Structural Engineering of Wood Over Podium Structures

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Course Description

Wood over podium structures have become common in the United States as demand has increased for dense, mixed-use spaces and multi-unit residences. Using the maximum allowable building heights can result in structures with five stories of wood over two stories of concrete; however, there are a number of unique design considerations for podium structures of this height. For wood superstructures, this includes gravity and lateral loads far greater than their low-rise counterparts, as well as fire-retardant treatment requirements for exterior walls. Meanwhile, concrete podium levels must be designed to support the wood superstructure, including large anchorage forces from the ends of the wood shear walls, while maintaining a thin profile so as not to exceed overall building height limits. This webinar will address these unique design considerations, particularly as they relate to the seismic design of five-story wood structures over post-tensioned concrete slabs.

Learning Objectives

1. Review code provisions from IBC and ASCE 7 that allow and limit podium type structures.

2. Highlight structural implications of utilizing fire retardant-treated wood in exterior wall assemblies of Type III construction.

3. Explain important engineering issues—such as stacked bearing wall forces and load path continuity—that must be considered to successfully design a mid-rise wood structure.

4. Demonstrate effective detailing practices for wood shear wall tie-down attachments to concrete podiums slabs.

Outline

Background

- Occupancy
- Construction Type
- Height Limitations
- Code Allowances

Wood Structure

- Fire-Retardant Treatment
- Exterior Wall Detailing
- Gravity
- Lateral

Concrete Structure

- Anchorage

Questions

Background: What? Why?

What are podium structures?

Background: How?

Horizontal Building Separation **IBC §510.2**

"A building shall be considered as separate and distinct buildings" if:

- 3-hour fire-rated horizontal separation
- Type IA below horizontal separation
- Group A (<300), Groups B, M, R, S above the horizontal separation
- 2-hour fire ratings for vertical shafts through the horizontal separation

Background: How?

Two-Stage Lateral Analysis

ASCE 7 §12.2.3.2

"Flexible upper portion above a rigid lower portion"

- Stiffness of lower ≥ 10x Stiffness of upper
- Period of structure ≤ 1.1x Period of upper
- Upper designed using R_{upper} and ρ_{upper}
- Lower designed using R_{lower} and ρ_{lower}
- Reactions from upper applied to lower and amplified by $(R/\rho)_{upper} / (R/\rho)_{lower} \geq 1$
- Upper analyzed with ELF or modal response
- Lower analyzed with ELF

Background: How?

Two-Stage Lateral Analysis

ASCE 7 §12.2.3.2

"Flexible upper portion above a rigid lower portion"

- **Stiffness of lower ≥ 10x Stiffness of upper**
- Stiffness, $k = F/\delta$
- Use stiffness of a representative wall (engineering judgement)
- Upper: wood wall deflection equations
- Lower: concrete shear wall deflection from analysis

Background: How?

Two-Stage Lateral Analysis

ASCE 7 §12.2.3.2

"Flexible upper portion above a rigid lower portion"

- **Period of structure ≤ 1.1x Period of upper**
- ASCE 7-10 Eq. 12.8-7:

$$T_a = C_t (h_n)^x$$

- Often doesn't meet criteria
- FEMA 450 Eq. C5.2-1:

$$T = 2\pi \sqrt{\left(\sum_{i=1}^{n} w_i \delta_i^2\right) / \left(g \sum_{i=1}^{n} f_i \delta_i^2\right)}$$

Occupancy

IBC Chapter 3

Lower portion

- Parking
  - Storage: Group S-2
- Commercial/Retail
  - Assembly: Group A
  - Business: Group B
  - Mercantile: Group M

Upper Portion

- Residential
  - Apartments, Dormitories: Group R-2
  - Hotels: Group R-1

Construction Types

IBC Chapter 6

Type I/II
- Noncombustible

Type III
- Exterior Walls Noncombustible

Type IV
- Heavy Timber

Type V
- Any

Subcategories “A” and “B” are applied to Type I, II, III, and V. Type A indicates an extra 1 hour fire-rating on most primary and secondary structural elements over the requirements of Type B.

