost heave. In frost susceptible soils, the most common solution is to prevent the soil from freezing.

The first criterion can be evaluated by comparing the energy cost of the below grade heat loss with the cost of the insulation system. Several simplified methods are available [6,7] for calculating below grade heat losses. To date, the second criterion has been primarily investigated in theoretical studies. Numerical techniques exist for calculating soil temperatures; however, they require accurate data on foundation design, boundary conditions and material properties and behavior.

Moisture content, soil component conductivities, grain size distribution, density and temperature are all known to have an effect on the thermal conductivity of soils. In his comprehensive summary of the methods for calculating soil thermal conductivity, Farouki [8] has shown that there is a wide variation in the predicted values based on these available methods. Furthermore, all of these methods require detailed information on the moisture conditions within the soil (moisture content and distribution). Precipitation, surrounding trees and structures, temperature and surface cover are just some of the many factors that influence the soil moisture conditions around basements.

This report summarizes six years of frost penetration data measured around four residential foundations in Saskatoon, Saskatchewan. These data are compared with Brown's design curve and provide a method for estimating frost penetration adjacent to similar insulated foundations. The soil temperature and thermal conductivity data also comprise a data base that may be used by other researchers for comparison with analytical models. The basements had various insulation configurations and structural designs. An earlier paper [9] outlined specific site details and preliminary frost penetration data. Field measurements of the soil thermal conductivity were taken (at approximately two week intervals) from November, 1984 to October, 1985.

FOUNDATION DESCRIPTIONS

Houses A, B, and C are occupied, single-family residences with full basements. Houses A and C have electric resistance forced air heating systems, house B has a natural gas forced air furnace. Building D is a wood-framed single storey garage/workshop with a natural gas forced air furnace. The foundation is a slab-on-grade, with a thickened edge to provide structural support and to accommodate a forced air duct. Specific house details are given in Table 1 and Figure 1. Detailed house descriptions can be found in Reference 9.

MEASUREMENT SYSTEMS

The soil temperatures at each site were measured on a two dimensional grid perpendicular to the foundation at approximately the mid point of a long straight wall (Figure 1). The temperatures were measured using 24 gauge type T (copper-constantan) thermocouples. The thermocouples were soldered and sealed with lacquer to prevent corrosion [10]. They were in-

Table 1. Foundation detail summary.

House Code	Soil Type	Depth of Footing Below Grade (m)	Below Grade Wall Insulation (RSI)	Floor Insulation (RSI)
A	Sand 50% Silty Clay 50%	2.26	7.7	3.5
B	Sand 98% Silt 2%	1.83	3.5	0
C	Sand 94% Silt 6%	0.92	7.7	3.5 (plus horizontal rigid insulation outward at top of footing)
D	Sand	0	N/A	1.8 (rigid insulation on edge of slab and 0.6 m horizontally under slab)

serted down 38 mm diameter augered holes and the holes were backfilled with existing soil. An additional thermocouple was installed at the inside wall surface of houses A and B. The temperatures were obtained using a DORIC model 477 digital thermocouple calibrator/indicator calibrated to within ±0.3°C for the temperature range of +25°C to −20°C. Soil temperature and snow cover measurements were taken on a monthly basis until October, 1983. Due to equipment failure, soil temperatures were not measured during the winter of 1982–83.

Soil conductivity measurements [11] were taken with NRC designed and calibrated thermal conductivity probes with accuracies of ±4%. The probes are 0.5 m long, 3 mm diameter stainless steel rods with an internal heater and temperature measuring thermistor. Probes were installed horizontally, perpendicular to the foundation (Figure 1). Field measurements were taken approximately every two weeks from November, 1984 to October, 1985. Grain size analyses were obtained from soil samples taken during thermocouple installation (Table 1).

Atmospheric Environment Service weather records for the Saskatoon monitoring station [12] were used to obtain the maximum depth of frost penetration in an open field under natural snow accumulation conditions.

