Frost-protected Shallow Foundations: Applying FPSF Technology

by Steve Belzak, C.B.O.
Lead Plans Examiner
City of Spokane
Spokane, Washington

*Involved in building codes since 1980, **Steve Belzak, C.B.O.,** is lead plans examiner for the City of Spokane, Washington. Mr. Belzak holds ICBO certifications in five categories and is certified by the Council of American Building Officials as a building official and by the National Academy of Code Administration as a professional code administrator. He functions as a codes consultant to public and private agencies, local jurisdictions and industry; is a member of the Association of Energy Engineers; and participates in code simplification activities.*

INTRODUCTION

In 1992, the City and County of Spokane, Washington, in conjunction with the Spokane Home Builders Association, established a City/County/Industry Code Coordination Committee to provide cooperation and coordination among code administrators and the construction industry. An ongoing concern of the committee has been the declining affordability of new housing. The potential application of new construction technologies and methods to meet affordability concerns fostered the creation of a subcommittee of code administrators, home builders and geotechnical engineers who agreed to study foundation design. One of the targets of this subcommittee has been to research the application of frost-protected shallow foundation (FPSF) technology to local construction conditions. This article is an outgrowth of that research.

Background

Frost-protected shallow foundation technology is nothing new. It has been accepted in Scandinavian building codes for more than a quarter of a century; it is estimated that over one million frost-protected shallow foundation applications have been constructed for residential and commercial buildings in Finland, Norway and Sweden. In these countries, the benefits derived from FPSF have resulted in the almost complete conversion from basements and deep crawl spaces to FPSF in a short period of time.

The first FPSF studies were undertaken in this country during the late 1940s. It wasn't until the 1980s, however, that this technology was seriously considered as an alternative construction practice in the United States.

Frost-protected shallow foundations have the potential to save construction costs and reduce the amount of energy used for residential space conditioning. Studies have projected an estimated national savings of more than $330 million per year in construction costs and energy savings of nearly 2 trillion British thermal units per year in 10 years for residential building applications.

The views expressed here are those of the author and do not necessarily reflect the opinion or agreement of the International Conference of Building Officials.

This article should help foster an understanding of the FPSF concept and proposes ways to employ the FPSF approach as a recognized alternative to conventional foundation systems.

FPSF CORE PRINCIPLES

Frost-protected shallow foundations are the result of scientific research into the behavior of soils and frost action in soil. The basic principles behind FPSF are not complicated and are predicated on a few very basic discoveries.

The earth's geothermal heat is generally sufficient to prevent deep ground soil frost penetration when insulation is installed close to the earth's surface. The penetration of freezing temperatures into soil is based on three factors:

1. The thermal conductivity of the soil.
2. The "heat capacity" of the soil.
3. The latent heat of fusion (the heat released in the phase change from liquid to solid).

TABLE 1—FREEZING AND HEAVING INDEX FOR SOIL TYPES

TYPE OF SOIL	FREEZING SUSCEPTIBILITY	FROST HEAVE SUSCEPTIBILITY
Sands, gravel	High	Low
Clay	Low	Low
Silts	Medium	High
Turf, peat	Low	Medium

Table 1 is a freezing and heaving index for different soil types. The reader will note a disparity between the freezing and heaving potential for different soil types. Coarse sand and gravel generally will freeze the fastest because they contain less water than other soil types. Less latent heat is therefore involved in the phase change process for these materials. For example, a large body of water takes longer to freeze solid than a smaller body of water. Coarser soil types freeze easily, but do not support heaving (the expansion of water in soil). Fine-grained soils such as silt, on the other hand, do not freeze as easily, but support frost expansion. This phenomenon will be explained further through a discussion of frost action in soils.

Frost Penetration in Soils

Water expands approximately 9 percent by volume when it freezes. In coarser soils (sand, gravel), minimal frost expansion occurs because the "free area" between soil particles is taken up with homogenous freezing, i.e., the space between the soil particles takes the frozen expansion and soil particles are not displaced. Such coarse soils will freeze, but will not *heave* unless poor drainage or high water table conditions exist. There is little capillarity in these soils.

Although possessing the smallest soil particles, clays are not particularly susceptible to freezing for another reason—the lack of permeability in most clays does not support capillarity. To illustrate this, consider that dams can be constructed of clay. Of course, clay may be unsuitable for foundations for other reasons, but it does not generally support frost expansion.

