Winter Updates: ACI 332 Requirements & Frost Protected Shallow Foundations

Presented by:
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Course Outline

- Soils:
  - Determine type and bearing and lateral loads
  - Web Soil Survey
- Footings
  - Design
  - Forming and reinforcement placement
  - Construction issues
- Foundation walls
  - Determination of reinforcement
  - Backfilling
  - Construction Issues
- Concrete Materials
- Concrete: Environmental Considerations
  - Cold and Hot weather concrete
- Frost Protected Shallow Foundations
  - Premise/Science
  - Details
  - Design Examples

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Determination of Soil Type:

- Without a geotechnical report, other resources need to be utilized to determine the likely soil conditions. Resources include:
  - Contact local geotechnical engineer in the area to see if any studies have been performed nearby.
  - Personal experience or the experience of other local officials.
  - Web Soil Survey:
    - Online resource "Web Soil Survey" provides information on soil types to a depth of approximately 6' below grade
    - https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
    - The following slides illustrate an example of soil data obtained from the Web Soil Survey

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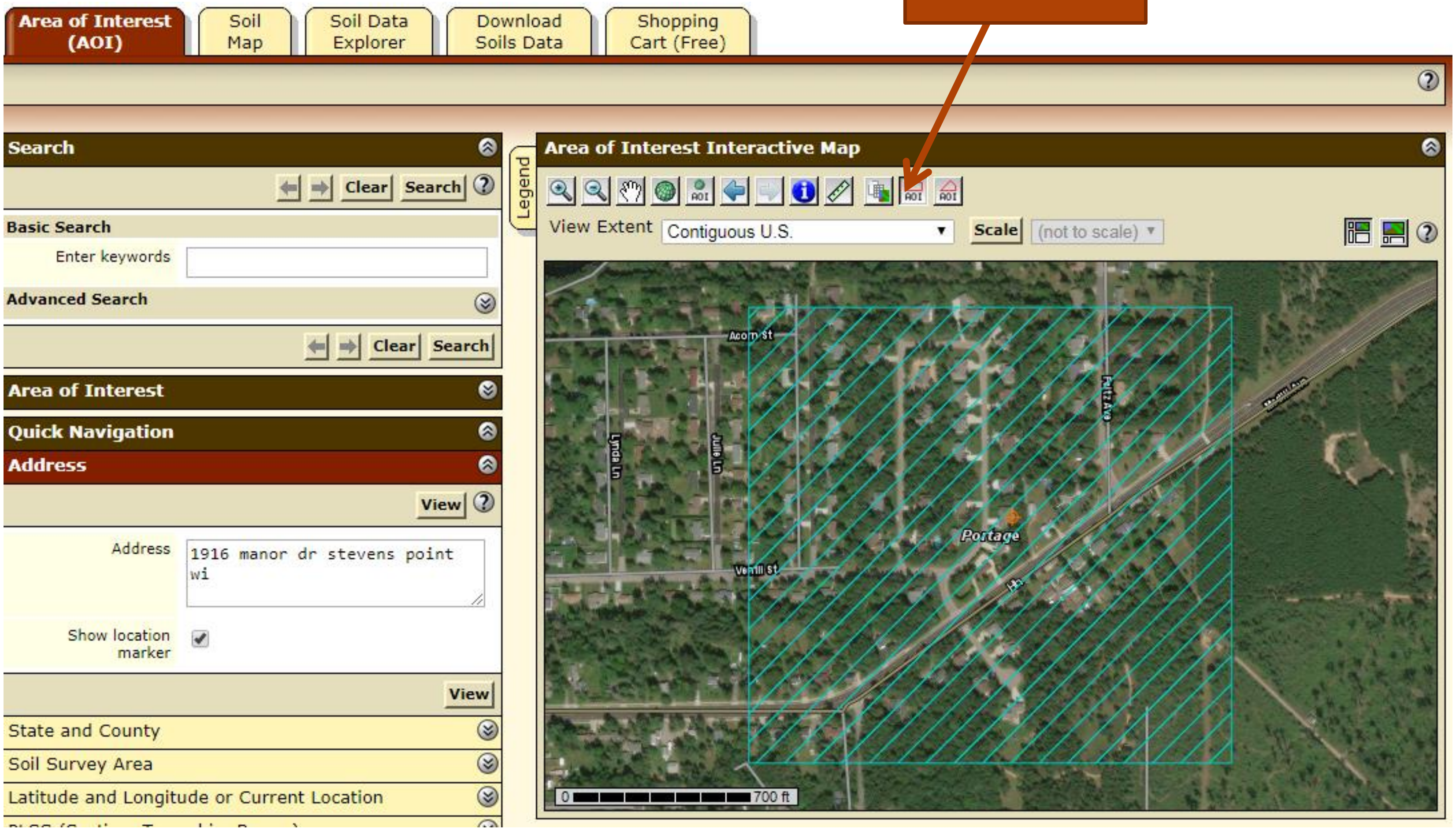
Web Soil Survey: AOI

Select AOI



Use address and then draw an “Area of Interest” AOI

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Web Soil Survey: Soil Map

Area of Interest (AOI) | **Soil Map** | Soil Data Explorer | Download Soils Data | Shopping Cart (Free)

Printable Version | Add to Shopping Cart

Search

Clear | Search

Basic Search

Enter keywords

Advanced Search

Clear | Search

Map Unit Legend

Portage County, Wisconsin (WI097)

Portage County, Wisconsin (WI097)

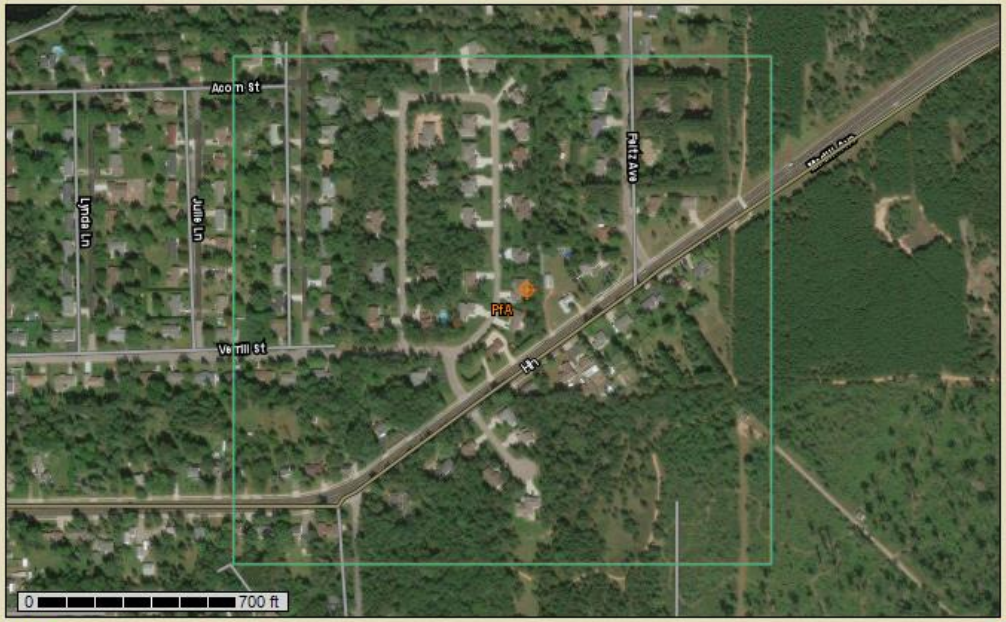
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
PfA	Plainfield loamy sand, 0 to 2 percent slopes	79.0	100.0%
Totals for Area of Interest		**79.0**	**100.0%**

Material Description

Soil Map

Legend

Scale (not to scale)



Warning: Soil Map may not be valid at this scale.

You have zoomed in beyond the scale at which the soil map for this area is intended to be used. Mapping of soils is done at a particular scale. The soil surveys that comprise your AOI were mapped at 1:20,000. The design of map units and the level of detail shown in the resulting soil map are dependent on that map scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

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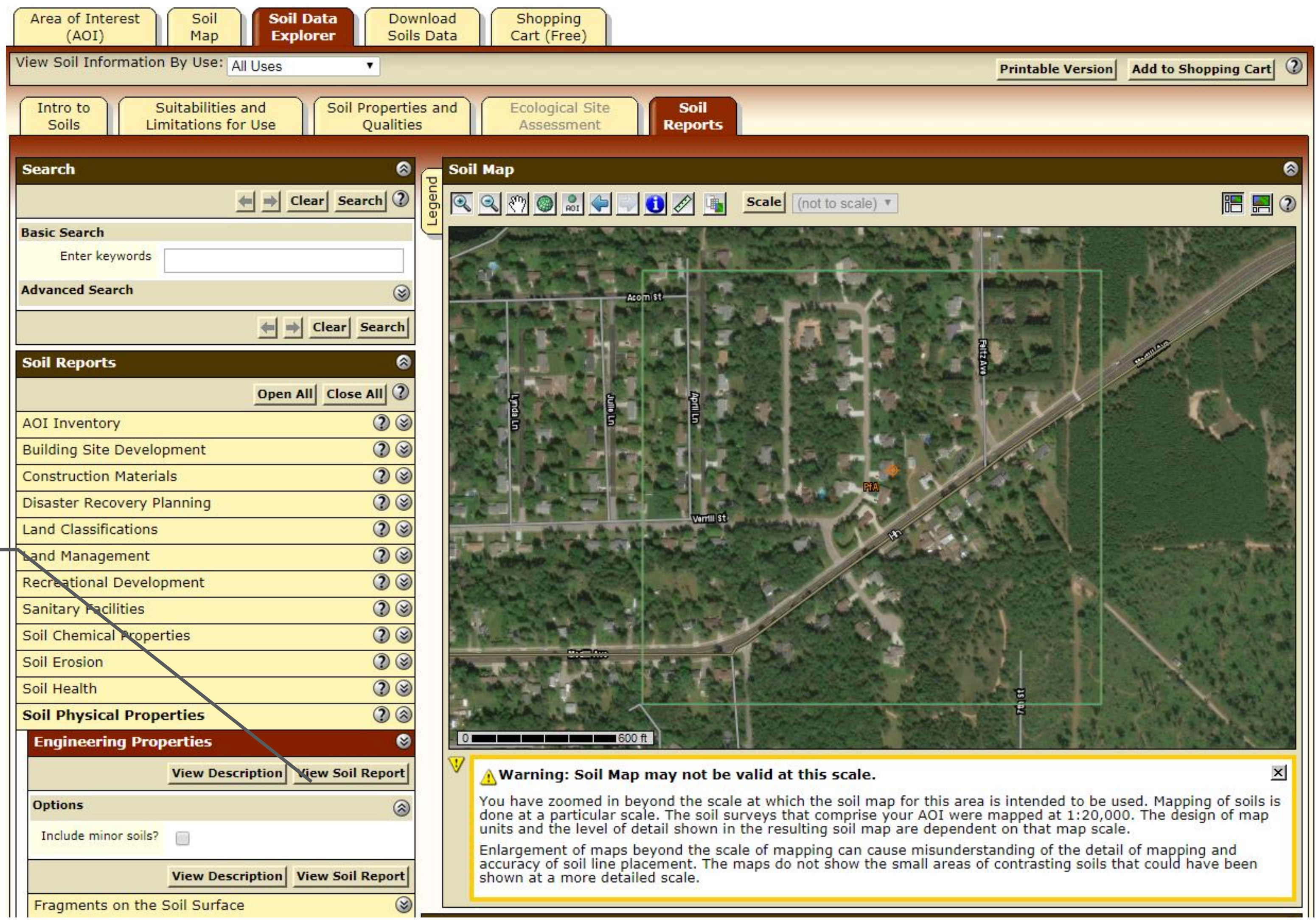
Web Soil Survey: Soil Data Explorer – Soil Reports



