SEISMIC ASSESSMENT AND RETROFIT OF ONE- AND TWO-FAMILY WOOD-FRAME DWELLINGS

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Abstract

FEMA P-1100, *Vulnerability-Based Seismic Assessment and Retrofit of One- and Two-Family Dwellings*, was developed in 2018 with funding from the California Earthquake Authority (CEA) and the Federal Emergency Management Agency (FEMA), through the Applied Technology Council's ATC-110 Project series. Volume 1 of this document is developed as a Prestandard, and subsequent volumes provide electronic plan set documents for easy implementation of retrofits and technical supporting documentation. The methodology in the Prestandard covers seismic assessment and vulnerability-based retrofit of cripple wall, living-space-over-garage, and hillside vulnerabilities in one- and two-family dwellings. Also included is assessment and retrofit of masonry chimneys and fireplace surrounds. Although simplified for the purposes of implementation, retrofit methodologies have been developed using best available numerical tools and performance objectives consistent with the philosophies of current seismic codes and standards. The Prestandard provides both simplified engineered retrofit design provisions, and prescriptive (pre-engineered) provisions, also provided as easy-to-use plan set documents. This presentation will discuss these retrofit provisions and the performance related issues that were considered during development.

Keywords: seismic retrofit, residential, cripple walls, living-space-over-garage, hillside house, chimneys, wood-frame, prescriptive

1. Introduction

Specific seismic vulnerabilities in single-family wood-frame dwellings (herein called "houses") have been observed to cause costly and disruptive damage in earthquakes in the state of California in the Western United States. However, houses properly mitigated or retrofitted against these vulnerabilities have performed well in damaging earthquakes (Fig. 1).

Fig. 1– The un-retrofitted house on the left came off its foundation during the 2014 South Napa earthquake (California, United States) rendering the house uninhabitable for over two years. The retrofitted house on the right had damage but the occupants were able to stay in their house during repairs. (photo credit: CEA).

These observations from past earthquakes have demonstrated the need for standards for the assessment and seismic retrofit of residential wood-frame structures with specific seismic vulnerabilities. In response to this need, in 2013 the California Earthquake Authority (CEA) and the Federal Emergency Management Agency (FEMA) began funding the Applied Technology Council (ATC) through the ATC-110 Project to develop a prestandard for the evaluation and retrofit of one- and two-family wood light-frame residential buildings. The resulting publication, FEMA P-1100, *Vulnerability-Based Seismic Assessment and Retrofit of One- and Two-Family Dwellings* [1], is expected to serve as a basis for a nationally recognized, ANSI-approved consensus standard that will further help in disseminating and incorporating the approaches and technology of the prestandard into the mainstream of design and construction practices in the United States. Volume 1, developed as a prestandard, is supported by three additional volumes 2A, 2B and 2C. This Prestandard provides a stand-alone resource for assessment and retrofit, incorporating all provisions required for implementation, and includes figures containing prescriptive, pre-engineered structural drawings and commentary, as well as appendices that are expected to remain non-mandatory.

The specific seismic vulnerabilities addressed by this prestandard are:

- Crawlspace dwelling anchorage to foundation, cripple wall bracing, and connection to the framed floor immediately above
- Living-space-over-garage (LSOG) dwelling ground story bracing
- Hillside dwelling anchorage to foundation and cripple wall bracing
- Brick masonry chimneys
- Anchorage of masonry fireplace surrounds.

In the case of the crawlspace and fireplace vulnerabilities, in the State of California, these are potentially found in houses constructed before seismic standards were adopted into the building codes. The benchmark years for proper seismic bracing was post 1980 for crawlspace houses and post 1994 for masonry chimneys, fireplace surrounds, and LSOG houses. Houses constructed after these dates are assumed to not have these specific seismic vulnerabilities.

The seismic vulnerabilities addressed in the prestandard are not limited to California houses. Consequently, the assessment and retrofit solutions in the prestandard were designed to be appropriate for wood-framed single-family houses throughout the Western United States.

