Seismic Retrofit Guidelines for Detached, Single-Family, Wood-Frame Dwellings

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U.S. DEPARTMENT OF HOMELAND SECURITY

FEMA

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Seismic Retrofit Guidelines for Detached, Single-Family, Wood-Frame Dwellings

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Notice

Cover Photos: Source: FEMA G225-CD, *Seismic Retrofit Training for Building Contractors & Inspectors*, 2006.

Foreword

The Federal Emergency Management Agency (FEMA) has the goal of reducing the ever-increasing cost that disasters inflict on our country. Preventing losses before they happen by designing and building to withstand anticipated forces from these hazards is one of the key components of mitigation, and is the only truly effective way of reducing the cost of disasters. As part of its responsibilities under the National Earthquake Hazards Reduction Program (NEHRP), and in accordance with the National Earthquake Hazards Reduction Act of 1977 (PL 94-125) as amended, FEMA is charged with supporting activities necessary to improve technical quality in the field of earthquake engineering. The primary method of addressing this charge has been supporting the investigation of seismic technical issues as they are identified by FEMA, the development and publication of technical design and construction guidance products, the dissemination of these products, and support of training and related outreach efforts.

In recent earthquake events, typical wood-frame residential structures were observed to have suffered more damage than had traditionally been thought. This risk is magnified by the sheer numbers of these buildings that exist in moderate and high seismic regions in our country.

This residential seismic retrofit guidelines document and a companion seismic assessment procedure were originally developed by the Applied Technology Council (ATC) for the City of Los Angeles using FEMA disaster funds following the 1994 Northridge earthquake. At a recent workshop on seismic rating systems, one of the recommendations was to update and expand that original ATC-50 seismic assessment system for national use. FEMA supported the development of the expanded residential rating system (FEMA P-50) and this accompanying retrofit guidelines document (FEMA P-50-1) to be applicable in all high seismic areas of the country. FEMA supported this work not to promote the use of a residential rating system, but to provide a tool that communities or other entities could then use to encourage the seismic retrofitting of residential structures, thereby reducing future earthquake losses.

FEMA wishes to express its gratitude to Robert Bruce, the principal developer of this report, and the Project Review Panel of Kelly E. Cobeen, Susan Dowty, Ronald T. Eguchi, and Douglas C. Hohbach.

Federal Emergency Management Agency

Preface

In September 2011 the Applied Technology Council (ATC), with funding from the Federal Emergency Management Agency (FEMA) under Task Order Contract HSFEHQ-08-D-0726, commenced the updating of the ATC-50-1 report, *Seismic Retrofit Guidelines for Detached, Single-Family, Wood-Frame Dwellings* (ATC, 2002), which had been written for use in Los Angeles, California. The project's purpose was to make the ATC-50-1 document nationally applicable and, at the same time, take advantage of technological developments, including code developments, that have occurred since 2002. The update effort was one of several projects in a task order series to develop written guidance for FEMA on the creation, update, and maintenance of seismic evaluation and retrofit documents for existing buildings.

The ATC-50-1 report was originally developed in 2002 (first printing) and modified in 2007 (second printing) to include updated contact information for important related resources. The original project was prompted by high economic losses resulting from damage to single-family, wood-frame dwellings during the 1994 Northridge earthquake, and focused on the development and testing of standardized procedures for voluntary seismic evaluation and retrofit. In addition to the ATC-50-1 report, two additional documents were also prepared in the original project: (1) the ATC-50 report, *Simplified Seismic of Detached Detached, Single-Family, Wood-Frame Dwellings*; and (2) the ATC-50-2 report, *Safer at Home in Earthquakes: A Proposed Earthquake Safety Program.*

In a separate recent related FEMA-funded project, ATC also updated the ATC-50 report to incorporate an expanded Simplified Seismic Assessment Form for national application. Evaluation of a dwelling using the Simplified Seismic Assessment Form enables an inspector to assign a Seismic Performance Grade for the dwelling and identify portions of the dwelling in need of retrofit. The updated document is now available as FEMA P-50, *Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings* (FEMA, 2012).

This FEMA P-50-1 *Guidelines* document includes specific guidance for retrofitting a dwelling's seismic deficiencies (identified using the FEMA P-50 Simplified Seismic Assessment Form) and potentially improving its

Seismic Performance Grade. The updated *Guidelines* incorporate methods that utilize:

- the Cripple Wall and Anchorage Provisions of the *International Existing Building Code*;
- the *International Residential Code* Provisions
- prescriptive or engineered methods for the retrofit of nonstructural building elements; and
- engineered structural retrofit procedures.

ATC is indebted to Robert Bruce, who was the principal developer of these updated *Guidelines*, and to the Project Review Panel, which consisted of Kelly E. Cobeen, Susan Dowty, Ronald T. Eguchi, and Douglas C. Hohbach. Thomas R. McLane served as Project Manager, and Peter N. Mork and Bernadette Hadnagy provided report production services. The affiliations of these individuals are provided in the list of Project Participants.

ATC also gratefully acknowledges the input, support, and guidance provided by Michael Mahoney (FEMA Project Officer) and Jennifer Lynette (FEMA Region IX).

Christopher Rojahn
ATC Executive Director

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Chapter 1
Introduction

1.1 Background

As revealed by the extensive damage to thousands of wood-frame houses in moderate-to-large earthquakes in California, such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes, and lesser damage from recent earthquakes in Washington, Illinois, Idaho, Virginia, and Hawaii, many wood-frame homes are vulnerable to damage when exposed to significant earthquake forces. Homes that have been seismically strengthened by key retrofit measures, however, can perform well in earthquakes. Homes retrofitted for earthquake vulnerabilities are safer to live in and easier to sell and insure.

The main purpose of these *Guidelines* is to give the intended users listed in Section 1.2 practical information on retrofit measures to improve the earthquake resistance of a particular home.

These *Guidelines* assume that the home in question has first been evaluated by a trained inspector using the "Simplified Seismic Assessment Form" from the companion FEMA P-50 report, *Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings* (FEMA, 2012), and that retrofit opportunities were identified during the investigation and noted on the assessment form. The assessment form is shown in Figures 1-1 through 1-6.

1.2 Intended Users of the Guidelines

The intended users of these *Guidelines* include building owners, building officials, home inspectors, design professionals, home builders, emergency planners, insurers, lenders, and other persons involved in implementing or using results from the FEMA P-50 simplified seismic assessment methodology.

1.3 Purpose and Scope of the Guidelines

The *Guidelines* address everything from preliminary decisions to illustrations of specific retrofit details. Extra attention is given to retrofits that have the greatest impact on building seismic performance. Well-known vulnerable elements such as cripple walls, porch roofs, water heaters, masonry veneer, and chimneys are addressed.

The intent of the retrofit measures in these *Guidelines* is to promote public safety and welfare by reducing the risk of earthquake-induced damage in existing wood-frame dwellings. The retrofit measures described below do not necessarily strengthen the whole building to new building code seismic requirements, or address all of the building's seismic vulnerabilities. These retrofit measures are intended to significantly reduce damage and increase occupant safety for existing buildings, but they will not make the building immune to all earthquake damage.

1.4 Contents and Organization of the Guidelines

These *Guidelines* have been organized to include concise, practical information, as follows:

Chapter 1, Introduction, discusses the background of the Simplified Seismic Assessment Form, identifies the intended audience, discusses the purpose, scope, and organization of the *Guidelines*, and lists related documents and references.

Chapter 2, Basics of Typical Wood Frame House Construction and Seismic Demand and Resistance, introduces the reader to these topics so that the discussions to follow are more understandable.

Chapter 3, Interpretation of Simplified Seismic Assessment Results, explains the form, and discusses the assessed vulnerability items within each Section, the resulting Structural Score, and the final Seismic Performance Grade. This chapter also discusses the limitations of the simplified assessment approach.

Chapter 4, Retrofit Method Options and Reassessment of the Seismic Performance Grade, presents the prescriptive and engineered Methods 1-4 that may be used to design and construct retrofit measures. (Prescriptive methods do not require engineering calculations) These various methods are based on the *International Building Code* (IBC), *International Residential Code* (IRC), and *International Existing Building Code* (IEBC) documents introduced later in this chapter.

Chapter 5, Detailed House Survey Before Retrofit, describes the survey of the house that a homeowner, contractor or engineer might perform prior to finalizing the design of the retrofit measures. This house survey is similar to but subsequent to the survey performed to complete the Simplified Seismic Assessment Form, and concentrates more on specific conditions to be addressed in the retrofit.

Chapter 6, Method 1: IEBC Cripple Wall Provisions Method, is a detailed description of a cripple wall or basement house retrofit in accordance with the

‘IEBC Cripple Wall and Anchorage Provisions’, the current prescriptive standard for this retrofit method.

Chapter 7, Method 2: Retrofit Method for Nonstructural Building Elements, presents the prescriptive retrofits for nonstructural elements, such as chimneys, masonry veneer, water heaters, porch roofs, and gas-shutoff valves.

Chapter 8 describes Method 4: Engineered Structural Retrofit Method.

Chapter 9, Example Buildings Retrofitted by Methods 1 and 4, provides examples of buildings that have been retrofitted to improve the Seismic Performance Grade, using the retrofit design process for different buildings, seismic hazard zones, and methods.

1.5 Key References

These *Guidelines* refer to several references that serve as the basis for local building codes, or that have been developed from engineering and construction experience and from observations of the past behavior of wood-frame buildings in earthquakes. These include:

- **FEMA P-50:** *Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings* (FEMA, 2012). This companion document describes in detail the Simplified Seismic Assessment procedures and background.
- **IBC:** *International Building Code* (ICC, 2011a). This model code document (or earlier year editions) has been adopted by numerous state and local jurisdictions. It contains the complete provisions for the construction of buildings of any size, including engineered seismic design, which is based on the ASCE/SEI 7 document (below). The *Guidelines* reference the IBC in Chapter 8, Engineered Structural Retrofit, and Chapter 9, Example Building Retrofits.
- **IEBC:** *International Existing Building Code* (ICC, 2011b). This model code document contains numerous sections related to existing buildings. The Chapter 6 prescriptive retrofit method for cripple wall crawl space houses and basement houses of the *Guidelines* is based on the IEBC, Appendix Chapter A3, Prescriptive Provisions for Seismic Strengthening of Cripple Walls and Sill Plate Anchorage of Light, Wood-Frame Residential Buildings.
- **IRC:** *International Residential Code* (ICC, 2011c). This model code document (or earlier year editions) has been adopted by numerous state and local jurisdiction. It contains numerous non-engineered, prescriptive requirements suitable for the construction of one- and two-family

dwellings and townhouses. The *Guidelines* reference the IRC Chapter 6 prescriptive method of determining the seismic adequacy of existing or retrofitted seismic-resisting (shear) walls.

- **ASCE/SEI 7:** *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2012). The seismic hazard maps and specifications in the ASCE/SEI 7 are the basis for the seismic provisions in the IBC.
- **JLC:** *Journal of Light Construction*. This monthly magazine is invaluable for informative articles on wood light-frame construction. The JLC Archives, on DVD, contain all of the magazine articles from 1986 to the present. Searching the Archives by the following topics and subtopics will display numerous articles of interest for the retrofit work as described in these *Guidelines*:
    - Foundation and Sitework – Seismic
    - Framing and Structure – Seismic and Wind Resistance
    - Exterior – Stucco
- **FEMA 232:** *Home Builder's Guide to Seismic Resistant Construction* (FEMA, 2006). This 212-page document contains valuable information on seismic resistant wood-frame construction. While directed primarily to new construction, the document includes information regarding retrofitting. (http://www.fema.gov/library/viewRecord.do?id=2103)

A more complete list of related references can be found in the list of References at the end of this document and in the companion FEMA P-50 document, *Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings*.

FEMA P-50

Simplified Seismic Assessment Form
For Detached, Single-Family, Wood-Frame Dwellings
(Please print all information)

Grade

Street Address ____ Community/Area/City ____ ZIP Code ____ Date ____

Owner ____ Inspector ____ Inspection Form # (optional) ____

For each question, circle only one answer. Circle the one with higher penalty if more than one answer applies. Exception: question B-1

A. Foundation (If the dwelling has a crawl space, the inspector should view all the areas that are accessible.)

		Penalty
*A-1	The exterior footing is:	
a.	continuous concrete or reinforced masonry	[0]
b.	other footing conditions	[4.2]
A-2	The lowest floor of the dwelling is:	
a.	slab-on-grade	[0]
b.	wood framed over crawl space or basement	[2.9]
c.	combination of slab-on-grade and wood framed floor over crawl space or basement	[2.9]
*A-3	At the dwelling crawlspace or basement interior, the lowest floor framing is supported on:	
a.	continuous stem walls or a combination of continuous stem walls and beams on posts bearing on concrete footings/piers	[0]
b.	beams on posts bearing on piers/pad footings	[0.8]
c.	beams on posts supported directly on soil	[2.2]
d.	not applicable: slab-on-grade	[0]
A-4	For a foundation on a slope of 3 horizontal to 1 vertical or steeper, the top of the footing or foundation stem wall on which wall studs or posts are supported is:	
a.	sloped parallel to the ground slope	[3.7]
b.	stepped	[1.8]
c.	at a constant elevation with no steps	[0.6]
d.	not applicable	[0]

		Penalty
*A-5	At the dwelling perimeter walls, where the foundation system supports a wood framed floor:	
a.	the foundation sill plate (mudsill) is bolted to the foundation with average anchor bolt spacing of 72 in. or less	[0]
b.	the foundation sill plate is fastened to the foundation with retrofit anchors equivalent to 72 in. or less anchor bolt spacing	[0]
c.	the anchor bolts have average spacing that is > 72 in. but <= 108 in.	[1.7]
d.	the anchor bolts have > 108 in. average spacing	[4.6]
e.	the foundation sill plates have extensive decay, splitting, or inadequate edge distance at one-third or more of the anchor bolt locations such that significant slip of the sill plate could occur	[10.0]
f.	the anchor bolts have significant corrosion at one third or more of the anchor bolt locations such that significant slip of the sill plate could occur	[10.0]
g.	there are no foundation anchor bolts	[15.0]
h.	there are no foundation sill plates to connect to the foundation	[15.0]
i.	not applicable	[0]
	Total	

B. Superstructure Framing and Configuration (Every accessible area such as the attic and under-floor area that reveals structural elements must be inspected.)

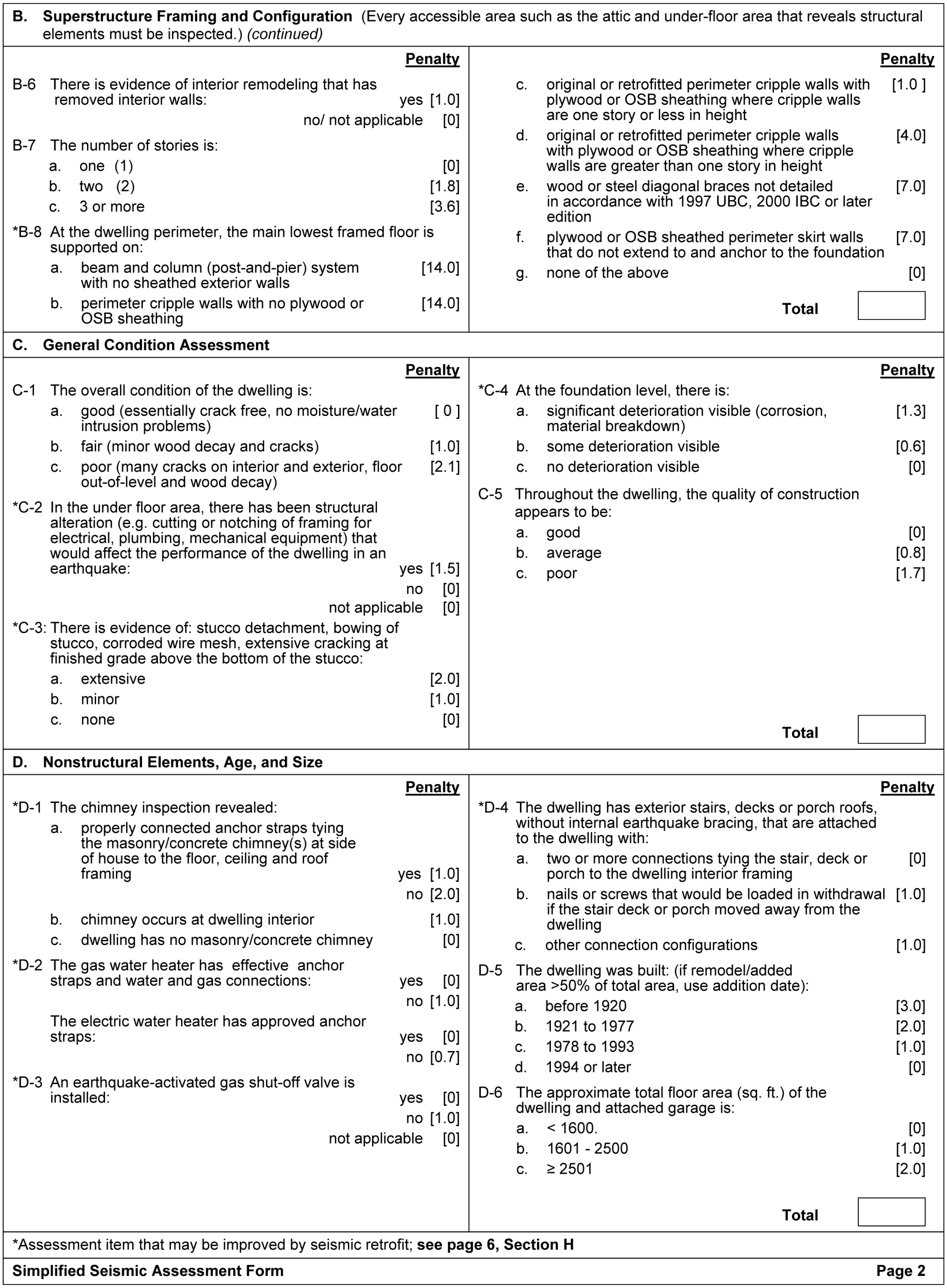
		Penalty
B-1	The dwelling has: (circle all that apply, a to e)	
a.	unsymmetrical wall strength (torsion problems)	yes [1.6]
b.	reentrant corners (seen in plan view)	yes [0.3]
c.	split-level floor construction	yes [2.0]
d.	out-of-plane offsets of more than 4 ft. in exterior walls	yes [0.4]
e.	non-orthogonal seismic resisting systems	yes [0.6]
f.	none of the above, or built in accordance with 1994 UBC, 2000 IBC, 2000 IRC or later edition	yes [0]
*B-2	For exterior walls at the lowest occupied story, the summed length of full story height wall sections (between openings, excluding < 2'-8" panels) on any face is less than:	
a.	20% of the length of the wall, if a single story	yes [3.2]
b.	25% of the length of the wall, if two stories	yes [3.2]
c.	40% of the length of the wall, if three stories or more	yes [3.2]
d.	none of the above	[0]
*B-3	If the roofing is heavy (i.e., clay or concrete tile) the dwelling is:	
a.	single story	[1.6]
b.	multi-story	[3.5]
c.	not applicable: roofing is light.	[0]

		Penalty
*B-4	For an attached garage with a second floor above, the narrow walls at the side of the garage door openings have:	
a.	wood structural panels on each narrow wall pier	[0]
b.	structural steel frames around or alongside the door	[0]
c.	prefabricated narrow shear walls, installed in accordance with manufacturer's recommendations	[0]
d.	none of the conditions specified in conditions a, b, or c above (that are visable)	[3.0]
e.	not applicable (single story) or built in accordance with 1997 UBC, 2000 IBC, 2000 IRC or later edition	[0]
*B-5	The exterior wall covering is primarily:	
a.	siding known to be over plywood or OSB sheathing	[0]
b.	siding not known to be over plywood or OSB sheathing	[2.5]
c.	plywood (T1-11) or diagonal wood siding	[0]
d	stucco	[1.0]
e.	masonry veneer not more than 10 feet above the supporting foundation	[2.5]
f.	masonry veneer more than 10 feet above the supporting foundation	[3.5]

*Assessment item that may be improved by seismic retrofit; **see page 6, Section H**

Simplified Seismic Assessment Form **Page 1**

Figure 1-1 Simplified Seismic Assessment Form, Page 1.



B. Superstructure Framing and Configuration (Every accessible area such as the attic and under-floor area that reveals structural elements must be inspected.) *(continued)*

Penalty

B-6 There is evidence of interior remodeling that has removed interior walls: yes [1.0]
no/ not applicable [0]

B-7 The number of stories is:
- a. one (1) [0]
- b. two (2) [1.8]
- c. 3 or more [3.6]

*B-8 At the dwelling perimeter, the main lowest framed floor is supported on:
- a. beam and column (post-and-pier) system with no sheathed exterior walls [14.0]
- b. perimeter cripple walls with no plywood or OSB sheathing [14.0]
- c. original or retrofitted perimeter cripple walls with plywood or OSB sheathing where cripple walls are one story or less in height [1.0]
- d. original or retrofitted perimeter cripple walls with plywood or OSB sheathing where cripple walls are greater than one story in height [4.0]
- e. wood or steel diagonal braces not detailed in accordance with 1997 UBC, 2000 IBC or later edition [7.0]
- f. plywood or OSB sheathed perimeter skirt walls that do not extend to and anchor to the foundation [7.0]
- g. none of the above [0]

Total ☐

C. General Condition Assessment

Penalty

C-1 The overall condition of the dwelling is:
- a. good (essentially crack free, no moisture/water intrusion problems) [0]
- b. fair (minor wood decay and cracks) [1.0]
- c. poor (many cracks on interior and exterior, floor out-of-level and wood decay) [2.1]

*C-2 In the under floor area, there has been structural alteration (e.g. cutting or notching of framing for electrical, plumbing, mechanical equipment) that would affect the performance of the dwelling in an earthquake: yes [1.5]
no [0]
not applicable [0]

*C-3: There is evidence of: stucco detachment, bowing of stucco, corroded wire mesh, extensive cracking at finished grade above the bottom of the stucco:
- a. extensive [2.0]
- b. minor [1.0]
- c. none [0]

Penalty

*C-4 At the foundation level, there is:
- a. significant deterioration visible (corrosion, material breakdown) [1.3]
- b. some deterioration visible [0.6]
- c. no deterioration visible [0]

C-5 Throughout the dwelling, the quality of construction appears to be:
- a. good [0]
- b. average [0.8]
- c. poor [1.7]

Total ☐

D. Nonstructural Elements, Age, and Size

Penalty

*D-1 The chimney inspection revealed:
- a. properly connected anchor straps tying the masonry/concrete chimney(s) at side of house to the floor, ceiling and roof framing yes [1.0]
  no [2.0]
- b. chimney occurs at dwelling interior [1.0]
- c. dwelling has no masonry/concrete chimney [0]

*D-2 The gas water heater has effective anchor straps and water and gas connections: yes [0]
no [1.0]

The electric water heater has approved anchor straps: yes [0]
no [0.7]

*D-3 An earthquake-activated gas shut-off valve is installed: yes [0]
no [1.0]
not applicable [0]

Penalty

*D-4 The dwelling has exterior stairs, decks or porch roofs, without internal earthquake bracing, that are attached to the dwelling with:
- a. two or more connections tying the stair, deck or porch to the dwelling interior framing [0]
- b. nails or screws that would be loaded in withdrawal if the stair deck or porch moved away from the dwelling [1.0]
- c. other connection configurations [1.0]

D-5 The dwelling was built: (if remodel/added area >50% of total area, use addition date):
- a. before 1920 [3.0]
- b. 1921 to 1977 [2.0]
- c. 1978 to 1993 [1.0]
- d. 1994 or later [0]

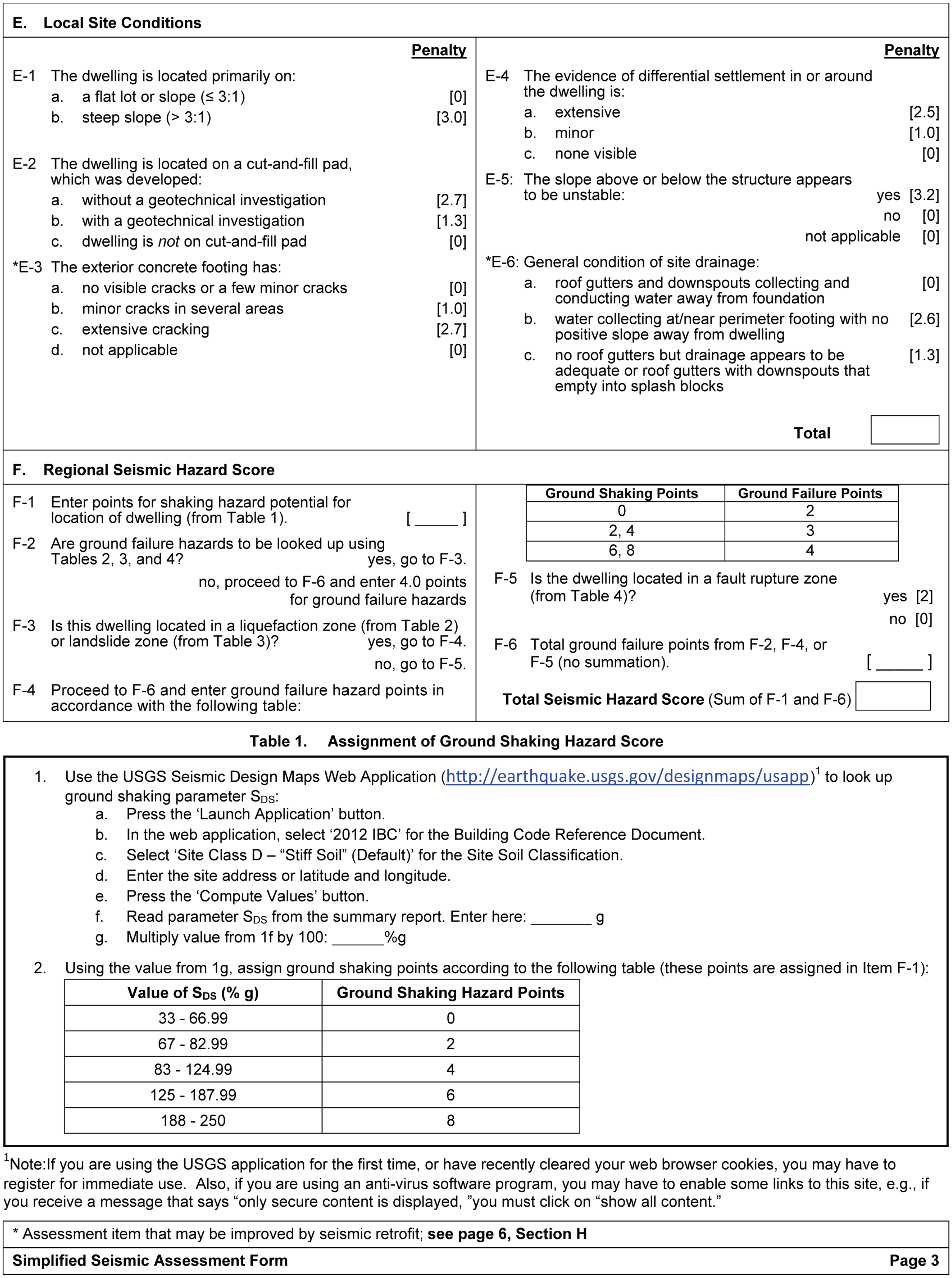
D-6 The approximate total floor area (sq. ft.) of the dwelling and attached garage is:
- a. < 1600. [0]
- b. 1601 - 2500 [1.0]
- c. ≥ 2501 [2.0]

Total ☐

*Assessment item that may be improved by seismic retrofit; **see page 6, Section H**

Simplified Seismic Assessment Form **Page 2**

Figure 1-2 Simplified Seismic Assessment Form, Page 2.



E. Local Site Conditions

Penalty

E-1 The dwelling is located primarily on:
  a. a flat lot or slope (≤ 3:1) [0]
  b. steep slope (> 3:1) [3.0]

E-2 The dwelling is located on a cut-and-fill pad, which was developed:
  a. without a geotechnical investigation [2.7]
  b. with a geotechnical investigation [1.3]
  c. dwelling is *not* on cut-and-fill pad [0]

*E-3 The exterior concrete footing has:
  a. no visible cracks or a few minor cracks [0]
  b. minor cracks in several areas [1.0]
  c. extensive cracking [2.7]
  d. not applicable [0]

Penalty

E-4 The evidence of differential settlement in or around the dwelling is:
  a. extensive [2.5]
  b. minor [1.0]
  c. none visible [0]

E-5: The slope above or below the structure appears to be unstable: yes [3.2]
  no [0]
  not applicable [0]

*E-6: General condition of site drainage:
  a. roof gutters and downspouts collecting and conducting water away from foundation [0]
  b. water collecting at/near perimeter footing with no positive slope away from dwelling [2.6]
  c. no roof gutters but drainage appears to be adequate or roof gutters with downspouts that empty into splash blocks [1.3]

Total ☐

F. Regional Seismic Hazard Score

F-1 Enter points for shaking hazard potential for location of dwelling (from Table 1). [_____]

F-2 Are ground failure hazards to be looked up using Tables 2, 3, and 4? yes, go to F-3.
  no, proceed to F-6 and enter 4.0 points for ground failure hazards

F-3 Is this dwelling located in a liquefaction zone (from Table 2) or landslide zone (from Table 3)? yes, go to F-4.
  no, go to F-5.

F-4 Proceed to F-6 and enter ground failure hazard points in accordance with the following table:

Ground Shaking Points	Ground Failure Points
0	2
2, 4	3
6, 8	4

F-5 Is the dwelling located in a fault rupture zone (from Table 4)? yes [2]
  no [0]

F-6 Total ground failure points from F-2, F-4, or F-5 (no summation). [_____]

Total Seismic Hazard Score (Sum of F-1 and F-6) ☐

Table 1. Assignment of Ground Shaking Hazard Score

1. Use the USGS Seismic Design Maps Web Application (http://earthquake.usgs.gov/designmaps/usapp)[1] to look up ground shaking parameter S_{DS}:
   a. Press the ‘Launch Application’ button.
   b. In the web application, select ‘2012 IBC’ for the Building Code Reference Document.
   c. Select ‘Site Class D – “Stiff Soil” (Default)’ for the Site Soil Classification.
   d. Enter the site address or latitude and longitude.
   e. Press the ‘Compute Values’ button.
   f. Read parameter S_{DS} from the summary report. Enter here: _______ g
   g. Multiply value from 1f by 100: ______%g
2. Using the value from 1g, assign ground shaking points according to the following table (these points are assigned in Item F-1):

Value of S_{DS} (% g)	Ground Shaking Hazard Points
33 - 66.99	0
67 - 82.99	2
83 - 124.99	4
125 - 187.99	6
188 - 250	8

[1] Note:If you are using the USGS application for the first time, or have recently cleared your web browser cookies, you may have to register for immediate use. Also, if you are using an anti-virus software program, you may have to enable some links to this site, e.g., if you receive a message that says “only secure content is displayed, ”you must click on “show all content.”

* Assessment item that may be improved by seismic retrofit; **see page 6, Section H**

Simplified Seismic Assessment Form **Page 3**

Figure 1-3 Simplified Seismic Assessment Form, Page 3.

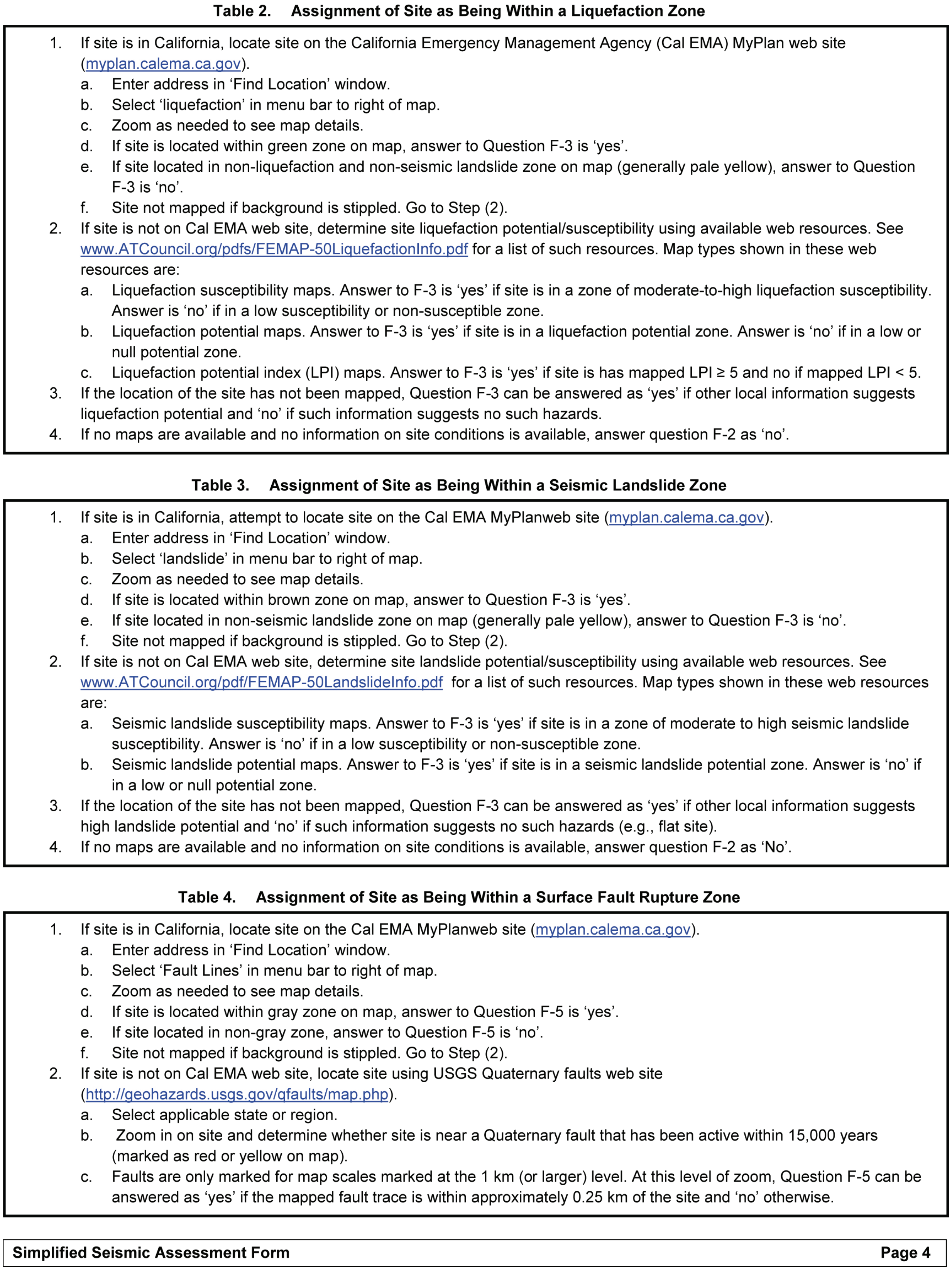


Table 2. Assignment of Site as Being Within a Liquefaction Zone

1. If site is in California, locate site on the California Emergency Management Agency (Cal EMA) MyPlan web site (myplan.calema.ca.gov).
   a. Enter address in 'Find Location' window.
   b. Select 'liquefaction' in menu bar to right of map.
   c. Zoom as needed to see map details.
   d. If site is located within green zone on map, answer to Question F-3 is 'yes'.
   e. If site located in non-liquefaction and non-seismic landslide zone on map (generally pale yellow), answer to Question F-3 is 'no'.
   f. Site not mapped if background is stippled. Go to Step (2).
2. If site is not on Cal EMA web site, determine site liquefaction potential/susceptibility using available web resources. See www.ATCouncil.org/pdfs/FEMAP-50LiquefactionInfo.pdf for a list of such resources. Map types shown in these web resources are:
   a. Liquefaction susceptibility maps. Answer to F-3 is 'yes' if site is in a zone of moderate-to-high liquefaction susceptibility. Answer is 'no' if in a low susceptibility or non-susceptible zone.
   b. Liquefaction potential maps. Answer to F-3 is 'yes' if site is in a liquefaction potential zone. Answer is 'no' if in a low or null potential zone.
   c. Liquefaction potential index (LPI) maps. Answer to F-3 is 'yes' if site is has mapped LPI ≥ 5 and no if mapped LPI < 5.
3. If the location of the site has not been mapped, Question F-3 can be answered as 'yes' if other local information suggests liquefaction potential and 'no' if such information suggests no such hazards.
4. If no maps are available and no information on site conditions is available, answer question F-2 as 'no'.