Building Limits

Maximum allowable:

- Building Height
- Number of Stories
- Building Area

Based on:

- Occupancy
- Construction Type
- Sprinklers

NFPA 13 sprinklers generally:
•Increase building height by 20ft
•Increase stories by 1
•Increase area by 3x
Note: CBC does not allow height/story increase *and* area increase simultaneously

Height and Story Limits

IBC Tables 504.3 & 504.4

Building Height (ft)[1] / Number of Stories[1]					
Occupancy	Sprinklers	Type III		Type V	
		A	B	A	B
R-2	None[2]	65 / 4	55 / 4	50 / 3	40 / 2
	NFPA 13R	60 / 4	60 / 4	60 / 4	60 / 3
	NFPA 13[3]	85 / 5	~~75 / 5~~	70 / 4	60 / 3

1. Measured from grade
2. Sprinklers are required for new construction.
3. CBC does not allow area increase & height increase simultaneously.

Code Allowance

Horizontal Building Separation

IBC §510.2

- "Separate and distinct buildings" for:
  - Area determination
  - Number of stories
  - Construction type
- Building height *still measured from grade*

Height and Story Limits

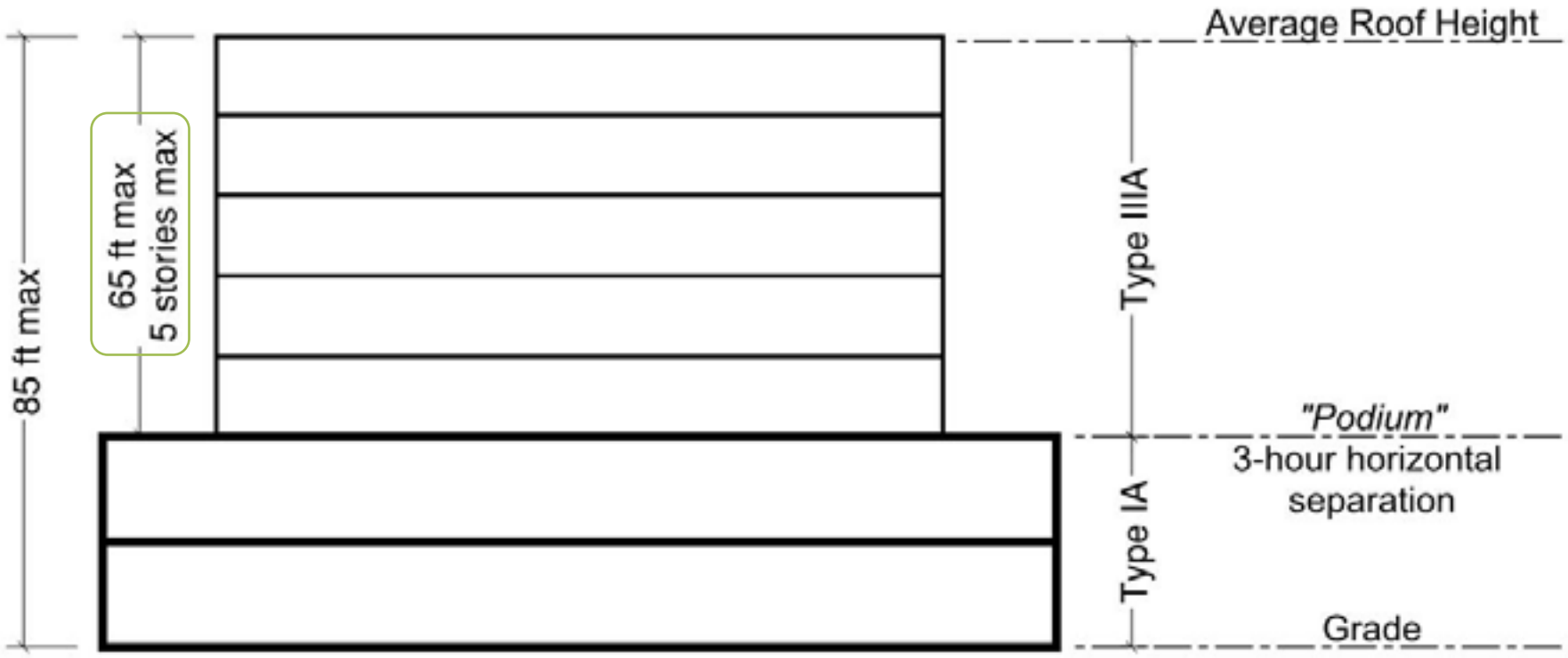
SFRS Height Limits

Wood shear walls

ASCE 7 Table 12.2-1

- Seismic Design Category D, E, F
- 65-foot maximum
- Measured from base
- Base is the level at which horizontal seismic ground motions are imparted
- Base = top of podium

