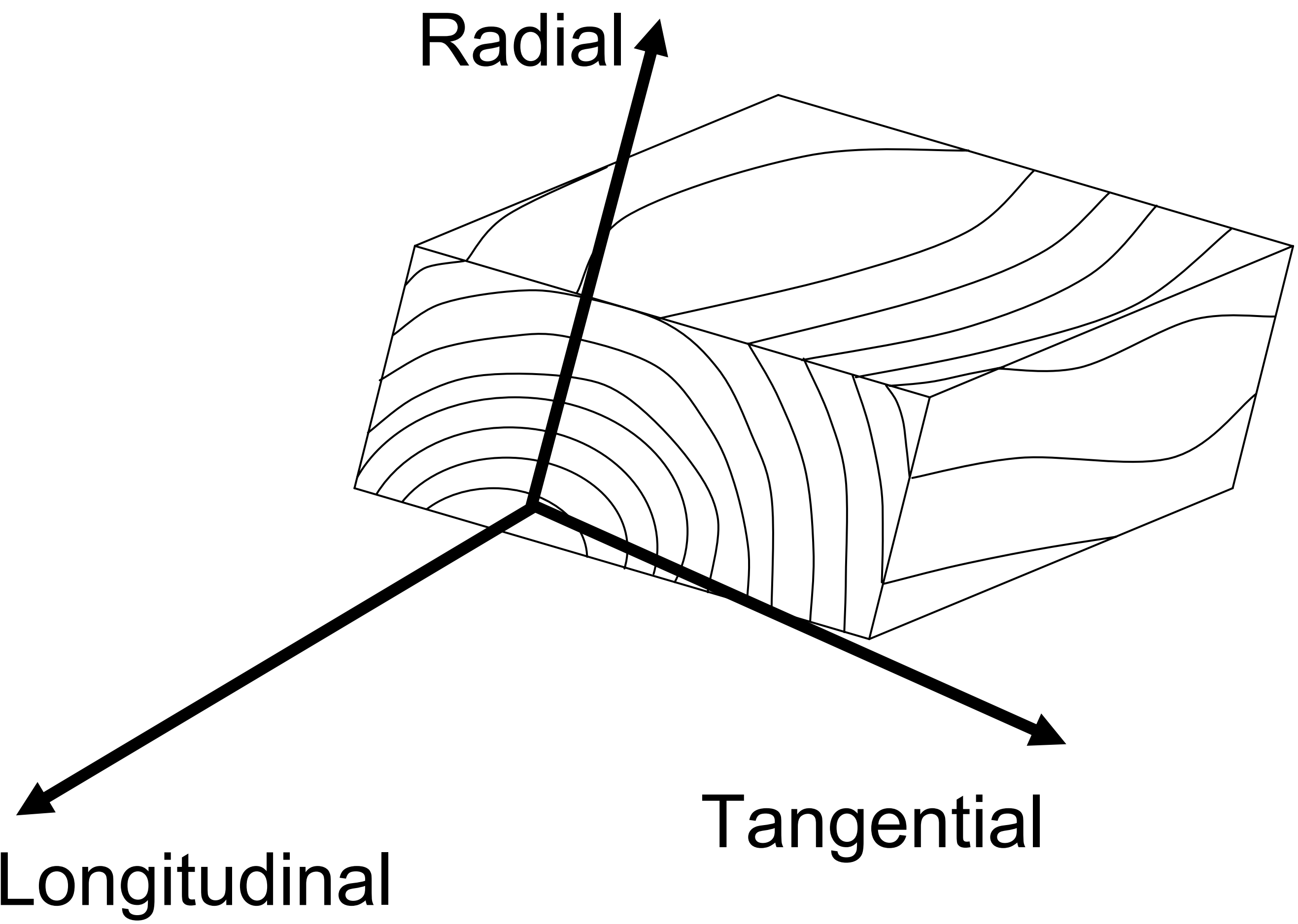
WOOD STRUCTURES

Objectives of Topic

Understanding of:

- **Basic wood behavior**
- **Typical framing methods**
- **Main types of lateral force resisting systems**
- **Expected response under lateral loads**
- **Sources of strength, ductility and energy dissipation**
- **Basic shear wall construction methods**
- **Shear wall component behavior**
- **Analysis methods**
- **Code requirements**

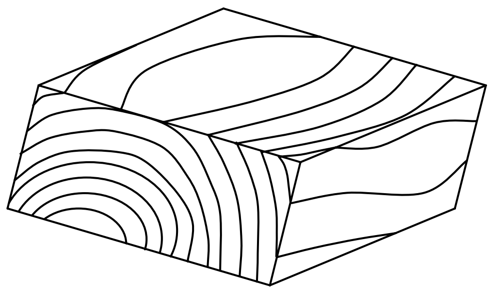
Basic Wood Material Properties



Wood is orthotropic

- **Varies with moisture content**
- **Main strength axis is longitudinal - parallel to grain**
- **Unique, independent, mechanical properties in 3 different directions**
- **Radial and tangential are "perpendicular" to the grain – substantially weaker**

Basic Wood Material Properties



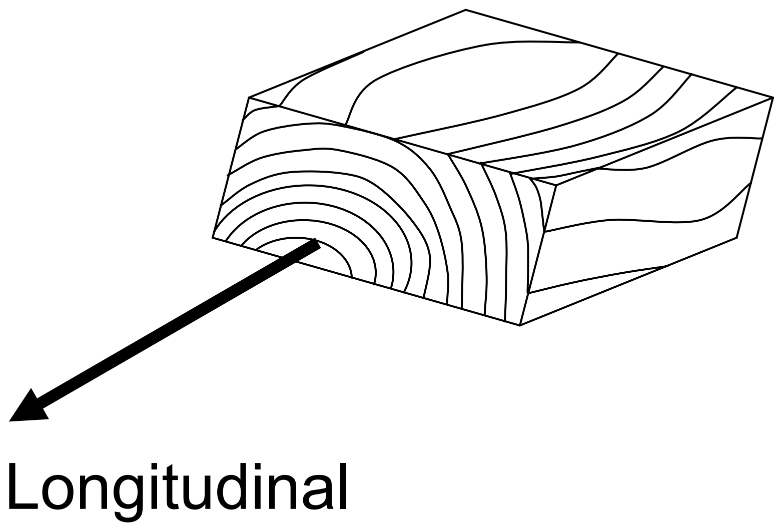
"Timber is as different from wood as concrete is from cement."

– Madsen, Structural Behaviour of Timber

Concept of "wood" as "clear wood": design properties used to be derived from clear wood with adjustments for a range of "strength reducing characteristics."

- Concept of "timber" as the useful engineering and construction material: "In-grade" testing (used now) determines engineering properties for a specific grade of timber based on full-scale tests of timber, a mixture of clear wood and strength reducing characteristics.

Basic Wood Material Properties



Sample DFL longitudinal design properties:

- **Modulus of elasticity: 1,800,000 psi**
- **Tension (parallel to grain): 1,575 psi**
- **Bending: 2,100 psi**
- **Compression (parallel to grain): 1875 psi**

Basic Wood Material Properties

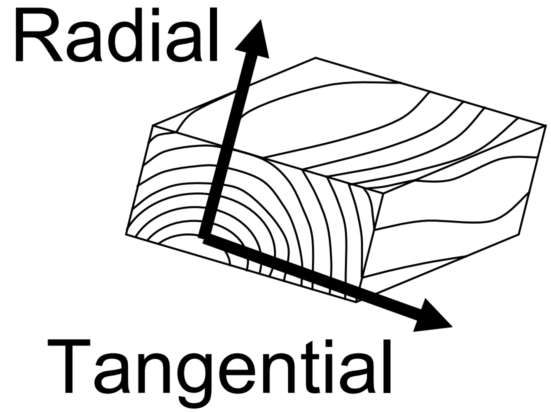
Sample DFL perpendicular to grain design properties:

- **Modulus of elasticity: 45,000 psi (2.5 ~ 5 % of $E_{||}$!)**
- **Tension (perpendicular to grain): 180 to 350 psi**

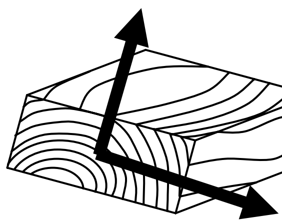
FAILURE stresses. Timber is extremely weak for this stress condition. It should be avoided if at all possible, and mechanically reinforced if not avoidable.

- **Compression (perpendicular to grain): 625 psi.**

Note that this is derived from a serviceability limit state of ~ 0.04” permanent deformation under stress in contact situations. This is the most "ductile" basic wood property.



Basic Wood Material Properties



Shrinkage

- **Wood will shrink with changes in moisture content.**
- **This is most pronounced in the radial and tangential directions (perpendicular to grain).**
- **May need to be addressed in the LFRS.**

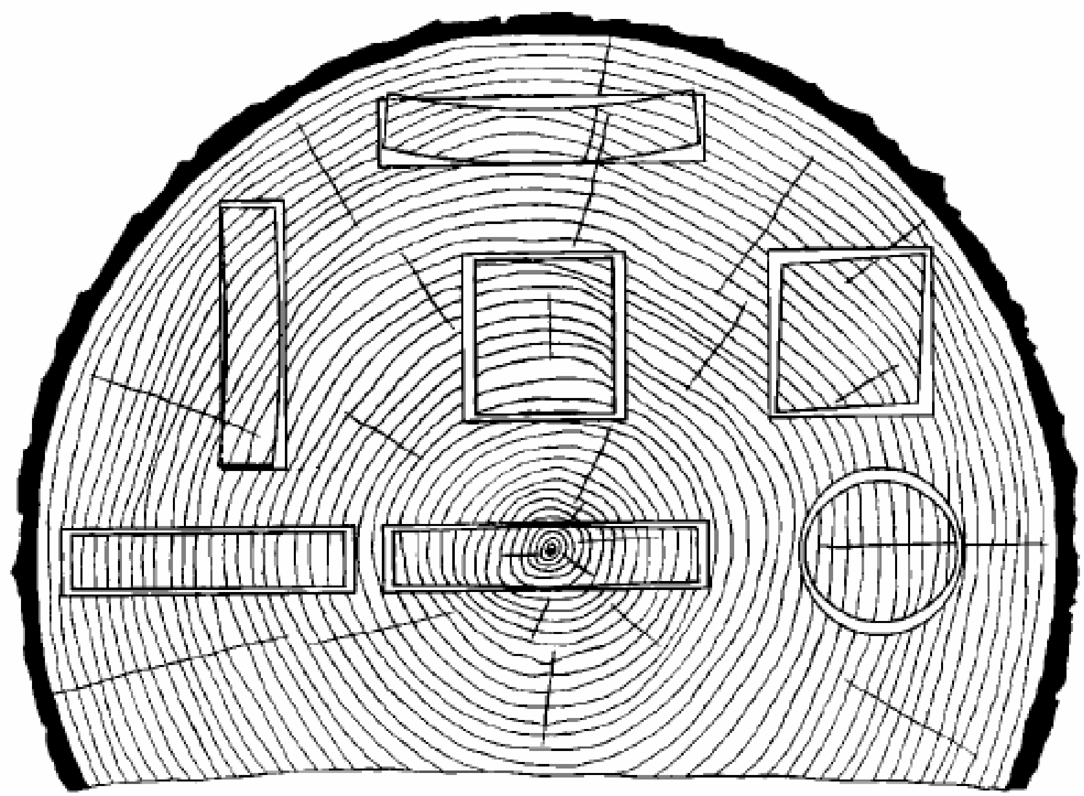
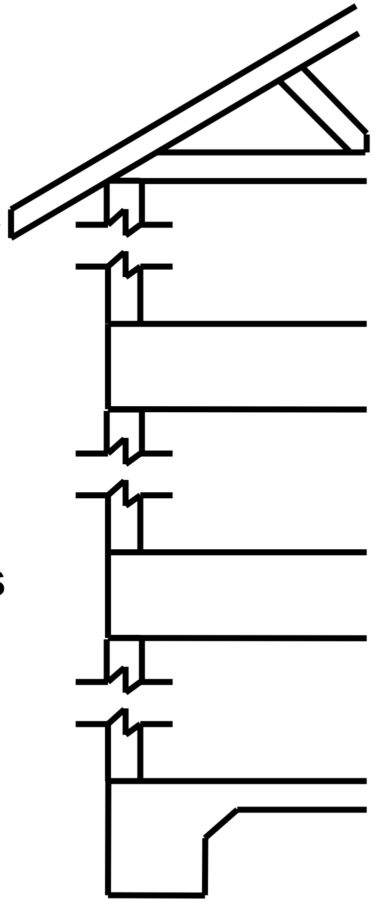


Figure 3–3. Characteristic shrinkage and distortion of flat, square, and round pieces as affected by direction of growth rings. Tangential shrinkage is about twice as great as radial.

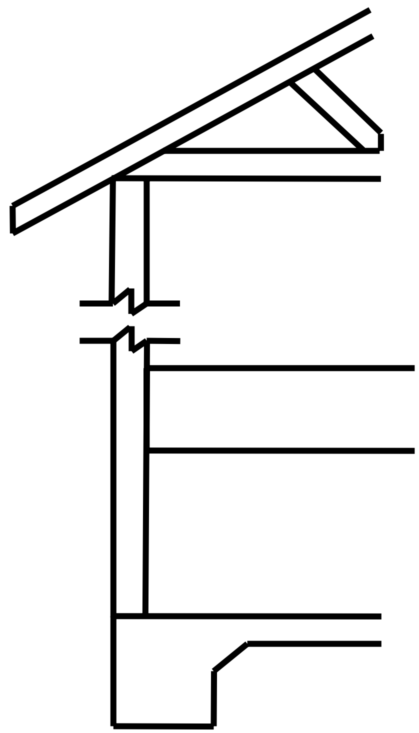
(Wood Handbook, p. 58)

Wood Structure Construction Methods: Gravity

Platform



Balloon



- Walls are interrupted by floor "platforms."
- Floors support walls.
- Most common type of light-frame construction today.
- Economical but creates discontinuity in the load path.
- Metal connectors essential for complete load path.

- Walls feature foundation to roof framing members.
- Floors supported by ledgers on walls or lapped with studs.
- Not very common today.

Wood Structure Construction Methods: Gravity

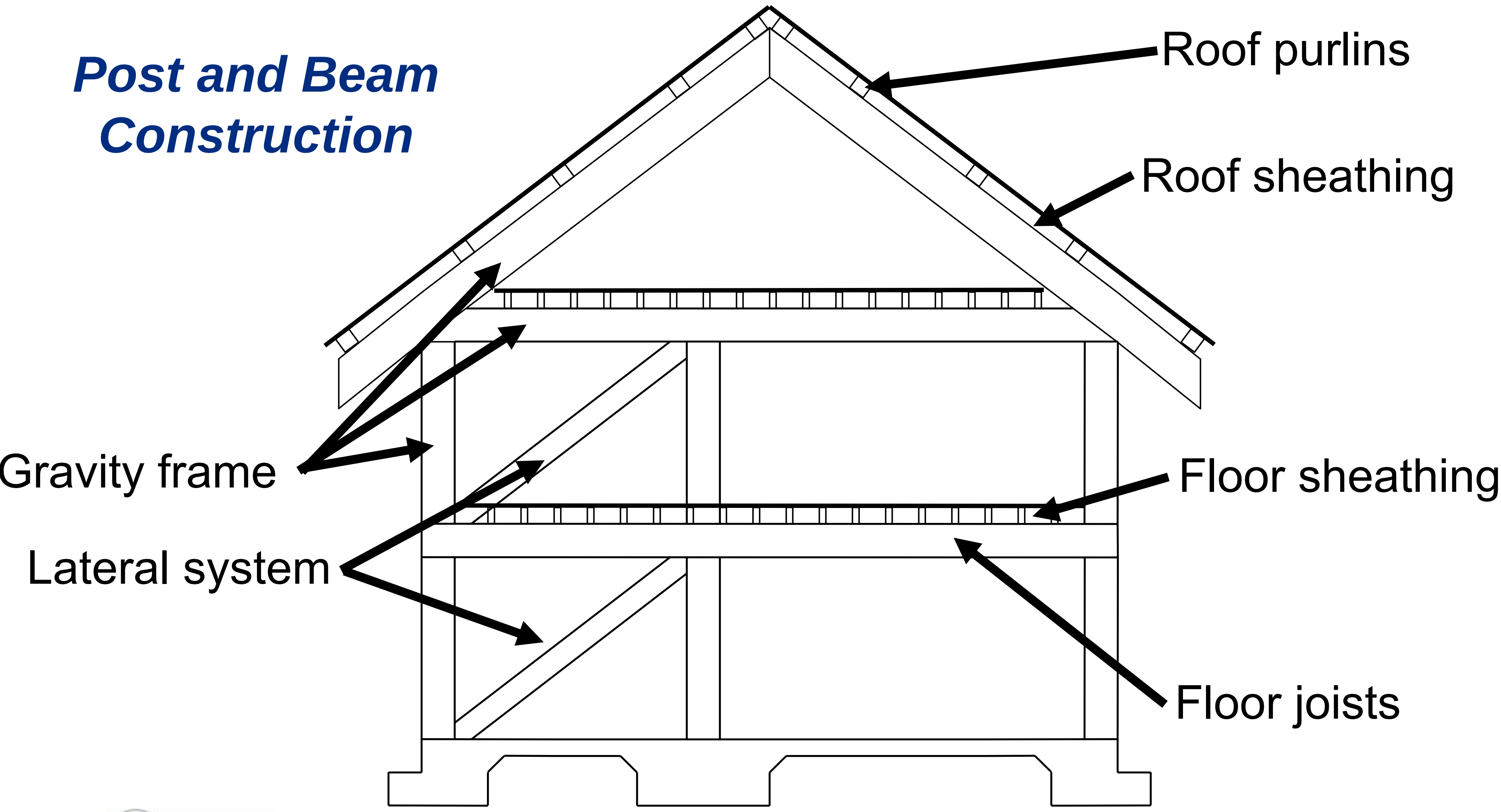
Post and Beam

- Space frame for gravity loads.
- Moment continuity at joint typically only if member is continuous through joint.
- Lateral resistance through vertical diaphragms or braced frames.
- Knee braces as seen here for lateral have no code design procedure for seismic.

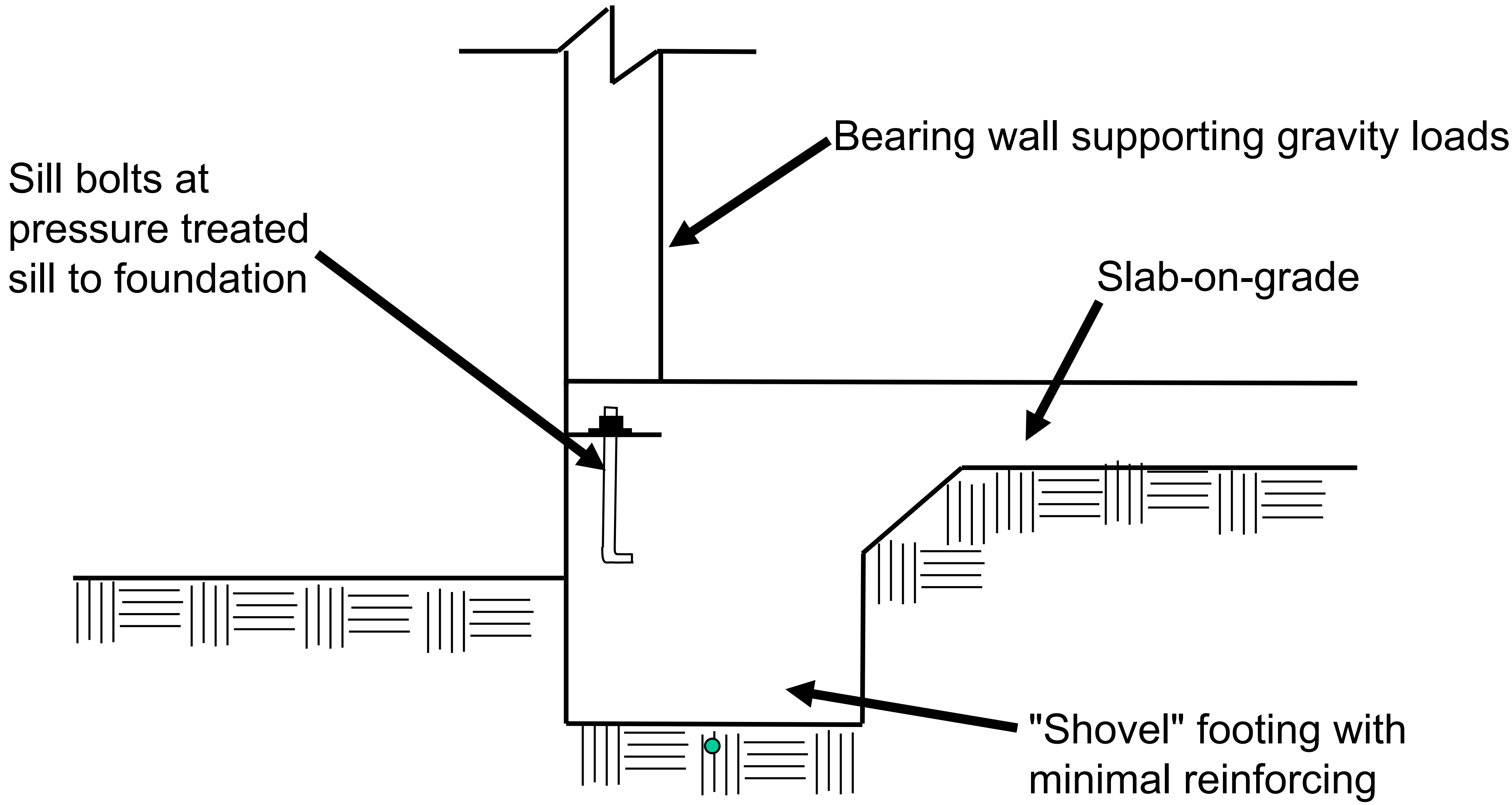
Six story main lobby Old Faithful Inn, Yellowstone, undergoing renovation work in 2005. Built in winter of 1903-1904, it withstood a major 7.5 earthquake in 1959.