Top soils with a high degree of humus, such as peat or turf, do not freeze very readily because of the insulating effect of the humus material.

Silty types of soil are generally the most susceptible to frost heave. Silts do not freeze as readily as coarser grain soils but they are permeable and readily support capillary action.

Frost Heave in Soils

Structural frost heave damage to buildings typically occurs because of the growth of "ice lenses" in the soil supporting the structure, so called because they resemble in shape lenses with the convex (or "bulging out"—think of your belly) side closest to the top of the soil surface.

These crystalline lenses are created by moisture migration in the soil toward the area of freezing temperatures in the soil. The formation of these lenses requires a stable period of freezing temperatures, a water supply and a degree of capillarity in the soil. Water moves through surrounding soils through drainage action or via a water table. This water reaches a "freezing front" in the ground and solidifies. Additional water is "pumped" to this freezing front via capillary action. The crystalline lens structures grow and expand, exerting upward pressure on the adjoining soils. The ground heaves at right angles to the frost line, which is usually in plane with the surface of the ground. Most heaving will therefore occur upward (at right angles from the ground). Under certain conditions, such as at a retaining wall, frost heave can occur in a horizontal fashion. Frost will penetrate through the retaining wall, freezing the earth behind the wall, and then push horizontally against the wall surface.

For frost heave conditions to develop, it is necessary to have frost-susceptible soil, freezing ground temperatures, a water source and a transport mechanism. Ice lenses will grow in the soil at the line of freezing, drawing water through capillary action. All four elements noted above must be present for frost heave to occur. Appropriate placement of perimeter insulation will prevent freezing ground temperatures at the building foundation. The use of nonfrost-susceptible substrates under the footings will prevent capillary action and frost-expansion effects. Control of bulk moisture sources will mitigate the availability of surface drainage water to the frost front. All the physical factors that generate frost heave can therefore be controlled or manipulated by using simple techniques.

Thawing Process

During the typical spring heat wave, the majority of soil mass will thaw from the top down. Some geothermal heat will also move in from below. Drainage is blocked by frozen soil layers underlaying the upper thawing surface. Soil in this condition is in a very plastic state and deformation occurs readily.

Adfreezing Phenomenon

An interesting condition termed "adfreezing" has occurred in frost-susceptible climates. In this situation, the frozen ground actually adheres to the exterior sides of building foundation walls and lifts them upward. In this condition, frost may never penetrate to foundation depth, but frost lifting of adjacent vertical wall surfaces has occurred. The destructive potential of adfreezing was demonstrated in Finland, where heavy winter rains of 1986 followed by -30°F (-34.4°C) temperatures (a 100-year event) damaged 1 percent of FPSF foundations in that country. As a result, new FPSF designs specify exterior insulation or the placement of a thin membrane between the ground and exterior foundation walls.

FROST DEPTH RESEARCH

Before FPSF core principles can be applied to a given climate area, it is essential to use accurate climatic data. Traditionally, data related to frost depth have been obtained from cemetery and right-of-way excavations. Such data tend to be conservative.

(continued)

(continued)

Graveyards are typically open, unsheltered and subject to wind-washing. Most right-of-way excavation occurs adjacent to heavily trafficked areas with deep-driven frost. Typically, there are wide variations in measurements observed. An accurate database based on "freezing degree" days and average air temperatures is needed to correctly ascertain frost depth. This database was made available in 1989 when the National Oceanic and Atmospheric Administration developed a generalized air freezing index map for the United States applied to a 100-year-return period.

PRACTICAL APPLICATIONS OF FPSF

The practical use of FPSF design and research is clear. In addition to foundation construction, FPSF applications may include shallow trenching, daylight basements and garage door slab edge protection. These and other applications are discussed below.

Foundation construction. In areas that require deep footing placement to provide frost protection, FPSF [which may allow a foundation depth as shallow as 12 inches (305 mm)] can provide immediate benefits in terms of reduced labor and material costs. For example, only one concrete pour is required to complete an insulated FPSF monolithic slab application. The FPSF insulation may serve as the concrete form work and can be used to satisfy energy code requirements. For daylight basements, FPSF technology can be used to allow a reduced foundation on the daylighted portion of the slab. Frost-protected shallow foundation techniques can be applied to all or a part of a given foundation design, and may be used for conventional foundations, per 1994 *Uniform Building Code*™ (UBC) Table 18-I-D, or for engineered foundation designs.

