Frost-Protected

By Elizabeth M. Steiner

Frost-protected shallow foundation (FPSF) design provides cold weather durability without excavation below the frost line. Recently designated a U.S. Department of Housing and Urban Development's (HUD's) Partnership for Advancing Technology in Housing (PATH) Top Ten Technology for 2004, the FPSF design concept has gained acceptance due to its insulation benefits, energy efficiency, and cost effectiveness.[1]

The FPSF system comprises a rigid foam polystyrene (EPS) insulation foam placed around the outside of a foundation, which directs heat loss from the building toward the foundation and takes advantage of natural geothermal energy.

It is based on the principal that heat loss through a building's foundation keeps the ground beneath from freezing and heaving by raising the frost depth at the foundation's perimeter. For example, the earth surrounding the foundation of a heated building will not freeze as deep as it would under a cleared road or on a windswept hill. It is therefore unnecessary to extend the foundation as deep into the ground as for an unheated building. This is especially true for slab-on-grade foundations with slab-edge insulation where the primary path for heat loss is underneath the foundation wall or footing.

There are two types of frost heave: normal and tangential. The former is vertical—frost lenses build beneath the footings, expand upward, and raise the building. Tangential heaving, on the other hand, occurs when the ground freezes to the foundation. As the ground rises, it adheres (adfreezes) to the foundation and raises the building with it. A strong tangential heaving force can far exceed the weight of a house and foundations. During a thaw, the adfreeze bond can weaken and break, releasing the building. In the United States, foundations are typically begun below the frost line. This method offers little protection against tangential frost heave, especially in unheated buildings.

Frost heave and settlement can cause severe structural damage to buildings. Some traditional foundation materials, which are low in tensile strength and resistance to shear forces, are particularly


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Shallow Foundations

susceptible to cracking. Some other structures are more elastic than concrete—that is, they are more capable of being deformed by frost heave and settlement, and then returning to their original form after the frozen solid thaws and consolidates. However, irreversible damage can also occur to wood buildings when the foundation deforms the building it supports.

Since FPSF relies on the building foundation's thermal interaction with the ground, the frost line near a foundation rises when the building is heated. This effect is magnified when plastic foam insulation is strategically placed around the foundation. For heated buildings, this insulation—along with the earth's geothermal energy—can keep the soil temperature under the building above freezing, preventing frost heave.

In residential projects, garages are particularly susceptible to frost damage since they are usually unheated and typically have high rates of air infiltration. Cold air moving under the garage door can cool and freeze the ground beneath the slab—the floor will show a gradual rise toward the center of the door opening. FPSF works on unheated buildings by conserving geothermal heat below them. Unheated areas of homes may be constructed in this manner.

Design considerations

Changes to frost-protection requirements adopted in the *2003 International Codes* now allow for foundations constructed in accordance with Structural Engineering Institute/American Society of Civil Engineers (SEI/ASCE) 32-01, *Design and Construction of Frost-Protected Shallow Foundations (FPSF).* The code recognizes FPSF use for applications above the design frost line or for those built on solid rock. Realizing benefits in heated, semi-heated, or unheated structures, FPSF promises to help improve frost protection for public access buildings, commercial and office buildings, and one or two-family dwellings.

Using conventional, readily available materials, FPSF is an alternative to stem wall and floating slab foundations, however, it is most suitable for slab-on-grade homes on sites with moderate to low sloping grades. Frost-protected shallow foundation design can be used effectively with walk-out basements by insulating the foundation on the house's downhill side, eliminating the need for a stepped footing. FPSF may also be useful in remodeling projects, as it helps minimize site disturbance. In addition to residential, commercial, and agricultural buildings, the technology has been applied to highways, dams, underground utilities, railroads, and earth embankments.

Except for the insulation placement and footing depth, FPSF is similar to traditional foundations. While traditional systems are protected from frost-heave damage by placing the footing below the frost line, FPSF can be placed just 305 mm to 406 mm (12 in. to 16 in.) below grade in the most severe climates. FPSF insulation is strategically positioned to raise the frost depth around the construction site and direct the building's heat loss downward. When required in colder climates, 'wing' insulation extends outward horizontally from the footing. The colder the climate, the further the wing insulation is extended. This can help reduce excavation depth and amount of concrete, making FPSF an economical alternative for frost-damage protection. (Wing insulation may be unnecessary in moderate climates.)

EPS products have been specified for over 30 years as sub-slab insulation in residential, commercial, and industrial floor systems. With proper slab design, molded EPS insulation can deliver cost-effective thermal performance to the specifier and building owner. ASTM International C 578-04, *Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation,* is the standard covering the types, physical properties, and dimensions of cellular polystyrene intended for use as thermal insulation in the United States. In Canada, the national standard specifying requirements for EPS insulation material is Underwriters Laboratories of Canada (CAN/ULC) S 701-01, *Standard for Thermal Insulation, Polystyrene Boards and Pipe Covering.*

EPS insulation's compressive stress/strain characteristics are determined using ASTM D 1621, *Standard Test Method for Compressive Properties of Rigid Cellular Plastics*, or ASTM C 165, *Standard Test Method for Measuring Compressive Properties of Thermal Insulations.* When selecting a proper density for preliminary design, compressive properties of EPS insulation are available from various resources These properties will vary to some extent depending on the specific manufacturing techniques and raw materials employed.

