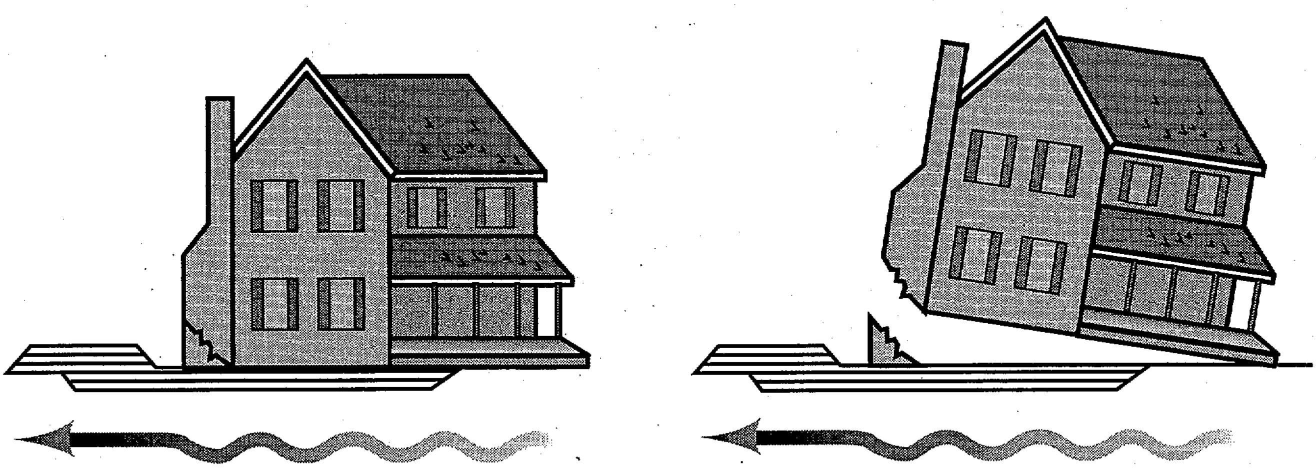
FEDERAL EMERGENCY MANAGEMENT AGENCY FEMA 232/AUGUST 1998

HOME BUILDER'S GUIDE TO SEISMIC RESISTANT CONSTRUCTION



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FEDERAL EMERGENCY MANAGEMENT AGENCY

HOME BUILDERS GUIDE TO SEISMIC RESISTANT CONSTRUCTION

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ACKNOWLEDGMENTS

PREFACE

One of the primary goals of the Federal Emergency Management Agency (FEMA) and the National Earthquake Hazards Reduction Program (NEHRP) is to encourage design and building practices that address the earthquake hazard and minimize the resulting damage to both life and property. The cornerstone of FEMA's program to accomplish this goal is *mitigation* — that is, to strengthen the building and all of its' components against the force of the earthquake *before* it strikes.

This Guide updates, revises, and replaces the FEMA-232 Document, dated July 1992, which was based on "The Home Builder's Guide for Earthquake Design", published by the Department of Housing and Urban Development (HUD) in June 1980.

FEMA wishes to express its gratitude to the contractor, "SOHA Engineers", and the many subcontractors, contributers, and reviewers that were involved in this effort. It was their hard work and dedication that resulted in the successful completion of this guide.

Federal Emergency Management Agency

1. INTRODUCTION, BACKGROUND AND SEISMIC RISK AREAS

A. INTRODUCTION

The primary purpose of this Home Builders Guide to Seismic Resistant Construction, hereafter referred to as the "Guide", is to encourage homeowners and builders of one and two family residences to employ construction practices intended to provide resistance to damage from earthquakes. This Guide can be used as a convenient resource for gaining an understanding of the basic principles of seismic resistant construction. The Guide presents a discussion of how earthquake forces impact conventional residential construction. A discussion is included on how basic structural components can be assembled to achieve earthquake resistance and how essential features such as foundations, walls, floors and roofs interact to resist earthquakes. Warnings are included regarding special requirements for easily damaged components and configurations such as masonry chimneys, masonry veneers, split level plans and floor plan irregularities.

By using information available in the Guide, residential units can be built with structural features that are positioned, dimensioned, constructed and interconnected properly to resist earthquakes. The Guide incorporates lessons learned from the 1994 Northridge and other recent earthquakes. Application of the principles contained in the Guide should improve the overall quality of the home building process and will result in better performance of residential buildings.

Limitations on the application of information presented in the Guide must be carefully reviewed. The Guide is NOT a substitute for seismic resistant design provisions of the applicable local Building Code. The Guide may not be used in place of the Building Code. It is a reference document providing details of construction some of which may not be specifically described or presented in the Code.

In regions where earthquake resistance is of interest, but seismic resistant construction practices are not required by code or regulation, the Guide can provide direction to builders. Also, in some instances, the Guide will recommend construction practices that are more conservative than code requirements. These are usually the result of lessons learned from the Northridge and other earthquakes. Following the recommended practices in this Guide should result in better performing houses. The Guide may not apply to conditions found in the design and construction of houses that do not conform to conventional configurations and construction practices. Specific reference to unusual conditions are noted in the Guide. Professional guidance in designing earthquake resistant houses should be sought where houses do not conform to conventional configurations.

