ROTATION IN WOOD FRAMED BUILDINGS

The original version of the interim rules prohibited all rotational distribution of lateral forces. The interim law amended form allows the principle for one story uninhabited accessory buildings. The maximum diaphragm depth normal to the opening was set at 25 feet to prevent the creation of large torsional forces. In most cases, the remaining three walls are strong enough to maintain structural integrity although not to prevent damage. A problem can arise in High Wind Areas that use portland cement plaster shear walls. The in plane shear, with the added torsional component, can exceed the new recommended allowable for plaster. See the attached calculation[A40]. <u>Therefore all accessory buildings with open fronts in High Wind Areas should use structural wood panel shear walls or be redesigned to a full box structure.</u>

STUCCO & DRYWALL

Multi-story structures with only stucco or drywall shear walls performed poorly when tested by the Northridge Earthquake. Stucco or drywall are no longer allowed as wall bracing at the ground floor of all multi-story buildings. The allowable shear values for stucco and drywall were lowered to decrease their use as wall bracing (shear walls) and to encourage wood panel use. Buildings with plywood shear walls still standing in devastated neighborhoods attest to the superiority of plywood. Even though plywood walls had their share of problems, the material performed recognizably better in multi-story applications than either stucco or drywall.

PORTLAND CEMENT PLASTER

Poor stucco performance indicated problems with the lath fastening and furring from the building paper or felt backing. Large sections of lath and plaster detached from wood frame walls. This was typical of self furring type lath fastened by staples. This lath did not penetrate well into the middle of the plaster making the lath reinforcement ineffective. The stapled lath was also more likely to detach from the wood framing. For these reasons, the use of self furring lath and staple fasteners was removed from shear wall construction options in Table 47-I Item 1. Exterior lathing for non structural purposes may be by any method recognized in the code.

Narrow stucco sections also cracked to failure when remaining attached. The minimum height to width ratios was therefore reduced from 2:1 to 1:1 and the allowable shear value for stucco was reduced 50% to 90 lbs. per foot and is prohibited as wall bracing on the ground floor of multi-story buildings.

DIMENSION RATIOS

The reduction of allowable height to width ratios for plywood walls from 3½:1 to 2:1 is an attempt to limit deflection caused by panel bending and rotation and address narrow panel strength loss[19]. It also has the benefit of reducing the effects of vertical slippage from holdown devices. The vertical slip of the holdown anchor translates into horizontal displacement of the top of the shear panel by the ratio of the height to width of the panel. This significant component of shear wall deflection is hence reduced 43%.

Almost half of the allowable shear panel capacities in Table 25-K-1 allow deflection in excess of 0.005h story drift limits at a panel aspect ratio of 3½:1 This occurs without considering the contribution of holdown slippage. See the attached table.[A34] Holdowns are normally required on the narrow panels and can contribute significantly to their deflection. When the slippage effects of the common bolted holdown connections are included, *no panel configuration is known to meet the story drift limits.*

Increased panel widths as well as reduced allowables will decrease actual deflection. The panel configurations may have sufficient strength but the stiffness criteria of present code is not being met. One of the single greatest improvements in wood frame seismic performance may well come from the increased minimum aspect ratio of shear walls. See the attached shear wall deflection calculations.[A35-38]

MECHANICAL PENETRATIONS

All the good work of conscientious engineers and carpenters can be for nought if excessive mechanical penetrations penetrate shear walls. Large holes in beams or columns are rare because most tradesmen understand the vertical load paths intuitively. The same approach needs to be taken for that vertical diaphragm (ie cantilever wood panel beam). Large openings in diaphragms must be detailed on the plan with all of the appropiate opening reinforcement shown. This is done more often on floors and roofs but shear walls need the same attention. Simple tables and notes will help reduce a problem that stems from poor coordination of the mechanical and structural designs.