All Together Now



Fire-Retardant-Treated Wood (FRT)

In Type III Construction

IBC §602.2, Table 601, Table 602

- Permitted in exterior wall assemblies with 2-hour rating or less
  - Exterior bearing walls: 2-hour fire rating
  - Exterior non-bearing walls: 0-2-hour fire rating, depending on fire separation distance (for all occupancies except H)
- FRT in accordance with 2303.2

Fire-Retardant-Treated Wood (FRT)

Material Considerations

IBC §2303.2, NDS §2.3.4

- Labeling requirements
- Strength reduction factors
  - Testing-based
  - Manufacturer-specific, listed in evaluation report
  - Consult manufacturers, use “worst-case”
  - State assumption in material specifications
  - Incising is not included, if required
- Cannot be ripped

Fire-Retardant-Treated Wood (FRT)

Strength Reduction Factors

Property		Brand 1	Brand 2	Brand 3
F_b	Bending Stress	0.97	0.972	0.90
F_t	Tension Parallel to Grain	0.95	0.874	0.87
F_c	Compression Parallel to Grain	1.00	0.935	0.91
$F_{c\perp}$	Compression Perpendicular to Grain	0.95	--	--
F_v	Shear Stress	0.96	0.985	0.94
E	Modulus of Elasticity	0.96	1.000	0.98
	Fasteners/Connectors	0.90	0.900	--

Preservative-Treated Wood (PT)

IBC §2303.1.9

Standard U1

- Use Category
- Includes FRT Use Categories
- Species and preservative combinations

Borate

- Interior applications only
- Sill plates in contact with concrete
- Incising not required
- Specialty fasteners not required

Treated Wood

Incising

NDS §4.3.8

- Additional strength reduction per NDS
- Species that are difficult to penetrate
  - Coastal Douglas-fir
  - Hem-fir
  - Spruce-Pine-Fir
- Consult manufacturers, contractors
- State assumption in material specifications

Treated Wood

PT and FRT

NDS §4.3.8

- Sill plates in exterior walls
- FRT does not replace PT
- Consult manufacturers for products that provide *both* types of protection

Treated Wood

Fasteners & Connectors

IBC §2304.10.5

- PT (not Borate)
  - Hot-dipped zinc-coated galvanized
  - Stainless
- Borate-treated
  - Allows plain carbon steel
  - Interior, dry environment
- FRT
  - Refer to manufacturer

Treated Wood – A Rainbow

Borate-Treated

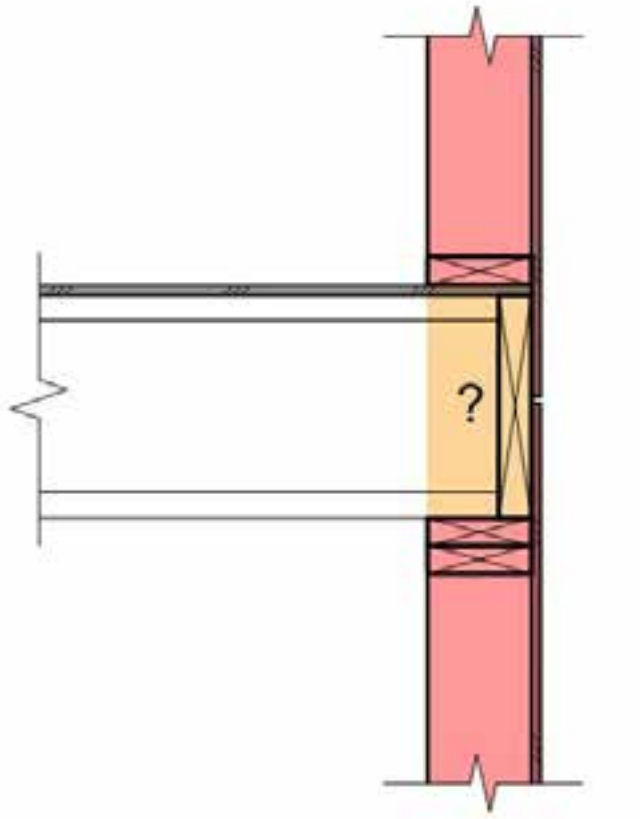
Fire-Retardant-Treated

Preservative-Treated

Exterior Wall Details

FRT Continuity

- Is FRT required at the floor intersection?
  - Varies by jurisdiction



Exterior Wall Details

FRT Floor/Wall Intersection:

- Consult with local jurisdiction
- FRT may not be required
- Maintain fire rating of walls & floors
- DCA 3 document by AWC
  - Wall Assemblies
  - Floor Assemblies
  - Intersections!