The freezing index (FI) is defined as "the cumulative total of degree days of air temperature below freezing during the entire winter. The FI is calcu-

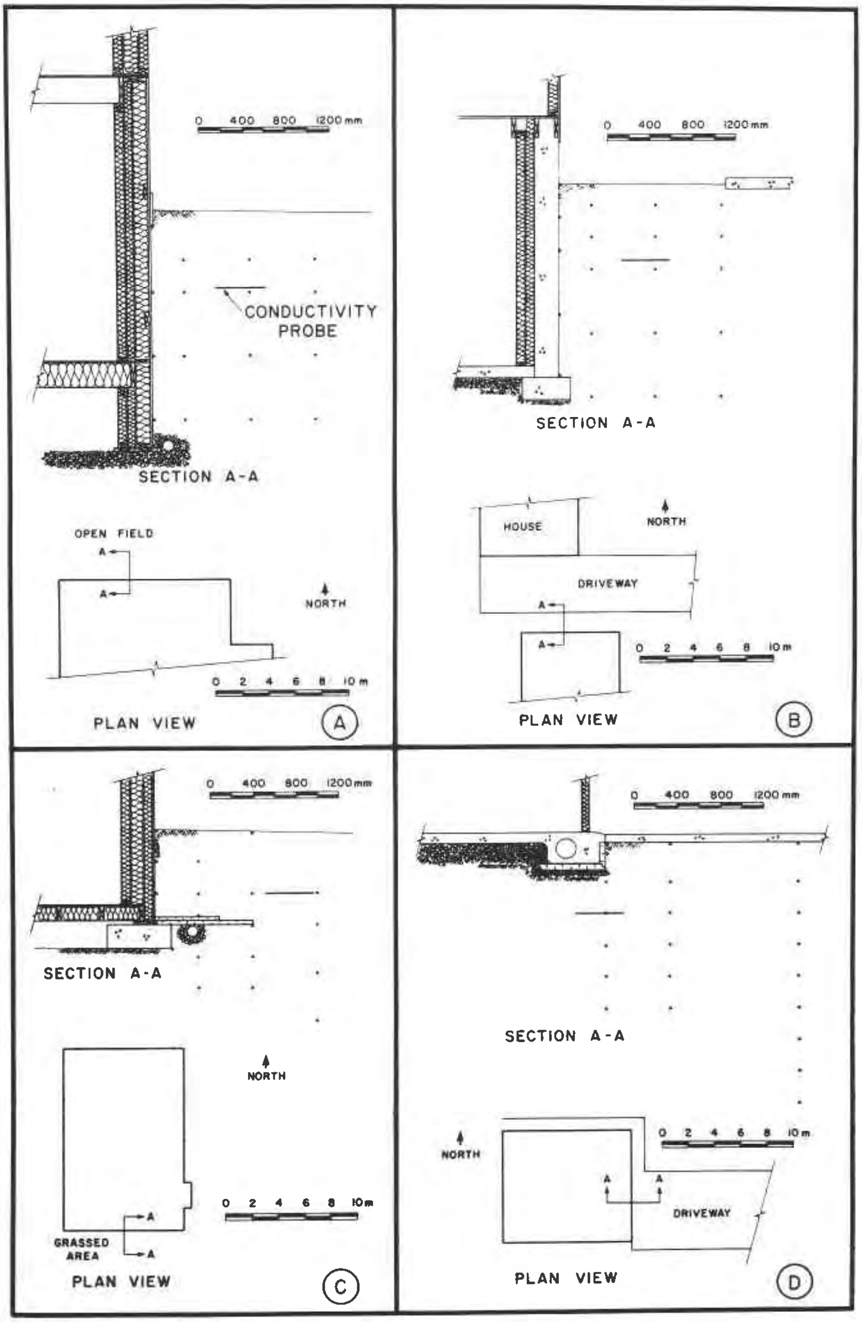

FIGURE 1. Plot plans and cross sections for foundations A-D.

lated using the mean daily temperatures with subtractions for days above freezing" [2].