Details should not be selected at random from the Guide. A complete earthquake resistance system requires all the necessary elements to be present. Random selection of details without consideration of the building as a complete system may result in ineffective earthquake resistance.

To use the Guide properly, a builder should first attempt to understand the principles of seismic resistance as they are presented in the Guide. Once the principles are understood, the importance of following the information provided in the Guide will be apparent.

B. BACKGROUND

Three model building codes are available for use by home builders in specific areas of the country. In the western states, the Uniform Building Code (UBC) published by the International Conference of Building Officials (ICBO) is used by most government agencies regulating building construction. Most southern states use the Standard Building Code (SBC) sponsored by the Southern Building Code Congress International (SBCCI). The northeast and parts of the midwest use the National Building Code (NBC) issued by the Building Officials and Code Administrators, International (BOCA). Local codes may apply in certain areas. The three model codes noted above will be replaced by the International Building Code (IBC) scheduled to be released in the year 2000.

The UBC includes prescriptive requirements that apply to residential construction. The other two model Codes refer to the CABO One and Two Family Dwelling Code published by the Council of American Building Officials. This Code is a compilation of data from the model codes and standardizes the requirements for home construction in a single document. The CABO Code is scheduled to be replaced by the International Residential Code (IRC) in the year 2000. The purpose of the model codes, as stated in the UBC, is to provide minimum standards to safeguard life or limb, health, property and the public welfare by regulating the design construction, quality of materials, use, occupancy, location and maintenance of all buildings and structures.

To encourage a national awareness of the hazards of earthquakes, the Federal Emergency Management Agency (FEMA) initiated the preparation of this document.

The Guide is not intended to supplant the CABO One and Two Family Dwelling Code or the three model codes, but rather to offer explanations, advice and construction details for use when constructing a home to provide for resistance to earthquakes. It is a reference to be used by home builders and others to help in understanding how earthquakes cause damage and how homes can be constructed with increased resistance to earthquakes.

In certain areas of the country, other natural hazards such as wind and flood may dictate structural requirements. An analysis of these hazards and their mitigation requirements should be made to compare the recommendations of this Guide with the requirements for other hazards to determine whether construction to mitigate one hazard will satisfy the others.

C. SEISMIC RISK AREAS

Details presented in the Guide are suggested for three areas of earthquake activity and severity in the United States. These three areas are referred to in the Guide as high, moderate and low seismic risk areas. This designation of seismic activity may differ from the methods used by the three model codes and CABO to define areas or zones of seismic activity and risk. See Table No. 5 on page 65 for a comparison of CABO One and Two Family Dwelling Code, SBCCI, BOCA and UBC risk designations and the seismic risk areas used in the Guide. For purposes of this Guide, high, moderate and low seismic risk areas can be determined from a map taken from the Uniform Building Code, see page 65, and comparing the CABO and UBC zone designations with the Seismic Risk Areas indicated in Table 5, page 65.

When referring to this map, the home builder should be aware that the seismic risk areas shown may differ from similar geographical areas or seismic zones which apply locally. If doubt exists as to whether the location is in a high, moderate or low seismic risk area, the local building official should be consulted.

2. PRINCIPLES OF SEISMIC RESISTANCE IN DWELLINGS

Earthquakes result in ground motions, both horizontal and vertical, which can be compared to waves. The motion is generally vibratory and will cause a structure to move rapidly first in one direction and then another.

Earthquakes generate internal forces in a structure due to inertia. Inertia can be described as the tendency of a body at rest to remain at rest and a body in motion to remain in motion. See Figure 1. The internal forces depend on the direction of ground motion caused by an earthquake and act side to side (horizontal) and/or up and down (vertical). The more pronounced earthquake forces are usually horizontal, i.e., lateral forces acting back and forth parallel to the ground. Because the ground motion moves back and forth, the effects of inertia cause a building to be distorted and can result in severe damage. The effects of vertical acceleration are normally considered to be offset by the building weight and will only cause damage in unusual situations.

The sketches shown in Figure 2 illustrate the effects of inertia on a simple structure caused by back and forth motion parallel to the ground. Similar effects would occur if the ground were stationary and a horizontal force was applied in a back and forth manner at the roof line. Earthquake effects are usually represented in this manner. The objective of earthquake resistant construction is to resist the effects of ground movement.

In the remaining discussion, applied forces parallel to the ground (horizontal or lateral) will be considered as representative of earthquake forces.