Garage slabs. Insulation techniques for FPSFs may be used to prevent heaving of the exterior edge of garage slab floors. In freezing climates, these floors tend to rise at the center (the coldest portion) of the garage door opening because cold air moving under the garage door opening cools and freezes the ground beneath the slab, causing the slab to gradually heave at the center of the garage door.

Retaining wall design. The frost line is horizontal in soil, but changes to vertical at the retaining wall face and exerts horizontal pressure against the wall. Damage caused by horizontal thrust in frozen soils can be avoided by placing insulation along the vertical face of the wall. Retaining wall depth can be reduced by placing appropriate insulation (typically extruded polystyrene) under the foundation and extending it horizontally well beyond the base of the wall.

Utility trenches. Shallow-depth utility piping may be placed inside a thick insulated box filled with gravel to prevent crushing or by placing polystyrene board above the piping. In these applications, heat from water or sewer pipes is sufficient to maintain a liquid state—even at a 12-inch (305 mm) bury depth. The required insulation thickness and width for pipe cover can be computed from simple formulas that are readily available.

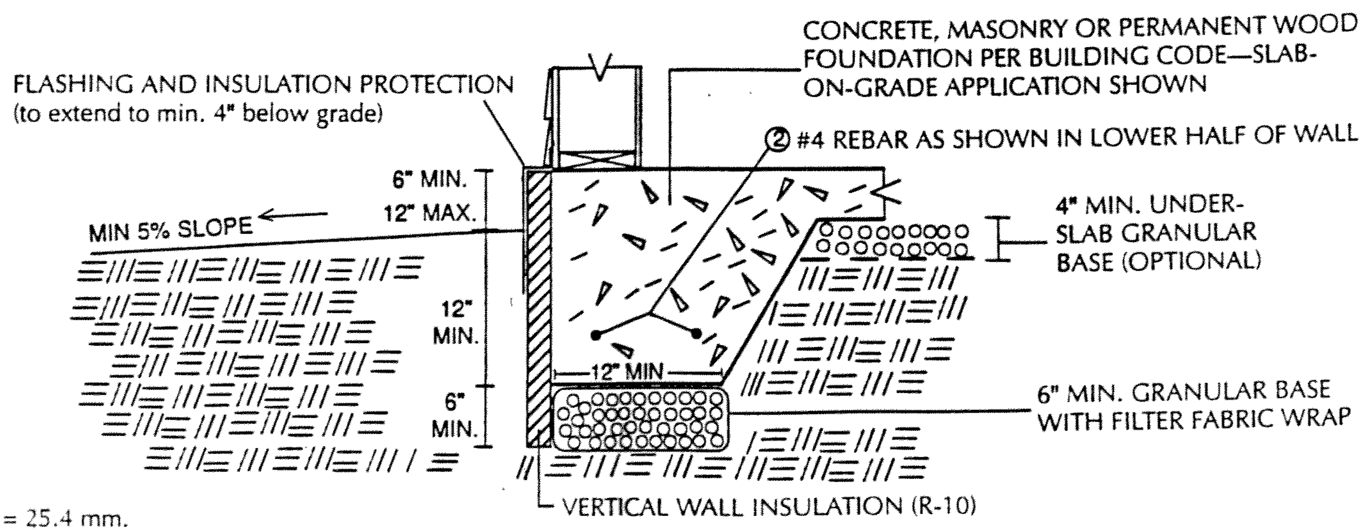
Frost-free foundations. Another application developed from FPSF research, frost-free foundation is very similar to an FPSF foundation except that it is designed to tolerate frozen conditions. Insulation is not required. A typical application would involve digging a trench to the recognized frost depth and filling that trench with appropriate drainage materials (fine-free gravels encased with filter fabric). A shallow concrete foundation would rest on the top of the trench. This application could work well for unheated structures as an alternative to using heavy insulation around the perimeter or under the slab, or both.

FPSF APPROVAL CRITERIA

The following considerations and suggested performance applications explore potential requirements for the application of FPSF technology. These criteria must be considered prior to, and form the basis for, the issuance of detailed regulations.

