Review of Earthquake Brace and Bolt Program's Photographic Database

A Report for the "Quantifying the Performance of Retrofit of Cripple Walls and Sill Anchorage in Single-Family Wood-Frame Buildings" Project

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EXECUTIVE SUMMARY

This report was developed during a multi-year, multi-disciplinary project coordinated by the Pacific Earthquake Engineering Research Center (PEER) and funded by the California Earthquake Authority (CEA). The overall project is titled "*Quantifying the Performance of Retrofit of Cripple Walls and Sill Anchorage in Single-Family Wood-Frame Buildings*," henceforth referred to as the "PEER–CEA Project." The overall objective of the PEER–CEA Project is to provide scientifically based information (e.g., testing, analysis, and resulting loss models) that measures and documents the seismic performance of wood-frame houses with cripple wall and sill anchorage deficiencies as well as retrofitted conditions that address those deficiencies.

This report was developed as a project resource document and summarizes the results of the Earthquake Brace and Bolt (EBB) photographic database review conducted as part of the PEER–CEA Wood-Frame Project. The photographs are part of the required documentation within the EBB Program, which (typically) includes nine photographs of each house that has been retrofitted under the program, including images of the exterior and crawlspace before and after seismic retrofit. The information contained in the photographic database provides insights on details and statistics for houses in California with seismically deficient crawlspace framing. A total of 1012 randomly selected EBB house files were reviewed with extractable information documented. Targeted information reflects the initial building variant list proposed by Working Group 2 as part of the PEER–CEA Wood-Frame Project.

The general observations from the EBB database review are as follows:

- 75% of the reviewed houses are one-story structures, and the remaining 25% are two-story structures;
- 57% of the reviewed houses have cripple walls, and the remaining 43% have a raised stem wall foundation;
- The most common roofing material is asphalt shingle (71%), followed by clay tile roofing (15%), concrete tile (3%), with the remainder unidentifiable; and
- The most common exterior material is stucco (66%), followed by horizontal wood siding (25%), with the remainder being an exterior with a combination of finishes or other less common cladding materials.

The geometric characteristics of houses with unbraced crawlspaces are broken into four categories that comprised different percentages of the total sample, namely: stem walls (43%), level cripple walls (25%), uneven height cripple walls (13%), and "zero-height" cripple walls (combination of uneven cripple wall and stem walls; 19%). For all cripple wall types (excluding stem walls), the most common wall heights were between one and four feet. While cripple wall heights greater than four feet were observed, they were significantly fewer than those with heights *less* than four feet.

The presence of structural sheathing beneath the exterior material was difficult to identify from the brace and bolt files, but it was positively identified for 325 cases—about one-third of the total. The most common exterior cladding and sheathing combination was stucco with horizontal sheathing, followed by stucco without structural sheathing. Horizontal wood siding was observed

with similar frequency, with and without horizontal wood sheathing. Very few cases were observed with diagonal sheathing.

The photographs show that several different bracing conditions occurred in roughly one-third of the houses constructed with cripple walls. This ranged from the most common cut-in bracing to much more detailed retained block bracing in a small sub-set of cases. The presence of bracing is important to note since it can contribute significantly to the seismic resistance of the existing cripple wall, depending on the type of exterior finish and presence (or absence) of wood sheathing.

1 Introduction

This report was developed as a project resource document during a multi-year, multi-disciplinary project coordinated by the Pacific Earthquake Engineering Research Center (PEER) and funded by the California Earthquake Authority (CEA). The overall project is titled "*Quantifying the Performance of Retrofit of Cripple Walls and Sill Anchorage in Single-Family Wood-Frame Buildings*," henceforth referred to as the "PEER–CEA Project." The overall objective of the PEER–CEA Project is to provide scientifically based information (e.g., testing, analysis, and resulting loss models) that measures and documents the seismic performance of wood-frame houses with cripple wall and sill anchorage deficiencies as well as retrofitted conditions that address those deficiencies.

The PEER–CEA Wood-Frame Project evaluated a large number of building variants representing older residential houses with unbraced cripple walls and sill anchorage deficiencies. Working in cooperation with the California Earthquake Authority (CEA), the PEER Team reviewed and documented information from the CalOES and CEA sponsored Earthquake Brace and Bolt (EBB) program that collects photographic documentation as part of its seismic retrofit incentive program.