Wood Structure Construction Methods: Gravity

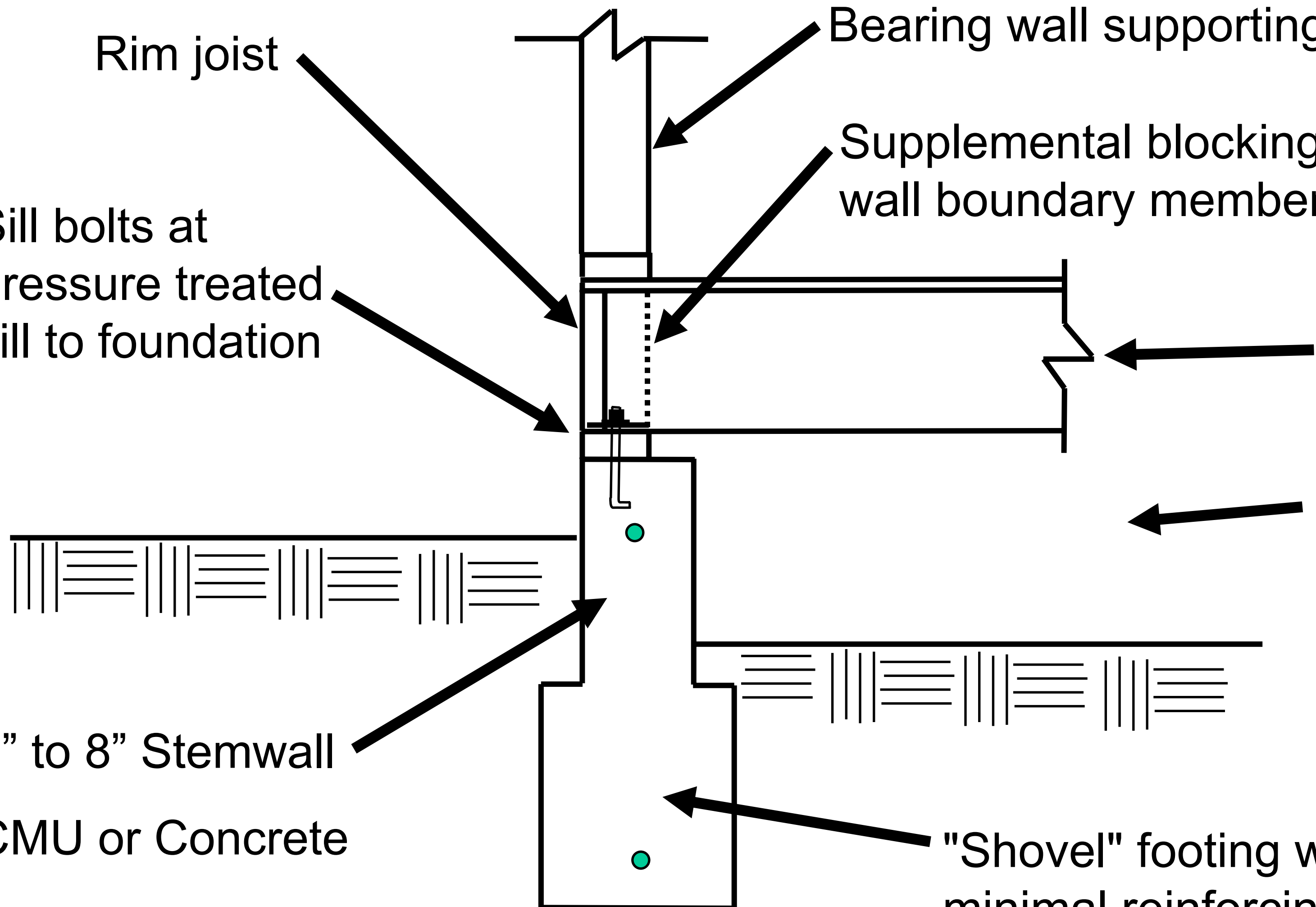
Post and Beam Construction



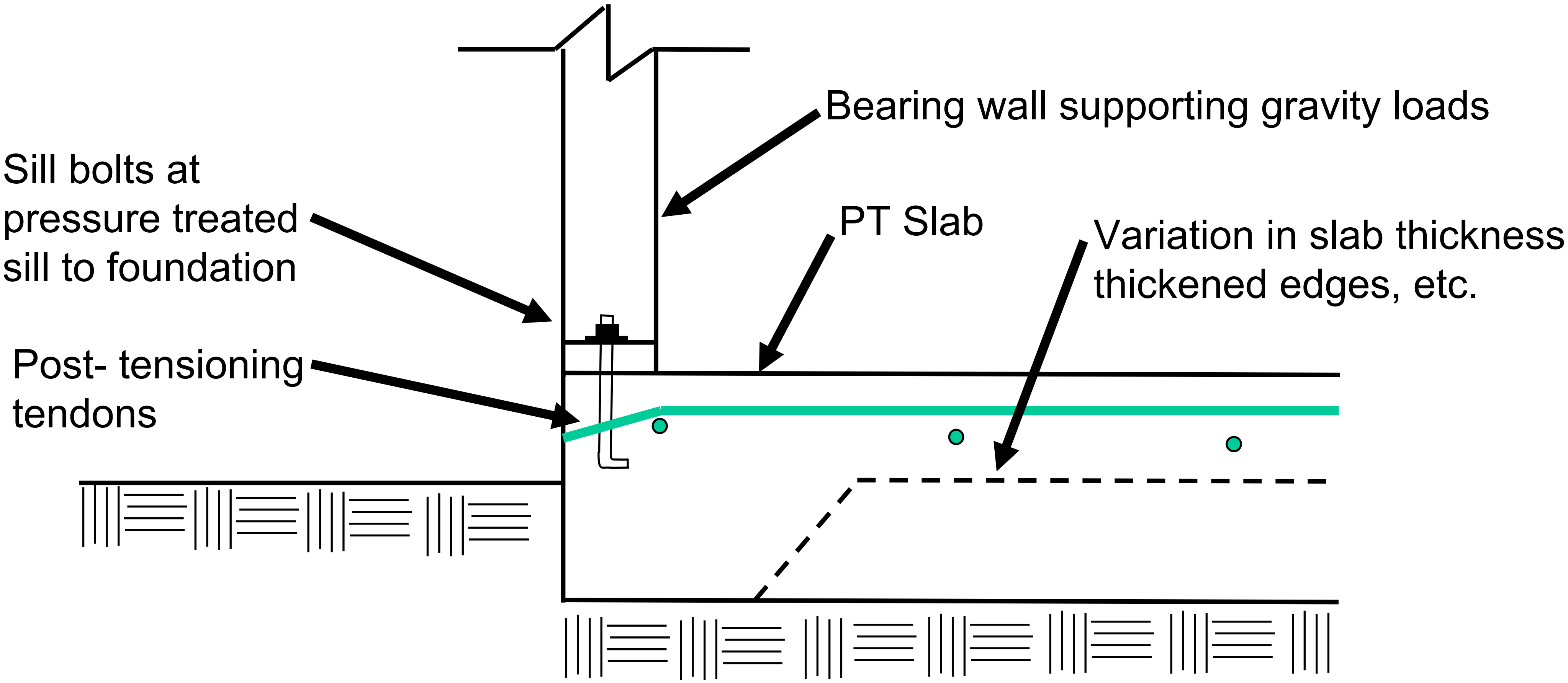
Typical Light-Frame Foundation: Slab-On-Grade



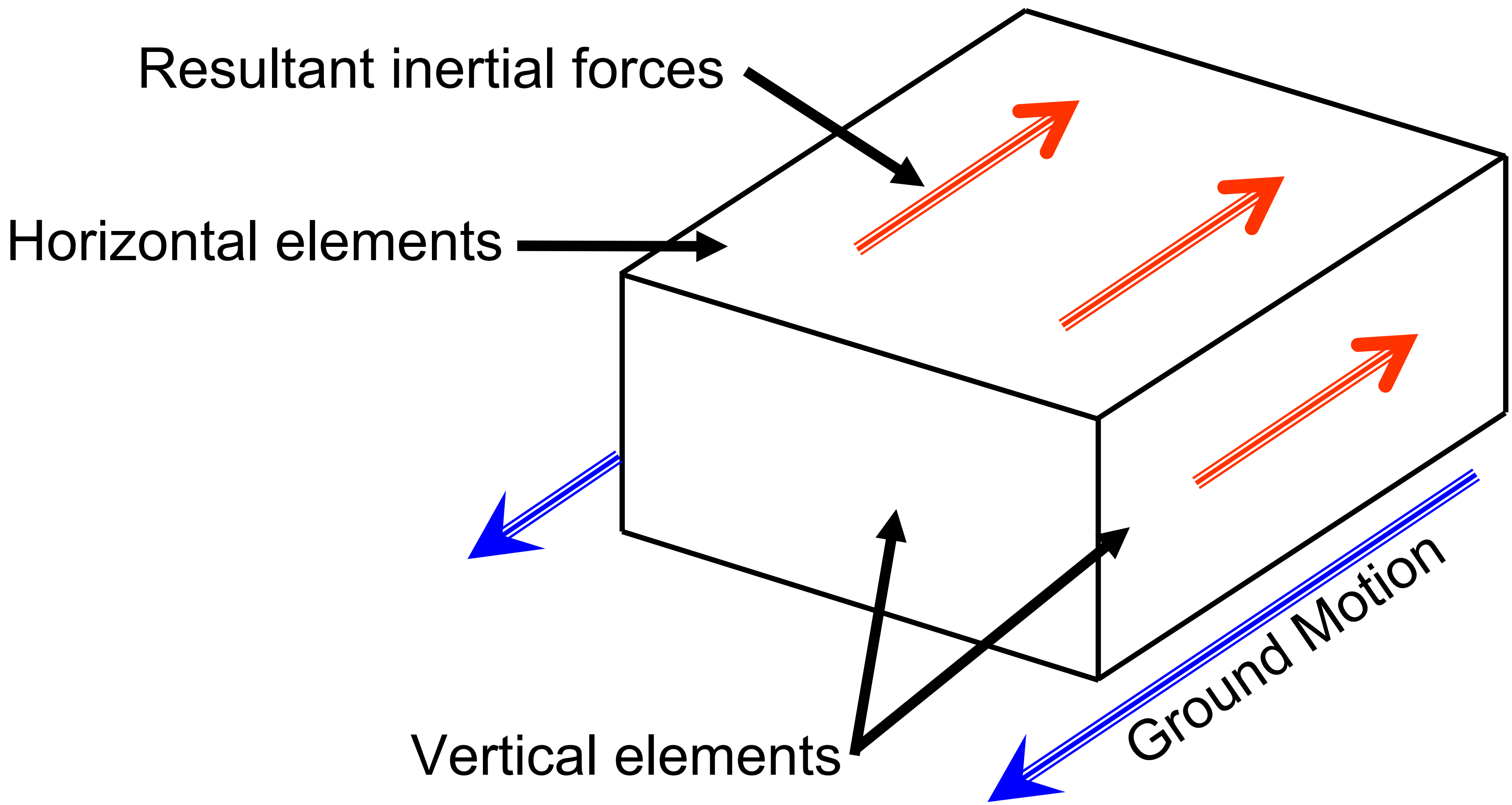
Typical Light-Frame Foundation: Raised Floor



Typical Light-Frame Foundation: Post Tensioning



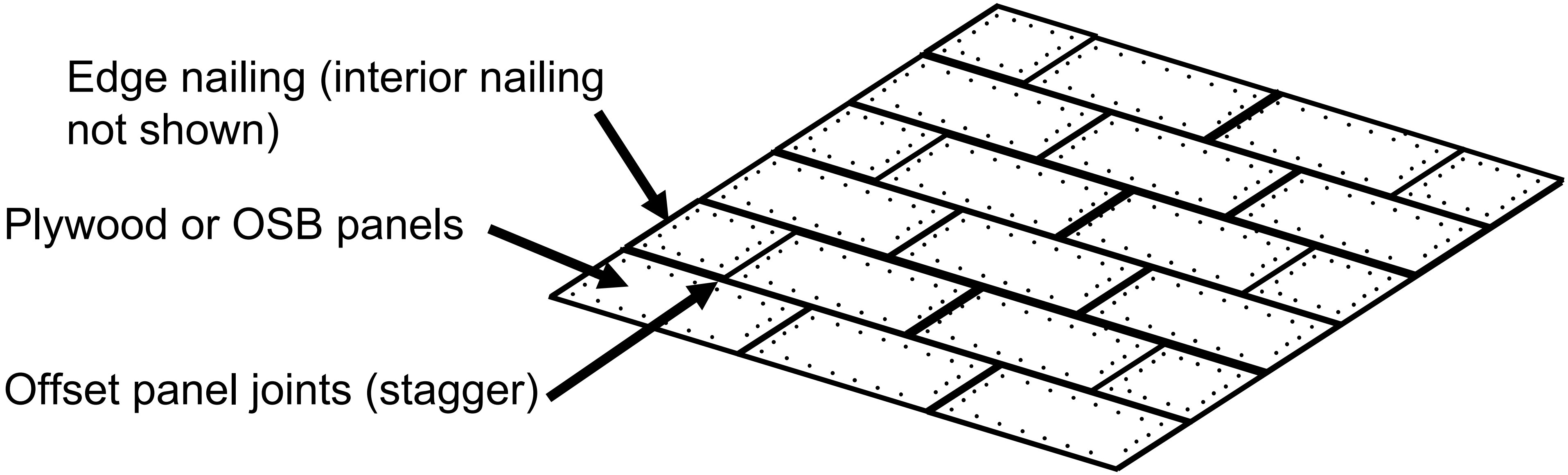
Wood Structure Construction Methods: Lateral



- **The basic approach to the lateral design of wood structures is the same as for other structures.**

Wood Structure Construction Methods: Lateral

Horizontal elements of LFRS

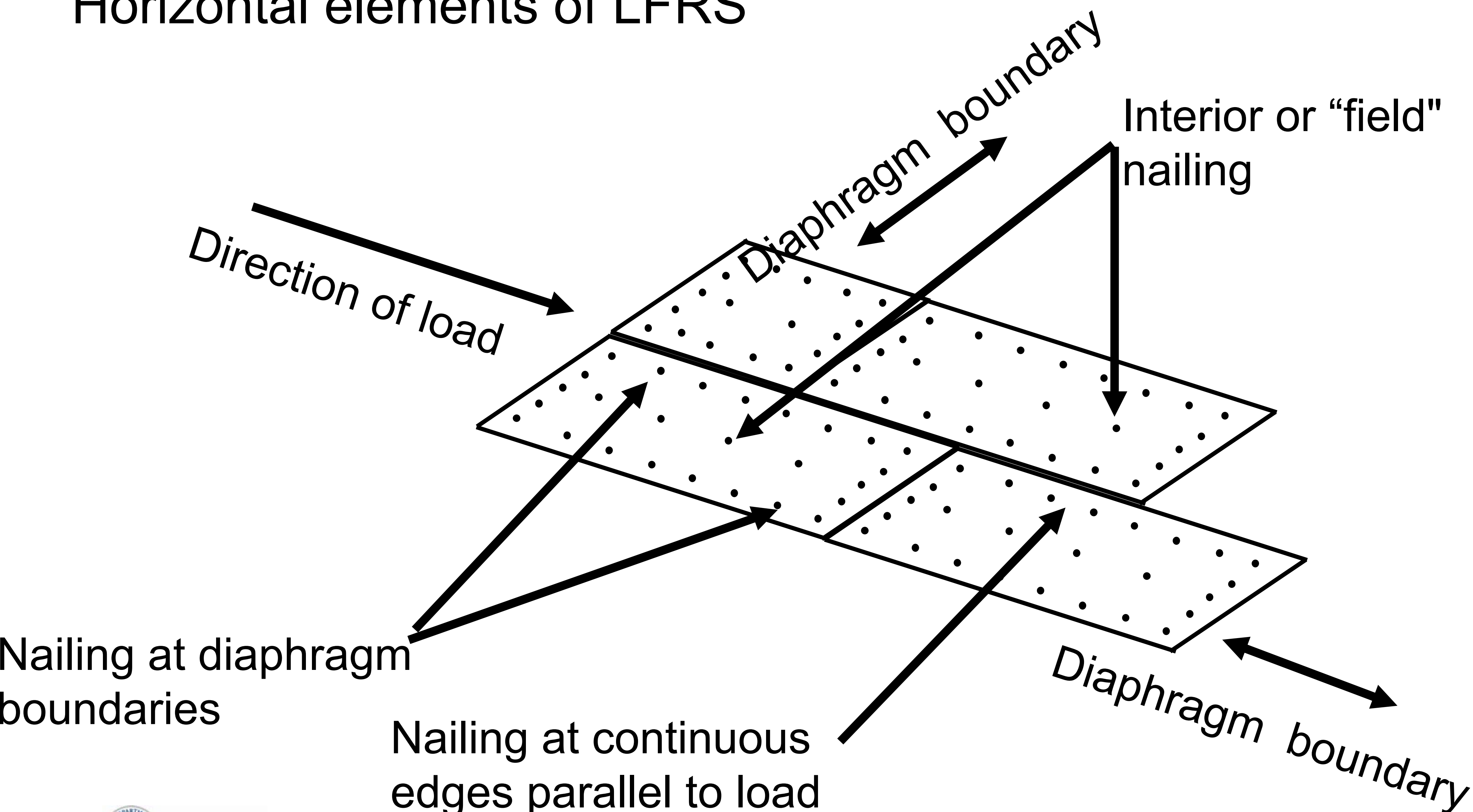


- **Most structures rely on some form of nailed wood structural panels to act as diaphragms for the horizontal elements of the LFRS (plywood or oriented strand board – OSB).**

- **Capacity of diaphragm varies with sheathing grade and thickness, nail type and size, framing member size and species, geometric layout of the sheathing (stagger), direction of load relative to the stagger, and whether or not there is blocking behind every joint to ensure shear continuity across panel edges.**