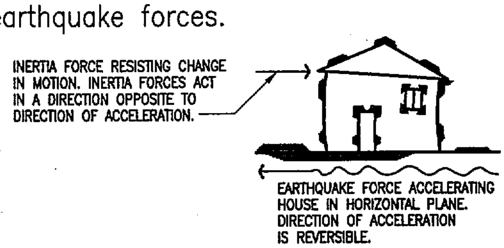


Figure 1

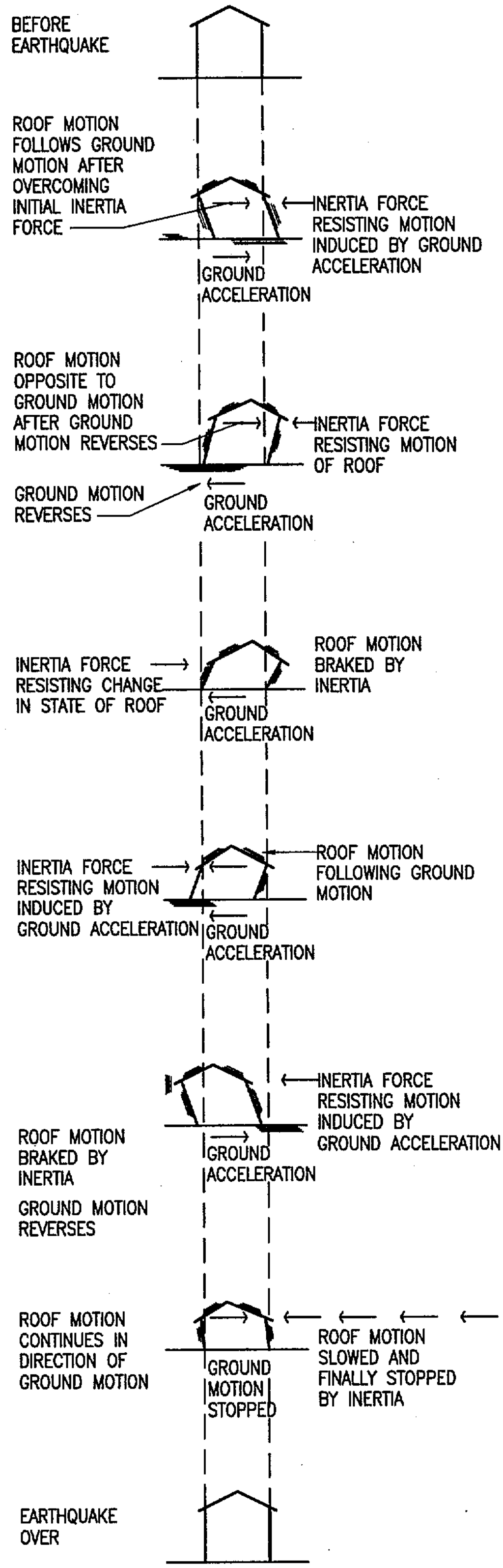


Figure 2

In discussing earthquake resistance in subsequent sections, engineering terminology will be used that may not be familiar to the user of the Guide. The most frequently used terms are:

Shear – the tendency of a force applied to one part of an element to cause sliding relative to the remainder of the element along a plane parallel to the force. See Figure 3.

Tension – the force causing the pulling apart of one element from another or causing elongation of a material. See Figure 4.

Compression – the force causing pushing of one element on another or causing shortening of material. The opposite of tension. See Figure 5.

Chord – used as a synonym for flange of a diaphragm or shear wall.

Collector – a member (usually wall top plates) used to accumulate forces from a horizontal diaphragm along the portion of its length where no shear wall exists and delivers the forces to a shear wall or another diaphragm. See Figure 11.

Diaphragm Ratio – The ratio of the length to width of a horizontal diaphragm. See Figure 6.

Aspect Ratio – The ratio of the height to width of a shear wall. See Figure 6.

Deflection/Drift – The displacement of the top of the wall relative to the fixed bottom of the same wall.

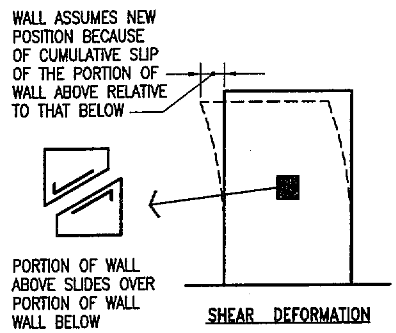


Figure 3

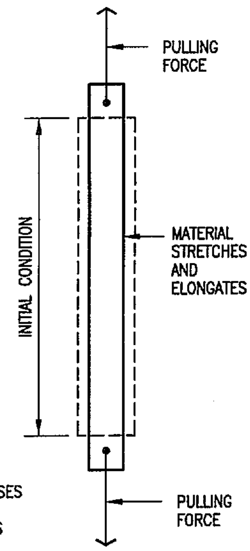


Figure 4

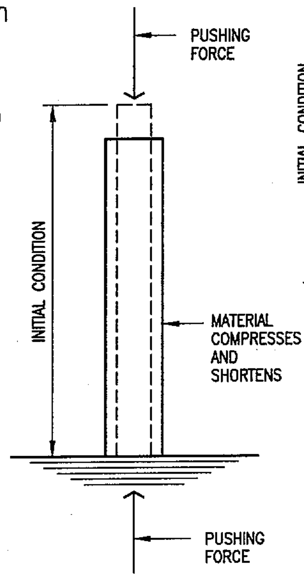


Figure 5

Conventionally constructed dwellings can resist earthquake forces because of their box-like configuration. To be effective, the box-like configuration must be complete and well tied together, with mostly square or rectangular floors and roofs and solid wall panels on all four sides of the building. This is presented in Figure 7.

Roofs and framed floors are known as horizontal diaphragms. Floors are usually flat and in the same plane. Roofs may be flat, pitched or gabled. Each roof configuration can be made to function effectively as a horizontal diaphragm as shown in Figures 8 and 9.

