Chapter 6
Vulnerability-Based Assessment and Retrofit of Hillside Dwellings

6.1 General

This chapter contains provisions for vulnerability-based assessment and retrofit of *base-level diaphragm* anchorage and *crawlspace walls* in wood light-frame *hillside dwellings* (Figure 6.1-1).

Vulnerabilities addressed by this chapter are shown in Figure 6.1-2 and include:

- Anchorage of the base-level diaphragm to the *uphill foundation*
- Wood light-frame crawlspace walls between the base-level diaphragm and the foundation

The primary purpose of this chapter is the reduction of earthquake-induced damage to wood light-frame hillside dwellings. Not addressed by this chapter are potential site soil hazards. See Section 1.9 and non-mandatory Appendix S for further information.

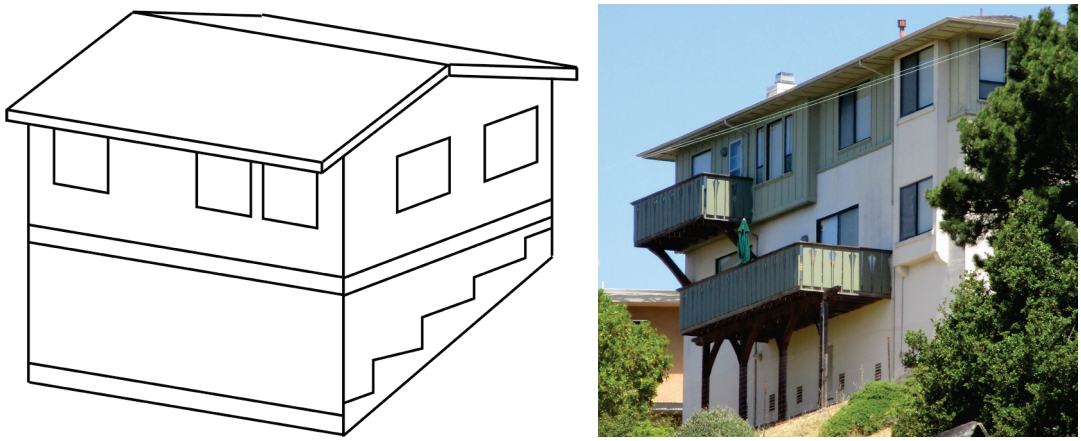

Figure 6.1-1 Hillside dwelling schematic isometric and photo.

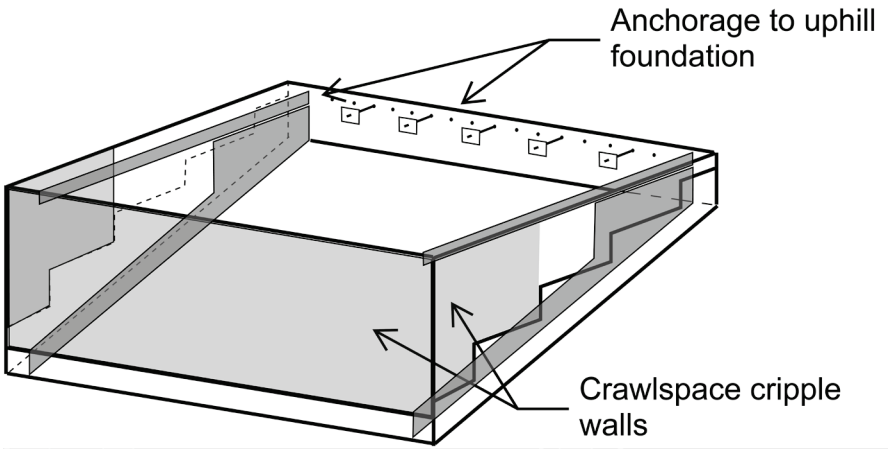

Figure 6.1-2 Hillside dwelling schematic isometric of dwelling crawlspace including anchorage to uphill foundation and crawlspace walls.

