Structural Design for Residential Construction

Cynthia Chabot, P.E.
Chabot Engineering
www.chabotengineering.com
What is residential construction?

• One and two family dwellings
• Typically wood framed construction in this part of the world
What does a structural engineer typically do?

- Analyze load paths to ensure they go down to a foundation
- Connections – connections – connections
- Roof, floor, and wall assemblies
- Beams, columns, headers
- Lateral load resisting system (diaphragms, shear walls, collectors, struts, anchorage, overturning analysis)
- Footings/foundations
What does a structural engineer typically not do?

- Land surveying
- Geotechnical engineering
- Layout of rooms
- Room sizes, ceiling heights
- Egress, ventilation & lighting
- Stairway geometry
- Mechanical, electrical, & plumbing
- Fire protection
- Energy efficiency
- Permitting
Gray areas

• Chimneys
• Moisture protection
• Termite mitigation
• Drainage
All you need to know about structure

- Equal and opposite forces
- What is up must come down
- The wind will always blow it over
Code Requirements

• Building Codes:
  – MA: State Building Code, 6th Edition (Ch. 36, 1&2 family dwellings)
  – NH: IBC 2000/1&2 family dwellings per town
  – RI: IBC 2003/IRC 2003
  – VT: BOCA National Building Code

• Minimum standard
• Residential code – prescriptive vs. engineered
Parts of structure

- Connections, connections, connections
- Beams, columns, headers
- Diaphragms, shear walls, collectors, struts, anchorage (lateral force resisting system)
- Foundations to hold it all up
- Soil is part of the structure too
What we don’t use as part of the structure

- We do not use the plywood as a T beam to increase the capacity of the joists – instead the plywood is the diaphragm to transfer lateral loads to shearwalls
- Interior partitions (excluding center bearing wall) are dead loads only
- The gypsum board inside is dead load
- Interior walls not used to resist horizontal forces from wind.
Ground Snow Loads
Note a 15% increase in the allowable capacity of wood for loads that include snow, which is a short-term load.

<table>
<thead>
<tr>
<th>Slope</th>
<th>$C_S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/12</td>
<td>0.99</td>
</tr>
<tr>
<td>8/12</td>
<td>0.91</td>
</tr>
<tr>
<td>9/12</td>
<td>0.83</td>
</tr>
<tr>
<td>10/12</td>
<td>0.75</td>
</tr>
<tr>
<td>11/12</td>
<td>0.69</td>
</tr>
<tr>
<td>12/12</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Note that roofs exceeding an angle of 30 degrees may reduce the ground snow load.
Wind Loads

Table 1611.3, Wind velocity “fastest mile” 30 feet above the ground, exposure C Mass. State Code, 6th Ed.

Reference wind pressures

<table>
<thead>
<tr>
<th>Zone</th>
<th>Pressure (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Western Mass.)</td>
<td>12</td>
</tr>
<tr>
<td>2 (Central Mass.)</td>
<td>17</td>
</tr>
<tr>
<td>3 (Eastern Mass.)</td>
<td>21</td>
</tr>
</tbody>
</table>

Above, Figure 1609, Basic Wind Speed (3-second gust), 33 feet above ground, exposure C IBC 2003
Soil and Surchare

Unbalanced fill
Seismic??
Dead Loads

**FLOOR**
- 3/4" wood floor fins 3.0 psf
- 5/8" plywood 1.9 psf
- 2x10s @ 16" o.c. 3.0 psf
- Gypsum + plaster/paint 3.0 psf
- Total 10.9 psf

**DECKING**
- 5/4" decking 4.2 psf
- 2x12s @ 16" o.c. 3.5 psf
- Total 7.7 psf

**TILE FLOOR**
- 5/8" ceramic tile & thinset 7.8 psf
- 5/8" tile and thinset 7.8 psf
- Wood shingles 2.0 psf
- Felt paper 1.0 psf
- 1/2" plywood 1.7 psf
- 2x6s @ 16" o.c. 1.1 psf
- Batt insulation 0.5 psf
- Gypsum + plaster/paint 3.0 psf
- Total 10.9 psf