Select this option

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Web Soil Survey: Soil Data Explorer Soil Reports

Report — Engineering Properties

Absence of an entry indicates that the data were not estimated. The asterisk '*' denotes the representative texture; other possible textures follow the dash. The criteria for determir
2007(http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba). Three values are provided to identify the expected Low (L), Representative Value (R), an

Portage County, Wisconsin

Map unit symbol and soil name	Pct. of map unit	Hydrologic group	Depth	USDA texture	Classification	
					Unified	AASHTO
			In			
PfA—Plainfield loamy sand, 0 to 2 percent slopes						
Plainfield	90	A	0-9	Loamy sand	SP-SC	A-2-4
			9-23	Sand, loamy sand	SP-SM	A-2-4
			23-32	Sand, coarse sand, stratified sand to fine gravelly coarse sand	SP-SM	A-3
			32-79	Sand, coarse sand, stratified gravelly coarse sand to sand	SP-SM	A-1, A-1-b

Description — Engineering Properties

Can be used to determine allowable bearing and lateral loads from UDC tables

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Web Soil Survey

Table from IBC

TABLE 1806.2
PRESUMPTIVE LOAD-BEARING VALUES

CLASS OF MATERIALS	ALLOWABLE FOUNDATION PRESSURE (psf)[d]	LATERAL BEARING (psf/ft below natural grade)[d]
1. Crystalline bedrock	12,000	1,200
2. Sedimentary and foliated rock	4,000	400
3. Sandy gravel and/or gravel (GW and GP)	3,000	200
4. Sand, silty sand, clayey sand, silty gravel and clayey gravel (SW, SP, SM, SC, GM and GC)	2,000	150
5. Clay, sandy clay, silty clay, clayey silt, silt and sandy silt (CL, ML, MH and CH)	1,500[c]	100

SPS 321.15 (3) Soil Bearing capacity table

Type of soil	PSF
1. Wet, soft clay; very loose silt; silty clay	2,000
2. Loose, fine sand; medium clay; loose sandy clay soils	2,000
3. Stiff clay; firm inorganic silt	3,000
4. Medium (firm) sand; loose sandy gravel; firm sandy clay soils; hard dry clay	4,000
5. Dense sand and gravel; very compact mixture of clay, sand and gravel	6,000
6. Rock	12,000

UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART

COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.)		
GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	Clean Gravels (Less than 5% fines)	
	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (More than 12% fines)	
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	Clean Sands (Less than 5% fines)	
	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly graded sands, gravelly sands, little or no fines
	Sands with fines (More than 12% fines)	
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS (50% or more of material is smaller than No. 200 sieve size.)		
SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fat clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

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ACI Codes adopted by the 2016 Wisconsin UDC

American Concrete Institute
Always advancing

- SPS 321.02
  - SPS 321.02(3)(d)
    - (1) ACI Standard 318, Building Code Requirements for Structural Concrete
    - (2) ACI Standard 332, Residential Code Requirements for Structural Concrete
    - ACI 117 is adopted within the text of ACI 332

Note: Concrete construction in one and two-family dwellings should meet the standards established in ACI 332. Construction means, materials, or methods not addressed in ACI 332 should meet the standards established in ACI 318.

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Foundation Design: Continuous Footings

- SPS 321.15(2) Size and Type
  - (a) Continuous Footings. The minimum width of the footing on each side of the foundation wall shall measure at least 4 inches wider than the wall. The footing depth shall be at least 8 inches nominal…
- ACI 332: Section 6.2.1
  - **6.2.1.1** Wall footing width shall not be less than the applicable dimensions specified in Table 6.2 or the supported wall thickness plus 4 in., whichever is less.
  - **6.2.1.2** Wall footing thickness shall not be less than the greater of 6 in. or half the footing width minus the supported wall thickness.

These two sets of criteria differ slightly; however, SPS 321.15(2) has minimum requirements that are greater than ACI 332 and those would govern.

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Foundation Design
Use of ACI 332, Table 6.2

Use the methods described in preceding slides to determine the allowable bearing pressure

Table 6.2—Minimum specified width of wall footings, in.*†‡

	No. of stories above grade§	Allowable soil-bearing capacity, lb/ft²					
		1500	2000	2500	3000	3500	4000
Conventional wood frame construction (above grade)	One-story	16	12	10	8	7	6
	Two-story	19	15	12	10	8	7
	Three-story	22	17	14	11	10	9
4 in. brick veneer over wood frame; 8 in. hollow concrete masonry unit (above grade)	One-story	19	15	12	10	8	7
	Two-story	25	19	15	13	11	10
	Three-story	31	23	19	16	13	12
8 in. grouted concrete masonry unit	One-story	22	17	13	11	10	9
	Two-story	31	23	19	16	13	12
	Three-story	40	30	24	20	17	15

These two sets of values will likely be used in 95% of residential applications

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Foundation Design: Isolated Footings

- SPS 321.15(2) Size and Type
  - *(b) Column or pier footing*. 1. The minimum width and length of column or pier footings shall measure at least 2 feet by 2 feet.
- ACI 332: Section 6.2.2
  - 6.2.2 Isolated footings—Isolated footing dimensions shall not be less than the applicable dimensions specified in Table 6.3.
  - R6.2.2 The tributary area supported by an isolated footing is shown in Fig. R6.1. Isolated footings are also referred to as pier or column footing

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Foundation Design

ACI 332 Example:
Tributary area = 12'x8'
Supporting roof & one floor
Roof SL = 30 psf, DL = 20 psf
Floor LL = 40 psf, DL = 20 psf
P = 96 sf x (50 psf) + 96 sf x (60 psf) = 10,560lbs
Soil = 3000 psf, A >= 10,560/3000 = 3.5sf
(Design table is conservative $A_{provided}$ = 9 sf)

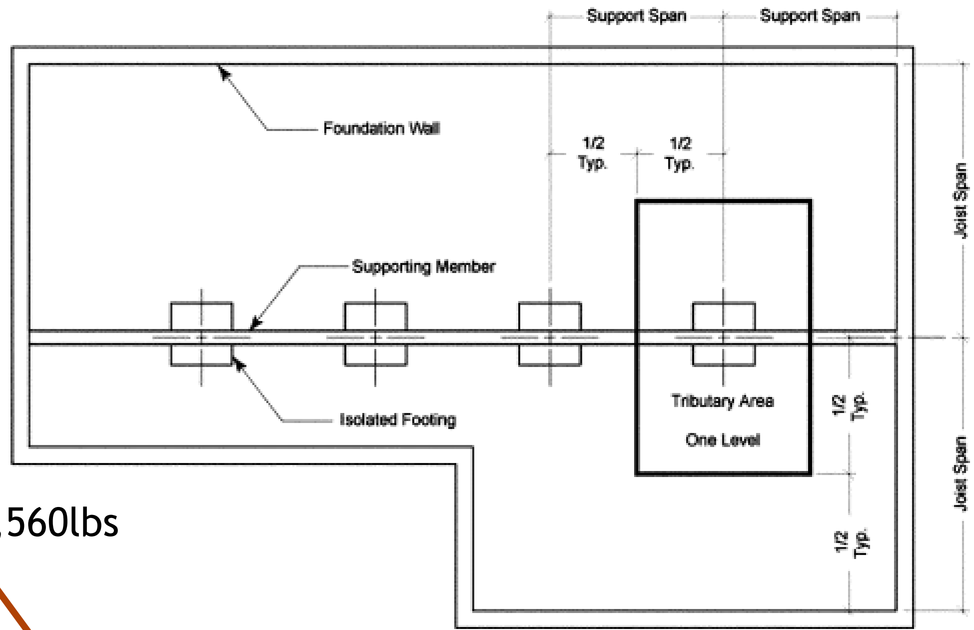

Fig. R6.1—Tributary area for isolated footing.

Table 6.3—Minimum specified size and reinforcement for isolated footings, in.*†‡

Tributary area	Allowable soil-bearing capacity, lb/ft²					
	1500	2000	2500	3000	3500	4000
Footing supporting roof load	36 x 36 x 8 in. with 3 No. 4 each way	30 x 30 x 8 in. with 3 No. 4 each way	30 x 30 x 8 in. with 3 No. 4 each way	24 x 24 x 8 in. with 3 No. 4 each way	24 x 24 x 8 in. with 3 No. 4 each way	24 x 24 x 8 in. with 3 No. 4 each way
Footing supporting roof and one floor	48 x 48 x 10 in. with 3 No. 4 each way	48 x 48 x 10 in. with 3 No. 4 each way	36 x 36 x 10 in. with 3 No. 4 each way	36 x 36 x 10 in. with 3 No. 4 each way	30 x 30 x 10 in. with 3 No. 4 each way	30 x 30 x 10 in. with 3 No. 4 each way
Footing supporting roof and two floors	60 x 60 x 12 in. with 4 No. 5 each way	60 x 60 x 12 in. with 4 No. 5 each way	48 x 48 x 12 in. with 4 No. 5 each way	48 x 48 x 12 in. with 4 No. 5 each way	42 x 42 x 12 in. with 3 No. 5 each way	36 x 36 x 12 in. with 3 No. 5 each way

*Specified minimum concrete strength f_c' shall be 2500 psi.
†Specified minimum yield strength f_y shall be 40,000 psi.
‡Maximum tributary area is 20 x 32 ft (based on loads prescribed in Table 6.1).

These two sets of values will likely be used in 95% of residential applications

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Formwork and Rebar placement Tolerances:

ACI 117: Specifications for Tolerances for Concrete Construction

- ACI 117 is adopted by ACI 332 in section 7.3:
- **7.3—Construction**

  7.3.1 *Forms*—Foundation wall forms shall be stable during placement of concrete and shall result in a final structure that conforms to the shapes, lines, and dimensions required by the design drawings and specifications. Blockouts, inserts, bulkheads, embedded items, and reinforcement shall be installed in the forms in such a manner that their final dimensions, alignments, and elevations are maintained within the tolerances specified in ACI 117.

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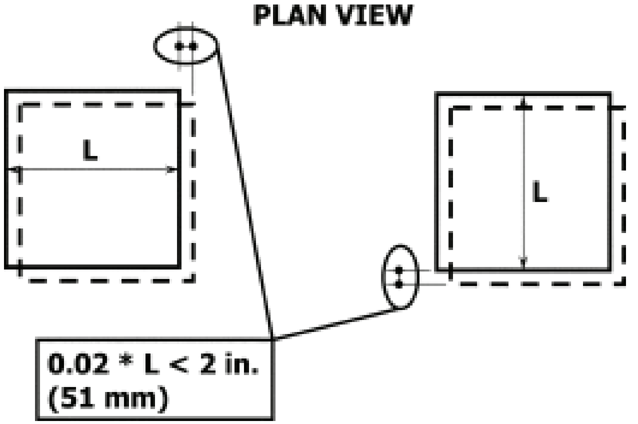
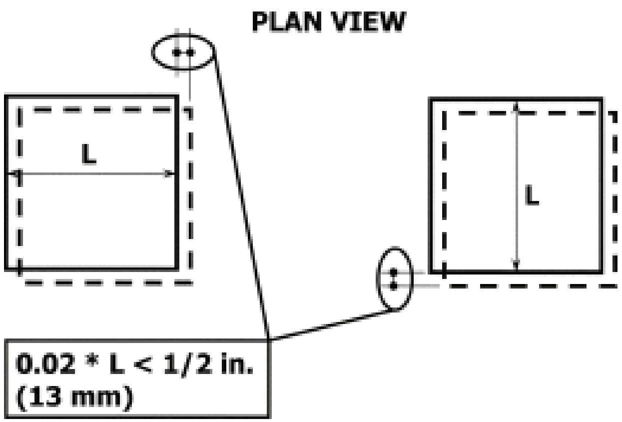
ACI 117: Section 3: Foundations forming tolerances

- 3.2.1 Deviation from location:
  - Horizontal deviation of the as-cast edge shall be the lesser of ±2% of the foundation's width or ±2 in.



