PDHonline Course S231 (4 PDH)

Basics of Frost Protected Shallow Foundation Design

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Andrew J. Bibb, P.E.

INTRODUCTION:
Section 1805.2.1 of the International Building Code 2003 and 2006 editions requires foundations for all but the most minor of structures to be constructed in such a manner that they will not be adversely affected by freezing of the surrounding and supporting soils. This protection can be achieved by constructing the foundations on bedrock, constructing the foundations so the bottom of footing is below the frost depth of the locality, or by protecting the foundation per the requirements of ASCE 32. This course will cover the basics of the last method. The primary advantage in using this type of construction is, as is so often the case, lower construction cost. Strategically placed rigid insulation allows shallow frost protected foundations to be build at depths as little as 16 inches in areas that would normally require excavations of 48 inches or more using a conventional design.

ASCE 32-01, "Design and Construction of Frost-Protected Shallow Foundations", contains several different, code approved, methods to design shallow foundations of various types. The reference booklet you downloaded for this course, the HUD "Revised Builder's Guide to Frost Protected Shallow Foundations" contains design methods for the most common foundation types. The methods in the builders guide are all contained in ASCE 32 and therefore meet the requirements of the IBC code.

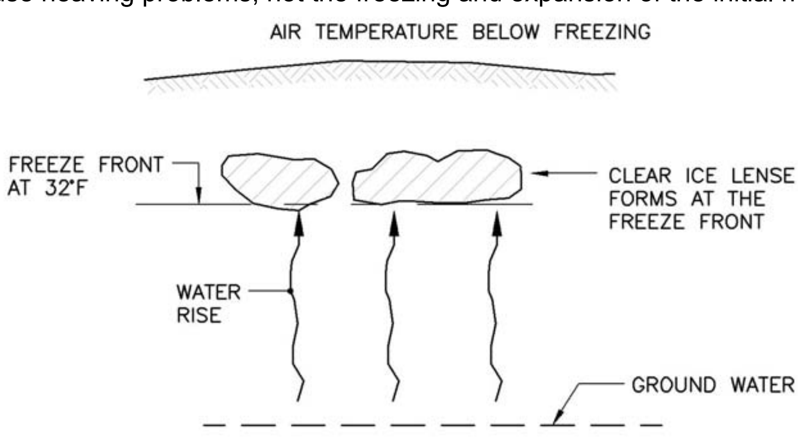
For this course ASCE 32 is an optional reference. The HUD builders guide is required.

BEHAVIOR OF SOILS AS THEY FREEZE:
Most materials will contract in volume as they become colder, and dry soil is no exception. Even water will contract as it becomes colder, however it has the somewhat unique property of expanding just as it freezes. This volume increase is approximately 9%.

Recall that the porosity of soil is defined as the void volume divided by the total volume, and is most commonly expressed as a percentage. Typical soils have a porosity in the range of 20% to 30%. Consider then the volume change 1 cubic foot of saturated soil with a porosity of 25% as it freezes. Because the soil is saturated, 25% (or .25 ft^3) of the initial volume is water, and 75% (or .75 ft^3) is soil. Neglecting the contraction of the soil as it freezes the total change in volume of the initial 1 cubic foot is then:

$$\text{Volume after freezing} = .75\ ft^3 + 1.09(.25ft^3) = 1.02\text{ cubic feet}$$

This small volume change is not significant. For frost heave problems to occur some other mechanism has to come into play; that something is the addition of water to the freeze front. This water can come from the surface, but more commonly it comes from below the freeze front via capillary action. Water rises in the soil by capillary action and forms ice lenses at the freeze front as illustrated below. It is the volume of these ice lenses which continue to grow during the freezing season, which cause heaving problems, not the freezing and expansion of the initial moisture in the soil mass.



In order to obtain the quantity of water necessary for the growth of large ice lenses soils must be both permeable and have voids small enough to support capillary rise. Coarse sand has very poor capillary rise, but very good permeability. Clays have very good capillary rise, but poor permeability. Silts have both good capillary rise and good permeability which is why silts are generally considered frost susceptible.

There are three requirements that must be met simultaneously for soils to heave.

1. The soils must be frost susceptible.
   It takes a very small amount of fine material to contaminate an otherwise good granular soil. ASCE 32 defines a "small amount" as 6% or more by weight passing a number 200 sieve. A pure clay should theoretically not be frost susceptible due to its low permeability, however any type of clay or clayey soils are generally considered frost susceptible.

2. There must be a ready source of water available, usually from below but it could be from surface water.

3. Freezing air temperatures
   The soil must experience sub-freezing temperatures of a duration where any water in the ground can freeze.

Remove any one of these three and soil will not experience frost heave. This means that if there is no moisture available even a frost susceptible soil in a frozen state will not heave. It also means that a good coarse granular material, even if saturated and frozen, will not heave

FROST DAMAGE TO FOUNDATIONS:

There are three primary mechanisms where frost can damage a structure foundation.

1. Frost heave under the footing.
   The force exerted by expansion of ice can easily exceed the weight of any reasonable size structure. There is no practical way to resist these forces, and if frost heave is allowed to occur below footings the structure will be lifted.

2. Adfreeze
   This is loosely related to heaving under a footing, but with this mechanism the ice adheres to the side of a foundation. As free water in the ground freezes and expands it can adhere to the side of a foundation and lift the structure. This is sometimes seen in utility poles embedded into the ground. During the freezing season they are lifted by adfreeze. Soil will slough into the void created at the bottom of the hole. When the soils thaw in spring the pole will tend to settle back, but the soil that has sloughed into the hole will keep the pole from quite going back to its original level. Over time the pole can be jacked completely out of the ground.

3. Thaw Weakening
   Cohesive soils in a moist state can be prone to weakening while thawing. This process generally causes significant settlement.

