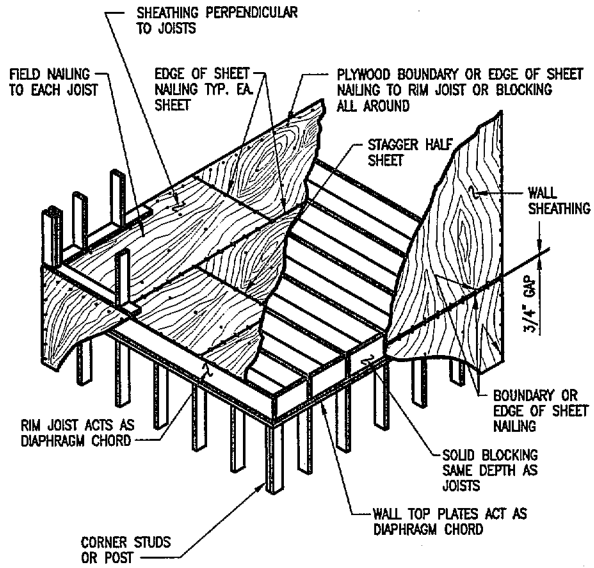
7. FLOORS

Floor diaphragms are significant structural elements especially in two story construction or if a first floor is required to span horizontally across a basement or over a crawl space. Ideally, the floor should be regular in shape and all in the same plane without vertical offsets. A simple rectangular, symmetrical shape (box) is the best configuration. See Figure 45. Where possible the earthquake forces in the floor diaphragm should be resisted by a symmetrical pattern of shear walls supporting the boundary of the floor.



TYPICAL DIAPHRAGM

Figure 46

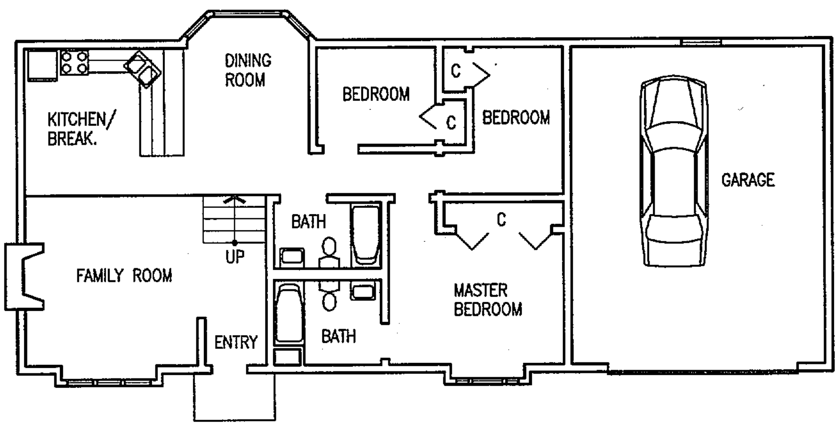
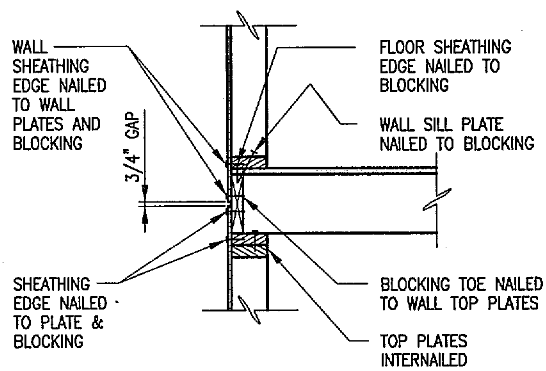


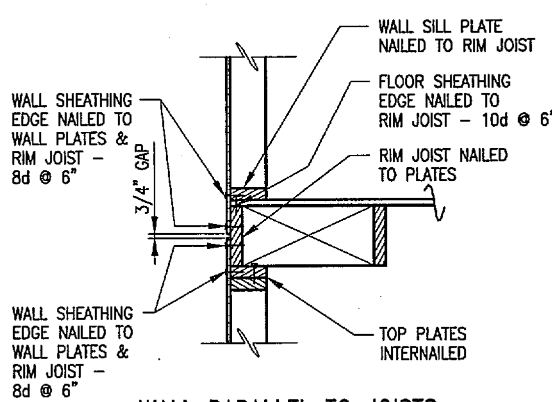
Figure 45



WALL PERPENDICULAR TO JOISTS

Figure 47

A diaphragm consists of joists, sheathing and edge members called chords. See Figure 46. Sheathing on floors serves the dual purpose of supporting the load of furnishings and occupants and of transferring earthquake or wind loads to the shear walls. Commonly used sheathing materials, when adequately nailed, carry the vertical floor loads and resist the earthquake loads in the plane of the diaphragm. Nailing for diaphragm action is generally greater than the nailing required for gravity loads.



WALL PARALLEL TO JOISTS

Figure 48

Plywood or oriented strand board for subfloors may be used in any seismic risk area. Tongue and groove sheets should be oriented with the long edge perpendicular to the framing and need not be blocked. The short edge of abutting sheets must be edge nailed to the same framing member. To achieve a stiffer diaphragm in areas of high seismic risk, square edge sheets with the long edges of each sheet nailed to blocking and short edges nailed to a common framing member should be used. Straight sheathing without a Wood Structural Panel overlay should be avoided except in low seismic risk areas.

For two story construction or floor framing supported on stud walls, top plates act as flanges or chords for floor diaphragms. They should not be interrupted by openings such as windows, ducts, piping or conduits, unless chord continuity can be satisfactorily restored with straps or ties. Top plates must be internailed and receive additional nailing at lap splices. See Figure 47, 48 and 49. Wall top plates must continue across the full width and length of the floor diaphragm from corner to corner without interruption. Diaphragm sheathing must be edge nailed to blocking or rim joists that are toe nailed to the top plates.

To function properly diaphragms must conform to specific shape limitations that are controlled by the diaphragm span–to–width ratio discussed before. If the allowable ratios are exceeded it is necessary to provide additional shear walls to divide the diaphragm in sections so that the sections meet the prescribed span–width diaphragm limits. Shear walls (panels) in line at the edge of a diaphragm, but separated, can be tied together by the wall top plates acting as collectors or drag struts between the shear walls. The top plates must be spliced for continuity. See Figure 50. Shear walls not at the edge of a diaphragm or within the diaphragm borders can also be used by employing light gage strap ties nailed to the shear wall and extending into and nailed to the diaphragm framing. See Figure 51.