Design for Code Acceptance

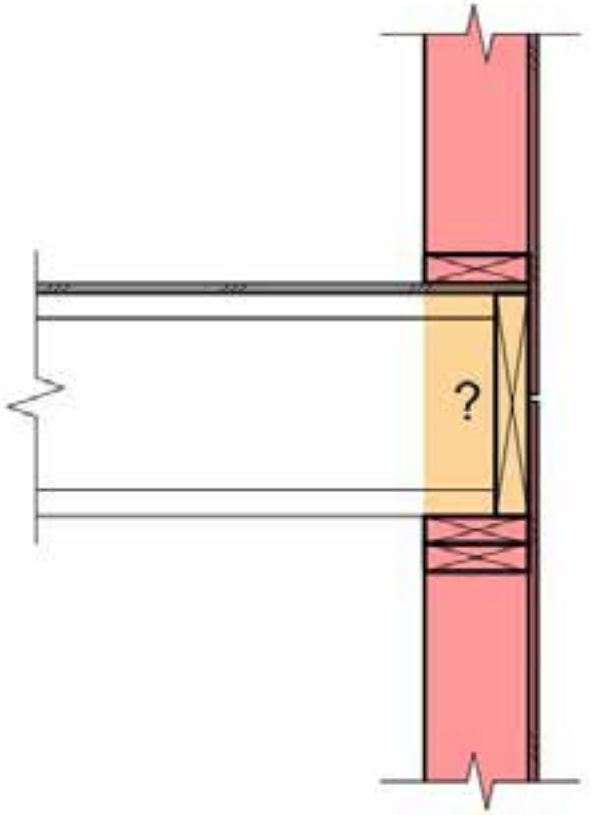
3

Fire-Resistance-Rated Wood-Frame Wall and Floor/Ceiling Assemblies

Exterior Wall Details

FRT Continuity

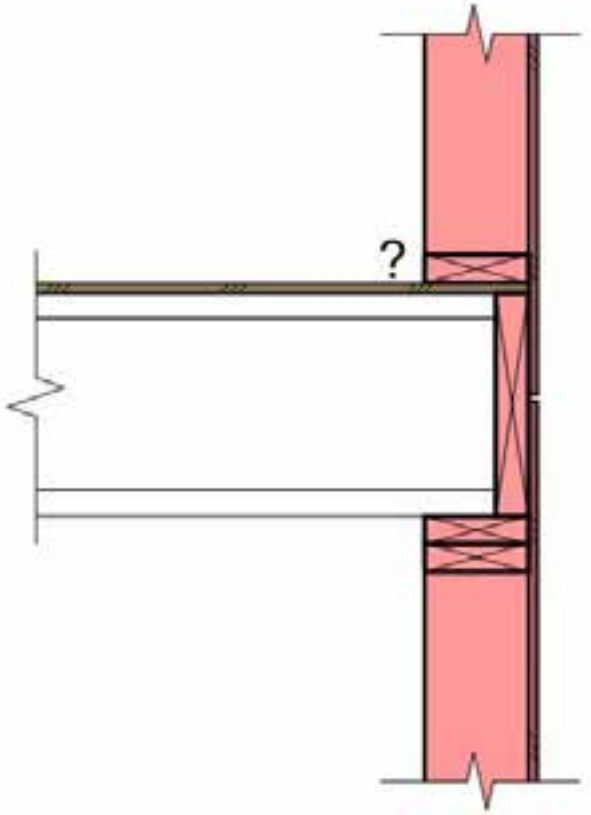
- Is FRT required at the floor intersection?
  - Varies by jurisdiction
- If yes, to what extent?



