



**FOAMULAR<sup>®</sup>**  
Energy-Saving, Moisture-Resistant XPS Insulation

# INSULATED BUILDING FOUNDATION SLABS

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**GEOTECHNICAL DESIGN AND INSTALL GUIDE**

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## **INSULATING BUILDING FOUNDATIONS AND SLABS**

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## INTRODUCTION

In areas with seasonal frost conditions, foundations of both heated and unheated structures can experience frost heave if the underlying soil is not kept free of frost. Non-frost-susceptible (NFS) fill can be used to prevent the underlying soils from freezing, but is often uneconomical. However, placing FOAMULAR® GEO extruded polystyrene (XPS) below and adjacent to a structure's foundation can provide economical frost protection. The insulation must be thick enough to prevent the soil temperature below the foundation from dropping below 32°F. This type of foundation is known as a Frost Protected Shallow Foundation (FPSF). The American Society of Civil Engineers (ASCE) 32-1: Design of Frost Protected Shallow Foundations standard provides detailed design methods for FPSF in areas with design air freezing indexes less than 4500 °F-days and mean annual air temperatures greater than 32°F.

The best design philosophy for structural foundations is to keep frozen ground frozen, and likewise, to keep unfrozen ground unfrozen. This minimizes settlement, or other undesirable movement, that may occur during the freeze-thaw cycle and maintains a steady thermal state of the in-situ soils. This is especially critical for buildings founded on permafrost. When designing foundations on permafrost soils, the soil under the foundation should remain frozen. This may require additional XPS insulation, or even active refrigeration or thermosyphons. (Thermosyphons provide passive refrigeration that transfers heat from the soil into the atmosphere.)

The table values provided in this guide can be extrapolated to permafrost areas, but care should be taken to capture the thermal influence of the structure on the surrounding soils. Heated structures in contact with frozen soil often cause thawing of the underlying permafrost, which results in a reduction in soil strength and an increase in settlement. More detailed design analysis may be required in permafrost areas. All figures and tables included in this guide are copyrighted by ASCE. Unless otherwise stated, all fill material is assumed to be NFS.

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## LIST OF VARIABLES FOR DESIGN

- E – Modulus of Elasticity, concrete (psi)  $\approx 57,000(f'_c)^{1/2}$
- H – Slab thickness (in)
- k – Modulus of subgrade reaction (pci)
- K – Insulation foundation modulus (Table 6) (pci)
- s – Allowable concrete tension stress (psi)
- D – Deflection (in)
- D<sub>xx</sub> – Insulation dimension x direction (in)
- P – Load (dead load plus live load) (lb)
- v – Poisson's ratio, 0.2 for concrete
- f'<sub>c</sub> – Compressive strength of concrete (psi)
- R – Thermal resistivity [(hr • ft<sup>2</sup> • °F)/BTU]
- t – Insulation thickness (in)
- F<sub>100</sub> – Air freezing index (°F • day)