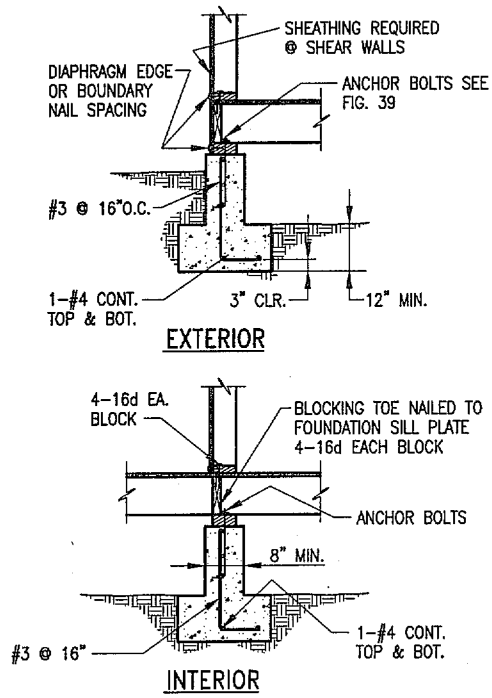


Figure 49

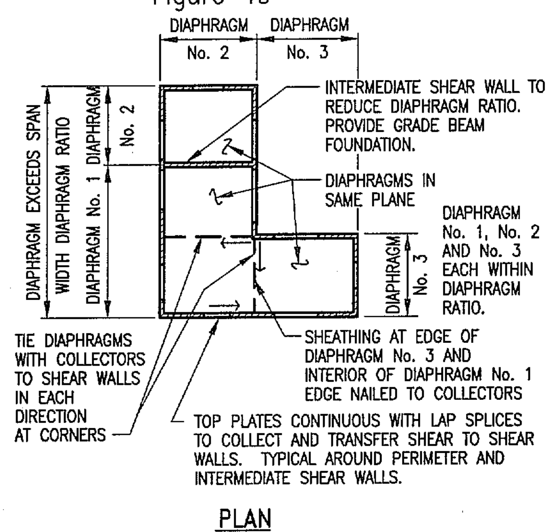


Figure 50

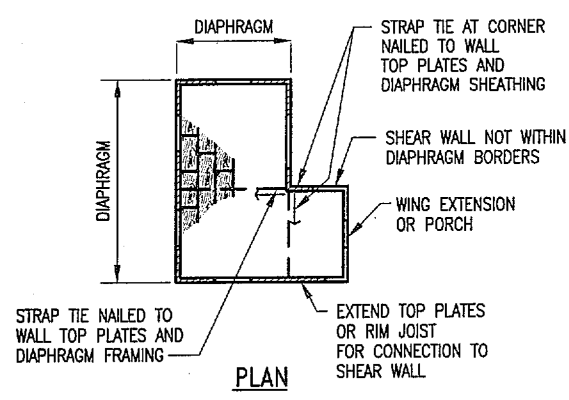
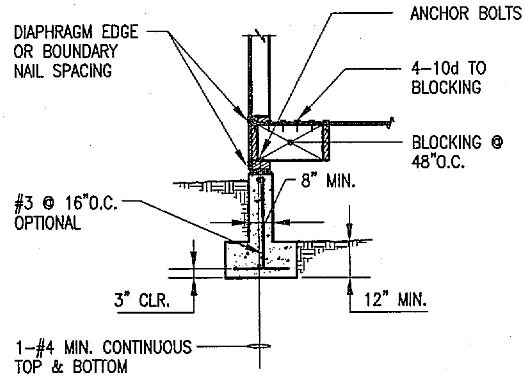


Figure 51

As for building wings, collectors or ties can be used to transfer earthquake loads developed in areas of a floor not supported on walls such as at porch enclosures that are open underneath and supported on posts. Collectors must be nailed to floor framing within enclosures and extend into and be nailed to floor diaphragm framing as shown in Figure 51 and 54.

Sill plates must be bolted to the top of the footing or stem wall. See Figures 49 and 53. In high seismic risk areas, chances of plate failure are reduced by using a larger number of anchor bolts over the width of the shear wall than may be prescribed by Code and by the use of plate washers. Hold–down anchor bolts, where needed, must be embedded in the footing as shown in manufacturers' catalogs. See Figures 31 and 55.

Where collectors or drag struts continue across a break in diaphragm planes the collectors or struts must be anchored to the vertical framing to prevent uplift when they are loaded by earthquake forces. See Figure 52.



SHEAR WALL SECTION
HORIZONTAL FRAMING PARALLEL TO WALL

Figure 53

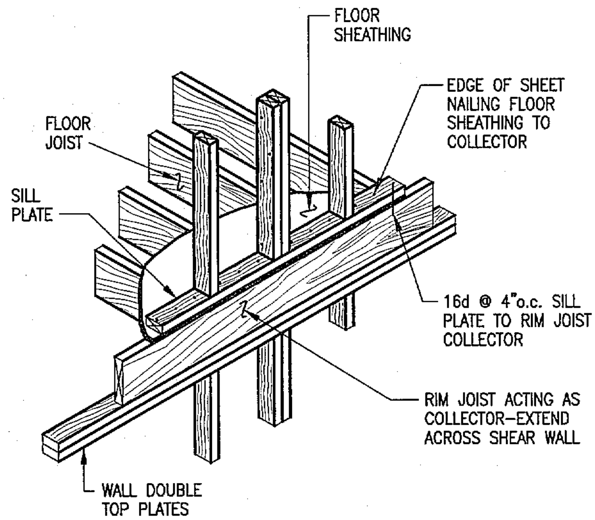
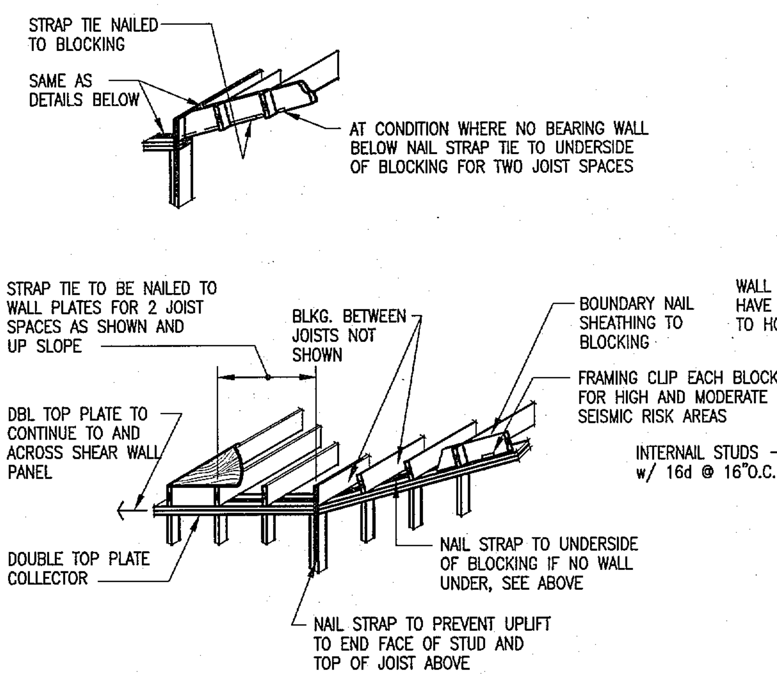
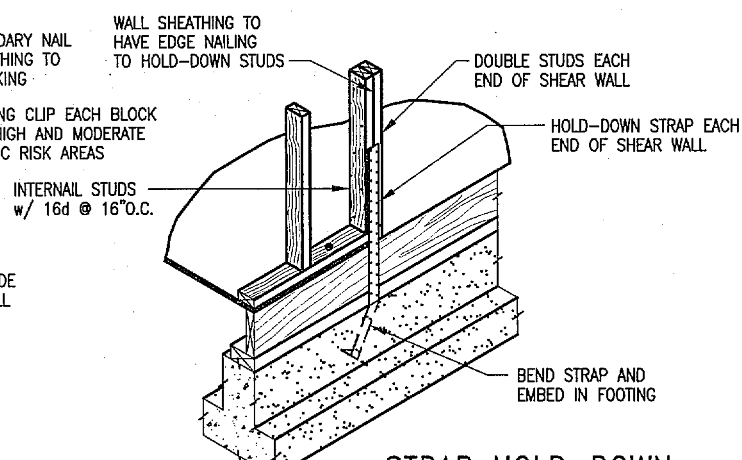


Figure 54



HORIZONTAL DIAPHRAM TIE

Figure 52



STRAP HOLD–DOWN

Figure 55

A floor diaphragm or any of its parts should, where possible, be in one horizontal plane between shear walls and not be broken by vertical offsets or ramps. Where a floor plane is interrupted, as in split level construction (see Figure 56), the floor will then be composed of more than one diaphragm. Each of these diaphragms must have a boundary shear wall along each edge. At the offset edge, each diaphragm may use the common shear wall to resist the earthquake forces in each diaphragm. See Figures 58 and 59 for split level floor framing details.