6.1.1 Use of this Chapter

In addition to the scope limits of Section 1.8, the dwelling shall comply with all of the eligibility criteria of Table 6.1-1. Where the dwelling is non-compliant with one or more of the eligibility criteria, assessment and retrofit in accordance with this chapter is not permitted.

6.1.2 Vulnerability-Based Assessment and Retrofit Methods

Assessment of dwellings shall be in accordance with Section 6.3. Where retrofit is required by Section 6.3, retrofit shall be in accordance with the simplified engineered vulnerability-based retrofit provisions of Section 6.5 or the general engineering retrofit provisions of Section 1.7. Prescriptive vulnerability-based retrofit provisions are not provided for hillside dwellings.

6.2 Definitions and Minimum Requirements

The definitions of Chapter 2 are applicable to all assessments and all retrofits designed in accordance with Chapter 6. The minimum requirements of Chapter 3 are applicable to all retrofits designed in accordance with Chapter 6.

Table 6.1-1 Eligibility Criteria for Use of Chapter 6

Eligibility Criteria		Compliant	Non-Compliant
1	The dwelling is a hillside dwelling, as defined in Chapter 2.		
2	The dwelling is a detached *one-* or *two-family dwelling* or the dwelling is a unit in a *townhouse* and assessment and retrofit will occur for each attached townhouse unit (the full *townhouse structure)*.		

Table 6.1-1 Eligibility Criteria for Use of Chapter 6 (continued)

Eligibility Criteria		Compliant	Non-Compliant
3	The dwelling is two stories or less above the base-level diaphragm.		
4	The dwelling is of wood *light-frame construction*.		
5	Existing perimeter walls below the base-level diaphragm are of wood light-frame construction, or a combination of wood light-frame and concrete construction.		
6	Existing perimeter walls below the base-level diaphragm are supported on a continuous concrete foundation or will be retrofit to be supported on a continuous foundation. Continuous foundation includes continuous perimeter spread footing with stem wall, or continuous grade beams or tie-beams supported on pier or caisson foundations with or without continuous concrete piers.		
7	The clear height of the tallest crawlspace stud wall does not exceed 16 feet.		
8	The site slope as measured along the sides of the dwelling, starting from the highest uphill point to the lowest downhill point exceeds 1 to 5 (vertical to horizontal).		
9	The *base-level diaphragm* is of wood light-frame construction and is entirely in one plane without vertical offsets, such as a step in the floor or *split level*.		
10	The garage is detached from the dwelling.		
11	The exterior framed walls immediately above the uphill foundation sit directly above the uphill foundation for not less than 75% of the uphill foundation length.		
12	No masonry *chimney* is attached to the side of the dwelling, extends through the dwelling, or sits on any floor level of the dwelling.		

6.3 Vulnerability-Based Assessment

6.3.1 Scope

The assessment criteria of this section shall be used to determine whether existing diaphragm anchorage to the uphill foundation and existing framed *crawlspace walls* and their *load path connections* are in conformance with the requirements of this chapter. Where they are in compliance with the requirements of this chapter, retrofit is not required. Where they are found to not be in compliance with the requirements of this chapter, retrofit is required.

Assessment shall be in accordance with the detailed vulnerability-based assessment provisions of Section 6.3.2 and the engineered vulnerability-based assessment provisions of Section 6.3.3, or the general engineering assessment provisions of Section 1.7. Assessment using a simplified vulnerability-based assessment approach is not provided for hillside dwellings.

In lieu of assessment, the dwelling may be retrofit in accordance with the requirements of this chapter.

6.3.2 Detailed Assessment

This section provides detailed vulnerability-based assessment criteria for foundations and crawlspace walls in hillside dwellings. Anchorage to the uphill foundation is required to be assessed in accordance with the engineered vulnerability-based assessment method of Section 6.3.3.