- 3.2.2 Foundations supporting masonry
  - Horizontal deviation of the as-cast edge shall be the lesser of ±2% of the foundation's width or +/-1/2"



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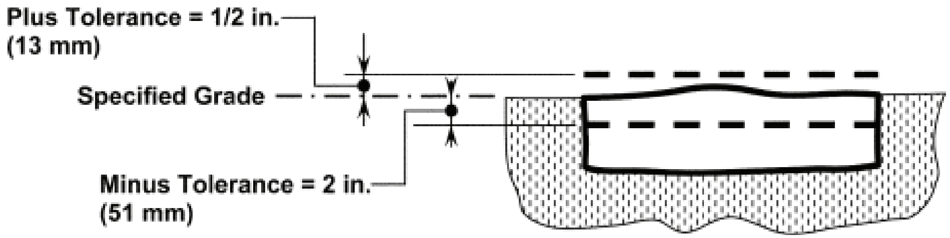
ACI 117: Section 3: Foundations forming tolerances

- 3.3. Deviation from elevation

3.3.1 *Top surface of foundations*

Vertical deviation ....+1/2 in. (13 mm)

....–2 in. (51 mm)



ELEVATION VIEW

ACI 117: Section 3: Foundations forming tolerances

- 3.5. Deviation from cross-sectional dimensions of foundations

3.5.1 *Formed footings*

Horizontal deviation .... +2 in. (51 mm)

.... –1/2 in. (13 mm)

3.5.2 *Unformed footings cast against soil*

Horizontal deviation from plan dimension

Where dimension is 2 ft (0.6 m) or less
.... +3 in. (76 mm)

.... –1/2 in. (13 mm)

Where dimension is more than 2 ft (0.6 m)
.... +6 in. (152 mm)

.... –1/2 in. (13 mm)

3.5.3 Deviation from footing thickness .... –5%

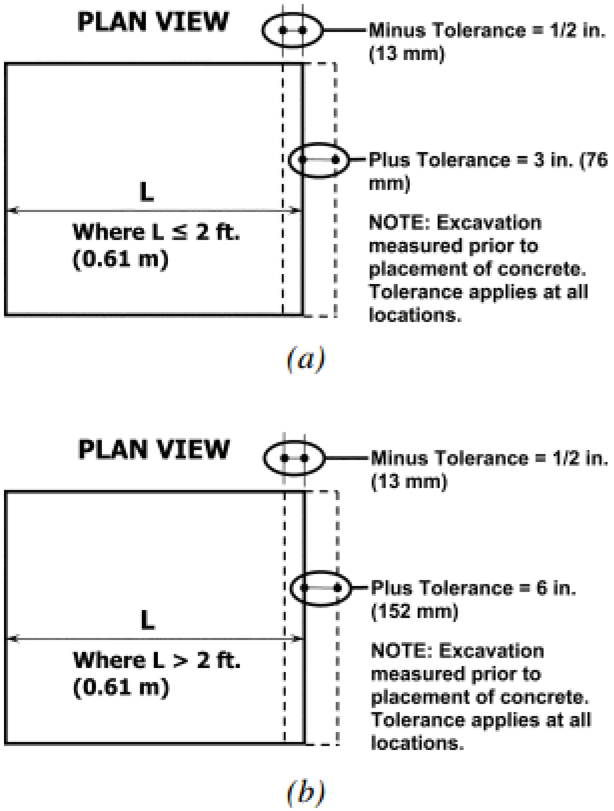


Fig. R3.5.2—Unformed footings cast against soil.

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ACI 117: Section 2.1: Reinforcement Steel Tolerances

- Section 2.2 Reinforcement Location

2.2.1 *Placement of nonprestressed reinforcement, measured from form surface*

When member depth (or thickness) is 4 in. (101 mm) or less .... ±1/4 in. (6 mm)

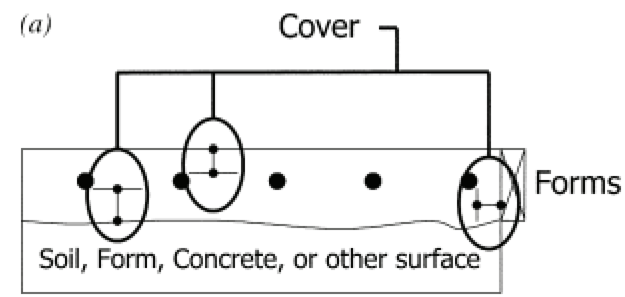
When member depth (or thickness) is over 4 in. (101 mm) and not over 12 in. (305 mm) .... ±3/8 in. (10 mm)

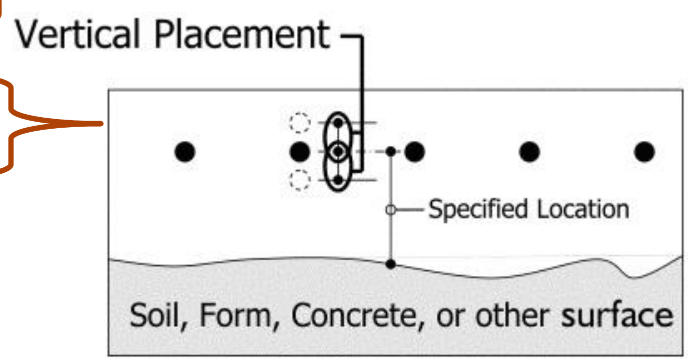
2.2.2 *Concrete cover measured perpendicular to concrete surface*

When member depth (or thickness) is 12 in. (305 mm) or less .... –3/8 in. (10 mm)

When member depth (or thickness) is over 12 in. (305 mm) .... –1/2 in. (13 mm)

2.2.3 Vertical deviation for slab-on-ground reinforcement .... ± 3/4 in. (19 mm)





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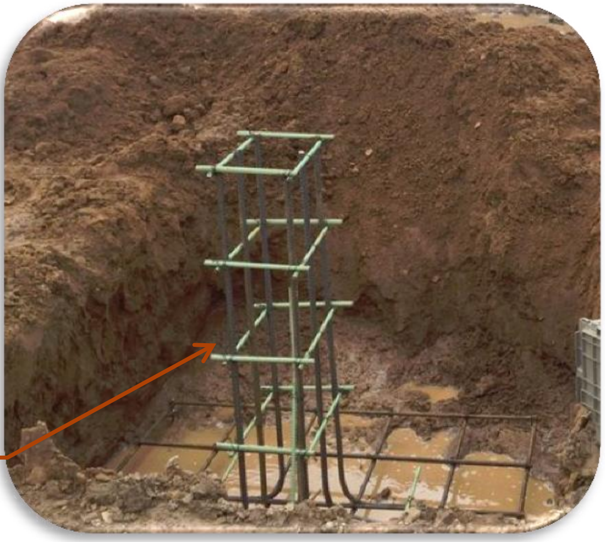
Additional placement tolerances covered in sections 2.2.4 – 2.2.10

Foundation Formwork: Continuous Footings

- ACI 332: Section 3.3
  - Forms, form ties, bulkheads, and other accessories shall be constructed of materials that are capable of performing the function for which they are intended.
  - *R3.3 Guidance on design and construction of formwork can be found in ACI 347 and ACI SP-4*
- ACI 332: Section 6.3.1
  - **6.3.1** *Unformed footings*—The excavated condition of unformed footings shall remain stable before and during concrete placement.
    ***R6.3.1** Frequently, unformed footings are used where frost depth is shallow or for interior load-bearing walls. Footings may be placed integrally with the floor slab…*

Location of reinforcement exceeds allowable tolerances



Bottom of footing excavation should not be filled with water at time of casting concrete. Concrete pier requires forms

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Properly Formed Footings with Reinforcement and Dowels

Image taken from: http://www.greenbuildingadvisor.com/community/forum/general-questions/57341/using-vertical-rebar-suspend-footing-rebar-cmu-stem-wall

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Discontinuous Footings

- Discontinuous footings (jump footings) are allowed with certain restrictions
  - Max distance = less than 4'
  - Additional reinforcement is required. See Figure R6.2

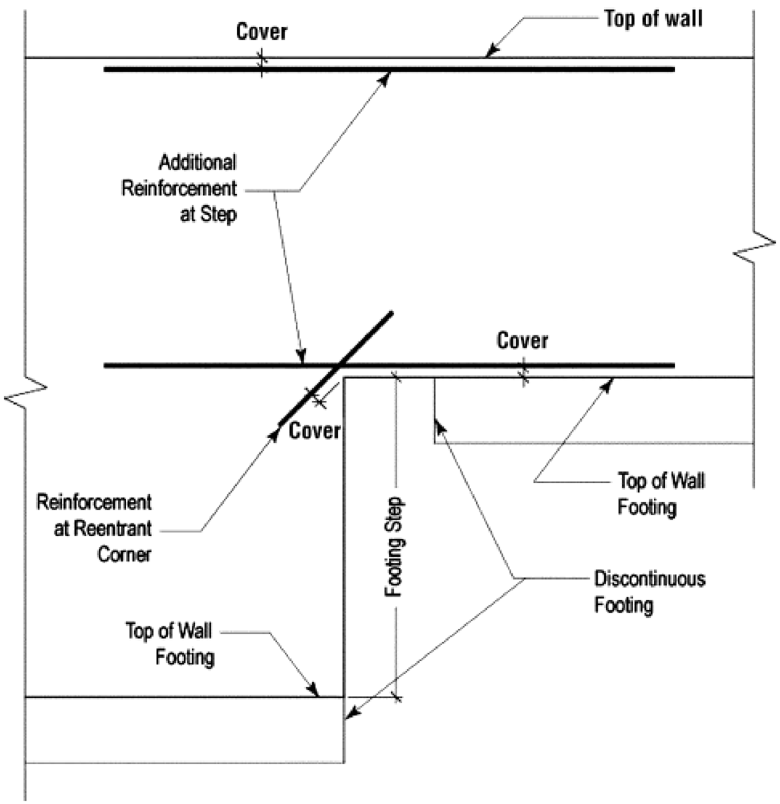

Fig. R6.2—Discontinuous wall footing and additional wall reinforcement.

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Foundation Reinforcement: Inspector question submissions:

- Is it OK for contractors to pour 2 – 3" of concrete and then place the rebar on top of the concrete and pour remainder on top?
  - Not really. There is no guarantee the bars will be placed or remain at the proper depth. Additionally, this practice can create a "cold joint" at the location of the tension reinforcement, essentially making it so that the reinforcement in not able to do the intended work.
- Form Release agents on structural rebar? Does this reduce the effectiveness of the rebar
  - *From ACI 332, Section 3.2.4: Surface conditions of reinforcement*—At the time concrete is placed, deformed bar and welded wire reinforcement shall be free of materials deleterious to development of bond strength between the reinforcement and the concrete.
  - However, research has proven the bond of rebar to concrete occurs as a result of the mechanical deformations of the bars. A bar with a bit of form release agent would not be a problem; however, the contractors should not be coating them intentionally

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Foundation Reinforcement: Inspector question submissions:

- Pier rebar cages
  - Location of ties: Occasionally ties are located inside of vertical rebar when the vertical arrangement is wider than the pre-formed rings.
  - This is absolutely not acceptable. The purpose of the ties is to confine the vertical cages of rebar. Placement of verticals must always be inside a column tie. Spacing of ties is also critical and would be in accordance with ACI 318

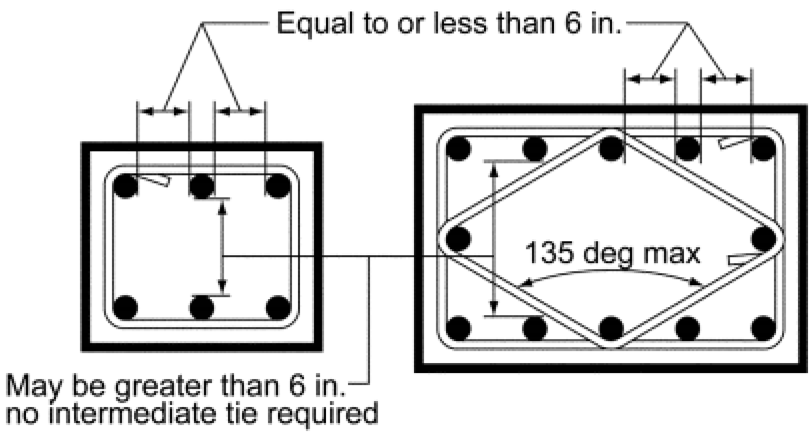

Fig. R7.10.5—Sketch to clarify measurements between laterally supported column bars.