Openings in floor diaphragms must be limited. Penetrations at corners should be avoided. Small openings for furnace ducts and registers, flue stacks and chimneys are permissible. See Figure 57. Large openings for stair wells must receive special framing and nailing of floor sheathing around the opening. Where any opening dimension reduces the effective length or width of a diaphragm by 50% or more, a shear wall should be placed parallel with the narrow edge of the diaphragm on each edge of, or in line with, the edge of the opening.

Ideally, floor diaphragms should be fastened with screw shank nails with a diameter equivalent to common or box nails. If nails other than common wire nails, such as box, sinker or staples are used, the spacing should be reduced from those prescribed in codes for common nails. To prevent squeaking a bead of construction adhesive should be applied on the top edge of floor joists when laying the sheathing. The use of adhesive in this manner has been shown to increase stiffness and improve performance of floor diaphragms in earthquakes.

In addition, nominal nailing (at 10" to 12" spacing) must be provided along framing members located between the edges of the sheets. This nominal field nailing secures the sheathing to the framing and prevents buckling of the sheets when the floor functions as a diaphragm during an earthquake. When using a nailing gun, care must be exercised to avoid overdriving the nails. The gun operator should also make sure that the nails penetrate the framing members below. It is good practice to locate the members below by snapping a chalk line on the top face of the sheathing. A new nail should replace each nail not properly driven.

Blocking or rim joists should be nailed to top plates with 4–10d toe nails each block or 10d toe nails at 4" centers for rim joists. Light gage angle clips can be used in lieu of toe nailing.

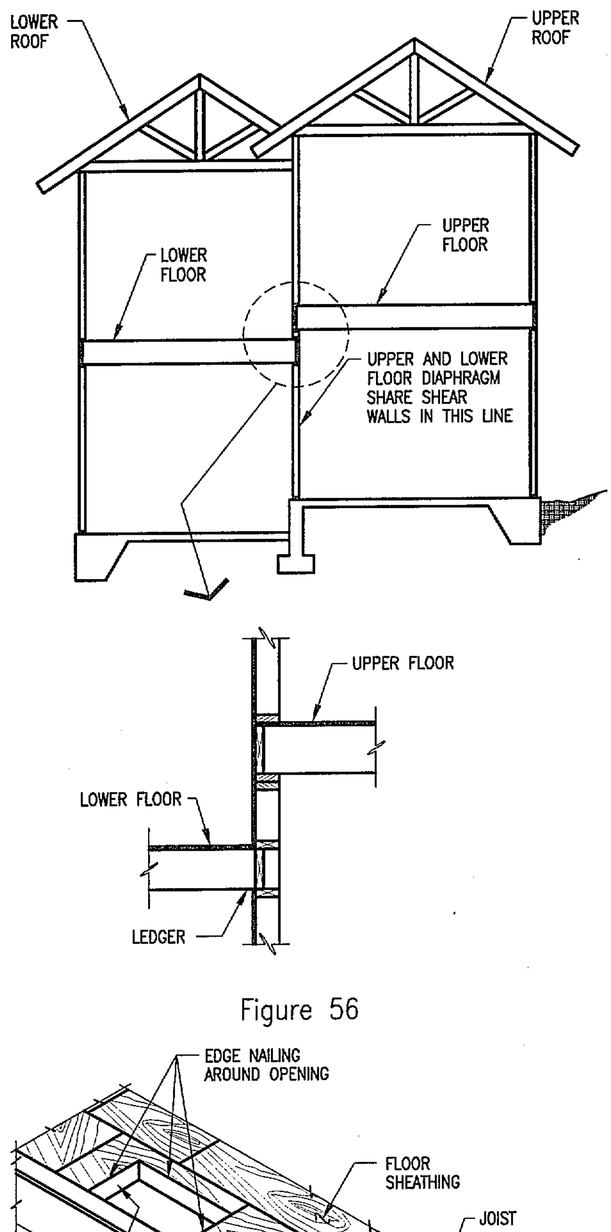


Figure 56

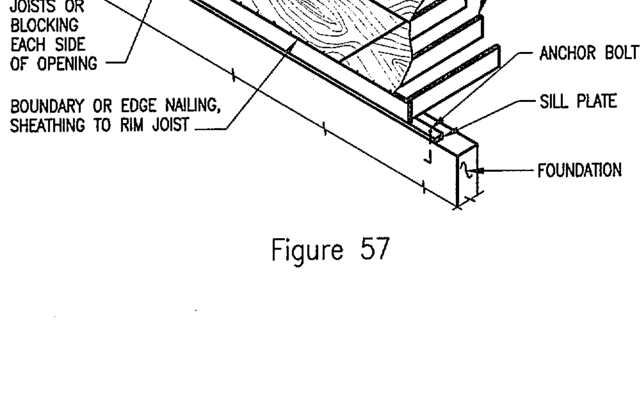
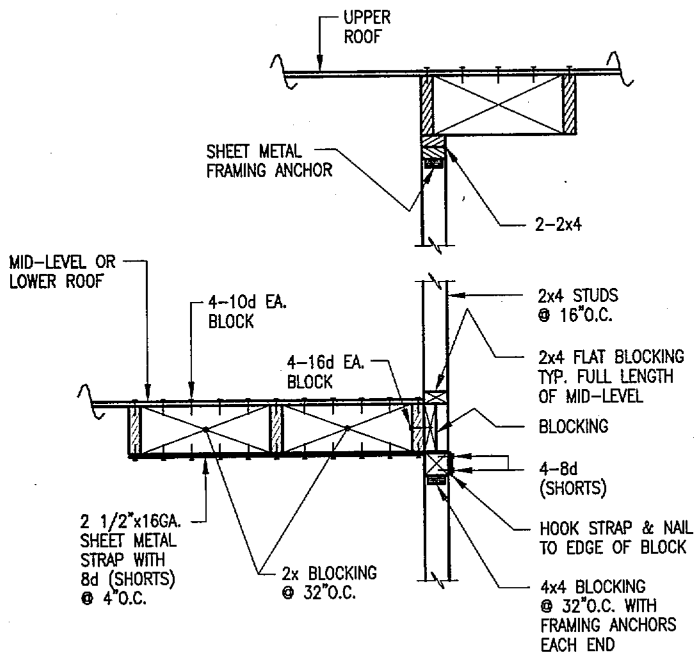
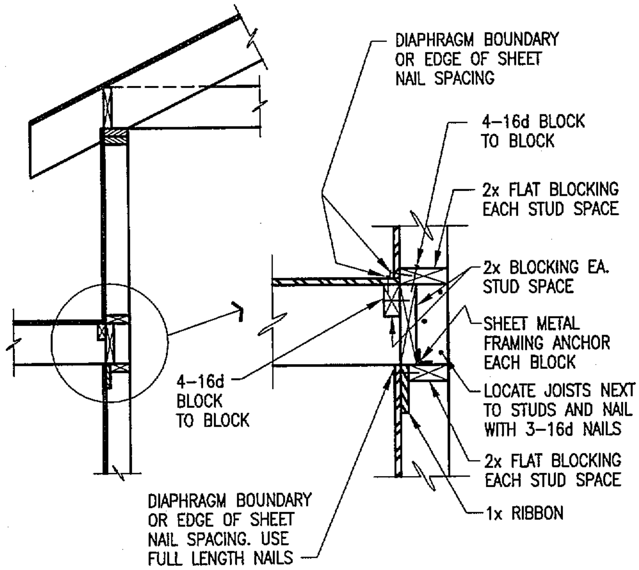