The mean daily outdoor air temperatures for Saskatoon were taken from Environment Canada weather summaries [12].

Initially, natural snow cover was allowed to accumulate over the monitoring sites. For the winters of 1983–84 and 1984–85, snow was removed from the sites and the surrounding area.

RESULTS

Conductivity

The measurements of the soil thermal conducitivity and surrounding soil temperature for each site are shown in Figure 2. The soil conductivities show annual cyclic variations consistent with changes in temperature and moisture conditions. These observations are consistent with data from an earlier study by Goodrich [13] where long term measured data from four test sites is presented. Detailed discussions of the data for each site follow.

FOUNDATION A

The thermal conductivity probe was located on the north side of the house; 0.86 m out from the foundation, 0.71 m below grade and 0.6 m west of the thermocouple field. In early November, 1984, the soil was frozen to 50 mm below the surface and may have been at its driest point. As soil water froze with colder soil temperatures, the conductivity increased.

Measured soil thermal conductivities ranged from 0.9 W/m · K** in early December when the soil was unfrozen to 1.27 W/m · K in early April when the soil was frozen. The soil was frost free from the conductivity probe depth to the soil surface in early May. In June and July, the soil conductivity remained fairly constant at 1.04 W/m · K and dropped to 1.0 W/m · K from August to October during the drier fall conditions. The constant conductivity readings during the summer and fall are attributed to the moisture holding capacity of the clay portion of the soil. No vegetation, other than grass with limited watering, covers the area involved in the study.

FOUNDATION B

The thermal conductivity probe is located on the north side of the house; 0.86 m out from the basement wall, 0.76 m below grade and 0.6 m east of the thermocouple field.