It is important to note material properties provided in product standards may not allow for the correct material selection for every application when actual design conditions are taken into account. Product standards such as ASTM C 578 and CAN/ULC S 701 are valuable for comparing different types of foam plastic insulation, and for evaluation or quality control purposes. However, North American product standards are rarely intended for use as standards addressing all end-use design conditions.

For instance, determining the thermal resistance in specific end-use application is an inexact science due to the numerous conditions experienced by the rigid foam insulation. However, EPS insulation is a rigid closed cell foam plastic that contains just air within its cellular structure—a characteristic that translates into a stable long-term R-value. R-value measures resistance to heat flow—the higher the R-value, the greater the insulating power.

Advantages of frost-protecting shallow foundations

Thanks to rising energy costs (and an increasing sensibility about environmental issues), energy efficiency and operating expenses are a prime consideration for owners of both residential and commercial structures.

Some expanded polystyrene (EPS) manufacturers recommend a secondary system to provide frost protection—underfloor radiant heating to keep the floors warm. The use of cross-linked polyethylene (PEX) pipes in similar systems was explored in the May 2004 issue of *Modern Materials*.

Builders and code officials initially responded by providing more thermal insulation in the above-grade portions of the home. Uninsulated foundations no longer represent 10 percent to 15 percent of a poorly insulated building's total heat loss. Instead, an uninsulated, conditioned basement may account for up to 50 percent of the heat loss in a house tightly sealed and well-insulated above grade.[2]

Only in the late 1980s were national building energy codes and standards revised to recommend foundation insulation in moderate to cold climates. The minimum requirements generally exceed existing energy code requirements. In addition to the initial cost savings achieved during construction, FPSF provides increased energy efficiencies due to its superior insulation properties. Some practical and economic advantages of FPSF, when installed properly, can include:

Reduction in homeowner utility bills

Insulating any foundation results in warmer floors during winter in above-grade spaces, improved comfort levels, and reduced energy consumption. As FPSF is insulated along the outside edges, it makes floors at the perimeter significantly warmer. It also helps reduce heat loss through the foundation.

EPS and Frost-Protection

Proven performance under tough conditions

ASTM International Committee C 16's test method, ASTM C 1512-01, *Standard Test Method for Characterizing the Effect of Exposure to Environmental Cycling on Thermal Performance of Insulation Products*, assesses the durability of insulation products. This test method began as a draft protocol, part of the 1995 exterior insulation basement systems (EIBS) joint research project conducted by the National Research Council of Canada/Institute for Research in Construction (NRC/IRC) and funded by the Expanded Polystyrene Association of Canada (EPAC).

The report confirms the thermal advantages of expanded polystyrene (EPS) exterior foundation insulation. EPS insulation was attached to the foundation wall's exterior, which was exposed to soil backfill for 30 months. The EPS insulation samples' moisture content removed after this length of exposure was in the range of 0.01 percent to 0.96 percent by volume. The project also instrumented and monitored specimen thermal performance, site weather conditions, and soil moisture content.

Thorough analysis detected water at the foam's outer surface during periods of heavy rain and major thaws, however, the concrete basement wall surface showed no evidence of water penetration through most of its height. The thermal performance of EPS was found to remain stable and was largely unaffected by water movement.

Additionally, EPS' durability in a below-grade application was demonstrated as part of the joint research project. The *in-situ* thermal performance of the insulation material was monitored continuously over the 30-month exposure period and found to be constant. Thermal and mechanical properties of material samples tested after removal from the application were also unchanged. Testing confirmed all types of EPS insulation retained their specified material properties even after being subjected to freeze-thaw cycling.

Test parameters

1. The EPS insulation was directly exposed to high moisture content solid conditions, yet the moisture content after the two-year exposure period was found to be less than 0.5 percent by volume on average.
2. The *in-situ* thermal performance of the EPS insulation was monitored over the two-year exposure period and found to remain constant (*i.e.* there was no loss in thermal resistance).
3. Samples taken from the field exposure underwent laboratory testing to confirm thermal performance and durability. Test results indicated there was no change in material properties after the two-year field exposure.
4. The research project included development of a durability test protocol to provide a means of assessing performance of all insulation types subjected to extreme thermal gradient and environmental cycling. Testing performed by NRC confirmed all types of EPS insulation retained their specified material properties even after being subjected to freeze-thaw cycling.

Testing conducted as part of the project confirmed the method provided valid comparative ratings for the products tested versus field performance. The draft protocol received final approval in October 2001. Measurements of moisture content after long-term exposure in below-grade applications confirm the performance of EPS insulation. Numerous published reports demonstrate water absorption by EPS insulation exposed in actual applications over extended periods of time is much less than values indicated by laboratory tests.