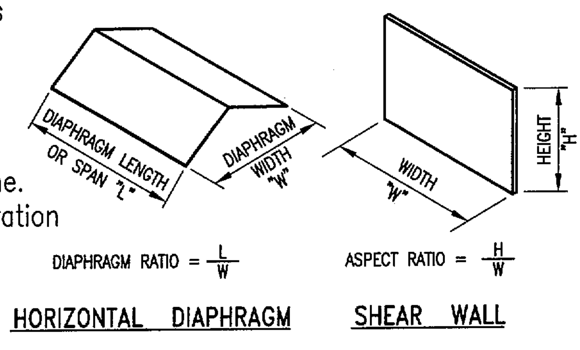


Figure 6

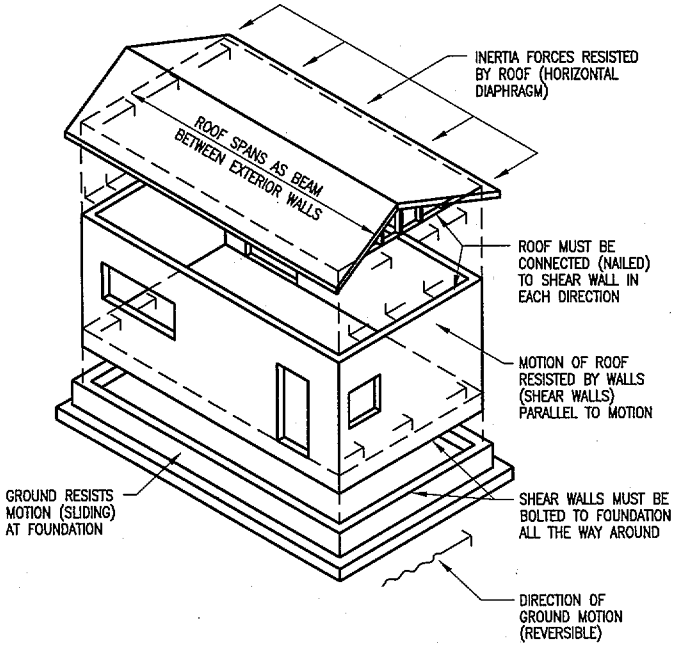


Figure 7

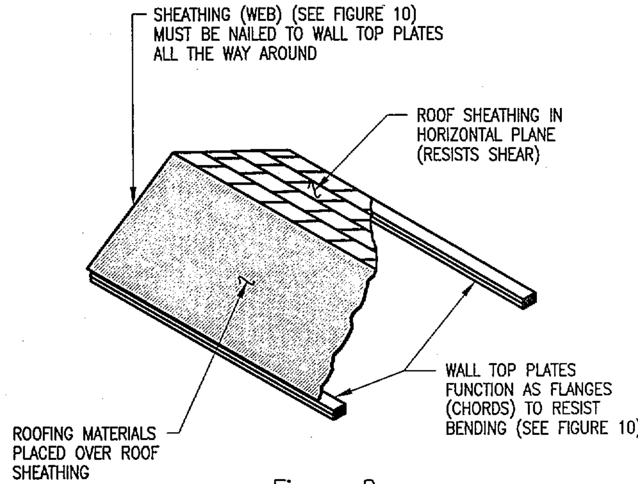


Figure 8

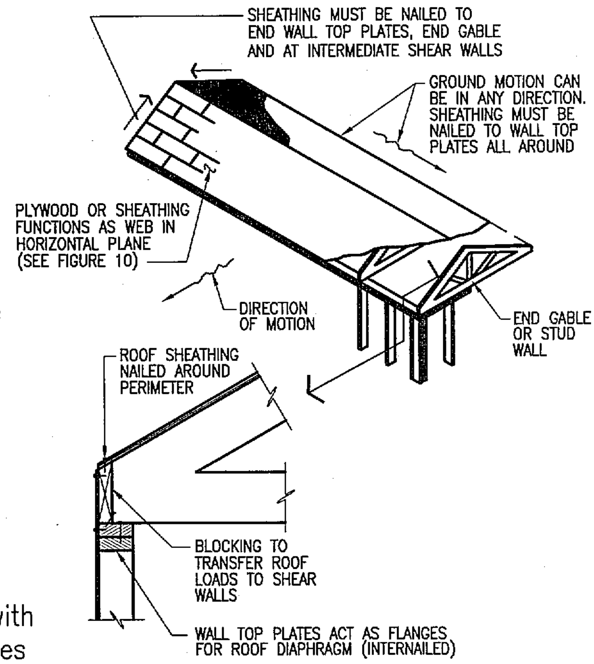


Figure 9

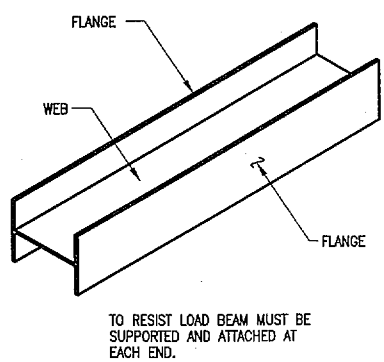


Figure 10

A horizontal diaphragm can be compared to a steel wide flange beam laid on its side with the web oriented in a horizontal plane and the flanges in a vertical plane. In residential construction, the exterior wall top plates act as flanges and the roof sheathing functions as the web. The flanges (top plates) carry tension or compression and the roof sheathing transmits the shear stresses caused by the earthquake. See Figures 9 and 10.