The need for more explicit information on older wood-frame dwellings is illustrated by briefly reviewing previous efforts to collect statistics on cripple wall houses; see Section 1.1. An overview of the EBB program and the initial building variant list developed by PEER–CEA Working Group 2 [Reis 2020] are provided in Sections 1.2 and 1.3, respectively. Finally, the main objectives of the photographic review are discussed in Section 1.4 before presenting results in Section 2.

1.1 EXISTING DOCUMENTATION OF CRIPPLE WALL DWELLING CHARACTERISTICS

Limited information exists with detailed documentation of houses with seismically deficient cripple and stem walls. Bhattacharjee [2017] summarized the CoreLogic tax roll database, focusing on information that could be extracted from houses with crawlspaces. Figure 1.1 shows an example of the information collected to classify residential housing according to age and foundation type, demonstrating that the relative percentages of raised crawlspace houses is on the order of 20% to 5% depending on the era of construction. Although it is logical that cripple wall dwellings do not represent the majority of foundation types, the data provided in Figure 1.1 does not provide much information as to the specific characteristics of the homes constructed with cripple walls.

One of the most in-depth surveys conducted for dwellings with cripple walls dwellings summarized in the work of Rabinovici and Ofodire [2017], who reviewed survey results from 633 houses following the 2014 South Napa earthquake. Of the total results, 603 cases provided information that allowed for the foundation and cripple wall type to be documented. The results in Figure 1.2 illustrate that the survey results analyzed by Rabinovici and Ofodire [2017] allowed for the range of cripple wall heights to be documented as a function of construction era. The information shows cripple wall heights between 2 ft and 4 ft represent the majority of observed cases across a range of construction eras.

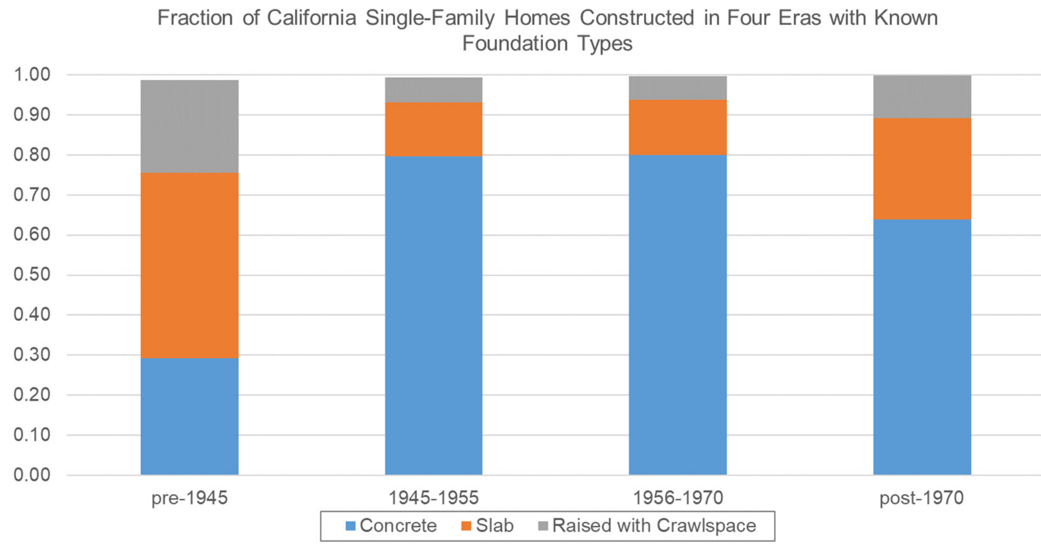


Figure 1.1 Distribution of foundation type for different eras of construction from Bhattacharjee [2017].