Building inspectors and good builders must pay careful attention to this ongoing problem. Guidelines in the past have not been uniform but some help is on the way. See the attached[A39] Table 23-1-Y-1 which proposes limits to the notching of shear wall plates. Other proposed code changes will limit all mechanical penetrations to no more than 20% of the shear wall length. Although these changes are not code yet, they are good advice now.

The reduction in the allowable values of drywall partitions effectively removes their use as shear walls except in small one story structures. One value of 30 lbs. per foot now covers all conditions of blocking, nailing and number of layers. The quality of work of the blocked wall construction was poor and many installations are actually screwed instead of nailed. This also follows a more recent trend in the Uniform Building Code (UBC) to reduce allowable shears for gypsum products in Seismic Zones 3 and 4. Recent tests have indicated a weakness in dynamic cyclic applications[19]. Gypsum panels are sensitive to deflection and are not compatible with other materials like plywood or stucco.

Proposed code changes will allow higher allowable values to resist wind loads as well as the use of stapled lath. The practical effect in design will be small in our Seismic Zone 4. The seismic proposals show a increase to 60 lbs/ft shear capacity for gypsum lath, sheathing board, wallboard or veneer base but this is still too low to be useful on most structures

OPEN SOFT STORY DESIGN

Many of the hazardous apartment buildings now sitting vacant in the City are buildings with soft story conditions. Even the ones still standing have drifted beyond structural integrity under a moderate seismic event. Previous building code editions left it up to the designer to determine compatible deflection and allowable drift requirements. Not until the 1988 version of the UBC did the code attempt to quantify many of the structural irregularities and problems that performed poorly in this earthquake. Repairing of these hazardous buildings must meet the current seismic code standards.

A common situation involves a wide flange or pipe column acting as both vertical support and lateral brace. Sometimes there is an independent shear wall or frame but their interaction must be investigated. Common problems to investigate include compatible deformations, shear distributions based on relative stiffness, collector tie continuity, calculated story drift and P-Δ effects. A thorough understanding of and compliance to present code is therefore required for the repair of these damaged buildings.

Here is an example of what can be required. A three story apartment building partially collapsed when the many drywall (and few plywood) shear walls failed in the transverse direction. An analysis of the longitudinal direction revealed sufficient strength in the end frames but no apparent continuity tie between them in the building. Intermediate pipe columns in this same line were near their vertical capacity. When subjected to $3R_w/8$ deflections, the columns failed the P-Δ test for combined vertical and bending stress even though the end frames met the story drift limit.

In this case plywood shear walls are required on the ground floor by the new code and the second and third floors by load for the transverse direction. The longitudinal direction requires additional stiffness to limit the intermediate column drift. The existing frames could be stiffened or another frame added near the middle of the building. In either case, continuity ties would have to collect and distribute the lateral forces to the frames. They are required to be verified as existing during construction or detailed and built from the new repair plans.

PLAN REVIEW

Plan check corrections are sometimes written from the perspective of the building official and not the designer who must comply with them. The requirements are stated in code language instead of simple and clear English. The code language approach is understandable because plan check engineers sometimes have to defend their assertions from code sections. But building officials can help applicants obtain their permits when they write comments on the plans and calculations that are clearly referenced and easy to understand. These tend to be more helpful than the code language type corrections written alone on a plan check correction form.

PLAN REQUIREMENTS

Perhaps the greatest contribution a structural designer can make for quality of construction is a good set of plans. A great many poorly constructed buildings can be traced to an inadequate representation of the code requirements on the plans. Contractors and building officials then need to spend a lot of time on detail changes or omissions. A real effort in plan check for plan thoroughness can help minimize this problem.

Review of plans on damaged buildings as well as current practice indicates a need for better detailing of the lateral system. In a novel approach, the City is specifically requiring certain plan elements by law for the first time. These include elements of the framing and foundation plan. They also include required elevations and details. The following minimum requirements are stated in a broad interpretation of that directive.

