Five-story Wood-frame Structure over Concrete Podium Slab

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Learning Objectives
At the end of this program, participants will be able to:

✓ Selection of appropriate building type and related provisions in the building code governing multi-story wood-frame buildings.
✓ Detailing and design for wood shrinkage. Learn how to calculate wood shrinkage amounts.
Learning Objectives

At the end of this program, participants will be able to:

- Detailing and design for lateral system. A summary of design assumptions and code criteria.
- Detailing and design for continuous tie-down systems. A summary of important design considerations for this type of system.

WoodWorks Design Examples

http://www.woodworks.org/education-publications/case-studies-design-examples/

2009 International Building Code

- Key code issues related to multi-story wood framed construction:

Increase for Sprinkler System

- 2009 IBC § 504.2 Automatic sprinkler system increase
- For Group R buildings equipped throughout with an approved automatic sprinkler system in accordance with § 903.3.1.2, the value specified in Table 503 for maximum building height is increased by 20 feet and the maximum number of stories is increased by one, but shall not exceed 60 feet or four stories respectfully.
Special Provisions-Podium Construction

2009 IBC § 509.2 A building shall be considered as a separate and distinct building for the purpose of determining area limitations, continuity of fire walls, limitation of number of stories and type of construction where:

- Two separate buildings one on top of each other separated by a 3-hour horizontal barrier.
- Mixed occupancies (uses)/ Mixed construction
- Total height limited to the smaller Table 503 Allowable Heights of the 2 buildings measured from the grade plane.

Special Provisions-Podium Construction

2009 IBC § 509.5 Group R-2 Buildings with Type IIIA construction

The height limitation for buildings of Type IIIA construction in Group R-1 and R-2 shall be increased to six-stories and 75 feet where the first floor construction above the basement has a fire-resistive rating of not less than 3 hours and the floor area is subdivided by 2-hour fire resistance rated walls into areas of not more than 3000 sq. ft.

5 Stories o/ Podium Slab
Building Floor Plan

Floor Area = 12,000 sq. ft.

Structural/Seismic Height Limitation

- 5 Stories Type IIIA Wood Framing over Type I Concrete
- Max. Height of Structure: ASCD 7-05 Table 12.2.1

Seismic Force-Resisting System (SFRS):
- Light Framed Bearing Wall System
- Seismic Design Category (SDC) D, E, & F the height limit is 65 feet.
- Seismic Design Category (SDC) B & C the height limit has no limit.

Type IA & Type IIIA

Lower Portion (1st Story):
- Type 1A Construction
- Occupancy is S2, B, E and A2
- Per IBC Table 503:
  - Allowable height is unlimited
- Per IBC Table 503:
  - Allowable area is unlimited

Fire, Life Safety & Area Limitations

Lower Portion (1st Story):
Fire, Life Safety & Area Limitations

**Upper Portion (2nd – 6th Stories):**

Type IIIA Construction

Occupancy is R2

Per IBC 509.5:

- Allowable height is 75 feet
- Allowable number of stories is 6
- Floor area is subdivided into 3,000 sq. ft. areas with two hour ratings.

2009 IBC §602.3

“Type III. Type III construction is that type of construction in which the exterior walls are of noncombustible materials and the interior building elements are of any material permitted by the code. Fire-retardant-treated wood framing complying with Section 2303.2 shall be permitted within exterior wall assemblies of a 2-hour rating or less.”

Fire-retardant-treated (FRT) wood

2009 IBC §2303.2

- Labeling
- Strength Adjustments
- Exposure to weather, damp or wet locations requires Exterior rating.
- Typical walls in “dried in” building can have Interior rating.

FRT Wood Labeling

[Diagram of FRT Wood Labeling]

Interiors Fire Retardants

- Approved Agency Name & Logo
- Product Name
- Treatment Plant
- Drying Method
- ASTM E-84 Reference
- Flame Spread 25 or less
- Product Species
- Flame Index 15 or less
Fire-retardant-treated wood

Strength Adjustments

<table>
<thead>
<tr>
<th>Property</th>
<th>Brand A</th>
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<th>Brand B</th>
<th></th>
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<tr>
<td></td>
<td>DF</td>
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<tr>
<td>$F_b$</td>
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<tr>
<td>$F_t$</td>
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<td>Nails/Bolts</td>
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</table>

Obtain actual adjustment factors from the Evaluation Service Report

Fasteners:

- IBC § 2304.9.5.4
  - Fasteners in fire-retardant-treated wood used in interior locations shall be in accordance with the manufacturer's recommendations. In the absence of manufacturer's recommendations, Section 2304.9.5.3 shall apply.