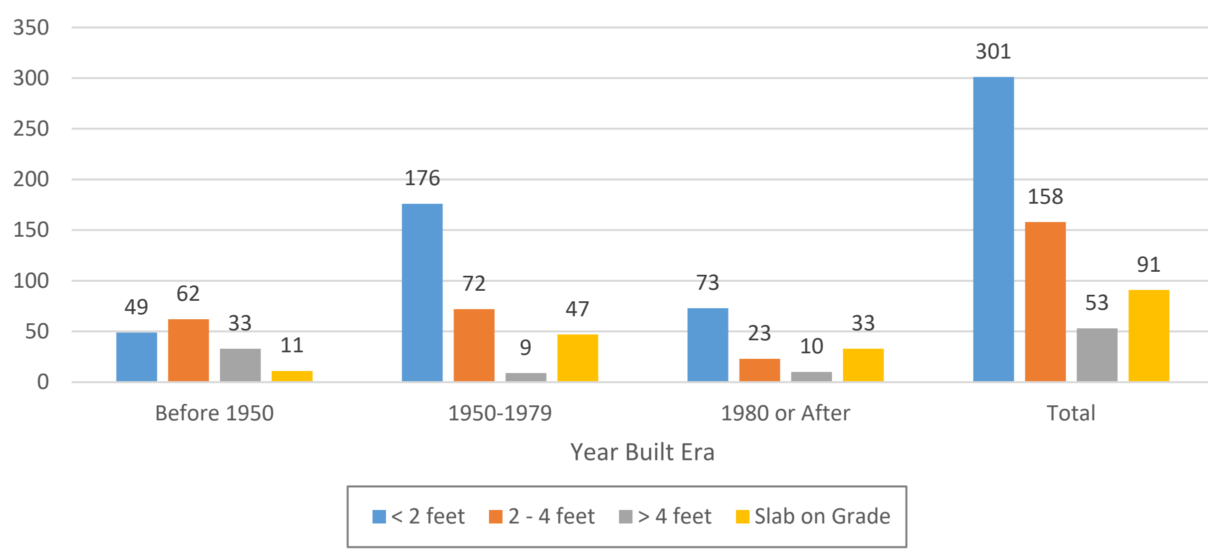


Figure 1.2 Breakdown of counts in the survey sample by construction era and cripple wall height following the 2014 South Napa event [Rabinovici and Ofodire, 2017].

1.2 EARTHQUAKE BRACE AND BOLT (EBB) PROGRAM OVERVIEW

The "Earthquake Brace and Bolt: Funds to Strengthen Your Foundation" is the first seismic mitigation incentive program offered by the California Residential Mitigation Program (CRMP), which was created and sponsored by the California Earthquake Authority (CEA; *www.earthquakeauthority.com*) and the California Governor's Office of Emergency Services (Cal OES; *www.caloes.ca.gov*). The EBB program offers up to $3000 toward a code-compliant seismic retrofit for qualifying homes.

To qualify, homes must be located in an EBB-Program-eligible ZIP code, be built prior to 1980, and sit on a level or low-sloped lot (among other requirements) [EBB 2019]. Homes can qualify for retrofit grants under two types, with the distinguishing characteristics largely following those described for retrofit design compliance according to the California Existing Building Code Chapter A3 provisions [ICC 2016]. Type 1 homes are either one or two stories tall, constructed on a cripple wall that does not exceed 4 ft in height, or a three-story-tall home with a cripple wall with a height of 14 in. or less. Type 1 homes, by definition, do not require retrofit designs to be prepared by a registered design professional. Type 2 homes are those that require a registered design professional to develop, sign, and certify plans that are in conformance to the California Existing Building Code Chapter A3 provisions [ICC 2016]. Type 2 homes include (but are not limited to) those with cripple wall heights between 4 and 7 ft, having more than three stories, and being partially constructed on concrete slab-on-grade foundations [EBB 2019].

Homeowners that successfully register and are accepted into the program must submit a series of documentation requirements (see [EBB 2019] for details), including photographic documentation. A minimum of six photographs is required of the pre-retrofit condition, including three photographs of the exterior of the home (front and two other sides) and three photographs of the existing condition of the crawlspace, foundation, and cripple wall if present. Following retrofit work, an additional three photographs must be submitted that illustrate the retrofit work done in the crawlspace, ideally in the same locations that the "before work" photographs were taken. An example of the nine photographs documented in the EBB photo database are provided in Figure 1.3. Note that the photographs depicting the exterior of the home have been grayed out in order to preserve anonymity of the house, as was agreed upon between PEER researchers and the CEA prior to obtaining access to the photographic database.

Figure 1.3 Example of nine photographs required for submission within the Earthquake Brace and Bolt (EBB) program: three exterior photographs (top row, not shown), three pre-retrofit photographs (middle row), and three post-retrofit photographs (bottom row)

1.3 PRELIMINARY BUILDING VARIANT SCOPE FOR THE PEER-CEA WOOD-FRAME PROJECT

The initial review of existing literature, census data, and expert opinion relating to inventory documentation allowed for the Building Variant Group (Working Group 2) to develop a preliminary list of building variants for analysis within the PEER–CEA Wood-Frame Project [Reis 2020].