Figure 57



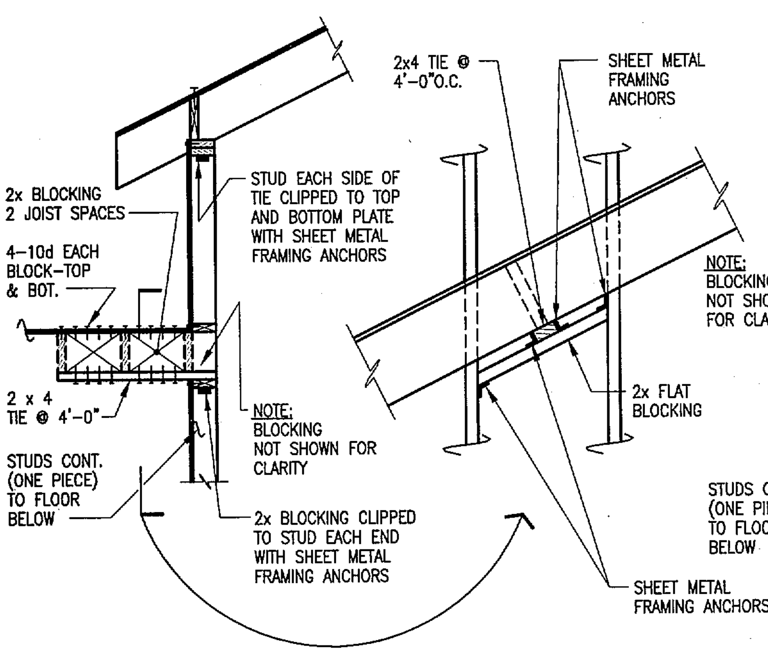
SPLIT-LEVEL TIE
FLOOR FRAMING PARALLEL TO WALL

Figure 58



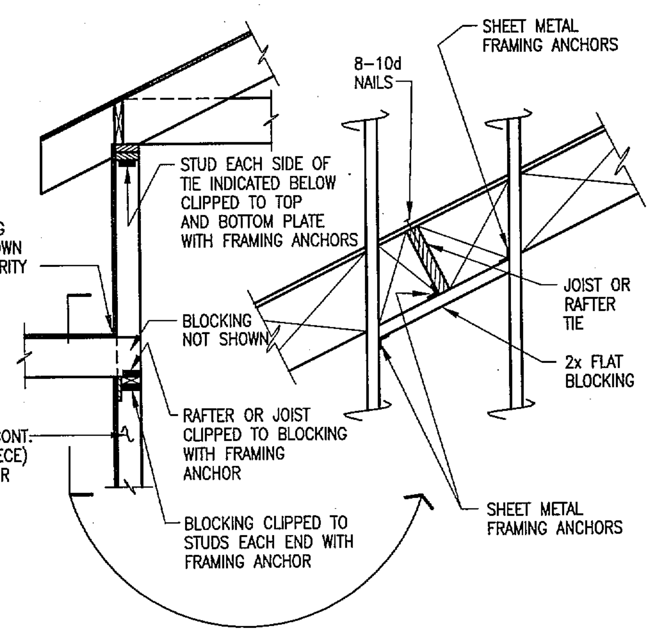
SPLIT-LEVEL TIE @ 32" o.c.
FLOOR FRAMING PERPENDICULAR TO WALL

Figure 59



SPLIT-LEVEL TIE
SLOPING ROOF FRAMING PARALLEL TO WALL

Figure 60



SPLIT-LEVEL TIE @ 32" o.c.
SLOPING ROOF FRAMING PERPENDICULAR TO WALL

Figure 61

8. SHEAR WALLS

Shear walls resist earthquake loads transmitted to them by floor and roof diaphragms. A shear wall is required along each side of the perimeter of thé floor or roof (horizontal) diaphragm, usually in each exterior elevation. The most effective locations for the exterior shear walls are at the corners of the building where the walls are mutually perpendicular to each other and have a common point of intersection. See Figure 62. To maintain symmetry, the same length of wall should be provided at each of parallel exterior walls. In order to minimize torsional rotation which can increase earthquake loading on shear walls, an unbalanced condition should be avoided. See Figure 63. Some codes limit the maximum distance between shear walls and specify the percentage of an exterior wall that must be sheathed. For long walls, this may require placing one or more shear panels between the corners. See Figure 64 below and Figure 67 on page 34. If shear walls can not be placed at the corners, they should be located as near to the corner as possible.

Shear wall configurations should conform to ratios that limit height to width. See Figure 29 on page 19 and Table 3 on page 39. With a ratio of 2:1 for height to width, and considering a usual story height of 8'–0", the minimum width of wall to be provided at each corner of each exterior wall should be 4'–0" for moderate and high seismic risk areas. This ratio limit is also recommended for low seismic risk areas.

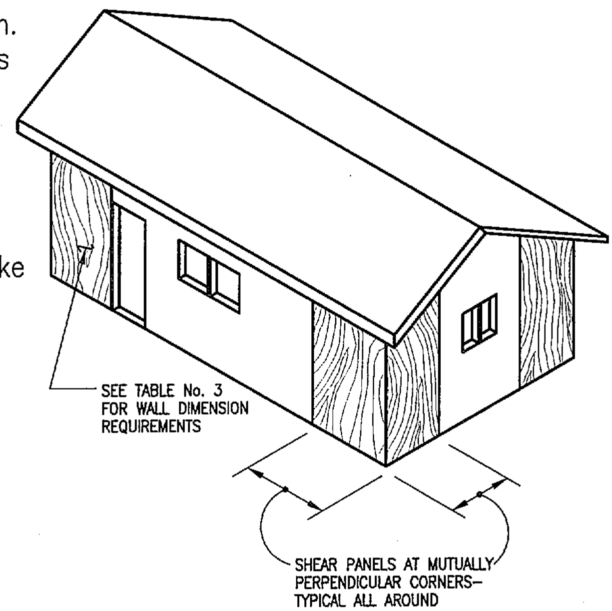
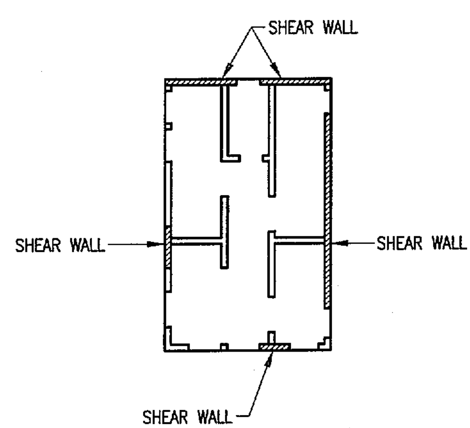