Hillside dwelling crawlspace walls below the base-level diaphragm and their load path connections, shall be assessed in accordance with all of the following:

- Foundations shall be assessed in accordance with foundation detailed assessment methods of Section 8.1.
- Anchorage of framed crawlspace walls to the foundation shall be assessed in accordance with *foundation sill plate* anchorage to foundation detailed assessment method of Section 8.2.
- Crawlspace wall sheathing shall be assessed in accordance with *bracing wall* sheathing detailed assessment method of Section 8.3.

Retrofit shall be provided as required to address deficiencies identified by this section.

6.3.3 Engineered Assessment

Existing base-level diaphragm anchorage to the uphill foundation shall be assessed in accordance with this section. An evaluation by a *registered design professional* shall demonstrate that existing anchorage is in compliance with this prestandard, using the simplified engineered vulnerability-based retrofit design criteria of Section 6.5. Where the anchorage is found to be compliant with the provisions of Section 6.5, it shall be deemed in compliance with this chapter. Where the anchorage is not compliant, the anchorage shall be retrofit.

As an alternative to the detailed vulnerability-based assessment provisions of Section 6.3.2, the foundation and crawlspace walls and their load-path

connections shall be permitted to be assessed in accordance with this section. An evaluation by a registered design professional shall demonstrate that existing diaphragm and framed crawlspace walls, including their anchorage to the foundation and to floor framing above, are in compliance with this prestandard, using the simplified engineered vulnerability-based retrofit design criteria of Section 6.5. Where the crawlspace walls and load path connections are found to be compliant with the provisions of Section 6.5, it shall be deemed in compliance with this chapter. Where they are not compliant, the anchorage shall be retrofit.

6.4 Prescriptive Vulnerability-Based Retrofit

Use of a prescriptive vulnerability-based retrofit is not provided for hillside dwellings.

6.5 Simplified Engineered Vulnerability-Based Retrofit

6.5.1 Scope

This section provides simplified engineered vulnerability-based retrofit provisions for foundations, base-level diaphragm anchorage to the uphill foundation, and the framed crawlspace walls and their load path connections.

Dwellings identified by Section 6.3 to require foundation retrofit shall comply with Sections 6.5.2 and 6.5.3.

Dwellings identified by Section 6.3 to require retrofit of anchorage to the base-level diaphragm shall comply with Sections 6.5.2 and 6.5.4.

Dwellings identified by Section 6.3 to require retrofit of crawlspace wall bracing, crawlspace wall anchorage to the foundation, or crawlspace wall connection to the floor framing above shall comply with Sections 6.5.2 and 6.5.5.

6.5.2 General

Retrofit of hillside dwellings shall use seismic design forces as follows:

1. In accordance with Section 6.5 and, where specified, by ASCE/SEI 7, or the adopted building code.
2. The material design provisions of the adopted building code shall be used, except as modified by Section 6.5.

6.5.2.1 Seismic Base Shear for Foundation Retrofit

Where construction of a new foundation or retrofit of an existing foundation is required, the foundation design shall be in accordance with the following:

1. Loads and load combinations shall be in accordance with the adopted building code. The seismic response modification factor, *R*, shall be taken as 4.0. The foundation shall be designed for the effects of *primary anchor* forces and shear anchor forces as per Section 6.5.4, except that the *R*-factor for primary and shear anchor forces is permitted to be taken as 4.0 for design of the foundation and transmission of forces to supporting soils. The foundation need not be designed for the effects of *secondary anchor* forces.
2. Primary, secondary, and shear anchors and their anchorage to the foundation shall be in conformance with the requirements of Section 6.5.4.