FOUNDATION PLAN

1. The size, type, location and spacing of all sill plate anchor bolts
2. The location and type of all holdown anchor bolts embedded in concrete
3. The required depth of embedment, edge and end distance of anchor bolts
4. The column size and location of all braced or moment frames
5. Referenced details for:
    a) all grade beam and footing sections
    b) frame to foundation connection
    c) grade beam to caisson connection
    d) stepped stem wall on grade beam top
    e) embedment of bolts into footing at slab cold joint if used

FRAMING PLAN

1. The width, location and material of all shear walls
2. The width, location and material of all frames
3. Referenced details for:
    a) column to beam connection
    b) beam to wall connection
    c) wall brace for short studs when used at roof sections
    d) shear transfer details at floor/roof lines (top & bottom)
    e) required nailing and length for top plate splices
4. Shear wall elevations showing
    a) panel heights and widths
    b) location of holdowns, collectors, straps and framing anchors
5. Shear wall schedule with the following:
    a) correct shear wall panel capacity in lbs. per foot
    b) nail type, length, and pennyweight-(ie 8d common, 10d full length common)
    c) complete material specification-(Struc 1 C-D Exposure 1)
    d) material thickness-(15/32", 7/8")
    e) top & sill plate fastener type and on center spacing
    f) holdown type, bolt or nail sizes and required thickness of end stud(s)
    g) required location of 3x or 2-2x edge members
    i) required nailing connection of double end members(when used)
    j) required edge distance for nails on plywood and framing members
    k) sill plate material assumed in design
    l) required flush nailing at plywood surface.
    m) limits of mechanical penetrations

INSPECTION REQUIREMENTS

Every person involved in the construction process has a part in the pursuit of quality. The original designer starts the process and has the most liability. The plan reviewer spot checks the designer and the building inspector spot checks them both. The inspector must rely on both the plans and his or her own sense of the normal. When that sense is violated, questions should be asked because building inspectors are the eyes and ears of the building department.

The most frequent dilemma for the inspector is to know what is important for the limited amount of available time to inspect. The following guidelines should be helpful for structural issues on wood frame buildings.

1. *Make sure all properly sized anchor bolts are firmly attached to form work* with the proper concrete and wood edge distances before approval is given to pour. No exceptions should be allowed for holdown bolts. Because most pressure treated sill plates come in 14 or 16 foot lengths, expect to see a pair of bolts for the ends at these distances. An embedded J bolt is preferred to an added expansion or epoxy bolt.
2. The depth of the footings in firm competent soil may require you to ignore the 6-8 inches of loose topsoil on flat lots. Let the builder get a soils engineer if there is a desire for shallower footings. Normally the deeper the footing is, the better the soil properties are. *A typical 12 inch footing may be 18 inches below existing grade in order to be in good soil.*
3. Verify if *a top plate splice* detail exists on the plans and look for 16d nails coming through the lower of the two top plates at the splice. *Typical details require 3 stud spacing of the splice and a dozen or so 16d sinkers or commons on each side of it.*
4. *Several nails are required at roof or floor to wall connections.* Although Table 25-Q usually shows these connections with 3-8d common or box nails, many carpenters substitute 2-16d sinkers instead. This was a former option in the code but has been removed to improve the quality of the toe-nailed connection. Rafter and ceiling joist connections to the top plate requires 3-8d, carpenters use 2-16d at each end of the blocking, 1-16d for the blocking into the top plate, and a minimum of 3-16d between the ceiling joist and rafter. That's 14 nails within 16 inches! *The ceiling joist to rafter and ceiling joist lap connections at the roof level are important for roof and box frame stability.*
5. *Studs are normally assumed to be built full height unless otherwise noted.* However, a frequent practice by carpenters is to frame walls in two sections at the roof. The first section is the 8 ft height. Rafters and ceiling joists are framed next. Finally cripple studs are framed into the bottom of the parallel rafter usually without a top plate. This construction requires a brace and performed poorly in the Northridge earthquake. Sometimes 2x6 studs are required near the ridge of the roof. This is because the unbraced maximum height of a 2x4 stud is only 14 feet unless an engineered brace or stud design is otherwise approved.See the attached detail for wall bracing on short studs.