Table 3. Assignment of Site as Being Within a Seismic Landslide Zone

1. If site is in California, attempt to locate site on the Cal EMA MyPlanweb site (myplan.calema.ca.gov).
   a. Enter address in 'Find Location' window.
   b. Select 'landslide' in menu bar to right of map.
   c. Zoom as needed to see map details.
   d. If site is located within brown zone on map, answer to Question F-3 is 'yes'.
   e. If site located in non-seismic landslide zone on map (generally pale yellow), answer to Question F-3 is 'no'.
   f. Site not mapped if background is stippled. Go to Step (2).
2. If site is not on Cal EMA web site, determine site landslide potential/susceptibility using available web resources. See www.ATCouncil.org/pdf/FEMAP-50LandslideInfo.pdf for a list of such resources. Map types shown in these web resources are:
   a. Seismic landslide susceptibility maps. Answer to F-3 is 'yes' if site is in a zone of moderate to high seismic landslide susceptibility. Answer is 'no' if in a low susceptibility or non-susceptible zone.
   b. Seismic landslide potential maps. Answer to F-3 is 'yes' if site is in a seismic landslide potential zone. Answer is 'no' if in a low or null potential zone.
3. If the location of the site has not been mapped, Question F-3 can be answered as 'yes' if other local information suggests high landslide potential and 'no' if such information suggests no such hazards (e.g., flat site).
4. If no maps are available and no information on site conditions is available, answer question F-2 as 'No'.

Table 4. Assignment of Site as Being Within a Surface Fault Rupture Zone

1. If site is in California, locate site on the Cal EMA MyPlanweb site (myplan.calema.ca.gov).
   a. Enter address in 'Find Location' window.
   b. Select 'Fault Lines' in menu bar to right of map.
   c. Zoom as needed to see map details.
   d. If site is located within gray zone on map, answer to Question F-5 is 'yes'.
   e. If site located in non-gray zone, answer to Question F-5 is 'no'.
   f. Site not mapped if background is stippled. Go to Step (2).
2. If site is not on Cal EMA web site, locate site using USGS Quaternary faults web site (http://geohazards.usgs.gov/qfaults/map.php).
   a. Select applicable state or region.
   b. Zoom in on site and determine whether site is near a Quaternary fault that has been active within 15,000 years (marked as red or yellow on map).
   c. Faults are only marked for map scales marked at the 1 km (or larger) level. At this level of zoom, Question F-5 can be answered as 'yes' if the mapped fault trace is within approximately 0.25 km of the site and 'no' otherwise.

Simplified Seismic Assessment Form **Page 4**

Figure 1-4 Simplified Seismic Assessment Form, Page 4.

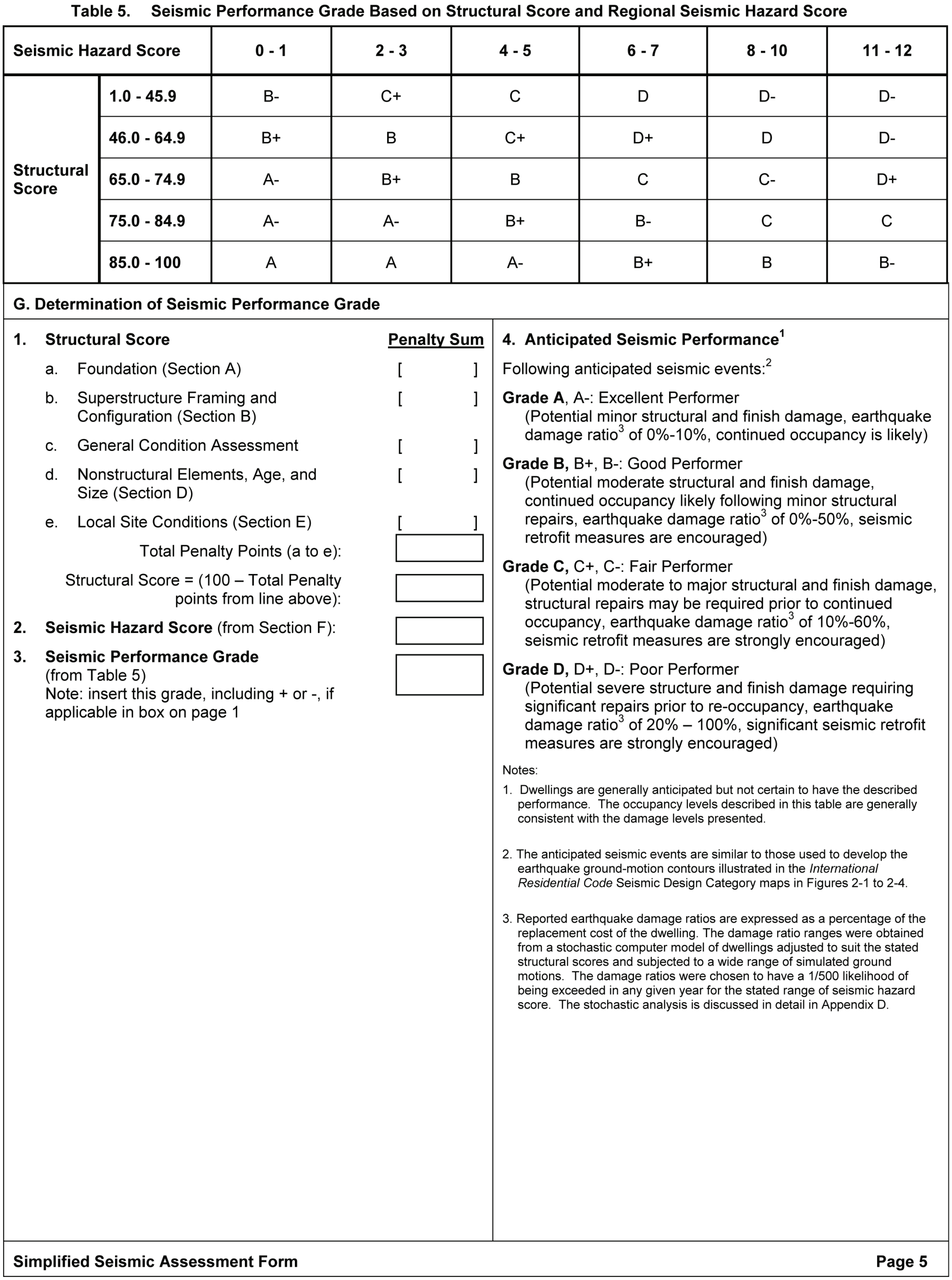


Table 5. Seismic Performance Grade Based on Structural Score and Regional Seismic Hazard Score

Seismic Hazard Score		0 - 1	2 - 3	4 - 5	6 - 7	8 - 10	11 - 12
Structural Score	**1.0 - 45.9**	B-	C+	C	D	D-	D-
	46.0 - 64.9	B+	B	C+	D+	D	D-
	65.0 - 74.9	A-	B+	B	C	C-	D+
	75.0 - 84.9	A-	A-	B+	B-	C	C
	85.0 - 100	A	A	A-	B+	B	B-

G. Determination of Seismic Performance Grade

1. Structural Score **Penalty Sum**

a. Foundation (Section A) [ ]

b. Superstructure Framing and Configuration (Section B) [ ]

c. General Condition Assessment [ ]

d. Nonstructural Elements, Age, and Size (Section D) [ ]

e. Local Site Conditions (Section E) [ ]

Total Penalty Points (a to e): ☐

Structural Score = (100 – Total Penalty points from line above): ☐

2. Seismic Hazard Score (from Section F): ☐

3. Seismic Performance Grade (from Table 5) ☐
Note: insert this grade, including + or -, if applicable in box on page 1

4. Anticipated Seismic Performance[1]

Following anticipated seismic events:[2]

Grade A, A-: Excellent Performer
(Potential minor structural and finish damage, earthquake damage ratio[3] of 0%-10%, continued occupancy is likely)

Grade B, B+, B-: Good Performer
(Potential moderate structural and finish damage, continued occupancy likely following minor structural repairs, earthquake damage ratio[3] of 0%-50%, seismic retrofit measures are encouraged)

Grade C, C+, C-: Fair Performer
(Potential moderate to major structural and finish damage, structural repairs may be required prior to continued occupancy, earthquake damage ratio[3] of 10%-60%, seismic retrofit measures are strongly encouraged)

Grade D, D+, D-: Poor Performer
(Potential severe structure and finish damage requiring significant repairs prior to re-occupancy, earthquake damage ratio[3] of 20% – 100%, significant seismic retrofit measures are strongly encouraged)

Notes:

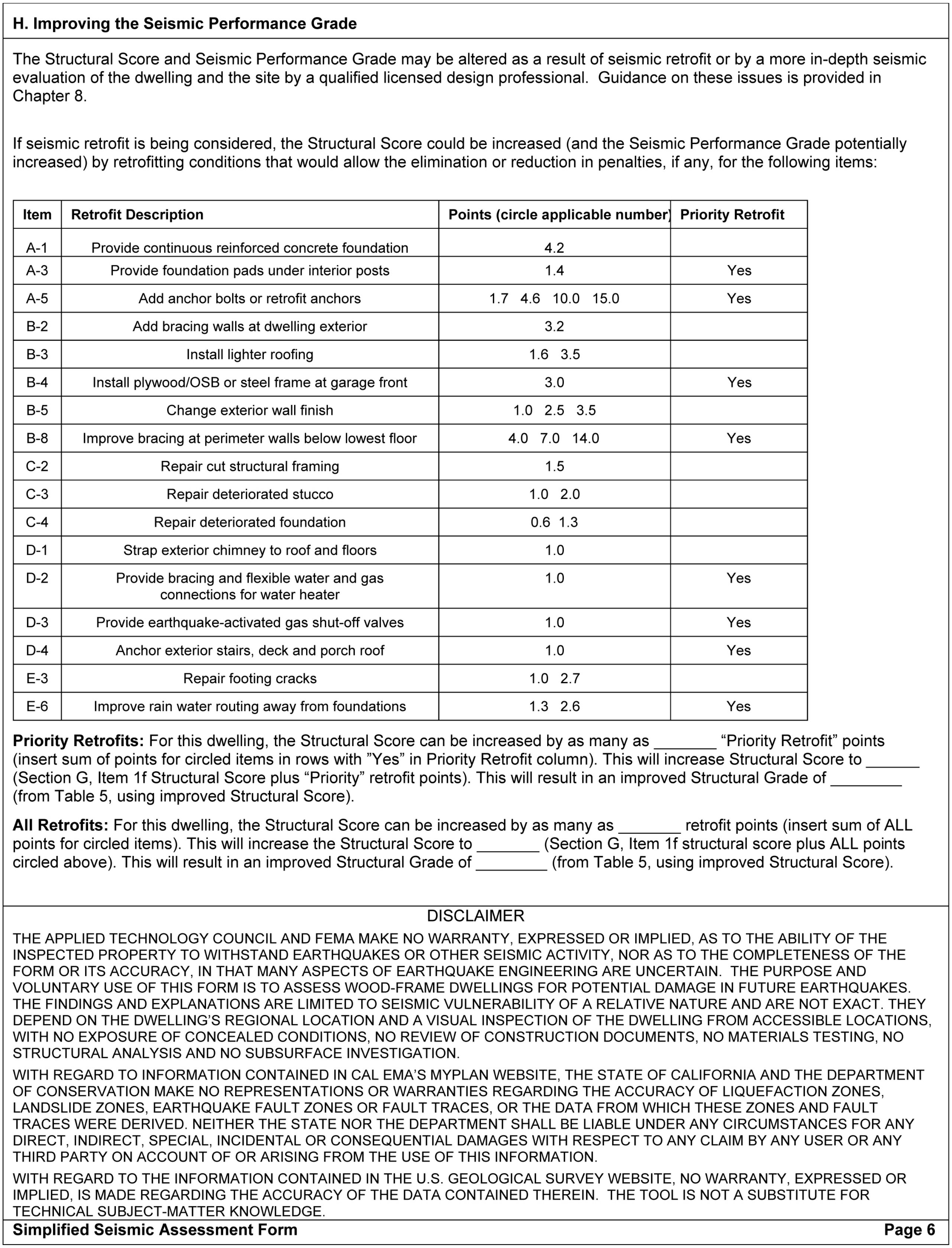
1. Dwellings are generally anticipated but not certain to have the described performance. The occupancy levels described in this table are generally consistent with the damage levels presented.

2. The anticipated seismic events are similar to those used to develop the earthquake ground-motion contours illustrated in the *International Residential Code* Seismic Design Category maps in Figures 2-1 to 2-4.

3. Reported earthquake damage ratios are expressed as a percentage of the replacement cost of the dwelling. The damage ratio ranges were obtained from a stochastic computer model of dwellings adjusted to suit the stated structural scores and subjected to a wide range of simulated ground motions. The damage ratios were chosen to have a 1/500 likelihood of being exceeded in any given year for the stated range of seismic hazard score. The stochastic analysis is discussed in detail in Appendix D.

Simplified Seismic Assessment Form **Page 5**

Figure 1-5 Simplified Seismic Assessment Form, Page 5.



H. Improving the Seismic Performance Grade

The Structural Score and Seismic Performance Grade may be altered as a result of seismic retrofit or by a more in-depth seismic evaluation of the dwelling and the site by a qualified licensed design professional. Guidance on these issues is provided in Chapter 8.

If seismic retrofit is being considered, the Structural Score could be increased (and the Seismic Performance Grade potentially increased) by retrofitting conditions that would allow the elimination or reduction in penalties, if any, for the following items:

Item	Retrofit Description	Points (circle applicable number)	Priority Retrofit
A-1	Provide continuous reinforced concrete foundation	4.2	
A-3	Provide foundation pads under interior posts	1.4	Yes
A-5	Add anchor bolts or retrofit anchors	1.7 4.6 10.0 15.0	Yes
B-2	Add bracing walls at dwelling exterior	3.2	
B-3	Install lighter roofing	1.6 3.5	
B-4	Install plywood/OSB or steel frame at garage front	3.0	Yes
B-5	Change exterior wall finish	1.0 2.5 3.5	
B-8	Improve bracing at perimeter walls below lowest floor	4.0 7.0 14.0	Yes
C-2	Repair cut structural framing	1.5	
C-3	Repair deteriorated stucco	1.0 2.0	
C-4	Repair deteriorated foundation	0.6 1.3	
D-1	Strap exterior chimney to roof and floors	1.0	
D-2	Provide bracing and flexible water and gas connections for water heater	1.0	Yes
D-3	Provide earthquake-activated gas shut-off valves	1.0	Yes
D-4	Anchor exterior stairs, deck and porch roof	1.0	Yes
E-3	Repair footing cracks	1.0 2.7	
E-6	Improve rain water routing away from foundations	1.3 2.6	Yes

Priority Retrofits: For this dwelling, the Structural Score can be increased by as many as _______ "Priority Retrofit" points (insert sum of points for circled items in rows with "Yes" in Priority Retrofit column). This will increase Structural Score to ______ (Section G, Item 1f Structural Score plus "Priority" retrofit points). This will result in an improved Structural Grade of ________ (from Table 5, using improved Structural Score).

All Retrofits: For this dwelling, the Structural Score can be increased by as many as _______ retrofit points (insert sum of ALL points for circled items). This will increase the Structural Score to _______ (Section G, Item 1f structural score plus ALL points circled above). This will result in an improved Structural Grade of ________ (from Table 5, using improved Structural Score).

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Figure 1-6 Simplified Seismic Assessment Form, Page 6.

Chapter 2

Basics of Seismicity, Wood-Frame House Construction, and Seismic Resistance

This chapter provides a basic overview of seismicity in the United Sates, and of the typical types of wood-frame houses and how they resist earthquake forces. It is intended primarily for homeowners and contractors who have little experience with seismic retrofit work. Additional information is available in the documents referenced in Chapter 1 and in the list of References.

2.1 Seismic Hazards in the United States

The map in Figure 2-1shows the earthquake shaking hazard levels in the United States. More detailed maps are provided in the companion FEMA P-50

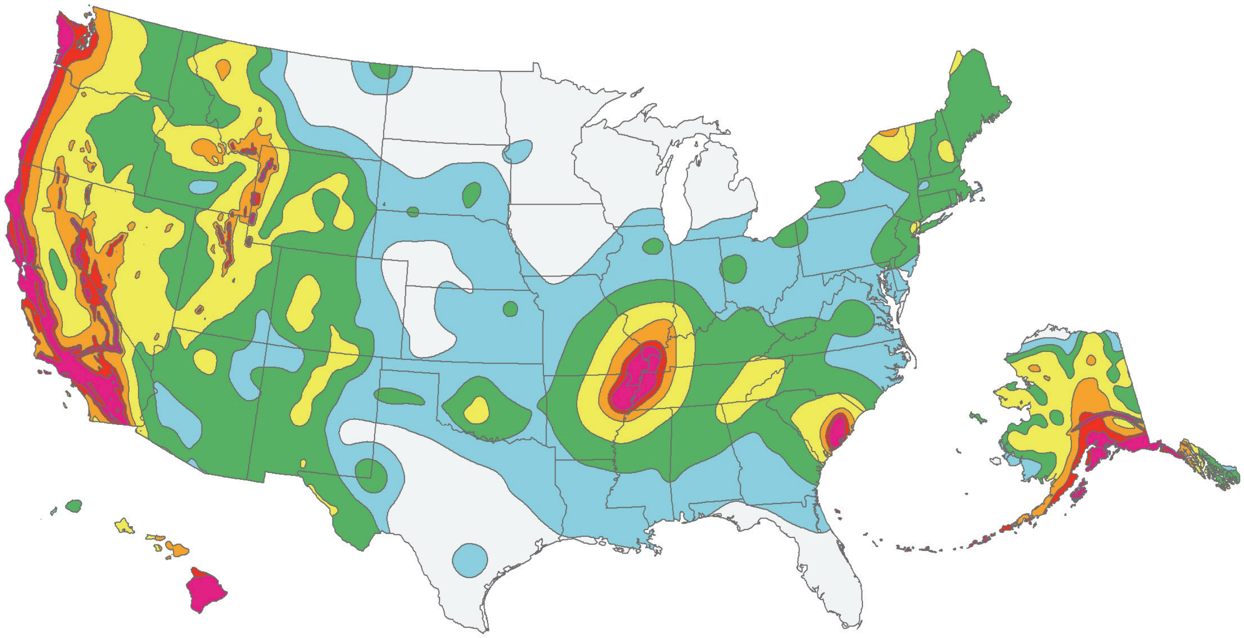


Figure 2-1 Seismic hazard map of the United States. Colors represent ranges of horizontal ground shaking, with grey representing the lowest hazard and pinkish-red representing the highest hazard. More detailed maps of acceleration response, S_{DS}, the parameter referred to in Table 1 of the Simplified Seismic Assessment Form, are provided in the companion FEMA P-50 report. (Source: U. S. Geological Survey.)

report, *Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings* (FEMA, 2012) and in the ASCE/SEI 7 and IRC documents. The latter two documents provide the basis for the seismic provisions of most state or local building codes. The shaking hazard for your home location can be obtained from the U.S. Geological Survey (USGS) Seismic Design Maps website: (https://geohazards.usgs.gov/secure/designmaps/us/). This procedure is described in detail in Table 1 in the Simplified Seismic Assessment Form (Figure 1-3).

The shaking experienced by a building is also affected by the soil under the foundation. Buildings founded directly on bedrock will shake with an acceleration similar to that of the bedrock beneath. However, buildings founded on deep soft sedimentary soils over the bedrock will experience horizontal shaking acceleration amplified by as much as five times, potentially causing more damage. An analogy is to consider a bowl of gelatin dessert being shaken; the gelatin dessert moves more than the bowl. Your building jurisdiction (local building department) may have information on soil types within the jurisdiction. An engineer designing a new building or a building seismic retrofit in accordance with the locally adopted version of the IBC will use this soil information and the bedrock shaking level to calculate the design seismic force.

2.2 Wood-Frame House Foundation Configurations

As explained more fully in Section 2.3, earthquake inertial forces accumulate in the upper parts of the building and are resisted at the foundation. The forces are larger near the foundation, and thus most earthquake damage occurs in the wood-framing adjacent to the foundation. The configuration of this framing at the foundation is critical to the seismic resistance of the dwelling.

There are four predominant configurations for supporting a wood-frame house on its foundation:

- cripple-wall crawl space,
- basement (crawl space with no cripple-wall),
- slab-on-grade, and
- post-and-pier.

A fifth common house configuration, the split-level house, is usually a combination of a slab-on-grade and a cripple-wall house configuration. Houses may have other combinations of elements of the different configurations as a result of remodeling or other considerations.

2.2.1 Cripple-Wall Crawl Space Houses

In a cripple-wall house, there is a perimeter foundation of unreinforced or reinforced concrete, brick or stone masonry, or concrete block. This perimeter foundation typically comprises a stem wall supported by a wider footing. The stem wall supports the bottom sill plate, or 'mudsill', of a short wood stud wall called the cripple, or pony, wall. The cripple wall encloses the crawl space, and supports the perimeter of the first floor. The construction of wood stud walls and floors then continues up to the roof. The minimum height of the crawl space is usually 18 inches. On a sloping site, the maximum crawl space height depends on the slope. Typically, the crawl space remains an unfinished utility space. Figure 2-2 is a section drawing through a typical cripple-wall crawl-space house. Note that, away from the perimeter cripple wall, the floor joists are supported by beams resting on posts set into concrete pier footings. Figures 2-3 and 2-4 are photographs of typical cripple-wall houses.

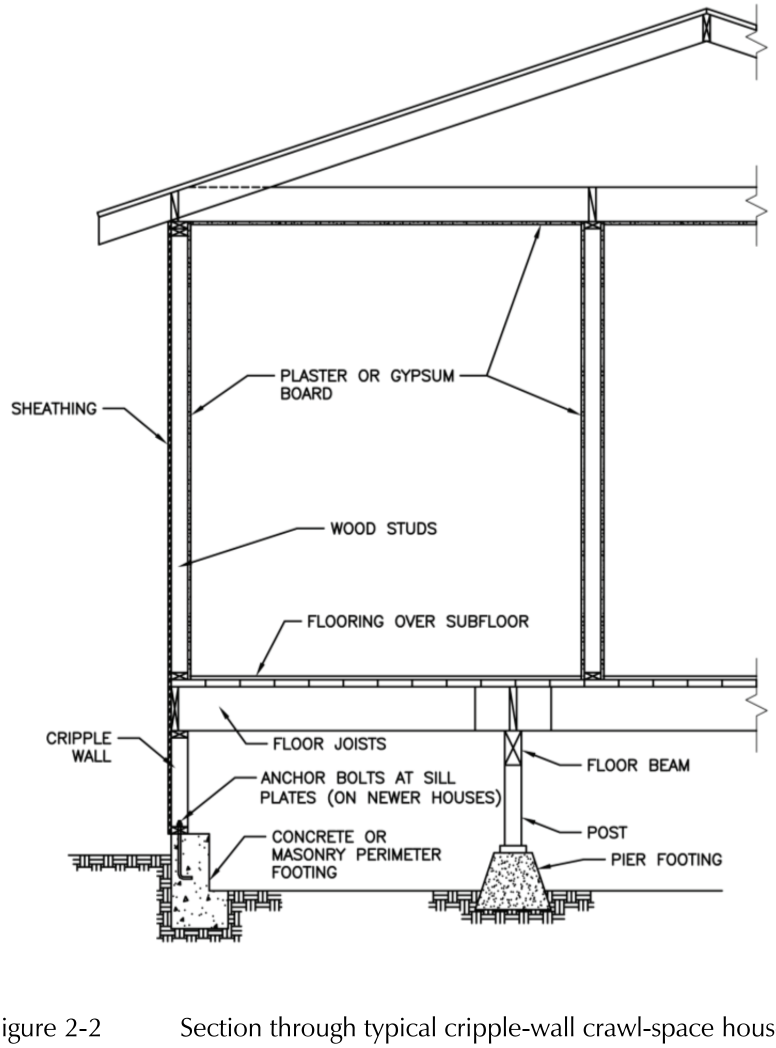


Figure 2-2 Section through typical cripple-wall crawl-space house (from ATC, 2002).

Figure 2-3 Typical one-story cripple-wall crawl-space house (from ATC, 2002).

Figure 2-4 Typical older one and one-half-story cripple-wall crawlspace house (from ATC, 2002).

Two common seismic vulnerabilities in cripple-wall houses are the insufficient strength of the cripple wall exterior sheathing and the lack of anchor bolts between the cripple wall sill and the foundation. The exterior sides of cripple walls are usually sheathed with stucco (with or without structural sheathing underneath), sawn wood siding, exterior finish structural panel sheathing, or other material. Figure 2-5 shows typical earthquake damage to a cripple wall, due to insufficient strength of the cripple wall

Figure 2-5 Typical earthquake damage to a cripple-wall house (from ATC, 2002).

stucco-only sheathing. It is also common for the posts to shake out, leaving the beams and joists with no support.

2.2.2 Slab-on-Grade Houses

A slab-on-grade house has a foundation formed by a cast-in-place concrete slab that lies directly on the leveled and compacted soil. Most of this foundation is a ground floor concrete slab of about four-inch thickness. At the perimeter, and often at the location of selected interior load-bearing walls, this slab is thickened to 12″ to 18″ to form a deeper footing. The slab and thickened footing are usually reinforced with steel reinforcing bars or two-way steel wire fabric. Sometimes, the slab is reinforced with sleeved pre-stressing steel tendons that are post-tensioned and anchored after the concrete has cured. Anchor bolts cast into the slabs and footings or shot-in nails connect the interior and exterior wood-frame stud walls to the slab and foundation. Interior stud walls are usually sheathed with gypsum board or plaster. Exterior walls are usually sheathed with gypsum board or plaster on the interior faces, and with stucco (with or without structural sheathing underneath), sawn wood siding, exterior finish structural panel sheathing, or other material on the exterior faces. Similar wood-frame construction proceeds upwards for the desired number of stories, with wood joists supporting the elevated floors. Figure 2-6 is a transverse section through a typical one-story slab-on-grade house. Figures 2-7 and 2-8 are typical photos of one and three-story slab-on-grade houses.

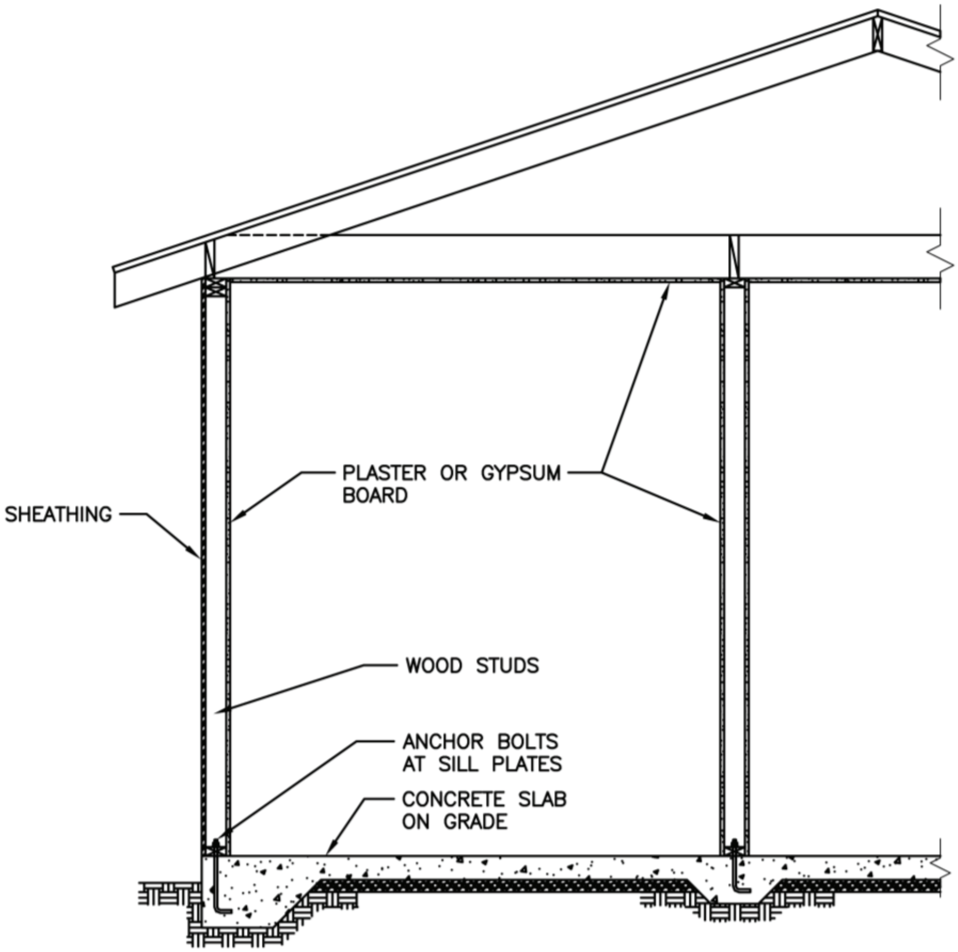


Figure 2-6 Section through typical one-story slab-on-grade house (from ATC, 2002).

Figure 2-7 Typical one-story slab-on-grade house (from ATC, 2002).

Figure 2-8 Typical three-story slab-on-grade house (from ATC, 2002).

A common seismic vulnerability in some two-story and many three-story slab-on-grade houses is the insufficient lateral-force-resisting strength of the first floor exterior and interior walls due to the large number of door and window openings in these walls and the limited strength of the sheathing materials. Figures 2-9 and 2-10 show typical earthquake damage to the first-story walls.

Figure 2-9 Cracking damage at the window to stucco first-floor walls of a two-story slab-on-grade house (from ATC, 2002).

Figure 2-10 Damage and racking displacement to the right in the first floor walls of a two-story slab-on-grade house (from ATC, 2002).

2.2.3 *Basement Houses (Perimeter Foundation with no Cripple Wall)*

The vertical-load-bearing elements of basement houses begin with full-height perimeter concrete or masonry basement walls founded on a concrete perimeter footing. A concrete slab is usually placed between these walls to form the basement floor. A wood sill plate supporting the first floor joists is placed on the top of the perimeter basement wall, and the wood-frame construction then proceeds upwards for the desired number of stories. Figure 2-11 is a section through a typical one-story basement house.

Figure 2-12 is a section through a crawl space house that is similar to a basement house. The perimeter walls are shorter, as they enclose a crawl space rather than a full-height basement. This configuration differs from a cripple-wall house in that the perimeter foundation walls enclosing the crawl space are of concrete or masonry rather than wood framing.

A common seismic vulnerability in basement houses is the lack of anchor bolts between the sill plate and the basement wall. Figure 2-13 shows a house of this type that was damaged in the 1992 Cape Mendocino earthquake in California as the sill plate slid along the top of the foundation wall.

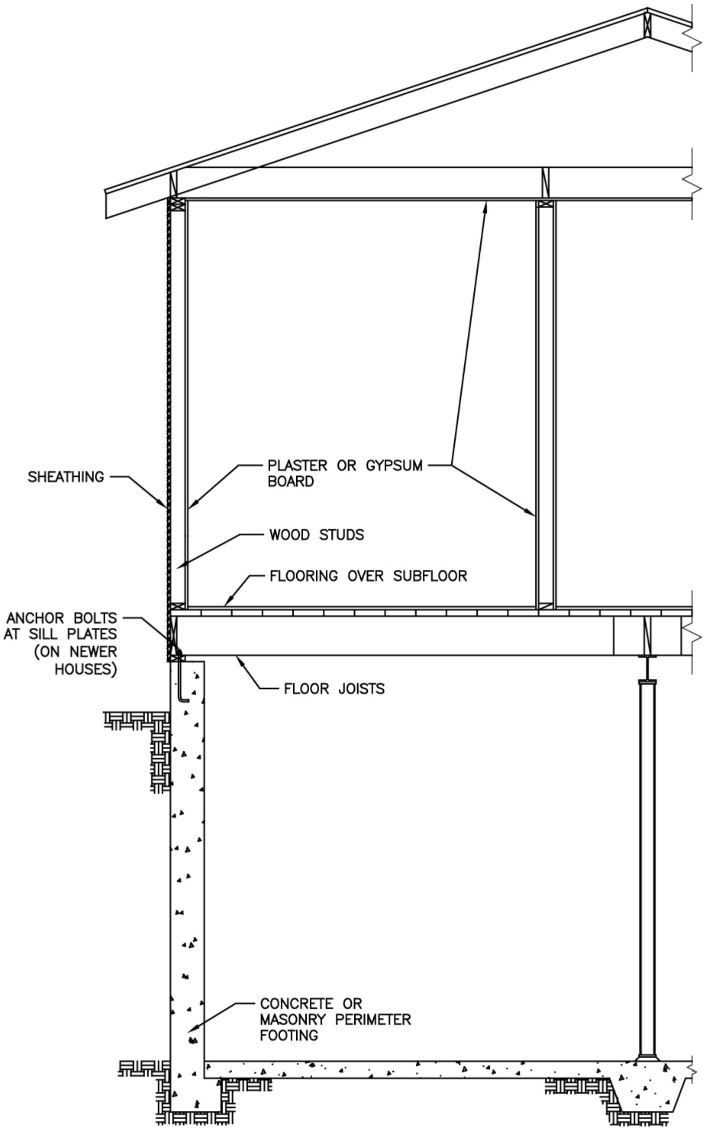


Figure 2-11 Section through a typical one-story basement house (from ATC, 2002).

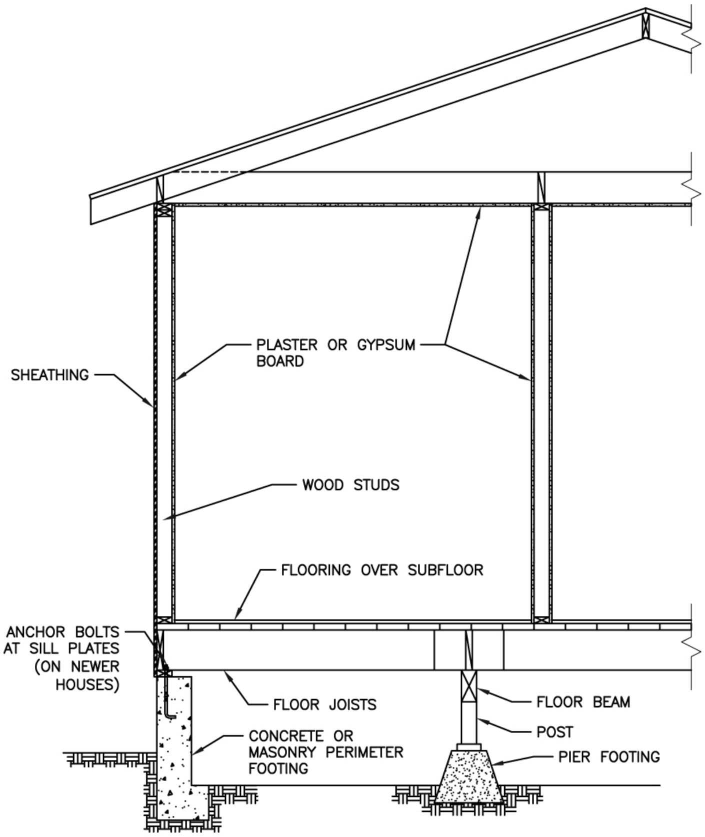


Figure 2-12 Section through a variation of the basement house where the perimeter foundation walls enclose a crawl space (from ATC, 2002).

Figure 2-13 Damage to a basement-type house where the sill plate slid on the top of the foundation wall (from ATC, 2002).

2.2.4 *Perimeter Post-and-Pier Foundation Houses*

In post-and-pier foundation houses, individual footings are spaced along the house perimeter and along interior lines. These footings may be shallow foundations or deep drilled piers, and may or may not be tied together by grade beams at ground level. The footings support wood or steel posts, or masonry or concrete piers. Posts are provided with lateral-force resistance by diagonal bracing, or the width/height ratio of masonry or concrete piers providing overturning capacity. The first-floor joists and the house superstructure are supported by girders supported by the posts or piers. Figures 2-14, 2-15 and 2-16 illustrate this house configuration on sloping and flat sites, respectively.

Figure 2-14 Steel post-and-pier foundation house on sloping site (from ATC, 2002).

Figure 2-15 Wood post-and-pier house on flat site (from ATC, 2002).

Figure 2-16 Masonry pier house on flat site (from ATC, 2002).

A common seismic vulnerability in post-and-pier houses is the lack of seismic-resisting strength in the post-and-pier foundation system or in the diagonal bracing system. Figure 2-17 shows earthquake damage to a post-and-pier foundation.

Figure 2-17 Earthquake-damaged perimeter post-and-pier foundation. The diagonally-braced post has overturned the shallow-founded concrete pier footing (from ATC, 2002).

