2012 Wood Frame Construction Manual: Foundation Design to Resist Flood Loads and WFCM Calculated Wind Loads

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Learning Objectives

At the end of this program, participants will:

1. Understand the concepts of load path for wind pressure applied to buildings
2. Understand how loads are distributed into foundations
3. Be able to describe various foundation systems best-suited for wind and flood loads
4. Understand the most likely foundation failures attributable to wind only

WFCM

- Basis for this webinar series is the 2012 Wood Frame Construction Manual (WFCM)
- Basis follows WFCM Prescriptive Provisions (Chapter 3).
- Prescriptive provisions are provided for:
  - WFCM 3.2 Connections
  - WFCM 3.3 Floor systems
  - WFCM 3.4 Wall systems
  - WFCM 3.5 Roof systems
- Provisions provide construction details and load tables
- WFCM also has engineering design in Chapter 2
Agenda – Webinar 4

- **Pile foundations**
  - Loads to piles from Webinar 3
  - Pile design
  - Lateral stiffness

- **Crawl space foundations**
  - Loads into crawlspace walls from Webinar 3 and WFCM
  - Crawlspace wall design issues
  - Flood damage prevention

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Vertical Loads

- **Live load**
- **Dead load**
- **Wind load**
Lateral Loads

Wind load

Flood load

Scour

WFCM Limitations – Section 1

1.1.4 Foundation Provisions

The foundation provisions specified in this document are limited to the attachment of the building to the foundation. An adequate foundation system shall be provided to resist all required loads. Engineered and prescriptive design of the foundation for gravity, lateral, and uplift loads, including uplift and hold-down anchorage, shall be provided in accordance with the governing building code.
Flood Design References

- ASCE 7 – Minimum Design Loads for Buildings and Other Structures
- ASCE 24 – Flood Resistant Design and Construction
- USACE Shore Protection Manual
- USACE Flood proofing Regulations
- FEMA 55 Coastal Construction Manual
- FEMA Technical Bulletins
- FEMA Flood mapping standards
- FEMA 550 Building Strong Foundations

Flood Loads

- Hydrostatic
- Hydrodynamic
- Breaking Waves
- Flood-borne debris
Information we need to design foundation

- Expected height of flooding
- Freeboard requirements from local gov’t.
- Expected velocity of water
- Any anticipated debris
- Expected erosion and scour at site
- Bracing requirements for all lateral loads
- Any foundation material constraints (wood, concrete, steel)
- And, of course, the loads

Foundation Design Method

- Select foundation material consistent with expected loads and hazards
- Select a height based on evaluation of all possible flood conditions
- Calculate flood forces – hydrodynamic, breaking waves, debris impacts
- Create a pile layout so piles not too close yet far enough to be cost efficient
- Determine other loads based on pile spacing (wind, seismic)
- Determine depth of embedment and iterate on solution until piles are not overstressed
Our Flood Failure Experience ...

- Shallow foundation failures
- Pile embedment insufficient
- Enclosures below the flood elevation
- Storm surge/waves cause damage
- Erosion/scour
- Debris

Design to Prevent Failures
Applying Loads for Foundation Design

Source: FEMA 55

Designing a Pile Foundation

Source: FEMA 55
Effective Length of Pile

**EQUATION 10.4. LOAD APPLICATION DISTANCE FOR AN UNBRACED PILE**

\[ L = H + \frac{d}{12} \]

where:
- \( L \) = distance between the location where the lateral force is applied and the point of fixity (i.e., moment arm) (ft)
- \( d \) = depth from grade to inflection point (inches); \( d = 1.8 \left( \frac{EI}{n_b} \right)^{\frac{1}{5}} \)
- \( H \) = distance above eroded ground surface (including localized scour) where lateral load is applied (ft)

Source: FEMA 55

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**\( n_b \) Modulus of Subgrade Reaction**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>( n_b ) Modulus of Subgrade Reaction (pound/cubic inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense sandy gravel</td>
<td>800 to 1,400</td>
</tr>
<tr>
<td>Medium dense coarse sand</td>
<td>600 to 1,200</td>
</tr>
<tr>
<td>Medium sand</td>
<td>400 to 1,000</td>
</tr>
<tr>
<td>Fine to silty fine sand</td>
<td>290 to 700</td>
</tr>
<tr>
<td>Medium clay (wet)</td>
<td>150 to 500</td>
</tr>
<tr>
<td>Soft clay</td>
<td>6 to 150</td>
</tr>
</tbody>
</table>

Source: FEMA 55
Floor Support Beam to Foundation (Pile)

U = 960 lbs
S = 1090 lbs
L = 1290 lbs

Source: FEMA

WFCM Figure 3.2e

Figure 3.2e Wall Assembly to Piles

Wall Stud
Bottom Plate
Band Joist
Subflooring
Joist

Wall Stud
Bottom Plate
Floor Joist
Steel Strap (see 3.2.2.2)
Pile
WFCM Figure 3.2e

Example Problem Pile Layout

Load distributed to piles
Example Problem

- Building weight assumed to be 40 psf
- Building size assumed to be 20 ft wide x 40 ft long x 1 story
- Wind speed assumed to be 140 mph – Exposure B conditions
- Lateral wind load at the foundation level are 1290 lbs/3 piles = 430 lbs at each pile
- Max shear wind load at the foundation level = 436 plf x 10 ft = 4360 lbs
- Uplift from wind is 970 lbs per pile at exterior wall line
Determining Length of Pile