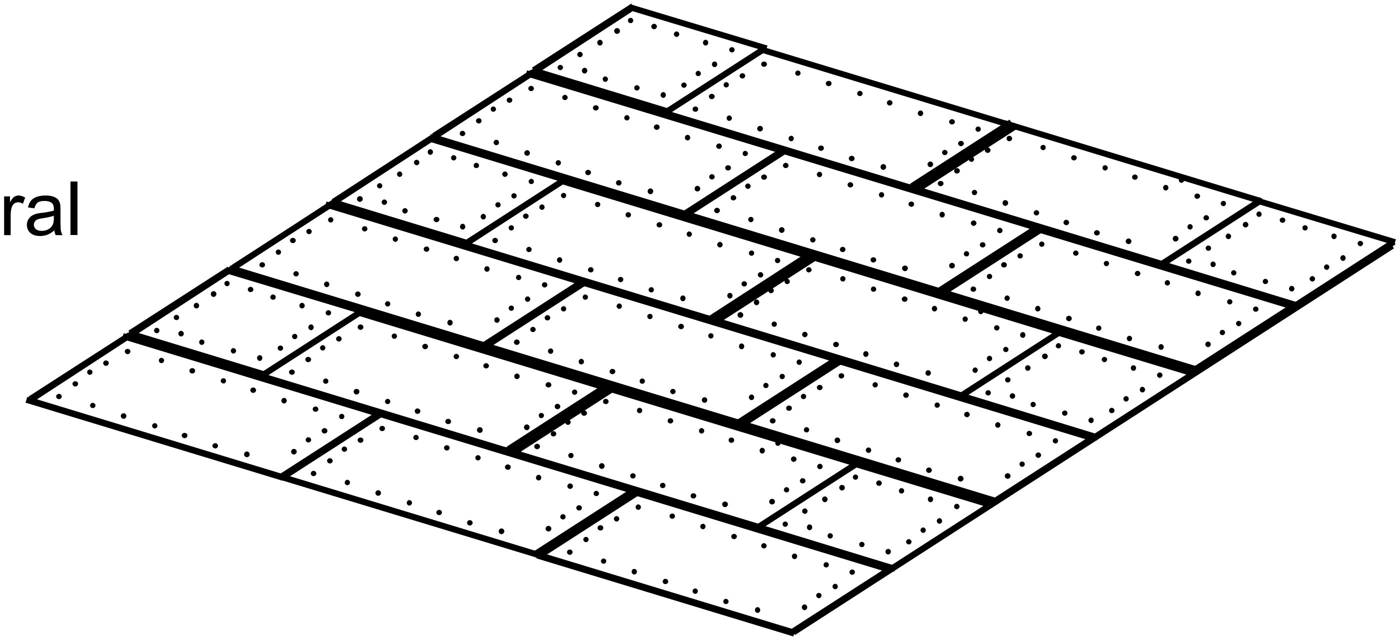
Wood Structure Construction Methods: Lateral

Horizontal elements of LFRS



Wood Structure Construction Methods: Lateral

Horizontal element: nailed wood structural panel diaphragm



- **The building code has tables of diaphragm design capacity (at either ASD or LRFD resistance levels) relative to all of the factors mentioned above.**

Wood Structure Construction Methods: Lateral

Vertical element: nailed wood structural panel diaphragm

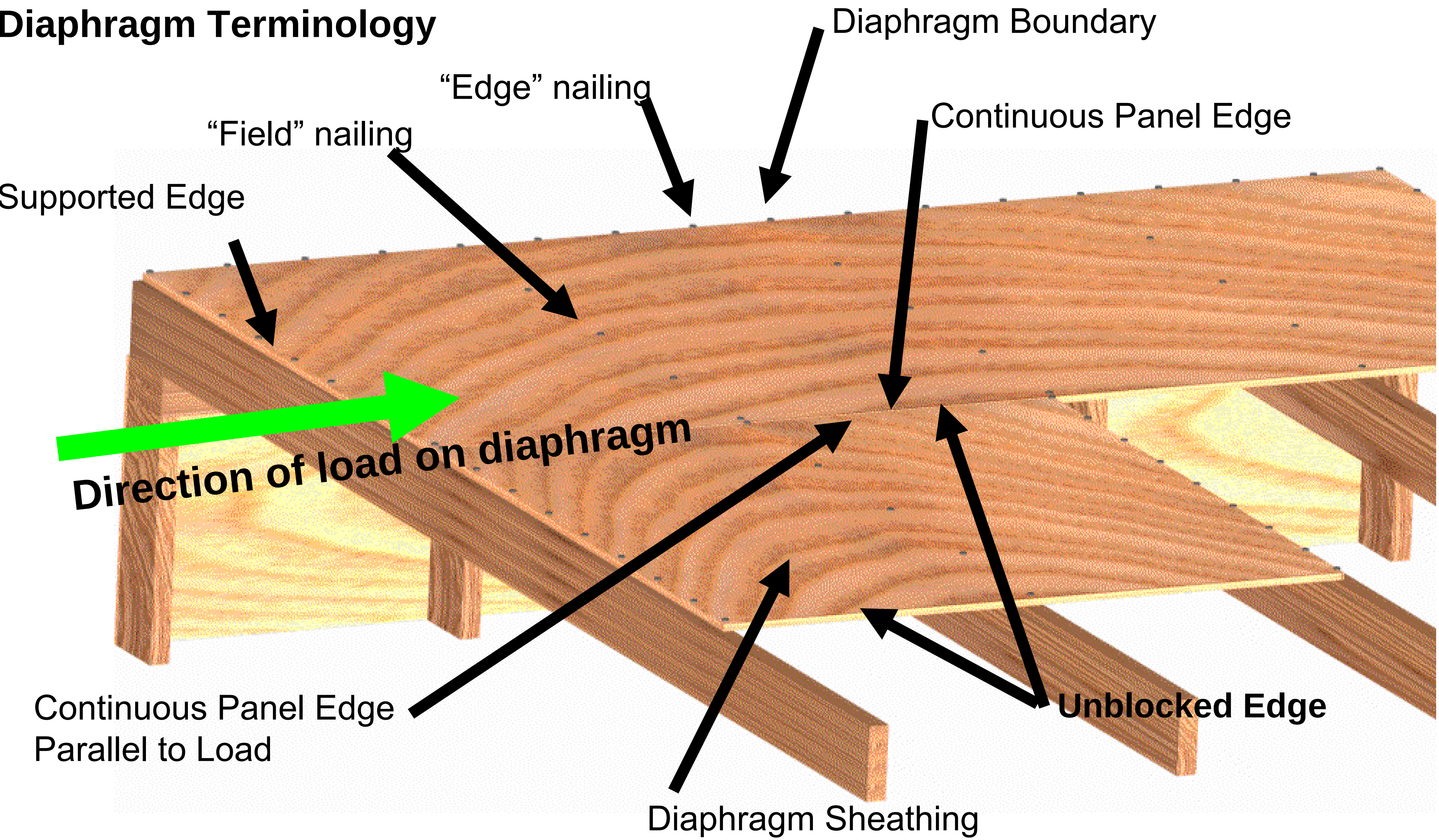
- **Shear capacities for vertical plywood/OSB diaphragms are also given in the codes, with similar variables impacting their strength.**
- **Heavy timber braced frames (1997 UBC) and singly or doubly diagonal sheathed walls are also allowed, but rare.**

Wood Structure LFRS Design Methods: Engineered

- If a structures does not meet the code requirements for "prescriptive" or "conventional" construction, it must be "engineered."
- As in other engineered structures, wood structures are only limited by the application of good design practices applied through principles of mechanics (and story height limitations in the code).
- A dedicated system of horizontal and vertical elements, along with complete connectivity, must be designed and detailed.

Wood Structure LFRS Design Methods: Engineered

Diaphragm Terminology



Wood Structure LFRS Design Methods: Engineered

Diaphragm Design Tables

- **Tables are for DFL or SYP – need to adjust values if framing with wood species with lower specific gravities.**
- **Partial reprint of engineered wood structural panel diaphragm info in 2003 IBC Table 2306.3.1.**
- **Major divisions: Structural 1 vs. Rated Sheathing and Blocked vs. Unblocked panel edges.**

RECOMMENDED SHEAR (POUNDS PER FOOT) FOR HORIZONTAL APA PANEL DIAPHRAGMS WITH FRAMING OF DOUGLAS-FIR, LARCH OR SOUTHERN PINE[a] FOR WIND OR SEISMIC LOADING

Panel Grade	Common Nail Size	Minimum Nail Penetration in Framing (inches)	Minimum Nominal Panel Thickness (inch)	Minimum Nominal Width of Framing Member (inches)	Blocked Diaphragms: Nail Spacing (in.) at diaphragm boundaries (all cases), at continuous panel edges parallel to load (Cases 3 & 4), and at all panel edges (Cases 5 & 6)[b]: 6 / Nail Spacing (in.) at other panel edges (Cases 1, 2, 3 & 4): 6	4 / 6	2-1/2[c] / 4	2[c] / 3	Unblocked Diaphragms: Nails Spaced 6" max. at Supported Edges[b]: Case 1 (No unblocked edges or continuous joints parallel to load)	All other configurations (Cases 2, 3, 4, 5 & 6)
APA STRUCTURAL I grades	6d[e]	1-1/4	5/16	2 3	185 210	250 280	375 420	420 475	165 185	125 140
	8d	1-1/2	3/8	2 3	270 300	360 400	530 600	600 675	240 265	180 200
	10d[d]	1-5/8	15/32	2 3	320 360	425 480	640 720	730 820	285 320	215 240
APA RATED SHEATHING, APA RATED STURD-I-FLOOR	6d[e]	1-1/4	5/16	2 3	170 190	225 250	335 380	380 430	150 170	110 125
			3/8	2 3	185 210	250 280	375 420	420 475	165 185	125 140
			3/8	2 3	240 270	320 360	480 540	545 610	215 240	160 180
	8d	1-1/2	7/16	2	255	340	505	575	230	170

(a) For framing of other species: (1) Find specific gravity for species of lumber in AFPA National Design Specification. (2) Find shear value from table above for nail si[illegible] for Structural I panels (regardless of a[illegible]ual grade). (3) Multiply value by [illegible] for species with specific gravity of [illegible] or greater, or 0.65 for all other sp[illegible]cies..

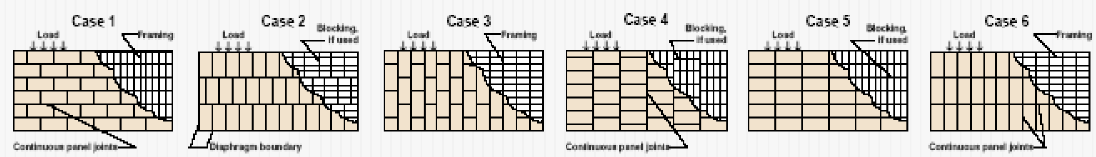
(b) Space nails maximum 12 in. o.c. along intermediate framing members (6 in. o.c. when supports are spaced 48 in. o.c.).

(c) Framing at adjoining panel edges shall be 3-in. nominal or wider, and nails shall be staggered where nails are spaced 2 inches o.c. or 2-1/2 inches o.c.

(d) Framing at adjoining panel edges shall be 3-in. nominal or wider, and nails shall be staggered where 10d nails having penetration into framing of more than 1-5/8 [illegible]es are spaced 3 inches o.c.

(e) 8d is recomme[illegible]d minimum for roofs due to negat[illegible] pressures of high winds.

Notes: Design for diaphragm stresses depends on direction of continuous panel joints with reference to load, not on direction of long dimension of sheet. Continuous framing may be in either direction for blocked diaphragms.



Wood Structure LFRS Design Methods: Engineered

Shear Wall Design Tables

- **Partial reprint of engineered wood structural panel diaphragm info in 2003 IBC Table 2306.4.1.**
- **Tables are for DFL or SYP – need to adjust values if framing with wood species with lower specific gravities.**
- **Major divisions: Structural 1 vs. Rated Sheathing and Panels Applied Directly to Framing vs. Panels Applied Over Gypsum Wallboard.**
- **NO UNBLOCKED edges allowed.**

RECOMMENDED SHEAR (POUNDS PER FOOT) FOR APA PANEL SHEAR WALLS WITH FRAMING OF DOUGLAS-FIR, LARCH, OR SOUTHERN PINE[(a)] FOR WIND OR SEISMIC LOADING[(b)]

Panel Grade	Minimum Nominal Panel Thickness (in.)	Minimum Nail Penetration in Framing (in.)	Panels Applied Direct to Framing: Nail Size (common or galvanized box)	Nail Spacing at Panel Edges (in.): 6	4	3	2[(e)]	Panels Applied Over 1/2" or 5/8" Gypsum Sheathing: Nail Size (common or galvanized box)	Nail Spacing at Panel Edges (in.): 6	4	3	2[(e)]
APA STRUCTURAL I grades	5/16	1-1/4	6d	200	300	390	510	8d	200	300	390	510
	3/8	1-1/2	8d	230[(d)]	360[(d)]	460[(d)]	610[(d)]	10d[(f)]	280	430	550	730
	7/16			255[(d)]	395[(d)]	505[(d)]	670[(d)]					
	15/32			280	430	550	730					
	15/32	1-5/8	10d[(f)]	340	510	665	870	—	—	—	—	—
APA RATED SHEATHING; APA RATED SIDING[(g)] and other APA grades except species Group 5	5/16 or 1/4[(c)]	1-1/4	6d	180	270	350	450	8d	180	270	350	450
	3/8			200	300	390	510		200	300	390	510
	3/8	1-1/2	8d	220[(d)]	320[(d)]	410[(d)]	530[(d)]	10d[(f)]	260	380	490	640
	7/16			240[(d)]	350[(d)]	450[(d)]	585[(d)]					
	15/32			260	380	490	640					
	15/32	1-5/8	10d[(f)]	310	460	600	770	—	—	—	—	—
	19/32			340	510	665	870	—	—	—	—	—
APA RATED SIDING 303[(g)] and other APA grades except species Group 5			Nail Size (galvanized casing)					Nail Size (galvanized casing)				
	5/16[(c)]	1-1/4	6d	140	210	275	360	8d	140	210	275	360
	3/8	1-1/2	8d	160	240	310	410	10d[(f)]	160	240	310	410

(a) For framing of other species: (1) Find specific gravity for species of lumber in the AFPA National Design Specification. (2)(a) For common or galvanized box nails, find shear value from table above for nail size for STRUCTURAL I panels (regardless of actual grade). (b) For galvanized casing nails, take shear value directly from table above. (3) Multiply this value by 0.82 for species with specific gravity of 0.42 or greater, or 0.65 for all other species.

(b) All panel edges backed with 2-inch nominal or wider framing. Install panels either horizontally or vertically. Space nails maximum 6 inches o.c. along intermediate framing members for 3/8-inch and 7/16-inch panels installed on studs spaced 24 inches o.c. For other conditions and panel thicknesses, space nails maximum 12 inches o.c. on intermediate supports.

(c) 3/8-inch or APA RATED SIDING 16 oc is minimum recommended when applied direct to framing as exterior siding.

(d) Shears may be increased to values shown for 15/32-inch sheathing with same nailing provided (1) studs are spaced a maximum of 16 inches o.c., or (2) if panels are applied with long dimension across studs.

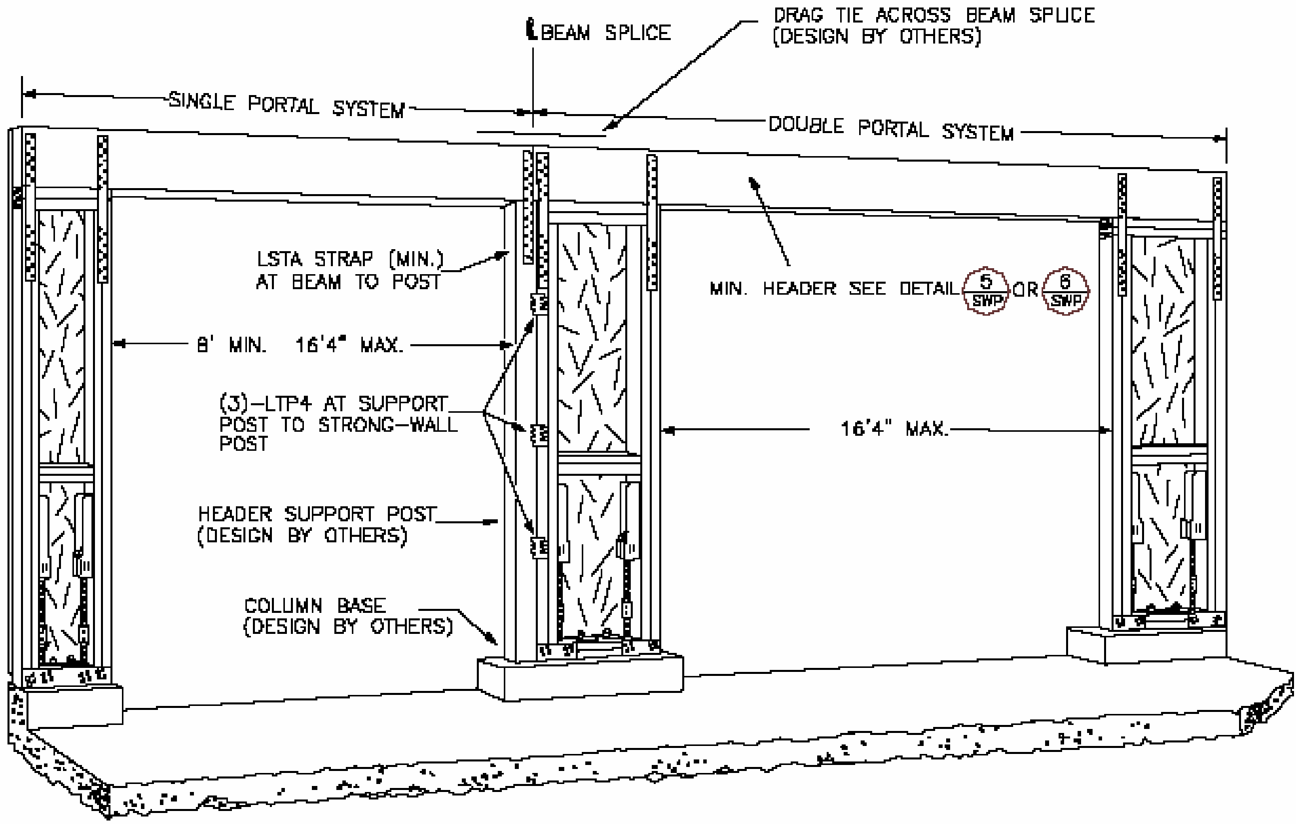
(e) Framing at adjoining panel edges shall be 3-inch nominal or wider, and nails shall be staggered where nails are spaced 2 inches o.c.

(f) Framing at adjoining panel edges shall be 3-inch nominal or wider, and nails shall be staggered where 10d nails having penetration into framing of more than 1-5/8 inches are spaced 3 inches o.c.

(g) Values apply to all-veneer plywood APA RATED SIDING panels only. Other APA RATED SIDING panels may also qualify on a proprietary basis. APA RATED SIDING 16 oc plywood may be 11/32 inch, 3/8 inch or thicker. Thickness at point of nailing on panel edges governs shear values.

Wood Structure LFRS Design Methods: Engineered

Proprietary Moment Frames



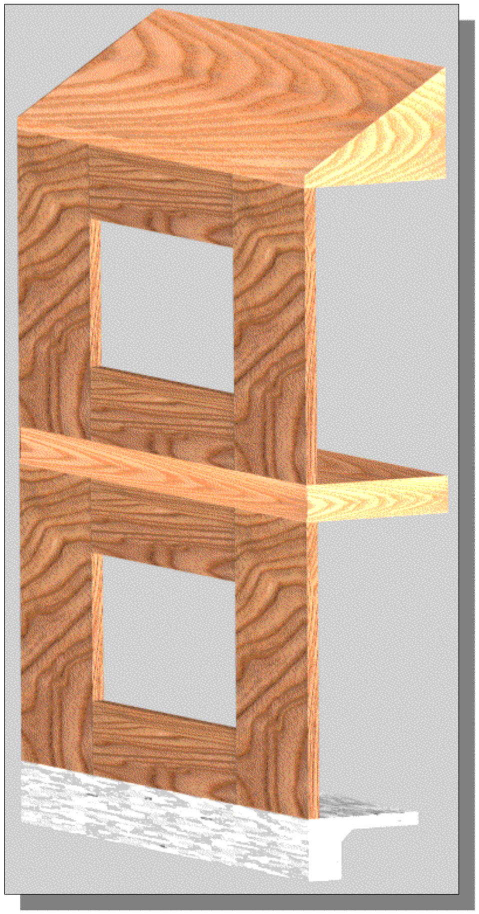
SINGLE & DOUBLE PORTAL ASSEMBLY

- **Traditional vertical diaphragm shear walls less effective at high aspect ratios.**
- **Prefabricated proprietary code-approved solutions available.**

Wood Structure LFRS Design Methods: Engineered

Complete Load Path

- Earthquakes move the foundations of a structure.
- If the structure doesn't keep up with the movements of the foundations, failure will occur.
- Keeping a structure on its foundations requires a complete load path from the foundation to all mass in a structure.
- Load path issues in wood structures can be complex.
- For practical engineering, the load path is somewhat simplified for a "good enough for design" philosophy.