Building variants target three main criteria for inclusion for analysis:

- A significant representation among California homes (greater than 10% of housing stock);
- The potential to have a significant impact on building earthquake damage; and
- The amount of reduction in damage due to seismic retrofitting is dependent upon the presence of the variant.

Based on these criteria, the initial building variant list proposed by Working Group 2 includes: (1) primary observable features (e.g., construction era and number of stories); (2) secondary observable features (e.g., cripple wall geometry); and (3) unobservable features (e.g., siding and underlying sheathing). A summary of the building variant list proposed by Working Group 2 is shown in Figure 1.4.

All cases	
Size and configuration	Generally 1,100 – 1,200 sf rectangular footprint with 2:1 to 4:3 aspect ratios
Nail spacing in siding/sheathing	Two nails per board
Foundation bolt diameter	1/2" if present
Bolt hole diameter	1/4" oversize if present
Building shear capacity	As per ATC-110 recommendations as function of age
Soft story	Ignore because difficult to assess impact on brace and bolt
Condition	Apply upper and lower bounds to achieve an average value of each index building
Retrofit	Both unretrofitted and retrofitted conditions

Combinations		
Pre 1945	Stories	1 or 2
	Sill bolting	Unbolted (wet-set sill)*
	Building weight	Heavy or Light
	Cripple wall height / Slope differential	0'/0', 2'/0', 2'/2', 4'/0', 4'/2', 4'/4', 7'/0', 7'/2', 7'/4', 7'/7''
	Siding / Sheathing combinations	Stucco/None, Stucco/Horizontal, Stucco/Diagonal, Horizontal/None
1945-1955	Stories	1 or 2
	Sill bolting	Unbolted (wet sill), Bolted (6' or better)
	Building weight	Heavy or Light
	Cripple wall height / Slope differential	0'/0', 2'/0', 2'/2', 4'/0', 4'/2', 4'/4', 7'/0', 7'/2', 7'/4', 7'/7'
	Siding / Sheathing combinations	Stucco/None, Stucco/Horizontal, Stucco/Diagonal, Horizontal/None
1956-1970	Stories	1 or 2
	Sill bolting	Bolted (6' or better)
	Building weight:	Heavy or Light
	Cripple wall height / Slope differential	0'/0', 2'/0', 2'/2', 4'/0', 4'/2', 4'/4', 7'/0', 7'/2', 7'/4', 7'/7''
	Siding / Sheathing combinations	Stucco/None, Stucco/Horizontal, Stucco/Diagonal, Horizontal/None, T1-11/None

* Unbolted (wet-set sill) condition occurs typically when contractor installs mudsill into the concrete footing when it is cast, using spikes or heavy nails in the sill to provide nominal anchorage to the footing.

Figure 1.4 Summary of the Working Group 2 preliminary list of building variants for analysis [Reis 2020].

1.4 OVERVIEW AND OBJECTIVE OF EARTHQUAKE BRACE AND BOLT PHOTO REVIEW

The main driving factor for the EBB photo database review is the need for real-world information about homes constructed with cripple walls. The information contained within the EBB photographic database is among the most detailed source of information regarding details of cripple wall dwellings. The more detailed information on the existing building inventory can assist decisions made in the PEER–CEA Project, and it can also serve future research efforts into the topic of seismic assessment of homes constructed with cripple walls. The main objective of the study is to extract information that can be obtained through review of the documented photographs.

2 Results of the Earthquake Brace and Bolt Photo Review

A total of 1012 houses (out of over 9000 available and counting in the database) were reviewed and documented. The first 132 cases were reviewed in-person at CEA headquarters in Sacramento, and the remaining 880 cases were reviewed at Stanford University under an off-site confidentiality agreement not to divulge details of the retrofitted houses so as not to the violate privacy rights of the homeowners. The initial review included about 20 random samples from each of the available sub-folders within the database (e.g., Bay and LA 1st Quarter 2015). The larger review was done in a similar manner, with samples of twenty homes being cycled through each of the sub-folders to randomize the cases considered.

2.1 GENERAL CLASSIFICATION OF REVIEWED HOMES

This section summarizes the characteristics of all 1012 houses reviewed from the EBB photographic database. These characteristics include the presence of a cripple wall, the number of stories, roofing material, and exterior wall material. These general characteristics are reviewed prior to focusing on more specific details pertaining to cripple walls and foundation details.