HOW THE PROTECTION SYSTEM WORKS:

It is generally not practical to ensure that the soils below and around a structure are completely non-frost susceptible. It is also not practical to ensure that the soils are completely dry, and more importantly that water can never migrate into them from below via capillary action. The frost protection scheme attacks the third criteria, exposure to sub-freezing temperatures.

A building will have a "heat bulb" stored in the soil below it. The heat comes from conduction of warm summer air, heating of the interior space, and heat from deep soil under the structure. This stored "heat bulb" will exist even below an unheated structure. This stored heat will tend to raise the freeze line in the vicinity of a building (refer to Figure 2 in the HUD Builders guide). Rigid insulation, properly designed and placed around the building perimeter, will raise the frost line even further. It is the insulation retarding the flow of stored heat, which in turn raises the frost line right at the building, which allows the extremely shallow footing depths to be used.

Added benefits to the system are reduced adfreeze against the foundation and reduced potential for thaw weakening. Both are due to lower depth of the freeze line against the building.

The thermal conductivity of soils is dependent upon the type of soil, and the moisture content of the soil. Because of all these variables there is no single R value for soil, and it is somewhat irrelevant anyway as all soils are poor insulators. In round numbers, an inch of polystyrene with R=4.5 is more or less equivalent in insulation value to 4 feet of soil. Polystyrene can also have remarkable allowable bearing capacities. The types of insulation used in frost protected foundations have allowable bearing capacities ranging from 1,200 to 4,800 pounds per square foot making it suitable for use under slabs, continuous strip footings, and isolated column footings.

TERMS USED:

- Air-Freezing Index.
  Mathematically the Air-Freezing index is the sum of the freezing degree days during a winter.

$$A.F.I. = \Sigma \left(\tfrac{1}{2} (T_{max} + T_{min}) - 32^{o}F \right)$$

T_{max} = maximum daily air temperature
T_{min} = minimum daily air temperature

- NFS soil or fill
  NFS is Non-Frost Susceptible soil. Defined by ASCE 32 as a granular soil with less than 6% by weight passing a number 200 sieve.

- MAT
  Mean Annual Temperature at a site. This number is used to calculate insulation requirements for unheated buildings.

PARTS OF THE SYSTEM:

The design method only applies to sites where the ground is seasonally frozen. It cannot be used in areas where the ground is permanently frozen (permafrost). ASCE 32 further limits it to localities with mean outdoor air temperatures greater than 32^{o}F and to areas with air freezing indexes less than 4,500F^{o}-days. By way of example, Elmendorf Air Force Base in Anchorage, Alaska has a mean annual temperature of 35^{o}F and an air freezing index of 3,430F^{o}-day. Even the climate of southern Alaska is in the range where this method of design can be utilized.

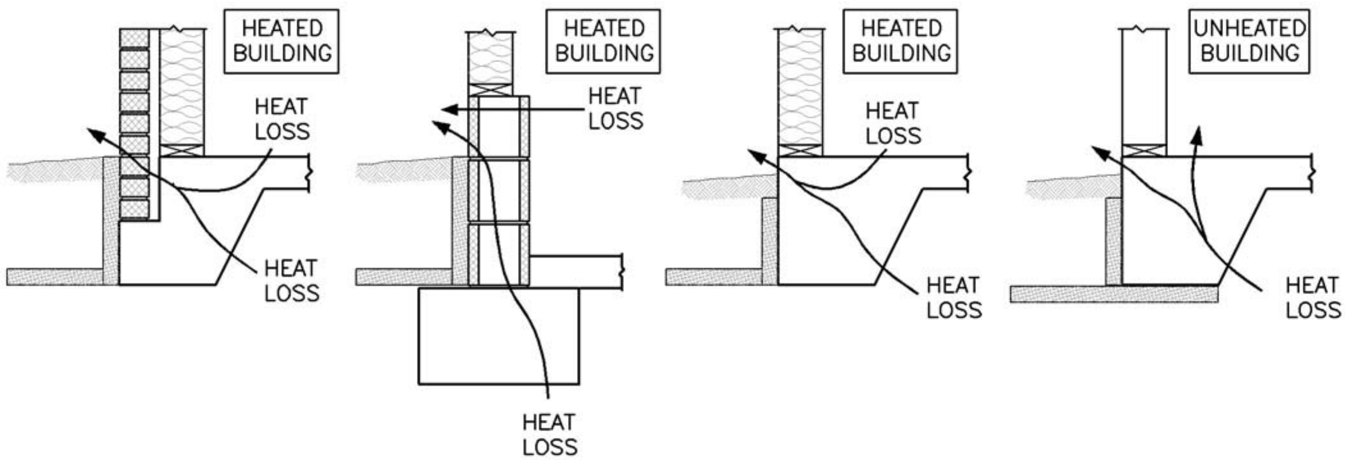
The significant cost savings associated with limiting excavation will not generally be seen in southern states as conventional foundations there can already be shallow. Southern states also can have a high probability of termite infestation. Below grade foam is not recommended in these areas unless special provisions have been made to protect the foam.

The polystyrene foam must comply with ASTM C578, Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation. The polystyrene can be either expanded (EPS) or extruded (XPS). EPS type IV and XPS types IV to VII all have published allowable bearing capacities. EPS type II and XPS type X have no allowable bearing capacity and therefore are only suitable for vertical applications. In general XPS has a higher strength and a higher R value. ASTM C578 does not address or test for possible degradation of the insulating properties for below grade use, so the Nominal R values are reduced approximately 10% for insulation placed vertically and 20% for insulation placed horizontally. These reduced values to be used for design are shown in columns 5v and 5h "Max. Effective R-value" in table 2 of the HUD builders guide.