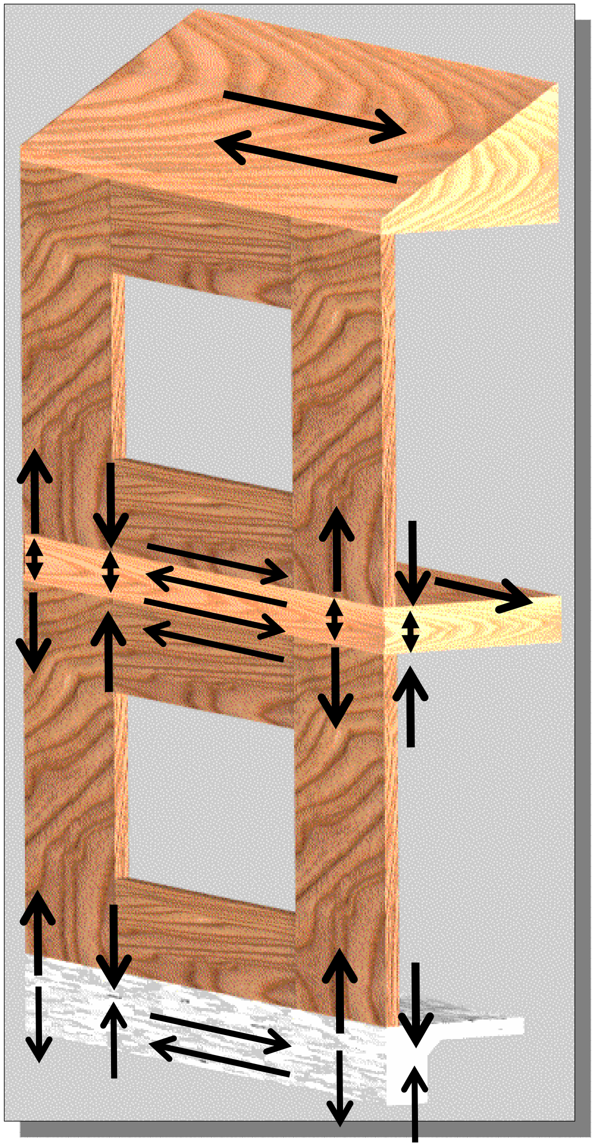


Wood Structure LFRS Design Methods: Engineered

Complete Load Path

- Diaphragm to shear wall

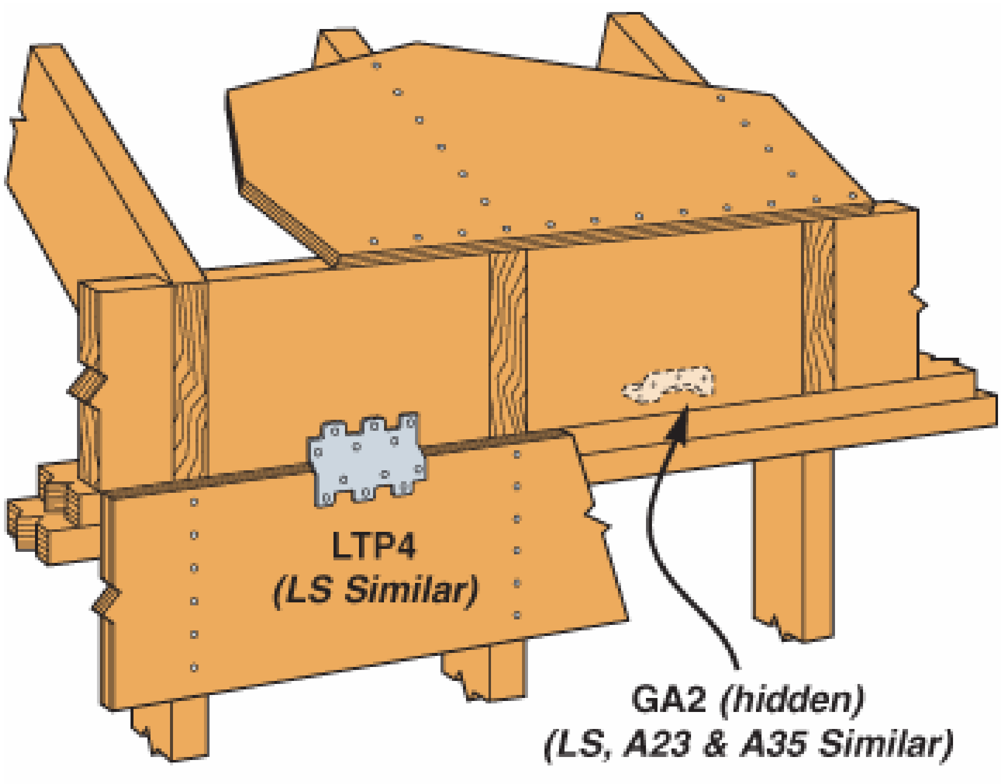
- Shear wall overturning
- Diaphragm to shear wall
- Overturning tension/compression through floor
- Shear transfer through floor
- Overturning tension/compression to foundation
- Shear transfer to foundation

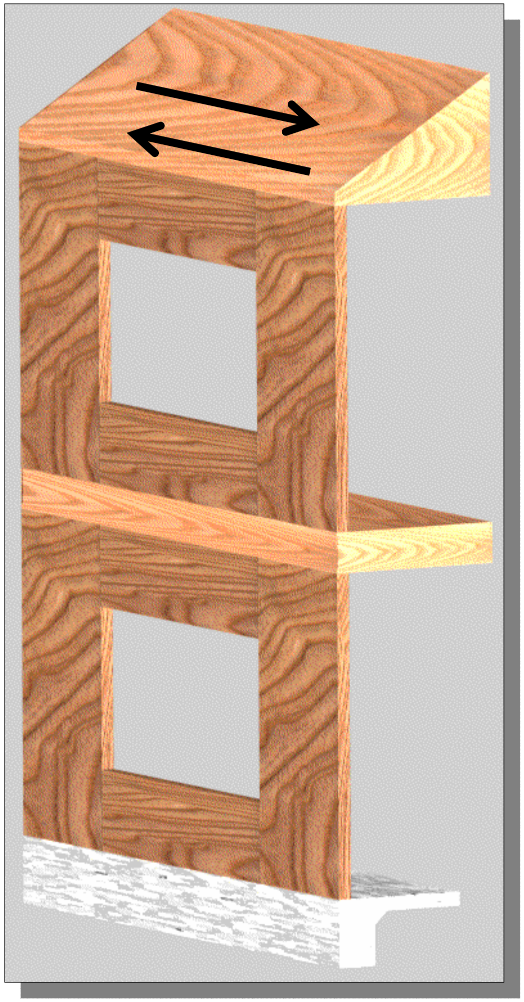


Wood Structure LFRS Design Methods: Engineered

Complete Load Path

- Diaphragm to shear wall



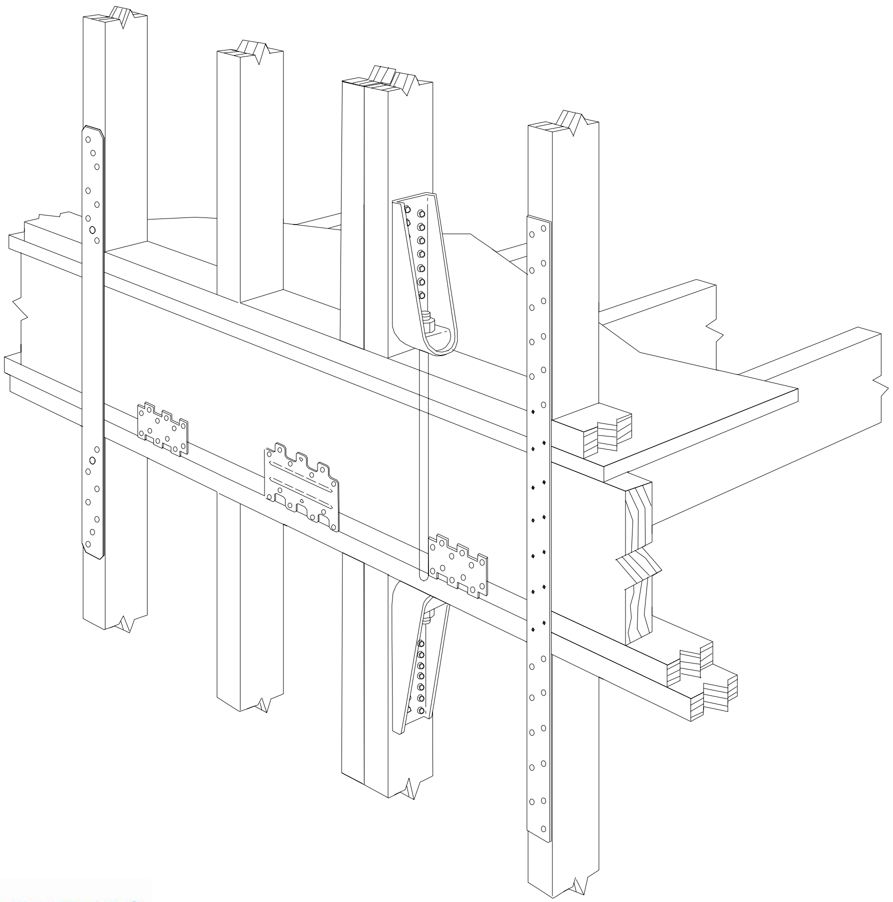


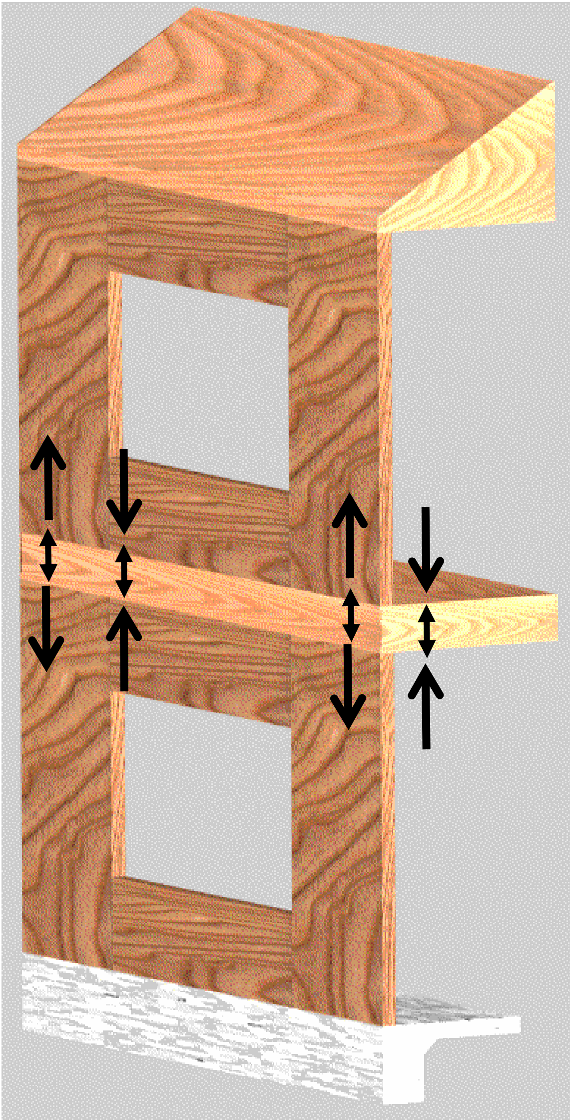
Toe nails: 2003 IBC 2305.1.4 150 plf limit in SDCs D-F.

Wood Structure LFRS Design Methods: Engineered

Complete Load Path

- Shear wall overturning / transfer of vertical forces through floor

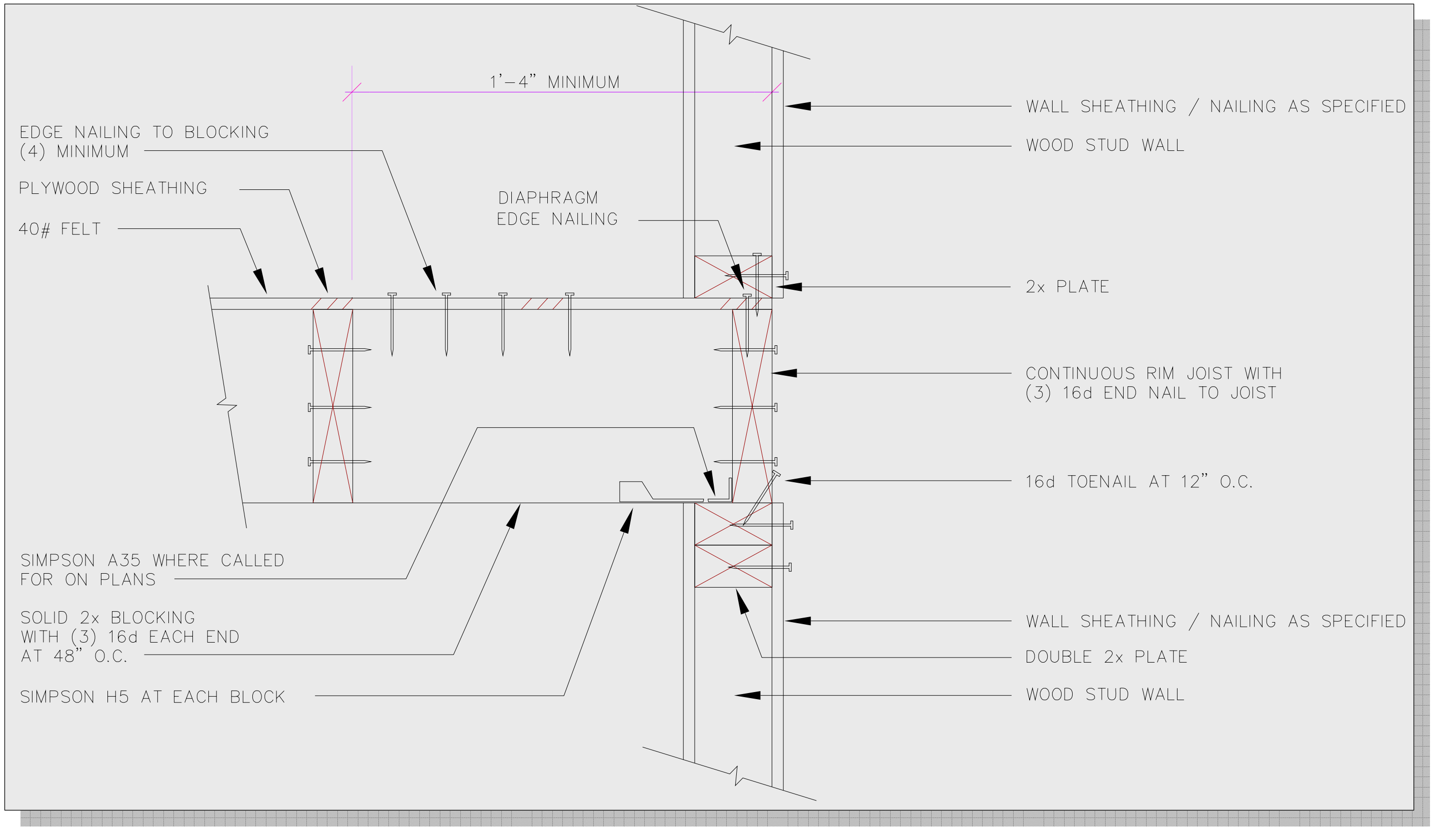


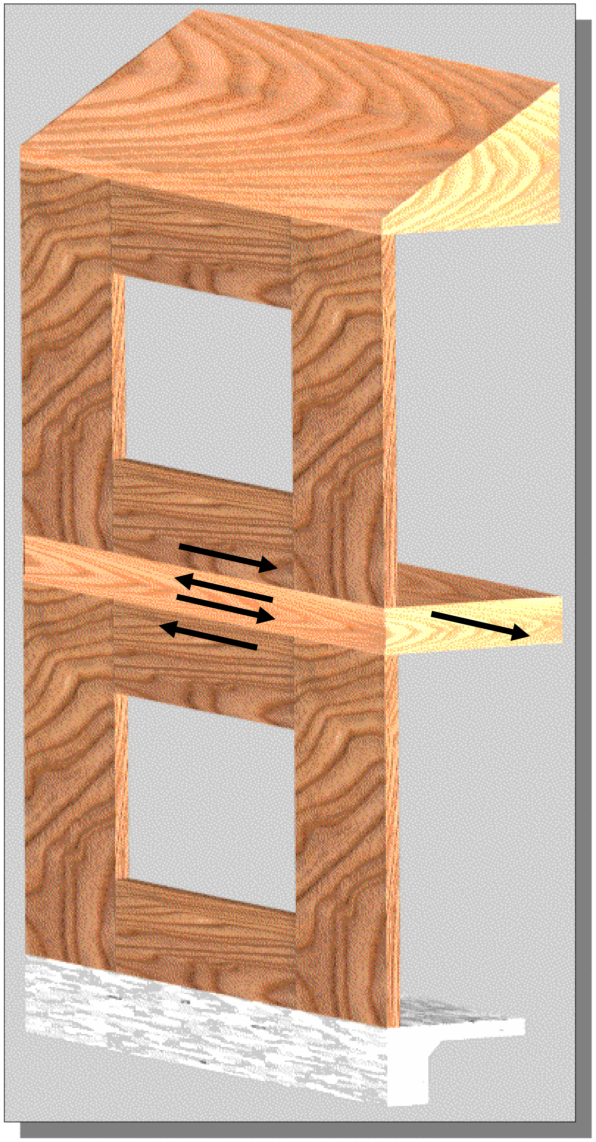


Wood Structure LFRS Design Methods: Engineered

Complete Load Path

- Diaphragm to shear wall / shear transfer through floor

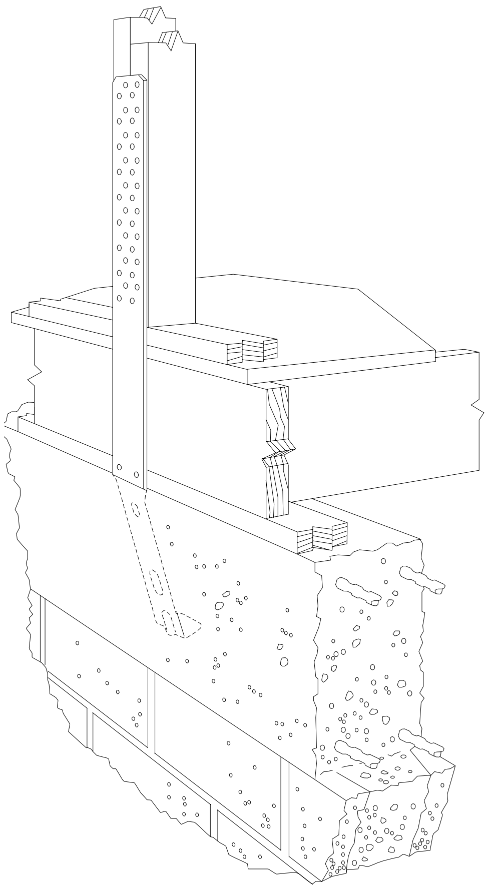


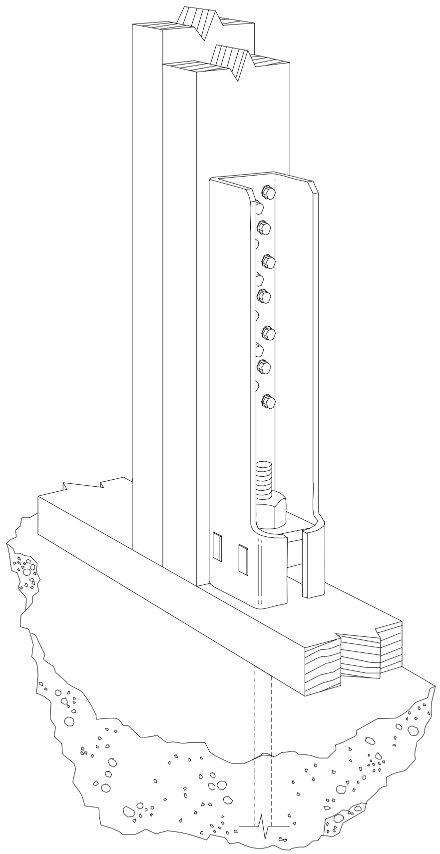


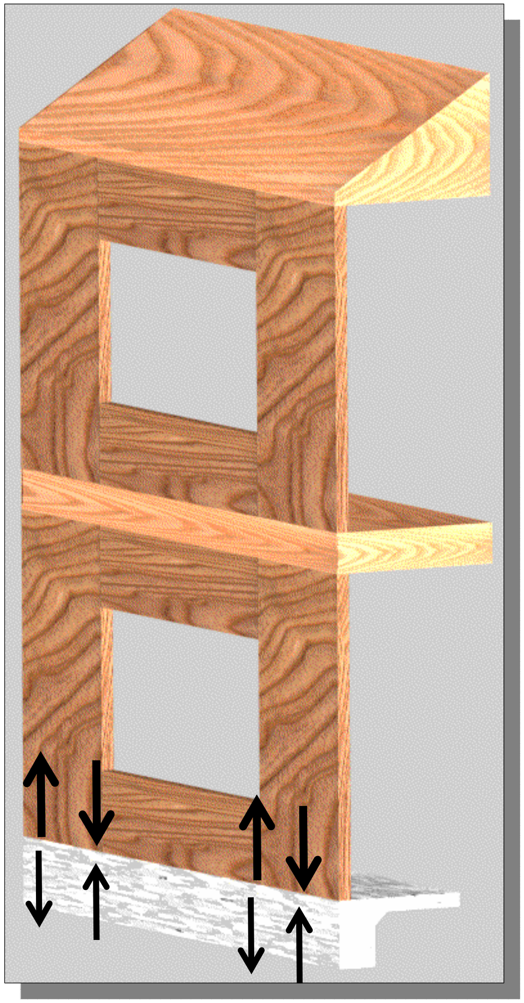
Wood Structure LFRS Design Methods: Engineered