Cutting, trimming ripping, boring:

- Treated lumber must not be ripped or milled as this will invalidate the flame spread.
- End cuts, holes are usually excepted (check ESR report).

Some suppliers of the treated wood require the wood to be treated to be first shipped to their plant.

Some suppliers stock most “saw lumber” (2x, 3x and 4x) for immediate shipping.

Treatment process adds about 50% to the cost of the material for Interior and 80% to the cost of the material for Exterior
Condition of Seasoning

S-GRN = >19% moisture content (unseasoned)
S-DRY, KD, KD-HT = 19% maximum moisture content (seasoned)
MC 15 or KD 15 = 15% maximum moisture content

Availability of Dry Lumber

☑ Varies on region and market conditions
☑ In Southwest region “green” (S-GRN) is common.
☑ Other parts of country “dry” (S-DRY) is common.
☑ Engineer should consider the availability of kiln dried lumber.
☑ WoodWorks website provides access to technical support looking for this type of information

Availability of Dry Lumber

☑ WoodWorks website provides access to technical support, either one-on-one or via wood associations nationwide.
☑ Visit Website:
  www.Woodworks.org/aboutWoodworks/technical-support.aspx

Wood Shrinkage

☑ Wood only shrinks perpendicular to grain.
  (Shrinkage parallel to grain is approximately 1/40 of the shrinkage perpendicular to grain and can be neglected.)
☑ The amount of shrinkage (or expansion) in wood is directly proportional to the change in moisture content.
☑ The higher the moisture content at time of construction, the more shrinkage that can occur in the structure.
| 29 | Modified Balloon Framing |
| 30 | Platform Framing |

**Wall Edge**

- Top Plate/Chord
- Ribbon/Chord

**Shrinkage Zone**

FRT is NOT available in LVL or LSL Lumber
Comprehensive Shrinkage Estimation

- For a dimensional change with the moisture content limits of 6 to 14 percent the formula is:

\[ S = D_i \left[ C_T (M_F - M_i) \right] \]

\( S = D_i \left[ C_T (M_F - M_i) \right] \)

Where:
- \( S \) = shrinkage (in inches)
- \( D_i \) = initial dimension (in inches)
- \( C_T \) = tangential shrinkage (percent) from green to oven dry
- \( S_T = 7.775 \) for Douglas Fir-Larch
- \( M_F \) = final moisture content (percent)
- \( M_i \) = initial moisture content (percent)

Equilibrium Moisture Contents (EMC)

- The final moisture content \( (M_F) \) for a building is referred to as the Equilibrium Moisture Content (EMC).
- The final equilibrium moisture content can be higher in coastal areas and lower in inland or desert areas. These ranges are normally between 6 to 15 percent (low to high).
Equilibrium Moisture Contents (EMC)

- The Western Wood Products Association has downloadable documents listing Equilibrium Moisture Contents (EMC) for all the major US cities for each month of the year.
- At the web address after login, go to “Shrinkage”, then “EMC Charts” (free user login with password is required):
  
  http://www2.wwpa.org/Shrinkage/EMCUSLocation

Calculation of EMC

\[
EMC = \frac{1800K}{W} \left[ \frac{KH + 2K_1K_2H^2}{1 - KH \left(1 + K_1KH + K_1K_2K_2H^2\right)} \right]
\]

- Where:
  
  \[W = 330 + (0.452T) + (0.00415T^2)\]
  
  \[K = 0.791 + (0.000463T) - (0.0000000844T^2)\]
  
  \[K_1 = 6.34 + (0.000775T) - (0.0000935T^2)\]
  
  \[K_2 = 1.09 + (0.0284T) - (0.0000904T^2)\]
  
  \[H = \text{relative humidity} \%\]

Average Moisture Contents - July

Average Moisture Contents - January

Map courtesy of US Forest Products Laboratory
### Average Moisture Contents

<table>
<thead>
<tr>
<th>City</th>
<th>High M/C</th>
<th>Low M/C</th>
<th>Difference</th>
<th>Avg. M/C</th>
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<td>7.9</td>
<td>11.3</td>
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<td>16.0</td>
<td>1.8</td>
<td>16.9</td>
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<td>4.0</td>
<td>4.5</td>
<td>6.2</td>
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Source: U.S. Forest Products Laboratory

### Average Moisture Contents

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<th>Difference</th>
<th>Avg. M/C</th>
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<td>4.0</td>
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<td>6.2</td>
</tr>
</tbody>
</table>