Those walls resisting the horizontal forces are known as shear walls or, in the case of a resisting element being a portion of a longer wall, as a shear panel. See Figure 7.

Shear walls or panels can be pictured as upright beams with the end studs of the sheathed portion acting as the flanges and the sheathing between end studs as the web. Thus, shear walls are the same as vertical cantilever beams (a beam supported at one end but not at the other) fixed at the foundation with the top of the wall being loaded by the roof diaphragm. See Figure 15.

Interior and exterior walls can resist the horizontal forces transmitted by the roof and floor diaphragms. Since earthquakes can create forces in any direction, opposite and parallel pairs of walls resist loads in a single direction while each of the exterior walls participates in resisting rotation or torsional distortion of the house. See Figure 11.

If shear walls, properly constructed and anchored, are located on each of four sides of a square or rectangular building and there is a floor and roof that can function as a diaphragm in either direction, then the building functions as a box. See Figure 7.

Provided that the horizontal diaphragms and shear walls are appropriately sized and constructed, forces introduced into a building by an earthquake can be resisted by the box configuration and damage to the building will be minimized.

In order for the box to function properly, the horizontal diaphragms and shear walls must be constructed to resist the induced forces without collapsing the box. It is essential that the horizontal diaphragm be connected to the shear walls and the shear walls be securely fastened to the foundations. See Figure 12.

In structures such as framed residential buildings, where connections of walls to foundations are adequate to prevent sliding, deflections or drift is the primary cause of damage. In high seismic risk areas, greater consideration should be given to increasing the overall stiffness of a house to control damage to brittle materials such as stucco, gypsum board finshes, interior furnishings, masonry chimneys and veneer, all of which are especially vulnerable to damage from drift. Limiting the height to width ratio of shear walls to two to one (2:1) in high and moderate seismic risk areas, and/or providing more shear wall width than is needed to meet minimum requirements of the building code will contribute to stiffness. Providing the correct location and adequate number of bolts for attaching sills to the foundations will prevent sliding and help to control damage.

Another effect of earthquake forces is to cause overturning of walls or shear panels. This tendency to rock on the foundation can be resisted by anchors that will hold the wall to the foundation, commonly referred to as hold–downs. With reference to Figure 13, as the ground accelerates to the left the inertia forces act in the opposite manner, to the right. Hold–down anchors should be inserted at the ends of shear walls to resist rocking. Since earthquake forces oscillate back and forth, hold–downs should be placed at each end of a shear wall or panel. See Figures 13 and 14.