Complete Load Path

- Overturning tension/compression to foundation



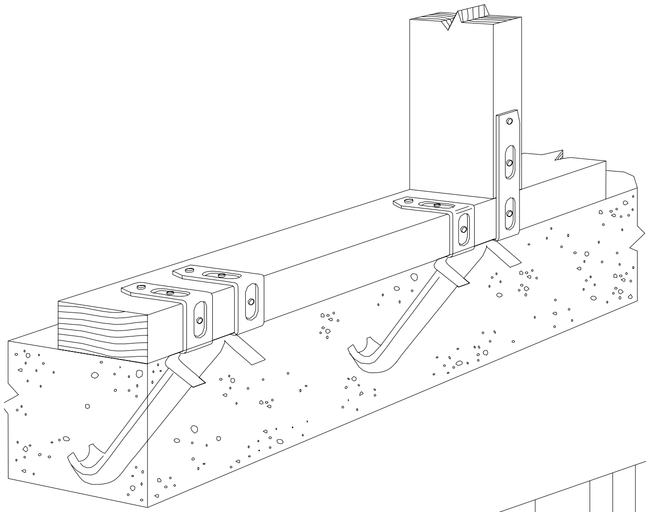


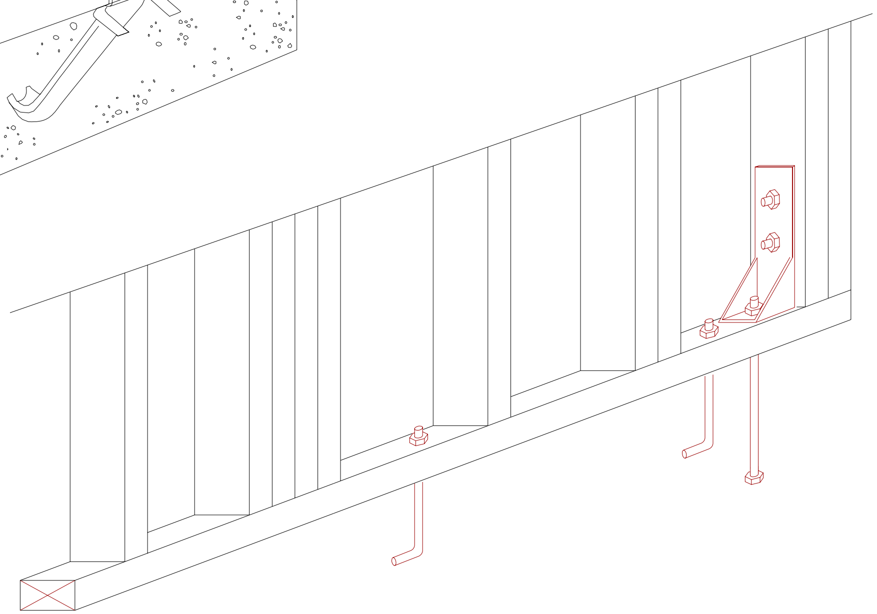


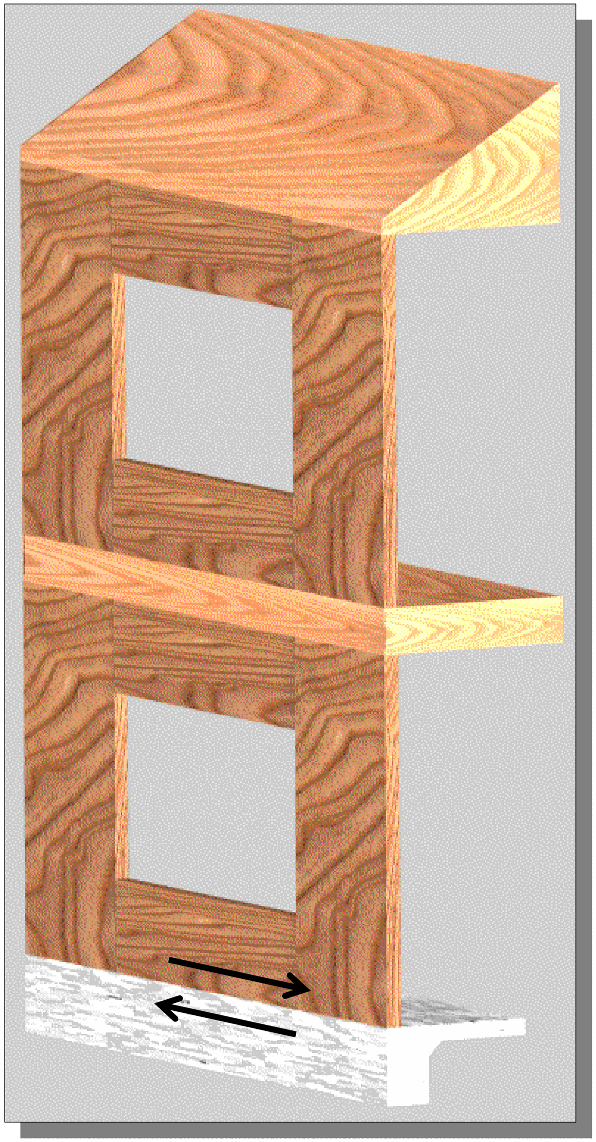
Wood Structure LFRS Design Methods: Engineered

Complete Load Path

- Shear transfer to foundation







Wood Structure LFRS Design Methods: Prescriptive

- Also referred to as "*Conventional Construction*" or "*Deemed to Comply*"

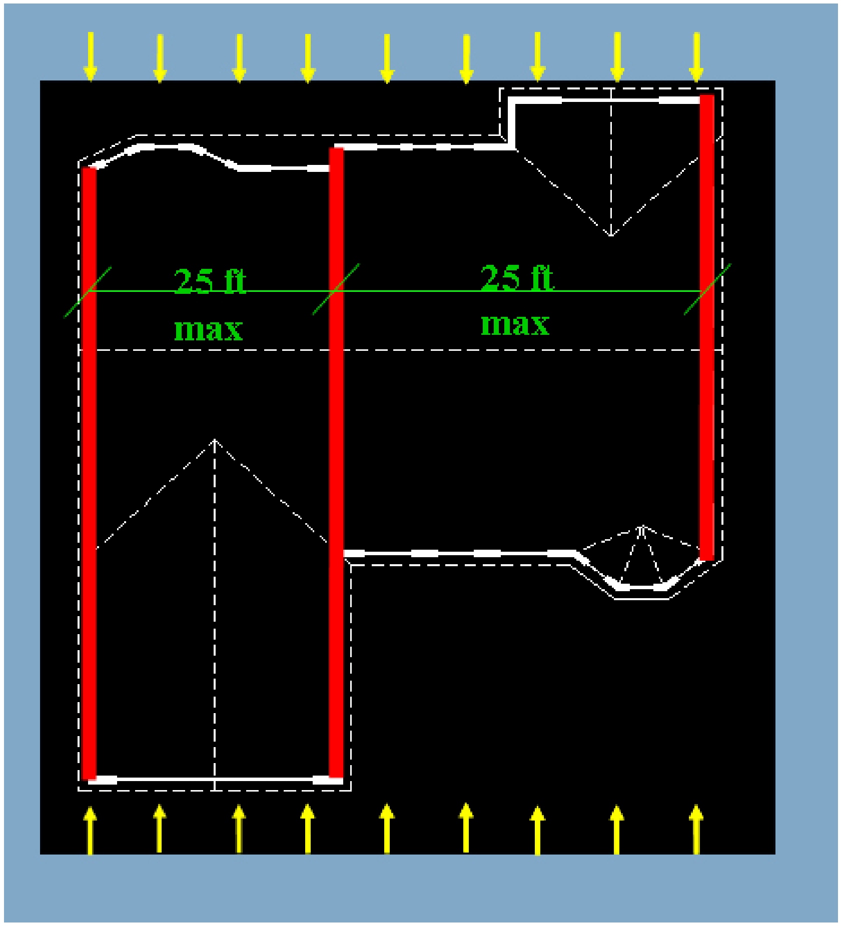
- Traditionally, many simple wood structures have been designed without "engineering."
- Over time, rules of how to build have been developed, most recently in the 2003 International Residential Code (IRC).
- For the lateral system, the "dedicated" vertical element is referred to as a *braced wall panel*, which is part of a *braced wall line.*
- Based on SDC and number of stories, rules dictate the permissible spacing between braced wall lines, and the spacing of braced wall panels within braced wall lines.

Wood Structure LFRS Design Methods: Prescriptive

- While rules exist for the "dedicated" elements, testing and subsequent analysis has show these structures do not "calc out" based on just the strength of braced wall panels.
- In reality, the strength, stiffness, and energy dissipation afforded by the "nonstructural" elements (interior and exterior sheathing) equal or exceed the braced wall panels in their contribution to achieving "life safety" performance in these structures.
- Load path not explicitly detailed.

Wood Structure LFRS Design Methods: Prescriptive

(Seismic Design Category D1 or D2 and/or Wind Speeds < 110 mph)

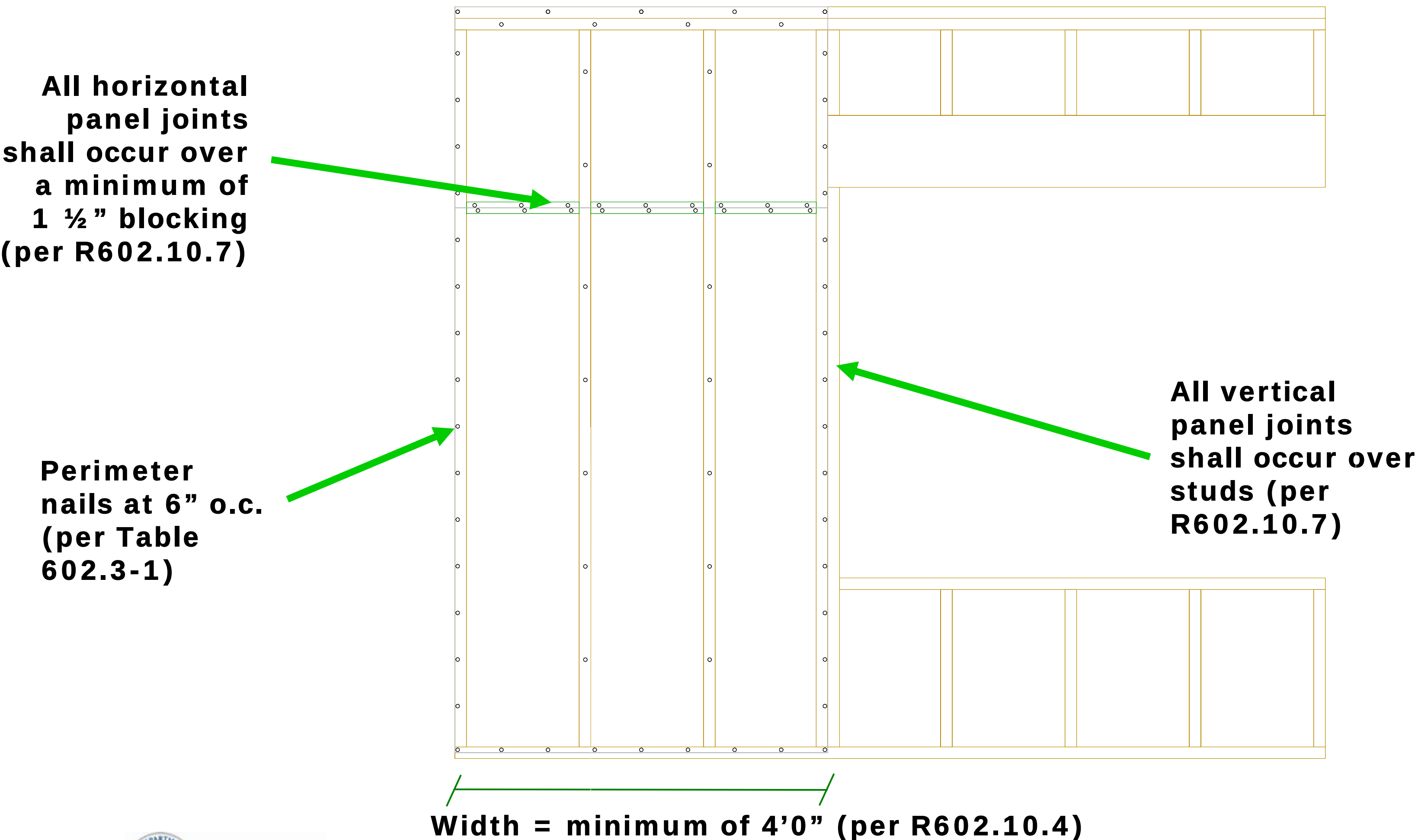


- **Example 2003 IRC Spacing Requirements for *Braced Wall Lines***

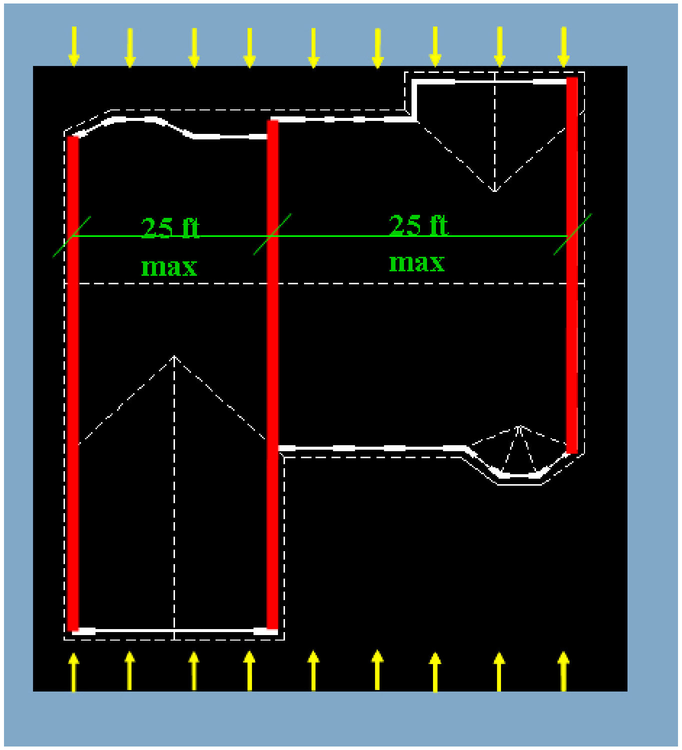
Wood Structure LFRS Design Methods: Prescriptive

- **Example of *Braced Wall Panel* construction (2003 IRC references)**

(R602.10.3 #3)



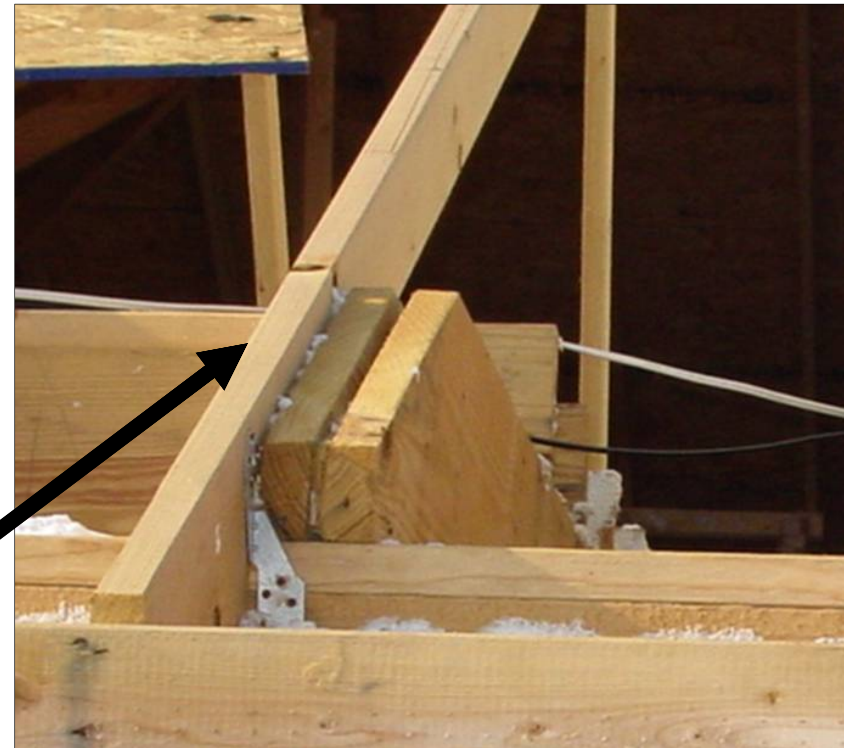
Wood Structure LFRS Design Methods: Prescriptive



- Prescriptive provisions in the 2003 IRC are more liberal than in the 2003 NEHRP *Provisions.*

- The NEHRP Provisions and Commentary can be downloaded from http://www.bssconline.org/. Also available from FEMA and at the BSSC website is FEMA 232, an up to date version of the *Homebuilders' Guide to Earthquake-Resistant Design and Construction*.