**The SI Unit, W/m · K, for thermal conductivity is the mathematical reduction of $W/m^2(K/m)$.

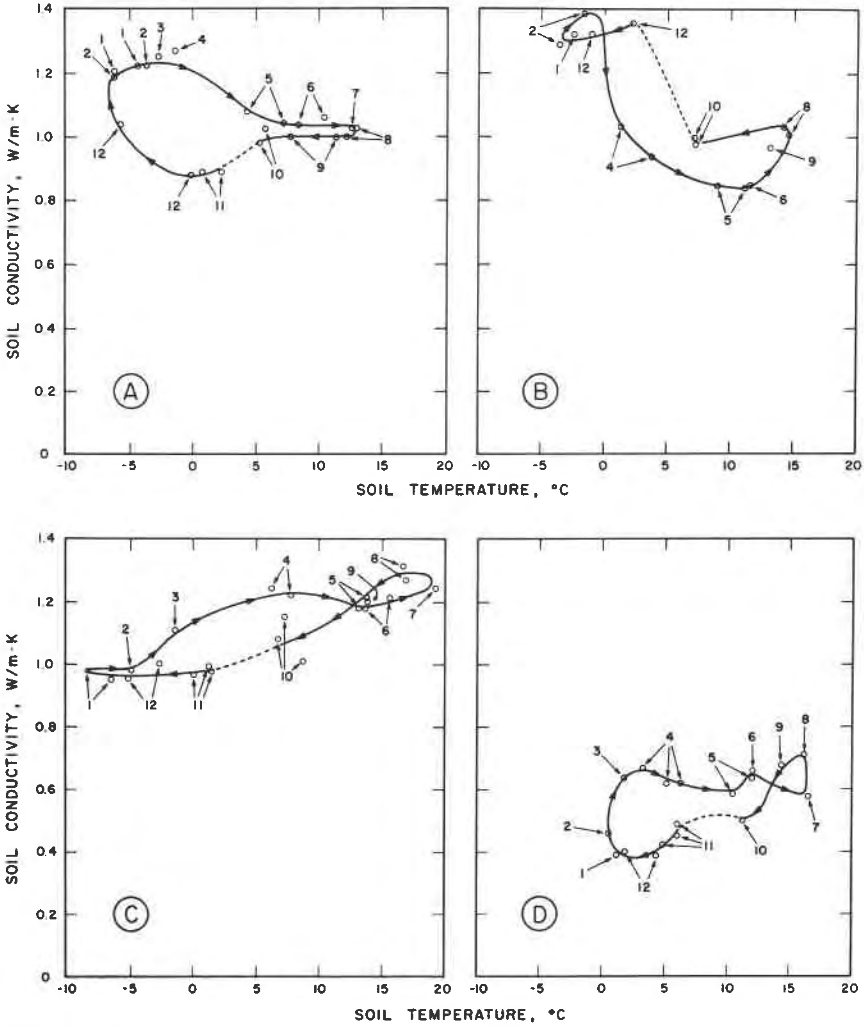

FIGURE 2. Measured soil conductivities and temperatures adjacent to foundations A-D (numbers 1 to 12 correspond to months January to December).

As for foundation A the soil was frozen to the 50 mm depth starting in November, but thermal conductivity readings did not start until December 5. Soil at the thermal conductivity probe did not freeze until near the end of December but remained frozen until March. As freezing at the probe occurred, the conductivity dropped slightly to 1.29 W/m · K and then gradually increased until late February to 1.39 W/m · K. The soil conductivity dropped very rapidly after the beginning of thawing in March to a low of 0.84 W/m · K in late May. The soil conductivity rose steadily until late August (1.03 W/m · K) and then decreased slowly in the fall to a value of 1.0 W/m · K in late October. The plotted data shows that in the spring, after surface thawing and the disappearance of melt water, the soil conductivity drops rapidly. The sudden rise in conductivity in the late fall corresponds to 59 mm of rainfall in October (35 mm on October 16).

FOUNDATION C

The thermal conductivity probe is located on the south side of the house; 1.36 m out from the foundation wall, 0.63 m below grade and 0.6 m east of the thermocouple field. Beginning on November 7, with the soil surface frozen, the soil thermal conductivity remained constant (0.95 W/m · K) until late February. The conductivity then gradually increased to 1.24 W/m · K by mid April when the soil had thawed and was at a higher water content than during the winter months. The summer to fall readings show a change from 1.2 W/m · K to 1.3 W/m · K. Lower June and July readings could be due to solar drying at this southern exposure. From late August to October, the soil conductivity dropped steadily from 1.3 W/m · K to 1.06 W/m · K when readings ceased. This drop is similar to foundation B which also has a high percentage of granular soil, the only difference being the magnitude of the decrease which is probably due to the higher water content of the soil at the northern exposure for foundation B.

FOUNDATION D

The thermal conductivity probe is located 1.22 m south of the north east corner of the building and 0.76 m below grade with the probe centre directly below the east edge of the slab. Beginning on November 7, with the soil surface frozen, the soil conductivity dropped from 0.49 W/m · K to 0.39 W/m · K in early December. It remained constant until the end of December when the freezing plane began to approach the conductivity probe. The soil conductivity then began to increase steadily until March when surface thawing and the recession of the freezing front increased soil water content and thus the soil conductivity to 0.63 W/m · K. By the middle of March the soil was frost free from the probe depth to the soil surface. This left the soil free to be dried by a small shrub and air evaporation thus lowering the soil conductivity from 0.64 W/m · K on April 2 to 0.59 W/m · K on May 17. In late May, lawn watering increased the soil water content and increased the soil conductivity to 0.66 W/m · K by mid-June. A decline in conductivity to 0.58 W/m · K on July 30 followed. The sudden increase in soil conductivity by late August (from 0.58 W/m · K July 30 to 0.71 W/m · K August 29) could be attributed to 10.5 mm of rain near the end of August plus excess lawn and shrub watering near the probe location. From late August to October, the soil conductivity decreased in this sandy soil as it did for foundations B and C.