- Assume BFE = 10’ elevation
- Add freeboard: 10’ + 1’ = 11’ (see next slide)
- Add distance to location of lateral load: 11’ + 1’ = 12’
- Existing ground surface elevation: 4’ assumed
- \[ H = 12’ - 4’ \] = 8’
- Must add 8’ to d which = 1.8(EI/nb)^{1/5}
  - Where: EI = material stiffness
  - nb = modulus of subgrade reaction

Determining d

- Let’s assume wood piles 12” round wood
- \[ E = 1500 \text{ ksi} \]
- \[ I = 4810 \text{ in}^4 \]
- \[ n_b \text{ ranges from 500 – 1000 lb/in}^3 \]
- \[ d = 3’ \text{ @ } n_b = 500 \text{ and } 2.6’ \text{ @ } n_b = 1000 \]
Pile Material Comparisons and ‘d’

<table>
<thead>
<tr>
<th></th>
<th>16” square wood</th>
<th>12” round wood</th>
<th>10” round steel</th>
<th>12” round FRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘d’ when ( n_b = 500 \text{ lb/in}^3 )</td>
<td>4 ft.</td>
<td>3 ft.</td>
<td>3.7 ft.</td>
<td>2.8 ft.</td>
</tr>
<tr>
<td>‘d’ when ( n_b = 1000 \text{ lb/in}^3 )</td>
<td>3.5 ft.</td>
<td>2.6 ft.</td>
<td>3.3 ft.</td>
<td>2.4 ft.</td>
</tr>
</tbody>
</table>

Determining L

\( H = 8' \)
Localized scour = 2'
Long term erosion = 2’ (??)
d = 3’
L = 15’ when the pile is 12” dia. wood
Combined Axial and Bending Stresses

\[(\frac{f_c}{F_c'})^2 + \frac{f_b}{[F_b(1-f_c/F_{cE})]} \leq 1.0\]

where:
- \(f_c\) = actual compressive stress (lb/in²)
- \(F_c'\) = allowable compressive stress (lb/in²)
- \(f_b\) = actual bending stress (from Formula 12.9)
- \(F_b\) = allowable bending stress (lb/in²)
- \(F_{cE}\) = Euler-based buckling stress (lb/in²)

Source: FEMA 55

Possible Overstress Solutions for Piles

- Reduce unbraced length (bracing)
  - Cross bracing
  - Knee bracing
  - Grade beams
- Reduce pile spacing
- Change pile material
- Stiffen pile at critical section
Crawlspace Foundation Issues

Anchor bolt spacing – governed by loads at the sill plate with maximum of 6 ft. o.c. established by IRC Section R403.1.6

Anchor bolt embedment governed by uplift loads and thickness of crawlspace walls

Crawlspace walls designed for lateral and shear loads at the sill plate/foundation interface

Crawlspace/footing connection – reinforcing steel sufficiently embedded in wall

Source: WFCM High Wind Design Guides
### Example Foundation Design

- Assume 8” CMU
- Assume 4 ft. high from footing to sill plate
- #4 bars @ 48” o.c. have plenty of capacity for the wind load resistance
- Consider having anchor bolt spacing and vertical reinforcement spacing line up in the same CMU cell so full grout or concrete will secure both within the cell and create the “continuous load path”

### Crawlspace Flood Issues

- Flood vents are required to equalize hydrostatic pressure
- FEMA has prescriptive guidance on opening sizes based on building footprint (1 sq. in. of opening for every sq. ft. of footprint)
- Cannot place solid foundation walls in high velocity flood zones
- Inside floor of crawlspace must allow flood water to drain from inside the crawlspace
Uplift Load Combination

- Uplift: 7680 lbs.
- Tension: 20 ft.

Sliding

- Resistance – connections: 32,000 #
- Hydrodynamic flow: 6,440 #
- Breaking wave: 5,160 #
- Shear resistance: 5160 #
Sliding Load Combination

- WFCM (ASD) Design Basis
- Consider sliding at house/foundation interface and at foundation (pile)/ground interface
- Combo No. 7 most restrictive (from ASCE 7 ASD load combinations)
- \(0.6D + W + 1.5F_a\) (wind pressure reduction for ASD has already been accounted for)
- Can use the frictional resistance of the house weight to help resist sliding, thus the inclusion of 0.6D in this lateral load combination

Overturning

7,680 # (Compression)
6,440 #
5,160 # (Tension)

Hydrodynamic flow
Breaking waves

Pivot point is at location of 'd'
Overturning Load Combination

- WFCM (ASD) Design Basis
- ASCE Combo No. 7 most restrictive
- \(0.6D \times \text{moment arm}\) (weight already considered in wind loads) + \(W \times \text{moment arms}\) + \(1.5F_a \times \text{moment arms}\)

Compression Load Combination

- WFCM (ASD) Design Basis
- ASCE Combo No. 2 most restrictive
- \(D + 0.75L + 0.75Lr\)
- However, must add overturning moment as increase in compression: overturning moment in ft-lb/pile spacing along L/no. of piles along W = additional compression on pile in lb.
- Total compression = Load combo 2 (lbs.) + overturning compression (lbs.)
Cross Bracing

Knee Bracing
Breakaway wall loads

- Loads on breakaway walls designed for largest of:
  - Wind load
  - Earthquake load
  - 10 psf
  - Not to exceed 20 psf unless:
    - Wall designed to collapse from flood that is less than design flood
    - Foundation designed for load combination specified in Chapter 2
FEMA Technical Bulletin - Breakaway Walls

- Refer to FEMA Technical Bulletin 9

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• NEW! Jan. 16th AWC’s Code Conforming Wood Design

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