Moisture Control

1. Ground surfaces must have a minimum slope of 0.5 unit vertical in 10 units horizontal (5% slope) away from foundation walls. It is important that bulk moisture be directed away from foundations.
2. Provide a gravel foundation base (drainage layer) consisting of a minimum of 6 inches (152 mm) of screened crushed rock or clean river gravel $3/4$ inch to $1\,1/2$ inches (19.1 mm to 38 mm) in size. Use of a gravel base provides drainage control and functions as a nonfrost-susceptible substrate. Gravel can be used as an economical method of increasing the footing bearing surface and as an adequate vertical load transfer medium (footing) by itself.
3. A suitable filter fabric is normally used between the drainage layer and ground surface. The fabric will prevent the plugging up of voids in the drainage layer.



For SI: 1 inch = 25.4 mm.

Figure 1—Slab-on-grade application (heated or unheated space)

Interior or Geothermal Heat Retention

1. Vertical polystyrene provided on the outside (or inside surface) of a slab-on-grade foundation wall or on the outside edge (preferably) of a thickened slab (Figure 1). Thickness, placement and depth requirements will vary with climate. One axiom—the higher the foundation wall projects above grade, the thicker the insulation needs to be.
2. Insulation may be placed on the interior or exterior of foundation walls. Exterior insulation is preferred because it provides a thermal mass effect, prevents adfreezing and keeps foundation walls from freezing. Insulation is usually required under the footing when the inside wall face is insulated. To achieve the minimum compressive strength needed in this application, extruded polystyrene with a minimum density of 1.87 lbs./cu. ft. (30 kg/m^3) must be used. Insulation installed in locations other than load-bearing footings may consist of lower-density molded polystyrene.

Insulation must have adequate long-term compressive strength in under-footing applications and, in all cases, must maintain thermal performance properties under freeze/thaw cycling, moisture and other detrimental conditions.

Additional insulation is placed on the ground in "colder" climates and for certain applications. This "wing" insulation projects out (in a parallel plane with the ground surface) from the foundation wall. Wing insulation can be very effective, but difficult to place. It is placed on the ground around the entire building foundation perimeter in very cold climates. Narrow building projections warrant additional placement, i.e., wider or thicker insulation wings around the foundation perimeter.

Code Requirement Checklist

The City and County of Spokane have developed a code compliance checklist as an aid to allow the application of FPSF technology under 1994 UBC Section 104.2.8. The checklist is based on the FPSF approval criteria described above. An Inspector/Contractor's Guide and a Homeowner's Guide for FPSF foundations also have been developed to assist in familiarizing clients with FPSF techniques and applications. A copy of the checklist or related guides are available from the City or County of Spokane building department.

Spokane Climate Application

Spokane has a relatively mild climate with an established frost depth penetration of 36 inches (914 mm). A 12-inch (305 mm) foundation depth [located on top of 6 inches (152 mm) of drainage rock] with R-4.5 vertical exterior foundation wall insulation has been determined to provide the necessary heat retention (as well as a nonfrost-susceptible drainage layer) for heated structures in the Spokane climate. The State Energy Code, however, mandates a minimum exterior foundation insulation level of R-10. Placement of the required (R-10) vertical perimeter exterior foundation insulation, therefore, meets energy codes and exceeds the required level of protection for FPSF. Identical requirements could also be applied to unheated structures because, in most cases, an 18-inch (457 mm) footing depth is all that is currently required. A frost-free (deep granular fill) option could also be used for unheated structures.

Applications in Other Climates

For applications in other climates, the best references available include the National Association of Home Builders' Phase I and II reports and the United States Department of Housing and Urban Development's *FPSF Design Guide for Frost Protected Shallow Foundations.* The National Oceanic and Atmospheric Administration now provides the Air Freezing Index (AFI) and Mean Average Temperature (MAT) data needed for FPSF applications.

SUMMARY

This article presented an understanding of the basic principles related to frost action in soils; practical examples of the application of FPSF technology; general criteria that may allow a building official to accept FPSF technology as an alternative method of construction under current codes; and an explanation of how a specific code requirement checklist was developed and applied to a given climate (1232 AFI/47.2 MAT) for the region of Spokane, Washington.