6. Shear panel construction is the most important part of the lateral system. *The nail size, spacing and edge distance are the most important elements.* Keep samples of common nail sizes for 6d, 8d and 10d to compare to the field specimens. The spacing is not as important as the number of nails it represents per foot of width. It is acceptable if the same number of nails are present and the spacing is approximately correct but do not count nails too close to the edge or that fracture the plywood surface. Nails that miss or are too close to the edge of the framing member or blocking should be removed.
7. Douglas fir-larch *sill plates* are critical for shear walls. The common field substitution of hem-fir reduces values 18% and is not normally considered by the designer or plan reviewer. Use of foundation redwood is worse with a 35% reduction in value. Read the Western Wood Products or other stamp on the piece to identify the species. *Return any engineered jobs to plan check* that do no show hem fir or redwood sill plates on the plans.
8. Grade of the plywood accounts for *10% of shear wall strength when Structural 1 is specified.* Look for the Structural 1 designation on the back of the panel. Exposure 1 is not Structural 1. Exposure 1 indicates exterior gluelines between the plies and it is required on all shear walls, floor and roof diaphragms. Normally, this requirement is not a problem since over 95% of all plywood panels are Exposure 1[26].
9. *A35F or increased sill plate nailing should be expected on all plywood shear panels* that span plate to plate on the same wall. Overlength sheets that break on the rim joist or blocking require edge nailing at the plate and edge of the plywood. That is four rows of nails at a break between two sheets. When the sheet is continuous over the floor/roof to wall connection, one row of nailing is required at the bottom plate, top plate and floor framing. That is a total of three rows at the floor diaphragm to shear wall connection.
10. Double or 3X members increase capacity 12%. Check *the nailing of the 2-2x pieces* together. The 16d sinker nail spacing on each side should be close to the shear wall nail spacing on panel seams or sill plates but *must be specified on the plans. See the table.*

SPECIAL DEPUTY INSPECTION REQUIREMENTS

Plywood shear walls will now require the use of a special deputy inspector when the design shear exceeds 300 lbs/ft. This is a new category of deputy inspector. The normal requirement for continuous inspection is not always required and some periodic special inspection is authorized under 91.306(e). The deputy inspector will be required in three distinct periods. The building inspector must verify the work of the s well as the work the deputy inspects.

The first duty of the wood deputy inspector will be to check the placement and size of anchor bolts for shear wall sill plates and holdown devices prior to the concrete pour. The next visit will be to insure the proper installation of sill plates during the initial phase of framing. Both of these inspections can be periodic. The actual installation of the plywood, its nailing and the connection of all hardware will be done under continuous inspection. The following is a general checklist for wood deputy inspection of shear wall systems.

PLAN & GENERAL REQUIREMENTS

1. All details and plans shall bear the approval stamp of the Department of Building & Safety and the stamp of an architect, civil or structural engineer registered in the State of California
2. All shear walls shall be of proper length and location as shown on floor and framing plans.
3. Any special conditions of the design or Department granted modifications of the code for the shear wall system shall be met.
4. All shear panel capacities greater than 300 lbs/ft require deputy inspection unless otherwise noted.

FOUNDATION

1. All shear wall sill plates shall be generally continuous and uninterrupted by utilities. The width of mechanical penetrations shall not exceed 20% of the shear wall length.
2. All foundation sill plates shall be connected to the foundation or foundation wall by minimum ½ diameter steel bolts with 7 inch embedment into **monolithic concrete** with bolt spacing at 6 feet on center maximum.