Figure 62



UNBALANCED SHEAR WALL CONDITION

Figure 63

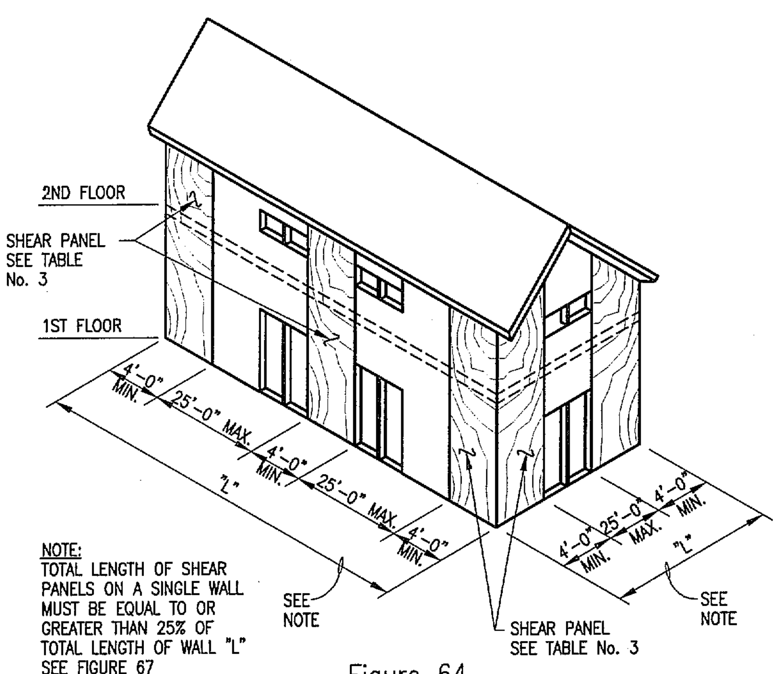
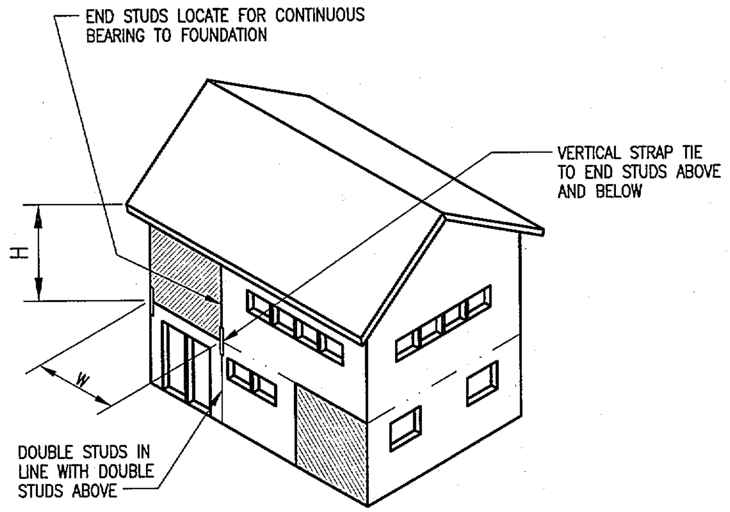
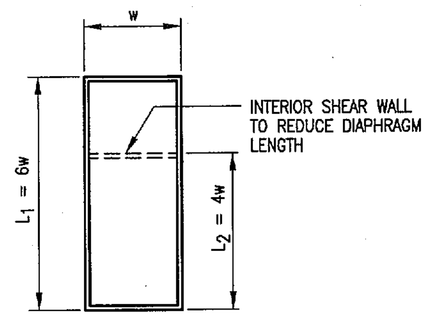


Figure 64



OFFSET SHEAR WALL

Figure 65



PLAN

Figure 66

Where horizontal diaphragm ratios are exceeded, interior shear walls are needed to reduce the diaphragm ratio. See Figure 66. Because interior shear walls are permanent and may interfere with flexibility in modifying floor layouts, care should be taken in determining their locations. When needed, interior shear walls should be walls that are natural separations such as garage walls or other walls regarded as permanent and should have a minimum number of openings. Plumbing walls should be avoided for use as shear walls.

The reasons for avoiding torsional rotation of buildings has been previously discussed. In equalizing the length of shear walls on all sides of a building, it is important to remember that the difference in stiffness in long and short walls is not directly proportional to the lengths of the walls. Equivalent stiffness of shear walls cannot be obtained by providing two separate 8' lengths of wall along one side and one 16' length along the other. Shear walls should not be spaced more than a prescribed distance apart (varies by seismic risk area, see Section 14 BUILDING CODES). Intermediate shear panels will be needed in long exterior wall lines.

Shear walls should extend continuously from foundation to roof line in single-story buildings and from foundation to floor line and floor line to roof line in two-story buildings. In two-story construction, it is not necessary for the shear walls to line up one above the other, but such continuity is encouraged to increase the stiffness of the wall. See Figures 65 and 68. If the walls in the top story are offset from the walls below, the overturning forces in the end studs or posts of the wall above must be carried down through the wall framing below to the foundation. The end studs could be located above a header, but special precautions must be taken to secure the studs to the header and the header to its supporting framing. Cripple studs should be placed under each end of the header. The studs supporting the header should be tied to the sill plate with framing clips or a hold-down.

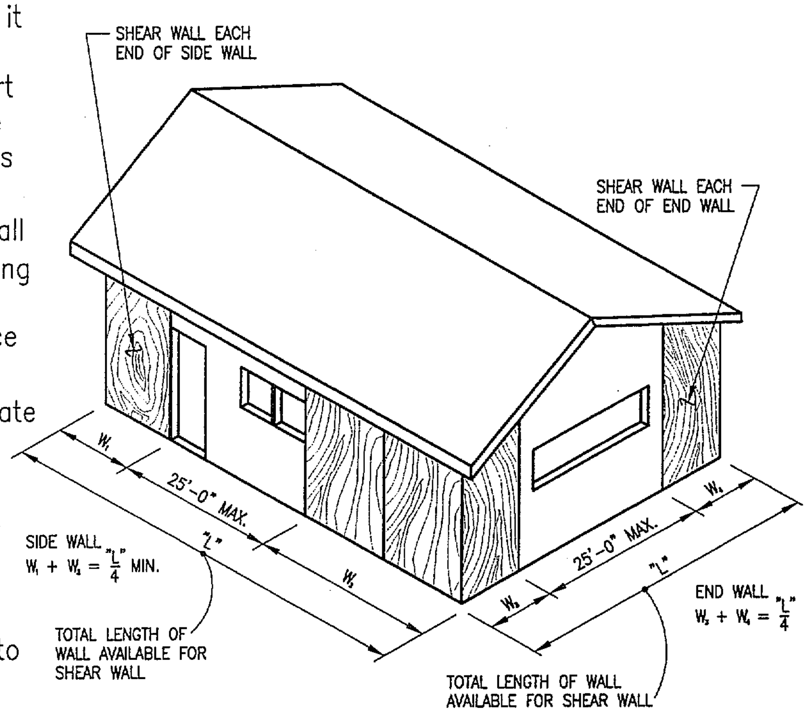
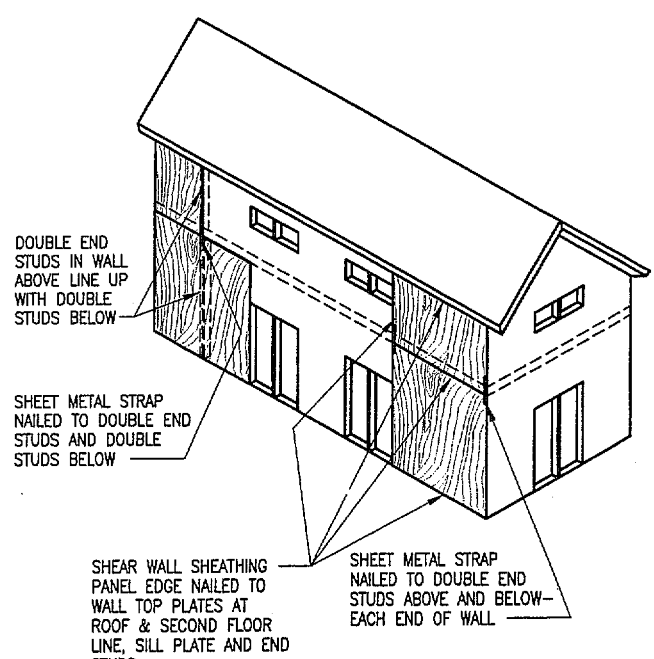