Expected Response Under Lateral Load: Wind



- **Unlike seismic *design* loads, wind *design* loads are representative of the real expected magnitude.**
- **When built properly, structural damage should be low.**
- **Missile or wind born projectile damage can increase damage (this could potentially breach openings and create internal pressures not part of the design).**

Expected Response Under Lateral Load: Seismic

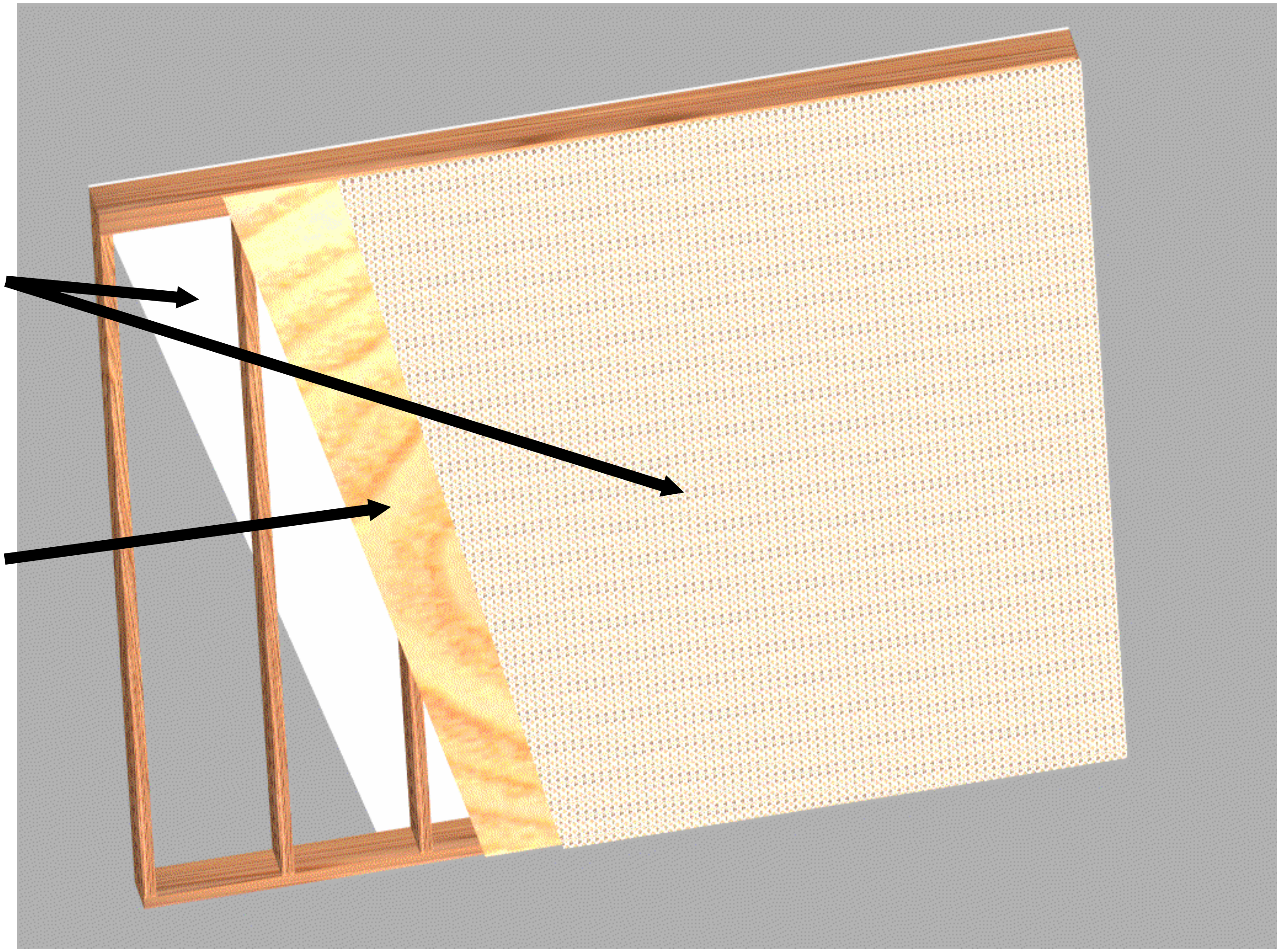
5.3 Daly City, CA March 22, 1957

7.0 Imperial Valley, CA Oct 15, 1957

- **Engineered wood structures are thought of as having good flexibility/ductility, but can also be quite brittle.**
- **Wood structures can be engineered with either "ductile" nailed wood structural panel shear walls or "brittle" gypsum board and/or stucco shear walls as their primary LFRS.**
- **2003 IBC *R* factors: Wood – 6.5; All Others – 2.0.**

Sources of Strength for Seismic Lateral Resistance

- **<u>Rough</u> estimates for *engineered single family home***

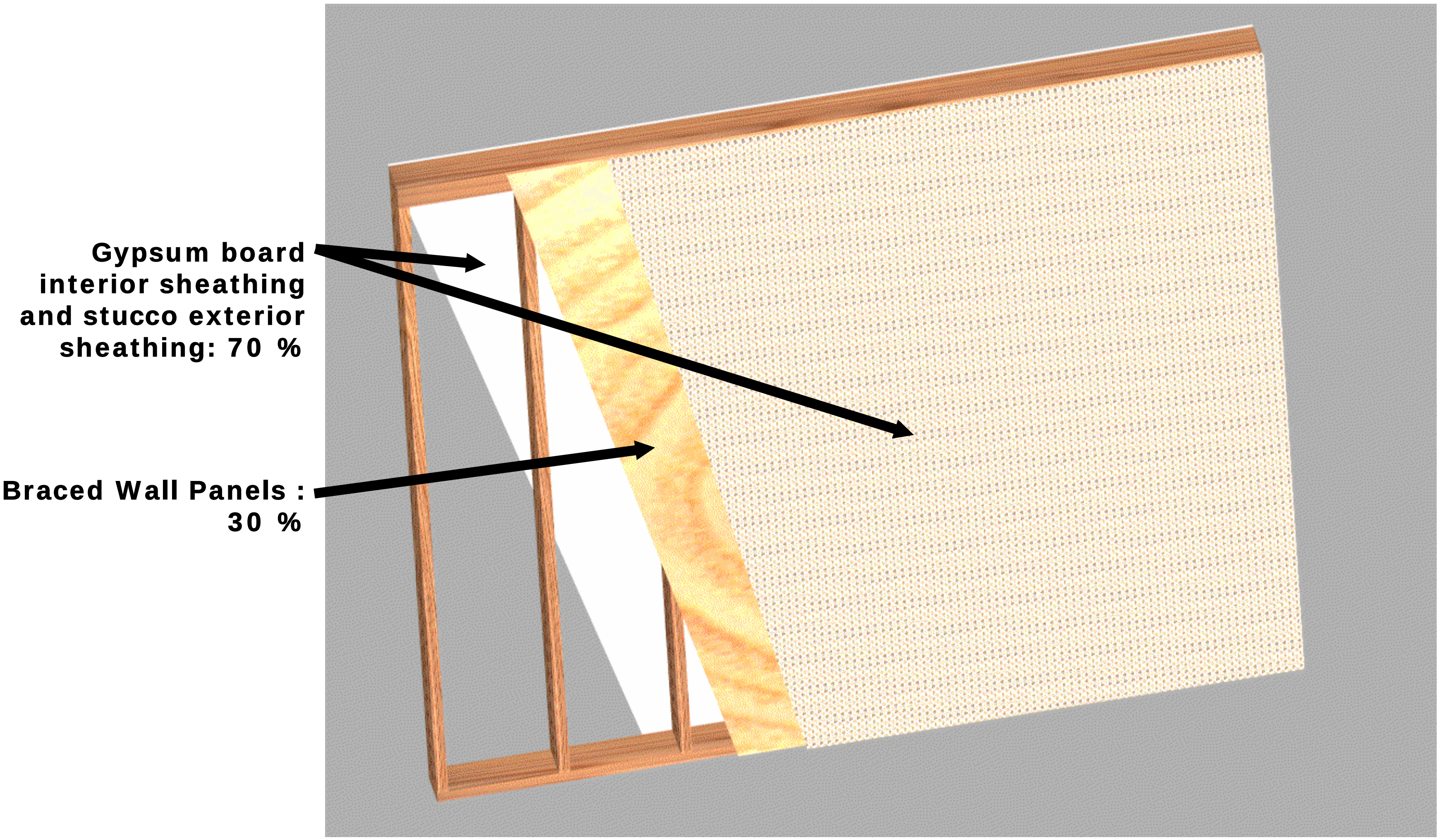


Gypsum board interior sheathing and stucco exterior sheathing: 50 %

Nailed wood structural panel shear walls : 50 %

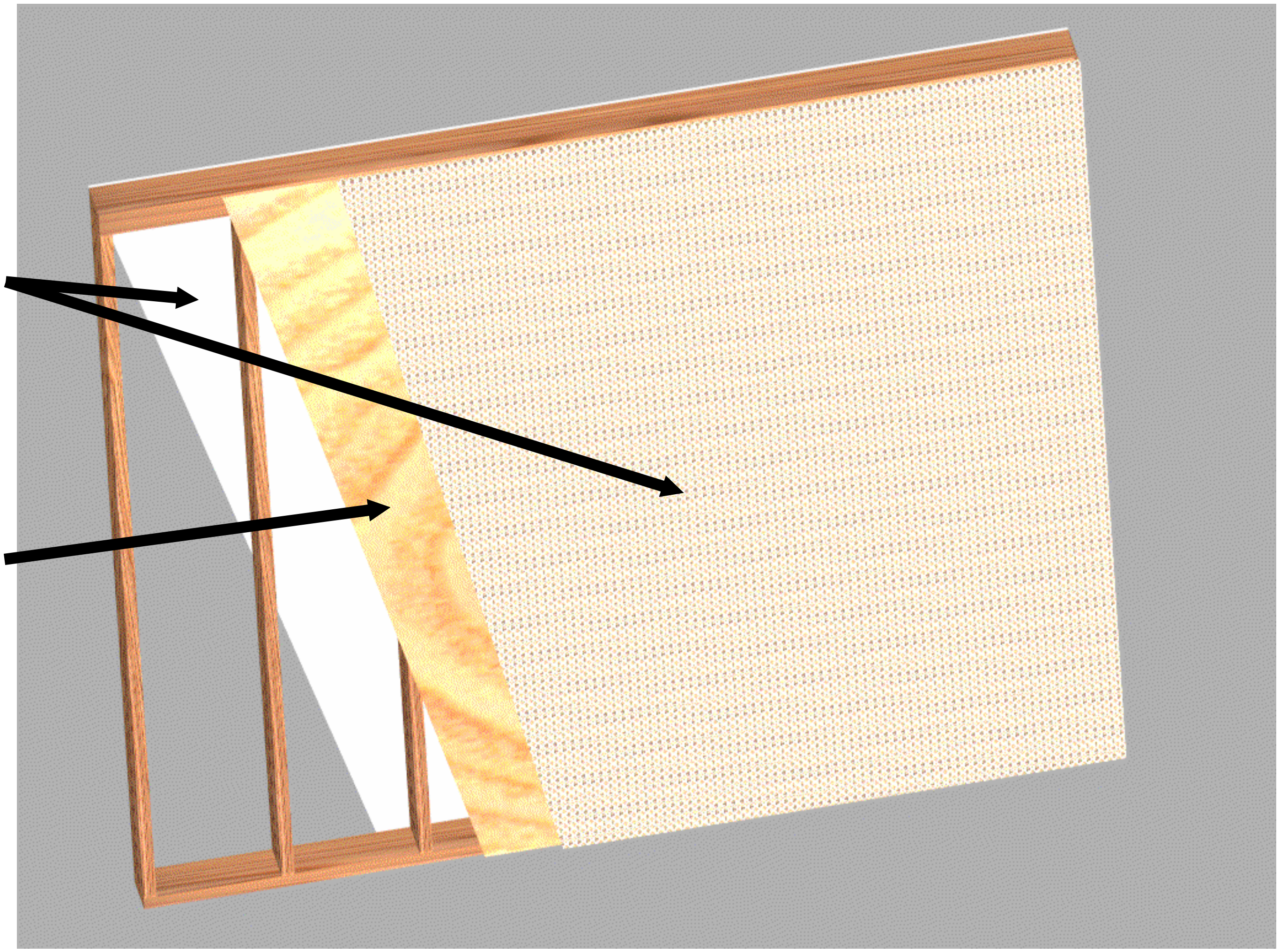
Sources of Strength for Seismic Lateral Resistance

- **<u>Rough</u> estimates for *prescriptive single family home***



Sources of Strength for Seismic Lateral Resistance

- **<u>Rough</u>** **estimates for *engineered light commercial* structures**



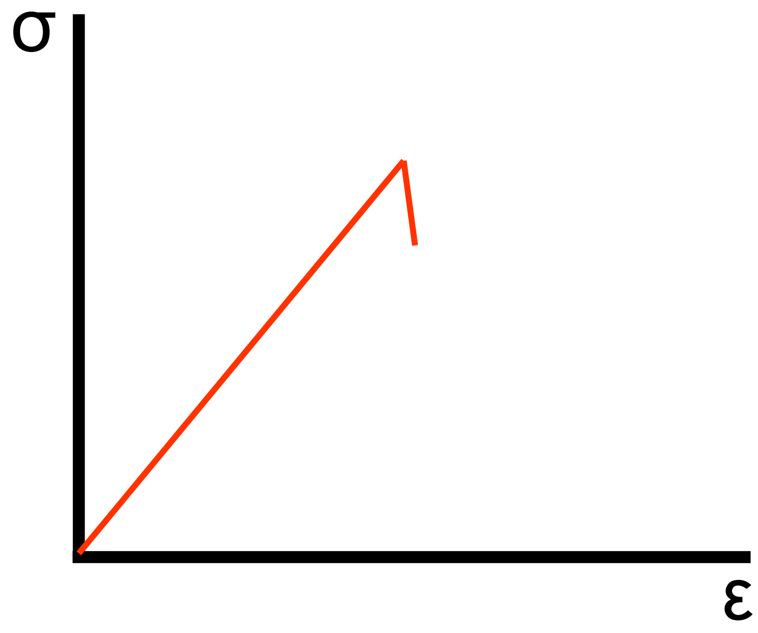
Gypsum board interior sheathing and stucco exterior sheathing: 30 %

Nailed wood structural panel shear walls : 70 %

Sources of Ductility and Energy Dissipation in Wood Structures

Stress in the wood

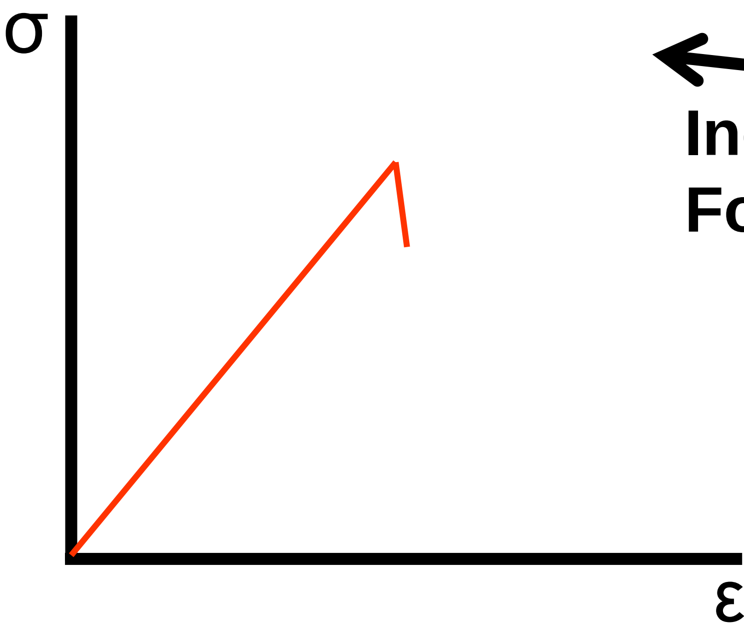
- **Tension parallel to the grain: not ductile, low energy dissipation**