Frost Penetration

The modified design curve for each foundation relates the maximum freezing index with the maximum depth of frost penetration. The actual freezing index at the soil surface will be affected by snow cover, wind speed and incident solar radiation, since these factors can cause the soil surface temperature to vary from the ambient air temperature. However, for this report, the original definition of the freezing index was used to calculate the FI values for the modified design curves. The modified design curves are based on measured maximum depth of frost penetration and FI data collected for a number of years. Therefore, the effect of annual changes in soil thermal conductivity and moisture content, snow cover and indoor air temperature must be accounted for. In this report, it is assumed that the average annual soil conductivity and moisture content did not vary significantly from year to year. The effect of snow cover was minimized by removing the snow from the sites on a regular basis. Since the buildings were privately owned and occupied, the basement air temperatures could not be controlled. The indoor temperatures were measured (or estimated) during each site visit.

To account for year to year variations in the indoor air temperature, the measured maximum depth of frost penetration for each year was adjusted to correspond to a common (reference) indoor air temperature. To do this, it was assumed that, for a given FI, the depth of frost penetration is inversely proportional to the annual heat input to the soil from the foundation. The following analysis was then applied:

Mitalas' model [6] assumes that the heat loss from a heated basement element is proportional to the temperature difference across the element and the over-all conductance. The instantaneous heat flux, $[q(t)]$, is the sum of a steady-state component (q_a) and a component which varies with time:

$$q(t) = q_a + q_v \cdot \sin(\omega t) \tag{1}$$

where q_v = a constant. Since the annual integral of the variable component of the heat flux will be zero, the annual heat loss from the foundation (or heat gain to the soil), Q_a, is approximated by the time integral of the steady-state component:

$$Q_a = \int_0^t q_a \, dt \tag{2}$$

From Mitalas' paper,

$$q_a = S \cdot (\theta_B - \theta_G) \tag{3}$$

where

S = a shape factor (constant) for the steady-state heat loss component ($W/m^2 \cdot K$)
θ_B = yearly average basement air temperature (K)
θ_G = mean ground temperature (K)

Evaluating Equation (2) for a 12-month period, the following expression is obtained:

$$Q_a = [S \cdot (\theta_B - \theta_G)]8.67 \quad \text{(kWh/year)} \tag{4}$$

Following the initial assumption that, for a given foundation/insulation configuration, the measured maximum depth of frost penetration (FD) is inversely proportional to Q_a, we can write:

$$FD = \frac{Z}{S(\theta_B - \theta_G)\,8.67} \tag{5}$$

where Z = constant of proportionality.

For the adjusted depth of frost penetration (FD_M) based on the mean indoor air temperature:

$$FD_M = \frac{Z}{S(\theta_M - \theta_G)\,8.67} \tag{6}$$

where θ_M = mean of the yearly average indoor air temperatures (mean indoor air temperature).

Combining Equations (5) and (6), we obtain:

$$FD_M = FD \times \frac{\theta_B - \theta_G}{\theta_M - \theta_G} \tag{7}$$

Equation (7) was used to calculate FD_M values from the yearly measured values. Using the method of least squares, a logarithmic relationship (modified design curve) was fitted to the paired values of FD_M and FI. These modified design curves are given in Figure 3. For reference, the design curve given by Brown [4] is also shown.

