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

- Basement walls
  - Determination of reinforcement
  - Backfilling
  - Construction Issues

- Concrete: Environmental Considerations
  - Cold and Hot weather concrete

- Frost Protected Shallow Foundations
  - Premise/Science
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
    - The following slides illustrate an example of soil data obtained from the Web Soil Survey

Web Soil Survey: AOI

Use address and then draw an “Area of Interest” AOI
Web Soil Survey: Soil Map

Web Soil Survey: Soil Data Explorer – Soil Reports

Select this option

Material Description
Web Soil Survey: Soil Data Explorer

Soil Reports

Report — Engineering Properties

Table from IBC

SPS 321.15 (3) Soil Bearing capacity table

Web Soil Survey
ACI Codes adopted by the 2016 Wisconsin UDC

- 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.

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.
Foundation Design
Use of ACI 332, Table 6.2

Use the methods described in preceding slides to determine the allowable bearing pressure. These two sets of values will likely be used in 95% of residential applications.

<table>
<thead>
<tr>
<th>Table 6.2—Minimum specified width of wall footings, in.</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of stories above grade</td>
<td>1500</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>----------------</td>
<td>------</td>
</tr>
<tr>
<td>Conventional wood frame construction (above grade)</td>
<td>One-story</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Two-story</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Three-story</td>
<td>22</td>
</tr>
<tr>
<td>4 in. brick veneer over wood frame; 8 in. hollow concrete masonry unit (above grade)</td>
<td>One-story</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Two-story</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Three-story</td>
<td>31</td>
</tr>
<tr>
<td>8 in. grouted concrete masonry unit</td>
<td>One-story</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Two-story</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Three-story</td>
<td>40</td>
</tr>
</tbody>
</table>

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.
Foundation Design

ACI 332 Example:
Tributary area = 12' x 8'
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 = 6 sf)

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.
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”

3.3. Deviation from elevation

3.3.1 Top surface of foundations

<table>
<thead>
<tr>
<th>Vertical deviation</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1/2 in. (13 mm)</td>
<td>+1/2 in. (13 mm)</td>
</tr>
<tr>
<td>-2 in. (51 mm)</td>
<td>-2 in. (51 mm)</td>
</tr>
</tbody>
</table>

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) or less, -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) or less
      - Where dimension is more than 2 ft (0.6 m): +6 in. (152 mm) or less
    - Deviation from footing thickness: -5%

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

ACI 117: Section 2.1: Reinforcement Steel Tolerances

- Section 2.2 Reinforcement Location
  - 2.2.1 Placement of non-prestressed 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)

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...

Properly Formed Footings with Reinforcement and Dowels

Discontinuous Footings

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

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.
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

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.
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

<table>
<thead>
<tr>
<th>Unsupported wall height, ft</th>
<th>Unbalanced backfill, ft</th>
<th>Reinforcing bar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

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).
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 designed for 100 psf/ft backfill, clay backfill material would be acceptable.

Helpful resource: CFA_TN-002_Backfilling_Foundation_Walls.pdf

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

Concrete Materials

- Wisconsin is considered a "severe" exposure

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

<table>
<thead>
<tr>
<th>Type or location of concrete construction</th>
<th>Weathering probability</th>
<th>Maximum slump, in.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1: Walls and foundations not exposed to weather, interior sidewalks and gutters, not including garage floor slabs</td>
<td>Negligible/Moderate</td>
<td>2500</td>
</tr>
<tr>
<td>Type 2: Walls, foundations, and other concrete work exposed to weather, except as noted in Type 3</td>
<td>Moderate</td>
<td>2500</td>
</tr>
<tr>
<td>Type 3: Driveways, curbs, sidewalks, ramps, patios, porches, steps, and entries exposed to weather and garage floor slabs</td>
<td>Severe</td>
<td>2500</td>
</tr>
</tbody>
</table>

*Specified maximum slump may be increased through the use of air entraining admixtures.

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

<table>
<thead>
<tr>
<th>Nominal maximum aggregate size, in.</th>
<th>Air content, % (Maximum ± 3.0%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>5.0</td>
</tr>
<tr>
<td>1</td>
<td>4.5</td>
</tr>
<tr>
<td>1-1/2</td>
<td>4.5</td>
</tr>
</tbody>
</table>
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

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 40°F
  - The air temperature is not greater than 50°F (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
ACI 306: Recommended concrete temperatures at time of placement