Exterior Wall Details

FRT Continuity

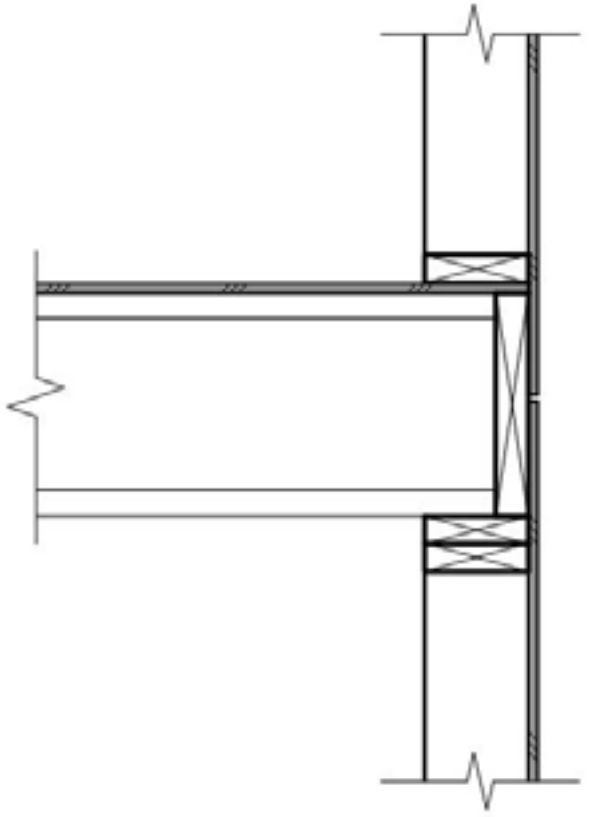
- If yes, to what extent?
  - Rim joist must be FRT
  - May non-FRT joists be let in?
  - Must rim joists be full-width?
  - If not, is fire blocking required
  - May non-FRT floor sheathing



Platform Framing

Benefits:

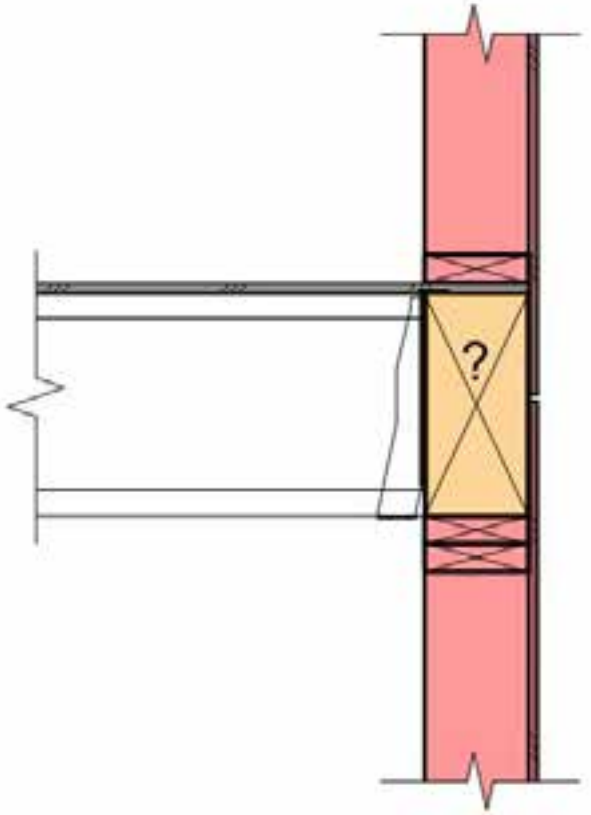
- Generally preferred for ease of construction
- Joists bear on walls; hangers not required
- Reduced stud height



Platform Framing

Challenges:

- Increased shrinkage potential
- Hangers required if joists may not be let in
- Availability of FRT rim



FRT Rim Joist Options

Engineered Lumber/Glulam:

- Pressure treatment not permitted
- Typically voids warranty
- Few proprietary products available

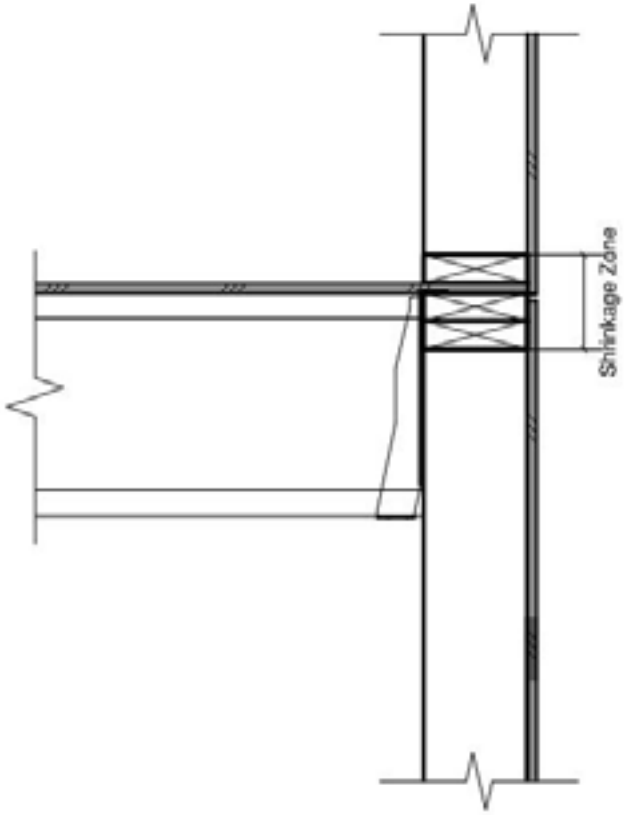
Solid Sawn Lumber:

- Depths not compatible with engineered joists
- Increased potential for shrinkage

Modified Balloon Framing

Benefits:

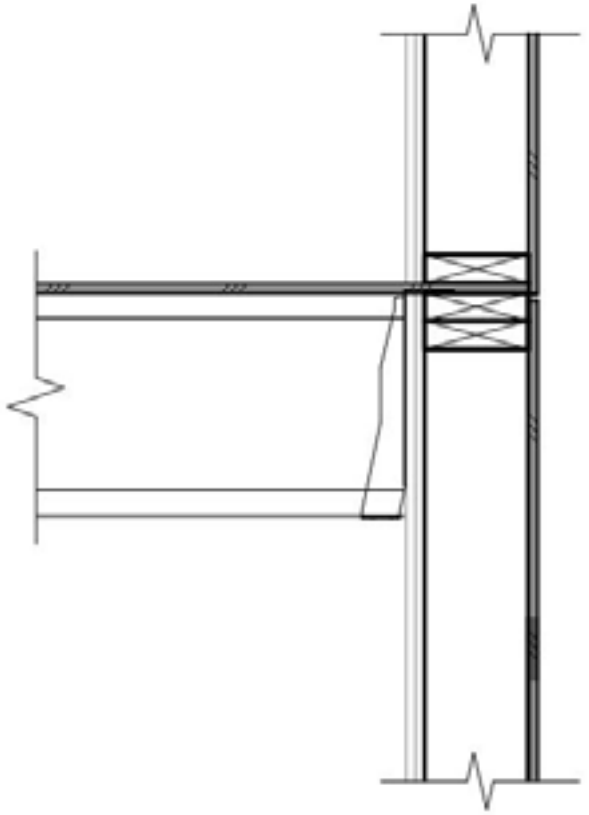
- No need for FRT rim
- Less ambiguous regarding FRT continuity
- Reduced shrinkage potential



Modified Balloon Framing

Challenges:

- Hangers required
- Increased stud height
- Less preferred construction method; sequencing concerns



Gravity Framing

5 Stories = Large Loads

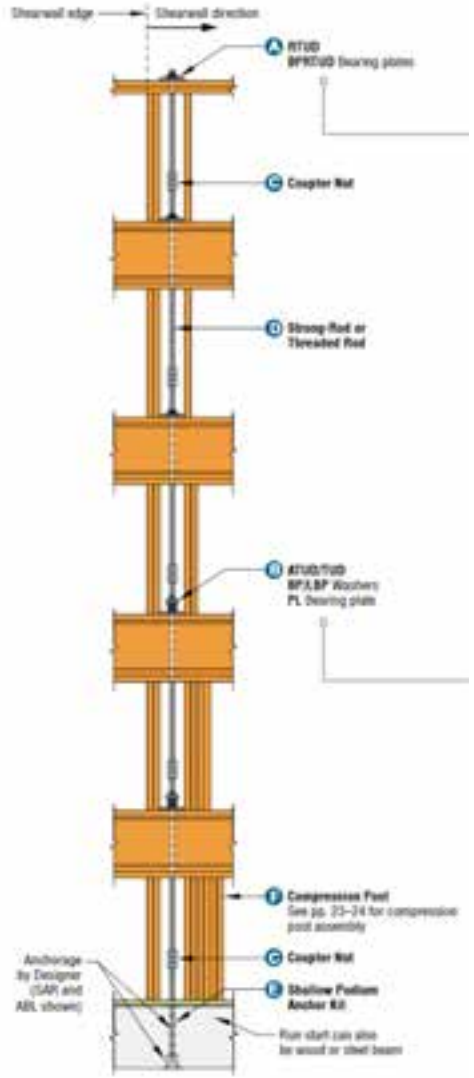
- Limit exterior bearing walls
  - Gravity combined with wind
  - May help with fire-rating
- Studs stack from floor to floor
  - 12”oc spacing may be required
- Increase stud size at lower levels
  - 4x4, 3x6 are not uncommon
- Increase grade/material at lower levels
  - Engineered studs
  - No. 1, or Select Structural