2.2.5 *Split-Level Houses, Multi-Level Hillside Houses*

Houses where adjacent floor levels are separated by less than a full story height are usually designated split-level houses. One typical configuration is shown in Figure 2-18. The right part of the house is of two-story slab-on-grade wood-frame construction, with the garage space occupying the lower floor. The attached portion on the left side is of one-story cripple-wall construction.

Figure 2-18 Split-level house, where the section of flooring above the garage is at a lower level than the main second-floor level (from ATC, 2002).

Other split level houses may have all slab-on-grade ground floors at different elevations, and may not have living spaces over the garage. These houses may be on either flat or sloped sites. On flat sites, the two lower levels may be at nearly the same elevation.

A common seismic vulnerability in split-level houses with living spaces over the garage is inadequate strength of the walls at each side of the garage door to resist seismic forces from the house portion above. Damage that was in part initiated by this vulnerability is shown in Figure 2-19. Another common vulnerability is insufficient strength of the cripple wall under the single-story portion of the house, when present, causing damage similar to that of Figure 2-5.

2.3 Elements of the Primary Seismic Load Path

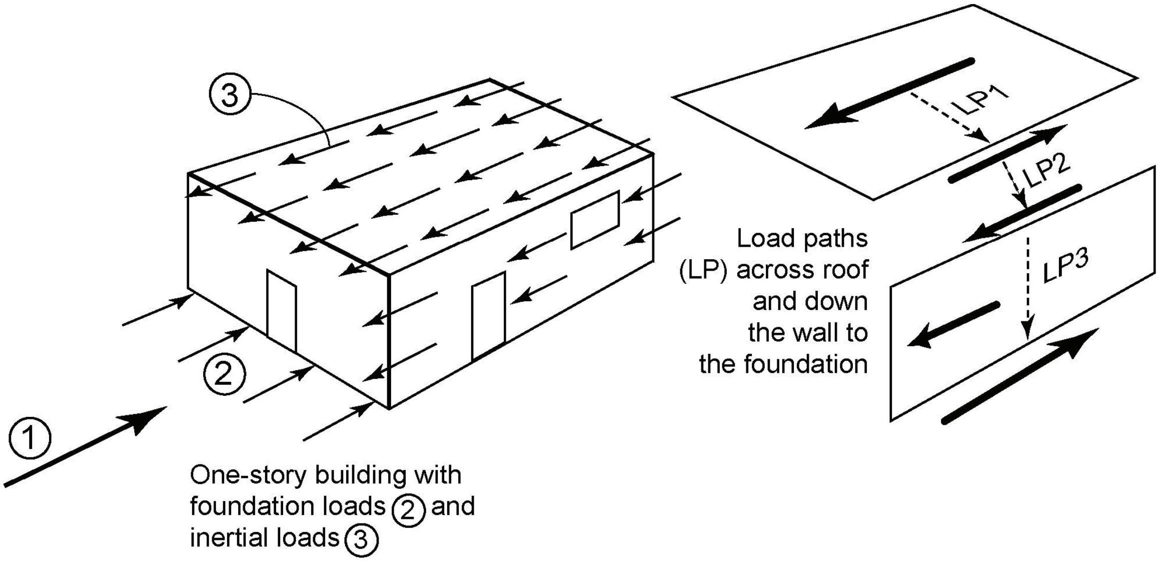
An understanding of how the various building elements work together along the primary seismic load path to resist earthquake forces will make the retrofit process more clear. A more in-depth explanation can be found in FEMA 232.

Figure 2-19 Split-level house with damage and collapse at the garage-level walls at two-story portion (from ATC, 2002).

Horizontal earthquake ground motion causes house foundations to accelerate back and forth. Because of the inertia of the heavier elements of a house structure, these heavier elements resist the tendency to follow the foundation motion. In so doing, these heavier elements supply "inertial" seismic forces to the attached structural elements. The seismic forces must be transferred along the ‘seismic load path’ from each element to the supporting ground. As discussed in more detail in Chapter 8, along this seismic load path may be, for example, horizontal diaphragms, nailed connections, shear walls, nailed and anchor-bolted connections, and the foundation.

2.3.1 Horizontal Diaphragms

Floors and roofs with continuous sheathing that is horizontal (or sloped, in the case of most roofs) are considered horizontal diaphragms. In the primary seismic load path, horizontal diaphragms serve to transfer the lateral inertial seismic forces from all attached elements into the shear walls or other vertical wall elements below the diaphragm level. Most often in houses, the horizontal diaphragm collects these forces from attached walls having planes perpendicular to the earthquake motion, and transfers these forces to lower shear walls whose plane is parallel to the earthquake motion. The forces are carried down through the walls to the foundation where they are resisted by friction or bearing ground reactions. Figure 2-20 illustrates this load path, with horizontal diaphragms transferring seismic horizontal forces to the tops of the shear walls, then down through the shear walls to the foundation.



Notes:

1 Peak ground acceleration, presumed constant, in direction left-right.

2 Entire foundation is moved left-right.

3 Building inertia causes bulding to lag to the left, as though every item of weight *W*, was acted on by a seismic inertial force *Wa* to the left.

LP1 Inertial forces in the roof diaphragm are transferred along LP1 to the edge of the roof by shear in the diaphragm.

LP2 Forces at the edge of the roof diaphragm are collected and transferred along LP2 to the top of the wall through connectors.

LP3 Forces at the top of the wall and inertial forces in the wall are transferred along LP3 to the foundation by shear in the wall diaphragm, nailed connections and bracing to the mudsill, and through bolt shear to the foundation.

Figure 2-20 Horizontal and vertical diaphragms (shear walls) transferring horizontal earthquake forces (from ATC, 2002).

2.3.2 Shear Walls

Shear walls have a capacity to resist earthquake forces in the direction of the plane of the wall. The sheathing of the wall must have sufficient strength to resist the shear force. The connections at the top and bottom of the wall must be strong enough to transmit the forces without breaking. The wall can only resist in-plane forces; other walls must be provided to resist forces in the perpendicular plan direction. The wall must support enough dead weight, or be connected adequately at the bottom, to resist being overturned by the horizontal shear force being applied at the top. Figure 2-21 illustrates a shear wall with applied lateral forces at the top and with dead weight and bottom restraints resisting overturning

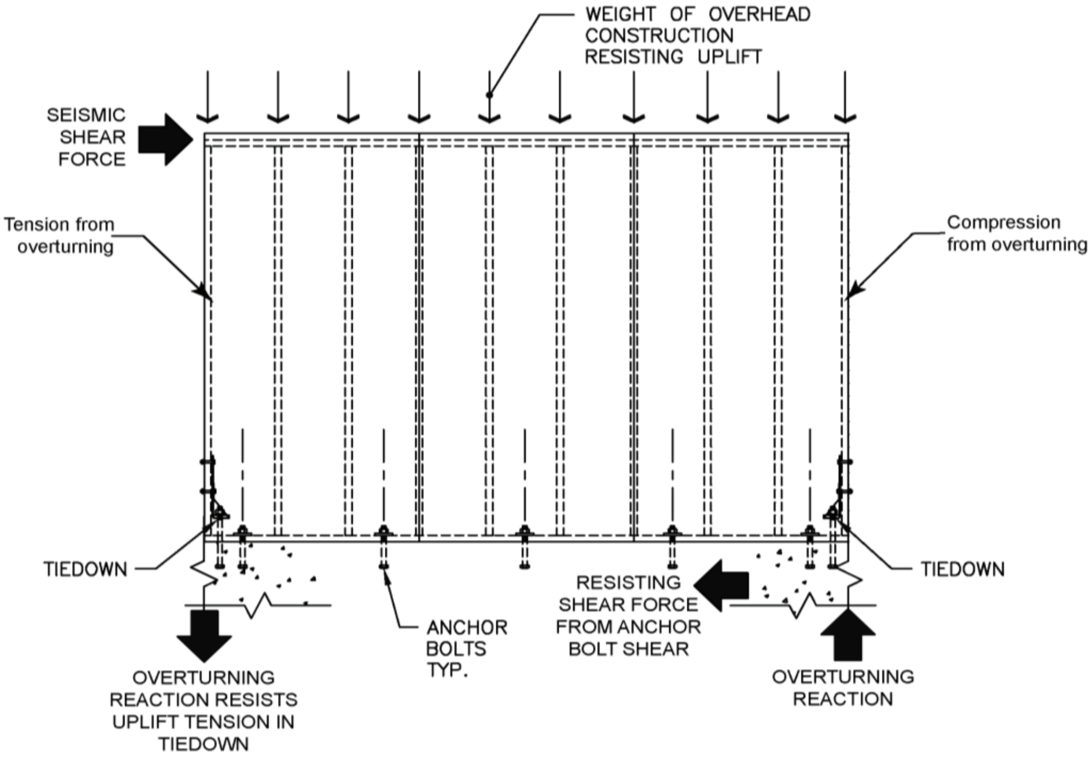


Figure 2-21 Shear wall with a seismic shear force applied at the top, and the resulting shear and overturning reactions at the base (from ATC, 2002).

Intended Shear Walls

In modern earthquake-resistant design, certain walls are designed and built to have the strength to resist a designated amount of earthquake force. The total capacity of these intended shear walls above a specific floor level must be greater than the design earthquake force at that level of the building.

Unintended Shear Walls

In many older buildings, no particular interior or exterior walls were intended to be shear walls. However, if the top edges of these walls are connected to a horizontal roof, ceiling, or floor diaphragm, and the bottom to a horizontal floor diaphragm or foundation, they will resist some amount of force as the building is shaken. The force will be resisted by the existing sheathing on the wall. These unintended shear walls may be evaluated for their capacity to contribute to the earthquake-resisting capacity of the building.

As part of an overall building retrofit, the strength of an existing wall can be increased. Existing interior walls usually already have interior sheathing on both sides, and exterior walls have interior and exterior sheathing. The wall strengthening is usually done by removing the interior sheathing for the full width of a room, improving top and bottom connections as needed, placing new structural sheathing, and placing new interior sheathing over the new structural sheathing. In an attached garage and certain other locations, the new interior gypsum board sheathing placed over new wood structural panel sheathing may need to meet fire-resistance rating requirements.

Tiedowns

Modern wood-frame houses often have steel tiedown hardware between the foundation and the shear walls or cripple walls above the foundation. The tiedowns connect the foundation to vertical boundary posts at the ends of the shear walls. They prevent the shear wall from overturning when a seismic force is applied in-plane to the top of the wall. Figure 2-21 shows the vertical force applied to a tiedown from a horizontal force at the top of the wall. Figure 2-22 illustrates typical commercially available tiedowns. The tiedown connects to the foundation with an embedded threaded rod or strap and to the post with bolts, nails, or screws. Tiedowns are required when the dead weight at the top of the wall is not sufficient to prevent overturning. This condition is more likely to occur in short walls with small length/height ratios.

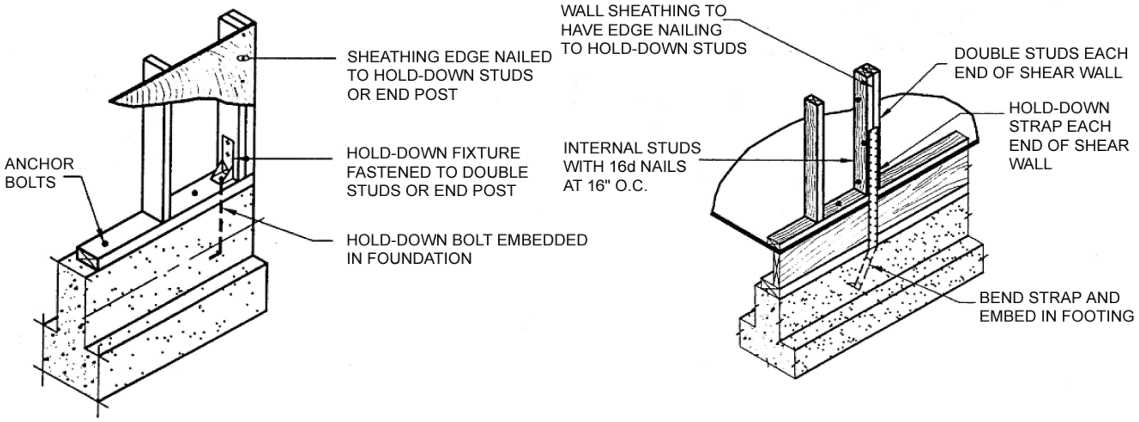


Figure 2-22 Typical commercially available tiedowns (from ATC, 2002).

2.3.3 Connections Between Walls and Horizontal Diaphragms

The connection of a roof or floor horizontal diaphragm to the walls above and below it must be adequate for the transfer of seismic forces. A typical sectional view of this connection is shown in Figure 2-23. The nailing of the wall sheathing, sills, subfloor, framing hardware and top plates forms a complete load path for the transfer of shear forces from the upper wall and the subfloor down into the lower wall.

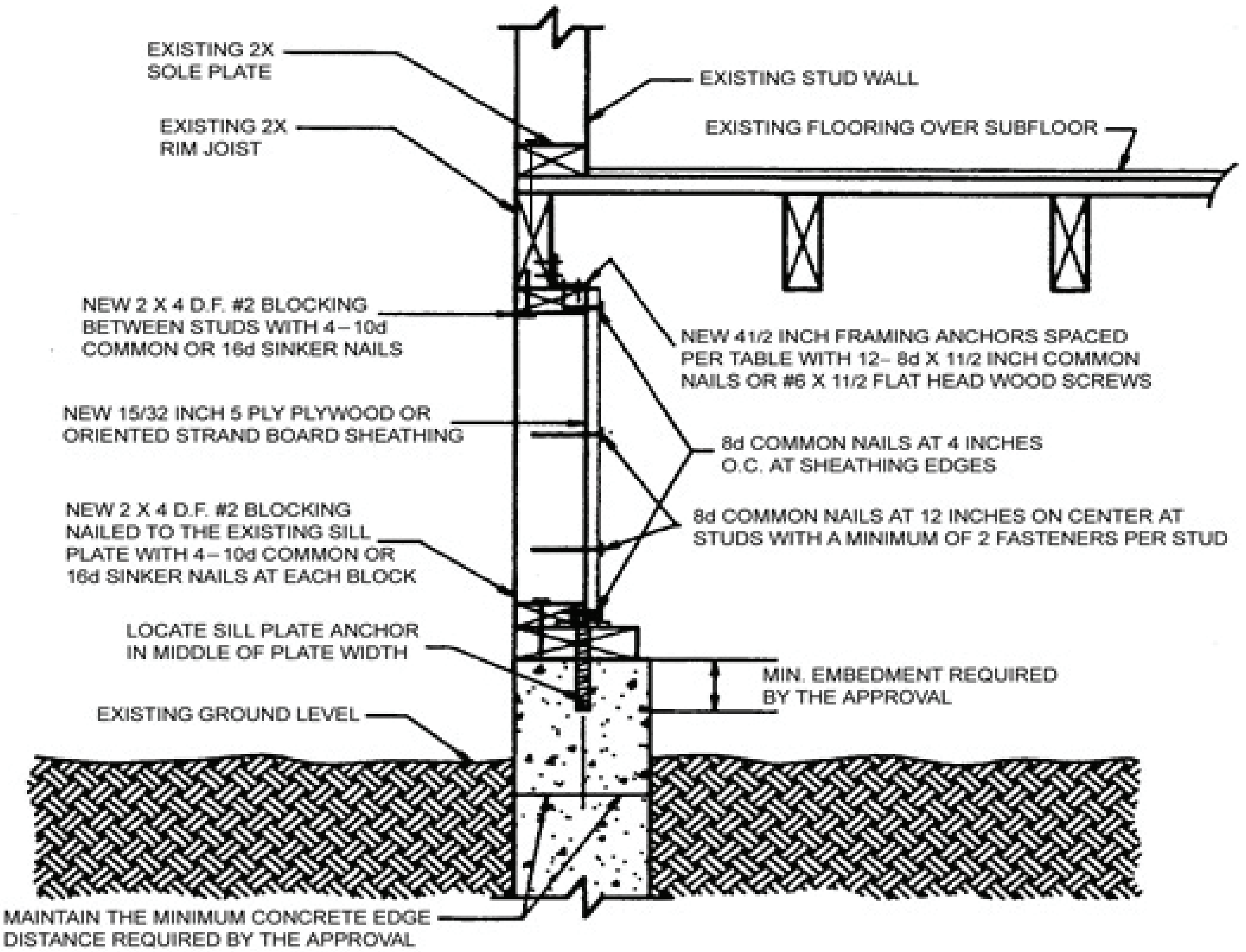


Figure 2-23 Detail from the Los Angeles Standard Retrofit Plan (See Chapter 6) of a connection between a wall and a horizontal floor diaphragm, with strengthening of the connection between the top of the cripple wall and the floor joist blocking above the wall (from ATC, 2002).

The IEBC Cripple Wall Provisions require that the connection between the top of the cripple wall and the floor joist blocking above it be strengthened. Various connection details, such as the one illustrated in Figure 2-23, are provided in the IEBC Cripple Wall Provisions.

2.3.4 Cripple Walls

The cripple walls are the lowest wood-frame walls in a cripple-wall building. All of the seismic forces collected in the horizontal diaphragms and the walls above the cripple walls are delivered to the cripple walls. As cripple walls typically are only on the building perimeter and have sheathing only on the exterior face, they have often failed when in-plane seismic forces delivered to them exceeded their capacity.

It is a very common seismic retrofit to increase the strength of the sheathing on a cripple wall. This is usually done by adding structural sheathing to the unsheathed inside face of the cripple-wall framing. By the prescriptive cripple wall retrofit provisions (to be introduced in Chapter 4), the length of an added wood structural-sheathing panel is to be at least twice the height of the cripple wall. Tiedowns are then not required because it is assumed that significant uplift forces do not occur with this length/height ratio.

2.3.5 Anchor Bolts

Anchor bolts serve to connect the bottom sill plate of the lowest-level shear walls to the foundation. All of the seismic shear forces from the wood-framed part of the house pass through the anchor bolts to the foundation. Many older houses do not have anchor bolts; once the friction and adhesion resistance of the sill plate on the foundation is overcome by earthquake forces, the sill plate can slide off the foundation.

Retrofit anchor bolts are often added to connect the sill plate to the foundation. Holes for the anchor bolts are drilled through the existing bottom sill plate and into the foundation. The new anchor bolts can be chemically bonded into the foundation with epoxy or other adhesive, or they can have a mechanical expansion wedge to grip the sides of the hole. When limited clearance in the crawl space prevents the installation of anchor bolts, hardware is available to substitute for new anchor bolts by connecting the side of the foundation to the side or top of the sill plate.

2.3.6 Foundations

The foundation receives the horizontal and overturning seismic forces from the wood-framed part of the house and transfers it into the ground. The foundation walls must have sufficient in-plane shear strength to resist the horizontal force, and they must have sufficient thickness/height stability to not collapse during the earthquake shaking. If shearwall tiedowns are used, the foundation must also have sufficient weight and bending strength to resist any vertical overturning forces they impose.

All or part of unstable, weak, or discontinuous existing perimeter foundations are sometimes replaced with new continuous reinforced concrete foundations as a part of a seismic retrofit. This is a major construction effort. Replacement of any significant length of foundation is usually done in alternating segments along the length of the foundation to avoid having to raise and support the entire house.

Post and pier foundations are usually of concrete, with a foundation pier at each post. Newer houses on hillsides, and newer houses on poorer soils are more likely to have deep pier foundations and to have grade beams connecting the piers together.

2.4 Platform Framing and Balloon Framing

Platform framing and balloon framing are the two predominant ways of using nominal two-inch thick wood framing lumber to frame a multistory house. Platform framing is much more common than balloon framing in newer houses.

In platform framing, the stud-framed walls are discontinuous at each floor level. A first floor platform is built of joists, rim joists or blocks, and subflooring. Stud walls made of bottom sill plates, studs, and double top plates, are then placed on the top of this floor platform. A second floor platform, again of joists, rim joists or blocks, is then constructed on top of these stud walls. This pattern is repeated for the required number of floors. The stud walls have exterior sheathing that is continued across the platform floors. Figure 2-21 illustrates one story level of a platform framed stud wall.

In balloon framing, the studs extend more than one story in height, usually the crawl space height and two more stories. The floor joists are supported on the studs by a ledger or a let-in “rimband”.

2.5 House Elements not on the Primary Seismic Load Path

Some house elements are considered nonstructural and do not serve to resist the earthquake force caused by the inertia of the full weight of the building. These elements resist the force from some smaller part of the building. The vulnerability of these elements is considered in Section D of the Simplified Seismic Assessment Form, and their retrofit is covered in Chapter 7.

2.5.1 Roofs and Floors of Porches and Decks

Porch and deck roofs and floors are often supported vertically by the house framing on one side and by posts on the outboard side. Earthquake forces can cause them to pull or pry away from the house framing, which allows the posts to hinge, collapsing the porch or deck. Porch and deck roofs and floors can be prevented from prying away from the house by tying their framing back into the house framing.

Posts supporting porch and deck roofs and floors often cannot resist earthquake shaking. Sometimes the upper part of the post is a wood member supported by a separate wood or brick lower post. As described in detail in

Section 7.6.2, this ‘hinged’ assembly can become unstable and allow the roof to collapse. These posts and post footings can be stabilized so that they continue to provide vertical support during earthquake shaking.

2.5.2 Interior Pier Foundations and Posts

In a crawl-space house, the interior beams supporting the first-floor floor joists are in turn supported by wood posts, as seen in Figure 2-2. The wood posts usually rest on concrete pier footings, although in some older homes they rest on the bare earth.

Even when the cripple walls are adequate, earthquake motion can shake these posts loose from the floor beams or the pier footings so that they no longer support the beams. The posts should be well-fastened top and bottom so that they continue to provide vertical support. Where the posts rest on bare earth, pier foundations should be added. Chapter 6 provides guidance for this retrofit work.

2.5.3 Chimneys, Veneer and Roof Tile

Unreinforced brick masonry chimneys are heavy and brittle. When subjected to earthquake forces, they often crack, break apart, and become falling hazards. Many building jurisdictions in high seismic hazard areas encourage the use of less vulnerable non-masonry chimneys. Steel-reinforced brick masonry chimneys are also likely to crack, but are less likely to become a falling hazard (see Chapter 7 for additional information).

Stone or brick veneer is often used as an exterior finish on wood-frame walls. The veneer is often not well fastened to the wall framing, making it vulnerable to being shaken off the wall surface by earthquake movement perpendicular to the wall. If the sheathing on the wall, behind the veneer or on the interior face, does not have adequate strength or stiffness to resist in-plane earthquake deformation, in-plane forces can also cause the veneer to come loose. To lessen the vulnerability of the veneer, the connection of the veneer to the wall framing can be improved. Full-thickness brick veneer can be removed and replaced with a lightweight facing that has the same appearance.

Roof tiles on houses built to older codes are often not well secured to the roof sheathing. Seismic shaking can dislodge the tiles, creating a falling hazard and roof leakage. It is possible, but difficult, to retrofit the roof tile connections to minimize this condition.

Brick veneer and roof tile significantly increase the weight of the house and thus increase the seismic forces on the house shear walls and horizontal diaphragms.

Chapter 7 provides guidance for the retrofit of chimneys, brick veneer, and roof tile.

Chapter 3

Interpretation of Simplified Seismic Assessment Results

This chapter discusses the Simplified Seismic Assessment Form, introduced in Chapter 1, that is used by a qualified inspector to identify seismic vulnerabilities in existing wood-frame houses. This chapter, along with the companion FEMA P-50 document, *Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings*, is intended to help homeowners better understand the assessment process and the results. It also directs the homeowner to the specific retrofit procedures in this document (*Guidelines*) that apply to particular vulnerability conditions.

3.1 The Simplified Seismic Assessment Form

3.1.1 Use of the Assessment Form

As discussed in Chapter 1, the usual scenario is that a homeowner living in a seismically-active area has concerns about the vulnerability of his or her dwelling. Through the local building jurisdiction or other means, the homeowner has arranged for an inspection by a qualified inspector using the Simplified Seismic Assessment Form shown in Figures 1-1 to 1-6.

In accordance with the assessment procedure, the inspector spends one or more hours observing elements and conditions in the dwelling that affect earthquake vulnerability. Based on these observations, the inspector addresses the 36 assessment items on the form. The accuracy of the assessment in predicting vulnerability is limited by the uncertainties associated with seismic shaking estimation and the uncertainties associated with predicting impacts that seismic shaking will have on a given dwelling. Moreover, no finishes are removed to observe concealed structural conditions, and there is no construction document review, material testing, structural analysis, or subsurface soil investigation. Despite these limitations, the assessment form enables a useful assessment of probable earthquake vulnerability.

The 36 assessment items on the form are grouped into six Sections:

- Section A - Foundation System
- Section B - Superstructure Framing and Configuration

- Section C - General Condition Assessment
- Section D - Nonstructural Elements, Age, and Size
- Section E - Local Site Conditions
- Section F - (Regional) Seismic Hazard Score

The conditions identified for each assessment item in Sections A to E have an associated numerical penalty point score that is higher for observed conditions that are more seismically vulnerable. Section F addresses issues pertaining to the sites' seismic hazard.

In Section G, the numerical scores from Sections A to E are summed and recorded as a total for each Section. The five Section totals are summed, then subtracted from 100 to calculate a Structural Score for the dwelling. This Structural Score and the Regional Seismic Hazard Score (Section F) are used to assign a Seismic Performance Grade.

3.1.2 Consideration of the Seismic Performance Grade

The Seismic Performance Grade estimates the overall vulnerability of the dwelling to earthquake forces and motions and provides a measure of the degree of damage to be expected in a major earthquake. Grades range from A to D with a supplementary + or -. An 'A' grade is the best grade, indicating a low level of expected damage to the home. A 'D' grade is the worst, indicating high vulnerability. Chapter 2 of the FEMA P-50 document includes more narrative about the anticipated seismic performance for each Seismic Performance Grade.

A house receiving a C or D grade should be seriously considered for retrofit strengthening in accordance with these *Guidelines*. However, as discussed below, it is possible for a house to receive an A or B grade and still have significant earthquake vulnerability.

The disclaimer on the form should be read carefully. It explains the preliminary nature of the evaluation and the fact that the completed form may be supplemented by a more in-depth evaluation by a qualified licensed design professional.

3.1.3 Improving the Seismic Performance Grade

As described in more detail below, each assessment item in Sections A through E of the assessment form indicates with an * whether the conditions associated with that item can be improved through retrofit. After the inspector has addressed each assessment item on the assessment form and circled the appropriate condition(s) for each item, and then calculated the

Structural Score and Seismic Hazard Score to determine the Seismic Performance Grade, the inspector then tallies in Section H of the assessment form (see Figure 3-1) the penalty points that can be regained through retrofit. Items identified as "Priority Retrofit" in Section H are expected to involve a moderate cost and high benefit-to-cost ratio, and are therefore strongly encouraged.

Item	Retrofit Description	Points (circle applicable number)	Priority Retrofit
A-1	Provide continuous reinforced concrete foundation	4.2	
A-3	Provide foundation pads under interior posts	1.4	Yes
A-5	Add anchor bolts or retrofit anchors	1.7 4.6 10.0 15.0	Yes
B-2	Add bracing walls at dwelling exterior	3.2	
B-3	Install lighter roofing	1.6 3.5	
B-4	Install plywood/OSB or steel frame at garage front	3.0	Yes
B-5	Change exterior wall finish	1.0 2.5 3.5	
B-8	Improve bracing at perimeter walls below lowest floor	4.0 7.0 14.0	Yes
C-2	Repair cut structural framing	1.5	
C-3	Repair deteriorated stucco	1.0 2.0	
C-4	Repair deteriorated foundation	0.6 1.3	
D-1	Strap exterior chimney to roof and floors	1.0	
D-2	Provide bracing and flexible water and gas connections for water heater	1.0	Yes
D-3	Provide earthquake-activated gas shut-off valves	1.0	Yes
D-4	Anchor exterior stairs, deck and porch roof	1.0	Yes
E-3	Repair footing cracks	1.0 2.7	
E-6	Improve rain water routing away from foundations	1.3 2.6	Yes

Figure 3-1 Matrix in Section H of Simplified Seismic Assessment Form for use by the inspector to indicate retrofit measures that could be implemented to improve the Seismic Performance Grade.

3.1.4 Consideration of the Individual Assessment Items

The wording of the 36 assessment items in Sections A-F of the Simplified Seismic Assessment Form, related optional conditions, and associated penalties, are reproduced below, along with commentary in some instances (in italics) describing each condition and an indication of the appropriate section or chapter of the *Guidelines* describing the desirability of retrofit for an existing condition.

Conditions for some assessment items cannot be changed through retrofit, such as the house being located on a steep slope (E-1, condition b). Conditions for other assessment items (those identified by an asterisk *) may be changed through retrofit, such as a foundation system supporting a wood framed floor for which there are no foundation anchor bolts (A-5, condition g).

3.2 Assessment of Foundation System (Section A)

Assessment Item A-1. This assessment item (see Figure 3-2) addresses the type of exterior footing.

		Penalty
*A-1	The exterior footing is:	
	a. continuous concrete or reinforced masonry	[0]
	b. other footing conditions	[4.2]

Figure 3-2 Assessment Item A-1. *denotes assessment item that may be improved by seismic retrofit.

Reinforced concrete and reinforced masonry footings have performed well in past earthquake, but other types of footings have not. Considerations for assignment of conditions a and b include:

a. Continuous concrete and reinforced masonry exterior footings have been better earthquake performers, suffering less damage, so are not penalized.

b. Included in condition b are continuous footings of other materials such as unreinforced brick or stone masonry. Also included are discontinuous footings such as isolated post-and-pier systems, isolated drilled pier systems without tie-beams, and partially continuous perimeter footings. These footing materials and types have been identified in past earthquakes as poorer performers, resulting in increased damage.

Penalty points can be regained with retrofit to include continuous concrete or reinforced masonry foundations, as discussed in Chapters 6 and 8.

Assessment Item A-2. This assessment item (see Figure 3-3) addresses the foundation type and whether the dwelling has a crawl space or basement.

		Penalty
A-2	The lowest floor of the dwelling is:	
	a. slab-on-grade	[0]
	b. wood framed over crawl space or basement	[2.9]
	c. combination of slab-on-grade and wood framed floor over crawl space or basement	[2.9]

Figure 3-3 Assessment item A-2.

Considerations for assignment of conditions a, b and c include:

a. Wood-frame dwellings supported directly on a concrete slab-on-grade avoid vulnerabilities inherent in wood-framed first floor systems, and therefore are not penalized.

b., c. *The occurrence of a framed first floor increases the potential vulnerability of the dwelling by increasing the number of resisting elements and connections required to transfer earthquake loads from the base of the first floor walls to the foundation. The assigned penalty points recognize this increased potential vulnerability.*

Retrofit to regain penalty points for the house configurations identified in this item is not practical.

Assessment Item A-3. This item (see Figure 3-3) addresses the type of support for the lowest floor framing.

		Penalty
*A-3	At the dwelling crawlspace or basement interior, the lowest floor framing is supported on:	
a.	continuous stem walls or a combination of continuous stem walls and beams on posts bearing on concrete footings/piers	[0]
b.	beams on posts bearing on piers/pad footings	[0.8]
c.	beams on posts supported directly on soil	[2.2]
d.	not applicable: slab-on-grade	[0]

Figure 3-4 Assessment item A-3. *denotes assessment item that may be improved by seismic retrofit.

Conditions a, b, and c describe various methods for supporting floor framing in the crawl space.

a. *Condition a applies where continuous footings are typical at the dwelling interior as well as exterior. This system is given no penalty because framing supports are least likely to shift off of the foundations.*

b. *Condition b (often called post-and-pier system) commonly occurs in older wood-frame dwellings There is an increased possibility that supporting posts can shift off of pier or pad footings, potentially causing damage.*

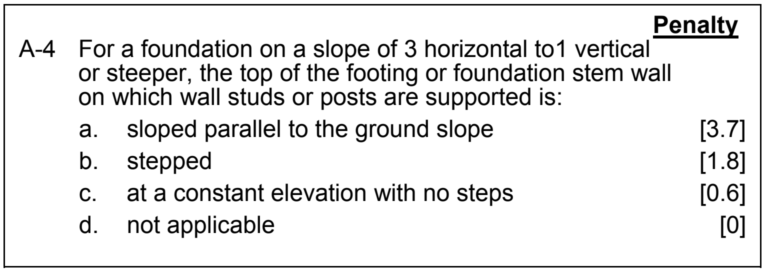
c. *Condition c reflects a condition in which the supporting post bears directly on the ground. Where this occurs, the possibility of damage and loss of support to the floor above is increased due to exposure to decay and termites.*

The damage caused due to loss of floor support can vary from very minor, where repair requires replacement of the affected post, to major, where significant finish and structural damage to the supported interior walls and floors above requires repair.

Condition b can be improved by strapping the post to the beam at the top and the post footing at the bottom to restrain it from shaking out, as detailed in Chapter 6. However, this does not improve the Structural Score.

Condition c can be improved by placing precast post footings under the posts, as detailed in Chapter 6. Retrofit of this condition is given a "priority" designation in Section H of the Simplified Seismic Assessment Form. Retrofit improves the Structural Score by 1.4 points by changing the c condition to the b condition.

Assessment Item A-4. This item (Figure 3-5) addresses optional conditions responses, such as those of dwellings on sloping lots.



			Penalty
A-4	For a foundation on a slope of 3 horizontal to1 vertical or steeper, the top of the footing or foundation stem wall on which wall studs or posts are supported is:		
	a.	sloped parallel to the ground slope	[3.7]
	b.	stepped	[1.8]
	c.	at a constant elevation with no steps	[0.6]
	d.	not applicable	[0]

Figure 3-5 Assessment item A-4.

In dwellings on sloping lots, the configuration of the foundation-wall system that supports the lowest framed floor can have a significant effect on the dwelling's seismic performance.

Considerations for assignment of conditions a through d include:

a. *If the top of the footing or foundation wall (and therefore sill plate) is parallel to the slope, the vertical stud and post supports below the lowest floor diaphragm will butt onto the sill plate at an angle that is not 90 degrees, creating a potentially unstable situation where studs or posts slide along the sill plate. This configuration is assigned the highest penalty.*

b. *A lesser penalty is assigned for dwellings on steep-sloping lots in which the foundation has horizontal surfaces stepping up to the highest level.*

c. *An even smaller penalty is assigned for dwellings on steep-sloping lots that have foundation stem walls with a constant top elevation (without steps) that support the lowest floor framing.*

d. *Condition d is applicable where no crawlspace exists or where the site slope is less than 3 horizontal to 1 vertical.*

Retrofit to regain penalty points for this item is not practical.

Assessment Item A-5. This assessment item (Figure 3-6), addresses the method used to fasten the sill plate to the foundation.

			Penalty
*A-5	At the dwelling perimeter walls, where the foundation system supports a wood framed floor:		
	a.	the foundation sill plate (mudsill) is bolted to the foundation with average anchor bolt spacing of 72 in. or less	[0]
	b.	the foundation sill plate is fastened to the foundation with retrofit anchors equivalent to 72 in. or less anchor bolt spacing	[0]
	c.	the anchor bolts have average spacing that is > 72 in. but <= 108 in.	[1.7]
	d.	the anchor bolts have > 108 in. average spacing	[4.6]
	e.	the foundation sill plates have extensive decay, splitting, or inadequate edge distance at one third or more of the anchor bolt locations such that significant slip of the sill plate could occur	[10.0]
	f.	the anchor bolts have significant corrosion at one third or more of the anchor bolts locations such that significant slip of the sill plate could occur	[10.0]
	g.	there are no foundation anchor bolts	[15.0]
	h.	there are no foundation sill plates to connect to the foundation	[15.0]
	i.	not applicable	[0]

Figure 3-6 Assessment item A-5. *denotes assessment item that may be improved by seismic retrofit.

Many older dwellings were constructed without anchor bolts. Fastening of wood mudsills to supporting foundation is extremely important to the seismic performance of wood-frame dwellings. Lack of anchorage, insufficient anchorage, or corroded anchor bolts and decayed mudsills, can allow the dwelling to slide off of the foundation, potentially resulting in significant damage and hazard to occupants. Poor performance has repeatedly been observed in past earthquakes for dwellings that are not anchored to the foundation.

It is impossible to observe the foundation bolts for dwellings with slab-on-grade floors, because the bolts are totally concealed by the concrete and wall coverings (with the possible exception of the garage). In observations of earthquake damage to date, slab-on-grade dwellings have not been observed to slide off their foundations. This may be because use of anchor bolts became very common in the time period where slab-on-grade foundations came into common use. As the slab-on-grade foundation system does not support a wood-framed floor, condition i “not applicable,” is chosen in that instance.

Up to 15 penalty points can be regained with the retrofit of the sill plate anchorage to the foundation. This retrofit, discussed in Detail in Chapter 6, is highly encouraged. Retrofit of this condition is given a “priority” designation in Section H of the Simplified Seismic Assessment Form.