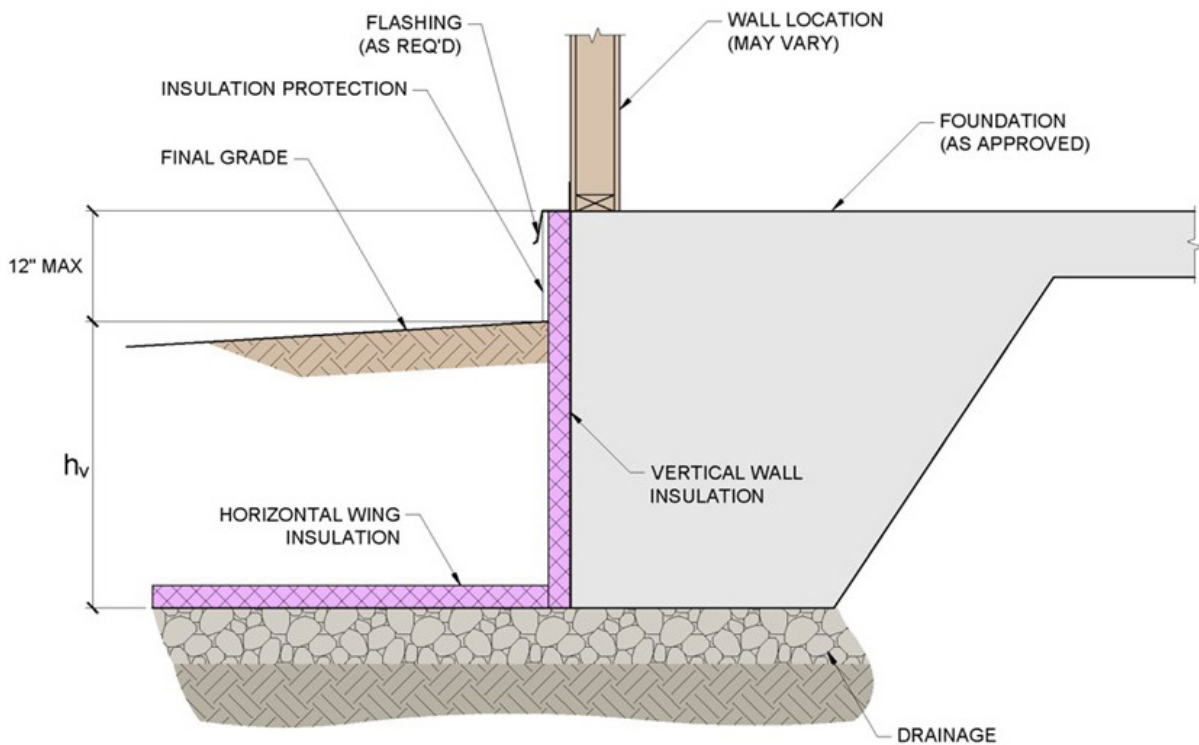
## HEATED BUILDINGS

Buildings can be considered heated, unheated, or semi-heated based on the minimum average monthly indoor temperature (Table 1). Heated buildings are typically classified as having a thermal resistance of the floor less than 28 (hr-ft<sup>2</sup>-°F)/BTU.

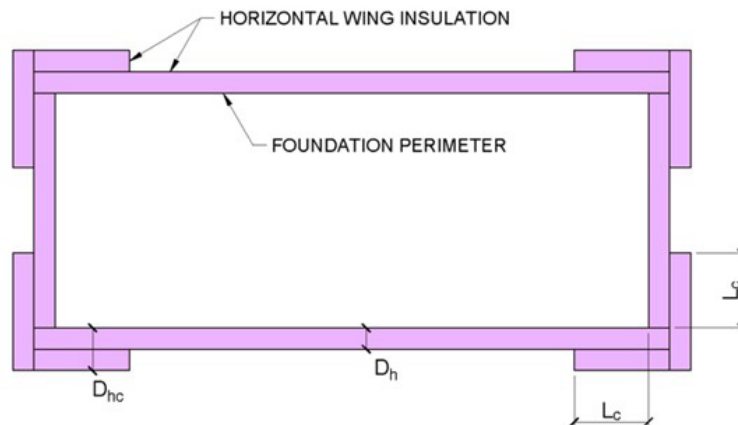
Table 1. Classification of Building Based on Indoor Air Temperature (Table 1 in ASCE 32-1)

Minimum Average Monthly Indoor Temperature	Thermal Classification
$T \geq 63^{\circ}\text{F}$ ( $17^{\circ}\text{C}$ )	Heated
$41^{\circ}\text{F}$ ( $5^{\circ}\text{C}$ ) $< T < 63^{\circ}\text{F}$ ( $17^{\circ}\text{C}$ )	Semi-heated
$T \leq 41^{\circ}\text{F}$ ( $5^{\circ}\text{C}$ )	Unheated

To prevent frost formation below the building, a Frost Protected Shallow Foundation (FPSF) should be used. In this design, horizontal “wing” insulation is extended beyond the perimeter of the building. Heated buildings typically require thicker insulation at the corners. A schematic showing the design parameters for a FPSF is shown in Figure 1.