6.5.2.2 Seismic Base Shear for Other Retrofits

The design seismic base shear for retrofit of base-level diaphragm anchorage to the uphill foundation and retrofit of crawlspace walls and their load path connections shall be determined in accordance with Equation 6.5-1, and shall be assumed to act on the system providing seismic bracing to the base-level diaphragm:

$$V = S_{DS}W / R \qquad (6.5\text{-}1)$$

where:

S_{DS} = The short period design spectral response acceleration parameter determined in accordance with ASCE/SEI 7 Chapter 11

W = The effective seismic weight of the structure as defined in ASCE/SEI 7. The seismic weight shall include all dwelling weight from the base-level diaphragm and above, plus half of the weight of walls from the underside of the base-level diaphragm to the top of the foundations

R = The seismic response modification factor, as defined in Sections 6.5.4 through 6.5.5

Where seismic loads are acting in combination with other load types, the loads and load combinations shall be in accordance with the adopted building code. Use of seismic load combinations that include overstrength are not required when using the seismic design forces of this section. Overstrength factors required for design of anchorage to concrete shall be used.

6.5.3 Retrofit of Foundations

New foundations or retrofits of existing foundations shall be designed in accordance with the loads and forces specified in Section 6.5.2.1, the seismic

design provisions of ASCE/SEI 7, and the material design provisions of the adopted building code.

6.5.4 Retrofit of Base-Level Diaphragm Anchorage

The scope of retrofit for anchorage of the base-level diaphragm to the uphill foundation shall include primary anchors, secondary anchors, and shear anchors, as identified in Figure 6.5-1.

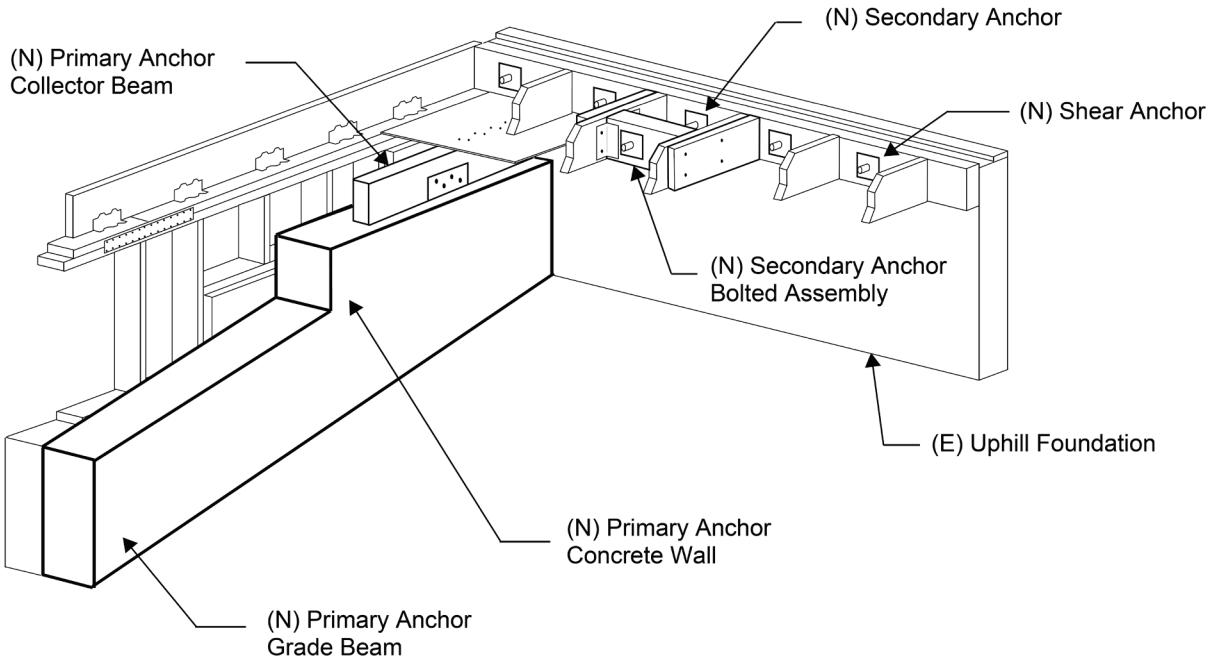

Figure 6.5-1 Interior uphill foundation corner isometric.