3.3 Assessment of Superstructure Framing and Configuration (Section B)

Assessment Item B-1. This assessment item (see Figure 3-7) addresses overall irregularities and asymmetry in the dwelling configuration that can increase its seismic vulnerability.

				Penalty
B-1	The dwelling has: (circle all that apply, a to e)			
	a.	unsymmetrical wall strength (torsion problems).	yes	[1.6]
	b.	reentrant corners (seen in plan view)	yes	[0.3]
	c.	split-level floor construction	yes	[2.0]
	d.	out-of-plane offsets of more than 4 ft. in exterior walls	yes	[0.4]
	e.	non-orthogonal seismic resisting systems	yes	[0.6]
	f.	none of the above, or built in accordance with 1994 UBC, 2000 IBC, 2000 IRC or later edition	yes	[0]

Figure 3-7 Assessment item B-1.

Retrofit to regain penalty points for this item is generally not practical. However, Chapter 8 includes a discussion of retrofit possibilities for condition c, split-level floor construction.

Assessment Item B-2. This assessment item (Figure 3-8) addresses the extent of available exterior shear walls to resist earthquake forces.

				Penalty
*B-2	For exterior walls at the lowest occupied story, the summed length of full story height wall sections (between openings, excluding < 2'-8" panels) on any face is less than:			
	a.	20% the length of the wall, if a single story	yes	[3.2]
	b.	25% the length of the wall, if two stories	yes	[3.2]
	c.	40% the length of the wall, if three stories or more	yes	[3.2]
	d.	none of the above		[0]

Figure 3-8 Assessment item B-2. *denotes assessment item that may be improved by seismic retrofit.

Adequate shear capacity is very important for the seismic performance of exterior walls. Therefore, various penalties are assessed for conditions that suggest inadequate shear capacity. Wall shear capacity is generally proportional to wall length, sheathing strength, and sheathing condition. A structure is penalized if there is an insufficient length of full-height wall between door and window openings. Sheathing strength and condition are considered separately below in items B-5 and C-3.

Penalty points can be regained by lengthening or strengthening the wall, which is also discussed in Chapter 8.

Assessment Item B-3. This assessment item (Figure 3-9) addresses the weight of roofing materials.

		Penalty
*B-3	If the roofing is heavy (i.e., clay or concrete tile) the dwelling is:	
a.	single story	[1.6]
b.	multi-story	[3.5]
c.	not applicable: roofing is light.	[0]

Figure 3-9 Assessment item B-3. *denotes assessment item that may be improved by seismic retrofit.

Heavy roofing materials increase the seismic force that must be resisted, thereby increasing the likelihood and extent of damage. Light roofing materials generally include composition shingles, wood shingles, metal deck, and rolled or membrane roofing. Heavy roofing commonly includes concrete and clay tile.

Given the many non-seismic benefits of clay or concrete roofing, other retrofit options may be more desirable, as discussed in Chapters 8 and 9. However, penalty points can be regained with a retrofit to replace heavy roofing with a lighter roofing type.

Assessment Item B-4. This assessment item (Figure 3-10) addresses the extent of first-story earthquake bracing provided in dwellings with a second floor over the garage.

At the front wall of a garage, it is common for the garage door opening to take up most of the wall length, often leaving narrow wall piers at each side of the opening as the only earthquake bracing. The lack of wall bracing makes this portion of the dwelling more vulnerable to earthquake damage.

		Penalty
*B-4	For an attached garage with a second floor above, the narrow walls at the side of the garage door openings have:	
a.	wood structural panels on each narrow wall pier	[0]
b.	structural steel frames around or alongside the door	[0]
c.	prefabricated narrow shear walls, installed in accordance with manufacturer's recommendations	[0]
d.	none of the conditions specified in conditions a, b, or c above (that are visible)	[3.0]
e.	not applicable (single story) or built in accordance with 1997 UBC, 2000 IBC, 2000 IRC or later edition	[0]

Figure 3-10 Assessment item B-4. *denotes assessment item that may be improved by seismic retrofit.

Penalty points can be regained with retrofit of the garage front condition, as discussed in detail in Chapter 8. Retrofit of this condition is given a "priority" designation in Section H of the Simplified Seismic Assessment Form.

Assessment Item B-5. The seismic strength and resilience of various types of exterior wall sheathing and finish materials varies significantly. This assessment item (Figure 3-11) penalizes materials that are less strong and less resilient.

			Penalty
*B-5	The exterior wall covering is primarily:		
	a.	siding known to be over plywood or OSB sheathing	[0]
	b.	siding not known to be over plywood or OSB sheathing	[2.5]
	c.	plywood (T1-11) or diagonal wood siding	[0]
	d	stucco	[1.0]
	e.	masonry veneer not more than 10 feet above the supporting foundation	[2.5]
	f.	masonry veneer more than 10 feet above the supporting foundation	[3.5]

Figure 3-11 Assessment item B-5. *denotes assessment item that may be improved by seismic retrofit.

Heavy masonry veneers on exterior walls, unless properly anchored, are likely to crack, separate from the wall framing, and fall during earthquakes. These veneers have the potential to injure the occupants who are outside or exiting the house. The penalty depends on the height of the veneer. Veneer that covers a full story is more hazardous than veneer that covers only the lower part of the walls.

As discussed in Chapter 8, penalty points can be regained in the three items with retrofit involving the strengthening of the walls.

Assessment Item B-6. This assessment item (Figure 3-12), addresses the issue of interior wall removal.

			Penalty
B-6	There is evidence of interior remodeling that has removed interior walls:	yes	[1.0]
		no/ not applicable	[0]

Figure 3-12 Assessment item B-6.

Dwellings with fewer interior walls tend to sustain more damage than dwellings with more interior walls. The removal of an interior wall significantly reduces the seismic-force-resisting capacity of the dwelling.

Retrofit to regain penalty points for this item is generally not practical.

Assessment Item B-7. This assessment item (Figure 3-13) addresses the number of dwelling stories.

		Penalty
B-7	The number of stories is:	
	a. one (1)	[0]
	b. two (2)	[1.8]
	c. 3 or more	[3.6]

Figure 3-13 Assessment item B-7.

Taller houses create larger earthquake forces and have historically suffered more damage.

Retrofit to regain penalty points for this item is not practical.

Assessment Item B-8. This assessment item (Figure 3-14) focuses on the system occurring between the lowest framed floor level and ground (foundation). As described in Chapter 2, configurations include cripple wall dwellings, post-and-pier dwellings, split-level dwellings and hillside dwellings. Where the bracing system below the lowest floor and ground is not adequate, significant and disproportional damage to the dwelling can occur, up to total loss. This damage can also endanger occupants of the dwelling.

		Penalty
*B-8	At the dwelling perimeter, the main lowest framed floor is supported on:	
	a. beam and column (post-and-pier) system with no sheathed exterior walls	[14.0]
	b. perimeter cripple walls with no plywood or OSB sheathing	[14.0]
	c. original or retrofitted perimeter cripple walls with plywood or OSB sheathing where cripple walls are one story or less in height	[1.0]
	d. original or retrofitted perimeter cripple walls with plywood or OSB sheathing where cripple walls are greater than one story in height	[4.0]
	e. wood or steel diagonal braces not detailed in accordance with 1997 UBC, 2000 IBC or later edition	[7.0]
	f. plywood or OSB sheathed perimeter skirt walls that do not extend to and anchor to the foundation	[7.0]
	g. no perimeter cripple wall	[0]

Figure 3-14 Assessment item B-8. *denotes assessment item that may be improved by seismic retrofit.

114 hillside dwellings, lacking the bracing described in Item B-8, were significantly damaged during the Northridge earthquake. Fifteen hillside dwellings collapsed or were so severely damaged that they had to be immediately demolished. Another 15 hillside dwellings were close to collapse.

Even on flat sites, cripple wall and post-and-pier wood-frame dwelling configurations have suffered significantly in past earthquakes.

Considerations for assignment of conditions include:

a. *Condition a applies when the crawlspace is exposed, not enclosed by cripple walls or concrete or masonry foundation walls. This system is significantly vulnerable to earthquake damage.*

b. *Condition b includes perimeter cripple walls sheathed with anything other than OSB or plywood. Other sheathing materials, including stucco and straight and diagonal wood sheathing, are vulnerable to earthquake damage. Provisions for seismic retrofit of cripple walls are presented in Chapter 6.*

c., d. *Modern provisions for bracing of cripple walls appeared in the 1997 Uniform Building Code (UBC) and the 2000 International Building Code.*

e. *Condition e applies to beam and column systems braced with steel diagonals or wood members that do not have detailing allowing the full capacity of the diagonal brace to be developed. Prior to the 1997 UBC, it was not common to design brace connections to develop the brace member capacity.*

f. *Condition f applies to dwellings that have sheathed walls that are not attached to the foundations, such as post and pier systems enclosed by "skirt" walls without adequate top and bottom connections.*

g. *Condition g applies to slab-on-grade dwellings and dwellings in which basement walls or foundation stem walls extend up to the underside of floor framing. These dwellings do not exhibit the vulnerabilities described in a through e or other similar vulnerabilities.*

Up to 14 penalty points can be regained with retrofit of these perimeter wall configurations, as described in Chapter 6. Retrofit of this condition is given a "priority" designation in Section H of the Simplified Seismic Assessment Form and is highly encouraged.

3.4 General Condition Assessment (Section C)

The condition of existing structural elements contributes to their performance. Most of the assessment items in Section C are directed towards identifying signs of poor maintenance and material degradation.

Assessment Item C-1. This assessment item (Figure 3-15) addresses issues that are significant and wide-spread enough to affect the dwelling's ability to resist earthquake loading.

		Penalty
C-1	The overall condition of the dwelling is:	
	a. good (essentially crack free, no moisture/water intrusion problems)	[0]
	b. fair (minor wood decay and cracks)	[1.0]
	c. poor (many cracks on interior and exterior, floor out-of-level and wood decay)	[2.1]

Figure 3-15 Assessment item C-1.

Water intrusion into a structure can cause wood decay and encourage termite infestation in the earthquake-resisting structural elements.

Homeowners should find and correct water intrusion conditions and replace decayed wood members, resulting in a retrofit point gain of one.

Assessment Item C-2. This assessment item (Figure 3-16) addresses framing alterations based on conditions observed in the crawlspace or basement.

			Penalty
*C-2	In the under floor area, there has been structural alteration (e.g. cutting or notching of framing for electrical, plumbing, mechanical equipment) that would affect the performance of the dwelling in an earthquake:	yes	[1.5]
		no	[0]
		not applicable	[0]

Figure 3-16 Assessment item C-2. *denotes assessment item that may be improved by seismic retrofit.

Chapter 8 addresses the reduction in seismic adequacy of dwellings when under-floor framing members are notched or bored.

Penalty points can be regained with retrofit of these critical altered structural framing members.

Assessment Item C-3. This assessment item (Figure 3-17) addresses stucco condition issues.

		Penalty
*C-3:	There is evidence of: stucco detachment, bowing of stucco, corroded wire mesh, extensive cracking at finished grade above the bottom of the stucco:	
	a. extensive	[2.0]
	b. minor	[1.0]
	c. none	[0]

Figure 3-17 Assessment item C-3. *denotes assessment item that may be improved by seismic retrofit.

Deterioration of the stucco decreases its effectiveness as earthquake-resisting sheathing. Finish grade (soil) extending above the bottom of the stucco can contribute to deterioration of the stucco and decay in the framing.

Penalty points can be regained with retrofit of the damaged stucco.

Assessment Item C-4. This assessment item (Figure 3-18) addresses foundation conditions issues.

			Penalty
*C-4	At the foundation level, there is:		
	a.	significant deterioration visible (corrosion, material breakdown)	[1.3]
	b.	some deterioration visible	[0.6]
	c.	no deterioration visible	[0]

Figure 3-18 Assessment item C-4. *denotes assessment item that may be improved by seismic retrofit.

A concrete foundation weakened by deterioration is more likely than a strong foundation to be damaged during an earthquake. However, as discussed in Chapter 8, a weak or cracked concrete foundation may still be quite adequate to resist the imposed seismic forces.

Penalty points for this item can be regained with repair of the deterioration or replacement of the deteriorated portion of the foundation.

Assessment Item C-5. This assessment item (Figure 3-19) deals with the quality of the original construction rather than the extent of deterioration that may or may not have occurred since the dwelling was built.

			Penalty
C-5	Throughout the dwelling, the quality of construction appears to be:		
	a.	good	[0]
	b.	average	[0.8]
	c.	poor	[1.7]

Figure 3-19 Assessment item C-5.

The damage to some of the newer homes during the Northridge earthquake was attributed to poor construction quality.

Retrofit to regain penalty points for this item is not practical.

3.5 Nonstructural Elements, Age and Size (Section D)

Past earthquakes have shown that damage to nonstructural elements, including porch roofs, chimneys, brick wall veneer, and water heaters, can in some cases cost more than structural damage.

Assessment Item D-1: This assessment item (Figure 3-20) addresses chimney anchorage.

		Penalty
*D-1 The chimney inspection revealed:		
a. properly connected anchor straps tying the masonry/concrete chimney(s) at side of house to the floor, ceiling and roof framing	yes	[1.0]
	no	[2.0]
b. chimney occurs at dwelling interior		[1.0]
c. dwelling has no masonry/concrete chimney		[0]

Figure 3-20 Assessment item D-1. *denotes assessment item that may be improved by seismic retrofit.

Unreinforced and improperly anchored masonry and concrete chimneys have been a major source of damage in previous earthquakes. In addition to the chimney damage itself, the fallen chimney can damage the roof and surrounding areas. Even properly anchored and reinforced masonry chimneys can become damaged, but are much less likely to become a falling hazard.

Options for chimneys are discussed in Chapter 7.

Assessment Item D-2: This assessment item (Figure 3-21) addresses anchorage of water heaters.

		Penalty
*D-2 The gas water heater has effective anchor straps and water and gas connections:	yes	[0]
	no	[1.0]
The electric water heater has approved anchor straps:	yes	[0]
	no	[0.7]

Figure 3-21 Assessment item D-2. *denotes assessment item that may be improved by seismic retrofit.

Overturned water heaters have caused significant damage in past earthquakes. Bracing of water heaters is discussed in Chapter 7.

Retrofit of this condition is given a “priority” designation in Section H of the Simplified Seismic Assessment Form.

Assessment Item D-3: This assessment item (Figure 3-22) addresses earthquake-activated gas shut-off valves.

		Penalty
*D-3 An earthquake-activated gas shut-off valve is installed:	yes	[0]
	no	[1.0]
	not applicable	[0]

Figure 3-22 Assessment item D-3. *denotes assessment item that may be improved by seismic retrofit.

Broken gas lines create a risk for fire, explosion, and asphyxiation. A penalty is assessed for any dwelling that does not have earthquake-activated shut-off valves on the gas line. Installation of shut-off valves is discussed in Chapter 7.

Retrofit of this condition is given a "priority" designation in Section H of the Simplified Seismic Assessment Form.

Assessment Item D-4: This assessment item (Figure 3-23) addresses stair, deck, and porch roof connections.

	Penalty
*D-4 The dwelling has exterior stairs, decks or porch roofs, without internal earthquake bracing, that are attached to the dwelling with:	
a. two or more connections tying the stair, deck or porch to the dwelling interior framing	[0]
b. nails or screws that would be loaded in withdrawal if the stair deck or porch moved away from the dwelling	[1.0]
c. other connection configurations	[1.0]

Figure 3-23 Assessment item D-4. *denotes assessment item that may be improved by seismic retrofit.

As discussed in detail in Chapter 7, stairs, decks and porch roofs often only have 'ledger' type connections that resist gravity forces but readily pry away from the house wall and collapse when subjected to lateral earthquake forces.

Retrofit of this condition is given a "priority" designation in Section H of the Simplified Seismic Assessment Form.

Assessment Item D-5: This assessment item (Figure 3-24) addresses dwelling age.

Penalties for older dwellings cover many aspects of earthquake performance. Older dwellings are less likely to have structural sheathing on the exterior walls and therefore are more likely to have inadequate shear capacity. Also, the older the dwelling, the less likely it is to have anchor bolts to hold the

			Penalty
D-5	The dwelling was built: (if remodel/added area >50% of total area, use addition date):		
	a.	before 1920	[3.0]
	b.	1921 to 1977	[2.0]
	c.	1978 to 1993	[1.0]
	d.	1994 or later	[0]

Figure 3-24 Assessment item D-5.

superstructure framing to the foundation. Soft or weak stories also tend to be more common and vulnerable in older homes. Some degree of penalty is assigned for all homes built before 1994.

Assessment Item D-6: This assessment item (Figure 3-25) addresses floor plan area.

			Penalty
D-6	The approximate total floor area (sq. ft.) of the dwelling and attached garage is:		
	a.	< 1600.	[0]
	b.	1601 - 2500	[1.0]
	c.	≥ 2501	[2.0]

Figure 3-25 Assessment item D-6.

Homes with larger floor plan areas have historically sustained more damage than smaller homes, all other conditions being equal. The form calls for the approximate sum of the areas of all the floors of the house and any attached garage. Three size categories are given on the form. Dwellings larger than 1600 square feet are assigned a penalty.

3.6 Assessment of Local Site Conditions (Section E)

Section E deals with the site topography, drainage and other site-related issues that can affect the performance of the structure in future earthquakes.

The following conditions could inhibit good seismic performance:

- Instability of slopes and surface material above or below a structure;
- Foundation instability caused by local liquefaction of granular foundation soils with shallow groundwater; and
- Differential settlement of foundation soils from seismic compression or liquefaction.

In addition to potential site design and construction oversights by the original site developer, these factors can be exacerbated by deterioration of slopes due to circumstances beyond the site developer's control: prior rain, elevation of the ground water table, and the construction of nearby cut-and-fill lots after initial site development was completed.

Three assessment items (E-1, E-2, E-5) are related to slope conditions. Both steep slopes (steeper than one vertical unit to three horizontal units) and cut-and-fill lots are penalized, while lots on flat or low slopes are not. A cut-and-fill lot is assessed an additional penalty if the lot was developed before the use of engineered fills, which began in 2000 nationally but considerably earlier in some local areas (e.g., 1964 in Los Angeles). Finally, there is an additional penalty if slopes above or below the house appear to be unstable (for example, loose surface material, bulges in the cut or filled slopes, and deformation of the slope material at the base of a slope).

Loose and unstable soils are likely to deform permanently during an earthquake. If saturated, loose soils are prone to liquefaction. If partially saturated, they are prone to shaking-induced contraction (referred to as seismic compression). Two assessment items (E-3, E-4) are intended to identify signs of unstable soil: foundation cracking and differential settlement. The size of the penalty depends on the extent of the cracking or settlement.

Assessment Item E-1: This assessment item (Figure 3-26) addresses slope instability.

		Penalty
E-1	The dwelling is located primarily on:	
	a. a flat lot or slope < 3:1	[0]
	b. steep slope (> 3:1)	[3.0]

Figure 3-26 Assessment item E-1.

Assessment Item E-2: This assessment item (Figure 3-27) addresses surface material above or below a dwelling.

		Penalty
E-2	The dwelling is located on a cut-and-fill pad, which was developed:	
	a. without a geotechnical investigation	[2.7]
	b. with a geotechnical investigation	[1.3]
	c. dwelling is *not* on cut-and-fill pad	[0]

Figure 3-27 Assessment item E-2.

Assessment Item E-3: This assessment item (Figure 3-28) addresses condition of exterior concrete footing.

		Penalty
*E-3	The exterior concrete footing has:	
a.	no visible cracks or a few minor cracks	[0]
b.	minor cracks in several areas	[1.0]
c.	extensive cracking	[2.7]
d.	not applicable	[0]

Figure 3-28 Assessment item E-3. *denotes assessment item that may be improved by seismic retrofit.

Assessment Item E-4: This assessment item (Figure 3-29) addresses differential ground settlement.

		Penalty
E-4	The evidence of differential settlement in or around the dwelling is:	
a.	extensive	[2.5]
b.	minor	[1.0]
c.	none visible	[0]

Figure 3-29 Assessment item E-4.

Assessment Item E-5: This assessment item (Figure 3-30) addresses slope stability.

			Penalty
E-5:	The slope above or below the structure appears to be unstable	yes	[3.2]
		no	[0]
		not applicable	[0]

Figure 3-30 Assessment item E-5.

Assessment Item E-6: This assessment item (Figure 3-30) addresses site drainage.

		Penalty
*E-6:	General condition of site drainage:	
a.	roof gutters and down spouts collecting and conducting water away from foundation	[0]
b.	water collecting at/near perimeter footing with no positive slope away from dwelling	[2.6]
c.	no roof gutters but drainage appears to be adequate or roof gutters with downspouts that empty into splash blocks	[1.3]

Figure 3-31 Assessment item E-6. *denotes assessment item that may be improved by seismic retrofit.

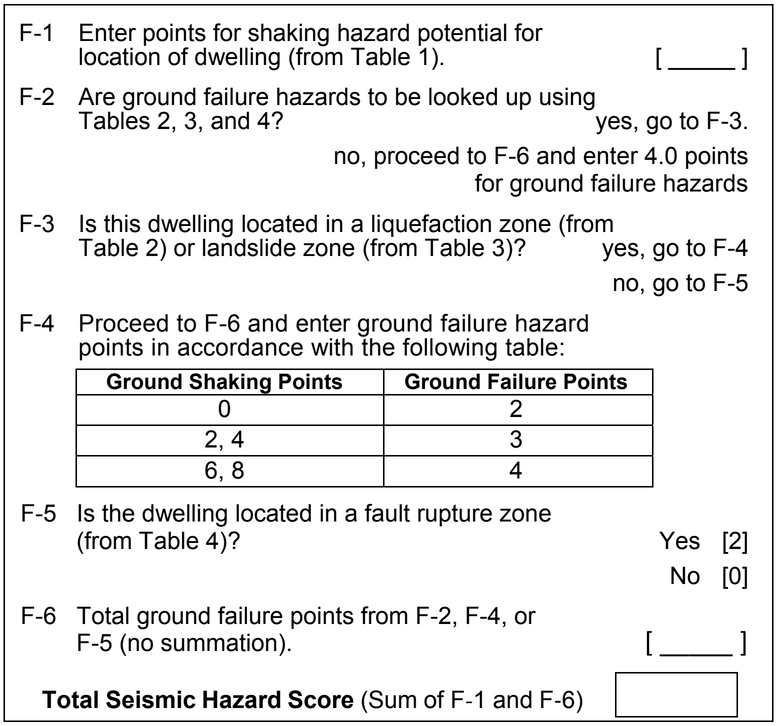
Poor drainage of surface water away from the foundation can weaken the supporting soil. On a larger scale, excessive water can promote soil liquefaction if the soil is sandy. Liquefaction is often associated with severe dwelling damage. The inspector looks for the presence or absence of roof gutters and downspouts and the degree to which water is diverted away from the foundation either naturally or with downspouts and drains. Retrofit work to improve the Structural Score for item E-6 is discussed in Chapter 8.

Retrofit of this condition is given a “priority” designation in Section H of the Simplified Seismic Assessment Form.

3.7 Regional Seismic Hazards (Section F)

Seismic hazards have strong regional variations in both intensity of ground shaking and geologic conditions, as can be seen on the map in Figure 2-1.

Section F of the assessment form (Figure 3-32) addresses regional seismic hazards that affect the site. These regional seismic hazards are due to conditions that are outside the homeowner’s control. Effects considered are: (1) the intensity of ground shaking used in designing new homes; (2) whether the house is in a location that makes it prone to surface fault rupture; (3) whether the house is located in an area that is susceptible to soil liquefaction because of the underlying soil conditions and water table; or (4) whether the location is vulnerable to seismic slope instability.



F-1 Enter points for shaking hazard potential for location of dwelling (from Table 1). [_____]

F-2 Are ground failure hazards to be looked up using Tables 2, 3, and 4? yes, go to F-3.
no, proceed to F-6 and enter 4.0 points for ground failure hazards

F-3 Is this dwelling located in a liquefaction zone (from Table 2) or landslide zone (from Table 3)? yes, go to F-4
no, go to F-5

F-4 Proceed to F-6 and enter ground failure hazard points in accordance with the following table:

Ground Shaking Points	Ground Failure Points
0	2
2, 4	3
6, 8	4

F-5 Is the dwelling located in a fault rupture zone (from Table 4)? Yes [2]
No [0]

F-6 Total ground failure points from F-2, F-4, or F-5 (no summation). [_____]

Total Seismic Hazard Score (Sum of F-1 and F-6) ☐

Figure 3-32 Section F of the Simplified Seismic Assessment Form.

The site’s Seismic Hazard Score is computed in this section as the sum of the penalty points for the various seismic hazards affecting the site, as described below. A higher number of seismic hazard penalty points is less desirable—it translates into an increased risk of damage during an earthquake.

It is not possible to reduce the number of seismic hazard penalty points by seismic retrofit of the dwelling.

3.7.1 Ground Shaking Hazards

Intensities of ground shaking for building code applications are mapped by the U. S. Geological Survey in collaboration with building code committees. Several ground motion parameters are mapped, but design-level spectral acceleration at 0.2 sec (referred to as S_{DS}) is used in the simplified seismic assessment procedure for ground shaking hazard scoring. Table 1 of the assessment form is used to assign a ground shaking hazard score, which is determined under assessment item F-1. The ground motions obtained from the procedures in Table 1 account for the magnitude and frequency of potential earthquakes and their site-to-source distances. Ground motions are evaluated for stiff soil site conditions, which is the default specified in building codes.

3.7.2 Liquefaction and Seismic Landslide Hazards

Analysis of data from past earthquakes has revealed that regions with increased susceptibility to soil liquefaction have sustained higher levels of damage than comparable areas without liquefaction On liquefiable soil, houses are shaken and damaged as though on firm ground until liquefaction occurs. Once liquefaction occurs, the structure may be subject to differential ground displacements (laterally or vertically) beneath the foundations, or the foundation may suffer a bearing failure into the weakened soil.

Landslides caused by earthquakes damage dwellings as a result of differential displacements beneath the foundations, or in some cases, soil or rocks impacting the structure.

3.7.3 Surface Fault Rupture Hazards

Surface fault rupture occurs when earthquake fault displacements extend to the ground surface, which is common for events of magnitude greater than about 7, but may or may not occur at lower magnitudes. Few dwellings are located over faults, so the potential for fault rupture beneath any single dwelling is low. However, when fault rupture occurs beneath a dwelling, the damage is typically severe.

3.8 Total Regional Seismic Hazard Points

Scores for ground failure, liquefaction, landslide, and fault rupture hazards are determined under assessment items F-2 through F-5, based on procedures described in Tables 2, 3, and 4 of the Simplified Seismic Assessment Form.

The inspector then sums the seismic hazard points from assessment items F-1 through F-5 to determine the Seismic Hazard Score. The sum is entered in the box provided in Section F and in the appropriate box in Section G.

3.9 Hazards Not Considered

There are other improbable and less common hazards associated with earthquakes that have not been addressed in this form. These include flooding due to dam failures or to seiche, lurching of softer soil, tsunami inundation, and the release of toxic materials. The losses from these sources are considered remote and difficult to quantify for a specific structure.

3.10 Determination of Seismic Performance Grade (Section G)

Section G of the Simplified Seismic Assessment Form (Figure 1-5) is used to determine the Seismic Performance Grade, which depends on the Structural Score and the Seismic Hazard Score.

The grade provides important information to the homeowner regarding the earthquake vulnerability of the dwelling. Grades are subdivided to include "+" and "-" descriptors that indicate the dwelling is expected to incur damage at the higher and lower ends, respectively, of the damage range for that grade. Qualitative and quantitative definitions for the various grades are provided in the companion FEMA P-50 document. Section G of the Form (Figure 1-5) contains a condensed version of these definitions.

Chapter 4

Retrofit Method Options and Reassessment of the Seismic Performance Grade

4.1 Choice of Retrofit Method

A homeowner choosing to execute seismic retrofits to lower the Structural Score on the assessment form has several retrofit method options. As detailed below, the method choices are determined by the house location, foundation configuration, degree of retrofit desired, and budget.

The choice of retrofit method involves a number of considerations. Four methods are available and are described briefly below and in more detail in chapters to follow:

- **Method 1:** Prescriptive *International Existing Building Code* Chapter A3 method for structural cripple wall and basement dwelling retrofit (IEBC Cripple Wall Provisions Method)
- **Method 2:** Prescriptive Retrofit Method for Nonstructural Building Elements
- **Method 3:** Prescriptive method for structural retrofit of various dwelling types (IRC Prescriptive Retrofit Method)
- **Method 4:** Engineered method for structural retrofit of various dwelling types (Engineered Structural Retrofit Method)

'Prescriptive' structural retrofit Methods 1 and 3 do not require the services of an engineer, whereas the 'engineered' Method 4 does. The structural retrofit methods apply to selected structural vulnerability assessment items covered in Sections A, B, C, D, and E of the Simplified Seismic Assessment Form. Nonstructural retrofit Method 2 applies to selected nonstructural vulnerability assessment items covered in Sections B and D, which in many instances can be implemented by the homeowner, but in some instances may require the services of a design professional.

The homeowner should be aware that the intent of the retrofit measures is to reduce the risk of earthquake-induced damage in the dwelling. The retrofit measures do not necessarily strengthen the whole building to new building code requirements, or address all of the dwelling's seismic vulnerabilities. The retrofit measures are intended to significantly reduce damage and increase occupant safety, but they will not make the dwelling immune to all earthquake damage.

The owner is highly encouraged to discuss the proposed retrofit with the local building jurisdiction and apply for a building permit for the work. Methods 1, 3, and 4, for overall structural retrofit measures, are based on the IEBC, IRC, or IBC model codes, respectively; the building jurisdiction can state whether these codes are adopted or at least accepted as the basis for the retrofit work. The prescriptive retrofit measures and the engineered procedures in these codes are based on the broad experience of many engineers, building officials and contractors. Following procedures recommended herein is preferable to an ad hoc retrofit that is not designed per local requirements or accepted engineering procedures, and therefore could be ineffective.

4.1.1 Method 1: IEBC Cripple Wall Provisions Method

Method 1, the *International Existing Building Code* Chapter A3 Prescriptive Provisions for Seismic Strengthening of Cripple Walls and Sill Plate Anchorage of Light, Wood Frame Residential Buildings (otherwise referred to as the IEBC Cripple Wall Provisions Method) meets the requirements for improving the Structural Score and potentially the Seismic Performance Grade through the retrofit of certain conditions identified in assessment items A-1, A-5, and B-8, as follows:

A-1: Replace an existing footing with a new continuous or masonry footing.

A-5: Add anchor bolts or retrofit anchors.

B-8: Improve bracing under lowest framed level perimeter walls.

These IEBC Cripple Wall Provisions can be used for both cripple wall houses and basement houses, as described in Chapter 2.

In specifying the strength capacity of the retrofit measures, Method 1 assumes that the house is in a high seismic region. The method adjusts the strength capacity for number of stories, and whether the house has roof tiles and stucco sheathing, which increases the weight and thus the seismic force in the building.

This prescriptive retrofit method is described completely in Chapter 6. It is to be used for retrofitting one- to three-story cripple-wall houses or basement houses that meet certain criteria, including:

1. The cripple-wall heights do not exceed 48 inches in one- or two-story buildings and do not exceed 14 inches in three-story buildings. The 48-inch height limit generally precludes houses on sloping sites; these houses would be retrofitted by Method 4 (Engineered Structural Retrofit Method).
2. The building is supported, or will be supported, at its perimeter by a continuous concrete footing and stem wall.

The IEBC Cripple Wall Provisions further specify that these Provisions cannot be used to retrofit the following types of houses:

- Houses with a lateral-force-resisting system using poles or columns embedded in the ground.
- Any case which the jurisdiction code official determines is beyond the scope of the IEBC Cripple Wall Provisions. This usually includes split-level houses and large or complex houses, especially those with mixed structural systems and foundations as a result of additions and remodeling.

The IEBC Cripple Wall Provisions also state, in Section A301.3, that if a cripple-wall house does not meet the above requirements and thus requires an engineered retrofit design, the design seismic force may be 75% of the required force per the IBC.

Using the story height and finish weight assumptions, Method 1 prescribes the length of the wood structural panel shear walls, as a percentage of the wall length in each plan direction, to be placed on each perimeter cripple wall inside face. The wood structural panel thickness and nailing is prescribed, as is the size and spacing of anchor bolts or alternative side anchors. Standard details are given for replacement continuous foundations, although a homeowner may want to consider the Engineered Structural Retrofit Method (Method 4) for this retrofit, as further discussed in Chapter 8.

Method 1 only provides for the strengthening of the cripple walls of the house. While these cripple walls are usually the most vulnerable element, other vulnerabilities may have been identified in the Simplified Seismic Assessment Form. Exterior and interior walls at higher levels may have significant vulnerability. The analysis and design involved to determine the shear and overturning forces in these upper walls is beyond the scope of Method 1. Method 4 (Engineered Structural Retrofit Method) would be required to analyze the vulnerability of these walls and other elements at all levels and to design a retrofit for them. A cripple-wall house owner may also choose Method 4 for certain conditions, as discussed in Chapter 6.

4.1.2 Method 2: Prescriptive Retrofit Method for Nonstructural Building Elements

Method 2, Prescriptive Retrofit Method for Nonstructural Building Elements, described fully in Chapter 7, can be used to retrofit building elements such as porch roofs and decks, chimneys, brick veneer, and water heaters.

This method can be used to improve the Structural Score and potentially the Seismic Performance Grade through the retrofit of certain conditions identified in assessment items B-5, D-1, D-2, D-3, and D-4 as follows:

B-5 Add additional fasteners to masonry veneer, or replace it with structural sheathing.

D-1 Strap exterior chimney to roof and floors.

D-2 Provide bracing and flexible water and gas connections for water heater.

D-3 Provide earthquake-activated gas shut-off valves.

D-4 Secure porch roofs to the main building.

These prescriptive retrofits are usually not done to a particular seismic force level as determined for the specific house location, with the possible exception of assessment item D-4.

4.1.3 Method 3: IRC Prescriptive Retrofit Method

Method 3, Wall Bracing and Cripple Wall Bracing in Accordance with the Prescriptive Provisions of Chapter 3 (Building Planning), Chapter 4 (Foundations), and Chapter 6 (Wall Construction) of the *International Residential Code* (otherwise referred to as the IRC Prescriptive Retrofit Method) can be used to improve the Structural Score and Seismic Performance Grade through the retrofit of certain conditions identified in assessment items A-1, A-5, B-2, B-3, B-4, B-5, and B-8, as follows:

A-1: Provide continuous reinforced concrete foundation.

A-5: Add anchor bolts.

B-2: Add bracing walls at dwelling exterior.

B-3: Install lighter roofing.

B-4: Install plywood/OSB frame at garage front.

B-5: Change exterior wall finish.

B-8: Improve bracing at crawlspace perimeter walls.

Chapter 3 of the IRC provides general requirements, the governing seismic zone maps, and exceptions to the limitations, discussed below, on the use of the IRC for seismic Zone E. Chapter 4 provides dimensions and other requirements for new continuous reinforced concrete or masonry foundations and sill-to-foundation anchor bolts.

Chapter 6 has prescriptive provisions for wall sheathing requirements for cripple walls and for each floor level of 1-to-3-story houses for various types of typical exterior and interior wall sheathing for Seismic Design Categories A through D_2. (a mapped seismic shaking intensity designation peculiar to the IRC). Maps showing the areas of each Seismic Design Category in the conterminous United States, Alaska, and Hawaii are provided in Figures 2-1 through 2-4 of the companion FEMA P-50 document, *Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings* (FEMA 2012). Buildings in IRC Seismic Design Category E, the area of highest seismic shaking in these maps, cannot be retrofitted by this method.

4.1.4 Method 4: Engineered Structural Retrofit Method

Method 4, Engineered Structural Retrofit Method, can meet the requirements for improving the Structural Score and potentially the Seismic Performance Grade through the retrofit of certain conditions identified in a broad range of assessment items, as follows:

A-1: Provide continuous reinforced concrete foundation.

A-5: Add anchor bolts or retrofit anchors.

B-2: Add bracing walls at dwelling exterior.

B-3: Install lighter roofing.

B-4: Install plywood/OSB or steel frame at garage front.

B-5: Change exterior wall finish.

C-2: Repair cut structural framing.

C-3: Repair deteriorated stucco.

C-4: Repair deteriorated foundation.

D-4: Brace nonstructural elements.

E-3: Repair footing cracks.

E-5. Improve rain water routing away from foundations.

Use of Method 4 to address these conditions is discussed in detail in Chapter 8, which also encourages homeowners to consider use of Method 4 (Engineered Structural Retrofit Method) when certain conditions exist. For example, an engineer analyzing the building may find that adding shear-resisting sheathing to interior walls can be used effectively and economically to strengthen the building.