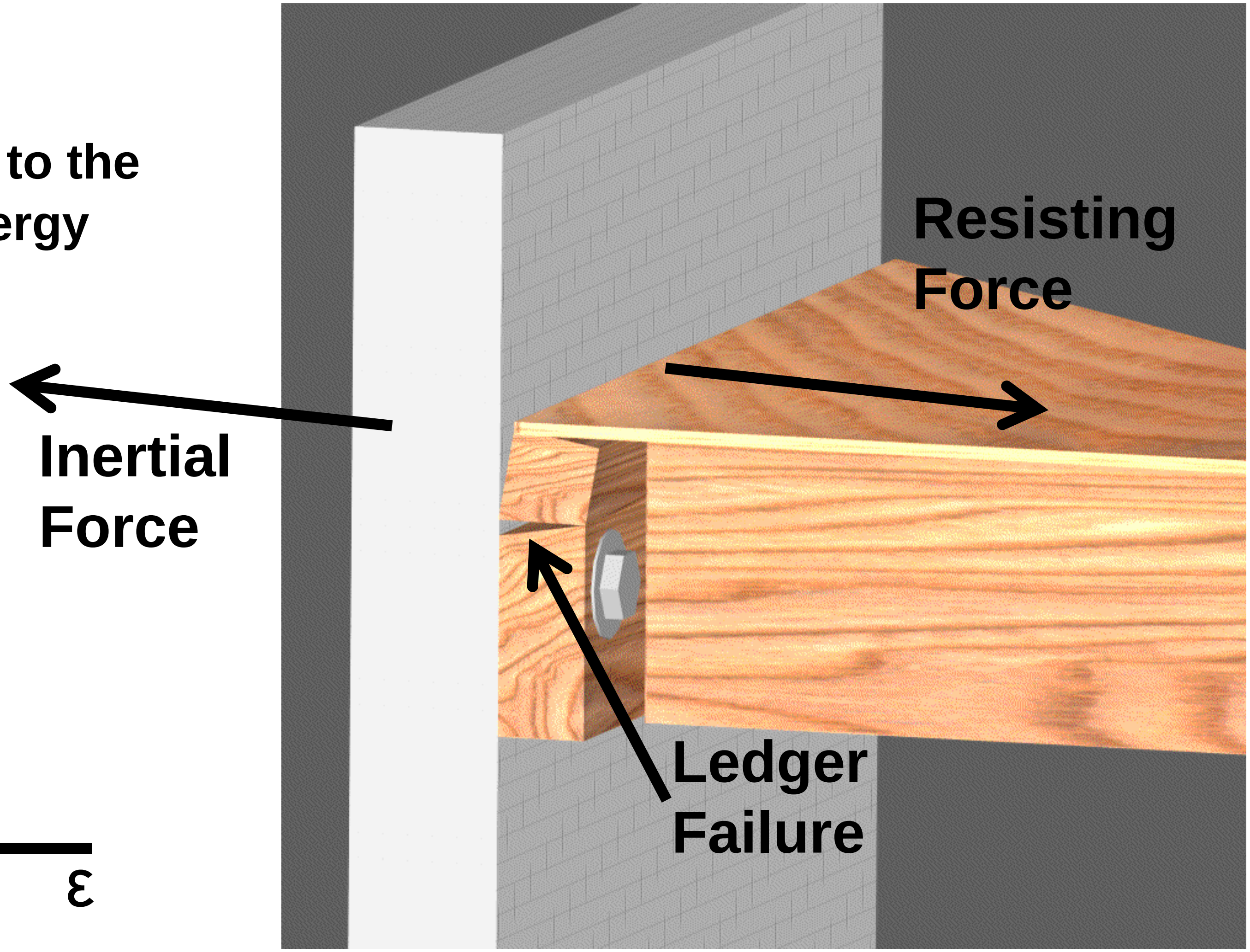


Sources of Ductility and Energy Dissipation in Wood Structures

Stress in the wood

- **Tension perpendicular to the grain: not ductile, low energy dissipation**

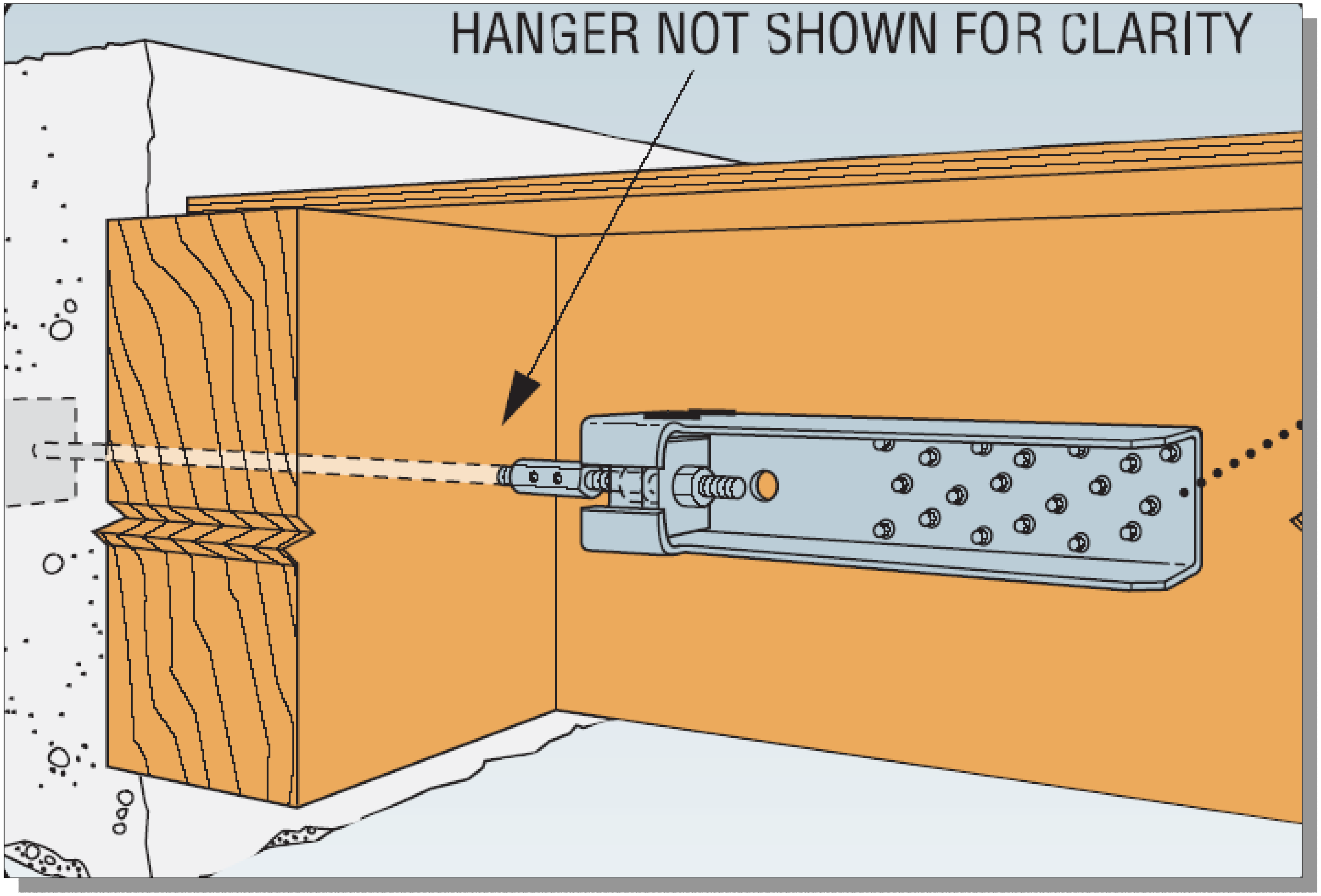




- **Need to have positive wall ties to perpendicular framing**

Sources of Ductility and Energy Dissipation in Wood Structures

Positive Wall Tie



Sources of Ductility and Energy Dissipation in Wood Structures

Stress in the wood

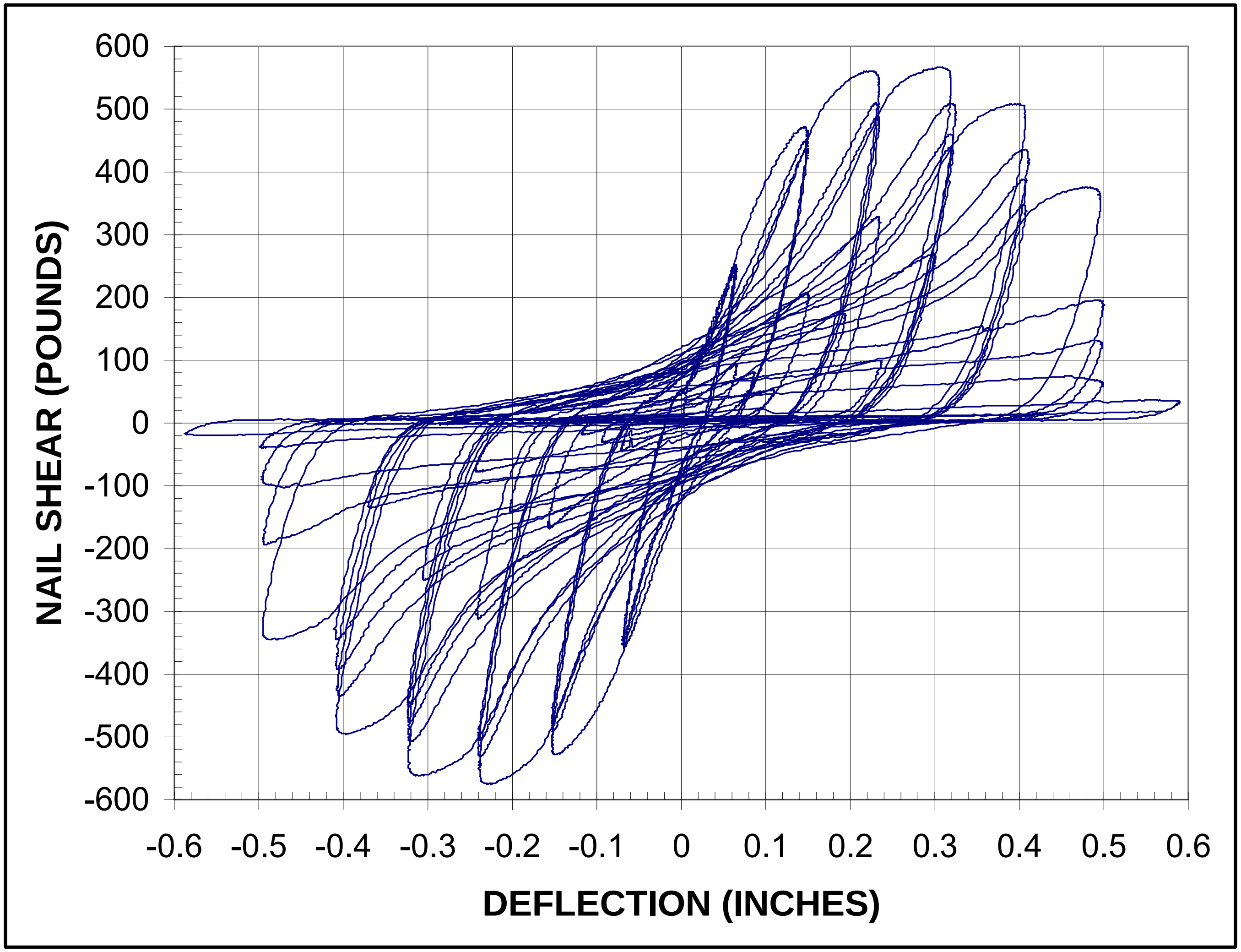
- Compression perpendicular to the grain: ductile, but not recoverable during and event – one way crushing similar to tension only braced frame behavior – ductile, but low energy dissipation
- Design allowable stress should produce ~0.04" permanent crushing

Sources of Ductility and Energy Dissipation in Wood Structures

Stress in the fastener

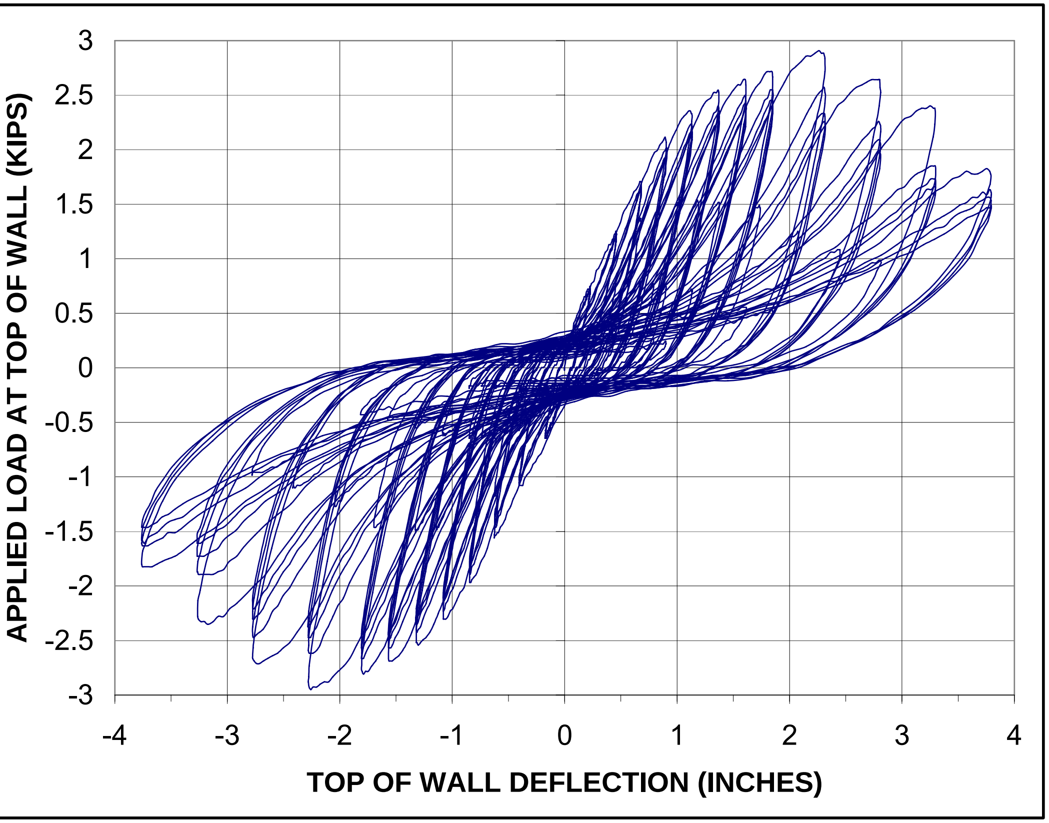
- Nailed joint between sheathing and framing is source of majority of ductility and energy dissipation for nailed wood structural panel shear walls.
- The energy dissipation is a combination of yielding in the shank of the nail, and crushing in the wood fibers surrounding the nail.
- Since wood crushing is nonrecoverable, this leads to a partial "pinching" effect in the hysteretic behavior of the joint.
- The pinching isn't 100% because of the strength of the nail shank undergoing reversed ductile bending yielding in the wood.
- As the joint cycles, joint resistance climbs above the pinching threshold when the nail "bottoms out" against the end of the previously crushed slot forming in the wood post.

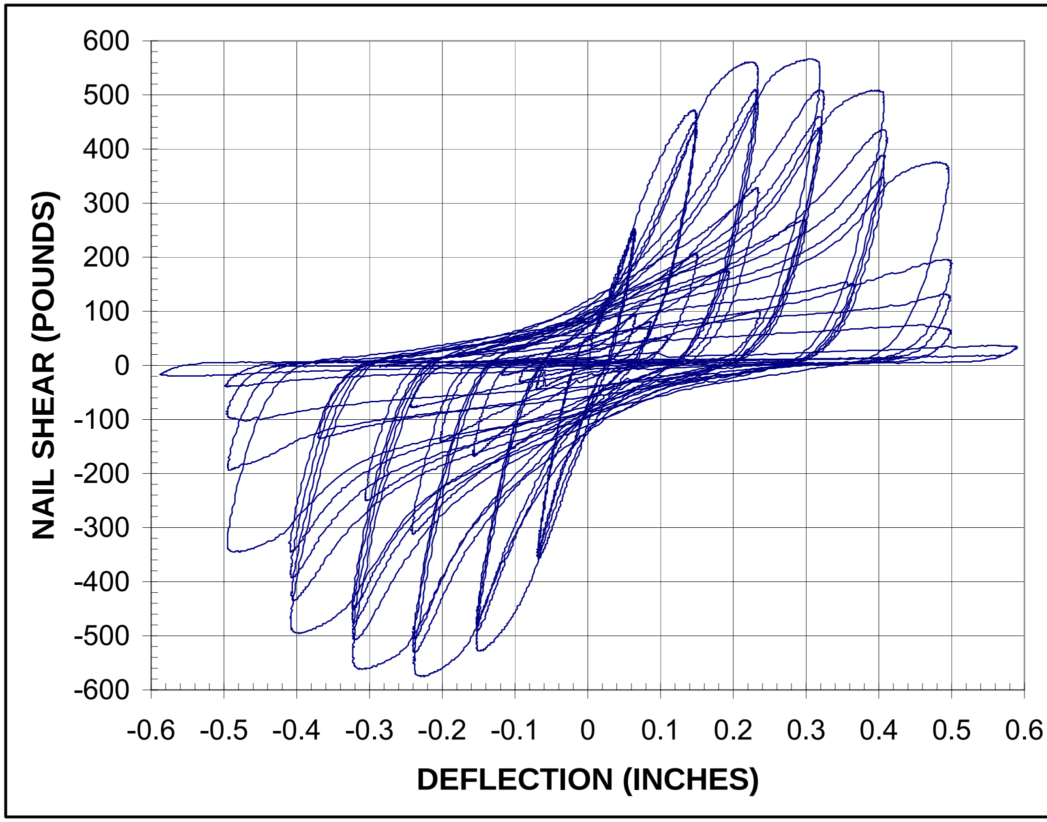
Sources of Ductility and Energy Dissipation in Wood Structures



Individual nail test

Sources of Ductility and Energy Dissipation in Wood Structures





Full-scale shear wall test

Individual nail test

Vertical Elements of the LFRS: Prescriptive

NEHRP Section 12.4

- Numerous geometry limitations
- Two types of braced wall panel construction: gypsum wall board and wood structural panel

IRC 2003 Methods

- Numerous geometry limitations
- Numerous types of braced wall panel construction: NEHRP methods + ~10 more

Vertical Elements of the LFRS: Engineered

NEHRP Methods

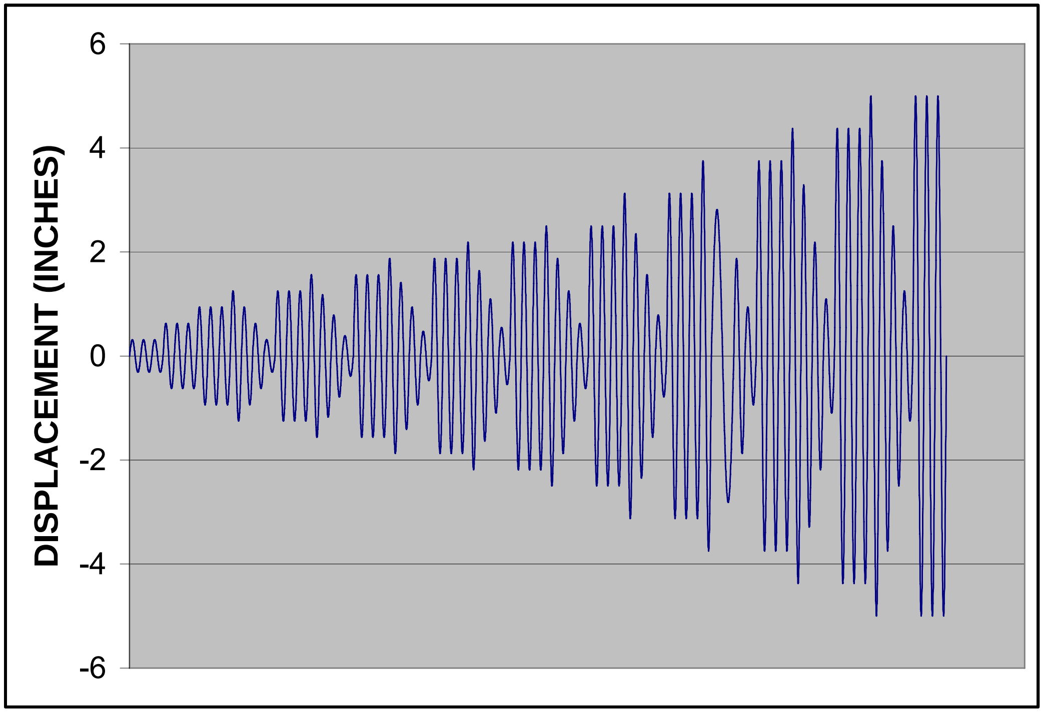
- Nailed/stapled wood structural panel
- Cold-formed steel with flat strap tension-only bracing
- Cold-formed steel with wood structural panel screwed to framing

IBC 2003 Methods

- Nailed wood structural panel shear walls
- Sheet steel shear walls
- Ordinary steel braced frames
- All others: gypsum and stucco
- Proprietary shear walls

Wall Performance Based on Testing

- First cyclic protocol to be adopted in the US for cyclic testing of wood shear walls.
- 62 *post yield* cycles.
- Found to demand too much energy dissipation compared with actual seismic demand.
- Can result in significant underestimation of peak capacity and displacement at peak capacity.



Cyclic Test Protocols TCCMAR (SPD)

Wall Performance Based on Testing

- Developed by researchers at Stanford University as part of the CUREE/Caltech Woodframe Project

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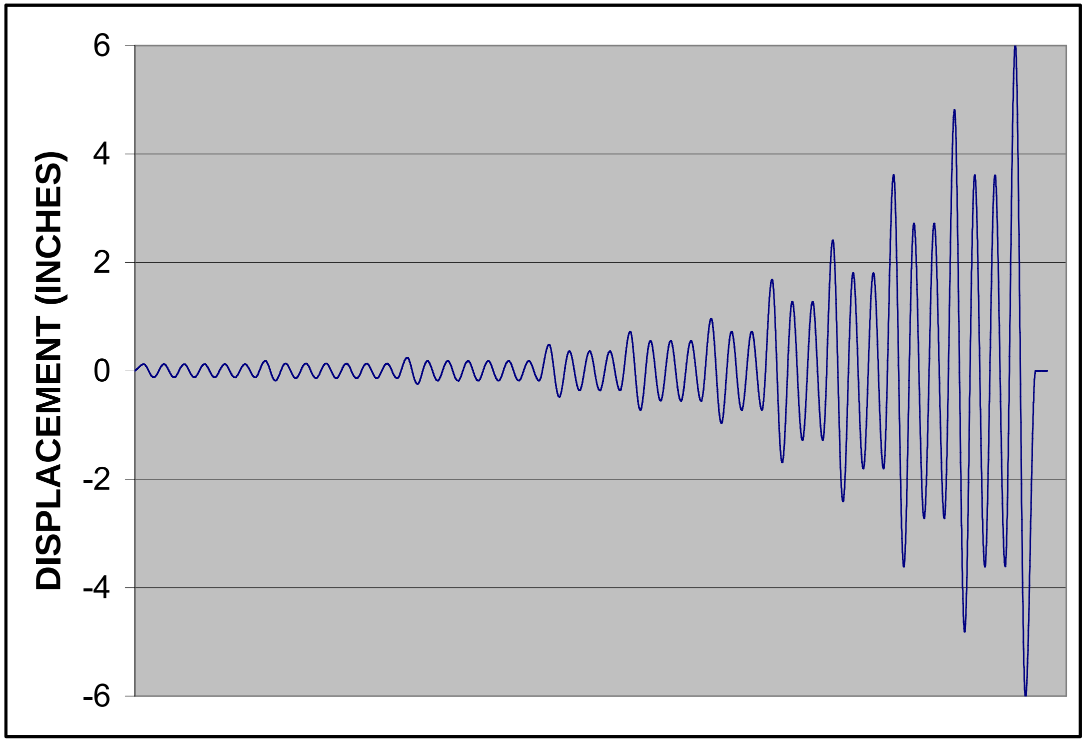
- Based on nonlinear time history analysis of wood structures considering small "non-design" vents preceding the "design event."
- Currently the "state-of-the-art" in cyclic test protocols.
- More realistically considers actual energy and displacement demands from earthquakes.



Cyclic Test Protocols -- CUREE

Code Basis of Design Values

Nailed Wood Structural Panel Shear Walls

- Values currently in the code were developed by the APA – The Engineered Wood Association (used to be the American Plywood Association) in the 1950s.
- These values are based on a principles of mechanics approach.
- Some monotonic testing was run to validate procedure.
- Testing was conducted on 8'x8' walls (1:1 aspect ratio), with very rigid overturning restraint.
- Test was more of a sheathing test, not shear wall system test.
- Extrapolation of use down to 4:1 aspect ratio panels proved problematic on 1994 Northridge earthquake.
- Code now contains provisions to reduce the design strength of walls with aspect ratios (AR's) > 2:1 by multiplying the base strength by a factor of 2 / AR.