   EXCEPTION: Chemical, mechanical or bearing type anchors may be used when shown on the approved plans and all conditions of the Research Report are complied with.
3. The bolt size, type and spacing shall match the shear wall and foundation plan schedule.
4. All foundation sill plates require a minimum of two bolts per member.
5. All holdown anchor bolts shall have the minimum required embedment into monolithic concrete as shown in the Research Report and manufacturer's catalog.

WALL FRAMING

1. All framing dimensioned lumber shall be:
   a) **Douglas Fir-Larch unless otherwise noted on the approved plans**
   b) a minimum of 2 inch nominal thickness except as noted below
   c) free of defects such as dryrot, mildew, and excessive wane or warping
2. All studs and/or blocking at adjoining panel edges and bottom sill plates shall be 3 inch nominal or wider thickness when the required shear shown in the shear wall schedule exceeds 300 lbs/ft.

   EXCEPTION:Substitution of a double 2 inch member for the 3 inch required may occur on existing buildings when the original member is not replaced. The nailing of these substituted members together shall match the nail size and spacing requirements detailed on the plan.
3. Studs or blocking at adjoining panel edges shall be 3 inch nominal or wider thickness when:
   a) the plywood nail spacing is at 2 inch on center
   b) 10d full length common plywood nail spacing is 3 inches or less on center
   c) plywood is applied to both faces of the wall with nail spacing less than 6 inches on center on either side and panel joints occur on the same framing member for each face of the wall.
4. Framing members or blocking shall be provided at all panel edges
5. Studs shall not be cut or notched to a depth exceeding 25% of their width.
6. Studs shall not have bored holes exceeding 40% of their width (60% if doubled). Bored holes shall be a minimum of 5/8 inch from the edge and not be located in a cut or notched section.
7. Framing members which split during plywood nailing shall be replaced.
8. Mechanical penetrations shall not exceed 20% of the wall length.

PLYWOOD

1. Plywood thickness and grade shall match the shear wall schedule for the given location
2. Plywood shall be properly marked with a grade stamp showing:
   a) performance rating- Structural 1 or Rated Sheathing
   b) conformance to US Product Std. 1-83 (UBC STD. 25-9)
   c) Exposure 1 or Exterior durability (glueline) classification
3. Panel joints shall occur on the centerlines of studs or double edge member joints.
4. Panel joints shall occur on separate studs when plywood is applied on both faces of the wall if the studs are less than 3 inch nominal width and the nail spacing is less than six inches on center on either side of the wall.
5. Plywood shall not be cut out for ductwork, piping, electrical conduits or equipment without the approval of plan check and the architect and/or engineer.

PLYWOOD NAILING

1. Nails shall be driven flush and not fracture the surface of the sheathing.
2. All nails shall be removed if not properly located in a stud, plate or blocking.
3. All nails shall have the wire gauge (diameter) and full head size of the Common type.
4. The maximum field nailing is 12 inches on center for 16 inch on center framing
5. The panel edge nail spacing shall match the shear wall schedule for its location
   NOTE: Field tolerance of 1/3 of spacing requirement is allowed provided the equivalent number of nails is provided.
6. The minimum panel nail edge distance is 1/2 inch for design strengths over 300 lbs/ft (3/8 inch for all others).
7. Nails shall be staggered at panel joints for spacing of 2 inches on center and for full length 10d nails spaced 3 inches or less on center.
8. Nails shall be staggered on each face of the wall when plywood is applied to both faces with panel joints on the same framing member.
9. Edge nailing is required on the framing member connected to any holdown device.
10. When plywood is approved to connect the wall to the floor or roof without framing anchors or increased sill plate nailing, then the following conditions apply:
    a) a row of edge nailing is required at the top and bottom plates of the shear wall
    b) a minimum of one row of edge nailing is required at roof or floor framing members and at all panel edges
    c) nails in blocking or a rim joist shall have the required nail end distance from the rim joist or blocking edge (3/4 inch for 6d, 8d and 13/16 inch for 10d).
    d) nails in floor or roof framing shall not be located in the ends of rafters or joists
    e) nails shall be staggered on floor or roof framing members
11. The diameter of a drilled hole,when used on seasoned framing members to prevent splitting of the wood, shall not exceed 75% of the nail diameter.
12. All nails shall be driven normal to the surface and shall not be toenailed except as required on panel edges.