2.1.1 Stem Wall vs. Cripple Wall and Number of Stories

The most general classification is made between cripple wall (i.e., those having a raised first floor supported by wood framing on at least two sides of the perimeter) and stem wall houses (i.e., those with first floor framing resting directly on a raised concrete perimeter foundation). The distribution of cripple wall versus stem wall houses is shown in Figure 2.1 with the numerical data provided in Table 2.1. The figure illustrates that the cases documented include comparable numbers of cripple wall (57%) and stem wall (43%) houses, with slightly more cripple wall cases being observed.

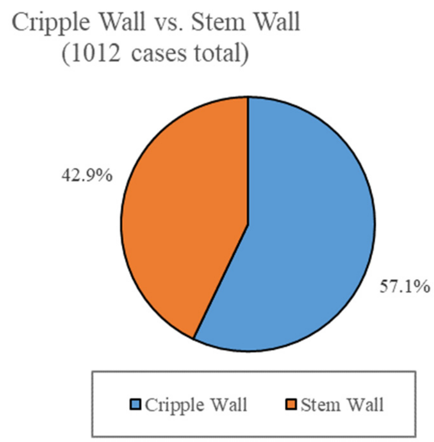


Figure 2.1 Distribution of observed cripple wall and stem wall dwellings.

Table 2.1 Data for observed cripple wall and stem wall dwellings.

Cripple wall vs. stem wall	No. of observations	Percent of sample
Cripple wall	578	57.1%
Stem wall	434	42.9%
Total	**1012**	**100.0%**

Figure 2.2 and Table 2.2 shows the observed cases separated according to foundation class and number of stories. When considering number of stories alone, the study included approximately 761 one-story homes (75%) and 251 two-story homes (25%). Notably, this proportion is in reasonable agreement with previous studies and available information on single-family dwellings in California [HUD 1994; Bhattacharjee 2017; and Reis 2020]. Figure 2.2 illustrates that were 195 out of 578 two-story homes with cripple walls versus 56 out of 434 (13%) homes with a stem wall configuration.

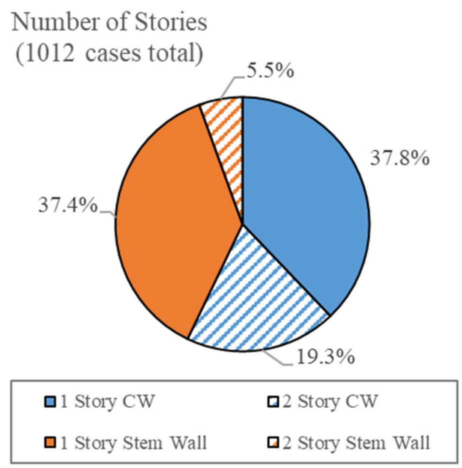


Figure 2.2 **Distribution of observed one- and two-story dwellings.**

Table 2.2 **Data for observed one- and two-story dwellings.**

Number of stories	No. of observations	Percent of sample
1-story cripple wall	383	37.8%
2-story cripple wall	195	19.3%
1-story stem wall	378	37.4%
2-story stem wall	56	5.5%
Total	**1012**	**100.0%**

2.1.2 Observed Roofing Material

The next general characteristic that utilizes all data points is the observed roofing material. As shown in Figure 2.3 (numerical data provided in Table 2.3), the most common roofing material observed was asphalt (or composite) shingle roofing at 71%. The next most common was clay tile roofing at 15%, with a much smaller observed fraction of concrete tile at 2%. The "Other" category was a small fraction–only 1%–of total cases: five examples of wood shakes; two examples of a mix of asphalt shingle and tile, two examples of tar and gravel roofing, and two examples of metal roofing. The "Unknown" category represents 12% of all cases where the exterior house photographs did not show the roofing material. The observed distribution of roofing materials (with a focus on the proportion of asphalt shingle to tiled roofing) is consistent with the findings of Rabinovici and Ofodire [2017], who compiled survey results of over 600 homes following the 2014 South Napa event.