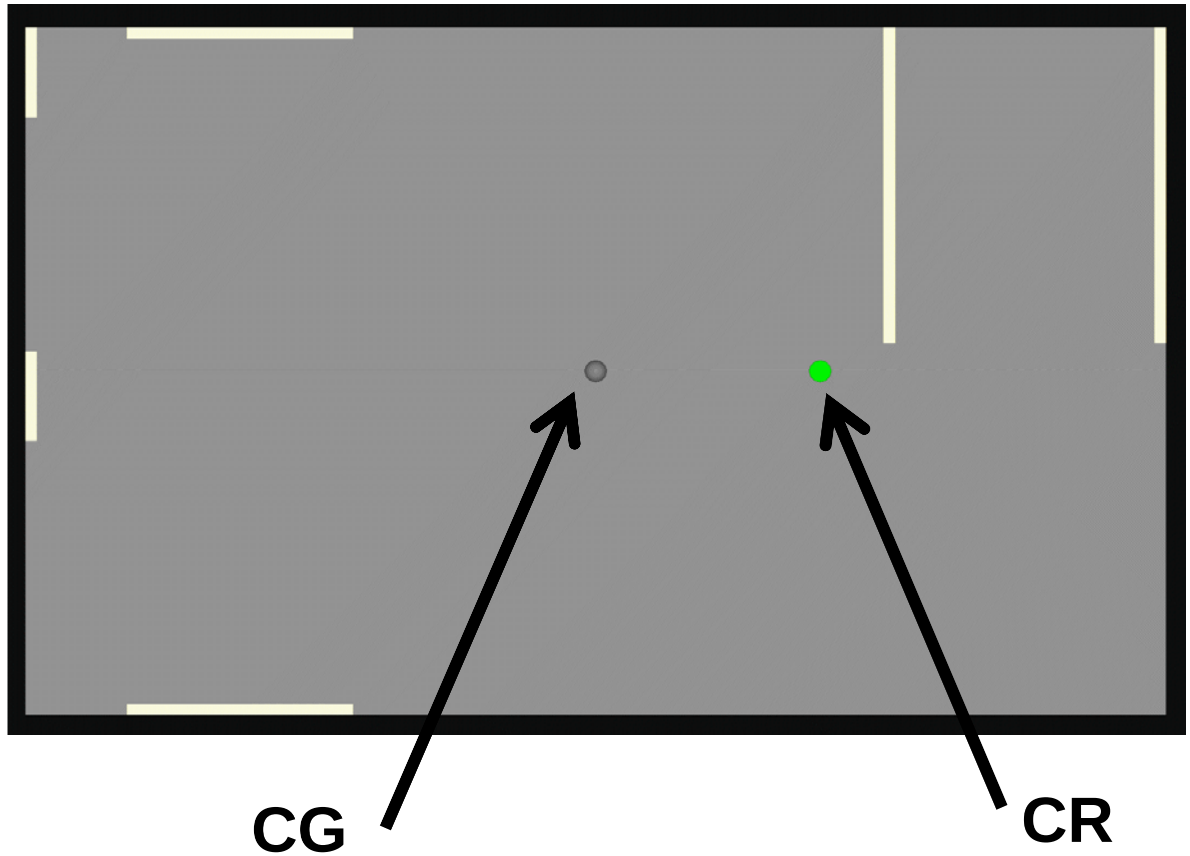
Code Basis of Design Values

Proprietary Wood Structural Panel Shear Walls:

- **Proprietary shear wall systems for light frame construction have been developed to provide higher useable strength when the AR exceeds 2:1.**
- **Values are determined according to Acceptance Criteria 130 (AC130) developed by the International Code Council Evaluation Services (ICC ES).**
- **AC130 requires full-scale cyclic testing of the wall seeking approval based on either SPD or CUREE protocols.**
- **Design rating based on either strength (ultimate / safety factor) or displacement (deflection which satisfies code deflection limits based on C_d, the deflection amplification factor associated with the rated *R* factor, and the appropriate maximum allowed inelastic drift ratio).**

Typical Woodframe Analysis Methods

- **Flexible diaphragm analysis**
- **Rigid diaphragm analysis**

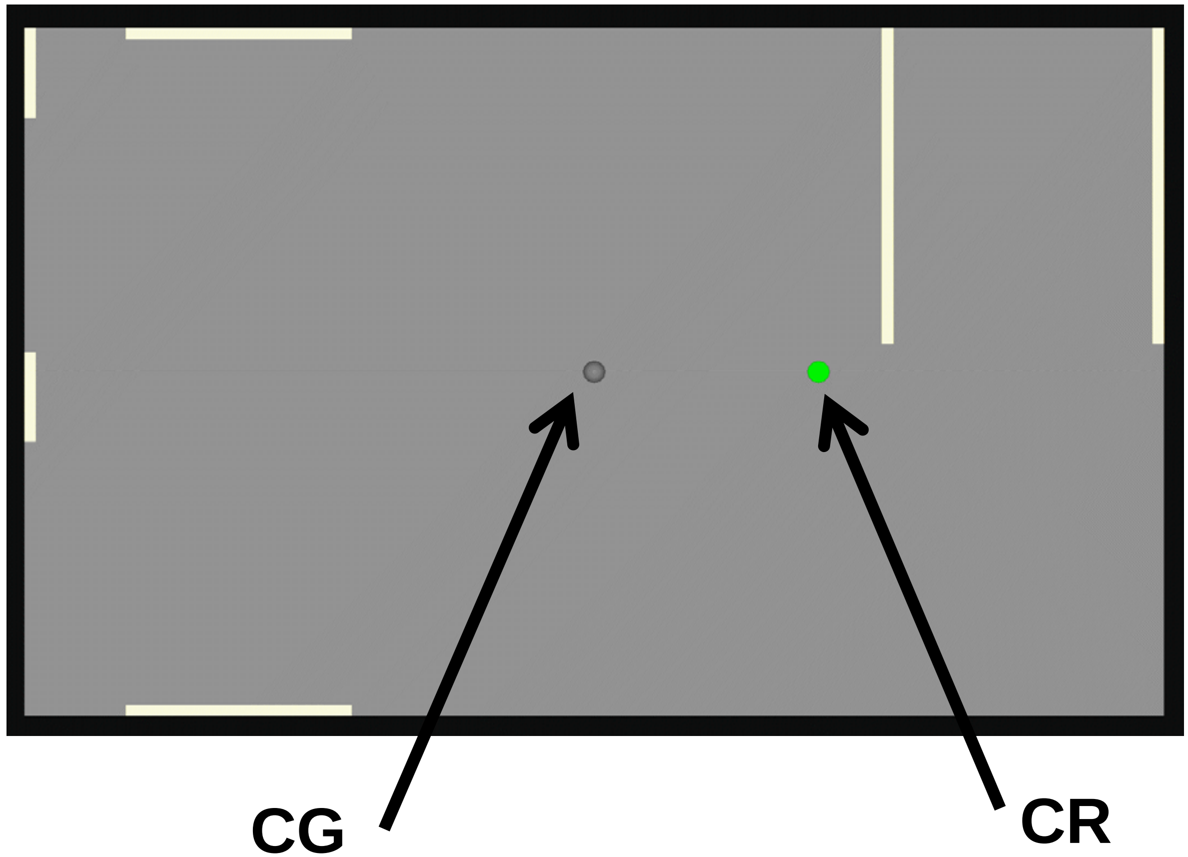


- **Worry about it??**

Typical Woodframe Analysis Methods

Flexible Diaphragm Analysis

- Lateral loads distributed as if diaphragm is a simple span beam between lines of lateral resistance.
- Diaphragm loads are distributed to lines of shear resistance based on tributary area between lines of shear resistance.

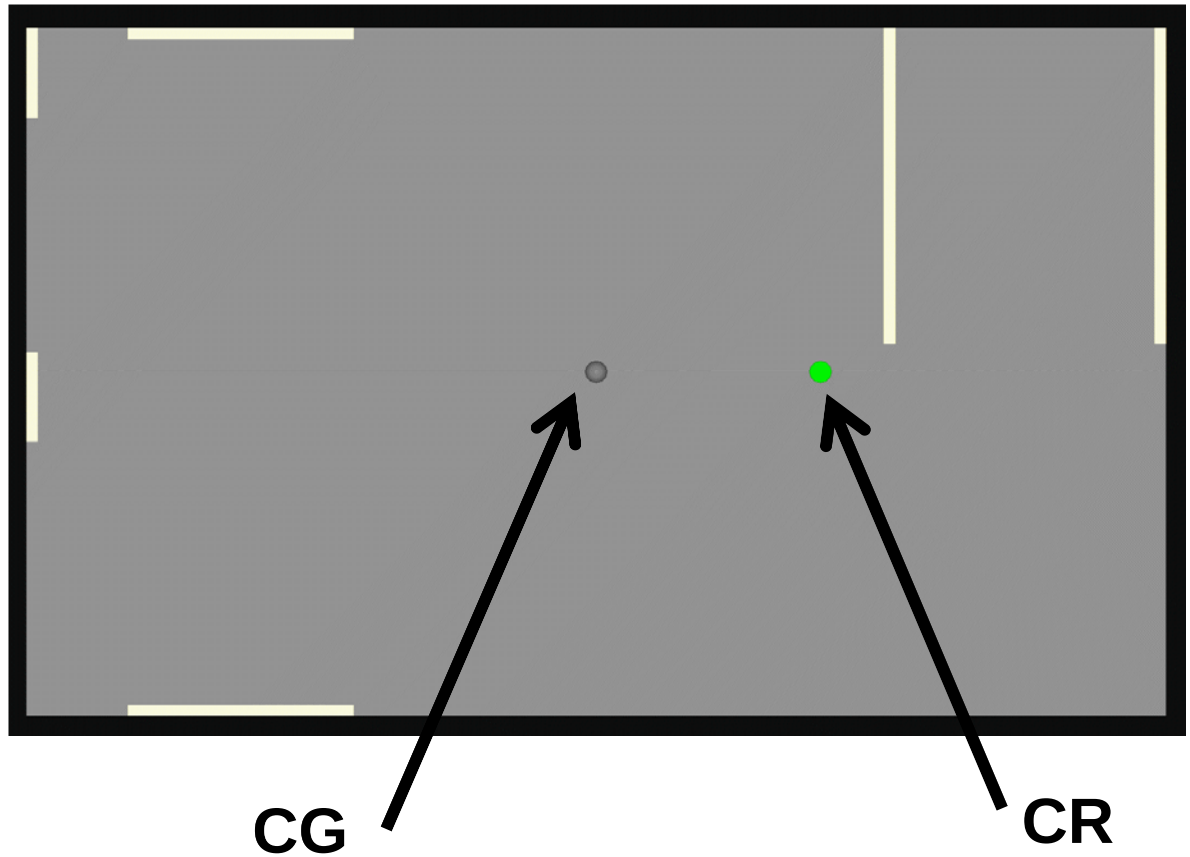


- Worry about it??
- No

Typical Woodframe Analysis Methods

Rigid Diaphragm Analysis

- Lateral loads distributed as if diaphragm is rigid, rotating around the CR.
- Force in shear walls is a combination of translational and rotational shear.

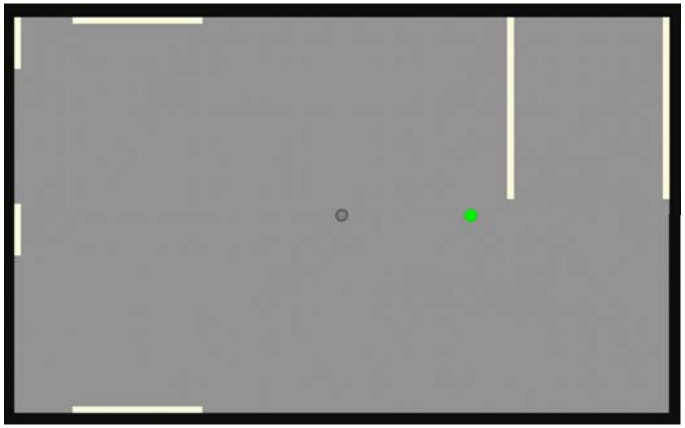


- Worry about it??
- Yes

Typical Woodframe Analysis Methods

Comments on Analysis Methods

- Neither the rigid nor flexible diaphragm methods really represent the distribution of lateral resistance in a typical structure.
- Both methods (typically) ignore the stiffness distribution of interior and exterior wall finishes.



- Wood structural diaphragms are neither "flexible" or "rigid" – they are somewhere in between. "Glued and screwed" floor sheathing makes floors more rigid than flexible. The nailing of interior wall sill plates across sheathing joints has the same effect. Exterior walls can act as "flanges", further stiffening the diaphragm.
- However, encouraging rigid diaphragm analysis is also encouraging the design of structures with torsional response – may not be a good thing!

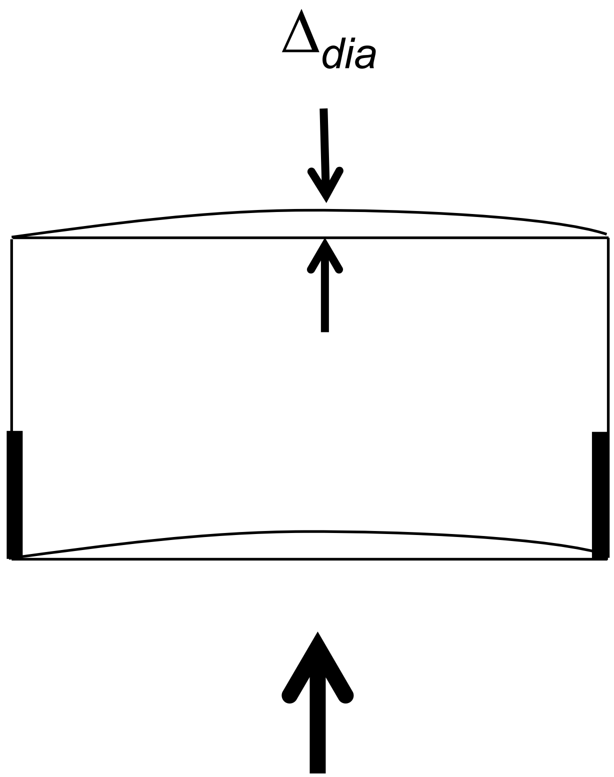
Rigid Diaphragms: When are they Rigid?

- **2003 *NEHRP Recommended Provisions* in Sec. 12.1.2.1 refers to the ASD/LRFD Supplement, *Special Design Provisions for Wind and Seismic*, American Forest and Paper Association, 2001:**

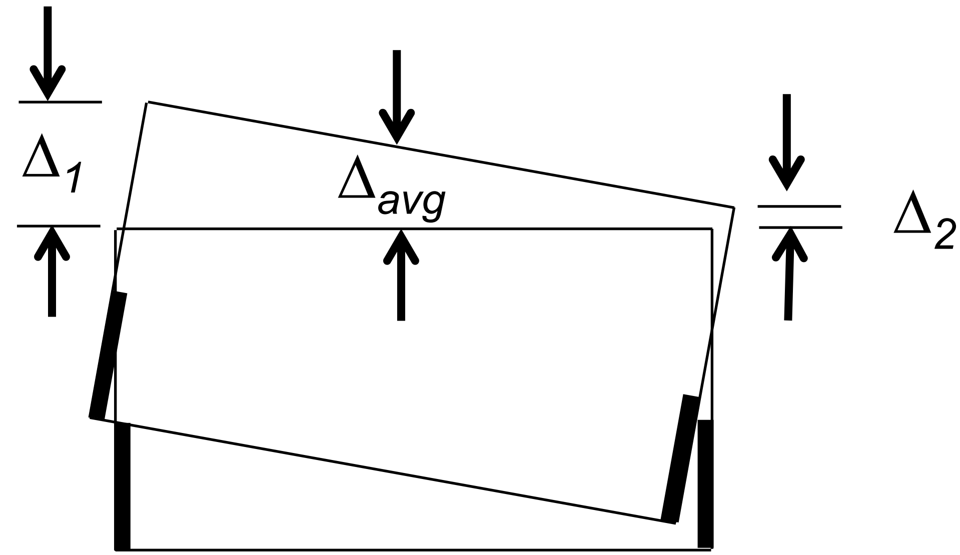
  "A diaphragm is rigid for the purposes of distribution of story shear and torsional moment when the computed maximum in-plane deflection of the diaphragm itself under lateral load is less than or equal to two times the average deflection of adjoining vertical elements of the lateral force-resisting system of the associated story under equivalent tributary lateral load." (Section 2.2, Terminology)

- **Same definition in 2003 IBC Sec. 1602.**

Rigid Diaphragms: When Are They Rigid?



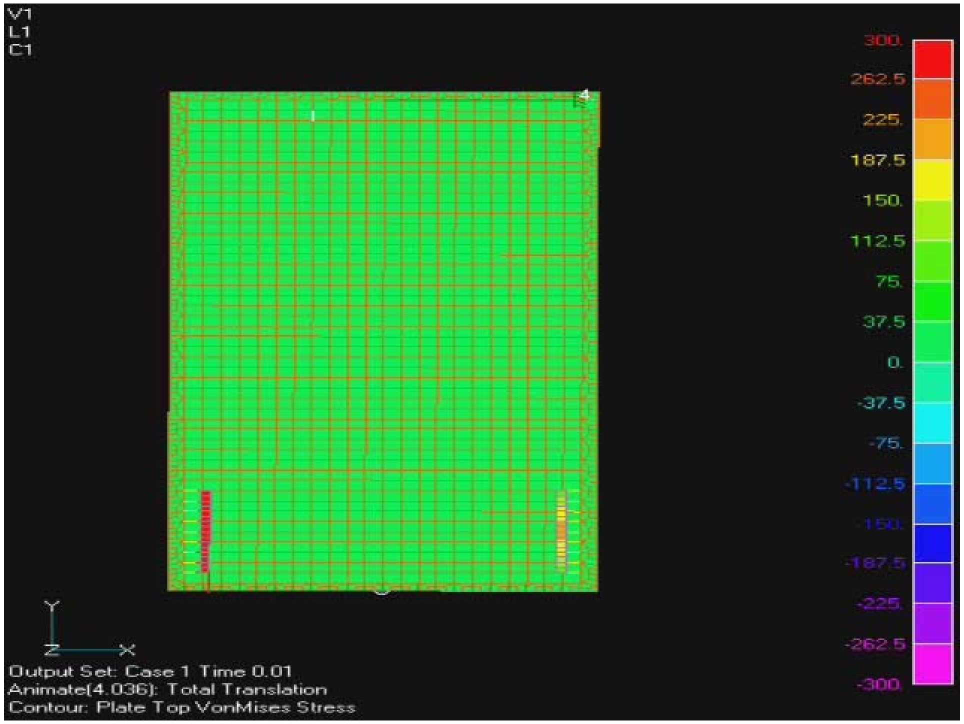
Load

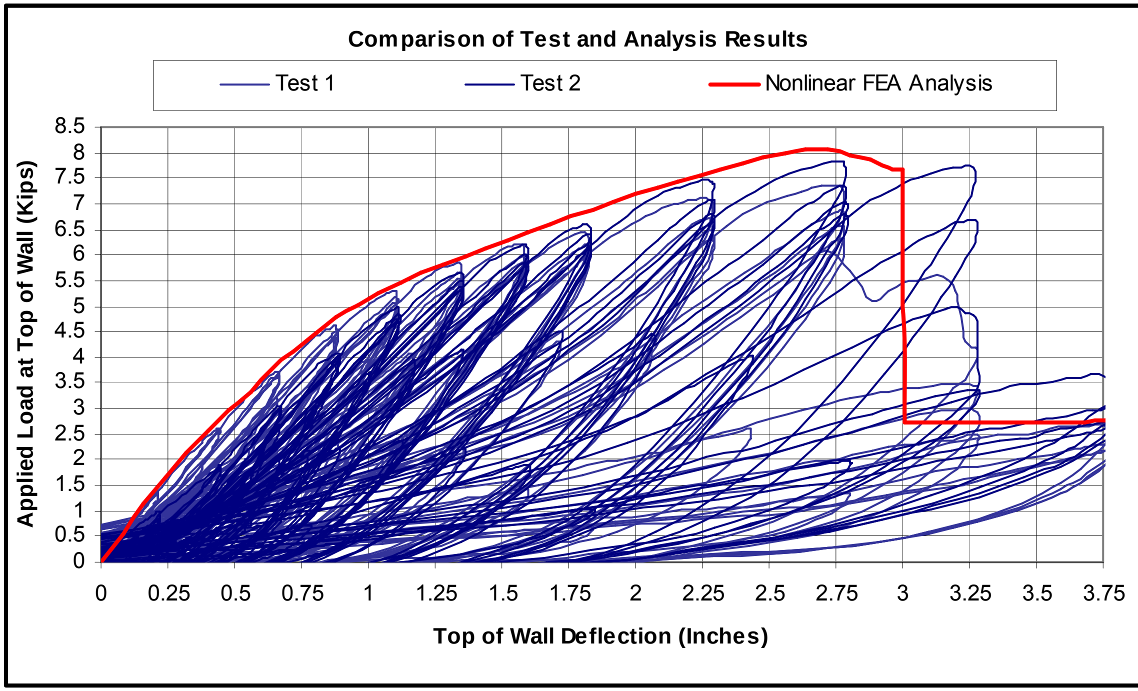


If Δ_{dia} [$2(\Delta_{avg})$ then diaphragm is classified as rigid

Advanced Analysis

- FEA : nail-level modeling is possible, with good correlation to full-scale testing.
- Requires a "true direction" nonlinear spring for the nails, as opposed to paired orthogonal springs.





Advanced Analysis

- NLTHA: rules based phenomenological elements fitted to full scale test data to predict structural response.
- Good correlation to simple tests – more work needed for complex, full structures.

Max Rel Disp		
Story	Predicted	Tested
1	1.14	1.57
2	2.65	2.3
3	1.76	1.92

Summary

- **Timber structures have a good track record of performance in major earthquakes**

- **Their low mass and good damping characteristics help achieve this.**

- **The orthotropic nature of wood, combined with the discontinuous methods of framing wood structures, requires careful attention to properly detailing the load path.**

- **There is still much room for improvement in our understanding of force distribution within wood structures, and the development of design tools to better model this.**