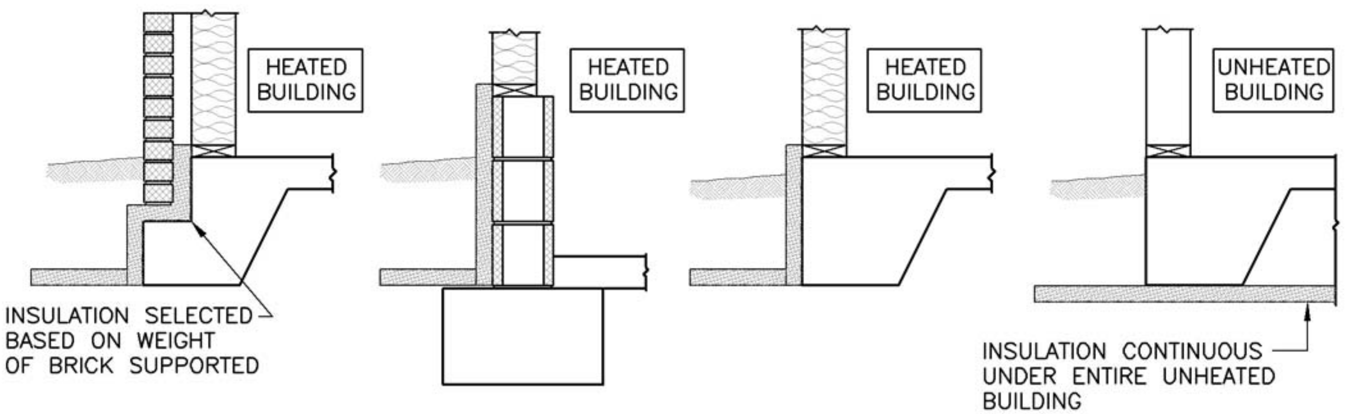
The insulation must be protected. Above grade insulation must have a covering to protect against both mechanical and ultraviolet damage, and the protection must extend for at least 6" below grade. Horizontal insulation must be firmly bedded on a smooth ground surface. The top of the insulation should be protected by a hard layer, and the HUD builders guide requires it for insulation that extends 24 inches or more from the foundation. The HUD Builders guide, appendix I has more information on sources of protective coatings.

ASCE requires an approved foundation drainage system or a layer of screened and washed gravel or crushed stone that is daylighted between the subgrade and insulation for subgrade soils other than GW, GP, SW, SP, GM and SM. As is good practice for a conventional foundation, the grade around the building should have a positive slope away from the building to drain away surface water.

One of the most important things to watch out for in detailing are cold bridges. A cold bridge occurs when a material with a very low thermal resistance (R value) is directly exposed to the outside air. These are very easy to detail into a building, particularly if it has concrete block walls above the base slab or brick veneer. In conventional construction Architects and Engineers generally try to conserve interior heat. This is certainly a concern with a shallow frost protected foundation, but with this type of foundation we are primarily trying to conserve the heat stored in the ground below the building. A cold bridge can completely negate the beneficial effects of the insulation placed around the foundation, resulting in an increased potential for frost heave. ASCE 32 forbids a cold bridge unless it is accounted for in the design. The diagrams below show some typical cold bridges, and ways to remedy them. Both the HUD Builders guide (figure 9) and ASCE 32 (figure 11) have examples of others.



EXAMPLES OF COLD BREAKS – TO BE AVOIDED



SECTIONS REVISED TO ELIMINATE COLD BREAKS

For heated structures, assuming cold bridges have been eliminated from the details, vertical insulation is generally required along the foundation and horizontal insulation is often required. In the simplified method the HUD builders guide requires vertical insulation wherever a shallow frost protected foundation is designed. ASCE 32 allows no insulation where the air freezing index is 500F^{o}-days or less. This is basically south of a line from Wilmington, DE, along the Kentucky-Tennessee border, along to the Kansas-Oklahoma border, through the upper third of Arizona and New Mexico, and then north west on the Nevada side of the California border through the western ¼ of Oregon and Washington.

Horizontal wing insulation is generally not required where the air freezing index is 2,000 F^{o}-days or less. This contour runs through the southern 1/3 of Maine, about midway through New Hampshire and Vermont, through the middle of New York and Michigan. It drops a little further south past the Great Lakes to follow the Wisconsin-Illinois border, through central Iowa and along the South Dakota, Nebraska border to where it turns a little north going into Montana. It then turns south for the Rocky Mountains. The Air-Freezing map shows all this in detail, the description is merely to show that there are large areas of the country that many would consider "cold" where horizontal wing insulation is not required using this method.

Where horizontal wing insulation is required there is always a wider zone or increased footing depth used at the building corners. The heat loss from a building is intensified at a corner because of the heat loss from the two adjacent walls. Extra insulation or increased footing depths are used at building corners to compensate.

Unheated structures are treated a little differently. In an unheated structure vertical insulation along the slab downturn or foundation wall is never required. Horizontal insulation is placed above or below a drainage layer of non-frost susceptible sand and gravel. The insulation is placed under the entire structure and extends a uniform distance beyond the building line on all sides. There is no added insulation used at the corners in unheated buildings.

ASSUMPTIONS IN THE DESIGN METHOD:
The assumptions that form the basis of the design are listed below and all are conservative.

- The air freezing index is based on a 100 year return period. The climate data used to develop the air freezing map is very good.
- It is assumed that there is no insulating ground cover from snow or other materials present over the course of the winter.
- The soils are assumed to be highly frost susceptible and very moist so they have a high thermal conductivity which encourages a deeper freeze line.
- The soils are assumed to be not so moist that the latent heat effects of water turning to ice reduce the depth of freeze.
- Average monthly indoor air temperature for heated buildings is greater than or equal to 63^{o}F and for unheated buildings is less than or equal to 41^{o}F for ASCE 32. Using the slightly more conservative HUD builders guide the limits are greater than 64^{o}F to be considered heated and less than 41^{o}F to be considered unheated.