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Foundation (Basement) Wall Design

IBC Load Table

TABLE 1610.1
LATERAL SOIL LOAD

DESCRIPTION OF BACKFILL MATERIAL[c]	UNIFIED SOIL CLASSIFICATION	DESIGN LATERAL SOIL LOAD[a] (pound per square foot per foot of depth)	
		Active pressure	At-rest pressure
Well-graded, clean gravels; gravel-sand mixes	GW	30	60
Poorly graded clean gravels; gravel-sand mixes	GP	30	60
Silty gravels, poorly graded gravel-sand mixes	GM	40	60
Clayey gravels, poorly graded gravel-and-clay mixes	GC	45	60
Well-graded, clean sands; gravelly sand mixes	SW	30	60
Poorly graded clean sands; sand-gravel mixes	SP	30	60
Silty sands, poorly graded sand-silt mixes	SM	45	60
Sand-silt clay mix with plastic fines	SM-SC	45	100
Clayey sands, poorly graded sand-clay mixes	SC	60	100
Inorganic silts and clayey silts	ML	45	100
Mixture of inorganic silt and clay	ML-CL	60	100
Inorganic clays of low to medium plasticity	CL	60	100
Organic silts and silt clays, low plasticity	OL	Note b	Note b
Inorganic clayey silts, elastic silts	MH	Note b	Note b
Inorganic clays of high plasticity	CH	Note b	Note b
Organic clays and silty clays	OH	Note b	Note b

For SI: 1 pound per square foot per foot of depth = 0.157 kPa/m, 1 foot = 304.8 mm.

a. Design lateral soil loads are given for moist conditions for the specified soils at their optimum densities. Actual field conditions shall govern. Submerged or saturated soil pressures shall include the weight of the buoyant soil plus the hydrostatic loads.

b. Unsuitable as backfill material.

c. The definition and classification of soil materials shall be in accordance with ASTM D 2487.

Traditionally, basement walls are designed for "at rest" soil loads. Active soil pressures can only be used when the top of the wall is assumed to be able to displace.

UDC Load Table

Table 321.18–A
SOIL LATERAL LOAD

Description of Backfill Material[e]	Unified Soil Classification	Design Lateral Soil Load[a] PSF per Foot of Depth
Well graded, clean gravels; gravel–sand mixes	GW	30[c]
Poorly graded clean gravels; gravel–sand mixes	GP	30[c]
Silty gravels, poorly graded gravel–sand mixes	GM	40[c]
Clayey gravels, poorly graded gravel–and–clay mixes	GC	45[c]
Well–graded, clean sands; gravelly sand mixes	SW	30[c]
Poorly graded clean sands; sand–gravel mixes	SP	30[c]
Silty sands, poorly graded sand–silt mixes	SM	45[c]
Sand–silt clay mix with plastic fines	SM–SC	45[d]
Clayey sands, poorly graded sand–clay mixes	SC	60[d]
Inorganic silts and clayey silts	ML	45[d]
Mixture of inorganic silt and clay	ML–CL	60[d]
Inorganic clays of low to medium plasticity	CL	60[d]
Organic silts and silt clays, low plasticity	OL	[b]
Inorganic clayey silts, elastic silts	MH	60[d]
Inorganic clays of high plasticity	CH	[b]
Organic clays and silty clays	OH	[b]

[a]Design lateral soil loads are given for moist conditions for the specified soils at their optimum densities. Actual field conditions shall govern. Submerged or saturated soil pressures shall include the weight of the buoyant soil plus the hydrostatic loads.

[b]Unsuitable as backfill material.

[c]For relatively rigid walls, as when braced by floors, the design lateral soil load shall be increased for sand and gravel type soils to 60 psf per foot of depth. Basement walls extending not more than 8 feet below grade and supporting flexible floor systems are not considered relatively rigid walls.

[d]For relatively rigid walls, as when braced by floors, the design lateral load shall be increased for silt and clay type soils to 100 psf per foot of depth. Basement walls extending not more than 8 feet below grade and supporting flexible floor systems are not considered relatively rigid walls.

[e]Soil classes are in accordance with the Unified Soil Classification System, ASTM D2487, and design lateral loads are for moist soil conditions without hydrostatic pressure.

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ACI 332 Foundation Wall Design

7.2—Design: Foundation walls shall be designed either by using the prescriptive tables in Appendix A or by wall provisions of ACI 318 as modified by provisions of this chapter. Foundation wall design shall be based on analyzing the wall as a simply supported vertical flexural member with the top and bottom laterally supported. Walls shall be designed as either plain concrete conforming to 7.2.1, reinforced concrete conforming to 7.2.2, or conforming to 7.2.3. All wall provisions of ACI 318 not specifically modified or excluded by this chapter shall apply to the design and analysis of foundation walls.

Table A.1—Vertical reinforcing bar spacing for concrete basement walls

	f_c' = 2500 psi		Specified maximum equivalent fluid pressure of soil, psf/ft											
	f_y = 40,000 psi		30			45			60			100		
			Specified minimum wall thickness, in.			Specified minimum wall thickness, in.			Specified minimum wall thickness, in.			Specified minimum wall thickness, in.		
Unsupported wall height, ft	Unbalanced backfill, ft	Reinforcing bar	7.5	9.5	11.5	7.5	9.5	11.5	7.5	9.5	11.5	7.5	9.5	11.5
8	5	No. 4 @ ... in.	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain
		No. 5 @ ... in.	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain
		No. 6 @ ... in.	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain
	6	No. 4 @ ... in.	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	12	Plain	Plain
		No. 5 @ ... in.	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	18	Plain	Plain
		No. 6 @ ... in.	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	Plain	26	Plain	Plain
	7	No. 4 @ ... in.	Plain	Plain	Plain	Plain	Plain	Plain	14	Plain	Plain	8	11	Plain
		No. 5 @ ... in.	Plain	Plain	Plain	Plain	Plain	Plain	22	Plain	Plain	13	17	Plain
		No. 6 @ ... in.	Plain	Plain	Plain	Plain	Plain	Plain	31	Plain	Plain	18	24	Plain

Portion of Table from ACI 322, Appendix A

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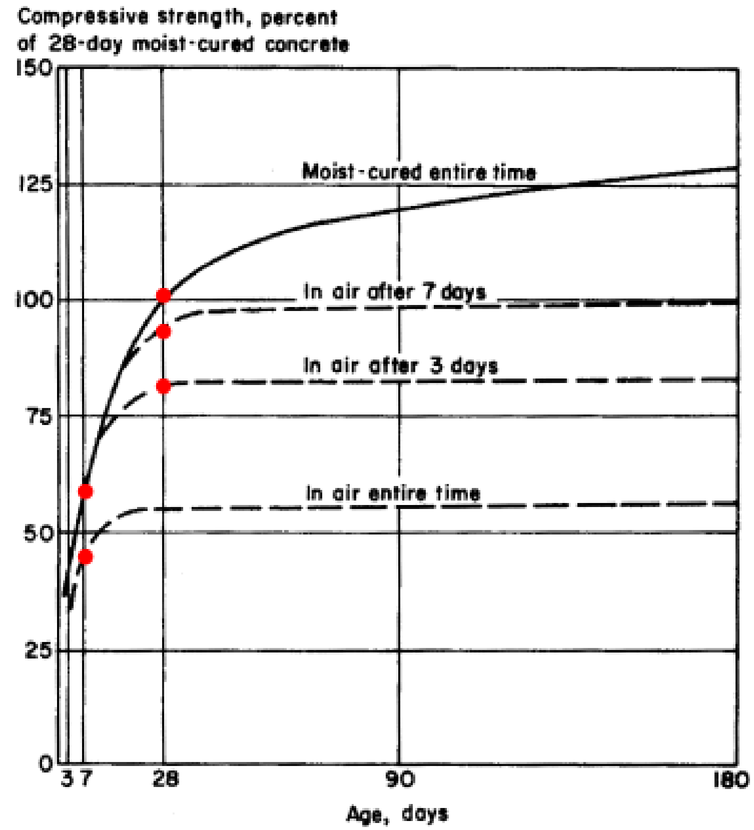
Foundation Walls: Form removal

- ACI 332
  - 5.3: Removal of forms shall not damage concrete surfaces
- ACI 347 (not adopted by 332, but a good reference)
  - 3.7.2.3. Because the minimum stripping time is a function of concrete strength, the preferred method of determining stripping time is using tests of job-cured cylinders or concrete in place. When the contract documents do not specify the minimum strength required of concrete at the time of stripping, however, the following elapsed times can be used. The times shown represent a cumulative number of days, or hours, not necessarily consecutive, during which the temperature of the air surrounding the concrete is above 50 °F.

Walls* .... 12 h
Columns* .... 12 h
Sides of beams and girders* .... 12 h



Based on the strength gain chart, removing the forms after 7 days will provide greater strength due to an increase in “moist cure time”. Walls should not be backfilled for at least 14 days (Ionic opinion).

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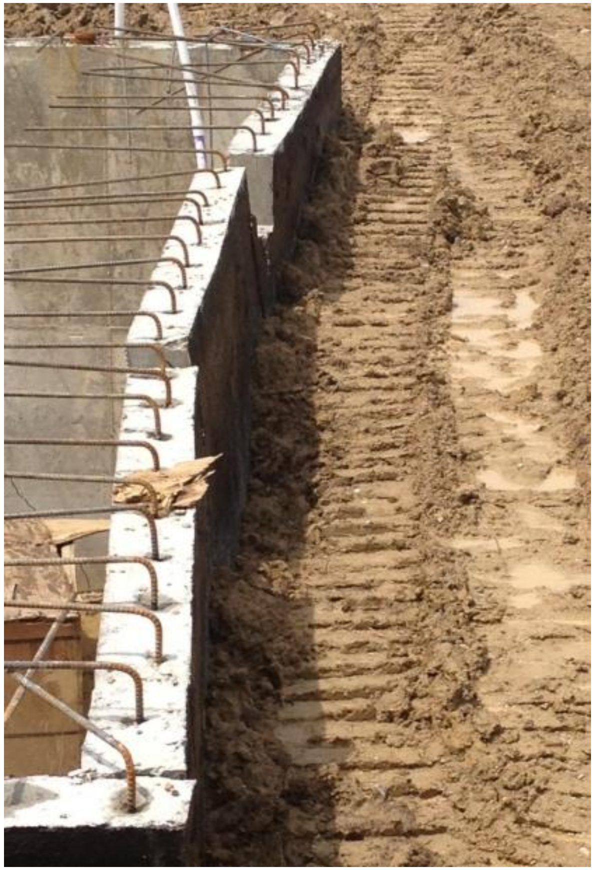
Foundation Walls: Backfill

- ACI 332
  - 7.2.5 Lateral restraint—The equivalent fluid pressure of the backfill shall be determined, but in no case shall be taken as less than 30 psf/ft. The foundation walls shall be restrained top and bottom against lateral movement. The top and bottom restraint for the foundation wall shall be in place before the introduction of backfill against the foundation wall. Temporary lateral restraint is permitted.
- Material Used for Backfill:
  - The material used for backfilling the basement wall is based on the design criteria. If the wall was designed for a low lateral earth pressure, clear draining granular fill would need to be used. If the wall is deigned for 100 psf/ft backfill, clay backfill material would be acceptable.