Frost-protected shallow foundation technology has been used successfully in a myriad of other countries, where it has performed to expectations. It is time to take advantage of the benefits that FPSF offers, particularly as an affordable and flexible alternative to conventional foundation systems. ■

ACKNOWLEDGMENTS

The author wishes to acknowledge Bob Eugene, Jim Manson, David Nakagawara, Joseph Wizner, Kim Goodman and Randy Vissia for their contributions to the research that resulted in this article.

BIBLIOGRAPHY

Bariether, Harlan D., et al. (1948). *Temperature and heat loss characteristics of concrete floors laid on the ground.* In cooperation with the United States Department of Commerce, Office of Technical Services, University of Illinois, Urbana, Illinois.

Morris, Richard (1988). *Frost Protected Shallow Foundations.* NAHB Research Center, Upper Marlboro, Maryland.

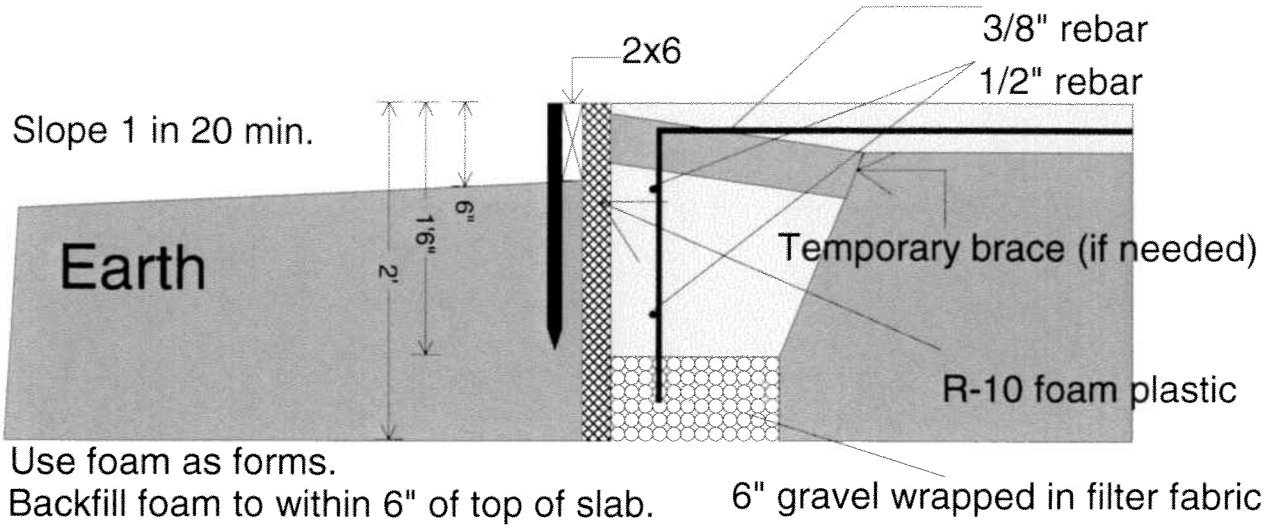
National Association of Home Builders (NAHB) (1988, 1991). *Frost Protected Shallow Foundations—Phase I (Current State-of-the-Art and Potential Applications in the U.S.) and Phase II Frost Protected Shallow Foundation Development Program.* NAHB Research Center, Upper Marlboro, Maryland.

Sterling, Raymond, et al. (1986). *Assessment of the energy savings potential of buildings foundation research.* University of Minnesota Underground Space Center for the Oak Ridge National Laboratory, Urbana, Illinois.

Steurer, Peter (1989). *Methods used to create an estimate of the 100-year return period of the air-freezing index.* National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, North Carolina.

United States Department of Housing and Urban Development, Office of Policy Development and Research (1994). *Design Guide for Frost Protected Shallow Foundations.* Washington, D.C.

Suggested method for forming frost protected shallow foundations



Use foam as forms.
Backfill foam to within 6" of top of slab.
Use 2x6 around the top for added stability.
Temporary braces may be necessary to keep the earth from bowing the foam in, they can be removed as soon as there is enough concrete in the trench to hold the foam in place.
The foam is required to be flashed with metal flashing to at least 6" below finished grade. The foam breaks down quickly in sunlight, and burrowing insects like to nest in it.
Use 3/8" rebar on a 2' grid, and bend every other one into the trench to support footing rebar