4.1.5 Seismic Retrofit in Accordance with the IBC

Section 3404.5 of the IBC, Voluntary Seismic Improvements, allows retrofit measures that improve the seismic force-resisting capacity of an existing building, subject to certain conditions, in part:

- The retrofit measures need not bring the structure to any specified seismic force-resisting capacity. This differs from the IEBC Cripple Wall Provisions Section A301.3, discussed above, that states that an engineered cripple wall retrofit design is to be for 75% of the IBC required force.
- An engineering analysis is to be submitted showing that the design of the particular retrofit measures meet IBC requirements, and that the measures do not diminish the existing building's compliance with certain IBC provisions.

This IBC section confirms the acceptability of voluntarily addressing a particular vulnerability. As an example, a 2-story narrow house has parking at grade level. The street level front wall has weak sheathing, and multiple openings for the garage door, stair, and windows, leaving little width of remaining wall. The owner sees the condition as being particularly vulnerable to seismic damage. At some expense, this house could be retrofitted with a steel moment frame at the garage door (See Chapter 8). However, the owner, in consultation with an engineer, chooses rather to sheath the interior face of the street level front wall with structural sheathing. This retrofit significantly improves the seismic resistance of the house, in conformance with IBC Section 3404.5, but does not necessarily bring it up to the 75% IBC required capacity, per IEBC Provisions Section A301.3. Consultation with the building jurisdiction regarding this distinction would be advised.

4.2 Reassessment of the Seismic Performance Grade by a Qualified Licensed Design Professional

The Seismic Performance Grade on the Simplified Seismic Assessment Form can be reassessed and, if appropriate, revised, as a result of further investigation by a qualified licensed design professional. Houses may be inappropriately penalized by the inspector if certain favorable conditions were not observed, not noted on the assessment form, or not reflected in the determination of the Seismic Performance Grade. A licensed engineer or architect experienced in structural engineering can provide reassessment of the Structural Score. A licensed engineer experienced in geotechnical engineering can provide reassessment of the Seismic Hazard Score.

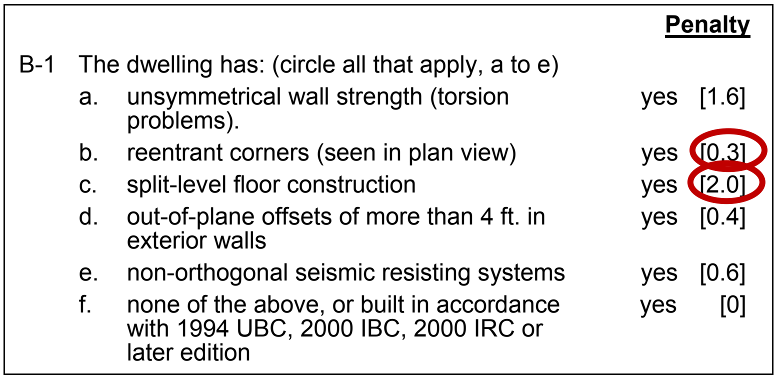
The process of performing a further investigation to reassess the Seismic Performance Grade would be as follows: A homeowner has had the dwelling assessed and has been given a copy of the completed assessment form with the assigned Seismic Performance Grade. The homeowner believes the dwelling has better seismic resistance than indicated by the grade. The homeowner engages a qualified licensed design professional to perform further assessment of the dwelling, and revise as necessary the conditions selected for various assessment items on the Simplified Seismic Assessment Form. This assessment would be more comprehensive than done for original completion of the assessment form, and may include: review of available drawings and specifications from original construction, review of soils reports or soils testing, and removal of finish materials to observe hidden conditions. A revision to assigned penalty points can be made where existing construction is better understood or where existing construction overcomes the vulnerability assumed in the assessment form.

At the conclusion of this assessment, the design professional reviews the original assessment form and develops an engineering report indicating how penalty points for assessment items should be revised (eliminated or revised to penalty assignments that better reflect the observed conditions). The engineering report should contain a summary section that shows the penalty points for each assessment item on the assessment form (including those that were not changed so that a reviewer could compare the engineering report with the original form to see where the changes occurred), re-calculates the Structural Score or Seismic Hazard Score and assigns a new Seismic Performance Grade based on the further assessment. The engineering report with an attached copy of the original assessment form replaces the original form as a record of the assessment process.

A revision can be made if the existing design and construction overcomes the vulnerability assumed in the form, as illustrated by the examples below:

4.2.1 Reassessment Example 1

Assessment item B-1 of the original Simplified Seismic Assessment Form indicated that penalties associated with conditions b and c were assigned (see Figure 4-1).



			Penalty
B-1	The dwelling has: (circle all that apply, a to e)		
a.	unsymmetrical wall strength (torsion problems).	yes	[1.6]
b.	reentrant corners (seen in plan view)	yes	[✓ [0.3]]
c.	split-level floor construction	yes	[✓ [2.0]]
d.	out-of-plane offsets of more than 4 ft. in exterior walls	yes	[0.4]
e.	non-orthogonal seismic resisting systems	yes	[0.6]
f.	none of the above, or built in accordance with 1994 UBC, 2000 IBC, 2000 IRC or later edition	yes	[0]

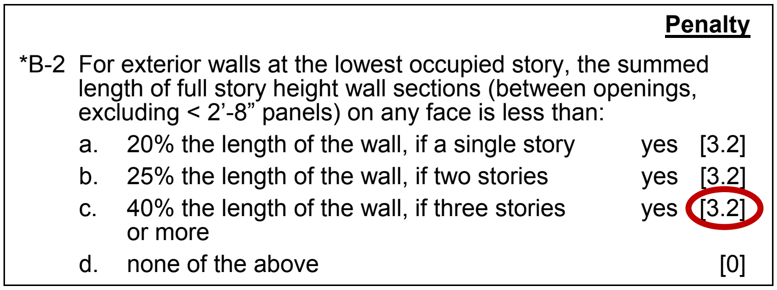
Figure 4-1 Assessment item B-1 with assigned penalties.

During the reassessment process, a structural design professional examined the design and construction of the house lateral force-resisting structural system and determined that it fully compensates for these configurations that are assumed by the assessment form to be vulnerable. The design professional changed the assigned penalty for B-1 from 2.3 to 0.0.

Retrofit to regain penalty points for this item is generally not practical. However, Chapter 8 includes a discussion of retrofit possibilities for condition c, split-level floor construction.

4.2.2 Reassessment Example 2

Assessment item B-2 of the original Simplified Seismic Assessment Form indicated that the penalty associated with condition c was assigned (see Figure 4-2).



			Penalty
*B-2	For exterior walls at the lowest occupied story, the summed length of full story height wall sections (between openings, excluding < 2'-8" panels) on any face is less than:		
a.	20% the length of the wall, if a single story	yes	[3.2]
b.	25% the length of the wall, if two stories	yes	[3.2]
c.	40% the length of the wall, if three stories or more	yes	[✓ [3.2]]
d.	none of the above		[0]

Figure 4-2 Assessment item B-2 with assigned penalty. *denotes assessment item that may be improved by seismic retrofit.

During the reassessment process, a structural design professional observed the existence of interior plywood sheathing that strengthens the walls sufficiently to fully overcome this common wall strength deficiency assumed by the assessment form, without blocking the openings. The design professional changed the assigned penalty for B-2 from 3.2 to 0.0.

4.2.3 Reassessment Example 3

Assessment item of the original Simplified Seismic Assessment Form indicated that the penalty associated with condition d was assigned (see Figure 4-3).

		Penalty
*B-4	For an attached garage with a second floor above, the narrow walls at the side of the garage door openings have:	
a.	wood structural panels on each narrow wall pier	[0]
b.	structural steel frames around or alongside the door	[0]
c.	prefabricated narrow shear walls, installed in accordance with manufacturer's recommendations	[0]
d.	none of the conditions specified in conditions a, b, or c above (that are visible)	[✓ [3.0]]
e.	not applicable (single story) or built in accordance with 1997 UBC, 2000 IBC, 2000 IRC or later edition	[0]

Figure 4-3 Assessment item B-3 with assigned penalty. *denotes assessment item that may be improved by seismic retrofit.

During the reassessment process, a structural design professional removed finishes at the narrow walls and observed an adequate steel moment frame spanning over the garage door opening. The design professional changed the assigned penalty for B-4 from 3.0 to 0.0.

4.2.4 Reassessment Example 4

Assessment item E-2 of the original Simplified Seismic Assessment Form indicated that the penalty associated with condition d was assigned (see Figure 4-4).

		Penalty
E-2	The dwelling is located on a cut-and-fill pad, which was developed:	
a.	without a geotechnical investigation	[✓ [2.7]]
b.	with a geotechnical investigation	[1.3]
c.	dwelling is *not* on cut-and-fill pad	[0]

Figure 4-4 Assessment item E-2 with assigned penalty.

During the reassessment process, a soils engineering design professional determined from construction documents or soil tests that the cut-and-fill placement was well designed and executed with a geotechnical investigation. The design professional changed the assigned penalty for E-2 from 2.7 to 1.3, the penalty for being on a cut-and-fill site.

Chapter 5

Detailed House Survey Before Retrofit

This chapter is intended as guidance for homeowners considering a retrofit and as guidance to contractors new to seismic retrofit. This chapter describes a survey of the house that a homeowner, contractor or engineer might perform prior to finalizing the design of the retrofit measures. This house survey is similar to but subsequent to the survey done by the Simplified Seismic Assessment inspector, and concentrates more on specific conditions to be addressed in the retrofit. The survey is appropriate for any of the structural retrofit methods introduced in Chapter 4. This chapter does not include the observation of nonstructural elements that are covered in Chapter 7.

For the purposes of designing and constructing retrofit measures, the house should be surveyed to determine all existing conditions, dimensions, and other considerations significant to the retrofit construction. The results of this survey are best recorded with notes, photographs, sketches, and a plan-view drawing. This survey will help to determine the scope of work required and the method of retrofit design to be used. The survey will show whether a retrofit according to the prescriptive measures of the IEBC Cripple Wall Provisions, Method 1, is allowable and appropriate.

5.1 Pre-Retrofit House Survey

5.1.1 Plan View with Dimensions

To aid in the survey, a scaled plan drawing of the foundation level of the house should be made. A 1/4" = 1'-0" scale for the drawing should be adequate for field use to record the locations of pertinent existing conditions and dimensions. To be useful for planning the retrofit work, this plan view should show major exterior plan dimensions. For a crawl space house, it should show floor-joist orientation and other details, as discussed further in Section 5.1.4.

5.1.2 Exterior and Interior Sheathing Materials

Retrofit Methods 1, 3, and 4, from Chapter 4, can require that you determine if you have the heavier sheathing materials (exterior stucco, interior plaster, tile roofing) The following investigation procedures can be used to determine what sheathing materials are present.

On exterior walls, stucco, or Portland cement plaster, is applied over wire lath and building paper that has been fastened to the wood frame wall. The resulting finish has a rough appearance and is about 7/8 inch thick. Figures 2-3, 2-5, 2-8, and 2-9 show houses with stucco exteriors.

Slate, clay, or concrete tile roofs are easily distinguished from wood or asphalt composition shingles by their appearance. Figure 2-7 shows a house with a tile roof.

Gypsum board interior sheathing on walls usually has a more uniform flatness than does plaster, although gypsum board may have been textured with a thin plaster coat. Plaster sheathing is usually found in houses built before about 1940. Take the steps below to determine if the walls are of plaster.

1. Look at the top side of the ceiling from the attic. If it is plastered, there will be wood lath, gypsum board, or possibly metal mesh lath with plaster squeezed through the lath.
2. At a removed switch or outlet plate in the wall, plaster with wood lath can be identified by the ends of the 1-1/4 by 3/8 inch spaced wood strips that may show. Plaster with gypsum board lath can be identified by the paper surface on each side of the gypsum lath and the total thickness of about 7/8 inch.
3. A gypsum board wall can be identified at exposed cross sections by the paper surface of the inner and outer faces and the total thickness of 3/8 to 5/8 inches. Sometimes gypsum board will have a thin (1/8 inch) coating of textured plaster material, which is not considered the same as plaster for determining finish weight in Chapter 8.

5.1.3 Foundation Condition as Surveyed From Outside

Certain foundation conditions will increase the house's vulnerability to earthquake damage. Certain cracking patterns indicate that differential settlement has occurred. Generally, cracks in foundation walls that are wider at one end indicate that the foundation stem wall on one or both sides of the crack has rotated. Occasional cracks of even width, as shown in Figure 5-1, are usually caused in unreinforced foundations by concrete shrinkage, and they do not significantly increase seismic vulnerability. A series of thinner cracks may indicate that the foundation has embedded horizontal steel reinforcement, a desirable feature.

Figure 5-1 Shrinkage crack in unreinforced concrete perimeter footing wall.

The inspector may have assigned penalty points under item C-4 for foundation deterioration. To further assess the foundation, the strength of the footing concrete can be estimated by striking it with a hammer in various locations around the foundation wall perimeter. Always wear safety goggles when performing this test. The concrete should not readily break away following a hammer blow.

Unreinforced masonry footings and stem walls may be found. The masonry may be visible, as in Figure 5-2, or it may have been covered by a thin stucco-like coating of cement plaster. Method 1 (IEBC Cripple Wall Provisions Method), requires that the adequacy of an unreinforced masonry footing for seismic resistance be substantiated by a design professional before retrofit. This substantiation may be possible and prudent for unreinforced masonry footings and stem walls in good condition. Two preliminary evaluations should be done during the inspection to help determine whether to request this substantiation by the design professional:

- At several locations around the perimeter foundation, scrape along a horizontal mortar joint with your fingernail or a piece of wood. Weak mortar will abrade off; stronger mortar will not.
- At several locations around the perimeter foundation, measure the height and thickness of the masonry stem wall, if possible, digging down to the

Figure 5-2 Brick masonry foundation wall.

top of the footing to obtain the full height measurement. A height/thickness ratio of more than about 6:1 could be unstable in an earthquake if the mortar was found to be weak.

Exterior Grade Level

The *IBC* and *IRC* require that the exterior soil grade level be kept below the bottom sill plate of the cripple wall or the first floor wall. This soil clearance is shown in the left-hand side of Figure 5-3 for a slab-on-grade foundation and sill, but would be similar for a cripple wall foundation, mudsill, and sheathing. Very often, landscaping changes over the years result in the grade getting higher until it is at or above the sill plate level, as also shown in Figure 5-3 (right). Even though the sill and the bottom of the studs are separated from the soil by the siding or stucco, the soil moisture can raise the moisture content of the wood. The result is often the decay of even a preservative-treated sill, the bottom of the studs, and the sheathing. As new retrofit sheathing should never be placed over decayed sills or framing, it is important to check the grade level for all house types. This is most easily done at a vent or window opening where the distance down from the bottom of the opening to the outside grade and from the bottom of the opening to the bottom of the (inside) mudsill can be determined and compared.

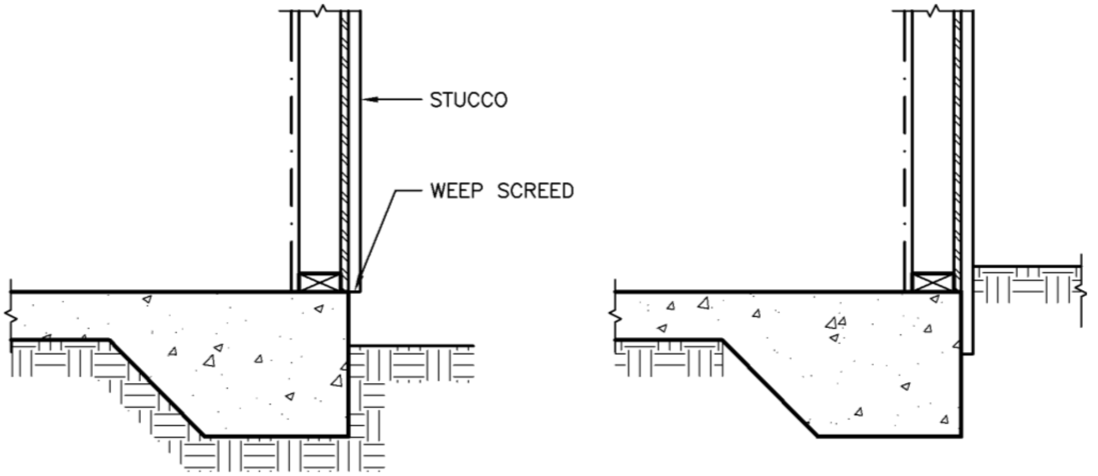


Figure 5-3 Left – A proper screeded stucco finish with soil clearance at a slab-on-grade foundation; Right - Unscreeded stucco placement and high soil height that can cause decay. Both conditions are similar for a crawl space foundation.

Site Drainage

The grade adjacent to the house should be sloped so that surface rainwater, sprinkler water, and water from roof gutter downspouts does not pool alongside the house. Chapter 8 considers this topic in greater detail.

Stucco Walls

Observe the condition of the stucco surface. Stucco that was poorly cured at placement may appear soft and will flake off with light hammer blows. Rust from the steel wire lath may be visible in the honeycomb pattern of the mesh. The stucco may be bowed, which usually is a sign that the sill plate behind it has decayed, allowing the studs to settle and transfer vertical load to the stucco. Sill plate replacement is discussed in Chapter 6.

The repair of degraded stucco walls is most important for multi-story houses, because the seismic forces to be resisted by the stucco sheathing are greater. To obtain the best seismic force-resisting strength in repaired stucco walls, the lapping of old and new lath, the embedment of the lath within the stucco, the curing of the stucco courses, and the nailing of the lath to the mudsill must be in accordance with good practice and the current building code.

Later editions of the IBC have required that weep screeds be placed at the bottom edge of wall stucco, as shown at the left in Figure 5-3. Earlier editions of its predecessor standard codes did not have this requirement. If properly placed and maintained to prevent paint or debris clogging, the screed allows water that has passed through the stucco to the backing paper to escape. In unscreeded walls, water can collect at the base of the wall backing paper, against the sill plate. As discussed below in 5.2, the sill plate should be checked carefully for decay in unscreeded walls. The right side of Figure 5-3 illustrates two undesirable conditions: unscreeded stucco sheathing extending below grade level and the grade level being higher than the sill.

Infestation

The wood framing of houses may become infested with subterranean, drywood, dampwood, or Formosan termites; powder post beetles; or carpenter ants. Any of these infestations can leave wood framing weakened to such an extent that retrofit sheathing should not be placed over it. Outside, and within the crawl space, look for obvious signs, such as mud termite tubes going up the walls, or fine ‘sawdust’ accumulating under powderpost beetle pinholes on the underside of wood members. Licensed pest control operators are trained to detect and eradicate these infestations. Infested wood framing members should be replaced.

5.1.4 Survey within the Crawl Space

Much can be learned about the condition of a crawl space home by a thorough crawl space inspection. For a crawl space inspection, carry a flashlight and expect to get dirty. A hard hat, dust mask, knee and elbow pads, a notepad, a camera, and clipboard with the 1/4" scale field plan, are also needed. The 1/4" scale field plan, begun outside, should show floor joist orientation, existing vents and other obstructions, possible locations and lengths of the retrofit sheathing, access hatch dimensions, and, eventually, Provisions figure details proposed to be used at each sheathing location.

Use caution regarding dust, broken glass, nails, the possible presence of asbestos-containing pipe insulation, passage clearances, rodents, and biting insects. Someone else should be aware that you are in the crawl space.

Cripple Wall Dimensions

The height of the cripple wall, from the bottom of the sill plate to the top of the upper top plate, should be measured all around the building. This measurement serves several needs.

First, if the height of the cripple wall is more than 48 inches at any point in a one- or two-story building, a Method 4 engineered retrofit design must be used. If the height of the cripple-wall studs is more than 14 inches at any point in a three-story building, the retrofit design must be engineered. These height measurements are also used to determine the amount of wood structural panel needed.

Obstructions to Retrofit Sheathing

There are usually obstructions along the inner face of the cripple wall that would prevent the retrofit sheathing from being applied continuously. Ventilation or flood equalization openings are the most common. Though not actually an obstruction, they must not be covered up by the retrofit sheathing. Other obstructions include pipes, ducts, equipment, chimney foundations, and thick structural posts. It is important that the locations of the obstructions be accurately measured and noted. Per Method 1 (IEBC Cripple Wall Provisions Method), a prescribed total length of retrofit sheathing will be required along each wall, and the length of each sheathing portion must be not less than twice its height. With the obstruction locations measured, noted and drawn in scale on the plan, the locations and lengths of the retrofit sheathing can be drawn.

Crawl Space Drainage and Ventilation

The IBC and IRC require prescribed sizes and configurations of ventilation openings for crawl spaces. This ventilation serves to keep the moisture content of the crawl space framing below the level conducive to wood decay, as has occurred in the example shown in Figure 5-4. It is important that this ventilation be present. Retrofit sheathing should not cover these vents, unless a vent of equivalent area and cross-draft effectiveness meeting code requirements is established elsewhere.

Figure 5-4 Decay of wood framing in damp crawl space.

The earthen floor of a crawl space is often damp. This is often not preventable, and usually is not a problem if proper crawl space ventilation is provided. However, standing water in crawl spaces is not desirable, and can lead to decay in the framing (Figure 5-4) and mildew in the spaces above. Proper ventilation and site drainage should be maintained to prevent standing water in crawl spaces.

Sill Plate

The sill plates in older houses may be found to be decayed or infested. The decay may be due to moisture accumulation from an increase in grade level or the lack of a weep screed, as discussed above, or other causes. The decay is often at the bottom back of the sill and not observable, as shown in Figure 5-5 at a crawl space foundation. This decay may be obvious by the uneven texture of the wood or visible white mold growth, as shown in Figure 5-6 at a slab-on-grade foundation. Also, observation holes can be bored vertically into the sill; dark soft chips from the drill holes indicate decayed wood. The replacement of decayed sill plates is discussed in Chapter 6.

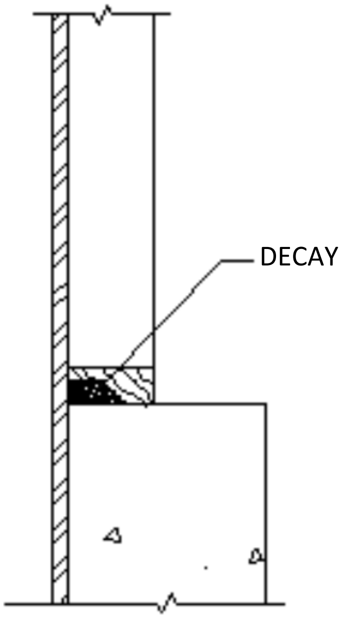


Figure 5-5 Section showing deep decay in sill plate.

If the moisture that caused the decay is still present, a moisture meter can be used along the sill to detect high moisture levels. Any reading higher than 20% should be followed by a closer investigation and the wood in this area probed with an awl for softness. If new anchor bolts are to be placed through the sill, these test holes can be sized and located for anchor bolt placement. If the hole is not to be used, it should be plugged with a dowel treated with copper napthenate preservative.

Figure 5-6 Obvious visible decay in a sill plate.

It is often believed that the application of copper napthenate, borate, or other wood preservative to the exposed surfaces of a crawl space sill plate will retard on-going decay or prevent new decay. Unfortunately, the preservative cannot penetrate the wood side grain to a depth sufficient to be of value. Also, the exposed part of the sill is the driest part, and is least likely to decay.

The width of the sill plate compared to the stud width should also be observed and recorded. If the sill plate is the same width as the studs, and if at least one inch of the side of the sill plate is exposed above the foundation concrete, the retrofit wood structural panel can be nailed to the sides of the sill plate. Otherwise, blocking must be placed above the sill and between the studs for nailing the retrofit wood structural panels, as discussed in Chapter 6.

Anchor Bolts

Anchor bolts seen in crawl spaces are usually rusted. Method 1 (IEBC Cripple Wall Provisions Method) allows existing anchor bolts in good condition to be used if a new steel plate washer with specified minimum dimensions is installed. Surface rust does not significantly affect the strength of the bolt; however, the amount of rust must allow the existing nut to be removed to install the new washer. If you have closely-spaced existing anchors with nuts too rusted to remove for washer placement, you may want to discuss this requirement with the building jurisdiction or your engineer, as the assessment form does not require that the plate washers be present on existing anchor bolts.

Deeper rust sufficient to significantly reduce the cross section of the bolt will impair its capacity to resist earthquake shear forces. Badly rusted anchor bolts can be revealed by hammer blows, twisting with locking pliers or a wrench, or prying with a crowbar. Note the location and spacing of sound anchor bolts on the field plan.

Post and Pier Footings

In a crawl-space house, the floor joists are often supported by floor beams that are supported by wood posts. These posts will be visible in the crawl space. The wood posts usually rest on wood blocks on concrete pier footings or on continuous interior concrete or masonry footings, although in some older homes they may rest on the bare earth.

Note the general location of the posts, and whether they bear on concrete post footings. Examine each post to see if it is connected at the top and bottom with at least three toenails or other positive connection.

Other Crawl Space Framing

Studs or posts that rest on decayed or infested sill plates may themselves be decayed or infested. Probing with an awl for softness can reveal decay at the base of a stud or post.

Some framing members may have notches or bored holes for the passage of pipes or conduits. Limited-size notches and holes in joists and in most studs will not affect the earthquake-resisting strength of the house. Size limits for these notches and holes are found in the IBC and IRC. Notches and large holes in the top plates of the cripple walls, unless strapped across, will affect the earthquake-resisting strength, as further discussed in Chapter 8.

Concrete Footings and Footing Stem Walls as Surveyed from Inside Crawl Space

The concrete in the foundation walls of older buildings is often weak. Fortunately, the seismic shear stresses in the footing walls of wood-frame buildings are often low, so that the capacity/demand ratio remains high in spite of the weakness, as further discussed in Chapter 8. For example, a 380 pounds-per-foot seismic load in a wood structural panel shear wall (the design force capacity required in the IEBC Cripple Wall Provisions) would result in a shear stress of 4 pounds-per-square inch in the 8-inch-thick footing wall below it. This is only 6% of the allowable shear stress in standard 2500 psi (ultimate compression strength) concrete. The thickness/height stability of a concrete wall is usually more of a concern than is the compressive strength.

Older unreinforced concrete foundation walls often have thin vertical cracks due to shrinkage. These vertical cracks do not significantly diminish the strength or stability of the wall. Only uniform-width cracks 1/4” or wider should be more carefully investigated. As discussed for the exterior investigation, tapered cracks indicative of differential settlement are of greater concern.

As discussed earlier regarding assessment item C-4, the strength of the footing concrete can be estimated by striking it with a hammer in various locations around the foundation wall perimeter. Always wear safety goggles when performing this test. The concrete should not readily break away following a hammer blow.

Method 1 requires that new foundation stem walls be a minimum of six inches thick for one-story houses, eight inches thick for two-story houses, and 10 inches thick for three-story houses. Existing foundation walls not meeting these thickness requirements should be examined more closely for height/thickness ratio, concrete strength, and presence of reinforcing steel.

Masonry Footing Walls

Unreinforced masonry footings and stem walls that were not obvious during the outside inspection may be observed from inside the crawl space. The test procedures discussed in Section 5.1.3 should be pursued if masonry footing walls are observed.

Access

Access to the location to be retrofitted must be adequate for the worker, tools, and materials, including the structural sheathing panels.

Figure 5-7 shows a typical access hatch to a crawl space. Commonly, these small access hatches, low floor clearances, and the presence of ducts and pipes create access problems. A larger, temporary access hatch may be necessary.

5.2 Additional Measurements and Survey Procedures for an Engineered Method 4 Analysis and Retrofit

Additional house measurements and survey procedures are needed if a Method 4 (Engineered Structural Retrofit Method) analysis and retrofit is to be performed on a house.

Figure 5-7 Typical crawl space access hatch.

Additional measurements are needed to determine floor areas to estimate building weights. A plan drawing should be made for each house floor level above the crawl space. These plan dimensions and vertical dimensions, notes on interior and exterior finishes, and other information can be placed directly on the drawings. For estimating building weights, an accuracy on the plan measurements of ± 6 inches is sufficient. More accurate measurements will be needed later for construction and material quantities.

The engineer engaged to perform the Method 4 analysis and retrofit will want to perform an extensive survey of both visible and covered conditions in the house. For a slab-on-grade house retrofit, the engineer may want to remove selected small areas of gypsum board or stucco finish to observe the pattern of existing anchor bolts, unless this pattern is obvious from exposed anchor bolts in the garage or by magnetic means. Finishes also may be removed to observe wood structural element dimensions and conditions, and nailing patterns. This survey is needed to best determine the best retrofit measures, as described more fully in Chapter 8.

Chapter 6

Method 1: IEBC Cripple Wall Provisions Method

This chapter provides homeowners and contractors with guidance on Method 1 (IEBC Cripple Wall Provisions Method), in accordance with the *International Existing Building Code,* Chapter A3, Prescriptive Provisions for Seismic Strengthening of Cripple Walls and Sill Plate Anchorage of Light, Wood-Frame Residential Buildings.

Method 1 also provides guidance for the retrofit of basement homes, but is not applicable to slab-on-grade foundation dwellings.

Selected specifications in the IEBC Cripple Wall Provisions are noted and discussed in this Chapter. However, the owner or contractor planning, permitting, and executing a Method 1 retrofit will need to have a copy of the IEBC Cripple Wall Provisions for reference.

This chapter applies to the retrofit of conditions identified in assessment items A-1, A-5, and B-8:

A-1 Provide continuous reinforced concrete foundation;

A-5 Add anchor bolts or retrofit anchors

B-8 Improve bracing at perimeter (cripple) walls

6.1 The IEBC Cripple Wall Provisions

The IEBC Cripple Wall Provisions are an 18-page appendix chapter of the *International Existing Building Code.* The Provisions should be carefully studied during the design and execution of the retrofit process.

Some important aspects of the IEBC Cripple Wall Provisions are noted below.

1. A retrofit in accordance with the Provisions will reduce the building's earthquake damage vulnerability but will not bring its seismic resistance to the level of new construction. Retrofit to the Provisions does not include the strengthening of full-height walls or other elements above the cripple walls, which may in fact be vulnerable.

2. The Provisions state in Section A301.3 that alternative retrofit measures may be used if designed by a registered design professional and approved by the building jurisdiction, as in a Method 4 (Engineered Structural Retrofit Method) retrofit.
3. The Provisions can also be useful for the retrofit of basement houses. Basement houses usually do not have cripple walls, but they may have inadequate anchor bolts (assessment item A-5). They may also have inadequate connections between the sill plate and the rim or end joists.
4. A building permit is usually required for the work. Inspection of the completed work by a building jurisdiction inspector is usually required. Inspection of work-in-progress is usually required for foundation replacement and for placement of the adhesive or expansion anchor bolts. Inspection requirements, as noted in Section A304.5 of the Provisions, should be discussed with the local building jurisdiction.

   The IEBC and the included Provisions may not be recognized as a basis for the local building code. A contractor or homeowner considering a cripple wall retrofit design based on the Provisions should consult with the building jurisdiction regarding both their acceptance and the required inspections.
5. The Provisions assume that the building is in a ‘high’ seismic region. The Provisions also adjust the retrofit capacity for the higher demands of more stories and heavier exterior finishes. Thus, the specified seismic-resisting capacity of the retrofit may be more than required for a building in a medium-or-low seismic region. Conversely, the capacity may be less than required for a building in a higher-demand ‘near-fault’ location, or a building that is heavier than considered in the Provisions. These considerations are discussed at the end of Chapter 8, and in Chapter 9.
6. As outlined in A301.2, cripple-wall buildings to be retrofitted must meet specific criteria, including number of stories (maximum of 3), and cripple-wall dimensions (maximum height of 48 inches). A building may also be considered ineligible by the code official.
7. The existing construction must first be investigated for evidence of decay, infestation, or other deterioration that would affect the strength of the retrofit construction, as detailed in Chapter 5.
8. Retrofit is to be in accordance with the standard details, dimensions and methods shown in the Provisions.

9. Where the retrofit is in response to an inspection that resulted in the completion of the Simplified Seismic Assessment Form described in Chapter 3, the inspection observations should be verified prior to proceeding with the cripple wall retrofit.

The Provisions address four vulnerabilities common in cripple-wall foundation construction (See Figures 2-2 and 2-23, sections through a typical cripple-wall crawl space house):

- An inadequate concrete or masonry perimeter foundation that supports the cripple wall (assessment item A-1);
- The inadequate attachment of the horizontal sill plate, at the bottom of the cripple wall, to the foundation (assessment item A-5);
- Inadequate sheathing of the inside or outside face of the cripple wall framing (assessment item B-8); and
- The inadequate attachment of the top of the cripple wall to the floor framing and house construction above.

The Provisions include:

- Text Provisions, which describe the purpose, scope and general requirements, and technical requirements for the retrofit materials and construction.
- Sixteen Section and Plan Drawings that illustrate various aspects of the retrofit construction.
- Tables that describe foundation dimensions, sheathing lengths, anchor bolt and nail spacing, and other parameters for each of the allowed building heights (one to three stories) and existing finishes.
- The IEBC is also available as code plus a commentary. The commentary to the Chapter A3 Provisions provides additional background and insight into the Provisions.

6.1.1 Key Parts of the Provisions

Key parts of the Provisions are discussed in some detail below, to aid the homeowner or contractor in their use.

> **A304.2.6**. All replacement sill plates are to be preservative pressure-treated or naturally durable wood permitted by the building code. Naturally durable wood permitted by the code is nearly impossible to buy. When preservative pressure-treated wood is used, the end cuts expose untreated wood; a field-applied preservative such as copper napthenate

should be used to treat these exposed surfaces. Sill plate replacement is often a difficult process, perhaps best done by experienced contractors. The sill replacement process is described in detail in (JLC, 1992).

Existing sills in older houses are usually full-sized unfinished lumber. Acceptable lumber for sill replacement will be finished lumber, which is smaller in width and thickness by about 1/2 inch. If a full 2-inch thick sill is replaced by a finished sill of 1-1/2-inch thickness, there will be a 1/2-inch gap between the sill bottom and the foundation top. This void should be completely filled with a dry-pack concrete grout, placed before the anchor bolts are tightened. This dry-pack grout should have small (3/8" or less) aggregate to fit in the void, and be made with very little water to form a stiff paste.

In other older houses, the sill is the same width as the studs. If a full 4-inch wide sill under full 4 inch wide studs is replaced by a finished 3-1/2" wide sill, it will not be possible to renail the existing siding or new retrofit wood structural panel sheathing, and the studs would not have full bearing. This situation should not be remedied by using treated wood 2 × 6 sills ripped to 4-inch width, as this will remove the treated part of the sill edge, exposing the interior to decay and infestation. If foundation-grade heart redwood can be found, it can be ripped. Otherwise, treated wood 2 × 6 (1-1/2” x 5-1/2” actual measure) sills should be placed, grouting as described above. The new sill will then be wider than the studs. As shown in Provisions Figure A3-6 (and similarly shown in Figure 2-23 of these Guidelines), blocks must then be nailed between each stud space so that the bottom edge of the retrofit wood structural panel can transfer shear forces to the sill. The nailing of these blocks is discussed further below.

A304.2: Foundations. This section is important to homeowners with existing footings of unreinforced masonry. The replacement of existing footings and stem walls significantly increases the scope of the retrofit project. The section addresses how unreinforced masonry may be used, subject to the building jurisdiction, if a licensed architect or engineer provides direction.

The Provisions do not provide direction for the use of concrete perimeter foundations found by the survey methods of Chapter 5 to be weak or cracked. Because wood-frame houses are relatively light, the seismic shear force demand-to-capacity ratio for the anchor bolts and the footing wall may be acceptable, even for relatively weak or cracked concrete. An architect or engineer may determine that the foundation is usable as is, or if certain repairs are made, such as injecting epoxy into cracks.

A304.3: Foundation Sill Plate Anchorage. This section gives the requirements for both adhesive-type and expansion-type anchor bolts.

Adhesive anchors are preferred when the existing foundation is thin or of relatively weak concrete, in which case expansion anchors might break up the adjacent concrete when they are tightened. The safety of the installer, as it relates to any fumes from the adhesive, must be considered with adhesive anchors, especially in a confined crawl space. Expansion anchor bolts are quite acceptable when the existing concrete foundation is thick and sound.

If the hole in the sill is more than 1/16 inch larger than the anchor bolt, the annular ring formed must be filled with grout adhesive, in accordance with Provisions Figure A3-3. Filling the gap minimizes movement of the sill plate in an earthquake.