SILL AND TOP PLATE CONNECTIONS

1. All foundation sill plates on concrete or masonry shall be treated Douglas Fir unless otherwise noted on the plans.
2. All foundation sill plates require a minimum of two bolts per member.
3. All anchor bolts shall be a minimum of 7 bolt diameters and a maximum of 12 inches from the end of the member.
4. All anchor bolts shall maintain a minimum of 3 bolt diameters from the concrete edge and 1½ bolt diameters from the wood edge of the sill plate.
5. All holes drilled in the plate for anchor bolts shall be a minimum of 1/32 and a maximum of 1/16 inch larger than the bolt diameter.

   EXCEPTION: Drilled holes for bolts subject to tension from holdown devices shall be 1/4 minimum and 1/2 inch maximum larger than the bolt diameter.
6. The use of standard circular cut washers on foundation anchor bolts is no longer allowed on shear walls with design strengths in excess of 300 lbs. per foot. The following table for oversized plate washers shall be used in its place:

BOLT DIAMETER$_{inch}$	PLATE SIZE$_{inch}$	THICKNESS$_{inch}$
1/2	2 X 2	3/16
5/8	2½ X 2½	1/4
3/4	2¾ X 2¾	5/16
7/8	3 X 3	5/16
1	3½ X 3½	3/8

10. All 2 inch nominal thickness sill plates over joists or blocking shall be face nailed with a 16d common, sinker or box nail at a minimum of 16 inches on center unless otherwise increased on the shear wall schedule.
11. All 3 inch nominal thickness sill plates over joists or blocking shall be attached as noted on the shear wall schedule. Increased blocking thickness shall be provided as required by the shear walll schedule.
12. All nails connecting sill plates shall be centered in the joist or blocking underneath and a minimum of 1 inch from their end.
13. All sill plates shall have increased nailing or framing anchors and be of the type and spacing as shown on the shear wall schedule.
14. All prefabricated framing anchors shall have current Research Report approval and be manufactured by a Department licensed fabricator
15. All framing anchors used as shear connectors shall have the long direction oriented horizontally and be attached directly to plate and roof or floor framing unless otherwise approved.
16. All top plate splices shall be nailed per the approved detail and be overlapped a minimum of 48 inches.

HOLDOWN CONNECTIONS

1. All prefabricated holdown devices shall have current Research Report approval and be manufactured by a Department licensed fabricator.
2. All drilled holes in studs for holdown devices shall be a minimum of 1/32 and a maximum of 1/16 inch larger than the bolt diameter.
3. All studs connected to the holdown device shall be of the width and number as shown on the shear wall schedule, manufacturer's catalog and current Research Report.
4. The holdown device shall normally be centered on the stud(s) to which it is connected but must maintain a minimum edge distance of 1½ bolt diameters.
5. When holdown devices are bolted to double 2 inch nominal members, the nail type and nail spacing of the double member shall be as noted on the shear wall schedule.
6. **All** washers on holdown device end studs shall be of the oversized type.
7. The proper sequence of bolted holdown installation is to first bolt and tighten the holdown to the studs. Then the tension bolt is tightened. This will help engage the stud bolts to help reduce slippage.
8. Anchor bolts placed in new concrete must have the proper embedment and cover as shown in the manufacturer's catalog and Research Report.
9. All prefabricated strap ties shall be attached to solid framing of the required width with the proper type and quantity of nails as shown in the Research Report, manufacturer's catalog, and structural calculations.
10. All prefabricated strap ties shall be centered vertically at the middle of the floor joists when used as holdowns.

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