Example of top of wall movement due to lack of top restraint prior to backfill
Image from https://www.forconstructionpros.com

Helpful resource CFA_TN-002_Backfilling_Foundation_Walls.pdf

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Concrete Materials

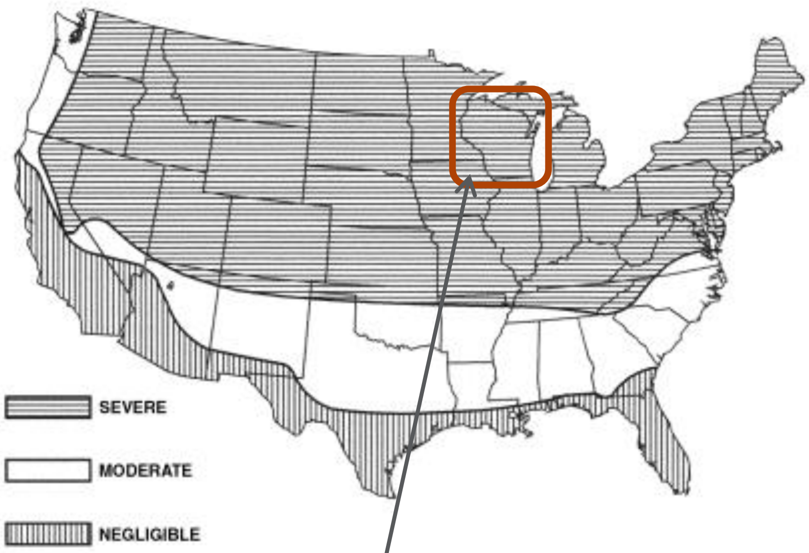

Table 4.1—Minimum specified compressive strength (f_c', psi) at 28 days and maximum specified slump of concrete

Type or location of concrete construction	Weathering probability: Negligible	Weathering probability: Moderate	Weathering probability: Severe	Maximum slump, in.*
Type 1: Walls and foundations not exposed to weather. Interior slabs-on-ground, not including garage floor slabs	2500	2500	2500	6
Type 2: Walls, foundations, and other concrete work exposed to weather, except as noted in Type 3	2500	3000	3000	6
Type 3: Driveways, curbs, walkways, ramps, patios, porches, steps, and stairs exposed to weather and garage floor slabs	2500	3500	4500	5

*Specified maximum slump may be increased through the use of mid-range or high-range water-reducing admixtures.

Table 4.2—Air content for Types 2 and 3 concrete under moderate or severe weathering probability

Nominal maximum aggregate size, in.	Air content, % (tolerance ±1.5%): Moderate	Air content, % (tolerance ±1.5%): Severe
3/8	6.0	7.5
1/2	5.5	7.0
3/4	5.0	6.0
1	4.5	6.0
1-1/2	4.5	5.5

Wisconsin is considered a "severe" exposure

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Concrete: Environmental Considerations

- Hot Weather: ACI 332, Section 5.5.
  - During hot weather, proper attention shall be given to ingredients, production methods, handling, delivering, placing, protection, and curing of concrete to prevent excessive concrete temperatures or water evaporation that could impair required strength or serviceability of the member or structure
  - Also refer to ACI 305
- Cold Weather: ACI 332, Section 5.4.
  - **5.4.1** During anticipated ambient temperature conditions of 35 °F or less, concrete temperature shall be maintained above freezing until a concrete compressive strength of 500 psi has been reached.
  - **5.4.2** Concrete materials, reinforcement, forms, and any earth with which concrete is to come in contact shall be free from ice, snow, and frost.
  - **5.4.3** Frozen materials or materials containing ice shall not be used
  - Also refer to ACI 306

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Cold Weather Concrete: ACI 306 Inspector Question Submissions:

When should cold weather provisions be used?

- Cold weather is defined as a period when, for more than 3 consecutive days, the following conditions exist:
  - The average daily air temperature is less than 40F
  - The air temperature is not greater than 50F (10 C) for more than one-half of any 24-hr period

What should the concrete temperature be at time of placing?

- During cold weather, the concrete temperature at the time of placement should not be lower than the values given in Chapter. The recommended minimum placement temperatures given in Table 3.1

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ACI 306: Recommended concrete temperatures at time of placement

Table 3.1 - Recommended concrete temperatures

Line	Air temperature	Section size, minimum dimension, in. (mm)			
		< 12 in. (300 mm)	12-36 in. (300-900 mm)	36-72 in. (900-1800 mm)	> 72 in. (1800 mm)
Minimum concrete temperature as placed and maintained					
1	-	55 F (13 C)	50 F (10 C)	45 F (7 C)	40 F (5 C)
Minimum concrete temperature as mixed for indicated air temperature*					
2	Above 30 F (- 1 C)	60 F (16 C)	55 F (13 C)	50 F (10 C)	45 F (7 C)
3	0 to 30 F (-18 to -1 C)	65 F (18 C)	60 F (16 C)	55 F (13 C)	50 F (10 C)
4	Below 0 F (- 18 C)	70 F (21 C)	65 F (18 C)	60 F (16 C)	55 F (13 C)
Maximum allowable gradual temperature drop in first 24 hr after end of protection					
5	-	50 F (28 C)	40 F (22 C)	30 F (17 C)	20 F (11 C)

*For colder weather a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.

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Cold Weather Concrete: ACI 306 Protection Period

Length of protection period for air-entrained concrete. Period of protection to be used during conditions listed on Line 1 of Table 3.1

Table 5.1 - Length of protection period required to prevent damage from early-age freezing of air-entrained concrete

Line	Exposure	Protection period at temperature indicated in Line 1 of Table 3.1, days*	
		Type I or II cement	Type III cement, or accelerating admixture, or 100 lb/yd³ (60 kg/m³) of additional cement
1	Not exposed	2	1
2	Exposed	3	2

*A day is a 24-hr period.

Period of protection for non-air entrained concrete.

Table 5.3 - Length of protection period for concrete placed during cold weather

Line	Service category	Protection period at temperature indicated in Line 1 of Table 3.1, days*	
		Type I or II cement	Type III cement, or accelerating admixture, or 100 lb/yd³ (60 kg/m³) of additional cement
1	1 - no load, not exposed	2	1
2	2 - no load, exposed	3	2
3	3 - partial load, exposed	6	4
4	4 - full load	See Chapter 6	

*A day is a 24-hr period.

Service category 1 typically includes foundations that are not subject to early load.

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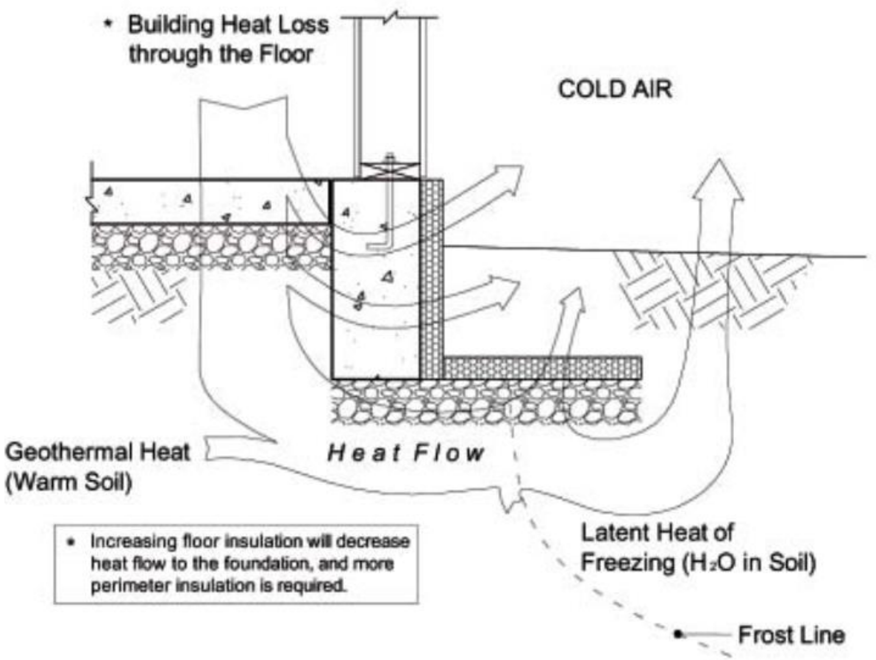
Frost Protected Shallow Foundations (FPSF)

- Purpose: Shallow foundations are more economical than deep foundations in areas where the frost depth is several feet.
- Concept: FPSF foundations place rigid foam insulation to trap the heat of the earth beneath the foundation and keep the ground from freezing. See Figure to the right
- Code: ASCE 32
- Variables
  - Geographic location
  - Heated / unheated structure
  - Foundation type



FPSF Heat Flow Diagram
(Revised Builders Guide to FSSF Shallow Foundations, Sept 2004)

Heat lost through the floor slab, as well as the geothermal heat of warm soil beneath the building, combine to keep frost from forming below the slab edge. Vertical insulation is installed along the exterior of the thickened slab edge; in the coldest climate zones, additional sheets of rigid foam are placed horizontally, extending out from the base of the slab