The Provisions require that prescribed steel plate washers are used to reduce the risk of splitting the sill during earthquake movements. These prescribed square plate washers, specified in Figure A3-3, are to be used at all anchor bolts. These square washers are larger than the commonly used standard round washers and are readily available.

Retrofit anchors bolted to the side of the foundation are an alternative often used where there is insufficient clearance to drill for and place vertical anchor bolts. Section A304.3.1 states that they may be used only when there is insufficient clearance to place anchor bolts through the sill plate, but the building jurisdiction may allow retrofit anchor use even when there is sufficient clearance to place anchor bolts.

The various types of retrofit anchors all work by fastening a metal plate to the side or top of the sill and to the side of the foundation wall. Certain proprietary retrofit anchors are configured to allow for different slopes in the foundation wall and different spacing between the wall and the side of the sill. This hardware is shown schematically in Figures A3-4A-C of the Provisions. The acceptability of similar-looking proprietary hardware should be confirmed with the jurisdiction prior to purchasing and placing.

Twist-strap anchors (see Figure 6-1) are a type of anchor that is not suitable for sill plate anchorage. This type of anchor has good uplift capacity, but does not have sufficient shear capacity in the plane of the wall to function adequately to anchor the sill, even when placed at close spacing.

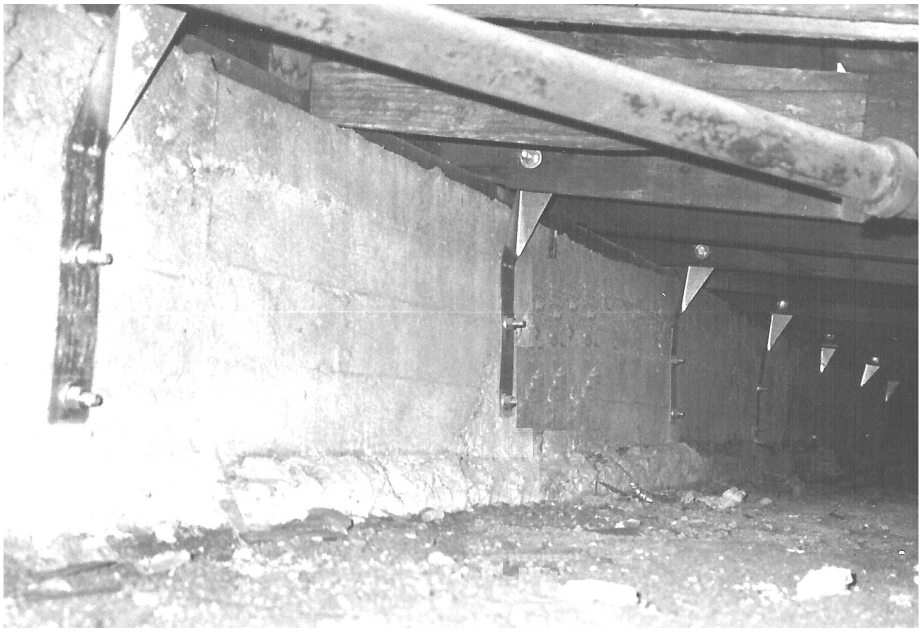


Figure 6-1 A retrofit anchor that is not appropriate for a retrofit to the IEBC Cripple Wall Provisions. Twist strap anchors between the foundation and the floor joists have insufficient strength to resist significant horizontal in-plane shear wall forces.

A304.1.3: Rim or End Joist Connection to Sill Plate and Floor Above. As can be seen in Figure 2-23, the seismic force load path, as discussed in Chapter 2, transmits horizontal forces from the first-floor walls into the first-floor diaphragm down through the building perimeter rim or end joists through the cripple-wall top plate and structural sheathing, and into the sill plate. As stated in Section A304.1.3, the existing nailing from the first-floor diaphragm to the perimeter rim or end joists, and from the perimeter rim or end joists into the sill plate or cripple-wall top plate can be considered adequate in a one-story building. In two-or-three story buildings, A304.1.3 states that the existing nailing from the first-floor diaphragm to the perimeter rim or end joists can still be considered adequate, but the nailing from the perimeter rim or end joists into the sill plate should be verified as being 8d toenails at 6 inches on center. If this nailing cannot be verified, the additions of steel framing angles as shown in Provisions Figure A3-8A-C is required.

Verification of this nailing is difficult at best, or impossible if the toenails were placed on the exterior side of the rim or end joist, as shown in Provisions Figure A3-8B. So adding the framing angles can be considered a necessary part of the project. In this confined space, the palm nailers discussed below are quite necessary.

A304.1.3 considers the existing connection at the top of the rim or end joists to be adequate. Standard carpentry practice is to nail 2-16d nails down through the first floor sill plate through the subfloor sheathing and into the top of the rim or end joist. Some retrofits have included a framing clip at the top of the end or rim joist. However, this connection risks having the nails protruding vertically from the framing clip into the first-floor sill plate strike wires or plumbing in the stud space.

Improvement of this rim or end joist top and bottom connection does not raise the Structural Score.

A304.4: Cripple Wall Bracing. This section covers requirements of framing placement and nailing, wood structural panel placement and nailing, and ventilation. It is important that the retrofit wood structural panels not cover ventilation or flood openings, and that the wood structural panel edges at these openings be blocked (see below).

Nailing of Framing Members. New framing members required by the Provisions for certain conditions include new blocks over the sills (Provisions Figure A3-6), new blocks at the floor joists (Provisions Figure A3-9), and new blocking at openings (Provisions Figure A3-7). There are several considerations regarding the nailing of blocking:

Because blocks are relatively short, face nails can cause them to split. Lumber for blocking is available either “S-GRN,” that is “green,” with a high moisture content; or “S-DRY,” that is “dry,” with a low moisture content. The “S-GRN” will be less likely to split.

Splitting can also be reduced by predrilling, whereby a pilot hole is drilled into the block for the nail. It is very important that the diameter of this pilot hole not be more than 75% of the nail diameter. The proper maximum drill bit diameter for each of the nail sizes allowed for a specific application by the Provisions (A304.5.1) are given below.

- 8d common: 3/32"
- 10d common: 7/64"
- 12d common: 7/64"
- 16d common: 1/8’

By Section A304.2.6, nails penetrating the preservative-treated sill plates must be hot-dip galvanized. Galvanized nails are more likely to cause splitting than ungalvanized nails.

Toenailing. "Toenailing" is required in much of the construction as shown in the Provisions figures. A toenail should be driven at about a 30º angle, one-third of the nail length from the end of the member. Predrilling is very useful when toenailing is to be done in confined spaces. By predrilling the slant hole in the block and starting the nail in the hole, the nail is held in place and alignment for final driving, and is less likely to split the wood.

Palm Nailers. Nailing of framing in confined spaces is greatly aided by the use of a "palm nailer." This device fits in the palm of your hand and uses a reciprocating action to drive a single nail. It is usually compressed-air powered, and can be rented with an electric-driven compressor of adequate capacity.

Fastening Framing Anchors. The Provisions allow framing anchors to be fastened with nails as specified by the framing anchor manufacturer. These specified nails may be "short" framing anchor nails, shorter than the usual nail of the same 'pennyweight' (d). They can be purchased where the framing anchors are sold, and the ungalvanized short nails are suitable for the dry locations noted in the plan where they do not penetrate preservative- treated wood. These nails can also be driven with the palm nailer. Never attempt to drive nails into framing anchors with a nail gun unless it is a gun specifically made for this application. If the nail is not exactly over the hole, it can dangerously ricochet from the framing anchor with great velocity.

Wood Structural Panel Nailing. The typical retrofit requires that hundreds of nails be driven through the 15/32 inch structural panel sheathing into the framing members. The fact that the earthquake forces are distributed amongst many nails along the seismic load path provides the structural system with redundancy and ductility that is very desirable for resisting earthquake forces. However, this nailing in close quarters can be very tedious and difficult.

The wood structural panel edges must be nailed with 8d common nails spaced at four inches on center. The wood structural panel bearing over studs not at panel edges must be nailed with 8d common nails, spaced at 12 inches on center. Do not use the "short" hanger nails for nailing wood structural panels.

For wood structural panels placed on the inside face of cripple walls, the inside face of enclosure walls of slab-on-grade or basement-type houses, or underneath siding on the exterior face of walls, and not being driven into preservative-treated wood, ungalvanized nails may be used. For wood structural panels placed on the outside face of an exterior wall as the final sheathing, such as T1-11 textured plywood, the nails should be hot-dip galvanized.

Driving all of the wood structural panel nails by hand is hard work, and many builders or even homeowners use powered nail guns to facilitate this work. There are several factors to consider for deciding when using a nail gun:

- Safety of use is the overriding issue. Injuries have occurred when the nail went through an insubstantial surface, or when the gun was impacted on someone's body. Always take care when impacting the gun. Always wear safety goggles when using the gun.
- The nails must be driven accurately, especially when two wood structural panel edges are being nailed to a common stud. Marking the nail line will facilitate placing the nails accurately. The wood structural panel nailing at a double top plate should be into the upper plate (Provisions Figure A3-7).
- The building inspector will require that these nails be accurately placed and not overdriven. Accurate placement means that the nail is 1/2 inch or more from the wood structural panel edge and framing member edges, as show in Provisions Figure A3-7. A nail is overdriven when the head of the nail is forced into the outer ply of the wood. It is relatively easy to overdrive nails with a nail gun. The gun must be adjusted so that this does not occur.
- The Provisions require that the wood structural panel nailing be done with 8d common nails with full heads. This means that nail guns that accommodate only nails with shaved, partial heads cannot be used.

6.1.2 Figures in the Provisions

The Provisions figures provide specific direction for details of the retrofit construction with certain existing conditions. These existing conditions include whether a cripple wall is present, and whether the joists are parallel to or perpendicular to a given wall. It is unlikely that all of the details will be needed for any one job.

Retrofit contractors often encounter existing conditions at a cripple wall that do not resemble any of the conditions shown in the Provisions figures. Additional details are available from the Los Angeles Standard Plan (see list of References at the end of this document). Use of details different from the Provisions figures should be confirmed with the building official. An engineer may have to be retained to design an appropriate detail. The engineer may then ask to be engineer-of-record for the entire retrofit, effectively making it into a Method 4 fully engineered retrofit.

6.1.3 Discussion of Selected Provision Figures

FIGURE A3-1. REPLACEMENT REINFORCED CONCRETE FOOTING AND STEM WALL. This drawing, and the associated table, provides a standard design for a replacement concrete foundation, if all or part of the existing foundation is found to be deficient. Provisions Figure A3-2 is similar for a reinforced concrete block footing.

FIGURE A3-4C. SILL PLATE BOLTING – TRAPEZOIDAL FOOTING. This connection shows the use of anchor side plates when there is insufficient overhead clearance for anchor-bolt placement and the footing is trapezoidal-shaped. Proprietary commercial side-plate anchors are available that make this connection without the need for the shim as shown. The acceptance of these anchors should be confirmed with the local jurisdiction prior to purchasing and installing them.

FIGURE A3-5. CRIPPLE WALL BRACING WITH WOOD STRUCTURAL PANELS ON EXTERIOR FACE OF CRIPPLE STUDS. Retrofit structural panel sheathing can be placed on the exterior of the cripple wall rather than on the interior. The disadvantage is that the exterior finish sheathing must be removed and replaced. The new finish sheathing must accommodate the additional wood structural panel thickness.

FIGURE A3-7. CRIPPLE WALL BRACING – OPENING BLOCKING. The structural panels should never cover existing vent openings, and the panel edges need to be blocked as shown. Toenail or face nail the blocking to the adjacent existing cripple studs.

Note that ventilation holes, two to three inches in diameter, are to be placed at the top and bottom of the retrofit wood structural panels at each stud space. This precaution allows sills and studs that had previously been exposed to continue to have air circulation. The presence of the holes in the wood structural panels are not believed to significantly reduce shear capacity. It is not necessary to provide blocking around these holes. Screens can be placed over the holes to keep out rodents.

FIGURE A3-8A-C. SILL PLATE BOLTING – NO CRIPPLE WALL PARALLEL OR PERPENDICULAR JOIST. These details are used where there is no cripple wall, as in the “basement-type” houses described in Chapter 2. Side plate anchors must be used.

TABLE A3-A. This table, repeated in part in Provisions Figure A3-10, states the retrofit requirements. Note that the length of the sheathing and anchor bolt spacing is increased for number of stories and weight of certain combined finishes.

6.2 Retrofit of Post Supports at Floor Beams in Crawl-Space Homes

In many crawl-space houses, wood posts support floor beams that support the floor joists, as shown in Figure 2-2. Often, these posts are vulnerable to shaking loose in an earthquake. The Pre-Retrofit House Survey described in Chapter 4 includes verifying construction of the posts. Assessment item A-3 of the Simplified Seismic Assessment Form penalizes questionable post construction.

The individual posts should (1) be supported by a concrete post foundation that at least prevents soil-wood contact, and ideally projects six inches above grade and (2) be connected top and bottom with three toenails or other positive connection. Although not required by the Provisions, deficient posts should be retrofitted as part of a cripple wall retrofit. If a post bottom rests on bare earth, as approved by the building jurisdiction, a precast concrete post foundation should be founded 12 inches into the soil grade (or more as needed to be below the frost line) to support it. The precast post foundation usually has a wood bearing block on the top, and the post should be shortened and nailed to the beam above and the block below with three toenails. The supported beam must be shored first. If this is done for all the posts on bare earth, it improves the Structural Score (see assessment item A-3) by 1.4 points (by changing from condition c to condition b). In a building with complete cripple walls to resist seismic forces, the posts should not be diagonally braced, as this can cause the concrete post foundation to overturn.

6.3 Retrofit of Basement Houses

The IEBC Cripple Wall Provisions can also be used for the retrofit of the sill and rim joist connections of basement houses. Basement houses usually do not have cripple walls, but they may have inadequate anchor bolts and inadequate connections between the sill plate and the rim or end joists.

The connection of the top of the basement foundation wall and the first-floor framing will be similar to Provisions Figure A3-4A or B. There is no clearance above the sill plate to install anchor bolts, so side plate connectors are to be used. The use of side plate anchors is discussed above and under Provisions section A304.3, Foundation Sill Plate Anchorage. The retrofit of the rim or end joist connection to the sill plate is discussed above and in Provisions section A304.1.3.

Basement houses typically have one or more wood or steel beams that support the first floor joists. The steel beams are usually supported midspan with wood or steel posts. The connection of the post to the beam above and the foundation below must be adequate to withstand the shaking of an earthquake without coming apart. It should be retrofitted if it appears inadequate.

The side plate anchor retrofit will improve the Structural Score, but the rim or end joist retrofit and the post retrofit does not.

6.4 Consideration of the Engineering Method for Cripple-Wall Houses or Basement Houses

The Provisions provide a satisfactory and conservative retrofit for cripple-wall houses and basement houses. However, there are three conditions (described below) for which it may be advisable to use Method 4 (Engineered Structural Retrofit Method) to ensure that the strengthening in accordance with the Provisions is sufficient. Method 4 usually should not be used to justify strengthening less than that determined by and in full compliance with the Provisions*,* but Method 4 may indicate the need for additional capacity for certain cripple walls, rim or end-joist connections, or anchor bolt lines. Houses with more than one of the three conditions described below should be especially considered candidates for Method 4. It should be noted that placement of additional strengthening, as provided for by Method 4, will not improve the Structural Score or the Seismic Performance Grade on the Simplified Seismic Assessment Form beyond the improvement afforded by a retrofit to the Provisions.

- *Condition 1: Unusually Heavy Finishes*. The IEBC Cripple Wall Provisions will not necessarily be conservative for the transverse cripple wall sheathing, rim or end-joist connections, or anchor bolts lines in one- to three-story houses with a combination of interior plaster sheathing (as opposed to gypsum board), stucco or brick veneer exterior sheathing, and a tile roof. The presence of all three of these heavy elements significantly increases the seismic force. For these houses, it is recommended that Method 4 be used to determine the necessary cripple-wall strengthening. Transverse cripple walls are considered to be those cripple walls along the short plan dimension of a house.
- *Condition 2: Narrow Floor Plans.* Figure 6-2 shows an example of a house with a narrow floor plan, in which case the length of the transverse walls is considerably less than the length of the longitudinal walls. The transverse cripple walls, rim or end-joist connections, and anchor bolt

lines in such a floor plan are more vulnerable than at the longitudinal walls because the same earthquake force must be resisted by a shorter-length wall. If the length of the transverse walls is less than about 2/3 of the length of the longitudinal walls, the Method 4 (Engineered Structural Retrofit Method) is recommended.

- *Condition 3: Potential for High Earthquake Ground Motions.* Certain locations are close to known active faults and thus are possibly subject to greater seismic shaking than other areas. These areas are shown in the seismic maps in the ASCE/SEI-7 document, and will be revealed if the U.S. Geological Survey Seismic Design Maps Web Application (https://geohazards.usgs.gov/secure/designmaps/us/) is used.

Figure 6-2 Cripple wall-type house with a narrow floor plan, with significantly shorter transverse walls than longitudinal walls (from ATC, 2002).

Chapter 7

Method 2: Retrofit Method for Nonstructural Building Elements

7.1 Introduction

This Chapter provides guidance on Method 2, Retrofit of Nonstructural Building Elements by Prescriptive or Engineered Methods, otherwise referred to as the Retrofit Method for Nonstructural Building Elements. This method uses both prescriptive and engineered methods.

Most houses have elements such as chimneys, masonry veneer, water heaters, decks, porch floors and roofs, and roof tile that are vulnerable to earthquake damage. These elements (evaluated in Section D of the Simplified Seismic Assessment Form) are commonly called nonstructural elements, because they are not in the primary seismic load path for the overall building. These elements should be retrofitted as necessary to resist earthquake shaking damage. This chapter provides information for homeowners and contractors on retrofitting these elements, including roof tiles. Some of the retrofits are prescriptive and can be done by a homeowner or contractor. Others will require an engineered design for use by a contractor.

This chapter applies to the retrofit of conditions identified in assessment items B-5, D-1, D-2, D-3, D-4, and E-6:

B-5: Add additional fasteners to masonry veneer, or replace it with structural sheathing.

D-1: Strap exterior chimney to roof and floors

D-2: Provide bracing and flexible water and gas connections for water heater

D-3: Provide earthquake-activated gas shut-off valves

D-4: Securing porch roofs to the main building

Assessment item E-6 (improve rain water routing away from foundations), also pertains to nonstructural building elements. This assessment item, however, is discussed in Chapter 8 because solutions pertaining to inadequate drainage may also involve an engineered solution (i.e., use of Method 4)

7.2 Masonry Chimneys (Assessment Item D-1)

It is very common for masonry fireplaces and chimneys to be damaged in earthquakes. The damage can occur to fireplaces and chimneys located both at the side of the house and within the house. Unreinforced fireplaces and chimneys are particularly vulnerable to fracture. In reinforced chimneys generally found in houses built after 1960 in more seismically active areas, vertical steel reinforcement bars is embedded into grout placed between the brick and the interior fire brick or flue liner. The reinforcement reduces the amount of fracturing, but does not eliminate it.

The most common type of damage is the fracture of the cantilevered part of the chimney that extends above the roof (Figure 7-1). When this occurs, masonry debris may fall through the roof into living spaces (Figure 7-2), lie on the roof and overload it, or slide down into the yard. As exemplified in the two figures, it is much more probable that large pieces of masonry debris will break from unreinforced chimneys than from reinforced chimneys.

7.2.1 Reducing the Vulnerability of Chimneys

As shown in Figures 7-1 and 7-2, the portion of the chimney that cantilevers above the roof is vulnerable to flexural damage from earthquake accelerations.

Figure 7-1 Chimney fractured at the roof line, with vertical steel reinforcement visible (from ATC, 2002).

Figure 7-2 Masonry debris from an unreinforced chimney has fallen through the roof into the living spaces (from ATC, 2002).

Prescriptive retrofit masonry chimney bracing suitable for low-to-moderate seismicity areas, shown in Figure 7-3, are described in the FEMA E-74 document, *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide*, (FEMA, 2011). Low-to-moderate seismicity areas are defined, for the purpose of simplified seismic assessment, as having acceleration response values less than 83% of the acceleration of gravity

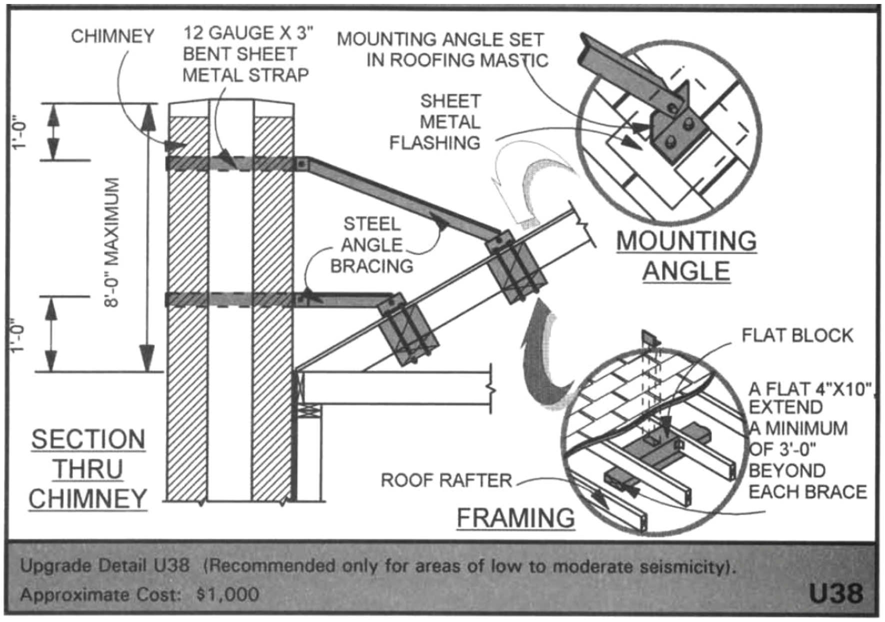


Figure 7-3 Prescriptive retrofit chimney bracing for areas of low-to-moderate seismicity (from FEMA E-74).

(i.e., as represented by 2 or less ground shaking hazard points as specified in Table 1 of the Simplified Seismic Assessment Form).

Unfortunately prescriptive retrofit masonry chimney bracing suitable for high seismicity areas (Ground Shaking Hazard Points of 4 - 8 from Table 1 and entry F-1 on the Assessment Form) is not recommended. An engineer may be willing to design bracing for a particular chimney. Many building jurisdictions in high-seismic areas encourage the use of nonmasonry chimneys because they are much less vulnerable to earthquake damage. These chimneys have a metal double-wall flue pipe inside an architectural enclosure. This type of chimney assembly is shown in Figure 7-4.

Figure 7-4 Non-masonry flue pipe with architectural enclosure.

7.3 Stone or Masonry Veneer (Assessment Item B-5)

Stone or brick veneer is often used as an exterior finish or trim detail on wood frame walls in houses. In older houses, the veneer was often not well fastened to the wall framing, making it vulnerable to being shaken off of the wall surface by earthquake forces perpendicular to the wall. Earthquake forces parallel to the wall can deform the sheathing on the wall behind the veneer, causing the veneer to crack and fall if it is not well-fastened.

Additional retrofit fasteners may be placed between veneer thicker than 1-1/2" and the wall studs. These fasteners are placed by first drilling a hole through the veneer into the wall stud, which must be accurately located. The fastener is then placed to engage the veneer by adhesion or expansion at the hole and screw into the stud. There are various proprietary versions of this connector available; an example is shown in Figure 7-5. The spacing of these fasteners might be 16 inches on center horizontally and 24 inches on center vertically. A disadvantage of these fasteners is that their penetration into the veneer is visible and may allow water entry. A sealant should be used at each fastener hole that matches the veneer color and texture and prevents water entry. These fasteners will reduce, but not eliminate, damage and falling hazard risks. An alternative is to remove existing masonry veneer, place structural sheathing if not present, and replace the veneer using building code-specified anchors to the sheathing and wall.

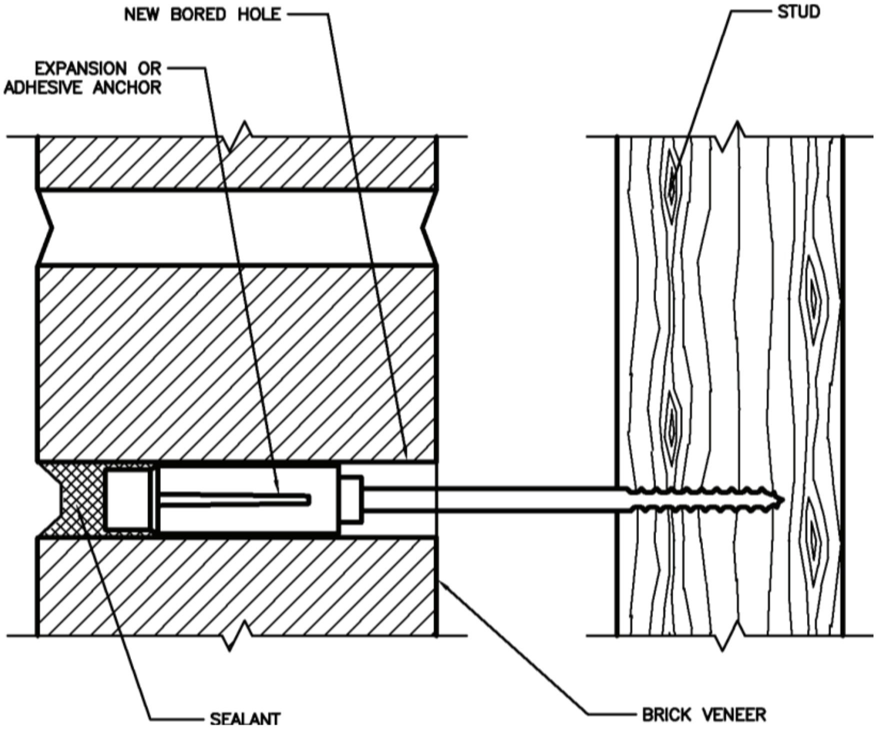


Figure 7-5 Typical retrofit fastener for brick or stone veneer (from ATC, 2002).

7.4 Water Heaters (Assessment Item D-2)

Because water heaters are tall and heavy, they are vulnerable to being overturned or left precarious by earthquake forces. On a gas-fired water heater, the gas pipe connection to the heater may break, and the exhaust flue connection may fully or partially disconnect from the top of the heater, allowing combustion gases to enter the room or space and possibly cause a fire. Toppling the water heater also causes the loss of stored water that could be useful if the water mains fail in the earthquake.

There are several methods of bracing a water heater that are considered acceptable. Most involve the use of straps, spacers, and lag screws to engage the water heater and secure it to the wall framing. Other restraint methods use both straps and conduit pipe struts for bracing. Brackets between the wall and the heater can be used for spacing and to restrain motion parallel to the wall, as shown in Figure 7-6. In all bracing methods, there should be a set of braces at the top and at the bottom. Water and gas connections of flexible pipe, if allowed in your building jurisdiction, should be used to allow for movement without breaking the pipes.

Figure 7-6 Water heater braced with straps and a V-shaped wall-mounted bracket.

Details of bracing with straps and struts along flat walls and at corners are shown in the FEMA E-74 document, *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide*, (FEMA, 2011), which also provides guidance for the seismic bracing of many other nonstructural elements. Another source is the Los Angeles Department of Building and Safety information bulletin, *How to Brace your Water Heater* (see Appendix A of this document). Over-the-counter water heater restraint kits, usually including the straps, spacers, and lag screws, are also often available at home supply stores.

While not posing as great a hazard, electric water heaters should also be similarly secured.

7.5 Gas System (Assessment Item D-3)

7.5.1 Gas Appliance Connections

Rigid pipe water and gas connections to any appliance may break if the appliance moves in an earthquake. Water and gas connections of flexible pipe, if allowed in your building jurisdiction, can withstand more movement by the appliance without breaking and thus are preferable.

7.5.2 Addition of Gas Shut-Off Valves

Building jurisdictions in seismically-active areas often encourage or require the use of seismically-activated gas shutoff valves, also called earthquake-sensitive gas shutoff valves. The valve is a system with a sensor and an actuator designed to automatically actuate a companion gas shutoff installed in the gas piping system. When the device is activated, it stops all flow of gas downstream of the gas shutoff mechanism in the event of a severe seismic disturbance. The valve is usually installed adjacent to the house's gas meter, as shown in Figure 7-7. Its safety value is that if an earthquake damages the house and ruptures the house gas piping, only the gas remaining in the house lines is available to support a fire.

7.6 Decks, Porches, Balconies and Patio Covers (Assessment Item D-4)

It is common for decks, porch floors, porch roofs, balconies and patio covers to break away from the house in an earthquake and to become dangerous falling hazards. Figures 7-8 and 7-9 show porch roof failures that luckily did not occur just as the occupants were leaving the house from the front door.

Generally speaking, the larger a deck, porch, balcony, or patio cover is, the heavier it is, leading to larger earthquake forces. Tile roofing or flooring also

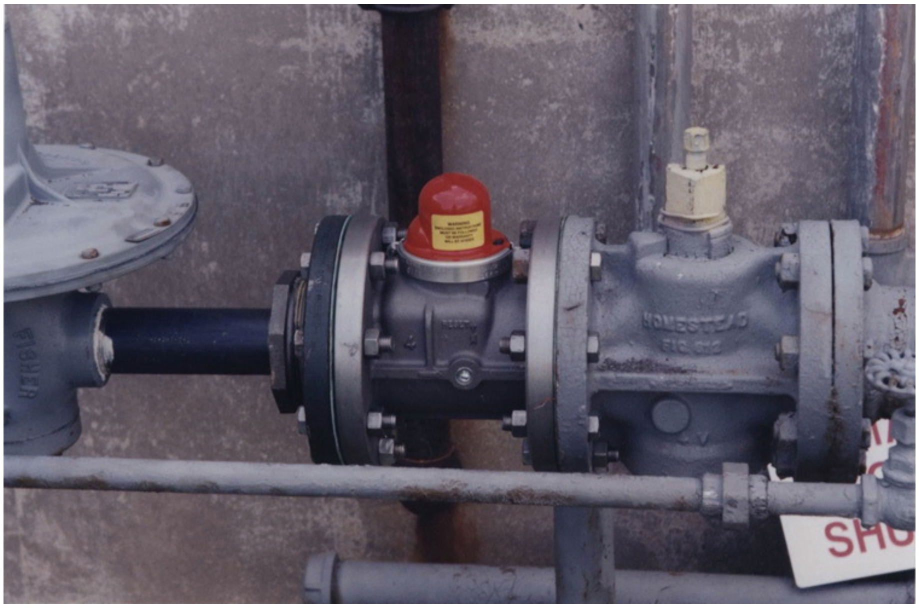


Figure 7-7 Typical installation of a seismically activated gas shutoff valve. The valve usually must be installed by an appropriately licensed contractor.

increases the earthquake force. Additionally, the greater the proportion of the length away from the house compared to the length parallel to the house, the more likely that it will be vulnerable to prying loose from the house during earthquake shaking. Figure 7-10 shows the action of earthquake forces on the connection to the house.

Figure 7-8 Porch roof failure (from ATC, 2002).

Figure 7-9 Porch roof broken off (and repositioned) in Mt. Carmel, Illinois, by the Richter magnitude 5.2 Mt. Carmel Earthquake in 2008. (Photo credit: Associated Press/Daniel R. Patmore)

This vulnerability can usually be minimized by either strengthening the connection between the roof and the house or by adding lateral-force-resisting strength to the supports away from the house. Adding lateral-force-resisting strength to the supports away from the house, such as diagonal bracing, is usually not desirable for access and aesthetic reasons. Additionally, strengthening the supports away from the house does not result in an improved Structural Score on the Simplified Seismic Assessment Form.

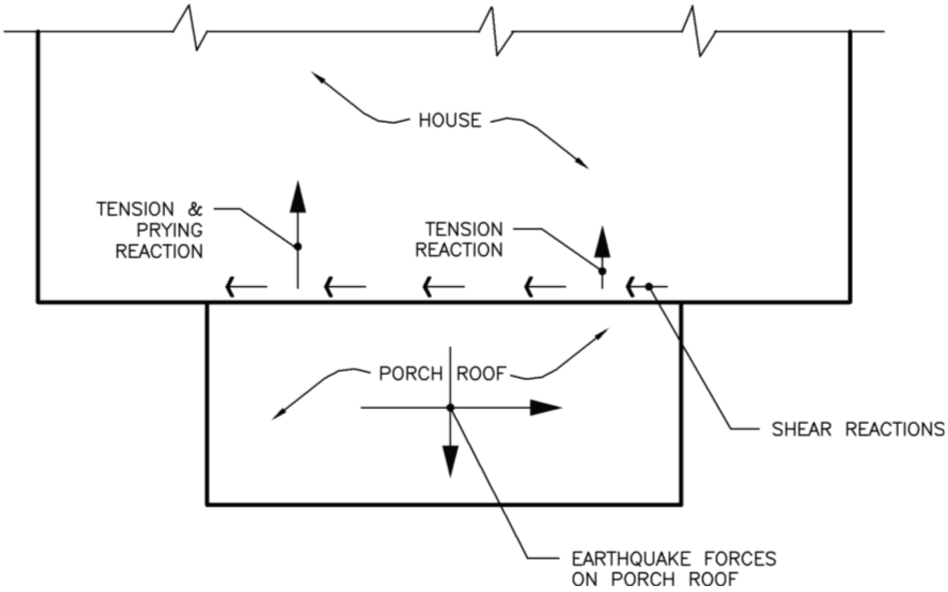


Figure 7-10 Earthquake forces and reactions on typical porch roof.

7.6.1 Strengthening the Connection to the House

The framing of a porch roof can be tied back to the framing of the house to better resist the forces shown in Figure 7-10. Measures for doing this for various framing configurations are shown schematically in Figures 7-11 through 7-13.

These measures utilize commonly available framing hardware elements. It is important that the porch framing member tied this way be either a rafter well-nailed by porch roof sheathing nails or a beam with many porch rafters nailed to it. The house framing member selected should be well-nailed to floor sheathing or ceiling finishes and other framing elements. Selection of well-nailed members ensures that the earthquake forces can be transferred into and out of these members.

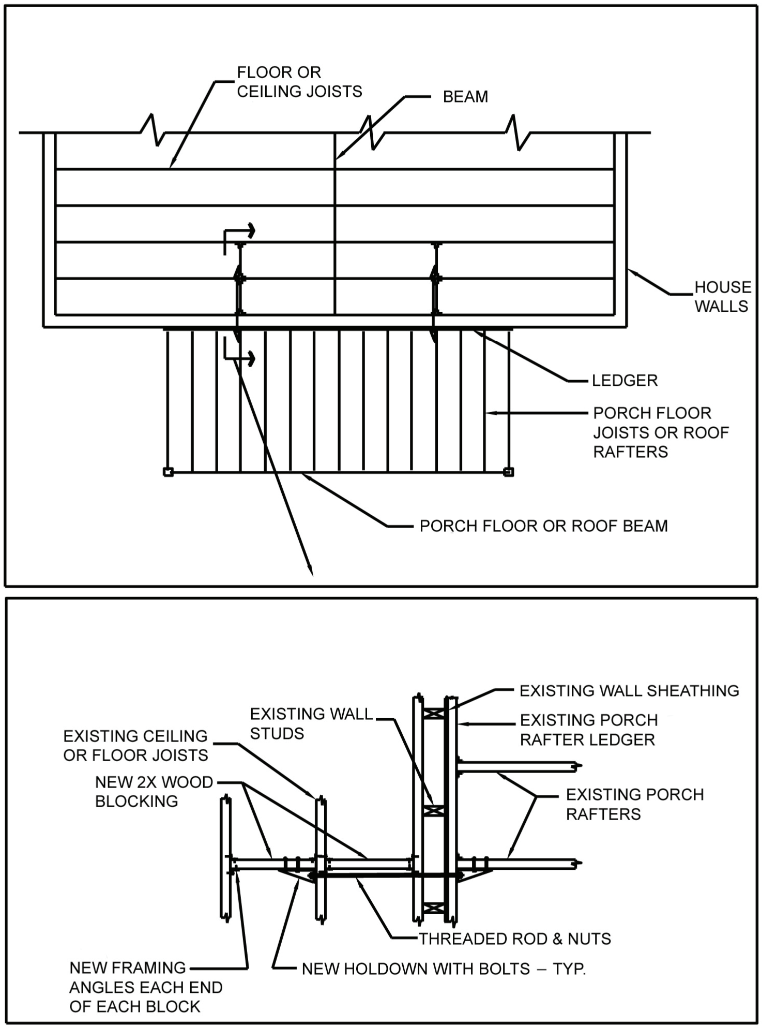


Figure 7-11 Retrofit connections of perpendicular porch roof framing to parallel joists within the house (from ATC, 2002).