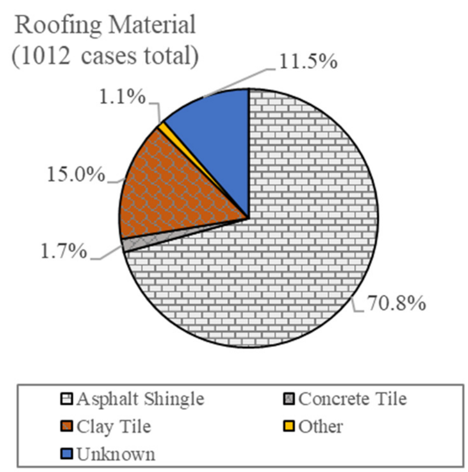


Figure 2.3 Roofing materials observed for all documented homes.

Table 2.3 Roofing material data for all one- and two-story dwellings.

Roofing material	No. of observations	Percent of sample
Asphalt Shingle	716	70.8%
Concrete Tile	17	1.7%
Clay Tile	152	15.0%
Other	11	1.1%
Unknown	116	11.5%
Total	**1012**	**100.0%**

2.1.3 Observed Exterior Material

The final general characteristic is the observed exterior material. The distribution of exterior materials, with the same categories as the Working Group 2 variant list [Reis 2020], is shown in Figure 2.4 (with values provided in Table 2.4). The most prominent exterior material was stucco (66%) followed by horizontal wood siding (25%). Very few cases were observed to have T1-11 siding. A significant portion of "Other" exterior materials comprised 92 out of 1012 cases (9%;). Although this category contained many mixed material cases that included T1-11 or similar panelized wood siding, the most common "Other" exterior material observed was wood-shake siding, as shown in comparison with all observed cases placed in the "Other" exterior material category in Table 2.5.

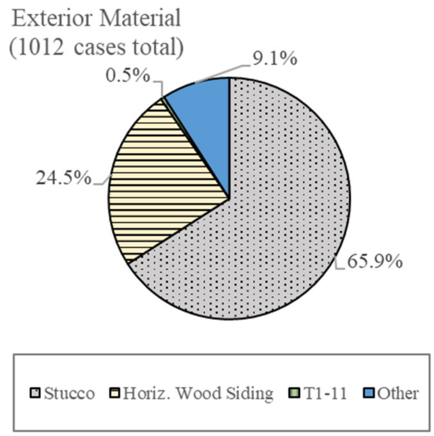


Figure 2.4 Distribution of exterior material for all dwellings.

Table 2.4 Data for exterior material for all dwellings.

Exterior material	No. of observations	Percent of sample
Stucco	667	65.9%
Horizontal Wood Siding	248	24.5%
T1-11	5	0.5%
Other	92	9.1%
Total	**1012**	**100.0%**

Table 2.5 Data for exterior material of "Other" category.

"Other" exterior materials	No. of observations	Percent of "Other" sample	Percent of Total Sample
Wood Shake	35	38.0%	3.5%
Stucco/Horizontal Siding	15	16.3%	1.5%
Stucco/T1-11	8	8.7%	0.8%
Stucco/Board and Batten	7	7.6%	0.7%
Brick Veneer	4	4.3%	0.4%
Stucco/Wood Shake	3	3.3%	0.3%
Stucco/Horizontal Siding/Brick Veneer	3	3.3%	0.3%
Stucco/Brick Veneer	2	2.2%	0.2%
Board and Batten	2	2.2%	0.2%
Stucco/Horizontal Siding/Board and Batten	2	2.2%	0.2%
Horizontal Siding/Brick Veneer	2	2.2%	0.2%
Concrete (Asbestos) Siding	2	2.2%	0.2%
Stucco/Board and Batten/Brick Veneer	2	2.2%	0.2%
Aluminum Siding	1	1.1%	0.1%
Horizontal Siding/T1-11	1	1.1%	0.1%
Horizontal Siding/Board and Batten	1	1.1%	0.1%
Prefabricated Tile System	1	1.1%	0.1%
Vinyl Siding	1	1.1%	0.1%
Total	**92**	**100.0%**	**9.1%**

2.1.4 Construction Era, Plan Dimensions, and Anchorage Condition

During the photo review, the difficulty in estimating the age of construction of variants was quickly apparent. Visual clues, such as the presence of rough sawn or dimensional lumber, did not provide enough information for estimating the age (range) of construction, especially considering transitional eras where construction practices may overlap. Moreover, the date of construction was not otherwise reported in the EBB photographic database. Similarly, an estimation of the plan dimension of houses was initially sought, yet quickly abandoned since this data was not accessible through the provided photographs. However, primary variants such as era of construction and floor area are, by definition, commonly documented and maintained in underwriting practices. Further work with the database could link individual cases (folder and ID number) to additional information that may be documented outside of the EBB photo database. Finally, a third characteristic that could not be accurately verified from the photographs was the sill anchorage condition (e.g., presence of anchor bolts or visible wet-set sill).