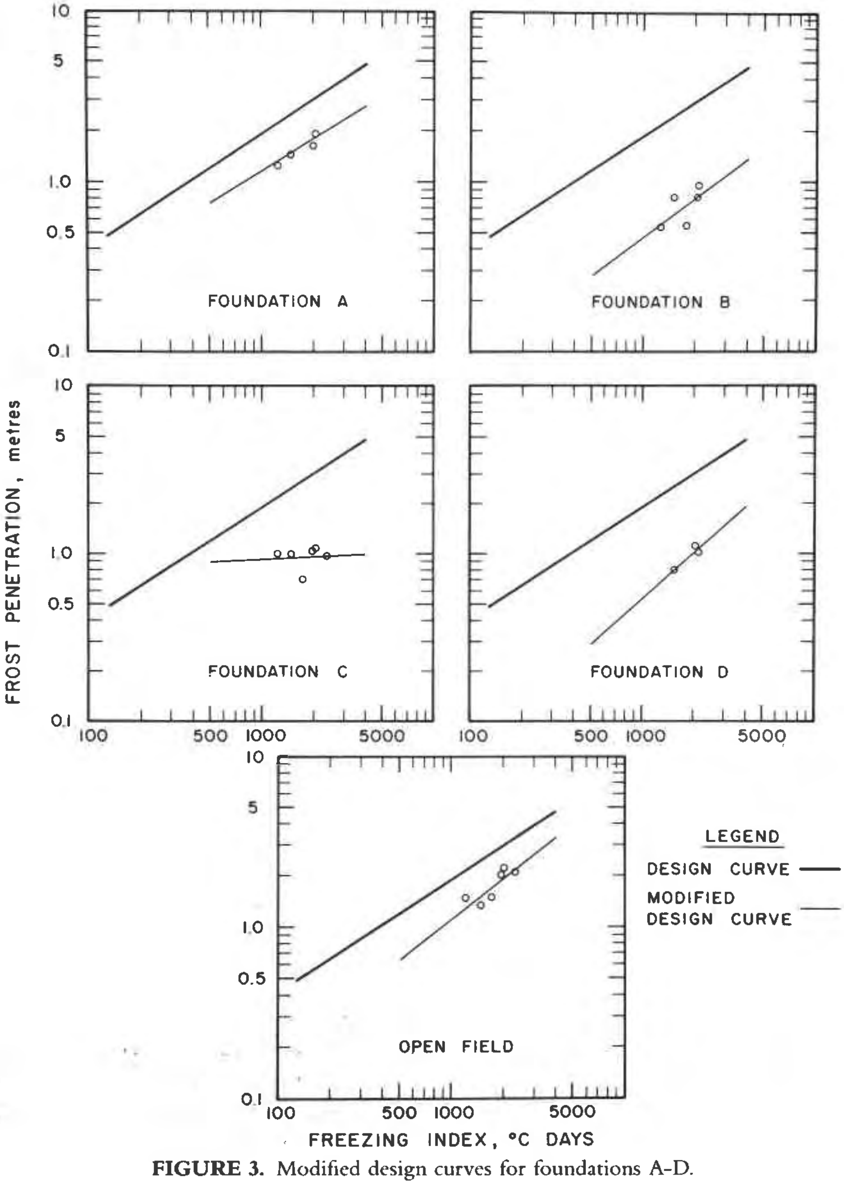

FIGURE 3. Modified design curves for foundations A-D.

FOUNDATION A

The results for foundation A show that the modified design curve has a slope similar to the design curve but is shifted downward. The actual frost penetration was approximately 65% of the design curve prediction. The modified design curve is based on a mean indoor air temperature of 18.9°C, RSI 7.7 wall insulation, RSI 3.5 insulated suspended wood floor and an average measured soil thermal conductivity of 1.06 W/m · K. For all years, the site was essentially clear of snow cover.

FOUNDATION B

The modified design curve for foundation B has the same slope as the design curve; however, the measured frost penetration was only 26% of the design curve value. The modified design curve is based on a mean indoor air temperature of 19.4°C, RSI 3.5 wall insulation, an uninsulated concrete floor slab and an average measured soil thermal conductivity of 1.08 W/m · K. The smaller frost penetration value at FI = 1757°C day corresponds to a natural snow accumulation of approximately 0.3 meters. For the remaining years, the site was essentially clear of snow cover.