For a properly designed frost protected foundation to heave several of these assumptions would need to be violated simultaneously.

DESIGN METHODS & EXAMPLES:
All designs start with determining the Air Freezing index for the site under consideration. A map of the Air-Freezing index is shown in Figure 4 of the HUD Builders guide, in figures A1 and A1a in ASCE 32, or from the source at:

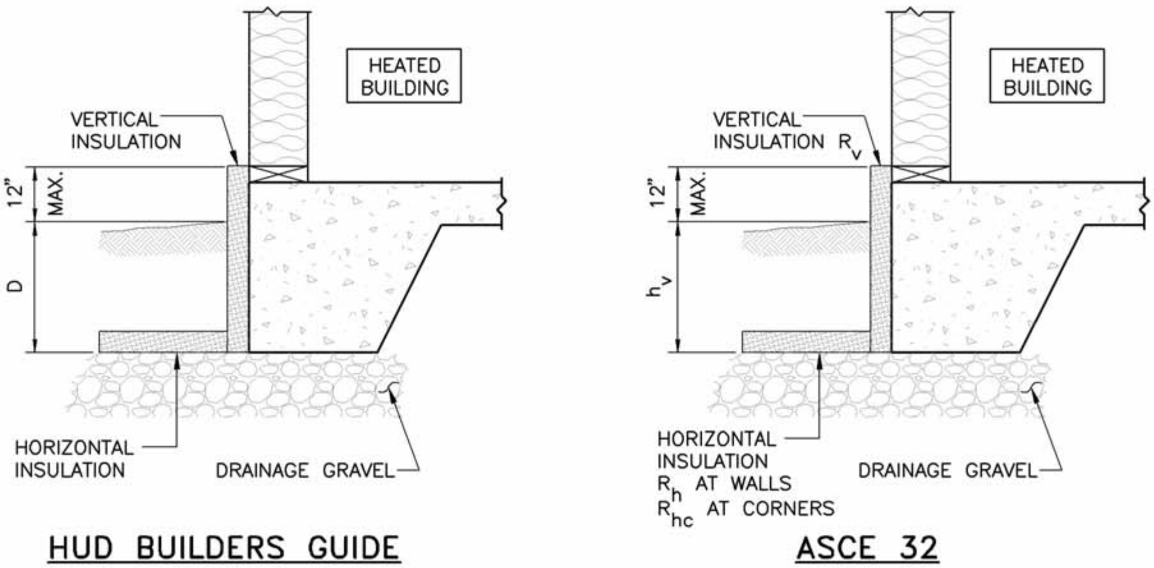
http://lwf.ncdc.noaa.gov/oa/fpsf/

One simply picks an Air Freezing index from the map or chart. Judgment should be used to account for local variations. Sites by a large body of water may have slightly lower F.I. values, while sites at significant elevations will probably have higher values than mapped.

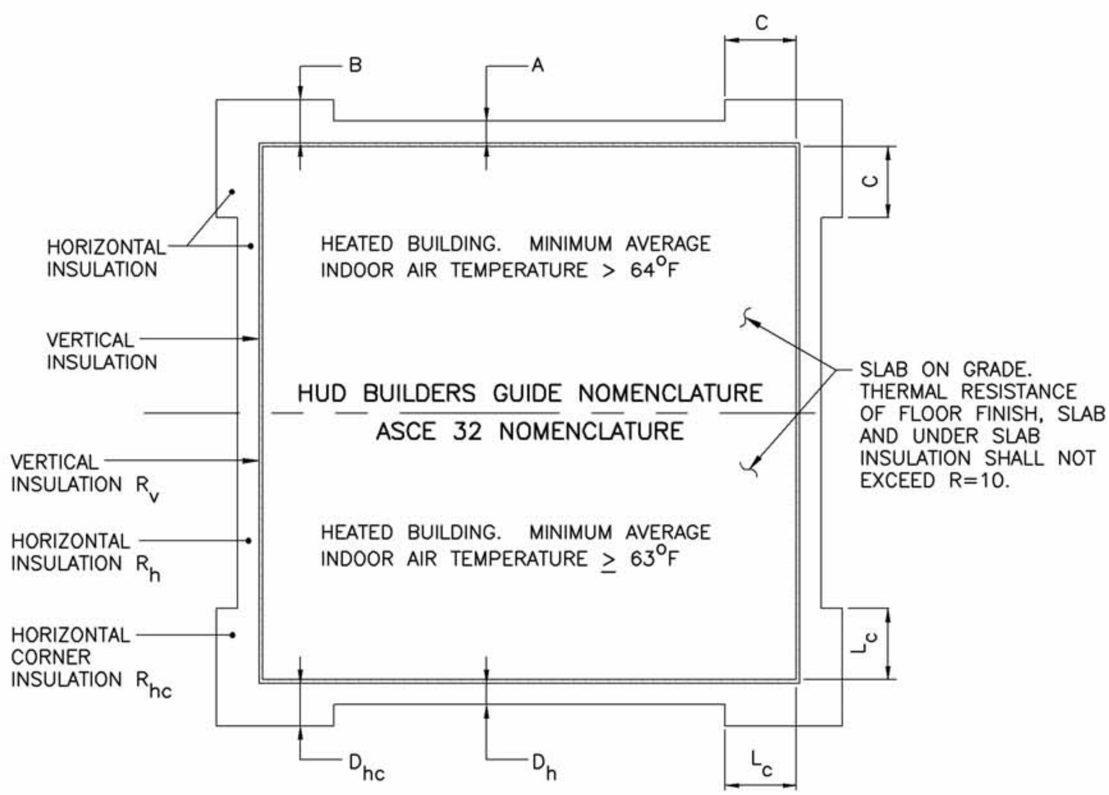
Simplified Method
This method is for heated buildings with slab on grade construction, with or without frost wall. As it is a simplified method the insulation requirements will probably be slightly higher than obtained by using the detailed method. There are also several geometric and construction constraints that must be met when using this design:

- There can be no more than 12" of the foundation exposed (and protected by insulation) above grade.
- The building must be classified as heated.
- The lowest floor must be slab; it cannot be framed over crawlspace.
- Total insulation value of the floor finish, slab, and under slab insulation shall be R=10 or less.