2.2 INFORMATION OBTAINED ON CRIPPLE WALL CHARACTERISTICS

The cripple wall cases were readily distinguished from stem wall cases by distinct differences in observable characteristics from the nine photographs provided for each home. The documented stem wall cases typically provide very little information about the sub-floor conditions (e.g., anchorage) due to the lack of space between the ground and first-floor framing (typically 18 in. in height). For the stem wall houses, this typically results in both existing and retrofit photographs showing the foundation and sill plate from an upward angle, where the retrofit photographs focus on illustrating that shear anchorage has been installed between the stem wall and sill plate. In contrast to the limitation of stem wall documentation, the photographs of the cripple wall cases allow for estimates of cripple wall geometry (i.e., height and slope differential) as well as (in many cases) information on the sheathing behind the exterior material. Accordingly, the cripple wall descriptions are presented in the following three subsections: (1) cripple wall classification; (2) cripple wall height distribution; and (3) observed exterior sheathing combinations.

2.2.1 Cripple Wall Classification

Using the EBB photo database, the houses are distinguished in the following groups:

- Level Cripple Walls: cripple walls that have the same height between foundation and first-floor framing around the perimeter of the house;
- Uneven Height Cripple Walls: cripple walls that vary in height from one end of the home to the other to accommodate the natural grade of a building site;
- "Zero-Height" Condition Cripple Walls: cripple walls that have a maximum height on one end of the home (i.e., downhill side) that reduces to the first-floor framing resting directly on the sill plate and foundation (i.e., the uphill side) where no cripple wall framing is used; and
- Stem Wall Condition: a sub-floor condition that has the first-floor framing supported around the perimeter by mudsill plates attached to the masonry or concrete foundation wall (i.e., a stem wall structure does not have a cripple wall).

The different classifications required the use of all nine photographs (i.e., three exteriors, three prior to retrofit, and three after retrofit) provided for each home. The exterior photographs were particularly informative in identifying whether or not the homes were sited on slopes.

The observed classes of cripple wall dwellings are shown in Figure 2.5 (numerical data provided in Table 2.6. Note that the proportion of observed stem wall dwellings is included to show the breakdown of the entire review sample (e.g., all 1012 cases). The figure illustrates that 578 out of 1012 (57%) with cripple walls, level cripple walls are the most common at 25%, followed by "zero-height" cripple walls at 19%, and uneven height cripple walls at 13%.

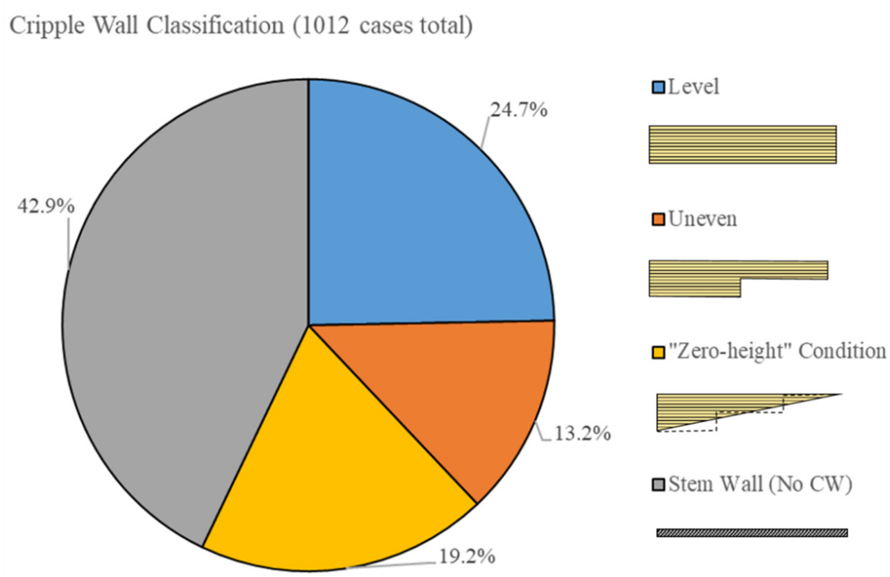


Figure 2.5 Distribution of different cripple wall types for all documented homes.