FOUNDATION C

The maximum frost depth for foundation C did not follow a typical design curve relationship due to the interference of the horizontal insulation skirt at the top of the footing. The frost depth reached the bottom of the insulation depth (0.90 m) for all years (except FI = 1757) but did not go below the bottom of the footing. The shallower frost depth for FI = 1757 may have resulted from a snow cover of approximately 0.15 m. For the other years, the site was essentially snow cleared. The modified design curve relationship is based on a mean indoor air temperature of 20°C, RSI 7.7 wall insulation, RSI 3.5 insulated suspended wood floor, RSI 2.6 insulation over the footing and an average measured soil thermal conductivity of 1.11 W/m · K.

FOUNDATION D

The modified design curve for foundation D has a slightly steeper slope than the design curve and the measured frost penetration was only 31% of the design curve value. The modified design curve is based on a mean indoor air temperature of 18.0°C, RSI 1.75 insulation on the footing and an average measured soil thermal conductivity of 0.54 W/m · K. The site was continuously snow cleared.

OPEN FIELD

The results for the open field frost penetration data show a curve almost parallel to the design curve. The modified design curve is shifted downward, indicating 62% of the design curve prediction. This offset could be the result of several factors including:

1) *Snow cover*:
The design curve is based on snow cleared conditions. Measured, naturally occurring snow accumulation for the open field site ranged from 2–30 cm.
2) *Soil conductivity*:
The design curve is based on airport pavements with granular base courses. The soils around all of the foundations and at the open field site were much finer grained. Also, the airport pavement would act as an effective moisture barrier; thus the moisture content for the granular base beneath the runway would be much lower.

DISCUSSION

In addition to being necessary input data for predicting the depth of frost penetration, soil thermal conductivity data are needed for calculating the below grade heat loss from a structure. Since low-energy houses typically have a higher ratio of below grade heat loss to total building heat loss than other buildings, errors in the below grade heat loss calculations can produce significant errors in the overall energy consumption calculations. For most below grade heat loss calculation routines, the user is required to specify a soil thermal conductivity, although this is normally a constant. Only by making successive, iterative calculations can the designer account for seasonal variations in soil thermal conductivity. It is recognized that conductivity will vary with depth; however, this characteristic was beyond the scope of this study. For foundation A the average measured soil conductivity was 1.06 W/m · K with an annual variation of −17% to +20%. For foundation B, C and D, the values were 1.08 W/m · K (−22% to +29%), 1.11 W/m · K (−14% to +18%) and 0.54 W/m · K (−28% to +31%), respectively.

When integrating the instantaneous heat loss of a building over a year to calculate the annual heating energy consumption, accounting for the variation in the soil thermal conductivity will allow more precise estimates.

Foundations B, C and D are located in high sand content soils (98%, 94%, 100%). Published [7] soil conductivity data for this soil type suggest a range of values from approximately 1.7 W/m · K for wet sand to 0.2 W/m · K for dry sand. The annual average soil conductivity values of 1.08 and 1.11 W/m · K for foundations B and C are consistent with physical observations of damp, sandy soil. The sand around the heated foundation of building D had a much lower average conductivity (0.54 W/m · K), indicating drier soil conditions than foundations B and C. The perimenter heating system would cause moisture to migrate from the probe area to colder soil.

Foundation A had a higher percentage of silt and clay than the other locations; however, the average measured soil conductivity was similar (1.06 W/m · K). These data compare well with a published [7] value for sandy, silty clay of 1.1 W/m · K.

Although limited, the frost penetration data for these locations is representative of the in situ performance of a variety of common residential foundations. The data in Figure 3 clearly show that increasing the amount of foundation insulation will result in an increased depth of frost penetration. Even the severe prairie climate, however, did not cause frost depths to go below the foundations that were studied in this report.

The modified design curve for foundation A shows that the heavily insulated basement closely approximates the open field frost penetration case.