The differences between ACSE 32 and the HUD builders guide using this method are very minor. As mentioned previously, ASCE will allow, in certain very mild climates, shallow frost protected footings to have no insulation, either vertical or horizontal. The HUD Builders guide always requires at least vertical insulation. The other primary difference is in nomenclature. The sketches on page 8 show the different abbreviations and notations for each part of the system. These sketches are drawn to show the unique parts the shallow frost protected foundation. Details such as sheathing, siding, anchor bolts, flashing, and weep holes in brick veneer are still used and would be required as in conventional construction. An example calculation utilizing this method and the HUD nomenclature is shown on page 14.



SIMPLIFIED METHOD – NOMENCLATURE



SIMPLIFIED METHOD – PLAN VIEW

HORIZONTAL INSULATION NOT REQUIRED WHERE AFI ≤ 2,000 F°–DAYS

Detailed Method for Heated Buildings

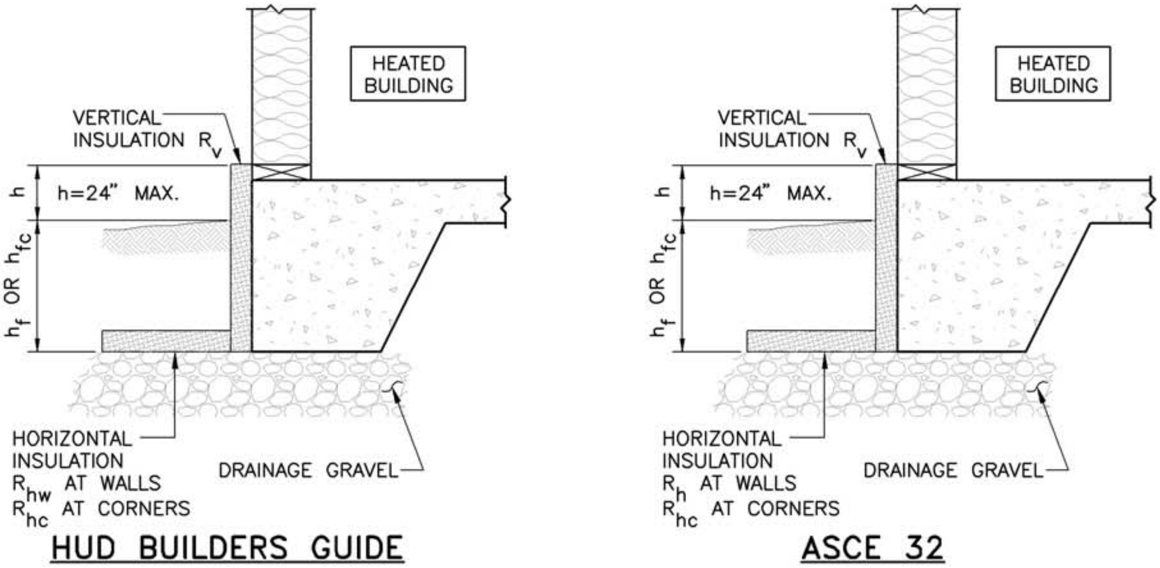
The detailed method allows more latitude in the geometry of the building. Some of the significant differences between the detailed and simplified method:

- There can be up to 24" of foundation exposed (and protected by insulation) above grade using this method.
- The lowest floor must still be a slab, except this method can be used to design the special case of an unventilated crawlspace foundation provided the framed floor has an R value of 28 or less, the crawlspace is heated, and the dimension from grade to underside of floor joist is 24" or less.
- The R value for the floor assembly is calculated and used in the design so this method can be used where energy codes also apply.
- This method allows for much more latitude in the design. The designer can trade off between the amount of horizontal insulation used and footing depth. It is possible using this design method to have foundations in the most severe climates use no horizontal insulation.