6.5.4.1 Design of Primary Anchors

Primary anchors shall be provided between the base-level diaphragm and the uphill foundation at each end of the dwelling uphill foundation. Additional primary anchors shall be provided at any location where a horizontal offset of four feet or more occurs in the uphill foundation between the foundation ends. Primary anchors, at locations referenced above, shall be located in line with existing walls in the story above, or as close thereto as possible.

The base shear, V, for design of primary anchors shall be determined in accordance with Equation 6.5-1, using a response modification factor, R, of 2.0. The primary anchors shall be designed to resist the entire base shear, V, for the most critical of the following three load conditions. Design of the primary anchors shall neglect the resistance provided by secondary anchors, crawlspace walls, and other existing lateral force resisting elements.

1. For *out-of-hill loading*, where two primary anchors are provided, each primary anchor at the ends of the uphill foundation shall be designed for

a seismic force of $V/2$. Where primary anchors are provided between the ends of the uphill foundation, each primary anchor shall be designed for a portion of V in accordance with the base-level diaphragm area tributary to the anchor

2. For *cross-slope loading*, the seismic base shear, V, shall be applied at the dwelling center of mass, with the base-level diaphragm treated as cantilevered from, and laterally supported only by, the uphill foundation. Each primary anchor, and its associated collector, shall be designed for the cantilever diaphragm chord force calculated at each end of the diaphragm as a result of the diaphragm cantilever.
3. In no case shall a primary anchor be designed to resist a seismic force of less than the larger of $V/4$ or 3 times the secondary anchor design force.

The primary anchor shall include a chord or collector element, extending the depth of the diaphragm at the anchor location and designed to resist applicable seismic forces.

The scope of retrofit for primary anchors shall include load path connections between the base-level diaphragm and the primary anchor chord or collector element, the design of the chord/collector element, and the anchorage of the chord/collector element to the uphill foundation.

The scope of retrofit need not include evaluation or strengthening of the base-level diaphragm, provided the primary anchor chord or collector element extends and is connected to the base-level diaphragm over the full depth of the diaphragm cantilever at the primary anchor location.

The scope of retrofit need not include evaluation or strengthening of the load path from the point of anchorage to the uphill foundation, into the supporting soils, provided that it can be demonstrated that the anchorage forces will engage the foundation system without causing a local (e.g., punching or shear) failure of the concrete foundation. Where retrofit element load paths impose overturning forces, the retrofit elements shall be capable of distributing the overturning to the existing foundation.

The scope of retrofit is permitted to include strengthening of existing foundations or new foundation elements for purposes of primary anchor load path.

Design capacities and detailing for all components shall be as specified in the adopted building code.

6.5.4.2 Design of Secondary Anchors

Secondary anchors shall be provided between the base-level diaphragm and uphill foundation, distributed along the length of the uphill foundation. Secondary anchors shall be provided at no more than four feet on center.

The base shear, *V*, for design of secondary anchors shall be determined in accordance with Equation 6.5-1, using a response modification factor, *R*, of 1.0. The secondary anchors shall be designed to collectively resist the entire base shear, *V*, for the out-of-hill force direction, neglecting the resistance provided by primary anchors, crawlspace walls, and other lateral force-resisting elements. Each secondary anchor shall be designed for a portion of the base shear, *V*, in accordance with the base-level diaphragm area tributary to the anchor.

The secondary anchor shall include a collector element, extending the depth of the diaphragm at the anchor location and designed to resist applicable seismic forces.

The scope of retrofit for secondary anchors shall include load path connections between the base-level diaphragm and the secondary anchor collector element, the design of the collector element, and the anchorage of the collector element to the uphill foundation.

The scope of retrofit need not include evaluation or strengthening of the base-level diaphragm, provided the secondary anchor collector element extends and is connected to the base-level diaphragm over the full depth of the diaphragm at the secondary anchor location.