**INSULATION DETAIL**



**HORIZONTAL INSULATION PLAN**

Figure 1. FPSF Design Parameters for Heated Buildings Using the Simplified Design Procedure (ASCE 32-1, Figure 1)

The following general procedure should be followed when designing a FPSF for heated buildings. Design tables and detailed guidance are available in ASCE 32-1.

1. Determine the design air freezing index and mean annual temperature as described in the Frost and Thaw Protection section in the "Roadways and Airfields" Design and Install Guide.
2. Determine the equivalent thermal resistance of the floor system by summing the thermal resistance of each material in the cross section (i.e. slab, stem wall or other foundation component resisting heat loss to the ground).
3. Determine the required R-value for vertical wall insulation (Table 2).

Table 2. Minimum Insulation Requirements for FPSF of Heated Buildings (Table 4, ASCE 32-1)

AIR-FREEZING INDEX, F <sub>100</sub> (°F-DAYS)	VERTICAL INSULATION R-VALUE, R <sub>v</sub>	HORIZONTAL INSULATION R-VALUE, R <sub>h</sub> (HR • FT <sup>2</sup> • °F/Btu)		HORIZONTAL INSULATION DIMENSIONS PER FIGURE 1 (IN)			MINIMUM FOOTING DEPTH (IN)
		ALONG WALLS	AT CORNERS	D <sub>h</sub>	D <sub>hc</sub>	L <sub>c</sub>	h <sub>v</sub>
500 or less	0	NR	NR	NR	NR	NR	12
1,500	4.5	NR	NR	NR	NR	NR	12
2,000	5.6	NR	NR	NR	NR	NR	14
2,500	6.7	1.7	4.9	12	24	40	16
3,000	7.8	6.5	8.6	12	24	40	16
3,500	9.0	8.0	11.2	24	30	60	16
4,000	10.1	10.5	13.1	24	36	60	16
4,500	12.0	12.0	15.0	36	48	80	16

\*Insulation requirements are for protection against frost damage in heated buildings. Interpolation between values is permissible. For interpolation purposes, NR = 0 (NR = not required)

4. Calculate the thickness of XPS insulation needed to provide the desired R-value. Insulation should be protected from water, weather, and petroleum-based products.
5. Select the foundation depth and required type, thickness and dimensions of XPS insulation needed for horizontal wing insulation for walls. Insulation should be protected from water, weather, and petroleum-based products.
6. Select the foundation depth and required thickness and dimensions of XPS insulation needed for or horizontal wing insulation at corners (Table 3). Where no horizontal wing insulation is desired, use the minimum foundation depth at the corners.

Table 3. Minimum Thermal Resistance of Wing Insulation, R<sub>hc</sub>, for Use at Corners with 16-inch Footing Depth (Table A7, ASCE 32-1)

F <sub>100</sub> (°F-DAYS)	L <sub>c</sub> (IN)	R-VALUES FOR VARIOUS WIND WIDTHS AT CORNERS, D <sub>hc</sub> (INCHES)					
		-----					
		16	24	30	36	42	48
2,250 or fewer	0	0.0					
2,625	40	6.5	4.9	4.0			
3,000	40	9.6	8.6	8.6	7.4		
3,375	60		11.1	11.1	9.8	9.1	
3,750	60		13.1	13.1	12.0	11.2	10.8
4,125	60				13.7	13.0	12.5
4,500	80				15.9	15.1	14.8

Interpolation shall be permitted

7. Check the compressive load acting on the horizontal insulation to ensure it does not exceed the allowable insulation bearing capacity. See the Bearing Applications section in the "Roadways and Airfields" Design and Install Guide.

### Example: Heated Building

A heated building will be constructed at a site with a freezing index of 4,000°F•day and mean annual air temperature of 38°F. The building footprint is 20 feet by 40 feet. The concrete slab will be 6 inches thick.