2. Vulnerability-Based Assessment and Retrofit Methodologies

The prestandard was written using vulnerability-based assessment and retrofit methodologies to allow for phased, affordable retrofits of houses. The intent was to prescribe a complete and effective retrofit of a specific vulnerability rather than describing a holistic retrofit of the entire structure. Most single-family seismic retrofits in the United States have been completed on a voluntary basis allowing the owner-builder or contractor the leeway to do incomplete or ineffective retrofits. The use of prestandard language, such as "shall" rather than "should", allows a local jurisdiction or retrofit funding source, such as a grant program, to have a standard to point to that describes a complete, code-compliant retrofit of a targeted vulnerability. Retrofits that do not address all applicable locations or do not include all applicable retrofit elements for a specific vulnerability being addressed are not designated as conforming to the prestandard.[1]

The prestandard recognizes that there are many houses with regular configurations that can be mitigated with simplified retrofit solutions outlined in pre-engineered plan sets. There are also other, more complicated houses that require a more detailed or engineered assessment and retrofit. The prestandard includes the following assessment and retrofit methods:

Assessment methods:

- Simplified vulnerability-based assessment
- Detailed vulnerability-based assessment
- Engineered vulnerability-based assessment
- General engineered assessment

Retrofit methods:

- Prescriptive vulnerability-based retrofit
- Simplified engineered vulnerability-based retrofit
- General engineered retrofit*

*Alternative engineered methods approved by the local jurisdiction are also allowed.

The simplified prescriptive assessment procedure by nature is more conservative and intended as an expedited check to determine whether existing conditions are acceptable, specific components require retrofitting, or whether a detailed assessment should be done. The detailed assessment procedure is still prescriptive by nature, but may require a registered design professional to complete. No calculations are anticipated to be completed as part of the detailed assessment procedure. The general intent of the detailed assessment procedure is to grandfather in those original construction conditions such as the IEBC Appendix Chapter A3 [2] or retrofits that include certain detailing that have been deemed to provide adequate safeguards although possibly less substantial than a retrofit provided in accordance with this prestandard, against these vulnerabilities.[1]

Chapters 1 and 2 of the prestandard are applicable to the assessment and retrofit of all vulnerabilities. Chapter 1 includes information on how to obtain the seismic de sign category, SDC, for the house. The SDC must be in accordance with Section 301.2.2 Seismic Provisions of the *International Residential Code* (IRC) [3]. The simplified methodology user is directed to the various sources that provide SDC for seismically active areas of the United States.

Chapter 3 contains minimum construction requirements that are applicable to all retrofits. These requirements are similar to what would be found in the conventional construction provisions of the IRC and other building codes.

Chapters 4 through 7 describe the specific retrofit of the crawlspace, LSOG, hillside and chimney vulnerabilities. Chapter 8 contains checklists that may be required in Chapters 4 through 7. Volumes 2A, 2B and 2C contain plan sets that can serve as documents suitable for obtaining a permit and for construction.

3. Earthquake Vulnerabilities in Crawlspace Houses

The prestandard defines the crawlspace house as:

"A dwelling in which: (1) the space below the lowest framed floor is predominantly unoccupied, including area enclosed by crawlspace walls, open areas, or a combination of the two; (2) the tallest crawlspace cripple wall clear height does not exceed 7'-0"; and (3) when averaged across the full length or width of the dwelling the grade slope does not exceed 1 vertical in 5 horizontal." [1]

Crawlspace houses typically have three to five steps from ground level up to the lowest occupied floor. The crawlspace is accessed through an opening in one of the perimeter walls or, less frequently, through a floor opening in an interior closet. Crawlspace houses can be separated into houses with cripple walls or stem walls supporting a wood-framed floor. Cripple walls are defined in the prestandard as: "A framed wall extending from the top of the foundation to the underside of the floor framing of the first floor above grade plane." [1] Stem walls are defined as: "A concrete or masonry wall bearing on a foundation and supporting structure above. For purposes of cripple wall and crawlspace wall retrofits, the stem wall acts as an extension of the foundation." [1]

Damage to crawlspace houses with insufficient anchors and bracing often includes a house sliding or toppling off of its foundation (Fig. 2). Depending on how high the cripple wall and how the house falls, the superstructure of the house (the portion above the lowest floor) can sustain cracking to finishes and racking. Utility lines are often damaged or severed with damaged gas lines creating a fire hazard. While it is often possible to lift the house and anchor it to a new foundation, damage to the superstructure may require removal of finishes, re-alignment of the house, and replacement of finishes. This damage is costly and disruptive. On average, houses that came off of their foundation in the 2014 South Napa Earthquake were not yet reoccupied two years after the event [4].