The scope of retrofit need not include evaluation or strengthening of the load path beyond the anchorage to the uphill foundation.

Design capacities and detailing for all secondary anchor components shall be as specified in the adopted building code. Where the secondary anchor consists of a tie rod to the uphill foundation, its diameter shall not be less than that of the shear anchor.

6.5.4.3 Design of Shear Anchors

Shear anchors shall be provided between the base-level diaphragm and uphill foundation and shall be distributed along the length of the foundation. Shear anchorage to the foundation shall be spaced at not more than 32 inches on center.

The base shear, *V*, for design of shear anchors shall be determined in accordance with Equation 6.5-1, using a response modification factor, *R*, of

1.0. The shear anchors shall be designed to collectively resist the entire base shear, V, in the cross-slope force direction, neglecting the resistance provided by primary anchors, crawlspace walls, and other lateral resisting elements. Each shear anchor shall be designed for a portion of the base shear, V, in accordance with the base-level diaphragm area tributary to the anchor.

The scope of retrofit for shear anchors shall include load path connections between the base-level diaphragm framing and the uphill foundation.

The scope of retrofit need not include evaluation or strengthening of the base-level diaphragm in-plane shear capacity.

The scope of retrofit need not include evaluation or strengthening of the load path beyond the anchorage into the uphill foundation.

Design capacities and detailing for all components shall be as specified in the adopted building code. Where the shear anchor consists of a tie rod to the uphill foundation, its diameter shall not be less than that of the secondary anchor.

Anchors serving as secondary anchors are permitted to also serve as shear anchors provided that anchorage is designed considering both tension and shear forces occurring concurrently.

6.5.5 Retrofit of Perimeter-Framed Crawlspace Walls

The scope of seismic retrofit for crawlspace walls shall include full height concrete or masonry walls over 4'-0" tall and wood light-frame crawlspace walls. The framed crawlspace walls shall include perimeter walls at the sloping sidewalls, at the downhill wall, any interior crawlspace walls, and the crawlspace wall supported on the uphill foundation, where applicable. Retrofit shall include the wall strength, anchorage to the foundation, and connection to floor framing above.

The base shear, V, for design of crawlspace walls and their load path connections shall be determined in accordance with Equation 6.5-1, using a response modification factor, R, of 4.0. Where a crawlspace wall occurs between the base-level diaphragm and the top of the uphill foundation, this crawlspace wall shall be designed to resist the full calculated base shear, V, and resulting overturning moment, neglecting resistance provided by primary anchors, secondary anchors, and other crawlspace walls. All other crawlspace walls shall be designed to resist the portion of the base shear tributary to the crawlspace wall, neglecting the resistance provided by primary anchors, secondary anchors, and other lateral resisting elements. Use of wood light frame crawlspace walls within the interior of the

crawlspace resisting the portion of the base shear tributary to the crawlspace wall shall be permitted, but shall not be used to reduce the seismic loading to the crawlspace wall sitting on top of the uphill foundation. If interior concrete or masonry cross slope crawlspace walls are located downslope of the uphill foundation, their tributary area can be used to reduce the seismic loading to the uphill foundation shear anchorage, but shall not be used to reduce primary or secondary anchor seismic forces.

The scope of retrofit need not include evaluation or strengthening of the base-level diaphragm capacity.

The scope of retrofit need not include evaluation or strengthening of the load path beyond anchorage of the crawlspace wall top plates to the base-level diaphragm framing or the anchorage to the foundation, except as required for *proprietary shear walls*.

Design capacities and detailing shall be as specified in the adopted building code. All framed crawlspace walls shall be retrofit to be sheathed with wood structural panel shear walls. The deflection of the crawlspace wall line, as defined by ASCE/SEI 7 Equation 12.8-15 and using $C_d = 4$, shall not exceed an allowable wall line drift of $0.02h_{sx}$. Where sheathed wood structural panel shear walls are stepped along their line, distribution of forces shall be based upon the relative stiffness of each step, and h_{sx} shall be taken as the average at the wall heights at each end.