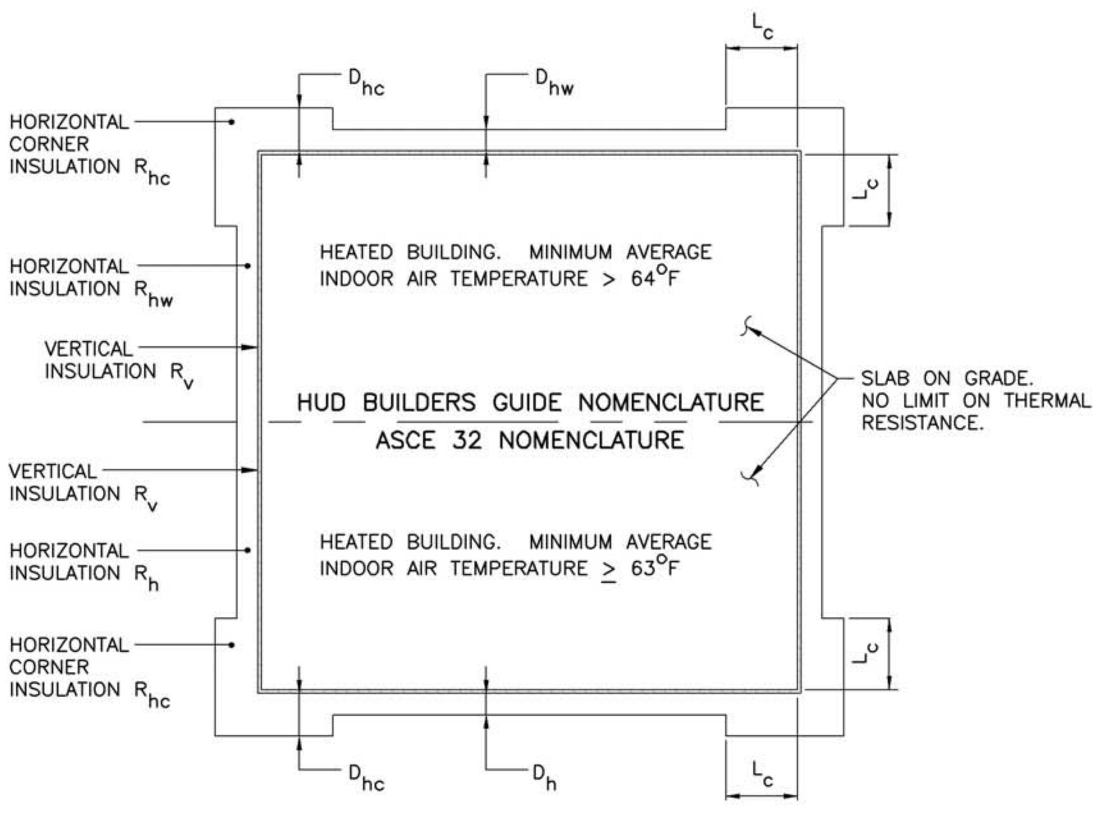
When calculating the thermal resistance of the slab one simple adds together the R values of all the elements. Values for typical building materials are shown in the HUD builders guide in Table 9 (appendix III) and in ASCE 32 table A2. The values for building materials are given in R per inch. The last two rows in the table, for carpeting, are the actual R value of the finish material.

The differences between ACSE 32 and the HUD builders guide using this method are even more minor than the simplified method. There are a couple of differences in the subscripts of terms, but other than that the two references are the same. The sketches on page 10 show the different abbreviations and notations for each part of the system. These sketches are drawn to show the unique parts the shallow frost protected foundation. Details such as sheathing, siding, anchor bolts, flashing, and weep holes in brick veneer are still used and would be required as in conventional construction

An example of this design method for a heated building is shown on page 15. The example has calculations for three options of footing depth. Option A is the minimum footing depth, but uses the most horizontal insulation. Option B has the bottom of all the footings at the same depth, but eliminates the horizontal wall insulation. Option C has no horizontal wall or corner insulation, but requires the slab or foundation wall at the corners to step down.



DETAILED METHOD – NOMENCLATURE



DETAILED METHOD – PLAN VIEW

HORIZONTAL INSULATION NOT REQUIRED WHERE AFI ≤ 2,250 F°–DAYS

Detailed Method for Unheated Buildings

The detailed design method for unheated buildings, from a complexity point of view, is about on par with the simplified method. The geometric and construction requirements are:

- The building must have a continuous layer of ground insulation that extends beyond the building line
- The ground insulation layer must be on top of or below an NFS drainage layer. For this class we will only deal with the arrangement of insulation over the drainage layer. This drainage layer is required and must be at least 6" thick. The drainage layer must be thicker if the insulation is placed below, refer to ASCE 32 for additional information.
- There must be at least 10" of soil over the insulation outside the building line.
- The building must be unheated.

In addition to the Air-Freezing Index the calculations of this method require knowledge of the mean annual temperature at the site. ASCE 32 has a contour map and also a table of Mean Annual Temperatures for selected cities in the United States. The contour map is also available online at the following link.

http://lwf.ncdc.noaa.gov/img/fpsf/tempnormallarge.jpg

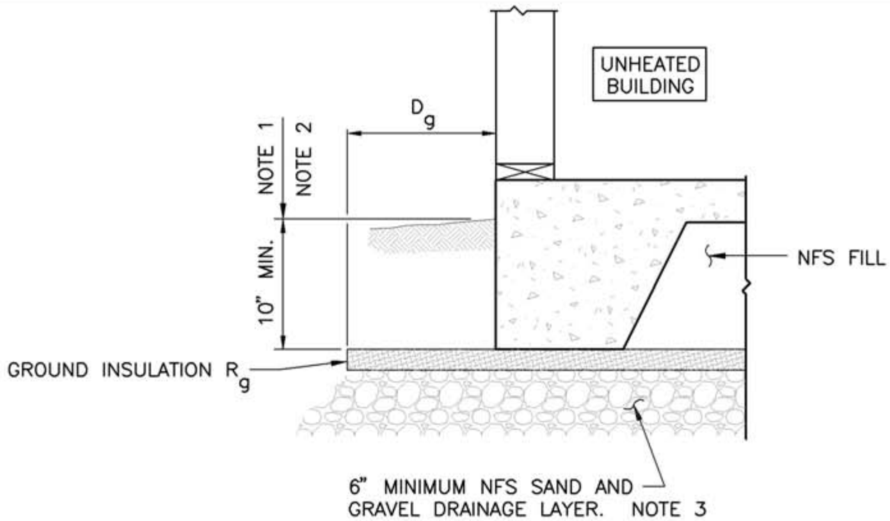
This method allows the insulation dimensions and R values to be adjusted depending on how far beyond the basic minimums the parts are installed. There are some differences between ASCE 32 and the HUD builders guide in these adjustments, with HUD being more conservative. The differences are as follows:

For each additional inch of soil cover beyond the 10" minimum ASCE 32 will allow the insulation extension, D_g to be decreased by 1.25", and the required R value of the insulation to be decreased by 0.3 R. The HUD builders guide only allows a 1" decrease on the D_g and 0.25 R decrease on the insulation for each additional inch of embedment.