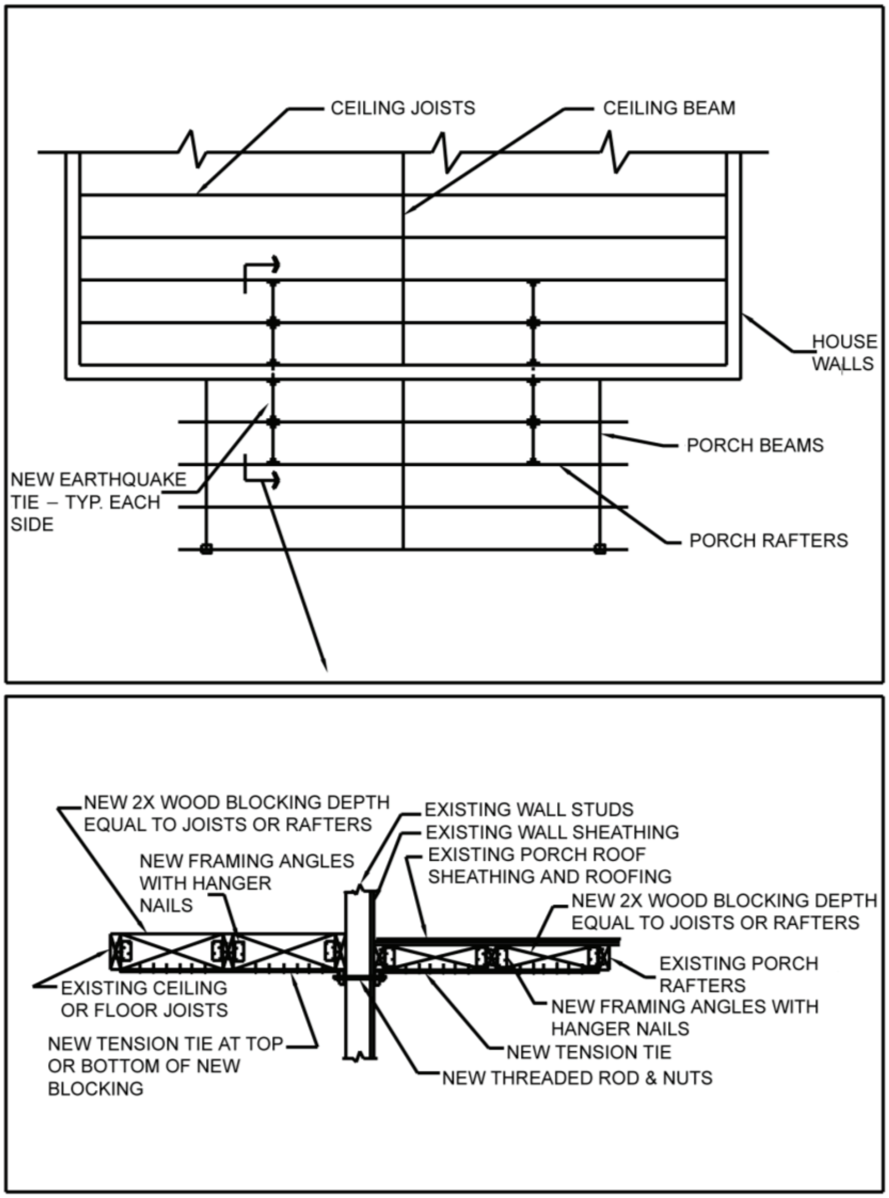


Figure 7-12 Retrofit connections of parallel porch roof framing to parallel joists in the house (from ATC, 2002).

7.6.2 Porch Roof Post Supports

It is also common for porch roof support posts to shake loose or become unstable (see Figure 7-14) in an earthquake, even if the porch roof does not pull away from the house. The partial support failure shown in Figure 7-14 is due to the post having upper and lower sections, creating a mid-height hinge that makes the post potentially unstable during earthquake shaking. This post should be replaced by a continuous post or be laterally braced in both directions at the hinge.

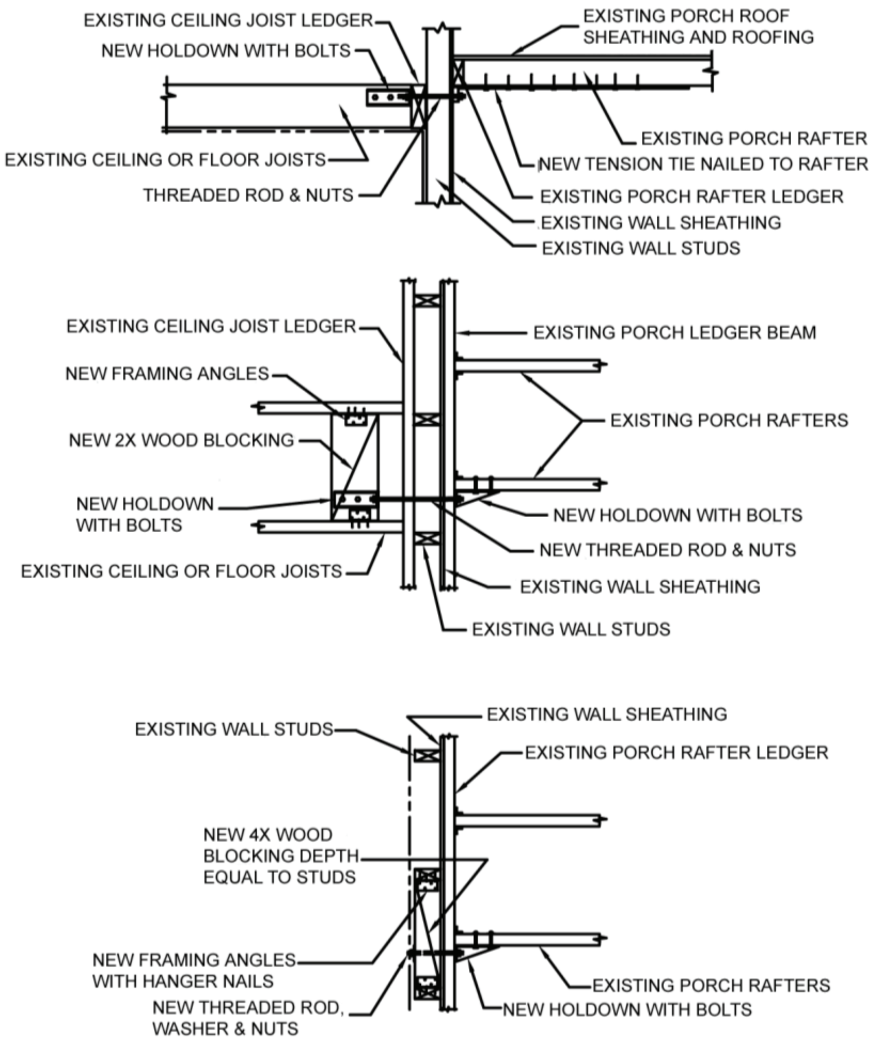


Figure 7-13 Schematic section and plan details of retrofit connections of porch roof framing to house framing (from ATC, 2002).

A support post can be prevented from shaking loose by strapping the post at the top and bottom, as shown in Figure 7-15. In a finely crafted wood-frame porch, care will be needed to design and build the strapping in such a way as to minimize its visual impact.

Brittle, slender, unreinforced masonry posts, such as in Figure 7-16, cannot be readily made less vulnerable to collapse from earthquake shaking. Even if the porch roof is tied to the house using the details of Figures 7-11 through 7-13, the masonry posts are vulnerable to failure, and should be replaced with adequate posts.

If passage is not required through the space between porch posts, diagonal braces could be added to restrain the lateral movement in the plane of the two

Figure 7-14 Failure of a porch roof support post by hinging at the middle (from ATC, 2002).

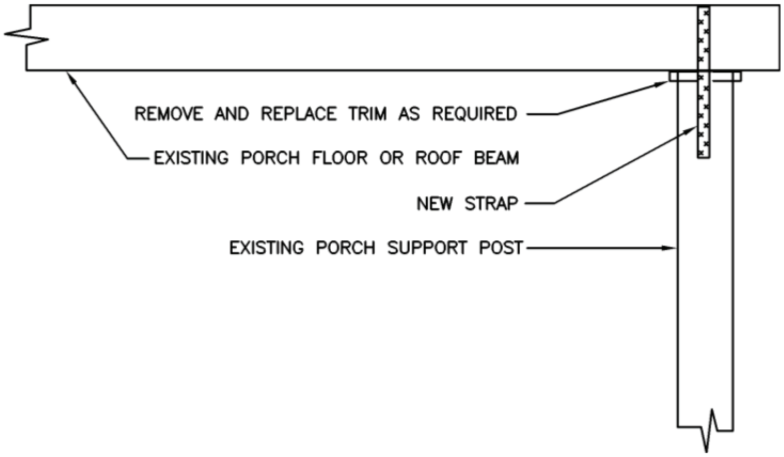


Figure 7-15 Typical strapping of porch roof support post (from ATC, 2002).

Figure 7-16 Brittle slender masonry porch support posts that will likely collapse during earthquake shaking (from ATC, 2002).

posts, and thus reduce the seismic force available to pry the porch roof away from the house. The entire load path of the diagonal braces, from the porch roof framing to the foundation, must be carefully designed and built to withstand the expected seismic force.

7.7 Roof Tile

Many houses have concrete or clay roof tiles (e.g., as shown in Figures 2-7 and 2-8). If earthquake shaking was not considered when the tiles were placed, they may shake loose and become falling hazards in an earthquake. Roof tiles on houses built since the mid-1960s in high seismic zones are more likely to be fastened to provide improved resistance to earthquake shaking. The tiles on these roofs were cast with a hole in the top part of the tile. A nail or wire passes through the hole and fastens to the roof framing. The tile may be shaken out of alignment, but is much less likely to slide and fall. The holes and wires are concealed by the overlapping of tiles in the rows above.

Retrofitting an older tile roof to minimize its potential as a falling hazard is difficult for several reasons. The retrofit must not cause water to dam up on the sloping tiles and thus create water intrusion. Boring new holes in the existing tiles to engage new wires or nails is difficult because of the brittleness of the tiles and difficult access. Tiles over solid sheathing are not accessible from the attic space. Some, but not all, of the tiles may be accessible from the attic space when spaced roof sheathing was used, and some means of securing the tiles may be devised.

The possibility of falling tiles is a lower threat to safety in yard locations around the roof perimeter that are seldom occupied. Tiles above entrances should be considered as a more serious falling hazard to be minimized by some method of retrofit. Ice restraints, commonly used in colder climates to restrain ice and snow from sliding off roofs at entrances, might be employed at the eave line to catch sliding tiles. Retrofitting tiles does not result in an improved Structural Score on the Simplified Seismic Assessment Form.

Chapter 8

Method 4: Engineered Structural Retrofit Method

8.1 Introduction

This chapter provides a non-mathematical and relatively non-technical overview of the approach to retrofit measures for the ‘structural’ systems in buildings found vulnerable by the Simplified Seismic Assessment Form that cannot be retrofitted in accordance with either of the prescriptive methods: Method 1 (IEBC Cripple Wall Provisions Method), as summarized in Chapter 4 and described in detail in Chapter 6; or Method 3 (IRC Prescriptive Retrofit Method), as summarized in Chapter 4. This chapter presents an overview of Method 4, the Engineered Structural Retrofit Method, which is based on the basic seismic resistance concepts described in Chapter 2. Background information for engineers and contractors unfamiliar with engineered dwelling seismic retrofit design and construction is provided, as is background information on Method 4 for homeowners.

This chapter applies to the retrofit of conditions identified in the following assessment items:

A-1: Provide continuous reinforced concrete foundation.

A-5: Add anchor bolts or retrofit anchors.

B-2: Add bracing walls at dwelling exterior.

B-3: Install lighter roofing.

B-4: Install plywood/OSB (oriented strand board) or steel frame at garage front.

B-5: Change exterior wall finish.

C-2: Repair cut structural framing.

C-3: Repair deteriorated stucco.

C-4: Repair deteriorated foundation.

D-4: Brace exterior stairs, decks, porch roofs.

E-3: Repair footing cracks.

E-6: Improve rain water routing away from foundations.

Retrofit measures for split level houses (see assessment item B-1) are also addressed, although a retrofit of this condition does not improve the Structural Score.

The discussions utilize the house weight values in Table 8-1, “Estimated Weights for Wood Frame Houses (pounds per square foot)”. This table, developed for the original ATC-50-1 guidelines (ATC, 2002), is based on a standard plan 30' x 40' house, with 100 linear feet of interior walls, a 1:2 pitched roof, and 8-foot ceiling heights. It shows the effect of various house configurations and wall and roof treatments on the weight of the house, in pounds per square foot, for the total floor area of the house.

For one- or two-story crawl space cripple-wall houses (Columns 1 and 2 under the “House Configuration” header row in Table 8-1), the weight from Line 5 of the Table times the house total area times the ‘allowable stress design base shear coefficient’ (discussed in Chapter 9) is the total seismic force in each plan direction to the cripple walls around the crawl space.

For one-, two-, or three-story basement houses (Columns 3-5 under the “House Configuration” header row of Table 8-1), the weight from Line 7 of the Table times the house total area times the ‘allowable stress design base shear coefficient’ is the total seismic force in each plan direction to the anchor bolts at the sill plate on top of the basement concrete or masonry wall.

For one-, two-, or three-story slab-on-grade houses (Columns 6-8 under the “House Configuration” header row of Table 8-1), the weight from Line 5 of the Table times the house total area times the ‘allowable stress design base shear coefficient’ is the total seismic force in each plan direction to the first floor exterior and interior walls.

Example seismic analyses (based on Table 8-1) of various types of houses are provided in Chapter 9.

8.2 Overview of Method 4

Method 4 vulnerability analysis and retrofit design should be done in accordance with the governing building code, by a licensed Civil or Structural Engineer with experience in this type of work. Normally, the engineer enters into an agreement with the house owner to perform the required services. This agreement is often in two phases. The first phase includes the physical investigation of the house to determine its structural system, construction, material properties, and dimensions, followed by structural analysis to determine the seismic vulnerability of the house. This analysis is much more

Table 8-1 Estimated Weights for Wood Frame Houses (Pounds per Total Area in Square Feet)

Line	Sheathing Conditions	House Configuration							
		One-story with cripple wall	Two-story with cripple wall	One-story with basement	Two-story with basement	Three-story with basement	One-story slab-on-grade	Two-story slab-on-grade	Three-story slab-on-grade
1.	Lightest weight house	28	22	18	17	17	19	18	17
2.	For plastered interior walls, add:	18	19	16	17	14	20	18	18
3.	For slate or tile roof, add:	19	9	19	9	6	19	9	7
4.	For stucco exterior walls, add:	11	9	8	8	7	9	8	8
5.	Estimated house weight, pounds/total square feet (add Lines 1 through 4)								
	For basement houses only:								
6a.	- for gypsum board interior walls:			10	5	4			
6b.	- for plastered interior walls:			13	6	5			
7.	Estimated house weight, pounds/total square feet, for anchor bolts in basement houses only. (Add Lines 5 and 6a or 6b.)								

thorough and specific than is the investigation documented on the Simplified Seismic Assessment Form.

If the analysis reveals seismic vulnerabilities, the owner and the engineer should discuss the nature, location and degree of the vulnerabilities. As discussed in Chapter 4, when a homeowner executes a voluntary seismic retrofit, he or she is not obliged by the code to strengthen the entire building to current code seismic capacities. The engineer's analysis might show, for a two-story dwelling, that the anchor bolts, cripple walls, and lowest level walls have only 30% of code-required seismic capacity, and the second-floor walls have 80% of code-required seismic capacity. The owner might then choose to retrofit the anchor bolts, cripple walls, and lowest level walls, but not the second-floor walls. So, the second phase will include the design of the retrofit of these elements, the production of construction documents for this retrofit work, and construction support services. Often, homeowners will choose to do other remodeling at the same time as the seismic retrofit work, and an architect for that remodeling could be engaged. As agreed between the owner and the engineer, construction services can include bidding services, construction contract administration, and site visits during construction.

Once the construction documents are complete, the procedures are similar to those for a Method 1 cripple-wall retrofit according to the IEBC Cripple Wall Provisions. The construction documents are submitted to the building jurisdiction as part of the permit application. After the construction documents are reviewed and approved by the jurisdiction, they are used to obtain bids from contractors. When a contractor is selected and the work has begun, the engineer, as agreed, will visit the site to observe the work in progress and to respond to unforeseen conditions revealed during the work. The jurisdiction inspectors will also visit the site to monitor the work in progress.

The placement of the retrofit construction will often require demolition of existing construction or finishes. For example, the interior gypsum board finish sheathing on a wall might need to be removed so that new wood structural panels can be placed on the wall to increase its strength. The gypsum board sheathing is then replaced and finished on top of the plywood. The extra plywood thickness will affect the fit of trim at doors and windows. If retrofit wood structural panel sheathing is being placed on the unsheathed inside walls of the attached garage in an older house, it is common for the jurisdiction to require that fire-rated gypsum wallboard be placed over the wood structural panels.

The process and considerations for the use of Method 4 (Engineered Structural Retrofit Method) to retrofit conditions under the assessment items identified at the beginning of this chapter, and the related design and construction considerations are described below. Discussions of related conditions are combined in one section (with the section heading identifying the related assessment items). A description of the process and considerations for the retrofit design of split-level houses and hillside houses, and a discussion of site soil stability, are also provided in this chapter.

8.3 Use of Method 4 to Retrofit Selected Conditions to Improve the Structural Score

8.3.1 Retrofitting Concrete or Masonry Foundations (Assessment Items A-1, C-4, E-3)

Retrofit measures to improve the vulnerable conditions of a concrete or masonry foundation identified under assessment items A-1, C-4, and E-3 can raise the building's Structural Score by as much as 8.1 points. Each of these potential retrofit measures, however, should be carefully considered in order to obtain maximum value in seismic resistance.

Buildings in high seismic hazard regions may have continuous concrete foundations that appear inadequate for expected earthquake motions and forces. The inspector may have observed 'significant' or' some' deterioration of the foundation concrete, and thus assigned penalty points under assessment item C-4. The inspector also may have observed 'minor' or 'extensive' cracking and further assigned penalty points under assessment item E-3. Such cracking and deterioration makes the footing less adequate for resisting seismic forces.

Retrofit Design and Construction Considerations. As noted earlier, the typical 380 pounds-per-linear-foot seismic load in a wood structural panel shear wall used in an IEBC Cripple Wall Provisions retrofit would result is a shearing stress of 4 pounds-per-square inch in the 8-inch-thick footing wall below it. This is only 6% of the allowable shear stress in standard 2500 psi (ultimate compression strength) concrete, or about 10% of the allowable shear stress in 1500 psi (ultimate compression strength) concrete, which is considered relatively weak concrete. The thickness/height stability of a concrete wall is usually more of a concern than is the shear strength, principally because the seismic shear stresses in the footing walls of wood-frame buildings are often very low, so that the capacity/demand ratio remains high in spite of the foundation concrete weakness. .

Older unreinforced concrete footing walls often have thin vertical cracks due to shrinkage (See Figure 5-1). These vertical cracks do not significantly diminish the strength or stability of the wall. Only cracks 1/4" or wider should be more carefully investigated. As discussed for the exterior investigation, tapered cracks indicative of differential settlement are of greater concern; the engineer will consider whether a soil or drainage condition causing the differential settlement needs to be addressed.

An engineer experienced in seismic retrofits and foundation design can observe the foundations and provide guidance as to whether repairing a deteriorated foundation, to satisfy retrofit assessment item C-4, or repairing cracks, to satisfy retrofit item E-3, is advised.

The IEBC Cripple Wall Provisions of Method 1require that new foundation stem walls be a minimum of six inches thick for one-story houses, seven inches thick for two-story houses, and eight inches thick for three-story houses. Existing foundation walls not meeting these thickness requirements would be examined more closely by the engineer for height/thickness ratio, concrete strength, and presence of reinforcing steel.

Unreinforced masonry footings and stem walls may be found. The masonry may be visible, as in Figure 5-2, or it may have been covered by a thin stucco-like coating of cement plaster. The IEBC Cripple Wall Provisions require that the adequacy of an unreinforced masonry footing for seismic resistance be substantiated by a qualified design professional before retrofit under the Provisions. This substantiation may be possible and prudent for unreinforced masonry footings and stem walls in good condition. Two evaluations methods to help determine the strength of the masonry and mortar are described in Chapter 5.

Buildings with perimeter post-and-pier foundations of wood, concrete, or masonry that are not founded deeply into the soil, as seen in Figures 2-15 and 2-17, will have limited seismic force-resisting capacity because they are easily overturned (Figure 2-17). This type of perimeter footing configuration can be replaced by a continuous perimeter reinforced concrete foundation (assessment item A-1), to improve the Structural Score. This must be designed carefully so that the vertical gravity forces and horizontal seismic and wind forces that were taken by the posts are transferred into the new footing, and so that the required crawl space vents are provided.

Post-and-pier foundations buildings with deep drilled pier concrete footings, as seen in Figure 2-14, usually will not have their footings overturn in an earthquake. Their seismic force-resisting load path includes the connection of the framing at the bottom of the occupied floors to the diagonal braces and down to the tops of the drilled concrete piers. Drilled concrete piers that are interconnected with concrete or steel grade beams have better seismic performance because the horizontal seismic force is distributed. The vulnerability analysis and retrofit of this type of footing is best done by an engineer working with a soils engineer.

8.3.2 Adding Anchor Bolts or Anchor Side Plates (Assessment Item A-5)

The addition of anchor bolts or side plates to improve conditions identified under assessment item A-5 through a Method 4 retrofit is similar to the process followed in a prescriptive retrofit, as discussed in Chapter 6. Section 6.4 of Chapter 6 and Example 3 of Chapter 9, however, discuss conditions where more closely-spaced anchors may be needed and when the involvement of an engineer is needed.

Retrofit Design and Construction Considerations. A cripple-wall house or basement house may have perimeter foundation walls of unreinforced and ungrouted concrete blocks. As discussed in Section 8.3.1, the engineer will first determine if these existing foundation walls have adequate capacity to resist seismic in-plane forces, or whether they need to be retrofitted or replaced. If the engineer determines that the existing walls are adequate, he or she will design a means to provide adequate anchorage for the sill plate. For concrete block walls, this is usually done by grouting the open cells in the top course of concrete blocks where anchor bolts or side plate retrofit anchors are to be placed.

The anchor bolts at exterior walls in slab-on-grade houses connect the sill plate of the exterior wall to the edge of the concrete foundation. Except in the garage, they are usually not visible, as there is usually a gypsum board interior finish and exterior siding extending down to the bottom of the sill plate. In that case, missing or inadequate anchor bolts might not have been noted as a penalty under assessment item A-5.

The anchor bolts at interior walls in slab-on-grade houses similarly connect the sill plate of the interior wall to the concrete slab and foundation. They also are usually not visible, as there is usually a gypsum board interior finish on each side of the wall extending down to the bottom of the sill plate.

Fortunately, most slab-on-grade houses have anchor bolts at the exterior walls, usually 1/2 inch diameter at about 6 feet on center. The size and spacing of anchor bolts at the interior walls may be similar, or they may not be anchor ‘bolts’ at all, but rather shot-in nails at similar spacing. The engineer may use a magnetic detector to determine anchor bolt spacing and determine if additional anchor bolts are needed.

8.3.3 Retrofitting Long Walls with Openings (Assessment Items B-2, B-5, C-3)

Walls in older houses are often found to be vulnerable to in-plane seismic forces. Their vulnerability is usually a function of the number of stories above them. Cripple walls in most houses, the transverse first-floor walls of two-story houses with narrow plans or large openings in the walls, and all the first-floor walls of three-story houses are usually the most vulnerable.

The retrofit of seismically vulnerable long walls with openings involves the improvement of conditions identified under assessment items B-2 (adding bracing walls at dwelling exterior), B-5 (changing exterior wall finish) and C-3 (repairing deteriorated stucco).

These three assessment items all address the same potential seismic weakness, that the walls enclosing the first occupied floor have insufficient strength to resist horizontal earthquake forces. Interior walls also contribute to the total wall strength to resist earthquake forces; this condition is addressed in assessment item B-6, regarding the removal of interior walls.

The retrofit measure can be designed by means of Method 3 (IRC Prescriptive Retrofit Method) or Method 4 (Engineered Structural Retrofit Method) depending on the seismicity zone in which the dwelling is located. By Method 3, the adequacy of existing interior and exterior sheathing and the need for additional sheathing can be determined by prescriptive means for houses not in the highest seismic zones. By Method 4, which is used primarily in the highest seismic zone, an engineer can determine the seismic forces on a dwelling, determine the adequacy of the existing interior and exterior wall sheathing, and design additional or replacement sheathing placement if needed.

Retrofit Design and Construction Considerations. Walls must resist both shear forces and overturning forces. As described in Chapter 2, overturning forces can be resisted by either house dead weight or by tiedowns below the wall. It can often be difficult for the engineer to design in a retrofit the means to resist overturning forces, especially for walls with openings, narrow walls, and walls that are not directly above one another.

Often, it will be desirable to make the entire width of a wall with door and window openings into a continuous shear wall, as shown in Figure 8-1. For this configuration to be effective, there must be a positive connection from the spandrel panel header beams, above doors and windows, to the framing of the full-height narrow wall panels on each side. To make this connection, vertical or horizontal straps and blocking are used adjacent to the openings, as shown. In this example, the right-hand opening was made narrower with stud framing so that vertical straps could be added at the header to provide overturning resistance to the wall panel. The horizontal straps at the left similarly increase the overturning resistance.

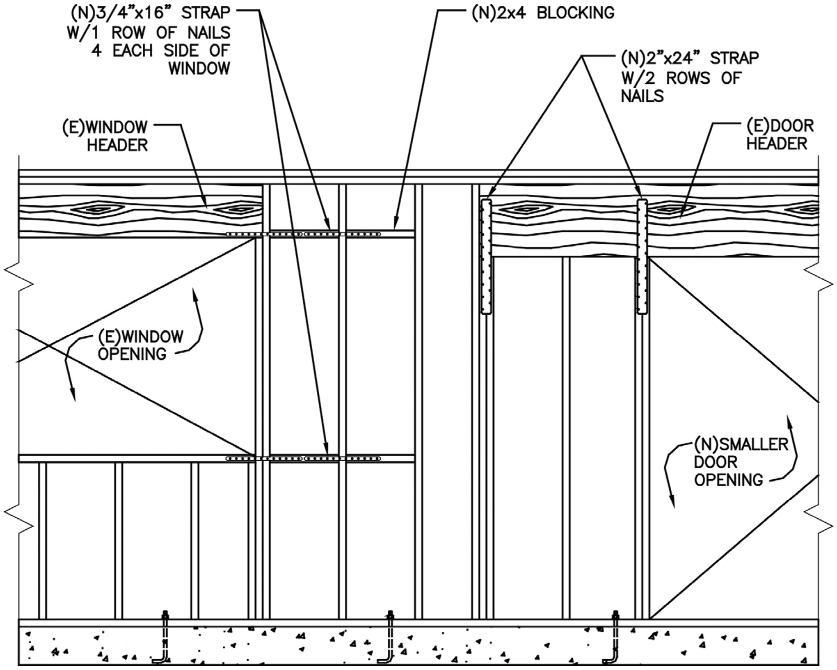


Figure 8-1 Wall with door and window openings and representative retrofit straps and blocking at inside corners (from ATC, 2002).

The retrofit work for such a configuration (Figure 8-1) consists of removing the existing interior or exterior sheathing, placing the new straps and blocking, strengthening the sill-floor connection as needed, placing new wood structural panels over the complete wall and spandrel area, and replacing the finish sheathing.

It is usually easier to apply retrofit sheathing, blocks, and strapping to an interior wall face than to an exterior wall face. Usually, the new wood structural panel sheathing is applied to the full width of the wall between intersecting walls, so that the added wood structural panel thickness is not noticeable. Adding wood structural panels to some part of an exterior wall would create a difference in thickness under the exterior finish sheathing, so this approach is usually avoided. The engineer will also try to avoid having to place new wood structural panel sheathing on kitchen and bathroom walls and on walls with high-value interior or exterior finishes. The extra thickness does affect door and window trim.

As an alternative to the strapping at spandrels discussed above, the engineer may elect to use the 'perforated wall' analysis, described in detail in the IBC.

8.3.4 Installing Lighter Roofing (Assessment Item B-3)

Assessment item B-3 addresses the weight of the roofing, which could consist of fired clay 'mission' tile or concrete roof tile that usually weigh about 10-15 pounds per square foot. Composition asphalt shingle roofs, on the other hand, usually weigh about 2.5 pounds per square foot. Replacing the tile roof with a composition asphalt shingle roof can significantly reduce the seismic force on the walls below the roof.

Retrofit Design and Construction Considerations. From Table 8-1, note that a 'one-story slab-on-grade house' with stucco exterior walls and an asphalt composition shingle roof weighs 19 + 9 pounds per square foot (the sum of Lines 1 and 4), or 28 pounds per square foot (psf). If this same house has a slate or tile roof, it weighs 47 psf, a 68% increase in both the house weight and the seismic force to the walls and anchor bolts in an earthquake. Fortunately, observations of house damage in past earthquakes reveals that one-story slab-on-grade houses with any type of roof often only suffer light damage to the walls. Clay tile roofs have appearance and serviceability advantages over asphalt composition shingle roofs. Before an owner chooses to replace the tile roof with a composition shingle roof, it would be prudent to consult with the engineer to analyze the building's seismic capacity and consider other retrofit options.

8.3.5 Installing Plywood/OSB-Sheathed Narrow Walls or Steel Frame at Garage Front (Assessment Item B-4)

Assessment Form Item B-4 addresses the specific condition of a garage door opening with narrow walls on each side and a second floor above. The narrow walls on older homes are usually inadequate for the seismic force from the second floor, often resulting in the type of failure seen in Figure 2-19.

A homeowner may also want to addresses the condition of a garage door opening with narrow walls on each side, but with no second floor directly above. These narrow walls may also be inadequate for the seismic force from the garage roof, resulting in the type of failure seen in Figure 8-2.

Figure 8-2 Earthquake damage at garage door opening in a one-story house (from ATC, 2002).

These weaknesses can be corrected, and the Structural Score improved when there is a second floor above, by a retrofit to install a steel moment-resisting frame across the garage door opening, or by a retrofit to construct stronger narrow walls on each side of the door opening.

Adding Steel Moment-Resisting Frames

The engineer may find that an adequate retrofit design cannot be done with stronger narrow walls on each side of the door opening. The shear forces can exceed the capacity of available narrow walls, and the overturning forces at the base of these walls can be much larger than can be resisted by the existing foundation. Figure 8-3 shows a house configuration with very narrow walls at each side of the garage door. It appears that an effective narrow wall could not be provided at the front of the house.

Figure 8-3 House where there appears to be insufficient wall width on each side of the garage door for effective wood structural panel shear wall sheathing (from ATC, 2002).

A solution to this problem is to provide a steel moment-resisting frame to withstand the lateral forces and reduce the uplift and overturning forces to the foundation. This solution may or may not require a new foundation beneath the frame columns. Steel moment-resisting frames are available commercially in many heights and widths, and are constructed so that field welding is not required. An example of a steel frame around the garage opening of a narrow row house is shown in Figure 8-4. A successful frame design by an engineer will address the considerations of transferring vertical and lateral loads into the frame; frame strength, stiffness, and stability; and transferring vertical and lateral loads from the frame into the foundation.

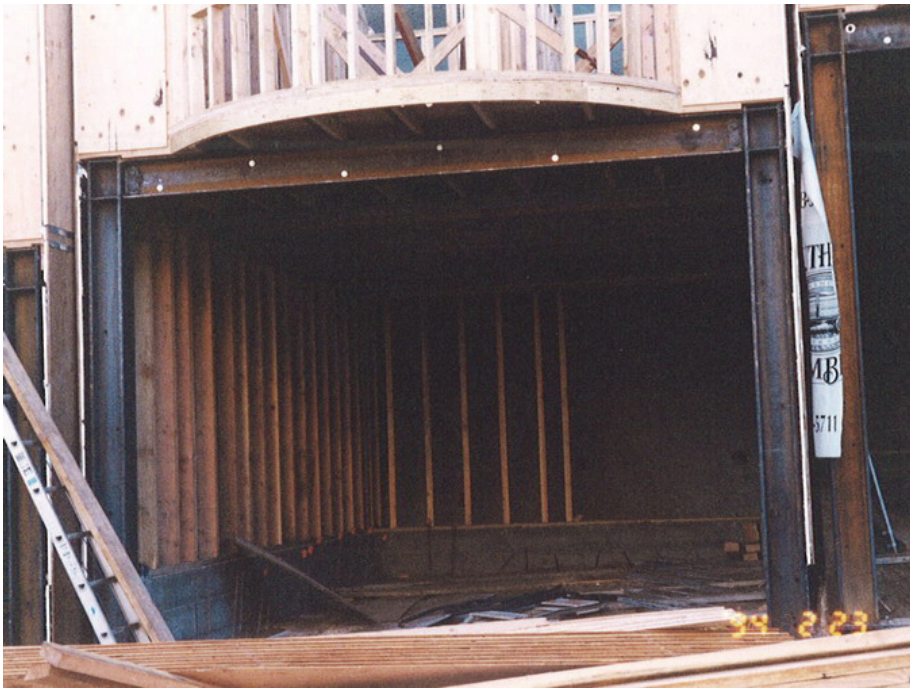


Figure 8-4 A steel moment-resisting frame at the garage opening of a row house (from ATC, 2002).

Adding Narrow Steel or Structural Panel Sheathed Walls

Manufactured slender wall assemblies similar to that shown in Figure 8-5 are available in various heights and widths. These wall assemblies have been carefully designed and built to provide much greater strength and rigidity than a field-built wood structural panel shear wall of similar proportions. To perform as intended, the walls must have an effective moment-resisting connection to the foundation below, and an effective moment-resisting connection to the girder over the garage opening at the top, or both. Thus, they are most useful in new construction where these moment reactions can be more readily provided.

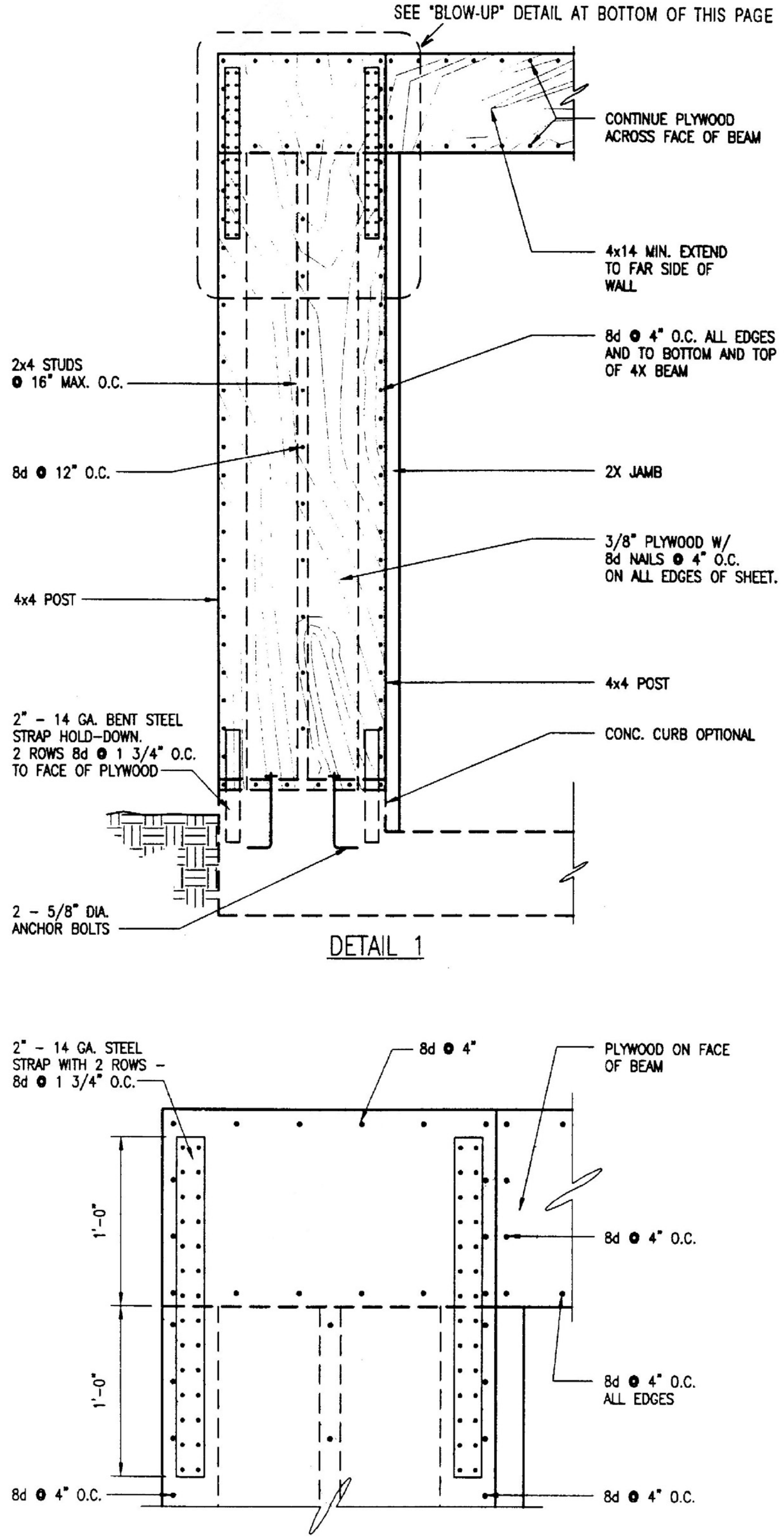


Figure 8-5 Field-built retrofit slender shear wall (from FEMA 232).