All crawlspace concrete or concrete masonry unit (CMU) walls taller than 4'-0" and connected directly to the base-level diaphragm floor framing shall be anchored to the existing diaphragm per ASCE/SEI 7 Section 12.14.7.5, Anchorage of Structural Walls. Where CMU or concrete *stem walls* occur in the same line as wood light-frame crawlspace walls, the wood light-frame crawlspace walls shall be designed to resist seismic forces based on tributary area, irrespective of relative stiffness.

The load path connections of crawlspace walls to the base-level diaphragm and foundation shall be designed using the seismic forces specified in this section for crawlspace walls, amplified by an overstrength factor, Ω_0, of 1.5.

Crawlspace walls shall be designed for overturning forces using the seismic forces specified in this section for crawlspace walls.

Exception:

Overturning of perimeter crawlspace walls, other than crawlspace walls between the base-level diaphragm and uphill foundation, need not be calculated provided:

1. Not less than 80% of the stud or crawlspace wall length is sheathed full height.
2. Ventilation and access openings in otherwise sheathed walls are permitted to be neglected for purposes of determining percent sheathed, as long as the length of openings does not exceed 20% of the crawlspace wall's entire length
3. A tie-down is provided at each downhill corner and at the end of each full-height sheathed segment, with an ASD capacity not less than the larger of ($1.6 \times S_{DS}$) and 2.5 kips. Tie-down design need not include evaluation or strengthening of the load path beyond the anchorage into the foundation, except as required for proprietary shear walls.

When designing crawlspace walls for overturning, using the exception above, in lieu of a more detailed overturning analysis of the entire dwelling, each crawlspace wall line shall be permitted to be designed to resist the overturning moment generated in the crawlspace wall based on the average height of the wall or wall segment, plus 10 percent of the total overturning moment of the superstructure above, calculated in accordance with the provisions of ASCE/SEI 7 Section 12.8 or 12.14 and using $R = 4.0$.

When the crawlspace wall occurs between the base-level diaphragm and uphill foundation, the crawlspace wall line shall be designed to resist the overturning moment generated in the crawlspace wall based on the average height of the wall or wall segment, plus not less than 50 percent of the total overturning moment of the superstructure above, calculated in accordance with the provisions of ASCE/SEI 7 Section 12.8 or 12.4 and using $R = 4.0$.

First story shear walls above the base-level diaphragms and over the uphill foundations shall be retrofit with tie-downs extending down into the uphill foundations and for the smaller of the force level noted above or the overturning strength capacity of the existing first floor shear wall above. Shear walls above the base-level diaphragm, over the uphill foundation, are not required to be strengthened. Proprietary shear walls are permitted to be used as an alternative to wood structural panel crawlspace walls provided they comply with all of the following requirements:

1. The proprietary shear walls complying with the requirements of ICC--ES AC 436, FEMA P-795, or shall have been tested in accordance with ASTM D7989 in a manner and with documentation acceptable to the *building official*, or shall be an *approved* equal.
2. The proprietary shear walls are designed using the seismic forces specified in Section 6.5.5.

3. The design of the collector and collector connection to the base-level diaphragm, up to but not including connections provided by the manufacturer, use the seismic forces of this section amplified by an overstrength factor, Ω_0, of 1.5.
4. The design of the foundation, up to, but not including anchorage provided by the manufacturer, use the seismic forces of this section amplified by an overstrength factor, Ω_0, of 1.5.
5. The proprietary shear wall demand to capacity ratio for wall shear strength does not exceed 1.5.
6. If multiple proprietary walls are used in a wall line, the seismic forces shall be distributed between them in accordance with their relative stiffness.

New foundations, where provided for proprietary walls, shall conform to Section 6.5.3.