For each additional inch the NFS drainage layer is increased beyond the minimum 6" thickness, both ASCE 32 and the HUD Builders guide allow the required R value of the insulation to be decreased by 0.3 R.

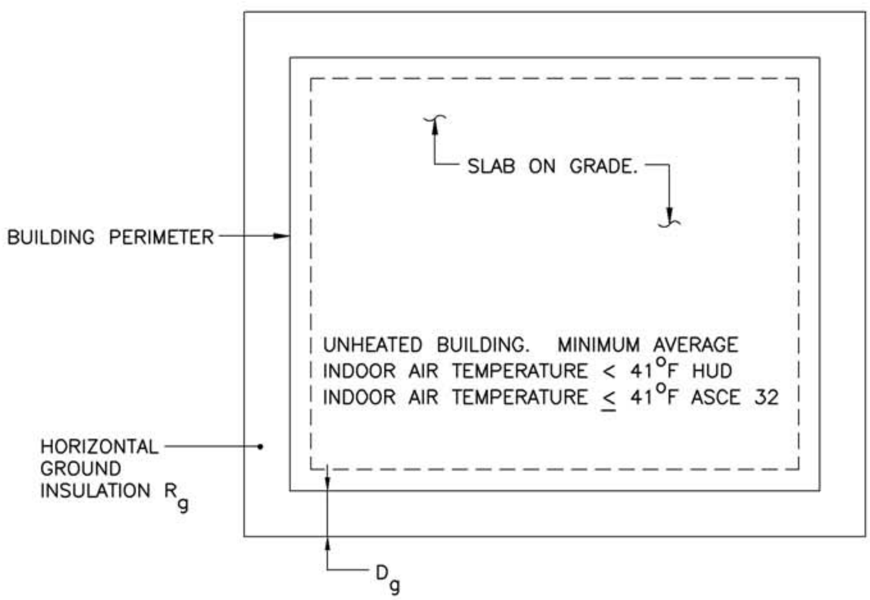
Page 12 has sketches showing the nomenclature particular to this type of foundation. These sketches are drawn to show that unique parts the shallow frost protected foundation. Details such as sheathing, siding, anchor bolts, flashing, weep holes in masonry are still used and would be required as in conventional construction

An example showing the design of a foundation for an unheated building is shown on page 16.



UNHEATED BUILDING – SECTION

1. HUD BUILDERS GUIDE: FOR EVERY INCH THE GROUND INSULATION IS BURIED BEYOND THE 10" MINIMUM DIMENSION D_g MAY BE REDUCED BY 1.00", AND THE GROUND INSULATION R_g MAY BE REDUCED BY 0.25R
2. ASCE 32: FOR EVERY INCH THE GROUND INSULATION IS BURIED BEYOND THE 10" MINIMUM DIMENSION D_g MAY BE REDUCED BY 1.25", AND THE GROUND INSULATION R_g MAY BE REDUCED BY 0.30R
3. FOR EVERY INCH THE SAND AND GRAVEL DRAINAGE LAYER IS INCREASED ABOVE THE 6" MINIMUM THE GROUND INSULATION R_g MAY BE REDUCED BY 0.3R



UNHEATED BUILDING – PLAN VIEW

<u>Detailed Method for Semi-heated Buildings</u>

This design method is not covered by the HUD Builders guide, but is covered by ASCE 32. This method only applies to the special case where the building is not warm enough to be considered heated, but is conditioned enough so that it exceeds the upper bound temperature to be considered unheated.

A foundation in this type of building is designed using the detailed method for heated buildings. You then simply add 8” to the calculated foundation depth in both wall and corner zones of the building.

<u>Additional Methods</u>

ASCE 32 has several additional design methods for more unusual cases. To do one of these designs will really require access to the standard, so we will only describe what other conditions are covered.

- Walkout basements in heated or semi-heated buildings
- Continuous foundation wall exposed to climate on both sides (vented crawl space)
- Column footings
- Small unheated areas in otherwise heated buildings
- Large unheated areas in heated buildings

ACCEPTANCE:

Frost protected shallow foundation technology is not new. The commentary in ASCE 32 has a very good, footnoted description of the history of the technology and is an excellent source for further study. I will only highlight some of the more significant portions here.

The first recorded use of the technology was by Frank Lloyd Wright in the 1930's. After that most of the installations have been in Scandinavia where the foundation system has been and is still used on a wide variety of residential, institutional and commercial projects. There have been over a million successful frost protected foundation systems constructed in Europe since the end of World War II.

In addition to the widespread acceptance in Scandinavia, the US Department of Housing and Urban Development constructed and instrumented test homes in Vermont, Iowa, North Dakota and Alaska. These houses were monitored to see how they compared to the European experience in keeping the soils below the foundations from freezing. The test houses performed comparably to the European model.

Simplified Design Method – Example

Criteria:
Heated building, slab on grade with no insulation below slab. 12" from top of slab to soil at the face of building, AFI = 3,000.