Source: U.S. Forest Products Laboratory

### Example Shrinkage Calculation

**Floor to Floor Height = 10’-0”**

- Shrinkage amounts are approximate.
- Shrinkage values not only differ between species of wood, but also between trees of the same species.
- Shrinkage also may vary slightly depending on drying conditions: low or high temperatures, rapid or slow drying.
Example Shrinkage Calculation

✓ Since our initial MC ($M_i$) is 19 percent and the final MC ($M_F$) is 12 percent, the equation is:

$$S = \frac{D(M_F - M_i)}{S_T} = \frac{3.5(12 - 19)}{30(100) - 30 + M_i} = \frac{30(100)}{7.775 - 30 + 19} = -0.065 \text{ inch}$$

✓ Our final size of our 4x4 is:

$$3.5 - 0.065 = 3.435 \text{ inch}$$

Quick Shrinkage Estimation:

✓ A close approximation that is much easier to determine amount of shrinkage is:

$$S = CD(M_F - M_i)$$

✓ Where:

- $S = \text{shrinkage (inches)}$
- $C = \text{average shrinkage constant}$
- $C = 0.002$
- $M_F = \text{final moisture content (percent)}$
- $M_i = \text{initial moisture content (percent)}$

Quick Shrinkage Estimation:

✓ Since our initial MC ($M_i$) is 19 percent and the final MC ($M_F$) is 12 percent, the equation is:

$$S = CD(M_F - M_i) = 0.002 \times 3.5(12 - 19) = -0.049 \text{ inch}$$

✓ Our final size of our 4x4 is

$$3.5 - 0.049 = 3.451 \text{ inch}$$

Quick Shrinkage Estimation:

✓ Note that this is quick estimation is within $\frac{1}{2}$ percent of the actual calculated dimension of 3.435 inch using the comprehensive formulas.

✓ Total shrinkage per floor level with the 4x4 top plate and 2x4 sole plate:

$$S = 0.049 + 0.021 = 0.07 \text{ inch}$$
Example Shrinkage Calculation

Quick Shrinkage Estimation:

- Determine shrinkage of sawn joists with platform framing
  \[ S = CD(M_F - M_i) = 0.002 \times 9.25(12 - 19) = -0.129 \text{ inch} \]

- Total shrinkage per floor level with the 4x4 top plate, 2x12 sawn joists and 2x4 sole plate:
  \[ S = 0.049 + 0.021 + 0.129 = 0.199 \text{ inch} \]

Wood Shrinkage

- A free “shrinkage calculator” can be downloaded from the Western Wood Products Association web site link: www2.wwpa.org

WWPA Shrinkage Calculator

- LWPA Shrinkage Calculator

- Developed by Western Wood Products Association and Oregon State University

- Example:
  - Species Group No. 1: Douglas Fir-Larch
  - Initial Moisture Content: SDRY (90 or 95)°
  - Final Moisture Content: 12°
  - Nominal Lumber Size (inches): 3\(\times\)32
  - Thickness: 3
  - Width: 32

- Results:
  - Change of MC (%): 7
  - Shrinkage (Green to Dry): 7.775
  - Initial Size (inches): 1.5
  - Estimated Shrinkage or Swelling (inches): 0.023
  - % of Size Change from Initial: 0.21
  - Estimated Final Size (inches): 1.472 by 11.04
Settlement Under Construction Gaps

- Small gaps can occur between plates and studs; this can include mis-cuts (short studs) and the lack of square-cut ends. And can account for up to a 1/8 inch per story. Where “perfect” workmanship would be 0 inches and a more “sloppy” workmanship would be 1/8 inch.
- This case study will use 1/10 inch.

Cumulative Displacement

<table>
<thead>
<tr>
<th>Level</th>
<th>Vertical Displacement</th>
<th>Design Displacement (in)</th>
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</thead>
<tbody>
<tr>
<td>5th Floor</td>
<td>0.170</td>
<td>0.68</td>
</tr>
<tr>
<td>4th Floor</td>
<td>0.170</td>
<td>0.51</td>
</tr>
<tr>
<td>3rd Floor</td>
<td>0.170</td>
<td>0.34</td>
</tr>
<tr>
<td>2nd Floor</td>
<td>0.170</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Notes on Plumbing & Electrical Drawings to accommodate these displacements.
Methods to Reduce Displacement

- Use kiln-dried plates (MC < 19 percent) or even MC15 (MC<15 percent) lumber or engineered lumber for plates.
- Consider single top plate instead of double top plate.
- Consider balloon framing or a modified balloon framing.