The R-value of concrete is 0.05 hr•ft<sup>2</sup>•°F/BTU/in given in equation 1. (Note that concrete thermal properties change with density)

$$R_{\text{floor}} = 6 \text{ in} \cdot 0.05 \frac{\text{hr}\cdot\text{ft}^2\cdot\text{°F}}{\text{BTU}\cdot\text{in}} = 0.3 \frac{\text{hr}\cdot\text{ft}^2\cdot\text{°F}}{\text{BTU}}$$

Determine the required vertical and horizontal R-values from Table 2:

$$R_v = 10.1 \text{ hr}\cdot\text{ft}^2\cdot\text{°F}/\text{BTU}$$

$$R_h = 10.5 \text{ hr}\cdot\text{ft}^2\cdot\text{°F}/\text{BTU}(\text{walls}), 13.1 \text{ hr}\cdot\text{ft}^2\cdot\text{°F}/\text{BTU}/\text{in}(\text{corners})$$

Use FOAMULAR 250 GEO for.  $R_{\text{ins}} = 5 \text{ hr}\cdot\text{ft}^2\cdot\text{°F}/\text{BTU}/\text{in}$ . The effective value must be used per Table 5.

$$t_v = 10.1/4 = 2.53 \text{ inches}$$

Need 3 inch of FOAMULAR 250 GEO under the slab

$$t_{\text{walls}} = 10.5/4.5 = 2.3 \text{ inches}$$

$$t_{\text{corner}} = 13.1/4.5 = 2.9 \text{ inches}$$

Need 2.5 inches of FOAMULAR 250 GEO along the walls and 3 inches at the corners.

From Table 2, the minimum footing depth  $h_v$  is 16 inches. The wing insulation must extend at least 24 inches from the walls. The corner insulation must extend a minimum of 36 inches from the corner.

Check the compressive load acting on the horizontal insulation using structural loads as prescribed by the local building code or design.

## UNHEATED BUILDINGS

According to ASCE 32-1, if the equivalent thermal resistance of a floor is greater than 28 (hr·ft<sup>2</sup>·°F)/BTU, the building should be considered unheated as should buildings that are intended to be permanently or periodically unheated. Unheated buildings are assumed to be built on thickened slab foundations. Continuous foundation walls exposed to exterior climate on both sides, such as vented crawlspaces, should also be treated as unheated foundations. A summary of the design process is as follows:

1. Determine the design air freezing index and mean annual temperature as described in the Frost and Thaw Protection section in the "Roadways and Airfields" Design and Install Guide.
2. Layout a continuous layer of XPS ground insulation over a minimum of 6 inches of NFS soil below the entire slab and extending the minimum distance outside the foundation, specified by ASCE 32-01 and summarized in Table 2 and Table 3. If the NFS soil layer is placed above the insulation, the layer thickness should be increased to 12 inches.
3. Determine the required R-value for the XPS ground insulation using Table 4.

Table 4. Minimum Thermal Resistance (R-Value) of Ground Insulation,  $R_g$ , and Horizontal Extension,  $D_g$ , for Unheated

$F_{100}$ (°F-DAYS)	$D_g$ (INCHES)	MEAN ANNUAL TEMPERATURE (°F):				
		≤32	36	38	40	≥41
750 or fewer	30	5.7	5.7	5.7	5.7	5.7
1,500	49	13.1	9.7	8.5	8.0	6.8
2,250	63	19.4	15.9	13.6	11.4	10.2
3,000	79	25.0	21.0	18.2	15.3	14.2
3,750	91	31.2	26.1	22.7		
4,500	108	37.5	31.8			

Interpolation shall be permitted

4. Calculate the necessary thickness of XPS insulation to provide the required R value using Table 5. Insulation should be protected from water, weather, and petroleum- based products.

Table 5. Design Values for FPSF Insulation Materials (Table A1, ASCE 32-1)

INSULATION TYPE PER ASTM C578	MINIMUM INSULATION DENSITY PER ASTM C578 (PCF)	EFFECTIVE RESISTIVITY, $r_{eff}^1$ (R PER INCH)		NOMINAL RESISTIVITY PER ASTM C578 (R PER INCH)	ALLOWABLE BEARING CAPACITY <sup>2</sup> (PSF)	MINIMUM INSULATION THICKNESS (INCHES)	
		VERTICAL	HORIZONTAL			VERTICAL	HORIZONTAL
Expanded Polystyrene							
Type II	1.35	3.2	2.6	4.0	NA	2	3
Type IX	1.8	3.4	2.8	4.2	1,200	1.5	2
Extruded Polystyrene							
Type X	1.35	4.5	4.0	5.0	NA	1.5	2
Type IV	1.6	4.5	4.0	5.0	1,200	1	1.5
Type VI	1.8	4.5	4.0	5.0	1,920	1	1
Type VII	2.2	4.5	4.0	5.0	2,880	1	1
Type V	3.0	4.5	4.0	5.0	4,800	1	1