With respect to construction style and insulation levels, foundation B represents a typical residential basement. Because of the moderate level of wall insulation and uninsulated floor slab, the frost penetration is relatively shallow when compared to the open field location.

Since building C has a heavily insulated foundation, the frost penetration may follow a modified design curve similar to the open field at low values of FI. The shallow foundation and horizontal insulation allows frost penetration to reach the insulation depth even during mild winters (FI = 1249°C day); however, the frost depth did not go below the footings during a severe winter (FI = 2409°C day). This observation highlights the necessity of providing frost protection for shallow, well insulated foundations.

Structure D, with wraparound insulation on the slab perimeter and in-slab perimeter heat, is not representative of common slab buildings. Typically slab buildings would have vertical insulation only. This vertical insulation configuration should allow more heat flow to the soil at the perimeter and reduce frost penetration under the slab perimeter.

CONCLUSIONS

The data from this study, while limited, provides some basic, long term information on the depth of frost penetration adjacent to insulated foundations.

1) Frost depth adjacent to the highly insulated basement (RSI 7.7 walls and RSI 3.5 floor) approximated the open field conditions.
2) The conventional concrete foundation (RSI 3.5 walls and uninsulated floor slab) had only 42% of the open field frost penetration.
3) Horizontal insulation over the footings of a well insulated shallow foun-

dation (RSI 7.7 wall and RSI 3.5 floor) was necessary to prevent frost from penetrating under the footings.

4) The horizontal insulation under the thickened perimeter of the slab on grade foundation resulted in frost penetration below the slab.

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REFERENCES

1. Penner, E. and K. N. Burn. "Adfreezing and Frost Heaving of Foundations," *Canadian Building Digest*, 128, Division of Building Research, National Research Council of Canada (1970).
2. Penner, E. and C. B. Crawford. "Frost Action and Foundations," Division of Building Research, National Research Council of Canada, NRCC 21089 (1983).
3. U.S. Corps of Engineers, Addendum No. 1, 1945–47, to report on Frost Penetration, 1944–45, Boston (1949).
4. Brown, W. G. "Difficulties Associated with Predicting Depth of Freeze or Thaw," *Canadian Geotechnical Journal*, 1 (1964).
5. Louie, T. M. "Freezing Index and Frost Depth," Technical Bulletin No. 88. Construction Materials Research and Development, Dow Chemical Canada Inc. (1979).
6. Mitalas, G. P. "Basement Heat Loss Studies at DBR/NRC," Division of Building Research, National Research Council of Canada, NRC 20416 (1982).
7. MacDonald, G. R., D. E. Claridge and P. A. Oatman. "A Comparison of Seven Basement Heat Loss Calculation Methods Suitable for Variable-Base Degree-Day Calculations," *ASHRAE Transactions 1985*, Vol. 91, Pt, 1B, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta (1985).
8. Farouki, O. "Evaluation of Methods for Calculating Soil Thermal Conductivity," CRREL Report 82-8, U.S. Army Cold Regions Research and Engineering Laboratory (1982).
9. Figley, D. A. and L. J. Snodgrass. "The Effect of Basement Insulation on the Depth of Frost Penetration Adjacent to Insulated Foundations," *Journal of Thermal Insulation*, 7:266–294 (April, 1984).
10. Johnson, G. H. "Instructions for the Fabricating of Thermocouple Cables for Measuring Ground Temperatures," National Research Council of Canada, NRCC 7561 (1963).
11. Goodrich, L. E. "Transient Probe Apparatus for Soil Thermal Conductivity Measurements," Associate Committee Geotechnical Research, pp. 44–55 (June, 1979).

12. Atmospheric Environment Service, Daily Soil Temperature Data 1977–1985, Environment Canada, ISSN 0703-6523.

13. Goodrich, L. E. "Field Measurements of Soil Thermal Conductivity," *Canadian Geotechnical Journal*, 23(1)51–59 (1986).

BIOGRAPHIES

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