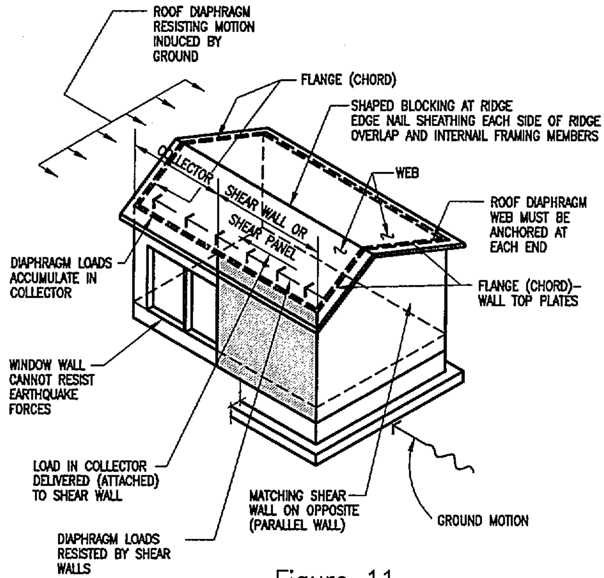


Figure 11

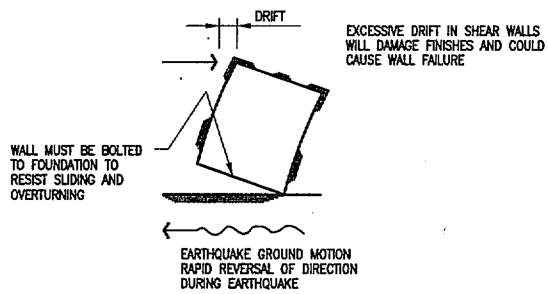


Figure 12

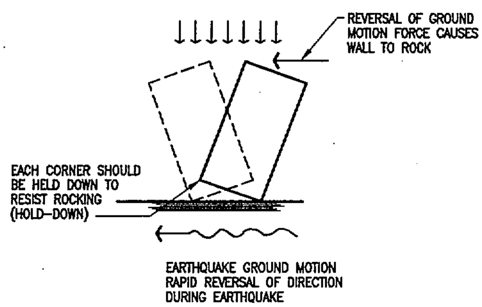


Figure 13

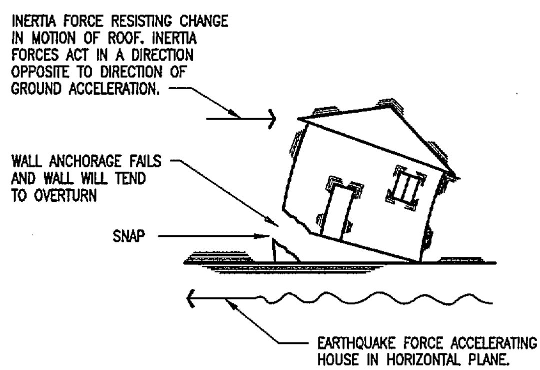


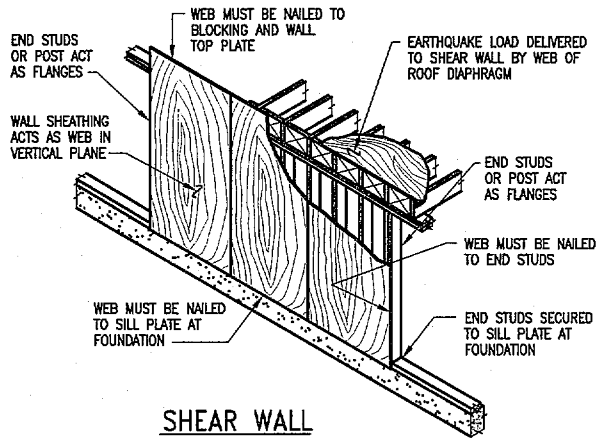
Figure 14

Earthquake forces in shear walls are transferred to the walls and back to the ground through the foundation. For one and two family dwellings, a continuous foundation located under the perimeter walls and interior shear walls is most commonly used. See Figure 16.

Sheathing of diaphragms and shear walls resists earthquake induced shear forces. Several types of sheathing are available. Plywood*, oriented strand board*, gypsum board and stucco are often used on wood framed shear walls. Plywood and oriented strand board are most effective. See Figure 15. All sheathing must be fastened to the framing. Nails are most often used. See Figure 17. The type of nails used can vary, but common or box nails are preferred for plywood and oriented strand board. Cooler nails are most frequently used with gypsum board. Staples have not proved to be universally satisfactory for attaching plywood or oriented strand board and should be avoided in high and moderate seismic risk areas unless proven installation methods are followed for the specific use.

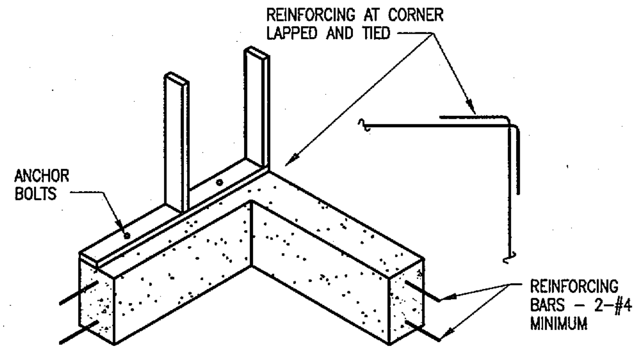
The degree of earthquake resistance required depends on the location and risk factor associated with that particular region of the country. The Guide uses high, moderate and low seismic risk area designations. The map on page 64 used together with Table 5 on page 65 indicates locations of the seismic risk areas.

* Wood Structural Panel



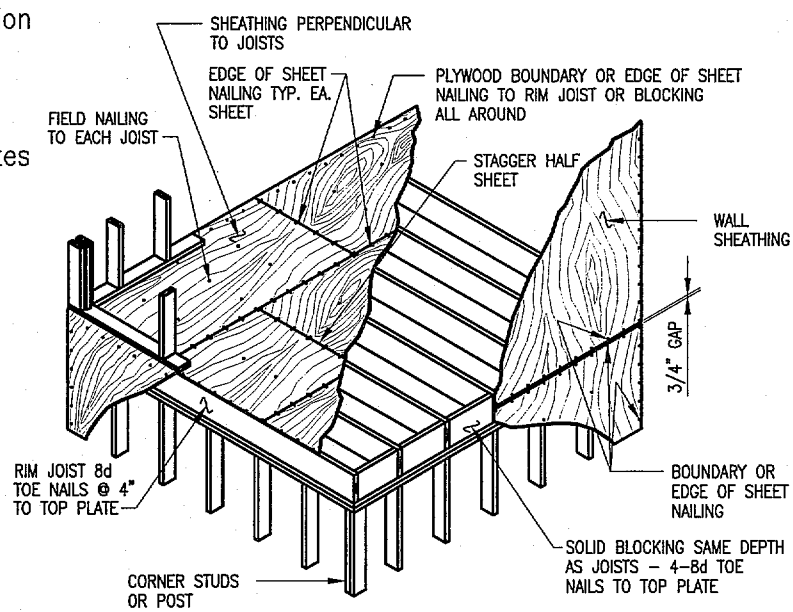
SHEAR WALL

Figure 15



CONTINUOUS FOUNDATION

Figure 16



NOTE:
ORIENTED STRAND BOARD LOCATED WITH LONG DIMENSION OF STRANDS PERPENDICULAR TO JOISTS

TYPICAL DIAPHRAGM

Figure 17

In the past, home builders have used all wood products for the construction of one and two family houses. Most builders are thoroughly familiar with the materials and construction practices for conventional wood construction. With growing concerns for the depletion of the country's natural resources and environmentalists' concern for clear cutting forests, cold–formed steel framing is coming into greater usage. Homes framed in steel employ steel studs and roof trusses made of cold–formed steel members or joists or rafters also fabricated from cold–formed steel material. Connections of framing members are usually made with self–tapping sheet metal screws. Conventional wall covering materials such as gypsum board and stucco are applied to the studs in a manner similar to that for wood framing. Because cold–formed steel framing for residential construction is not yet widely used, building codes have not adopted conventional construction requirements for this material. In some areas of the country using the UBC, cold–formed steel framing must be designed by a design professional.