<sup>1</sup>Effective resistivity is based on tests from laboratory and field studies of insulation products under long-term exposure to moist, below-ground conditions. 'Vertical' effective resistivity shall be used for insulation placed vertically on exterior foundation walls. 'Horizontal' effective resistivity shall be used for insulation placed horizontally, below ground.

<sup>2</sup>Allowable bearing capacity is based on ASTM C578 compressive strength at 10% deformation divided by a safety factor of 3.0 for conditions without cyclic loading (i.e., highway vehicle loading).

NA<sup>3</sup> prohibits use where structural foundation loads are supported (i.e., insulation below footings).

5. Check the compressive load on the XPS ground insulation to ensure it does not exceed the allowable compressive strength of the insulation. See the Bearing Applications section in the "Roadways and Airfields" Design and Install Guide.

**Example: Unheated Building**

Use the same structure as the Heated Building example. Note that for unheated buildings, the ground insulation extends the same distance from the foundation at the walls and corners.

Select the required R-value of the ground insulation using the FI and mean annual temperature. From Table 3, use interpolation:

$$R_g = 24 \text{ hr} \cdot \text{ft}^2 \cdot \text{°F}/\text{BTU}$$

$$D_g = 97 \text{ inches}$$

Determine the thickness of FOAMULAR 250 GEO required using the effective resistivity from Table 5.

$$t = 24/4.5 = 5.3 \text{ inches}$$

Use 5.5 inches of FOAMULAR 250 GEO extended 97 inches beyond the building perimeter.

Check the compressive load on the ground insulation does not exceed the allowable compressive strength. Additional cover can be added to the insulation to reduce the stress acting on the insulation, as discussed in the Bearing Applications section in the "Roadways and Airfields" Design and Install Guide.

**FLOOR SLABS**

Insulated concrete slabs are common in cold storage facilities to provide improved thermal resistance and reduce heat loss through the floor of the structure. The slab and the insulation layers below must be capable of supporting the live and dead loads imposed by vehicles, stationary and/or moving equipment, loaded storage racks, and pedestrian traffic. The slab and supporting layers must be designed with consideration given to the rigidity and allowable stress of each layer to avoid excessive deflection, which can result in cracking. A schematic of an unheated slab-on-grade is shown in Figure 2.