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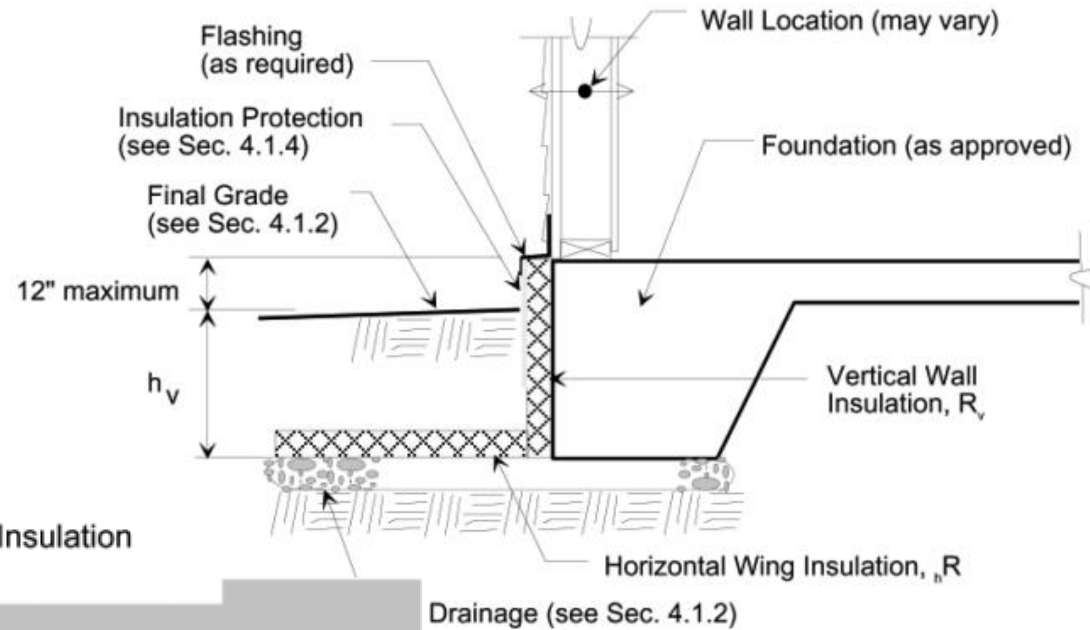
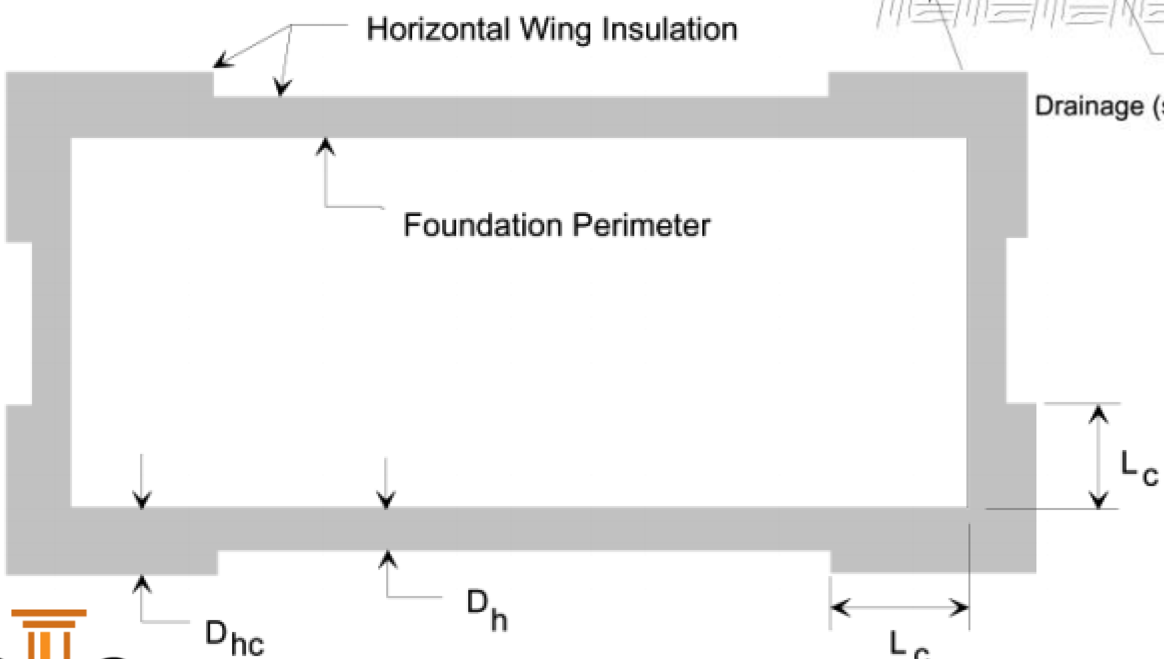
FPSF: Typical Details





Horizontal Insulation Plan

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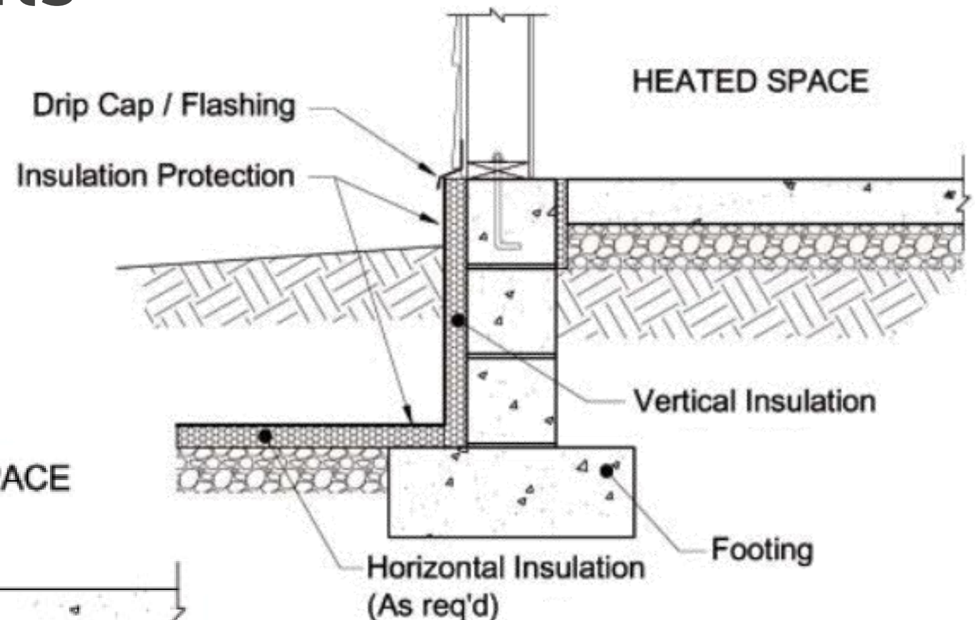
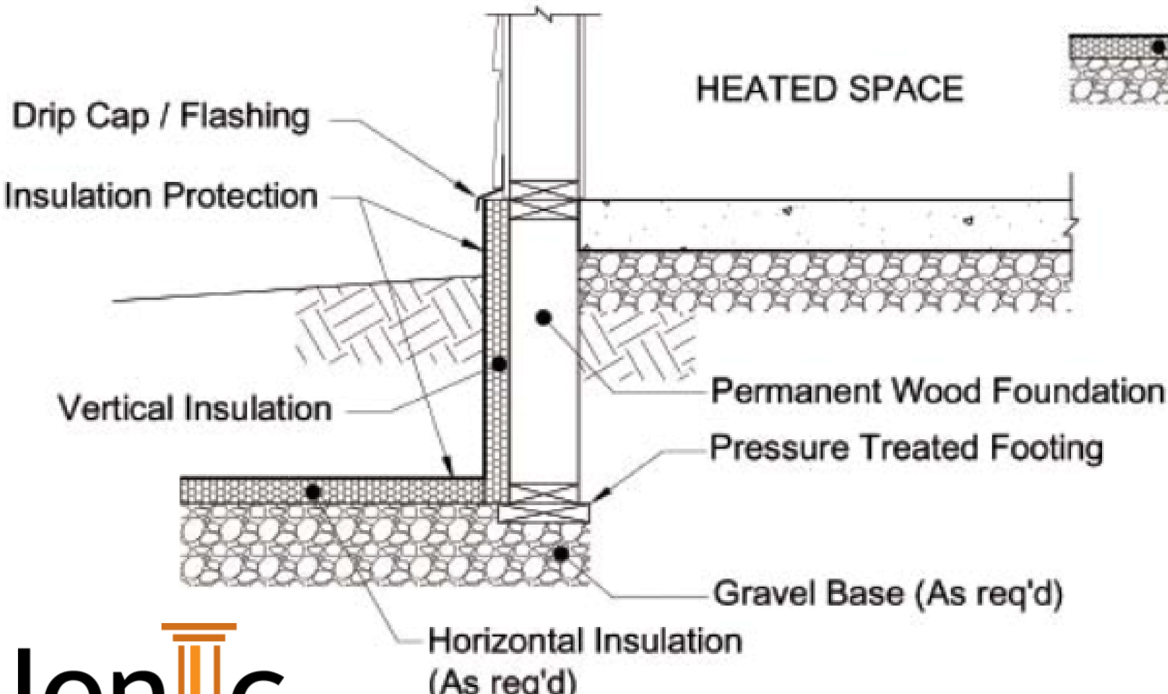
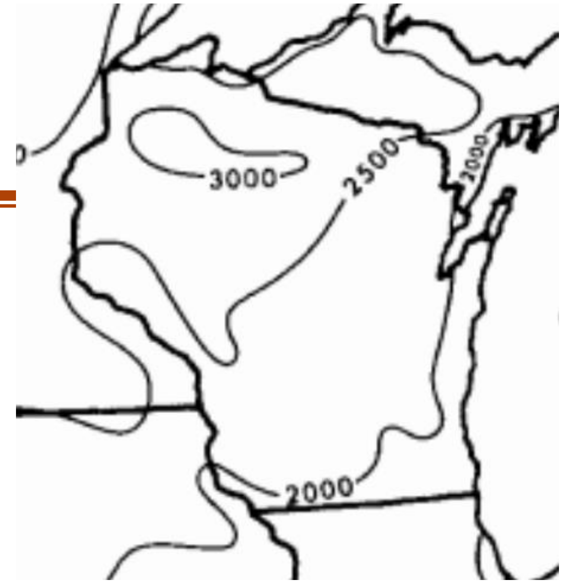
FPSF: Typical Details





FPSF: Simplified Design Procedure

1. Determine Air Freezing Index (AFI) for site
   - Wisconsin varies from 2000 to 3000
2. Determine Insulation Requirements for FPSF Foundations (Heated Buildings) in Table 4
3. Select Insulation types and calculate thicknesses
4. Detailed design procedure is also available, but yields very similar final design



AFI: Wisconsin

TABLE 4. Minimum Insulation Requirements for Frost-Protected Shallow Foundations of Heated Buildings[1]

Air-Freezing Index, F_{100} (° F-days)	Vertical Insulation R-value, R_v	Horizontal Insulation R-value, R_h ($hr \cdot ft^2 \cdot °F/Btu$)		Horizontal Insulation Dimensions per Figure 1 (in)			Minimum Footing Depth (in)
		Along Walls	At Corners	D_h	D_{hc}	L_c	h_v
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

FPSF: Detailed Design Procedure

- Wisconsin Energy Code, Section 322.31 requires minimum insulation values below the slab wherever the slab is within 12” of the exterior grade elevation

TABLE 322.31–1
INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

Zone	Fenestration U–Factor	Skylight U–Factor	Ceiling R–Value	Wood Frame Wall R–Value	Mass Wall R–Value[i]	Floor R–Value	Basement Wall R–Value[b]	Crawl Space Wall R–Value[b]	Heated Slab R–Value[c]	Unheated Slab R–Value[d]
1	0.35	0.60	49[e]	20[f] or 13+5[g]	15/19	30[h]	15/19	10/13	10/15	10
2	0.35	0.60	49[e]	21[f]	19/21	38[h]	15/19	10/13	10/15	10

The energy code insulation requirement beneath the slab changes the design of the FPSF since less heat is permitted to heat the soil below the foundation.