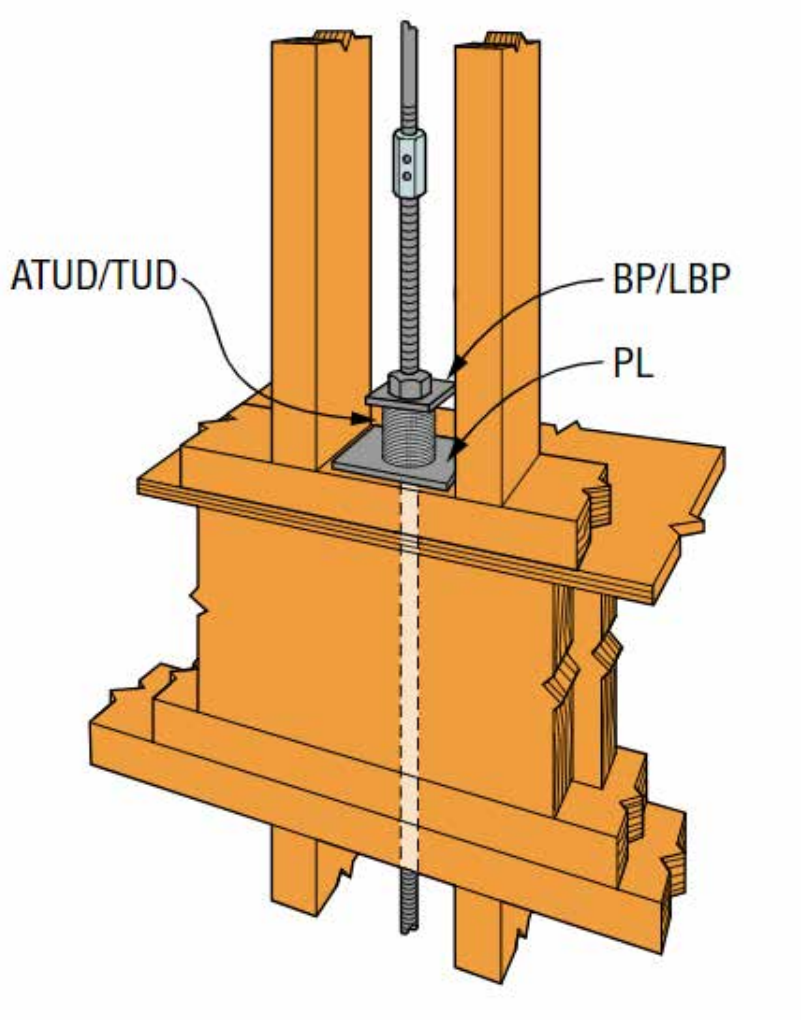
Lateral Loading

5 Stories = Large Loads

- Shorter walls may not be effective
  - Typical at exterior
  - Perforated or FTAO methods
  - Rigid/Semi-rigid diaphragm analysis
- Larger overturning forces
  - Continuous tiedowns in lieu of holdowns
- Deflection

Continuous Tiedowns





Tendon Profiles

ACI 318 Table 20.6.1.3.2

Tendon drape

- Mid-depth at slab edge
- Low point at midspan
- High point over supports

Cover

- 1” if exposed to weather
- ¾” if not exposed to weather

Fire Rating Requirements

3-Hour Fire Rated Assembly

IBC Table 721.1

- Bonded or unbonded tendons
- Solid slabs
- Carbonate, lightweight, sand-lightweight aggregate
- Unrestrained = 2” cover
- Restrained = 1” cover
  - Restrained = interior spans

Podium Design

Reactions

ASCE 7 §12.2.3.2

- Gravity reactions from wood applied to podium
- Seismic reactions (shear and overturning) from wood scaled up and applied to podium
  - $(R/\rho)_{upper} / (R/\rho)_{lower} \geq 1$
  - Shear often accounted for as a seismic weight included in concrete base shear calculation
  - Overturning often accounted for as point load reactions from wood shear walls