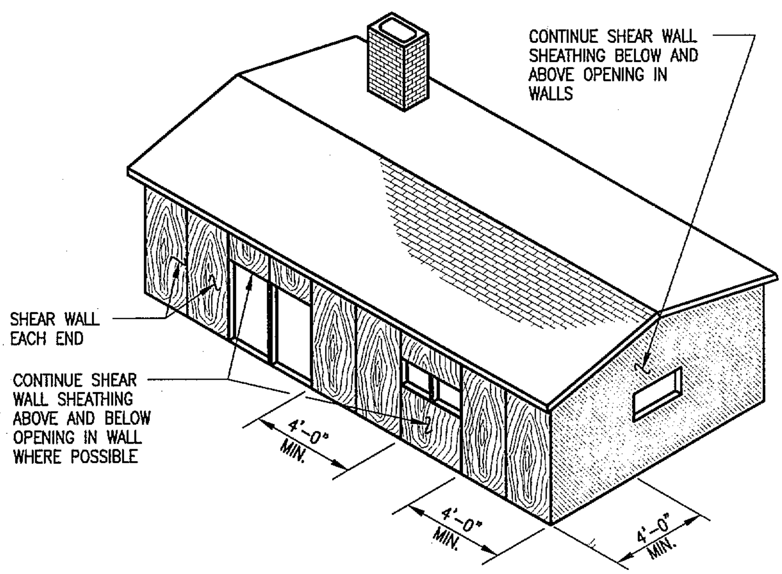
Figure 67



SHEAR WALL 2 STORY
HIGH SEISMIC RISK AREA

Figure 68

Shear walls should be solidly sheathed with limited openings for doors or windows. Small penetrations for vent openings are permissible, but there should not be more than one opening for every eight feet of wall length. Penetrations or openings should be avoided in 4'-0" long shear walls. Doors and windows should be centered in a wall, where possible; but, in any case, the edge of any opening should not be positioned within sixteen inches (16") of the vertical edge of a shear wall. The wall should extend a minimum of two feet eight inches (2'-8") beyond the other vertical edge of an opening. Wherever possible, the wall sheathing should continue above and below an opening. See Figure 69. In no case should openings interrupt sill plates or wall top plates.



WALL ELEVATION–
HIGH SEISMIC RISK AREA

Figure 69

Cripple stud walls are sometimes used to support floor framing over crawl spaces, partial height basement walls, stepped foundations, and split-level floor framing. Cripple walls must be sheathed as shear walls to transfer earthquake forces from the walls above the foundations. The widths of cripple shear walls and the construction details should be the same as for shear walls on the floor above, although the individual walls can be offset. In no case should there be less width of shear wall available in the cripple wall than there is in the wall above.

Four types of sheathing are permitted by code for shear walls. See Table No. 3 on page 39. Ideally, the same type of sheathing should be used throughout any level of any building. Sheathing should conform to the prescriptive requirements of applicable building codes.

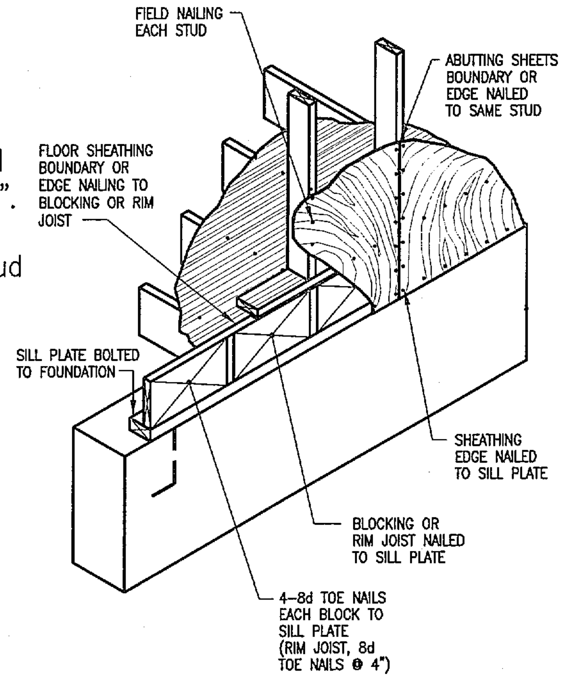
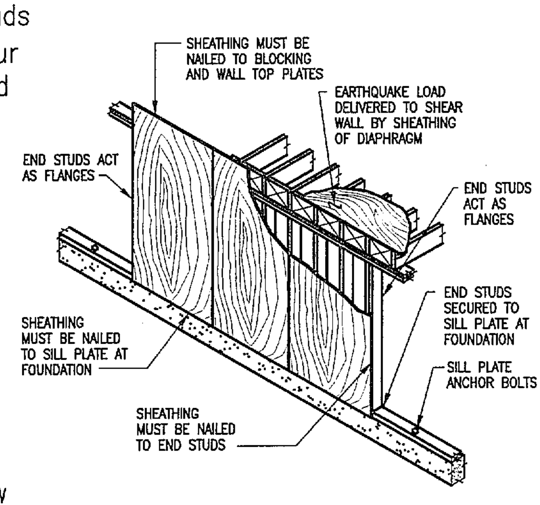


Figure 70

1) Wood Structural Panel (plywood or oriented strand board) for exterior and interior shear walls should be a structural grade with exterior glue and a minimum thickness of 3/8". When installed with long edges vertical, sheets should have vertical butt joints on the centerline of the same stud and the sheathing should extend from the sill plate to the wall top plates, rim joist or blocking. See Figures 70 and 71. Sheets may be installed with long edges horizontal, but the horizontal edges of each sheet should be nailed to flat blocking between studs. Sheathing should be edge nailed along all edges of each sheet. Wider spaced nailing to intermediate studs in the field of each sheet is also required. For high seismic risk areas, a 5 ply, 1/2" thick structural grade plywood is recommended for best performance and for added stiffness to reduce damage. See Figures 70, 71, 75 and 77.

2) Diagonal sheathing, although not commonly used, is still permitted by code in all seismic risk areas. If used it should consist of 1" nominal boards installed at an angle of 45 degrees to the studs. The boards should be nailed to each stud with two 8d nails for 1x 6 boards and three 8d nails for 8" wide boards. In addition, 6" boards must be edge nailed to sill plates, wall top plates and wall end studs with three 8d nails and 8" boards must be nailed with four 8d nails. Butt joints of adjacent boards must be separated by at least two stud spaces.



SHEAR WALL

Figure 71

3) Gypsum board may be used in all seismic risk areas, but experience from the Northridge Earthquake indicates that gypsum board should not be used in high seismic risk areas unless significant damage in the event of a strong earthquake is considered acceptable. The wall board may be applied with the long dimension parallel or perpendicular to the studs with flat blocking provided for all unsupported edges. Although gypsum board is discouraged in areas of high seismic risk, it is considered adequate as sheathing for shear walls in moderate and low seismic risk areas. See Table No. 3. For high and moderate seismic risk areas gypsum wall board sheathing should only be used on very long walls in order to keep stresses low. It is recommended that at least 50% of any exterior wall should be sheathed and the minimum length of each shear panel should be 8'–0".

4) Stucco applied over metal lath nailed directly to the studs can also be used to resist earthquakes. In high seismic risk areas, self–furring lath may not be reliable.
Lath should be nailed to the studs, sills and wall top plates. Applying the lath with staples is not recommended in high seismic risk areas. In the Northridge Earthquake, it was noted that where stucco was used with lath or furring applied directly to the studs extensive damage resulted from the earthquake shaking. Where stucco is used in high seismic risk areas, it is recommended that plywood or oriented strand board be used on shear walls with the lath applied to the face of sheathing. Metal lath can be nailed directly to the face of studs on portions of the walls not sheathed.