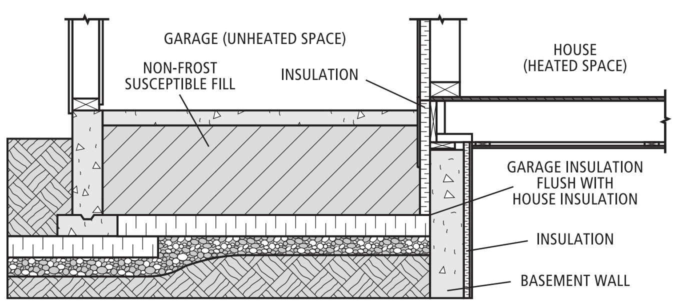

Figure 1. Insulation Detail for Unheated Attached Garage

Depth of Frost Line Below Foundation (D)	Thickness of Insulation (t)
450 mm (18 in.)	25 mm (1 in.)
900 mm (36 in.)	50 mm (2 in.)
1350 mm (64 in.)	75 mm (3 in.)
1800 mm (72 in.)	100 mm (4 in.)

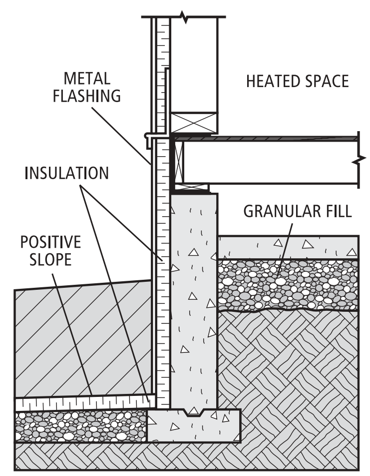

Figure 2. Insulation Detail for Heated Structures

Figure 1 shows the insulation detail for an unheated attached garage, while Figure 2 depict the detail for heated structures. The accompanying table show recommended insulation thickness for a proprietary FPSF system.

Figures courtesy Plasti-Fab Ltd.

Frost-protected shallow foundation insulation is strategically positioned to raise the frost depth around the construction site, and direct the building's heat loss downward. It also can help reduce excavation depth and the amount of required concrete, which may lead to cost savings.

A 1999 study prepared for the Kansas Corporation Commission's (KCC's) Energy Program by Joseph King, AIA, of Coriolis Architecture (Lawrence, Kansas), and Gene Meyer, PE (Kansas State University), showed slab insulation could reduce homeowner energy bills by $50 to $100 per year, depending on the region (in Kansas) and type of heating system. (Since savings vary, one should consult the provider's fact sheet on R-values.)[3]

Creation of more usable, comfortable below-grade spaces
Insulating basement foundations creates more comfortable conditions, helping to make the basement more useable at less cost.

Reduced construction costs
Raising the frost line can reduce construction costs by decreasing excavation depths and disturbing less soil on-site. Research findings from field evaluations in Denver, Colorado, and Freehold Township, New Jersey, show construction/excavation requirements and labor/material costs are 15 percent to 17 percent less for FPSF than conventional foundations. The savings range from $800 to $6000, depending on local frost depths, as well as builder overhead and markups.[4]

Avoidance of health risks due to soil gas
In areas where radon is present, the gas can reach high levels in buildings with poor outside air exchange. FPSF allows for sub-slab depressurization, helping permit the ventilation of accumulated radon beneath the slab.[5]

Notes

1 Together with PATH, HUD's Policy Development and Research Department has conducted extensive research on new building technologies, emerging trends, and other housing issues. The group's Top Ten Technologies for 2004 can be viewed at www.pathnet.org/sp.asp?id=10587.

2 For more information, visit the U.S. Department of Energy (DoE) energy efficiency and renewable energy Web site, www.energycodes.gov, and search for *Residential Insulation Foundation.*

3 Fuller, Robert, "Frost Protected Shallow Foundations," *Builder Magazine.* (May 2004)

4 Fuller, Robert, "Frost Protected Shallow Foundations," *Builder Magazine.* (May 2004)

5 Morris, Richard A., "Frost Protected Shallow Foundations," Society of the Plastics Industry: NAHB/NRC Project No. 2070, August 1998.

About the Author

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Resources

- For more information on frost-protected shallow foundations (FPSF) or other expanded polystyrene (EPS) building applications visit the EPS Molders Association (EPSMA) Web site, www.epsmolders.org.
- The National Association of Home Builders (NAHB) Research Center provides information and answers frequently asked questions on the use of FPSF at www.toolbase.org/fpsf. The Web page addresses FPSF standards, the air freezing index (AFI), mean annual temperature (MAT), radiant floor heating with FPSF, *I-Code* requirements for constructing an unheated garage connected to a home built on FPSF, and methods for insulating additions built on FPSF.
- The AFI table and a MAT map are available at www.ncdc.noaa.gov/oa/fpsf.
- To order a copy of the Structural Engineering Institute/American Society of Civil Engineers (SEI/ASCE) 32-01, *Design and Construction of Frost-Protected Shallow Foundations (FPSF),* visit www.asce.org.
- To order or download the 2004 revised Partnership for Advancing Technology in Housing (PATH) publication, *Design Guide for Frost-Protected Shallow Foundations,* visit www.toolbase.org. For more information on PATH's technology transfer efforts and its Top Ten Technologies for 2004, visit www.pathnet.org.