- Place floor joists in metal hangers bearing on beams or top plates instead of bearing on the top plates.
- The site storage of the material stock can negate all design and planning when the material is not properly stored on the site. Lumber should be kept away from moisture sources and rain.
**Tiedowns & Shrinkage Compensation**

<table>
<thead>
<tr>
<th>Level</th>
<th>Vertical Displacement Per Floor</th>
<th>Cumulative Displacement (in)</th>
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<tbody>
<tr>
<td>5th Floor</td>
<td>0.170</td>
<td>0.68</td>
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<tr>
<td>4th Floor</td>
<td>0.170</td>
<td>0.51</td>
</tr>
<tr>
<td>3rd Floor</td>
<td>0.170</td>
<td>0.34</td>
</tr>
<tr>
<td>2nd Floor</td>
<td>0.170</td>
<td>0.17</td>
</tr>
</tbody>
</table>

**Without Shrinkage Compensation**

**Take-up Devices**

- Devices are proprietary
- Purpose is to compensate for building shrinkage and settlement.
- Keep rotating the nut down or use a compression spring.

**Take-up Devices**

- ICC Evaluation Service has Acceptance Criteria (AC 316) for take-up devices.
Take-up Devices

Design Engineer should check to see that the proprietary devices conform to these criteria.

Location of Shear Walls

Location of Shear Walls
Shear Transfer at Floor

Wall Overturning

Eccentric vs. Concentric

Eccentric Boundary Posts
Cumulative Overturning

System Stretch

Design for following system elements for stretches ($\Delta_a$):
- Rod elongation
- Take-up device displacement
- Bearing Plate crushing
- Sill Plate crushing

Formally known as $d_a$

Rod Elongation

- Measured between restraint connectors.
- Rod elongation limit by itself does not eliminate the need to include the rod elongation in the shear wall deflection calculation.
- Rod elongation is the same for different yield strengths.
- If threaded rods used for entire length then net tensile area should be used ($A_t$ vs. $A_g$)

Rod Elongation

- Rod length is between points of restraint.
- Some jurisdictions have limits on the amount of rod elongation and some require that the “allowable stress area” ($A_e$ vs. $A_g$) be used in elongation calculations.
- Local building departments requirements should be checked.
**Rod Elongation**

- Design Example in publication uses $A_e$ for rod elongation and $A_g$ or $A_n$ for rod capacity.
- Many manufacturers will vary the yield strength in rods.
- With higher strength rod can actually increase the drift of the shear wall.

**Rod Elongation**: $\Delta = \frac{PL}{A_eE}$

- $\Delta$ The elongation of the rod in inches.
- $P$ The accumulated uplift tension force on the rod in kips (tension demand).
- $L$ Length of rod in inches from bearing restraint to bearing restraint, with the bearing restraint being where the load is transferred to the rod.
- $E$ 29,000 ksi
- $A_e$ The effective area of the rod in square inches. When smooth rods are used, the area is equal to the gross area ($A_g$). When threaded (all-thread) rods are used, the area is equal to the tension area ($A_e$) of the threaded rod. Since many of the proprietary systems that have smooth rods have long portions threaded at the ends, it is recommended that $A_e$ be used when calculating rod elongation.

**Tie-Down Rods**

- Rods usually A36/A307 steel
- High-strength rods are A449 or A193-B7. Usually marked with embossed stamp at end (sometimes on side).
- High-strength rods should have special inspection to confirm rod type (stamp may be hidden inside couple nut).
- High-strength rods are not weldable.

**Rod Couplers**

- Straight or Reducing
- Need “pilot” or “witness” holes for verification of proper embedment.
Rod Couplers

- Reducing Coupler
- High-strength Coupler

High-strength Coupler
Witness Hole

Shear Wall Boundary Forces

Uplift force from above

Differential Load:
34.55 - 23.16 = 11.39 k

Uplift force from above

Differential Load:
37.90 - 25.40 = 12.50 k
Bearing Plate Crushing

Bearing Plate Crushing

Bearing Plate Sizes & Capacities

Bearing Plate Crushing

<table>
<thead>
<tr>
<th>Level</th>
<th>Bearing Plate Sizes &amp; Capacities</th>
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<tbody>
<tr>
<td>Roof</td>
<td>Width (in)</td>
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<td>5.5</td>
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</table>