Table 3.1 - Recommended concrete temperatures

<table>
<thead>
<tr>
<th>Line</th>
<th>Air temperature</th>
<th>&lt;12 in. (300 mm)</th>
<th>12-36 in. (300-900 mm)</th>
<th>36-72 in. (900-1800 mm)</th>
<th>&gt;72 in. (1800 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum concrete temperature as placed and maintained</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>55 F (13 C)</td>
<td>50 F (10 C)</td>
<td>45 F (7 C)</td>
<td>40 F (5 C)</td>
</tr>
<tr>
<td>2</td>
<td>Above 30 F (-1 C)</td>
<td>60 F (16 C)</td>
<td>55 F (13 C)</td>
<td>50 F (10 C)</td>
<td>45 F (7 C)</td>
</tr>
<tr>
<td></td>
<td>0 to 30 F</td>
<td>65 F (18 C)</td>
<td>60 F (16 C)</td>
<td>55 F (13 C)</td>
<td>50 F (7 C)</td>
</tr>
<tr>
<td></td>
<td>(18 to -1 C)</td>
<td>70 F (21 C)</td>
<td>65 F (18 C)</td>
<td>60 F (16 C)</td>
<td>55 F (13 C)</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>50 F (28 C)</td>
<td>40 F (22 C)</td>
<td>30 F (17 C)</td>
<td>20 F (11 C)</td>
</tr>
</tbody>
</table>

Maximum allowable gradual temperature drop in first 24 hr after end of protection:

- 50 F (28 C) for <= 36 in. (900 mm)
- 40 F (22 C) for 36-72 in. (900-1800 mm)
- 30 F (17 C) for >72 in. (1800 mm)

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

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

<table>
<thead>
<tr>
<th>Line</th>
<th>Service category</th>
<th>Protection period at temperature indicated in Line 1 of Table 3.1, days*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type I or II cement, Type III cement, or accelerating admixture, or 100 lbf/ft³ (60 kg/m³) of additional cement</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>See Chapter 6</td>
</tr>
</tbody>
</table>

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

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.

**FPSF: Typical Details**
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

### Table 4. Minimum Insulation Requirements for Frost-Protected Shallow Foundations of Heated Buildings

<table>
<thead>
<tr>
<th>AFI (C°-Days)</th>
<th>Vertical Insulation R-value, $R_v$</th>
<th>Horizontal Insulation R-value, $R_h$ (hr °F/ft²·°F)</th>
<th>Dimensions (in)</th>
<th>Minimum Footing Depth (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 or less</td>
<td>0</td>
<td>6.5</td>
<td>NA</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>7.8</td>
<td>NA</td>
<td>12</td>
</tr>
<tr>
<td>1,500</td>
<td>5.7</td>
<td>6.5</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>2,000</td>
<td>6.7</td>
<td>6.5</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>2,500</td>
<td>7.8</td>
<td>8.6</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>3,000</td>
<td>9.0</td>
<td>11.2</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>3,500</td>
<td>10.1</td>
<td>12.0</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>4,000</td>
<td>12.0</td>
<td>12.0</td>
<td>36</td>
<td>16</td>
</tr>
<tr>
<td>4,500</td>
<td>12.0</td>
<td>12.0</td>
<td>48</td>
<td>16</td>
</tr>
<tr>
<td>5,000</td>
<td>12.0</td>
<td>12.0</td>
<td>60</td>
<td>16</td>
</tr>
</tbody>
</table>
FPSF: Unheated Buildings: Details

(c) Insulation Plan View

Slab-on-Ground Foundation for Unheated Buildings

FPSF: Unheated Buildings: Details

(a) Monolithic Slab

(b) Stem Wall

Non-frost susceptible layer above or below insulation with thickness and drainage (see Sec. 4.1.2)
FPSF: Design Procedure
Unheated Buildings

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. Determine placement of ground insulation
4. Select the Required R-value of Ground Insulation, Rg from Table A8

| MAT Map - Wisconsin |

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

<table>
<thead>
<tr>
<th>F_{100} (T-days)</th>
<th>Dg (inches)</th>
<th>≤32</th>
<th>36</th>
<th>38</th>
<th>40</th>
<th>≥41</th>
</tr>
</thead>
<tbody>
<tr>
<td>750 or fewer</td>
<td>39</td>
<td>5.7</td>
<td>5.7</td>
<td>5.7</td>
<td>5.7</td>
<td>5.7</td>
</tr>
<tr>
<td>1,500</td>
<td>49</td>
<td>13.1</td>
<td>9.7</td>
<td>8.5</td>
<td>8.0</td>
<td>6.8</td>
</tr>
<tr>
<td>2,250</td>
<td>61</td>
<td>19.4</td>
<td>15.9</td>
<td>13.6</td>
<td>11.4</td>
<td>10.2</td>
</tr>
<tr>
<td>3,000</td>
<td>79</td>
<td>25.0</td>
<td>21.0</td>
<td>18.2</td>
<td>15.3</td>
<td>14.2</td>
</tr>
<tr>
<td>3,750</td>
<td>91</td>
<td>31.2</td>
<td>26.1</td>
<td>22.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4,500</td>
<td>108</td>
<td>37.5</td>
<td>31.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FPSF: Special Details

Heated Building Area

Unheated Building Area

Heated to Large Unheated Space

Heated to Small Unheated Space
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
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:
  • Susan Lasecki
    ◦ Ionic Structures and Design, LLC
    ◦ 414-540-577
    ◦ slasecki@ionic-sd.com