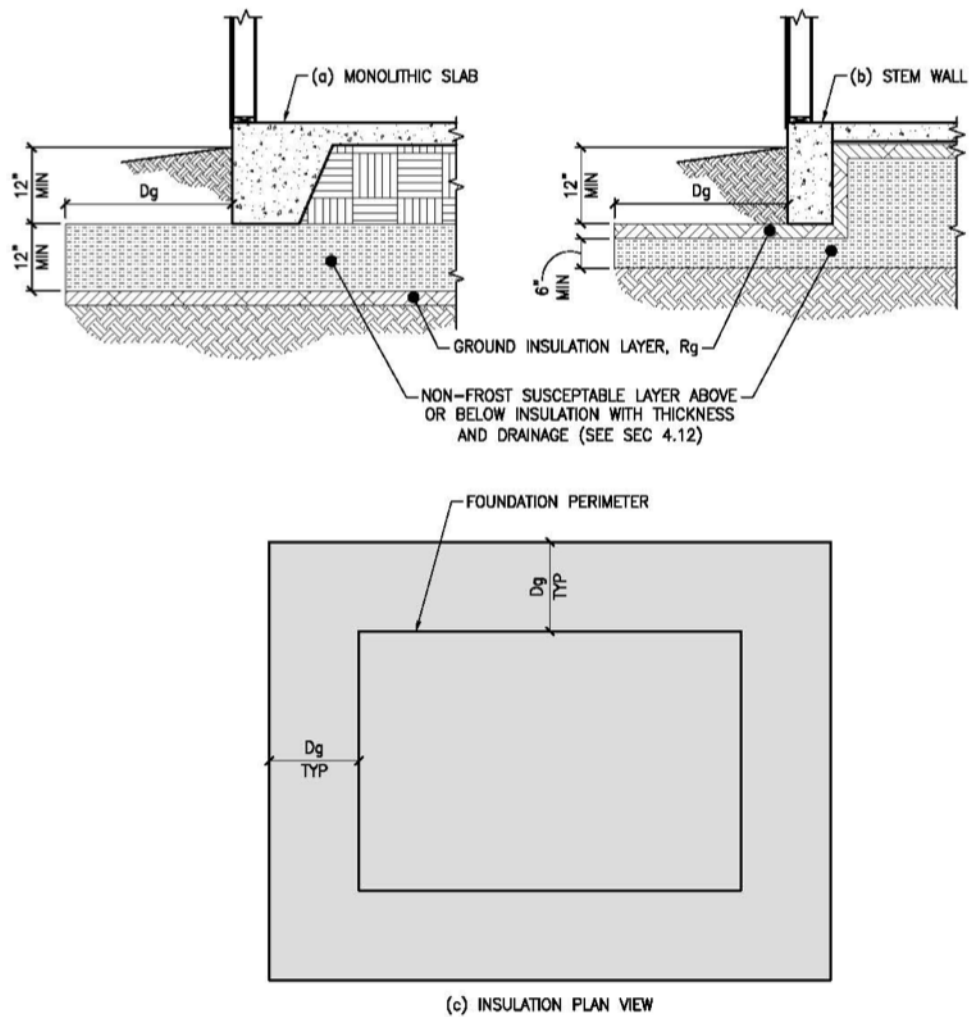


Figure 2. Slab-on-Grade Foundation for Unheated Buildings (Figure 5, ASCE 32-1)

The concrete slab should be capable of distributing loads so that the pressure on underlying insulation layers does not exceed the allowable compressive strength. This can be achieved by increasing the contact area of the concrete slab. To determine the stress that will be experienced by the insulation, the slab deflection and the foundation modulus must be known. The foundation modulus is a measure of how much a material deflects under a given load, expressed as pounds per inch of deflection per square inch of contact area, or pci. This number is then used to calculate the maximum allowable live load and slab deflection. The foundation modulus,  $K$ , for various thicknesses of FOAMULAR® GEO insulation is given in Table 6.



Table 6. Foundation Modulus for FOAMULAR® GEO

PRODUCT	FOUNDATION MODULUS (PCI)					
	THICKNESS (INCHES)					
	1"	1.5"	2"	2.5"	3"	4"
FOAMULAR 150	590	550	500	450	400	300
FOAMULAR 250	750	710	675	595	565	510
FOAMULAR® GEO 40	1100	1000	900	780	680	650
FOAMULAR® GEO 60	1520	1400	1275	1150	1040	790
FOAMULAR® GEO 100			2600			

### Determining Allowable Slab Load

Almost all slab-on-grade allowable loads are controlled by the strength of the concrete and stiffness of the subgrade, rather than the strength of the insulation.

The maximum allowable distributed stationary live load in a slab can be calculated as:

$$w = 237.87s \sqrt{\frac{kh}{E}}$$

#### Where

E = Modulus of Elasticity, concrete (psi),  $E \approx 57,000 (f'c)^{1/2}$

h = Slab thickness (in)

k = Modulus of subgrade reaction (pci) (use insulation foundation modulus)

s = Allowable concrete tension stress (psi)

w = Maximum allowable distributed stationary live load (psf)

#### Example: Allowable Slab Load Calculation

Determine the allowable load on an insulated slab on grade. Assume a 4" slab resting on 4" FOAMULAR 250 GEO. Concrete 28 day strength is 4,000 psi.