Fig. 2– One-story single-family crawlspace house that came off of its foundation in the 2014 South Napa earthquake. The gas meter was damaged and the toppled porch roof blocked the front door creating an unsafe condition. (Photo credit: CEA)

The retrofit solution for a crawlspace house is one of the most cost-effective retrofits available. The CEA Earthquake Brace and Bolt (EBB) grant program has provided up to $3000 (US dollars) for crawlspace retrofits to over 9,000 homeowners in California. The average cost of the retrofit is $5,200. The cost to repair a house that has come off its foundation is in the tens to hundreds of thousands of dollars. The retrofit to the cripple wall and stem wall house is very straightforward. New anchor bolts or foundation plates are installed to connect the mudsill (flat wood member on top of the foundation) to the foundation. Cripple walls, if present, are braced with structural sheathing such as plywood. Finally, the existing floor framing is clipped to either the top plate of the cripple wall or the mudsill in a stemwall condition (Fig. 3).

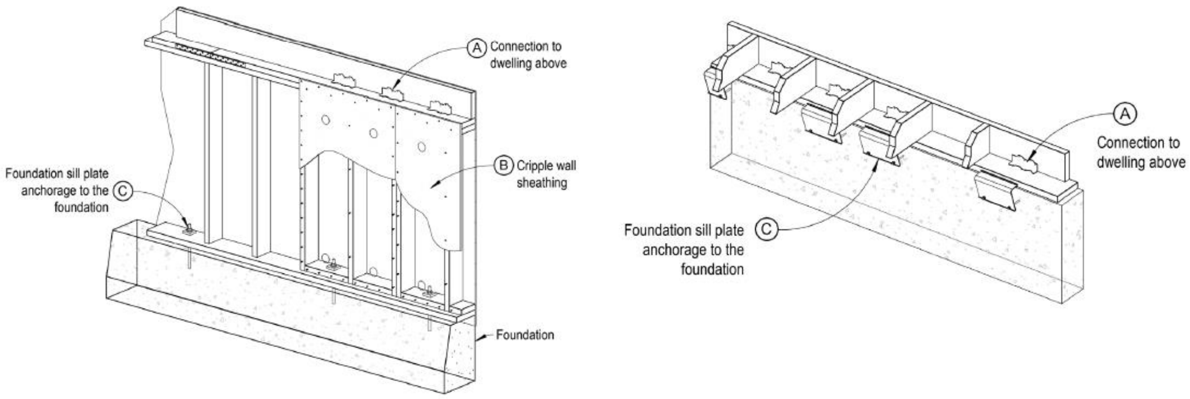

Fig. 3– Seismic retrofit of the cripple wall foundation (left) and the stem wall foundation (right). [1]

4. Earthquake vulnerabilities in houses with living-space-over-garage

The living-space-over-garage (LSOG) dwelling is defined as one in which a primary occupied living space occurs in an upper story that extends substantially or completely over a ground story constructed primarily as a garage, including utility and storage uses. [1] This seismic vulnerability is predominately the result of the introduction of the attached garage into single-family houses. Starting in the late 1940s, houses were often constructed with attached garages and storage areas tucked under the entire house or under one or two floors of a portion of the house. The lack of sufficient seismic bracing at the lowest level and, in particular, at the garage door wall creates a significant seismic vulnerability (Fig. 4).

Fig. 4– Single-family wood-framed house with the living-space-over-garage vulnerability severely damaged in the 1989 Loma Prieta Earthquake (California, United States). (Photo credit: FEMA)

The prestandard provides systematic, procedures in Chapter 5 for simplified, detailed, and engineered assessments of the LSOG house. For houses that qualify for the simplified assessment, prescriptive retrofit solutions are described in Chapter 5 and a prescriptive retrofit plan set is provided in FEMA P-1100 Volume 2B. The plan sets include details for new wood structural panels along the entire perimeter of the ground floor and either wood structural panels or a steel column or proprietary shear walls either side of the garage door opening (Fig. 5). The engineered retrofit may include adding structural panels to the bare first floor walls and either a cantilevered column or steel frame at the garage door wall.

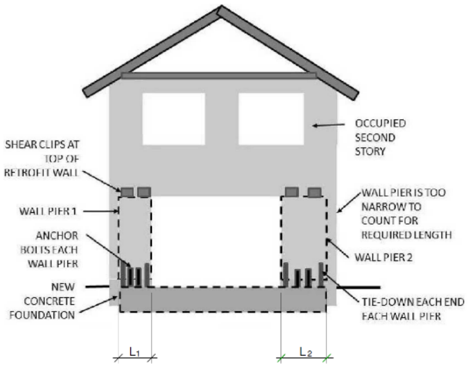

Fig. 5– Schematic elevation of the living-space-over-garage vulnerability showing new seismic retrofit elements either side of the garage door. [1]