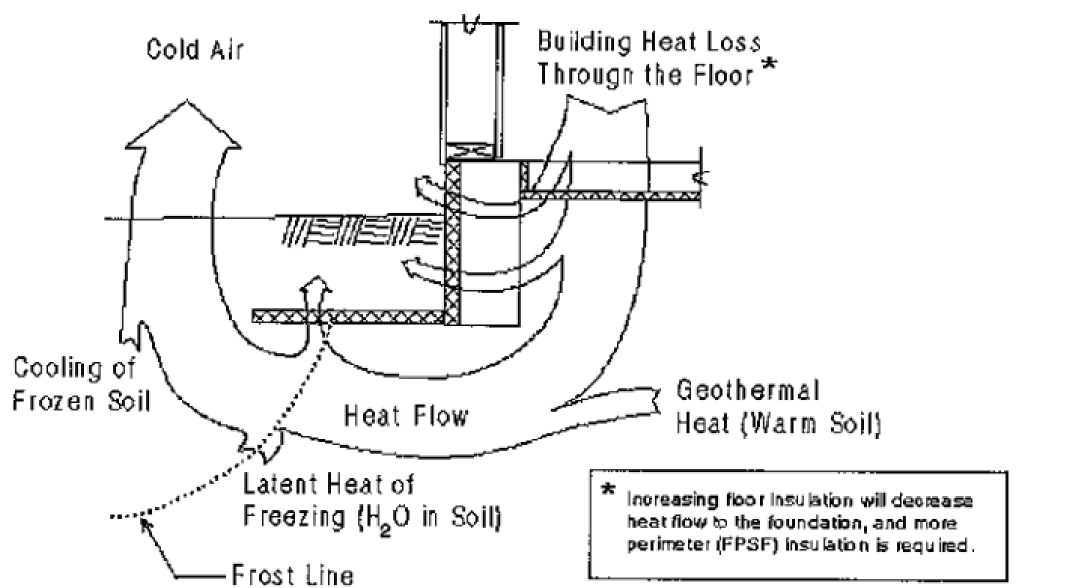


FIGURE C3. FPSF Heat Flow Diagram for a Heated Building with Optional Floor Insulation

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FPSF: Detailed Design Procedure for Heated Buildings (ASCE 32, Section 6.1)

1. Determine Air Freezing Index (AFI) for site
   - Wisconsin varies from 2000 to 3000
2. Determine the R-value for the Floor Slab (Rf). See Table A2
   - Example 4” concrete floor with R-10 insulation and carpet with fiber pad
   - R = .05*4 + 10 + 2.08 = 12.28

TABLE A2. Thermal Properties of Some Foundation and Floor Construction Materials (ASHRAE Handbook of Fundamentals, 1997)

Description	Resistivity {hr-ft^2-°F/Btu-in} [R per inch]
Building Materials	
Plywood or wood subfloor	1.25
Particleboard, low density (37 pcf)	1.41
Particleboard, high density (62.5 pcf)	0.85
Particleboard, underlayment (40 pcf)	1.31
Wood (lumber)	0.90
Brick	0.25
8” Concrete masonry unit (cmu), perlite fill	2.10
Cement mortar	0.15
Concrete	0.05
6 mil plastic	Negligible
Finish Flooring Materials	
Carpet and fibrous pad	R = 2.08
Carpet and rubber pad	R = 1.23

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FPSF: Detailed Design Procedure for Heated Buildings (ASCE 32, Section 6.1)

3. Select the R-Value for the vertical wall insulation (Rv) from Table A4.
   - Rf = 12.28, assume hf = 16”
   - Location for example is Wausau, WI (AFI = 2500)
   - Rv = 7.0
4. Select vertical insulation type and thickness in accordance with Table A1. 2” of extruded polystyrene. R = 9

TABLE A4. Minimum Thermal Resistance of Vertical Wall Insulation R_v (hr-ft^2-°F/Btu)

F_{100} (°F-days)	$R_f \leq 6.0$		$R_f = 15.0$		$R_f = 28.0$	
	h ≤ 12 in	h = 24 in	h ≤ 12 in	h = 24 in	h ≤ 12 in	h = 24 in
375 or fewer	0.0	3.0	4.5	5.7	5.7	8.5
750	3.0	4.6	5.7	5.7	8.5	11.4
1,500	4.5	5.7	5.7	5.7	8.5	11.4
2,250	5.7	5.7	5.7	7.4	8.5	14.2
3,000	5.7	5.7	6.8	8.5	9.7	15.3
3,750	5.7	6.8	8.0	9.7	11.4	17.0
4,500	6.8	8.0	10.2	11.9	13.6	19.3

Interpolation shall be permitted.

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FPSF: Detailed Design Procedure for Heated Buildings (ASCE 32, Section 6.1)

5. Determine the minimum buried foundation height. This value will be greater if wing insulation is not utilized. In this example, we will use wing insulation. Refer to table 5 below.
    - hf and hfc are both 16”
    - Lc = 40”
    - Dhc = 20”

TABLE A5. Minimum Foundation Depths Without Wing Insulation or with Wing Insulation at Corners Only

	Foundation Depth Along Walls with No Wing Insulation	Foundation Depth at Corners with No Wing Insulation		Foundation Depth at Corners with R = 5.7 Wing Insulation at Corners Only		
F_{100} (°F-days)	h_f (in)	L_c (in)	h_{fc} (in)	L_c (in)	h_{fc} (in)	D_{hc} (in)
1,500 or fewer	12	—	12	—	12	—
2,250	14	—	14	—	14	—
2,625	16	40	24	40	16	20
3,000	20	40	32	40	20	20
3,375	24	60	40	60	24	20
3,750	30	60	51	60	30	24
4,125	36	60	63	60	36	32
4,500	43	80	71	80	43	32

FPSF: Detailed Design Procedure for Heated Buildings (ASCE 32, Section 6.1)

6. Determine R-value of horizontal insulation along the wall from Table A6
   - For D_h = 12”, R_h>= 2.5
7. Select horizontal insulation type and thickness in accordance with Table A1. 2” of expanded polystyrene (Type IX). R = 5.6. (There is a 2” minimum allowable thickness for this material)

TABLE A6. Minimum Thermal Resistance of Wing Insulation, R_h, for Use Along Walls with 16-inch (0.4-m) Footing Depth

	R-values for Various Wing Widths Along Walls, D_h (inches)						
F_{100} (°F-days)	12	18	24	30	36	42	48
2,250 or fewer	0.0						
2,625	2.5						
3,000	6.5	6.1	5.3	4.5			
3,375		8.2	7.4	6.5			
3,750			9.1	8.5	7.7		
4,125			11.2	10.2	9.6	8.9	
4,500				12.3	11.4	10.7	10.0

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FPSF: Detailed Design Procedure for Heated Buildings (ASCE 32, Section 6.1)

8. Determine R-value of horizontal insulation along the wall from Table A6
   - For Dhc = 20”, Rhc >= 5.7
9. Select horizontal insulation type and thickness in accordance with Table A1. 2” of expanded polystyrene (Type IX). R = 5.6. (There is a 2” minimum allowable thickness for this material)

TABLE A7. Minimum Thermal Resistance of Wing Insulation, R_{hc}, for Use at Corners with 16-inch (0.4-m) Footing Depth

		R-values for Various Wing Widths at Corners, D_{hc} (inches)					
F_{100} (°F-days)	L_c (in)	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	8.0	7.4		
3,375	60		11.1	10.5	9.8	9.1	
3,750	60		13.1	12.5	12.0	11.2	10.8
4,125	60			14.5	13.7	13.0	12.5
4,500	80				15.9	15.1	14.8

FPSF Design Comparison: Simplified design and Detailed Design

Comparison Table

	Simplified Design	Detailed Design
Hf / Hfc / Hv	16”	16”
Rv	6.7	7.0
Lc	40”	40”
Rh (R – ground insulation)	1.7	2.5
Dh (width of insulation on ground)	12”	12”
Rhc (R – corner insulation)	4.9	5.7
Dhc (width of corner insulation)	24”	20”

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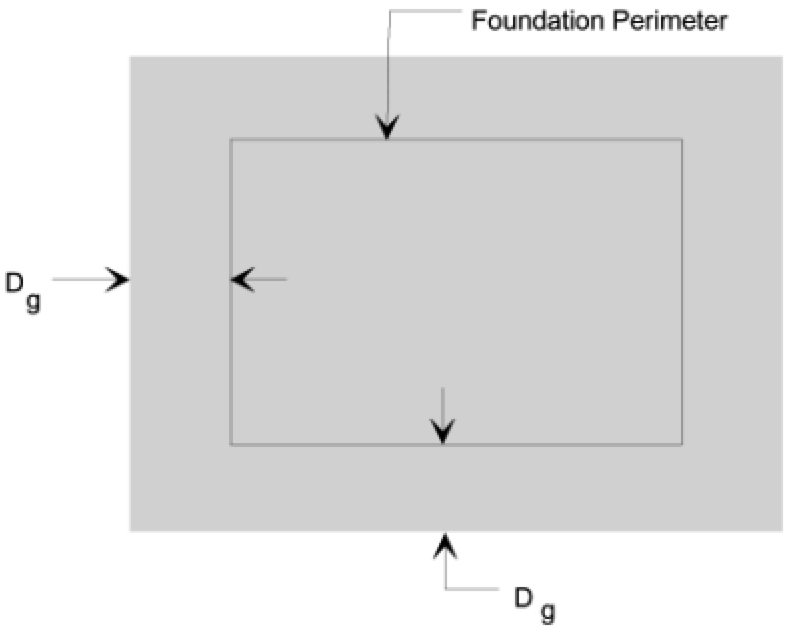
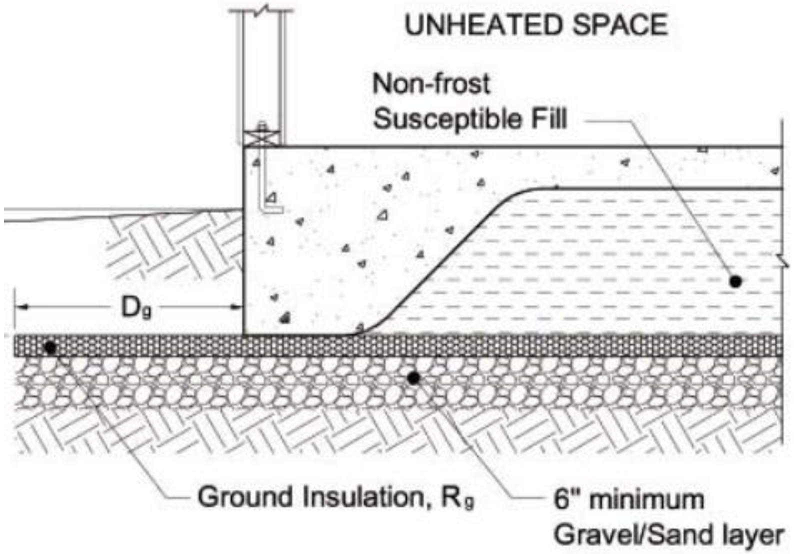
FPSF: Unheated Buildings: Details