The following data is given in the problem statement:

h = 4 inches

k = 510 lb/in<sup>2</sup>/in • 1 in<sup>2</sup> = 510 lb/in per square inch of surface area

f'c = 4,000 psi

E = 57,000 • (4,000)<sup>1/2</sup> = 3,604,907 psi

s = ~ 300 psi (to prevent cracking)

$$w = 257.87 * 300 \text{ psi} * \sqrt{\frac{510 \frac{\text{lb}}{\text{in}} * 4 \text{ in}}{3,604,907 \text{ psi}}} = 1,840 \text{ psf}$$

Note: This solution neglects any contribution from soil stiffness.

## Determining Slab Deflection and Insulation Stress

Deflection in the slab is calculated as:

$$D = \frac{P}{8 \sqrt{K * \frac{EH^3}{12(1-\nu^2)}}}$$

### Where

D = Deflection (in)

f'<sub>c</sub> = Concrete compressive strength (psi)

E = Modulus of Elasticity, concrete (psi), E ≈ 57,000 (f'<sub>c</sub>)<sup>1/2</sup>

h = Slab thickness (in)

k = Modulus of subgrade reaction (pci) (use insulation foundation modulus) K = Insulation foundation modulus (pci) (Table 6)

P = Load (dead load plus live load) (lb)

μ = Poisson's Ratio, 0.20 for concrete

The compressive stress in the insulation layer under the concrete slab is estimated as: **F = K • D**

If the XPS insulation is placed directly below the foundation, the compressive stress applied to the insulation can be conservatively calculated assuming a 2:1 (horizontal to vertical) stress projection through the concrete.

### Example: Slab Deflection and Insulation Stress Calculation

Determine the slab deflection and estimated insulation stress on an insulated slab-on-grade. Assume a 4" slab resting on 4" of FOMULAR 250 GEO. Concrete 28 day strength is 4,000 psi. The load applied is a concentrated 8,000 pounds live load and a 2,000 pounds dead load.

The following data is given in the problem statement:

P = 10,000 pounds total load

h = 4 inches

K = 510 lb/in<sup>2</sup>/in • 1 in<sup>2</sup> = 510 lb/in per square inch of surface area

f'<sub>c</sub> = 4,000 psi

E = 57,000 x (4,000)<sup>1/2</sup> = 3,604,907 psi

$$D = \frac{P}{8 * \sqrt{K * \frac{EH^3}{12(1-\mu^2)}}} = \frac{10000}{8 * \sqrt{510 * \frac{(3604907)(4)^3}{12(1-0.2^2)}}} = 0.0124 \text{ inches}$$

Deflection of the slab is 0.0124 inches.

F = K • D = 510 • 0.0124 = 6.3 psi = 908 psf

Compressive stress is 908 psf, which is less than the allowable bearing capacity of 1200 psf (ASTM C578 Type IV).

Check with 2:1 projection, assuming a 2.5 foot square contact area: 10000/(30"+16")<sup>2</sup> = 4.7 psi = 680 psf

The estimated stress is approximately 0.75 times the calculated stress in this case. Note that the previous equations do not account for any reinforcement in the slab. Consult a design manual, such as the American Concrete Institute Design of Slabs-on-Grade manual (ACI 360R-06), for design of the slab. The addition of reinforcement will increase the strength of the slab and may improve the stress conditions on an underlying insulation layer. Actual pressures for more highly concentrated loads, such as jack loads in a garage, may require higher strength insulation. Refer to ASCE 7 for further information on design loads for floors.

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## **INSTALLATION**

Vertical XPS insulation should be attached to walls using bituthene, tacky waterproofing or damp-proofing adhesive (per ASCE 32-01). Do not install FOAMULAR® GEO until damp-proofing or waterproofing membranes are fully cured. Use only Owens Corning recommended adhesives with FOAMULAR® GEO. Care should be taken to prevent damaging or puncturing the insulation board during storage and installation, which prevents cold bridging and moisture movement through the insulation.

Insulation panels should be butted together for a tight fit. Vertical joints of XPS insulation boards placed in layers Horizontal insulation placed in layers should be staggered so joints do not overlap. End joints should also be staggered.

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