Determining the overturning resistance capacity available from an existing foundation requires engineering judgment about both the likely dimensions, weight and existing steel reinforcement (if any) of the existing foundation. If the foundation is found to be inadequate, a stronger and heavier replacement foundation may be needed under the wall.

To resist overturning forces to a foundation considered to be adequate, the engineer will design steel tiedown connections that connect the narrow wall to the existing foundation, using threaded rod epoxied into deep drilled holes or straps anchor-bolted to the foundation wall.

8.3.6 Repairing Cut Structural Framing (Assessment Item C-2)

Assessment item C-2 addresses the adequacy of the wood members that are notched, cut, or bored excessively in order to place plumbing or wiring. Such structural alterations can severely reduce the seismic-resisting strength of a building if the seismic forces on affected members is greatly increased during an earthquake. The IBC and the IRC detail the extent and nature of cutting and notching considered allowable.

Depending on the house type, wood members in a house may or may not be visible during evaluation using the Simplified Seismic Assessment Form. Wood members are visible in crawl space houses and basement houses, and in the garage of older houses. Most wood members, however, are concealed in slab-on-grade houses, except in the attic.

Members on which forces are greatly increased during an earthquake include:

- The single or double horizontal top plates at the top of cripple walls (See Figure 2-2).
- Studs at each vertical edge of a plywood-sheathed shear wall.
- Beams or double joists directly under interior walls.

Members on which forces are not significantly increased during an earthquake include:

- Single floor joists.

Figure R602.6.1 in the IRC shows how to place a strap across a notch or bore hole in a cripple wall top plate to strengthen it.

The engineer can determine what cut or notched member can be retained as is, strengthened, or replaced.

8.3.7 Improving Rain Water Routing Away From Foundations (Assessment Item E-6)

Assessment item E-6 addresses site drainage and retention of water at the foundation and in a crawl space or basement. The retention of water at the foundation increases the vulnerability of the house to earthquakes by several means. Moist soil and standing water in a crawl space, especially if combined with inadequate ventilation, can raise the humidity of the space and promote decay and infestation of the framing and rusting of the anchor bolts. If the soil grade at the outside perimeter is above the sill plate level (see Figure 5-3), water can migrate through the stucco siding to decay the sill plate and studs. If the stucco extends continuously down the wall and into the ground, termites can find passages from the ground into the framing. High moisture content in supporting soils may promote differential settlement and subsequent cracking of the foundation.

Retrofit Design and Construction Considerations. Methods to improve site drainage range from those readily done by the homeowner to engineered and contractor-executed drainage systems:

The homeowner can minimize potential site drainage and moisture problems by taking several measures.

- Lead roof gutter downspouts well away from the house. This measure satisfies the requirement to improve the Structural Score, but the additional methods discussed below are well worth considering.
- Keep crawl space vents clear of obstructions. Common obstructions include stored items within the crawl space, ducts within the crawl space, and foliage or new construction outside the vent.
- Do not vent the clothes dryer exhaust into a crawl space or basement.
- Maintain plumbing in a crawl space or basement to prevent leakage.
- Keep the crawl space and exterior soil grade six inches below the level of the bottom of the sill plate.
- Store firewood and mulch well away from the house to discourage termite infestation.

Additional means requiring professional design and construction assistance may be required for the following conditions:

- The stucco sheathing can be rebuilt to end at the sill-plate level. The existing stucco will need to be cut back above the sill plate, with the wire mesh lap retained and properly nailed to the sill plate, to allow the placement of a weep screed properly lapped with the existing building paper. New stucco is then placed and finished.

- Difficult-to-drain sites may require professionally-designed and constructed drainage systems that include French drains, perforated pipe, underground wall waterproofing, and sumps.

8.4 Retrofitting Potentially Vulnerable House Configurations

8.4.1 Retrofitting a Split-Level House

As discussed in Chapter 2, houses in which adjacent floor levels are separated by less than a full floor height are usually designated split-level houses, a configuration/condition addressed under assessment item B-1. A common seismic vulnerability in split-level houses is the lack of seismic strength, in the walls adjacent to the garage door, to resist inertial seismic forces from the house portion above. Another common vulnerability is insufficient strength of the cripple wall under the single-story portion of the house. Because of their relative complexity and the difficulty of strengthening the wall at the garage door, split-level houses will usually require a retrofit designed by Method 4.

Retrofit Design and Construction Considerations. One of the many possible configurations of split-level houses is shown in Figure 2-18. The right part of this house is of two-story slab-on-grade wood frame construction, with the garage space occupying the lower floor. The attached portion on the left side is of one-story cripple-wall construction.

By Method 4, the building would be analyzed both for its behavior as a whole and for the separate behavior of each portion. The one-story portion, examined separately, could have a vulnerable cripple wall that could be retrofitted with new sheathing, as described in Chapter 6. The configuration of the slab-on-grade double-story portion of the building is such that there are three relatively continuous walls and one wall with narrow segments on each side of the large garage door opening (only the right segment is visible in Figure 2-18). This garage door wall is both weaker and more flexible than the others. When seismic forces from the center of mass of the floor above act on the four walls, the garage door wall will deform the most, causing the upper floor to rotate in torsion. While this rotation allows some of the seismic forces that would go into the garage door wall to go into the other three walls, the two-story portion is still likely to be vulnerable. Thus, sheathing all four walls (at the garage level) with wood structural panels may or may not be adequate. An alternative is to place a new steel moment frame, or possibly new narrow high strength shear walls, at the garage door opening, as discussed in Section 8.3.5.

Another method an engineer might consider for strengthening a split-level house is to increase the strength of the connections between the one-story and two-story portions. This can be done at the stud walls between the portions where floor or roof sheathing is supported by ledgers face-nailed to the studs. This connection can be strengthened to increase its capacity for lateral in-plane and out-of-plane forces. If this is done, the strength of the new cripple-wall retrofit sheathing under the single story portion would be increased to resist this added seismic force. Strengthening of this connection can involve considerable demolition and replacement of adjacent finishes.

Split-level houses built to more recent editions of the IBC require fire-rated gypsum board sheathing within the garage. This protects the living spaces from a vehicle or flammable-liquid fire in the garage. If this gypsum board is removed to place retrofit wood structural panels, fire-rated gypsum board selected, nailed, and taped in accordance with the code must be placed over the retrofit wood structural panels. Consult with the building jurisdiction to identify other walls that may require fire-rated gypsum board.

8.4.2 Retrofitting Hillside Houses in Accordance with the IBC

Many local jurisdictions, have special provisions regarding the seismic-resistant design and construction of hillside houses. For code purposes, a hillside house is usually defined as being on a site steeper than one unit vertical to three units horizontal. The special provisions usually address the lowest-level full-floor diaphragm; the diaphragms below it and their anchorage to the uphill foundations; the walls or diagonal braces perpendicular to and parallel to the slope; and the supporting columns, connections, grade beams and foundations. The requirements apply principally to new construction, but the engineer for a retrofit should check with the building department regarding the applicability of any special provisions to the retrofit of hillside houses.

8.5 Water Retention, Site, and Foundation Considerations

8.5.1 Site Stabilization Measures

Assessment item E-2 addresses cut-and-fill sites and the related possible differential settlement. It is assumed that cut-and-fill house sites developed without a geotechnical investigation increase the vulnerability of such houses to earthquakes by contributing to or causing differential settlement prior to or at the time of an earthquake. In a substandard cut-and-fill site, the fill portion of the site is not compacted sufficiently, or the back surface slope is too steep.

The adequacy of a cut-and-fill site is immediately suspect if cracking patterns in the foundation indicate settlement of the fill portion. Figure 8-6 shows a schematic section through a house on a cut-and-fill site with this cracking pattern.

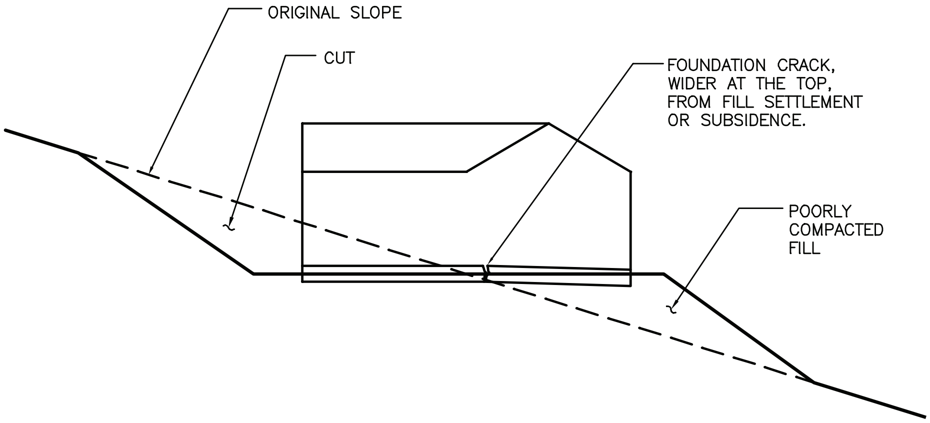


Figure 8-6 Foundation crack patterns indicative of fill settlement at a cut-and-fill house site (from ATC, 2002).

The adequacy of a cut-and-fill site can be further determined, at some expense, by a geotechnical engineer. The engineer may take borings at the site to measure the density of the compacted soil and underlying soil at various depths. From these data and other measurements, the settlement potential and site stability can be estimated. If the site is found to be deficient, appropriate retrofit measures can be quite extensive. Options include deep pier foundations extending through the fill to the underlying native soil or removal and recompaction of the fill soil while the house is shored.

The stability of natural features at the site may also be of concern. Figure 8-7 shows a boulder that was shaken from the slope above in an earthquake and came to rest against a house.

8.5.2 Liquefaction Potential

Liquefaction can occur in sandy soils below the water table if the soils are not at their most dense compaction. When the earthquake shakes the soil, it becomes more compacted. This displaces the water between the sand grains, and the displaced water flows upward toward the building foundations or the surface. At building foundations, it creates a temporary “quick” condition, allowing the foundation to sink down. Figure 8.8 shows two houses that settled differentially and came to lean against each other when liquefaction occurred along their common property line.

Figure 8-7 Boulder that was shaken loose from the slope above by an earthquake and came to rest against a house (from ATC, 2002).

Figure 8-8 Differential settlement of two houses caused by liquefaction along their common property line (from ATC, 2002).

The liquefaction potential for a given dwelling site can be determined or confirmed by a geotechnical engineer. Remedial preventive measures may be possible, but costly (ATC, 2002).

Chapter 9

Example Buildings Retrofitted by Methods 1 and 4

9.1 Introduction

This chapter provides a non-mathematical and relatively non-technical overview of examples of the process of developing the retrofit measures for buildings found vulnerable by the Simplified Seismic Assessment Form. The examples illustrate retrofits in accordance with Method 1 (IEBC Cripple Wall Provisions Method) and Method 4 (Engineered Structural Retrofit Method). Each example includes a description of the determination of the dwelling's Structural Score and Seismic Performance Grade, both before after retrofit.

9.2 Example Building Retrofits

9.2.1 Example 1: One-Story Slab-on-Grade House in Utah

This example one-story slab-on-grade rectangular plan house was built in 1964 on a 'stiff soil' flat site near Provo, Utah. It has plan dimensions of 28' × 44', with interior walls and wall openings at the first floor as shown in Figure 9-1. The site is not located in a liquefaction zone, a seismic landslide zone, or a surface fault rupture zone.

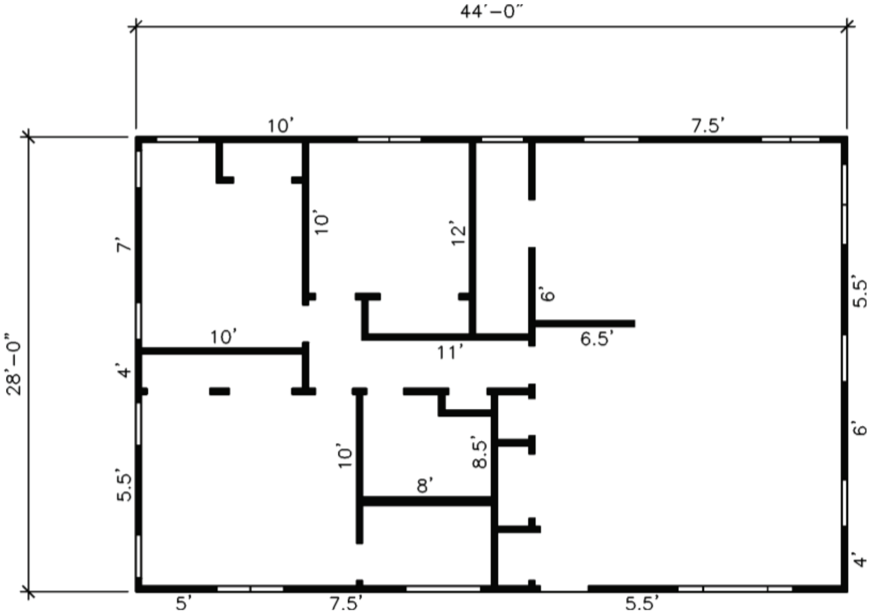


Figure 9-1 Example 1 floor plan.

The owner of the house commissioned a Simplified Seismic Assessment Form evaluation by a trained inspector. The inspection found that the house has gypsum board interior walls and ceiling, stucco exterior sheathing, and a pitched clay tile roof. The overall condition was determined to be good (assessment item C-1) and the length of the exterior wall panels satisfied assessment item B-2, as seen in the plan, and no penalties were assigned for either assessment item. The water heater was determined to be unbraced, however, and earthquake-activated gas-shutoff valves were not installed. The inspector assigned penalty points on the Simplified Seismic Assessment Form as follows:

Assessment Item/Condition	Penalty
B-3: heavy (tile) roofing:	1.6
B-5: stucco exterior wall covering:	1.0
D-2: water heater not braced	1.0
D-3: no gas-shutoff valves	1.0
D-5: age of house	2.0
Total penalty points	6.6

The Structural Score was thus 100 - 6.6 = 93.4.

The inspector used the U. S. Geological Survey (USGS) Design Maps web application, described earlier, to determine that the spectral response acceleration, S_{DS}, for the site is 68%, resulting in a ground shaking hazard score of 2 from Table 1 of the Simplified Seismic Assessment Form. Given that the site is not located in a liquefaction zone, a seismic landslide zone, or a surface fault rupture zone, the Seismic Hazard Score was determined from Section F of the form to equal 2. Using a Structural Score of 93.4 and a Seismic Hazard Score of 2, the Seismic Performance Grade was determined to be A (per Section G and Table 5 of the form).

Despite this high grade, the owner, knowing that the house is old, has a heavy tile roof, a heavy stucco exterior finish, and is in a relatively high seismic zone, engaged an engineer to perform a Method 4 (Engineered Structural Retrofit Method) analysis.

The engineer surveyed the house to determine dimensions and construction features. Since the gypsum board ceiling is being used to distribute seismic forces, the engineer observed from the attic space that the ceiling construction qualifies for this function in accordance with the IBC. The engineer chose to only include the capacity of wall segments longer than 4 feet, rather than the

2'-8" specified in assessment item B-2 in the Simplified Seismic Assessment Form. To determine the approximate building weight, the engineer used Table 8-1 in Chapter 8.

Seismic demand forces and the seismic capacity of the existing house were determined by the engineer, as follows:

- *Seismic Demand Force.* The total floor area is 28' x 44' = 1232 square feet. The weight per square foot from Table 8-1 is 19 pounds per square foot (psf) for a one-story slab-on-grade house, plus 19 psf for the tile roof, plus 9 psf for stucco exterior walls, totaling 47 psf (as summed on Line 5 of Table 8-1). The approximate weight of the house is then 1232 square feet times 47 psf = 57,900 pounds.

  Using the same USGS Design Maps web application as the inspector, the engineer confirmed that the S_{DS} value for the site is indeed 68%. The engineer used the seismic provisions of the IBC and the ASCE/SEI 7 standard, *Design Loads for Buildings and Other Structures*, as adopted by the local jurisdiction, to compute the 'allowable stress design base shear value', which is the fraction of the house weight that is applied as a horizontal force to be resisted by the exterior and interior walls in each direction. This calculation considered the S_{DS}, value, the 'stiff soil' site location, and the relatively low ductility of the plaster and stucco walls, to arrive at a 'base shear coefficient' of 24%. Thus, the horizontal seismic force to be applied in each direction to the resisting exterior and interior walls is 57,900 pounds times 0.24 = 13,900 pounds.

- *Existing Seismic Capacity.* To determine the seismic-resisting capacity of the house, the engineer measured the total length of effective interior and exterior wall sections that were at least 4 feet long. This approximate analysis assumes that these wall sections are 'effective' in that they do not lose strength and stiffness by overturning. The longitudinal (longer plan dimension) effective exterior wall total length was determined to be 35.5 feet, and the effective interior wall total length, 35.5 feet. The transverse (shorter plan dimension) exterior effective wall total length was determined to be 32 feet, and the transverse interior effective wall total length, 46.5 feet.

  The exterior walls have stucco on the outside face and plaster on the inside face. Because they have different stiffnesses, only the stiffer stucco can be counted by the IBC, which specifies that stucco sheathing has a capacity of 180 pounds per linear foot (plf).

  The interior walls have gypsum board on both faces. The engineer used a metal detector to determine the nail spacing of 7 inches, and limited demolition means to determine that the gypsum board is 1/2 inch thick and unblocked, and that the nails are as required. Per the IBC specification, the sheathing has a capacity of 100 plf, and so the wall, with sheathing on each side, has a capacity of 200 plf. The total house seismic capacity in each plan direction was determined by summing these values times the length of effective wall, as follows:

Longitudinal Wall Capacity

Longitudinal exterior stucco wall total length:

35.5 feet x 180 pounds/foot = 6,390 pounds

Longitudinal interior gypsum board wall total length:

35.5 feet x 200 pounds/foot = 7,100 pounds

Total longitudinal capacity = 13,490 pounds

Transverse Wall Capacity

Transverse exterior wall total length:

32 feet x 180 pounds/foot = 5,760 pounds

Transverse interior wall total length:

46.5 feet x 200 pounds/foot = 9,300 pounds

Total transverse capacity = 15,060 pounds

The engineer informed the owner that the longitudinal seismic demand force of 13,900 pounds exceeded the calculated longitudinal capacity of 13,490 pounds by 410 pounds, or approximately 3% above the capacity; and that the calculated transverse capacity of 15,060 pounds exceeded the transverse demand force of 13,900 pounds by 1,160 pounds, or approximately 8% above the demand. The engineer indicated to the owner that these capacity/demand ratios were close, given the approximate nature of the calculations, and that a retrofit to the walls was not recommended. The engineer recommended, however, that the owner brace the water heater and install the seismic gas-shutoff valves to eliminate the penalty points specified in the Simplified Seismic Assessment Form for these conditions. These two retrofits improved the Structural Score by 2.0 points, to 95.4, but did not change the 'A' Seismic Performance Grade.

9.2.2 *Example 2: One-Story Basement House in Utah*

This example house is located near the Example 1 building and has an identical age, superstructure (including exterior wall finishes and roofing system), lacks bracing for the water heater, and has no gas-shutoff valves. Rather than being a slab-on-grade house, however, it is a basement house with concrete basement walls and no foundation anchor bolts. As a result, the inspection determined the same number of penalty points for the identical conditions, or 6.6 points (for assessment items B-3, B-5, D-2, D-3, and D-5); in addition there were penalty points for conditions relating to the fact that it is a basement house with no foundation anchor bolts. Following are the penalty points assigned for the Example 2 Building:

Assessment Item/Condition	Penalty
B-3, B-5, D-2, D-3, D-5:	6.6
A-2: wood framed over crawl space or basement	2.9
A-5: no anchor bolts	15.0
Total penalty points	24.5

The Structural Score is thus 100 - 24.5 = 75.5 points.

Given that the site is not located in a liquefaction zone, a seismic landslide zone, or a surface fault rupture zone, and that it has the same shaking hazard as determined for Example 1 (i.e., a ground shaking hazard score of 2 from Table 1 of the Simplified Seismic Assessment Form), the Seismic Hazard Score was determined from Section F of the form to equal 2, as in the case of Example 1. Using a Structural Score of 75.5 and a Seismic Hazard Score of 2, the Seismic Performance Grade was determined to be A- (per Section G and Table 5 of the form).

The owner chose to brace the water heater and install the seismic gas-shutoff valves. At the engineer’s recommendation, the owner elected to retrofit the house using Method 1 (IEBC Cripple Wall Provisions Method), which can be used on basement houses. As the existing conditions prevented anchor installations through the sill plate (Provisions A304.3.1), the owner placed retrofit side-plate anchors at 6 feet on center, in accordance with Provisions Table A3-A for a one-story house with basement.

These retrofit measures improved the Structural score by 17 points, to 92.5 points, and the Seismic Performance Grade became an ‘A’.

9.2.3 Example 3: One-Story Crawl Space Cripple-Wall House in Missouri

This 1928 1200 square foot 30' × 40' one-story crawl-space cripple-wall house on a flat site, near Sikeston, Missouri is not located in a liquefaction zone, a seismic landslide zone, or a surface fault rupture zone. The owner commissioned a Simplified Seismic Assessment Form evaluation by a trained inspector, who found that the house has plastered interior walls and ceiling, horizontal ‘clapboard’ exterior sheathing with no structural plywood or OSB sheathing beneath on either the cripple walls below or the walls above, a continuous concrete perimeter foundation, no foundation bolts, and an asphalt composition shingle roof. The water heater is unbraced, and earthquake-activated gas-shutoff valves were not installed. The overall condition was determined to be fair.

The inspector assigned penalty points on the Simplified Seismic Assessment Form as follows:

Assessment Item/Condition	Penalty
A-2: wood frame over crawl space	2.9
A-3: floor beams on posts on pad footings:	0.8
A-5: no anchor bolts	15.0
B-5: siding not over structural sheathing	2.5
B-8: cripple wall without plywood or OSB siding	14.0
C-1: fair condition	1.0
D-2: water heater not braced	1.0
D-3: no gas-shutoff valves	1.0
D-5: age of house	2.0
Total penalty points	40.2

The Structural Score was thus 100 - 40.2 = 59.8

The inspector used the USGS Design Maps web application to determine that the spectral response acceleration, S_{DS}, for the site is 153%, resulting in a ground shaking hazard score of 6 from Table 1 from the Simplified Seismic Assessment Form. Given that the site is not located in a liquefaction zone, a seismic landslide zone, or a surface fault rupture zone, the Seismic Hazard Score was determined from Section F of the form to equal 6. Using a Structural Score of 59.8 and a Seismic Hazard Score of 6, the Seismic Performance Grade was determined to be D+ (per Section G and Table 5 of the form).

The owner chose to add anchor bolts and place structural sheathing on the interior face of the cripple walls in accordance with Method 1, having determined that this was acceptable to the local building jurisdiction.

The retrofit in accordance with the IEBC Cripple Wall Provisions required that 1/2 inch structural panels not less than 40% of the wall length be nailed with 8d common nails at 4 inches on center along the inside face of the four perimeter walls. One-half inch diameter expansion or epoxy-grouted anchor bolts, or equivalent side plate anchors, were required to be placed at 6 foot centers to anchor the sill plate to the top plate of the cripple wall. The owner also braced the water heater and installed earthquake-activated gas shutoff valves. This work removed the assessment item A-5, B-8, D-2, and D-3 penalty points totaling 31.0 points, raised the Structural Score to 90.8, and raised the Seismic Performance Grade to B+.

9.2.4 Example 4:- Two-Story L-Plan Crawl Space Cripple Wall House in South Carolina

This 1919 two-story crawl-space house, in fair condition and on a flat site, with ‘stiff’ soil, is located near Moncks Corner, South Carolina. The site is not located in a liquefaction zone, a seismic landslide zone, or a surface fault rupture zone. As shown in Figure 9-2, the house has plan dimensions of 60' × 40', forming an L-shaped plan. At the request of the owner, a Simplified Seismic Assessment Form evaluation was done by a trained inspector. The inspection found that the house has plastered interior walls, stucco exterior sheathing, a tile roof, and anchor bolts at about 10 feet on center.

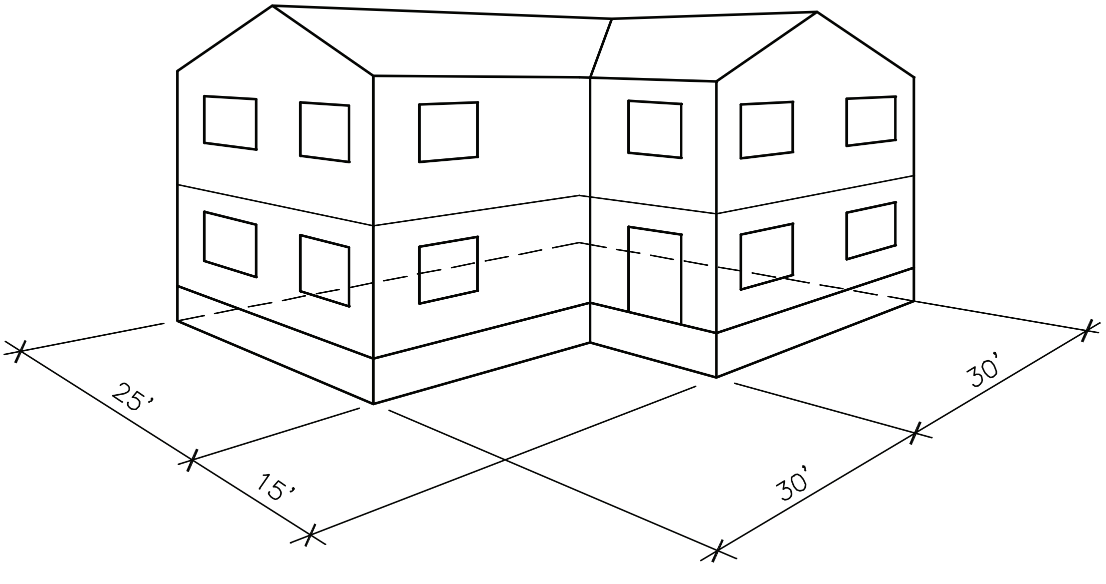


Figure 9-2 Example 3 two-story crawl space house.

The inspector assigned penalty points on the Simplified Seismic Assessment Form as follows:

Assessment Item/Condition	Penalty
A-2: wood frame over crawl space	2.9
A-3: floor beams on posts on pad footings:	0.8
A-5: widely-spaced anchor bolts	4.6
B-3: tile roof	3.5
B-5: stucco siding	1.0
B-7: two stories	1.8
B-8: cripple wall without plywood or OSB siding	14.0
C-1: fair condition	1.0
D-5: age of house	3.0
Total penalty points	32.6

The Structural Score was thus 100 - 32.6 = 67.4

The inspector used the USGS Design Maps web application to determine that the spectral response acceleration, S_{DS}, for the site is 126%, resulting in a ground shaking hazard score of 6 from Table 1 of the Simplified Seismic Assessment Form. Given that the site is not located in a liquefaction zone, a seismic landslide zone, or a surface fault rupture zone, the Seismic Hazard Score was determined from Section F of the form to equal 6. Using a Structural Score of 67.4 and a Seismic Hazard Score of 6, the Seismic Performance Grade was determined to be C (per Section G and Table 5 of the form).

As a two-story cripple wall house with a tile roof and stucco walls, Method 1 (IEBC Cripple Wall Provisions Method), per Provisions table A3-A, required that the prescribed retrofit wood structural panels extend along 70% of the wall length in each direction. Thus, in the transverse direction, it was required that a total of (40' + 25' + 15') x 0.70 = 56 feet of retrofit wood structural panels be placed on the three east-west walls. In the longitudinal direction it was required that a total of (60' + 30' + 30') x 0.70 = 84 feet of retrofit wood structural panels be placed on the three north-south walls.

New and existing 1/2-inch anchor bolts together were required to be at four feet on center, and framing anchors at the cripple-wall sill plate-to-rim block/joist connection were required to be at 32 inches on center.

Because of the retrofits to the anchor bolts and cripple-wall sheathing, the penalty points of 4.6 for assessment item A-5 and 14.0 penalty points for assessment item B-8 were eliminated, increasing the Structural Score to 67.4 + 18.6 = 86. By Table 5, the Seismic Performance Grade then changed from ‘C’ to ‘B+‘.

As the house has three finishes that are considered heavy, the owner chose to also have an engineer analyze this cripple wall bracing by Method 4 (Engineered Structural Retrofit Method). Dividing the house plan into two rectangles, the total floor area is found to be (25' x 60') + (15' x 30') = 1,950 square feet per floor times two floors = 3,900 square feet. As a two-story cripple-wall house with plastered interior walls, stucco exterior sheathing, and a tile roof, the weight per square foot from Line 5, Table 8-1, is 22 + 19 + 9 + 9 = 59 pounds per square foot. The approximate weight of the house is then = 3,900 square feet times 59 pounds per square foot = 230,100 pounds.

The engineer noted that the strength prescribed by the IEBC Cripple Wall Provisions for 1/2" wood structural panel retrofit sheathing nailed 8d at 4 inches on center is 380 pounds per foot. For the shorter 56-foot length of structural panel in the transverse direction, this provides a strength of 380 pounds per foot times 56 feet = 21,300 pounds of capacity. Similarly calculated in the longitudinal direction, the capacity is 31,920 pounds.

The engineer used the USGS Design Maps web application to confirm the inspector’s finding that the spectral response acceleration, S_{DS}, for the site is 126%. Using the IBC and the ASCE/SEI 7 standard and considering that the IEBC Cripple Wall Provisions allow a Method 4 (Engineered Structural Retrofit Method) analysis to consider 75% of the seismic forces specified for new building design, the engineer calculated an allowable stress design base shear coefficient of 0.102. Multiplying this base shear coefficient by the building weight, the engineer calculated a seismic force of 230,100 times 0.102 = 23,500 pounds.

The engineer noted that this seismic force of 23,500 pounds is less than the longitudinal capacity of 31,920 pounds, but it exceeds the transverse capacity of 21,300 pounds by 2,200 pounds, or by approximately 10%. As discussed in Chapter 6, this can be expected in buildings with relatively narrow floor plans and several heavy finishes.

While this 10% overstress might be overlooked, given the approximate nature of the analysis, the engineer decided to consider it. By using a closer anchor bolt spacing, and using one or more options of extending the length of the transverse panels beyond the required 70% of wall length, using stronger 'Structural I' sheathing panels instead of the standard grade, and placing the nails in the structural sheathing panels at a closer spacing, the engineer was able to design the anchor bolts and transverse cripple wall panels to provide somewhat higher capacity.

Appendix A

Water Heater Bracing Detail

INFORMATION BULLETIN / PUBLIC - PLUMBING CODE

REFERENCE NO.: LAPC 94.508.2 Effective: 01-01-2011

DOCUMENT NO.: P/PC 2011-003 Revised:

Previously Issued As: P/PC 2008-003

HOW TO BRACE YOUR WATER HEATER

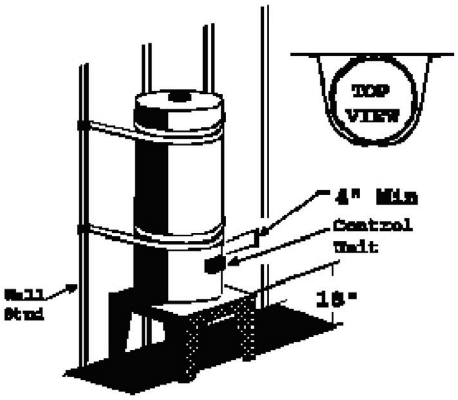
All water heaters must be strapped in at least two locations; the upper one-third of the unit and the lower one-third. The lower strap must be a minimum of 4" above the water heater control unit. The required clearances from a wall to the heater as stated on the unit nameplate are critical.

Lag screws not less than 1/4" in diameter must be used to anchor the restraints to the wall and each lag screw must have at least 1-1/2" thread penetration into wall stud. A large flat washer must be installed between each lag screw and strap for reinforcement.

NOTE: Perforated iron strap (plumber's tape) will not be an acceptable material for strapping or bracing water heaters over 40 gallons.

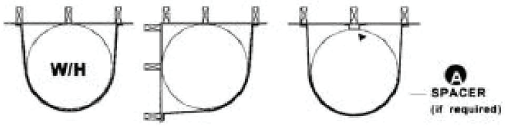
The State of California requires that all water heaters must be strapped to resist motion during an earthquake. This may be accomplished by installing an over the counter "water heater restraint" kit approved by the Office of State Architect (O.S.A.).

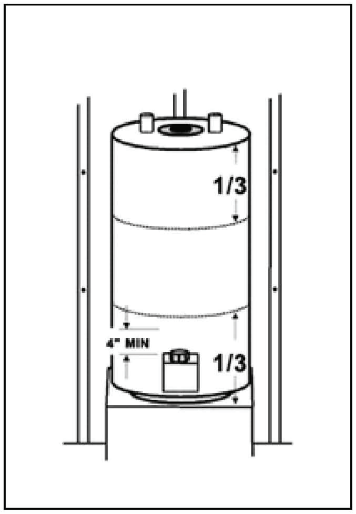
Example (wrap-around straps):

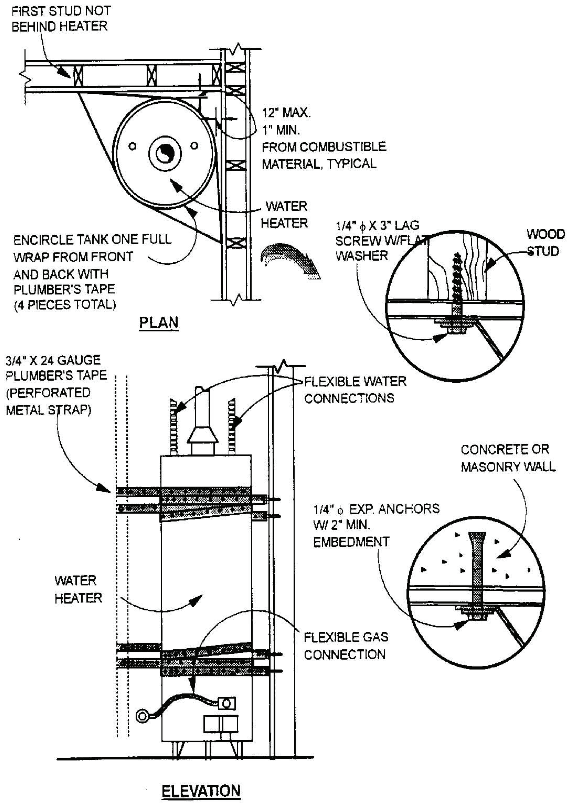


Drill pilot holes on the centerline of the stud (both sides of the heater), Insert screws through punched holes in the strap.

Use washers. Use minimum 22 Gauge X 3/4" wide metal strap.


W/H
A
SPACER
(if required)


1/3
4" MIN
1/3


FIRST STUD NOT BEHIND HEATER
12" MAX.
1" MIN.
FROM COMBUSTIBLE MATERIAL, TYPICAL
WATER HEATER
ENCIRCLE TANK ONE FULL WRAP FROM FRONT AND BACK WITH PLUMBER'S TAPE (4 PIECES TOTAL)
PLAN
1/4" ϕ X 3" LAG SCREW W/FLAT WASHER
WOOD STUD
3/4" X 24 GAUGE PLUMBER'S TAPE (PERFORATED METAL STRAP)
FLEXIBLE WATER CONNECTIONS
CONCRETE OR MASONRY WALL
1/4" ϕ EXP. ANCHORS W/ 2" MIN. EMBEDMENT
WATER HEATER
FLEXIBLE GAS CONNECTION
ELEVATION

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