5. Earthquake vulnerabilities in hillside dwellings

The hillside dwelling is defined in the prestandard as: “A dwelling in which: (1) the space below the lowest framed floor is predominantly unoccupied, including area enclosed by crawlspace walls, open areas, or a combination of the two; (2) the tallest crawlspace cripple wall clear height exceeds 7’-0” (or post and beam system post height exceeds 7’-0” when underfloor area is not enclosed); (3) when averaged across the full length or width of the dwelling the grade slope exceeds 1 vertical in 5 horizontal; and (4) where a wood light-frame crawlspace wall occurs between the base-level diaphragm and uphill foundation, the height of this crawlspace wall does not exceed 2’-0”.” [1] This vulnerability is deemed too complicated to be covered by a simplified assessment or prescriptive retrofit. Hillside dwellings are believed to be vulnerable due to the combination of brittle diaphragm anchorage to the uphill foundation and inadequate strength and stiffness of crawlspace walls or other bracing below the base-level diaphragm (main floor). [1] Hillside houses have detached from their foundations in earthquakes, causing them to slide downhill or collapse (Fig. 6).

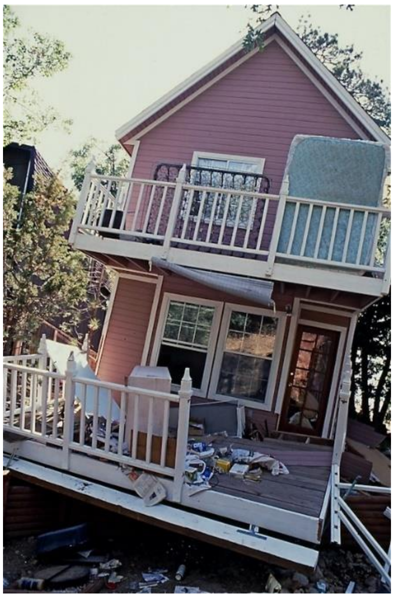

Fig. 6– Two-story wood-framed house that slid down the hill during the 1992 Big Bear earthquake (California, United States) sustaining significant damage to the superstructure. (Photo credit: California Office of Emergency Services, CalOES)

The prestandard provides design and retrofit methodologies and sample retrofit techniques for an engineered solution. Retrofit solutions may include adding additional anchorage at the uphill foundation, collectors and concrete shear elements at the sloped or stepped side foundations and bracing and bolting all perimeter cripple walls. (Fig. 7) There are no prescriptive plan sets for the hillside house. Rather, the prestandard includes examples of possible retrofit solutions to be used in the engineered solution.

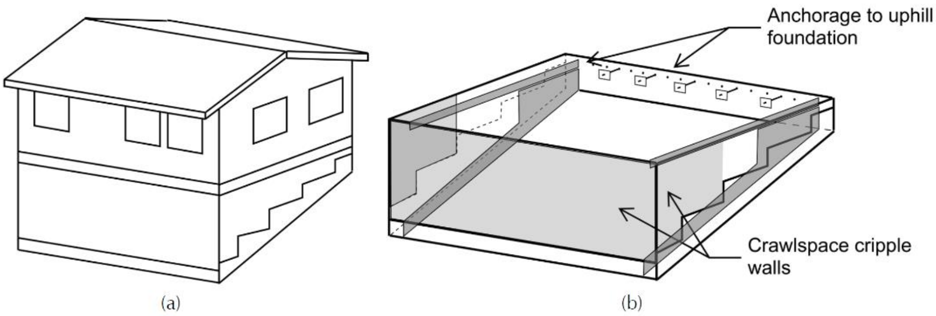

Fig. 7– Schematic of a downslope hillside house (a) and detail of the foundation (b). [1]

6. Earthquake vulnerabilities in brick masonry chimneys and masonry fireplace surrounds

A large portion of the existing stock of single-family dwellings in United States have been built with unreinforced or lightly reinforced masonry chimneys. Along with brittle wall finishes and large masonry fireplace surrounds, masonry chimneys are arguably the most vulnerable elements of conventionally-constructed, wood light-frame houses. [1] Chimneys are known to sustain damage in even moderate earthquakes as seen in the 2014 South Napa earthquake (Fig. 8).