**EXTERIOR WALL**
- 1/2" gyp. bd.
- Painted wood shingles over felt paper
- Wood shingles 2.0 psf
- Felt paper 1.0 psf
- 1/2" plywood 1.7 psf
- 2x6s @ 16" o.c. 1.7 psf
- Batt insulation 0.5 psf
- Gypsum + plaster/paint 3.0 psf
- Total 10.9 psf

**INTERIOR WALL**
- 1/2" gyp. bd.
- 1/2" plywood 1.1 psf
- Gypsum + plaster/paint 3.0 psf
- Total 7.1 psf

**ROOF**
- (unfinished below)
Notching and Boring
CONCENTRATED vs UNIFORM LOAD

2x10 required
12 feet

2x6 required
12 feet
LESSON LEARNED

Uniform loads …

  good

Concentrated loads …

  more of a challenge
SIMPLY SUPPORTED vs CONTINUOUS OVER SUPPORTS

2 simply supported beams

1 long beam spanning over center column

Higher shear stress and reaction to column compared to simple span

Stress reversal; compression at the top, tension at the bottom

Shear diagram

Moment diagram

Shear diagram

Moment diagram
Restraint against twisting & lateral stability

Aspect ratio, $d/b$

- $d/b \leq 2$ no lateral support required
- $2 < d/b \leq 4$ ends held in position
- $5 < d/b \leq 6$ laterally restrain ends and at intervals along length of less than 8ft. and compression edge held in position with sheathing
- $6 < d/b \leq 7$ laterally restrain ends both compression and tension sides shall be supported for the entire length.

Aspect ratios of common beam sizes:

<table>
<thead>
<tr>
<th>Beam Size</th>
<th>Single</th>
<th>Double</th>
<th>Triple</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x6</td>
<td>3.7</td>
<td>1.8</td>
<td>1.2</td>
</tr>
<tr>
<td>2x8</td>
<td>4.8</td>
<td>2.4</td>
<td>1.6</td>
</tr>
<tr>
<td>2x10</td>
<td>6.2</td>
<td>3.1</td>
<td>2.1</td>
</tr>
<tr>
<td>2x12</td>
<td>7.3</td>
<td>3.8</td>
<td>2.5</td>
</tr>
<tr>
<td>2x14</td>
<td>8.8</td>
<td>4.4</td>
<td>2.9</td>
</tr>
</tbody>
</table>
Blocking

RIM BOARD PROVIDES LATERAL STABILITY AT END OF JOIST

COLUMN SUPPORTING BEAM ABOVE

BLOCK BETWEEN SUPPORTING COLUMNS

BLOCKING UNDER BEARING WALL ABOVE

BLOCKING OVER BEARING WALL BELOW

COLUMN CONTINUING LOAD FROM ABOVE TO FOUNDATION
Connections of multiple LVLs

- **Nail together to provide stability**
- **Bolting required to transfer load to all beams**
- **Supporting girder**
Follow the load path due to gravity

Total = 1050 plf  1200 plf  1050 plf
Follow the load path due to gravity
The simple house framing

- 2X10s @ 16” O.C.
- 2X12s @ 16” O.C.
- 2X8s @ 16” O.C.
- TOP OF SLAB
- TOP OF SOIL

10”
Rafter/Ceiling Joist Heel Joint Connection

Dead and Live Loads (psf)

\[ \Sigma M_{\text{Ridge}} = 0 = T (H_c) + (D_L + L_L)(L/2)(L/4) - R_L(L/2) \]

\[ T = \frac{R_L(L/2) - (D_L + L_L)(L/2)(L/4)}{H_c} \]

Roof Slope

Roof Span (L)
Redundancy

- Unlike bridges, houses have many structural members.
- Credit is provided for repetitive members of joists.
Laterial force resisting system

- Horizontal Diaphragm (plywood subfloor)
  - Collectors
  - Cords
- Vertical Diaphragm (exterior wall)
  - Strut
  - Cords
- The building code provides some information on LFRS – see WFCM.
Follow the load path due to wind
North Wind affect to Horizontal Diaphragm
North Wind Horizontal Diaphragm affects to West/East Shearwalls
A closer look at the West Shearwall