Podium Design

Reactions

ASCE 7 §12.3.3.3

- Podium supports discontinuous walls
  - Point loads must include overstrength for the design of the podium
  - In ASCE 7, connections need not include overstrength (i.e. sill plate anchors, tiedown anchors)
  - In ACI 318, anchorage to concrete may require overstrength

Podium Design

Overstrength

ASCE 7 §12.4.3.1

- Seismic overstrength load “need not exceed the maximum force that can develop in the element… utilizing realistic expected values of material strengths.”
- Yielding of other elements limits the load that can be delivered to the system
- Alternative to Ω_o: use maximum expected strength of the rod
- Capacities without strength reduction, ϕ

Concrete Anchorage

Tension

ACI 318 §17.4

- Steel strength: §17.4.1
- Concrete breakout strength: §17.4.2
- Pullout strength: §17.4.3
- Side-face blowout strength: §17.4.4
- ~~Bond strength: §17.4.5~~
- Seismic requirements: §17.2.3
  - Seismic design categories C, D, E, F

Concrete Anchorage

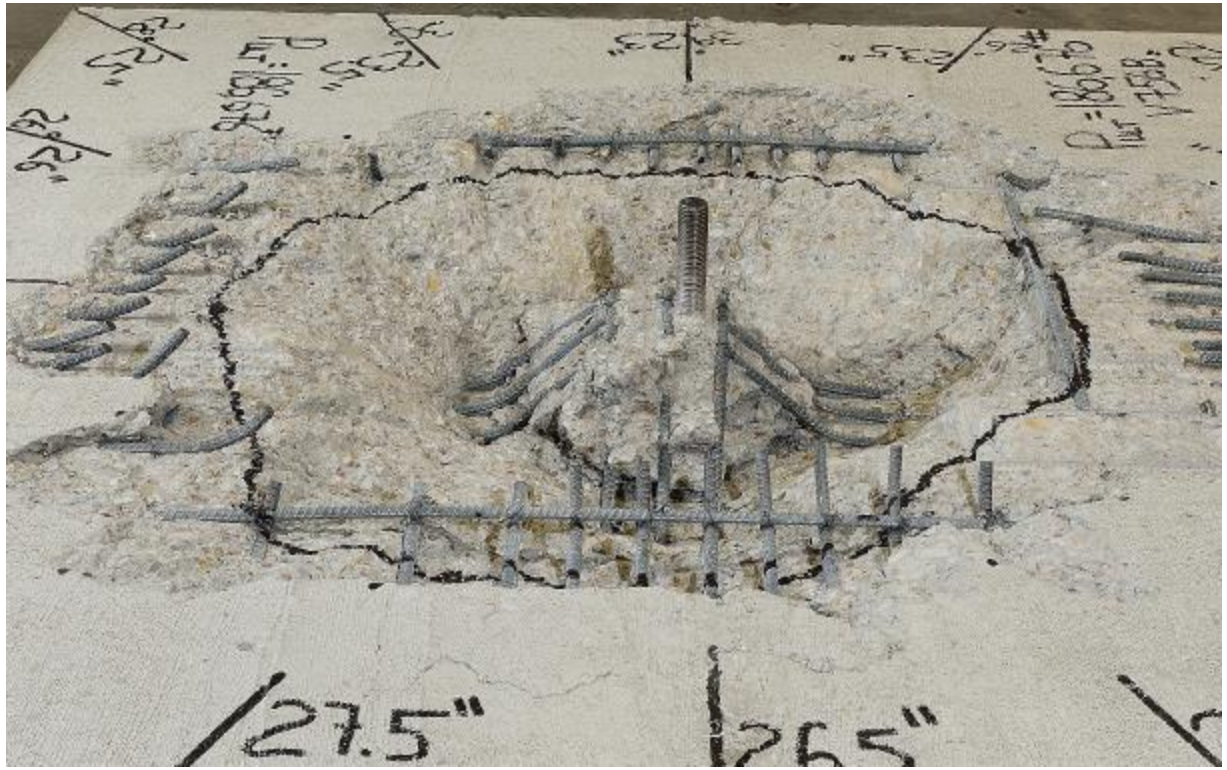
Seismic Requirements

ACI 318 §17.2.3.4.3

- Concrete strength > 1.2 * steel strength
  - Nominal strengths
  - Ductile steel element
- Maximum tension from yield mechanism
  - Including overstrength & strain hardening
- Maximum tension from non-yielding attachment
- Maximum tension including overstrength

Concrete Anchorage

Simpson Shallow Podium Anchorage



QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

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