Fig. 8– Unreinforced masonry chimney pulled away from the house in the 2014 South Napa Earthquake (California, United States). (Photo credit: CEA)

The prestandard does not include a retrofit solution that straps an unreinforced masonry chimney to the house. Rather, the prestandard takes the following position: “It is unclear whether older conventionally-constructed chimneys can achieve the reliably good seismic performance that forms the bases of modern building code provisions. As such, prescriptive provisions include the option of simply removing the masonry chimney and fireplace down to the foundation and replacing with lightweight factory components in a cold-formed steel or wood-frame chase.” (Fig. 9) [1]

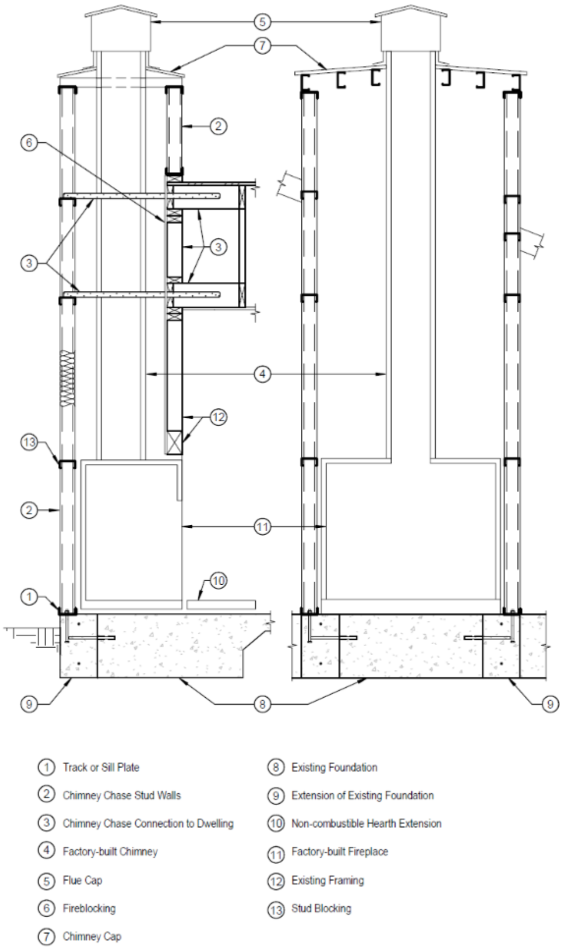

Fig. 9–New fireplace box and chimney from FEMA P-1100 Volume 2C. [1]

The assessment and retrofit methodology for masonry chimney surrounds takes into consideration both the anchorage of the masonry to the house framing as well as the capacity and connectivity of the framing itself. The prestandard retrofit requires the masonry to be removed and reconstructed as “anchored masonry veneer” in accordance with modern fireplace construction standards. (Fig. 10)

Fig. 10– Fireplace surround that peeled off the wall seriously injured a 13 year old boy in the 2014 South Napa Earthquake (California, United States). (Photo credit: ABC7 News)

8. Prescriptive plan sets

The three prescriptive plan sets that make up Volumes 2A, 2B, and 2C of the FEMA P-1100 series contain:

- Instructions for use
- General notes
- Supplemental technical notes for various retrofit elements (including proprietary elements)
- Tables describing various weight classifications based on finish materials
- Retrofit schedules with instructions
- Sample plans showing required elements to be provided by the user
- Retrofit details

The intent of the plan sets is that the user will develop a detailed plan showing the configuration and dimensions of the foundation and indicate which prescriptive details have been utilized for the retrofit. Where the retrofit work requires a permit from the local building department or jurisdiction, the intent is that the completed plan set will be submitted for approval and then used for construction. These prescriptive plan sets provide detailed instructions for complete retrofits of known seismic vulnerabilities. The plan sets can be used on a voluntary basis by homeowners, adopted and promoted by local building officials or, required by retrofit incentive programs like the CEA's EBB grant program.

The FEMA P-1000 document and supplemental plan sets provide assessment and retrofit solutions based on extensive engineering analysis, and technical and construction expertise. FEMA P-1100 is currently being developed into a nationally recognized, ANSI-approved consensus standard by the International Code

Council with CEA and FEMA support with the intent that it be adopted into either the International Existing Building Code or the International Residential Code. The inclusion of prescriptive plan sets is intended to provide affordable pre-engineered solutions to make seismic resilience within reach for as many homeowners as possible.

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6. References

[1] CEA (2018): *FEMA P-1100, Vulnerability-Based Seismic Assessment and Retrofit of One- and Two-Family Dwellings* Volumes 1, 2A, 2B, and 2C, based on ATC 110, prepared by the Applied Technology Council for the California Earthquake Authority (Sacramento, California, USA) and the Federal Emergency Management Agency.

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