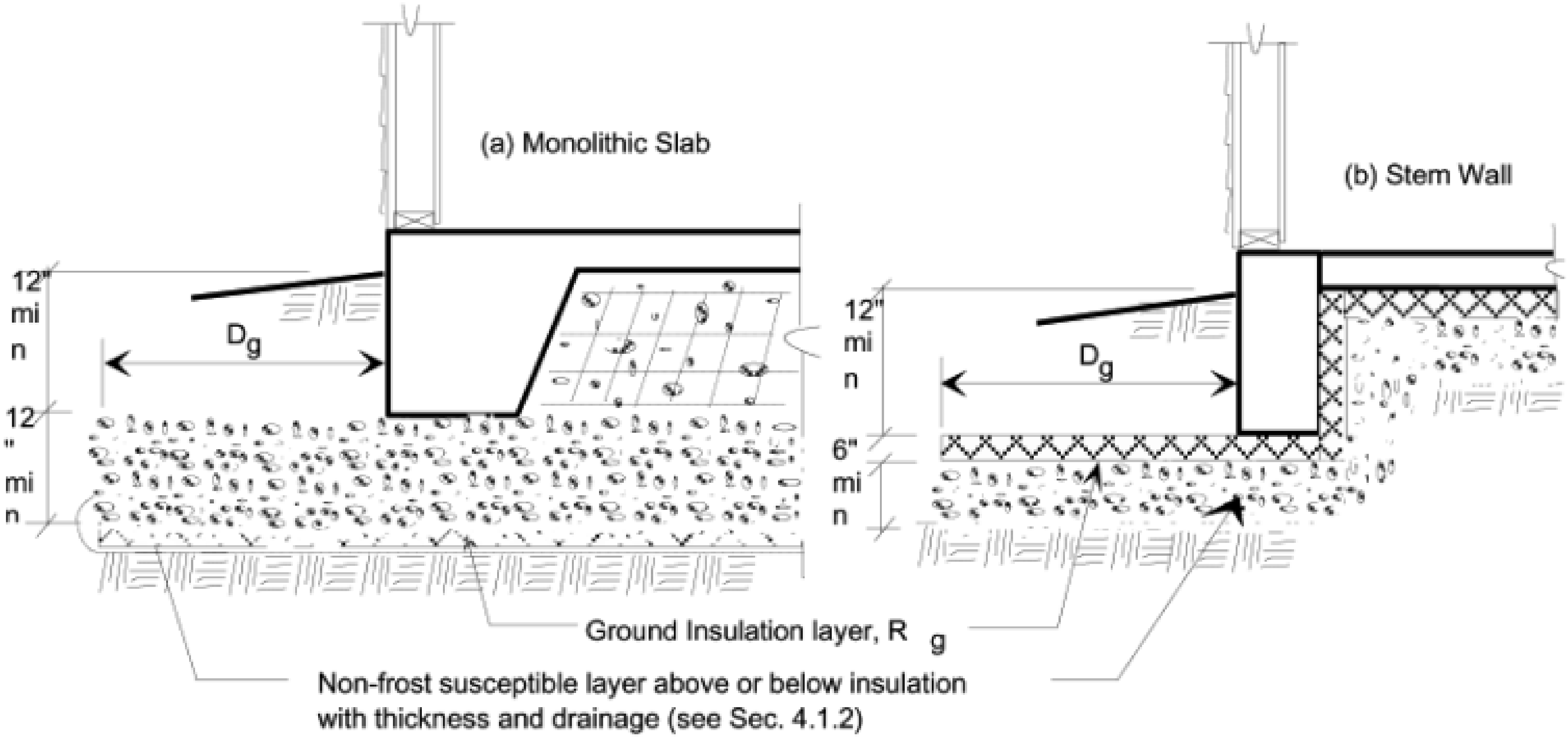


(c) Insulation Plan View



. **Slab-on-Ground Foundation for Unheated Buildings**

FPSF: Unheated Buildings: Details



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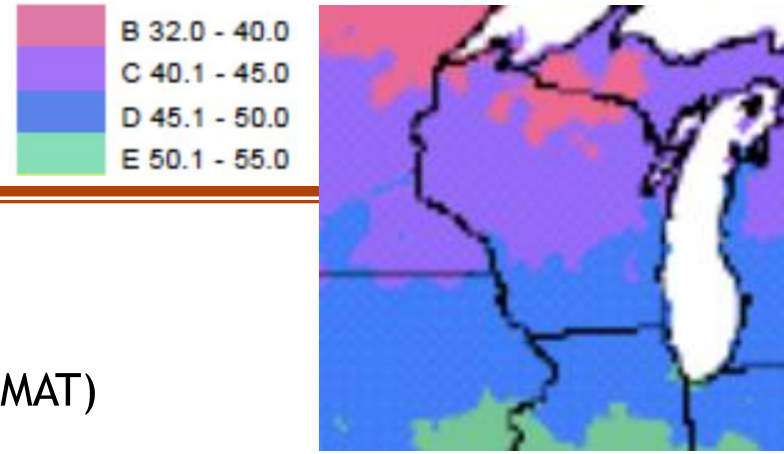
FPSF: Design Procedure Unheated Buildings



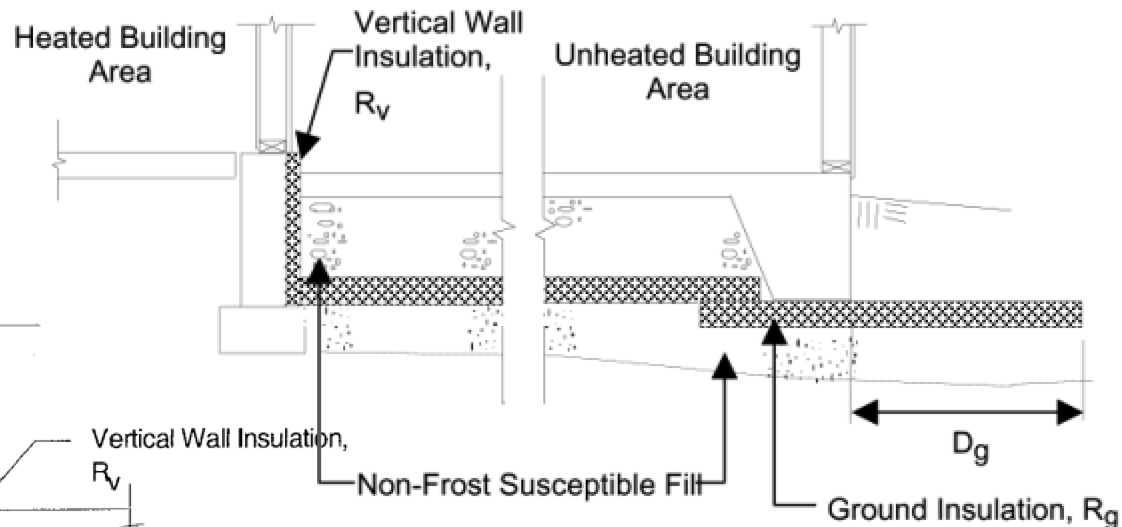
MAT Map - Wisconsin

1. Determine Air Freezing Index (AFI) for site
   - Wisconsin varies from 2000 to 3000
2. Determine the Mean Annual Temperature (MAT)
3. Determine placement of ground insulation
4. Select the Required R-value of Ground Insulation, Rg from Table A8

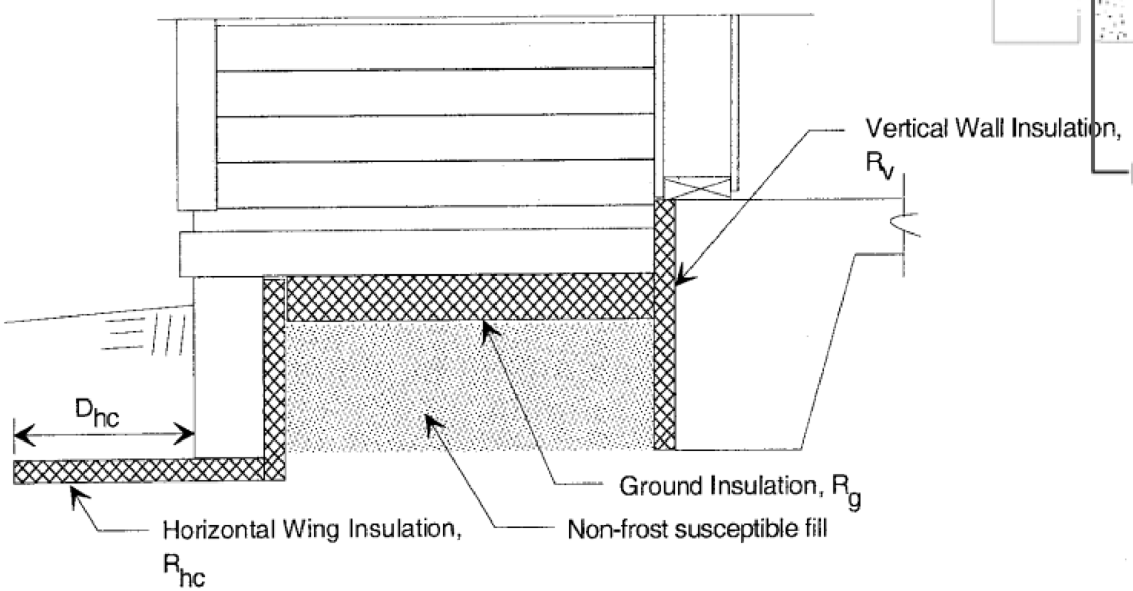
TABLE A8. Minimum Thermal Resistance (R-Value) of Ground Insulation, R_g, and Horizontal Extension, D_g, for Unheated Buildings

		Mean Annual Temperature (°F):				
F_{100} (°F-days)	D_g (inches)	≤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	—	—	—

FPSF: Special Details



Heated to Large Unheated Space



Heated to Small Unheated Space

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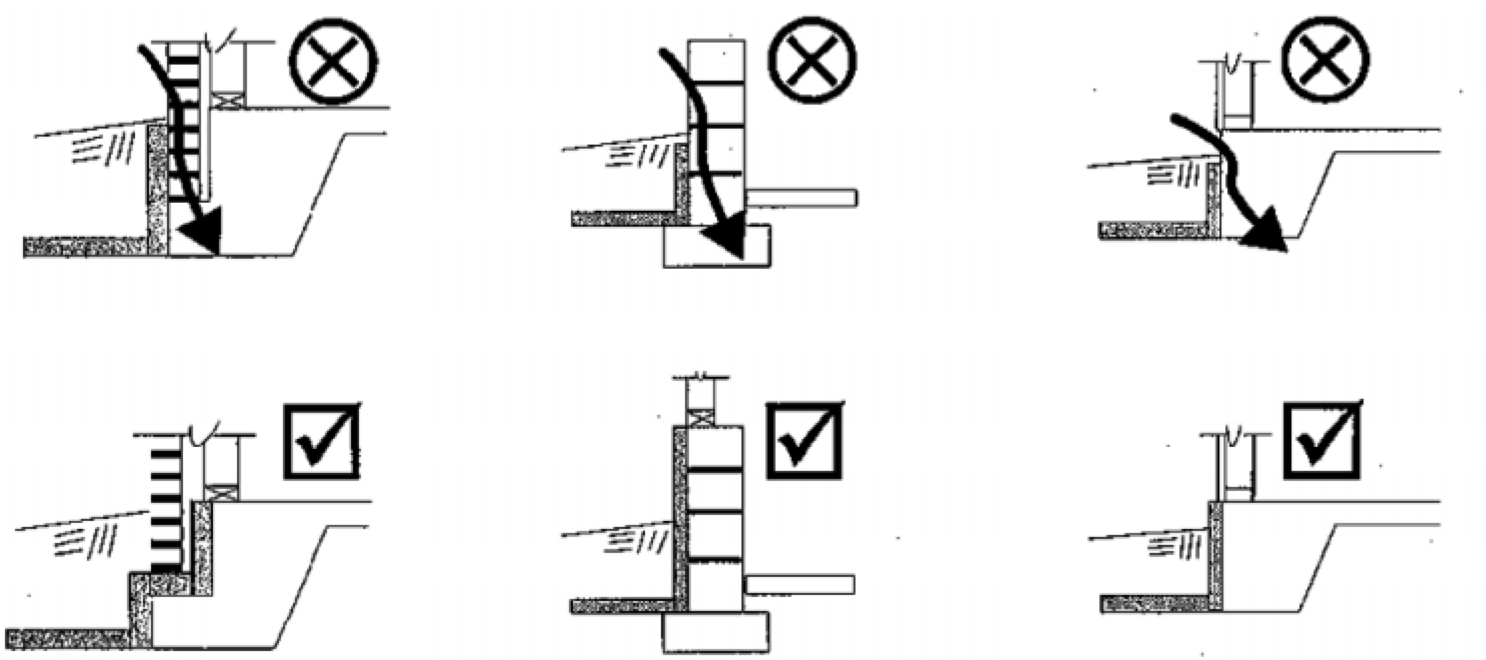
FPSF: Details that allow cold bridges and correct versions



(a) Cold-Bridge Through Brick Veneer and Correction

(b) Cold-Bridge Through Basement Wall and Correction

(c) Cold-Bridge Through Exposed Foundation Wall and Correction

Final thoughts: ACI 332

- Adoption of ACI 332 subsequently adopts by reference several other Codes, including
  - ACI 318
  - ACI 117
- Although many other Codes are referenced in the commentary of ACI 332, their provisions are guidelines and not official code adoptions. Such references include
  - ACI 305R
  - ACI 306R
  - ACI 347

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Final thoughts: FPSF Foundations

- The application of the methodologies in ASCE 32: Design and Construction of Frost-Protected Shallow Foundations is largely dependent on the following:
  - Knowledge of planned heating conditions of the facility
  - Correct detailing

Questions:

- If you have any additional questions with regard to this presentation or other structural conditions, please feel free to contact me at:
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  - Ionic Structures and Design, LLC
  - 414-540-8755
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