In high seismic risk areas, the overall performance of a building can be improved by continuing the sheathing across the entire wall from end to end. The sheathing should continue above and below window and door openings. See Figure 69. The type of sheathing should be uniform throughout. Plywood or oriented strand board is recommended.

Proper nailing of the sheathing is very important. Only nail types specified in building codes should be used and substitution of sinker or cooler nails for box or common nails is not permitted. Nailing guns should be adjusted to prevent overdriving and damaging the sheathing. Edge distances and nail spacing should be maintained. In high seismic risk areas, staples should not be substituted for nails unless staples have been tested for use with the specific application.

Two methods are available for bracing steel stud shear walls. Conventional practice is to use light gage steel diagonal strap bracing. See Figures 78 and 80 for wall bracing and Figure 79 for bracing at garage door openings. The straps should be in an "X" configuration or diagonally opposing each other with the straps being one piece from the sill plate to the wall top plates. Straps are secured to light gage steel gusset plates with sheet metal screws The straps should be attached to the studs at each stud crossing. Plywood sheathing can also be used over steel stud framing. Screws must be used to fasten the plywood to the studs and plates. Spacing and edge distances should be the same as for nails.

In the discussion of seismic resistant systems, it was noted that shear walls may tend to lift up at corners when resisting earthquake loads. To prevent this, the end studs or posts of shear walls should be anchored to the foundation with hold–down devices. See Figure 72. Hold–down anchors are usually needed at ends of shear walls where walls run parallel with the joists or rafters. Where bearing loads on the walls are sufficient to keep the walls from lifting at their ends hold–downs are not required.

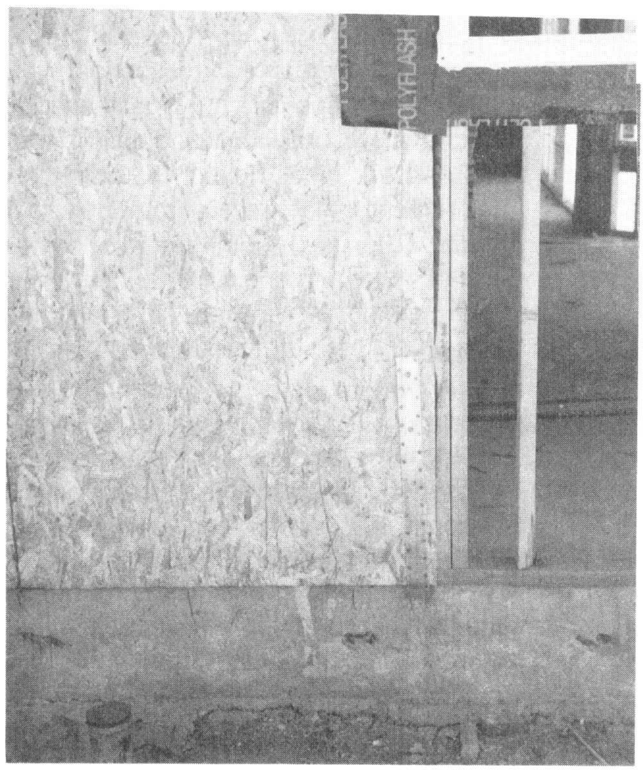


Figure 72

Several types of hold–down anchors are available and the types used should be based on the amount of uplift expected. i.e. short shear walls in high seismic risk areas need stronger devices. The most effective hold–down devices are either bolted or screwed to posts and bolted to the foundations. Where used they should be provided at each end of a shear wall. Hold–down bolts should be retightened just before closing in the walls. Other hold–down devices are available that can be embedded in the foundation and nailed to the end studs or posts. Strap hold–downs are desirable for all shear walls but can be omitted in areas of low seismic risk or as noted above. See Figure 76.

An attached garage on the side or end of a house may present a special problem as narrow wall elements on each side of the garage door opening may not function effectively as shear walls and will not, in most cases, meet height to width ratio requirements. To prevent rotation of the garage roof diaphragm special construction of the walls perpendicular to the garage door opening is required or a rigid steel frame can be put across the open front. See APPENDIX pages (A4) and (A5). If a shear wall is available adjacent to or in line with the garage door opening, it may be used to stabilize the garage and must be constructed as a conventional shear wall with earthquake loads transferred to the wall by continuous top plates or other collector or drag strut members. See Figure 73.

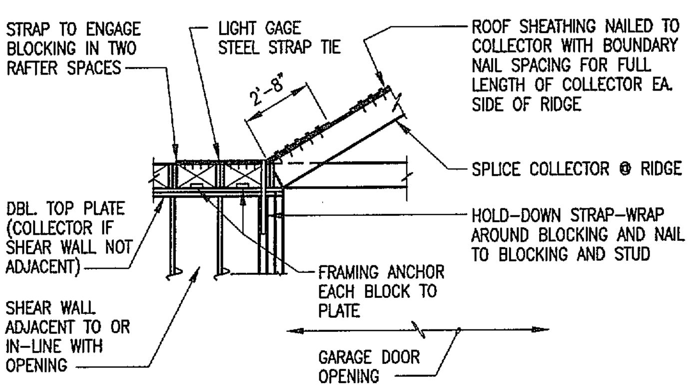


Figure 73

Where walls parallel to the roof framing do not extend uninterrupted to the roof sheathing they may require lateral support at the level of the top plates. See Figure 74. This detail is applicable primarily in high seismic risk areas, but should be considered for all seismic risk areas where wind loads are a concern. For gabled roofs, where this condition is most likely to occur, it is better to use full length studs from foundation to the roof plate line.