Cold–formed steel construction for seismic resistance is similar to that for wood framing. Steel stud framed shear walls can be braced with light–gage steel diagonal straps fastened with self tapping sheet metal screws. The straps are usually positioned in an "X" pattern. See Figure 18. The building official having jurisdiction should be consulted as to whether the use of plywood sheathing over steel studs is allowed for seismic resistance.

As in wood framed construction, hold–downs are usually required at each end of a shear wall. Hold–downs, in general, are steel strap type anchors with one end buried in the foundation and the projecting strap screwed to the edge of the steel studs in the end of the wall.

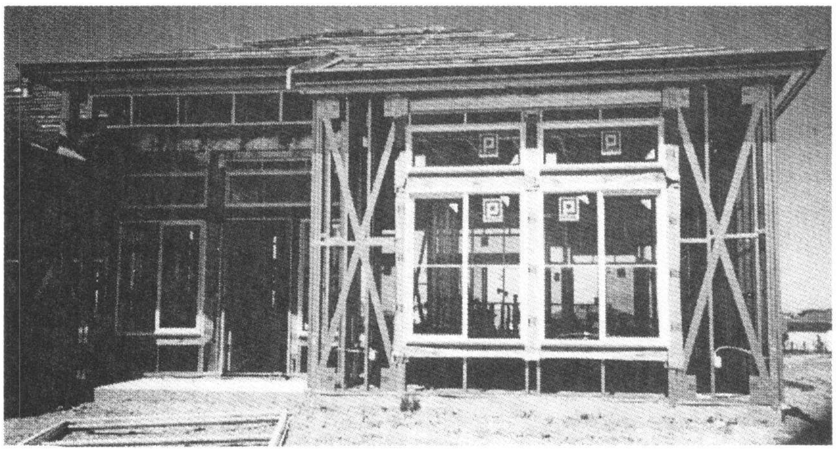


Figure 18

3. ARCHITECTURAL CONSIDERATIONS

The Guide has been developed for application to simple, conventional plans with regular and typical architectural features, see Appendix A. The Guide is most useful for dwellings with the following characteristics.

1) Regular or symmetrical floor plans.

2) Floor plans with balanced widths of shear wall or bracing in each exterior wall.

3) Elevations with limited openings.

4) Roof shapes that are symmetrical with minimal offsets and limited openings.

5) Conventional wall framing systems. Typically these are wood stud walls, steel stud walls, clay masonry walls and concrete masonry walls.

6) Chimneys located and anchored as described in the Guide.

Example floor plans indicating some of the most beneficial features for making residential buildings resistant to earthquake shaking are shown in the Appendix. These plans represent regular and reasonably symmetrical configurations. Variations of these plans that incorporate most of the features of the plans shown in the Appendix are appropriate for use with the Guide.

Architectural expression in dwellings may not be limited to conventional floor plans and exterior elevations. The guidelines and recommendations for earthquake resistant construction formulated for conventional types of dwellings may not apply to irregular or unusual structures. In general, however, adoption of the details and procedures outlined in this Guide should increase the ability of any building to resist earthquake forces. Some irregular and unusual structures may have details and configurations that are especially vulnerable to earthquake damage particularly in high and moderate seismic risk areas. Methods to specifically deal with these details and configurations are not covered in the Guide.

The following dwelling types and configurations listed below are not included in this Guide. Table No. 1 on page 11 illustrates 5 common examples.

1) Platform framing on stilt supports.

2) Post and beam framing with long, uninterrupted expanses of glass.

3) Overhanging two story construction where the exterior walls do not continue to the ground.

4) Staggered floor systems involving more than two levels.

5) Exterior glass walls without shear panels.

6) Floors and roofs with extreme overhangs and balconies.

7) Pole-supported framing.

8) Attached carports with open sides and corner posts.

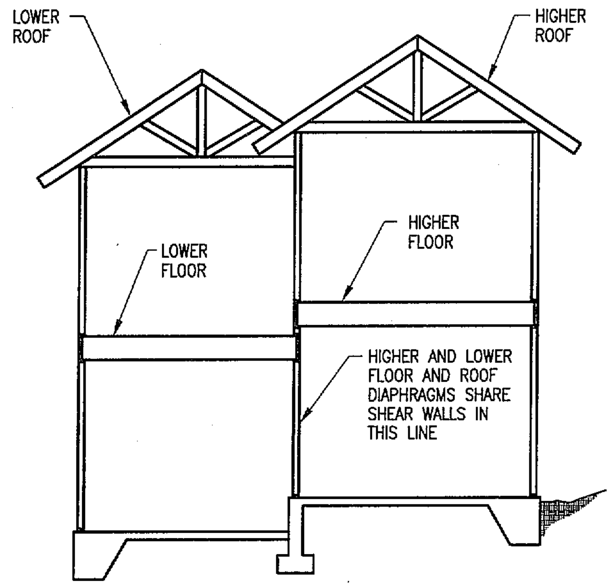
9) Open courtyards with all glass building wall enclosures.