Shearwall cord force reaction from attic diaphragm (compression)
E&O reaction from shearwall above

Shear force resisting chord force from attic diaphragm

Shearwall cord force reaction from attic diaphragm (tension)
Shear force resisting force from shearwall above plus 2nd floor diaphragm

E&O reaction from shearwall above added to shearwall cord force reaction from 2nd floor diaphragm in tension

E&O reaction from shearwall above added to shearwall cord force reaction from 2nd floor diaphragm in compression
West Wind affect to Horizontal Diaphragm
West Wind Horizontal Diaphragm affects to North/South Shearwalls
A closer look at the North Shearwall
Wind forces normal to the wall
Designed from top to bottom
Constructed from bottom to top
Shearwall anchorage
Plywood diaphragm details

6” spacing at supported edges

12” spacing in the field
Plywood on exterior walls

1/2" PLYWOOD

1/2" SHEETROCK OVER 1/2" STRAPPING

3/4" FINISH FLOOR 5/8" PLYWOOD

2X10s
Plywood installation to exterior walls

**Conventional Lumber**

- Horizontal joint detail at floor level: allow for shrinkage when using conventional lumber.
- Plywood sheathing.
- 1/2" gap.
- Galv. Z flashing.

**Horizontal joint detail within wall**

- Block behind horizontal panel joints of sheathing for all shear walls.
- Plywood sheathing.
- 1/8" gap.
- Galv. Z flashing.

---

**Definitions**

- Plywood sheathing: material used for sheathing on exterior walls.
- Galv. Z flashing: galvanized zinc flashing, commonly used for waterproofing.
- Conventional lumber: standard lumber used in construction.

---

**Notes**

- Ensure proper alignment and installation to avoid water infiltration.
Foundation bracing (walk-out basement)

STUD KNEE WALL
UNBRACED AT TOP OF FOUNDATION - DESIGN AS A RETAINING WALL
Foundation drainage

Filter fabric

Waterproofing
Addition on back of house

Sliding and drifting snow

Potential surcharge on existing foundation wall
Adding a shed dormer
Adding a second floor
Closing in a 3-season porch

- Consideration of added sail area.
- May need to reduce size of windows or provide a connection that will not translate at the roof.
- Don’t forget the roof diaphragm.
Decks

- Research at Virginia Tech. University, Department of Wood Science and Forest Products (see resources, “Load-Tested Deck Ledger Connection”)
- Loads on decks – consideration of size – new codes will require 100 psf for decks over 100 SF.
- Snow – drift & sliding?
- Firewood?
- Planters?
- Long-term loading such as planters more critical than snow
Pressure Treated Wood

- The Z-Max is recommended by Simpson Strong-tie
- Stainless steel may be an option
  - No posted connection capacities
  - Limited available types
  - ~ 4 X $
Built-up Column

2-2x4 studs fastened together for a column

≠

1-4x4 column

~ 60% less capacity
They don’t build ‘em like that anymore...

because It’s against the law.
Old house framing

- Mortise and tenon cut into 6x8
- Install ledger
- 5x4 @ 24" o.c.
- Install joist hangers
- May require additional support
Resources

- www.ChabotEngineering.com (slide presentation location)
  http://www.mass.gov/bbrs/NEWCODE.HTM web version; http://www.sec.state.ma.us/spr/sprcat/agencies/780.htm order a copy
  http://www.awc.org/Standards/wfcm.html
- “Design of Wood Structures”, D. Breyer, K. Fridley, & K. Cobeen
  http://www.apawood.org/level_b.cfm?content=pub_main
- The Journal of Light Construction
  http://www.jlconline.com/
- Fine Homebuilding
  http://www.taunton.com/finehomebuilding/index.asp
- International Building Code, 2003
  http://www.iccsafe.org/
- International Residential Code, 2003
  http://www.iccsafe.org/
Cynthia Chabot, P.E.
Chabot Engineering
Melrose, Massachusetts
(781) 665-7110
(781) 665-7727 (fax)
cchabot@chabotengineering.com