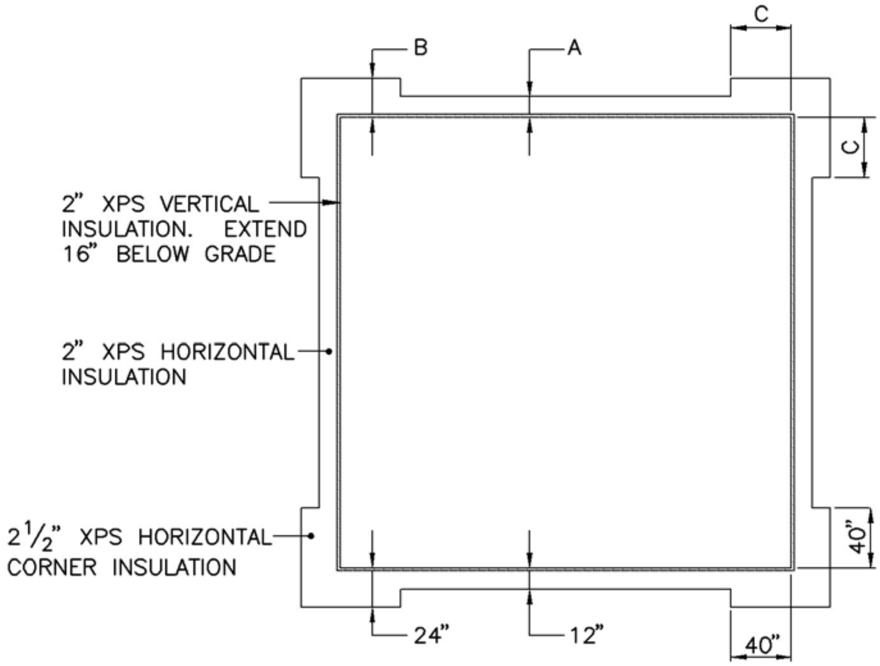
Solution:
From HUD Builders guide table 3 find:

Vertical Insulation R=7.8 extend to a depth below grade D=16"
Horizontal Insulation along walls R=6.5, extend outwards for A=12"
Horizontal Insulation at corners R=8.6, extend outwards for B=24", and away from corner C=40"

Use an Extruded (XPS) polystyrene. From the HUD Builders guide table 2, columns 5v and 5h find:

Effective R for vertical installation = 4.5 (per inch)
Effective R for horizontal installation = 4.0 (per inch)

Thickness of vertical insulation = 7.8 ÷ 4.5 = 1.73", use 2" board
Thickness of typical horizontal wall insulation = 6.5 ÷ 4.0 = 1.625", use 2" board
Thickness of horizontal corner insulation = 8.6 ÷ 4.0 = 2.15", use 2½ " board



Detailed Design Method – Heated Building Example

Criteria:
Heated building, 4" slab on grade with carpet and pad, no insulation below slab. 12" from top of slab to soil at the face of building, AFI = 3,000.

Solution:
Step 1: calculate the thermal resistance of the floor system.
From HUD Builders guide Table 9 (in appendix III)

Carpet and pad	R =	2.08
4" slab	R = 4*(0.05) =	0.20
Total	R_f =	2.28

Step 2: select an insulation type
Use an Extruded (XPS) polystyrene. From the HUD Builders guide table 2, columns 5v and 5h find:
Effective R for vertical installation = 4.5 (per inch)
Effective R for horizontal installation = 4.0 (per inch)

Step 3: find the vertical insulation
From HUD Builders guide table 4 find (for R_f = 2.28):
Vertical Insulation R_v = 5.7 depth will vary depending on step 4.
Thickness of vertical insulation = 5.7 ÷ 4.5 = 1.27", use 1½ " board

Step 4: find the horizontal insulation and footing depth. There are 3 possible options.
Option A: Select insulation for minimum footing depth. Use HUD Builders guide tables 6 and 7
h_f = h_{fc} = 16" (a constant dimension for all AFI's using this option).
Corner insulation dimension L_c = 40"
There are multiple choices for the horizontal wall and corner insulation:

Wall insulation using Table 6:

D_{hw}	R_{hw}	thickness	Use
12"	6.5	1.63"	2" board
18"	6.1	1.53"	2" board
24"	5.3	1.33"	1½" board
30:	4.5	1.13"	1½" board

Corner insulation using Table 7:

D_{hc}	R_{hc}	Thickness	Use
16"	9.6	2.40"	3" board
24"	8.6	2.15"	3" board
30"	8.0	2.00"	2" board
36:	7.4	1.85"	2" board

Option B: Select insulation and footing depths with only corner insulation. The foundation will be deeper than in option A, but the bottom of footing elevation will still be constant. Use HUD Builders guide table 5.
h_f = h_{fc} = 20" (Table 5, columns 1 and 5).
Horizontal wall insulation R_{hw} = none
Corner insulation R_{hc} = 5.7 (a constant using this option),
thickness = 5.7 ÷ 4.0 = 1.43", use 1½ " board
Corner insulation dimension L_c = 40" (Table 5 column 4)
Corner insulation horizontal dimension D_{hc} = 20" (Table 5 column 6)

Option C: No horizontal insulation, footings will be deeper and step down at corners. Use HUD Builders guide table 5.
Horizontal wall and corner insulation R_{hw} = R_{hc} = none
h_f = 20" (Table 5, column 1)
h_{fc} = 32" (Table 5, column 5).
Corner length dimension L_c = 40" (Table 5 column 2)

Detailed Design Method – Unheated Building Example

Criteria:
Unheated heated building with slab on grade. 12" from top of slab to soil at the face of building, AFI = 3,000, Mean Annual air temperature 38°F.

Solution:
From HUD Builders guide table 8 find:

Horizontal Ground Insulation R_g = 18.2
Ground insulation extends for D_g = 79" away from building.

Use an Extruded (XPS) polystyrene. From the HUD Builders guide table 2, columns 5v and 5h find:
Effective R for horizontal installation = 4.0 (per inch)
Thickness of horizontal ground insulation = 18.2 ÷ 4.0 = 4.55", use (2) 1½ " boards plus (1) 2" board

This is a somewhat unwieldy design, look at increasing the depth of the NFS layer below the insulation. R_g may be decreased by 0.3 R for every 1" of increase in the NFS fill below the insulation beyond the 6" minimum required (same in both HUD and ASCE 32).

Try increasing the NFS fill from 6" to 14"

Design R_g = 18.2 – (14" – 6")*0.3 = 15.8
Thickness of horizontal ground insulation = 15.8 ÷ 4.0 = 3.95", use (2) 2" boards