<table>
<thead>
<tr>
<th>Level</th>
<th>ASD Bearing Load (kips)</th>
<th>Strength Bearing Load (kips)</th>
<th>Bearing Plate $f_{ck}$ (ksi)</th>
<th>$0.73f_{ck}$ (ksi)</th>
<th>Crush (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
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<td>9.788</td>
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<tr>
<td>4th Floor</td>
<td>4.665</td>
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<td>9.788</td>
<td>0.681</td>
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<td>3rd Floor</td>
<td>5.395</td>
<td>7.707</td>
<td>15.396</td>
<td>0.501</td>
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</table>
Example Bearing Check:
Differential Load at 3rd Floor = 5,395 lb
Bearing Plate Width = 5.5 inches
Bearing Plate width at bottom of 4x4 top plate = (5.5+5.7+5.7) = 16.9 in

Net bearing area:
\[(16.9-6.0)\times 3.5 = 38.1 \text{ sq in}\]

Bearing stress:
\[f_{c,\perp} = \frac{5,395}{38.1} = 142 \text{ psi}\]
\[F'_{c,\perp} = 625 \text{ psi}\]

Posts at plate:
\[5,395/(2\times 3.5\times 3.5) = 220 \text{ psi}\]
\[F'_{c,\perp} = 625 \text{ psi}\]

Differential Load:
\[37.90 - 25.40 = 12.50 \text{ k}\]
Sill Plate Crushing

Load Deformation Curve

\[ F_{c\perp} \]

Deformation, in

- Eq. 1.0
- Eq. 2.0
- Eq. 3.0

Bearing Pressure

\( F'_{c\perp} \)

\( 0.73 F'_{c\perp} \)

Crushing (inches)

0.02

0.04

0.16
Crushing + Buckling

Squash Block

Load Transfer - Compression Posts

A) Platform Framed

B) Balloon Framed
### Sill Plate Crushing

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<th>Level</th>
<th>Posts</th>
<th>ASD Demand (kips)</th>
<th>Strength Demand (kips)</th>
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<th>0.73f&lt;sub&gt;c&lt;/sub&gt; (ksi)</th>
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<td>0.456</td>
<td>0.025</td>
</tr>
</tbody>
</table>

### Boundary Member Nailing

- **26.44’**
- **25.40 k**
- **37.90 k**

Differential Load:

\[37.90 - 25.40 = 12.50k\]

**E.N. SPACING PER PLAN**

<table>
<thead>
<tr>
<th>Edge Nail Spacing to Each Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 POSTS</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

**Boundary Member Nailing**

- 2 POSTS EACH SIDE
- 3 OR MORE POSTS EACH SIDE
- Edge Nail Spacing
Tie-Down Assembly Displacement

With Shrinkage Compensators

<table>
<thead>
<tr>
<th>Level</th>
<th>Rod Elong. (in)</th>
<th>Shrinkage (Vertical Displacement) (in)</th>
<th>Chord Crashing (in)</th>
<th>Bearing Plate Crushing (in)</th>
<th>Take-up Deflection Elongation (in)</th>
<th>Total Displacement $d_c$ (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>0.047</td>
<td>0.03</td>
<td>0.007</td>
<td>0.010</td>
<td>0.03</td>
<td>0.124</td>
</tr>
<tr>
<td>5th Floor</td>
<td>0.098</td>
<td>0.03</td>
<td>0.023</td>
<td>0.018</td>
<td>0.03</td>
<td>0.199</td>
</tr>
<tr>
<td>4th Floor</td>
<td>0.183</td>
<td>0.03</td>
<td>0.015</td>
<td>0.047</td>
<td>0.03</td>
<td>0.305</td>
</tr>
<tr>
<td>3rd Floor</td>
<td>0.138</td>
<td>0.03</td>
<td>0.025</td>
<td>0.025</td>
<td>0.03</td>
<td>0.248</td>
</tr>
</tbody>
</table>

Sample Drawing Specification:

☑ Specify a particular manufacturer.
☑ Specify cumulative uplift forces and compression forces at each level.
☑ Specify displacement limits (if any) for tie-down system at the specified uplift forces.
☑ Specify whether or not restraint connections must be at every floor.
☑ Specify estimated wood shrinkage per floor

Sample Drawing Specification:

☑ Specify whether of not shrinkage compensating devices are required.
☑ Specify maximum bored hole size for utilities.
☑ Specify minimum boundary post sizes.
☑ Substitutions from specified system shall include shop drawings and design calculations for review/approval.
  ▪ Design calculations must be stamped and signed by a licensed Civil or Structural Engineer.
Summary

- Wood Construction can be an more economical than steel, masonry and concrete.
- When Type III construction is necessary, consider Fire-Retardant Treated wood.
- Consider shrinkage in design and detailing of structure.

Questions?

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