10) Buildings constructed on slopes steeper than 3:1.

It is possible to build earthquake resistive dwellings which have configurations and features such as those described above. However, the Guide is not appropriate for use with such dwellings without consultation with design professionals familiar with earthquake resistant design. Many of the details included in the Guide may be helpful to design professionals.

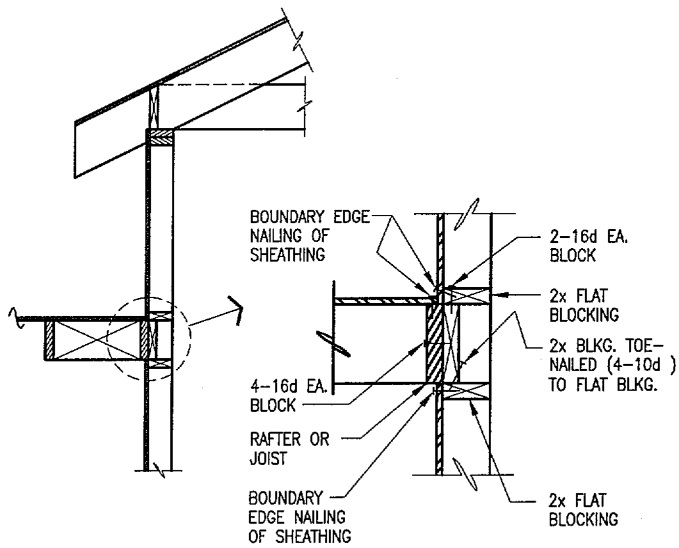
Split–level construction is defined as construction having two floor levels separated by a vertical offset that interrupts the planes of the floor or roof diaphragms. Figure 19 illustrates an offset at the floor and roof levels.

Split–level houses require special details at the plane of intersection of the floors and roof with the wall. Details are included in the Guide to provide for connecting elements together to resist earthquakes. Split–level homes can be particularly vulnerable to damage in high and moderate seismic risk areas unless appropriate details as presented in the Guide are used. Figure 20 shows an example of the type of detail needed. See Section 7 for additional discussion of split–level construction.



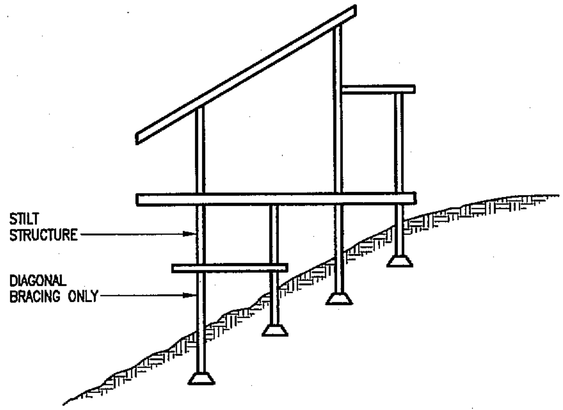
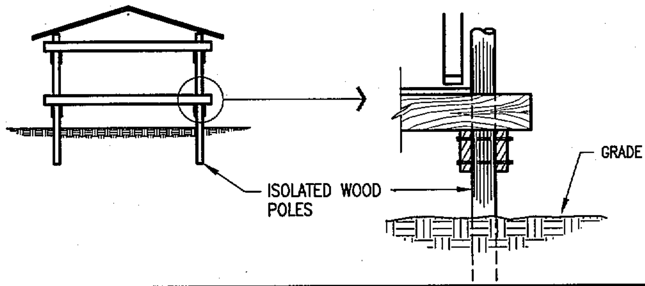
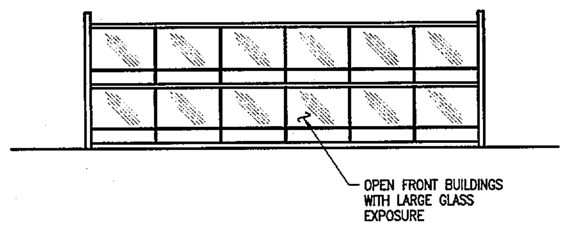
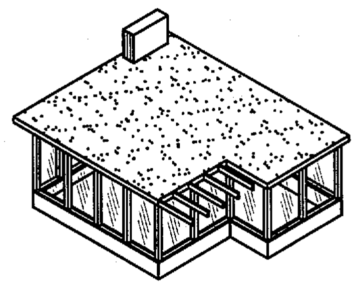
Note
See Split–Level Floor Tie Details on Page 31

Figure 19



SPLIT–LEVEL TIE
FRAMING PERPENDICULAR TO
SHEAR WALL

Figure 20

Table No. 1 Architectural Design Exclusions	
Platform Framing on Stilt Supports	
Pole Supported Houses	
Long, Uninterrupted Exterior Glass Walls	
Post and Beam Framing with All Glass Exterior Exposure	
Overhanging Two Story Construction (Corner Columns Do Not Continue to Ground)