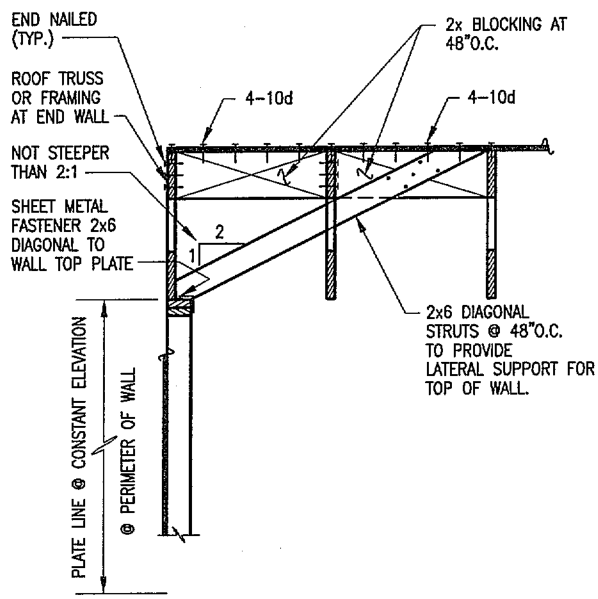
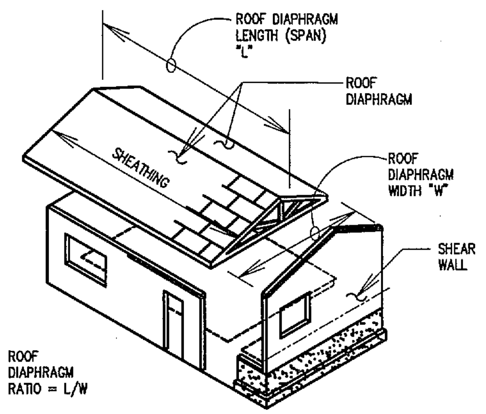
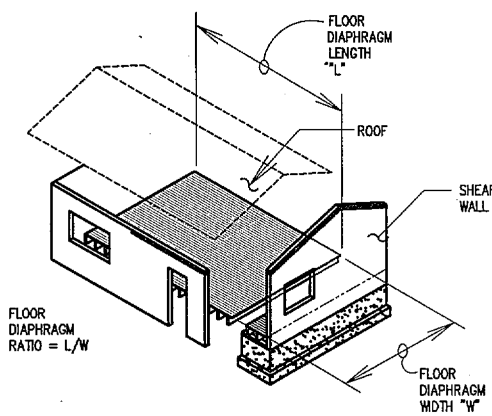
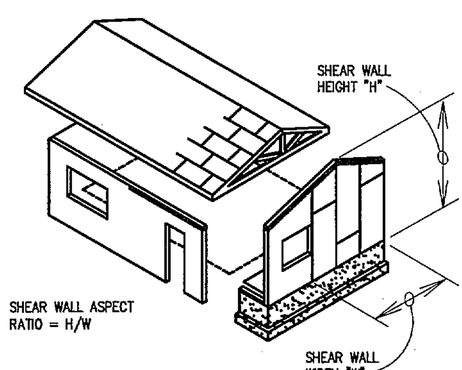
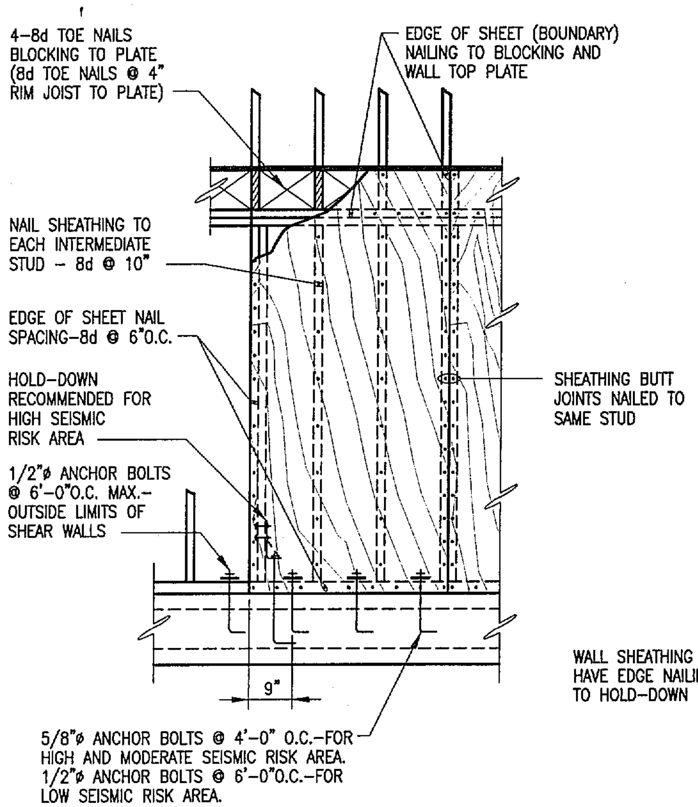


Figure 74

Table No. 3 Maximum Floor and Roof Diaphragm and Wall Aspect Ratios

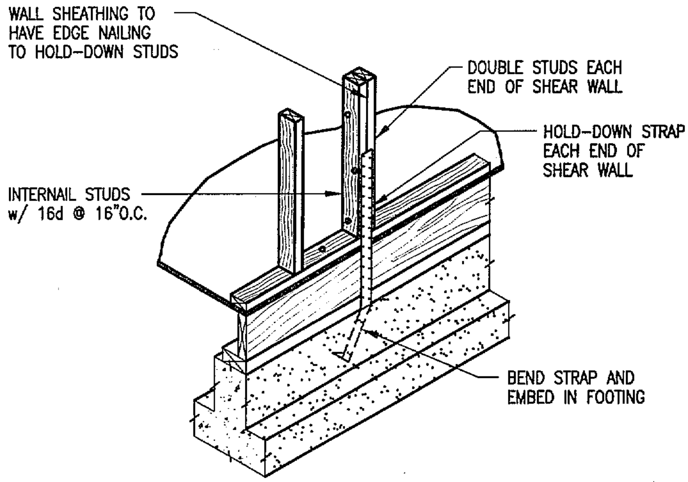
	Sheathing		Seismic Risk	L/W	H/W
 ROOF DIAPHRAGM	Wood Structural Panel	Plywood	High	4*	
			Moderate	4*	
			Low	4	
		Oriented Strand Board	High	4*	
			Moderate	4*	
			Low	4	
	Diagonal Sheathing		High	2	
			Moderate	2	
			Low	2	
	Straight Sheathing		Low	2	
 FLOOR DIAPHRAGM	Wood Structural Panel	Plywood	High	4*	
			Moderate	4*	
			Low	4	
		Oriented Strand Board	High	4*	
			Moderate	4*	
			Low	4	
	Diagonal Sheathing		High	2	
			Moderate	3	
	Straight Sheathing		Low	2	
 SHEAR WALL	Wood Structural Panel Plywood Oriented Strand Board		High		2
			Moderate		2
			Low		$3\frac{1}{2}$
	Gypsum Board Stucco		High		2
			Moderate		2
			Low		3
	Diagonal Sheathing		Moderate		2
			Low		$3\frac{1}{2}$

* All edges blocked. Reduce to 3 for unblocked edges.



WOOD STRUCTURAL PANEL
SHEATHED SHEAR WALL

Figure 75



STRAP HOLD-DOWN

Figure 76

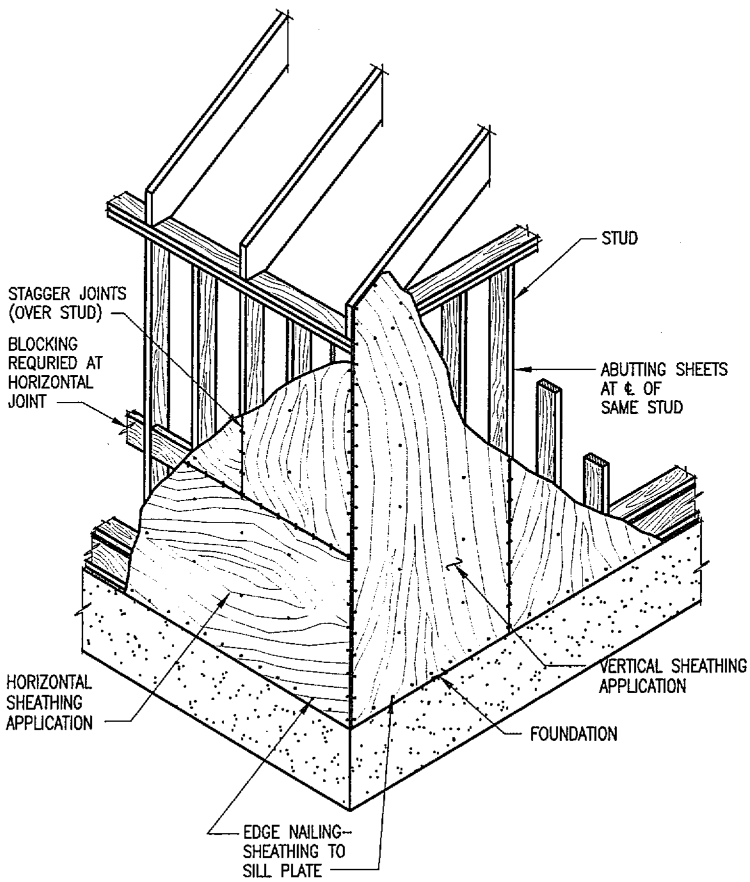


Figure 77