Table 2.6 Data for cripple wall classification for all documented homes.

Cripple wall classification	No. of Observations	Percent of sample
Level	250	24.7%
Uneven	134	13.2%
"Zero-height" Condition	194	19.2%
Stem Wall (No cripple wall)	434	42.9%
Total	**1012**	**100.0%**

2.2.2 Observed Cripple Wall Height Distribution

The variation in observed heights of *level cripple walls*, are shown to the nearest foot (i.e., +/- 6 in.) in Figure 2.6 (numerical data provided in Table 2.7). Of the 250 cripple walls observed, those 2 ft tall and less were the most commonly observed, with 1-ft- and 2-ft-tall walls comprising 68%. The next most common cripple walls were those 3 ft (21%) and 4 ft (10%) tall, respectively. Very few level cripple walls over 4 ft tall were observed. It is uncertain whether the number of walls over 4 ft tall in the EBB database is affected by the stipulation within Chapter A3 of the California Existing Building Code [ICC 2016] that requires engineered retrofit (as opposed to prescriptive) for those cases. However, for level cripple walls, it is logical that taller wall heights would be less common, since the cripple wall mainly serves to provide an access (i.e., crawlspace) to the first-floor framing and space to run utilities lines. Taller cripple walls tend to be a bit more prevalent in the uneven height cases, where the site terrain can affect the maximum cripple wall height. An exception to this may be areas located in a known flood plain, where the increased cripple wall height could be intentional to prevent to occupied spaces from being affected by flooding, such as homes located in Napa [FEMA 2015].

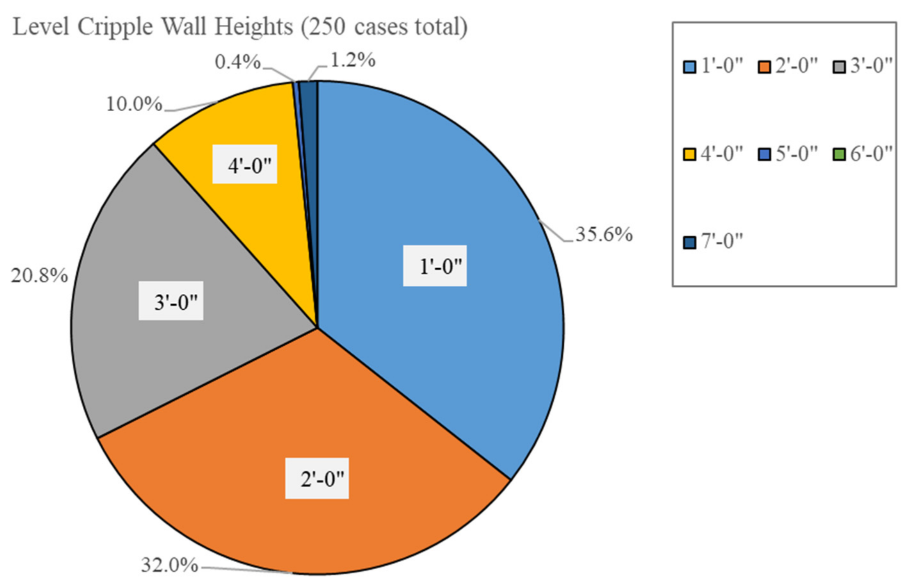


Figure 2.6 Distribution of observed level cripple wall heights.

Table 2.7 Data for observed level cripple wall heights.

Level cripple wall heights	No. of observations	Percent of sample
1 ft-0 in.	89	35.6%
2 ft -0 in.	80	32.0%
3 ft -0 in.	52	20.8%
4 ft -0 in.	25	10.0%
5 ft -0 in.	1	0.4%
6 ft -0 in.	0	0%
7 ft -0 in.	3	1.2%
Total	**250**	**100.0%**

*Cripple wall heights estimated to nearest foot.

The height distributions for *uneven cripple walls* are presented in Figure 2.7 (numerical data provided in Table 2.8). While there were many combinations of uneven wall heights observed in the photo database, this group was the smallest subset of the cripple wall cases (i.e., 134 out of 1012 cases). The three most commonly observed uneven cripple wall heights were either 2 ft to 1 ft, 3 ft to 2 ft, or 4 ft to 2 ft, respectively. These three cases are annotated in Figure 2.7.

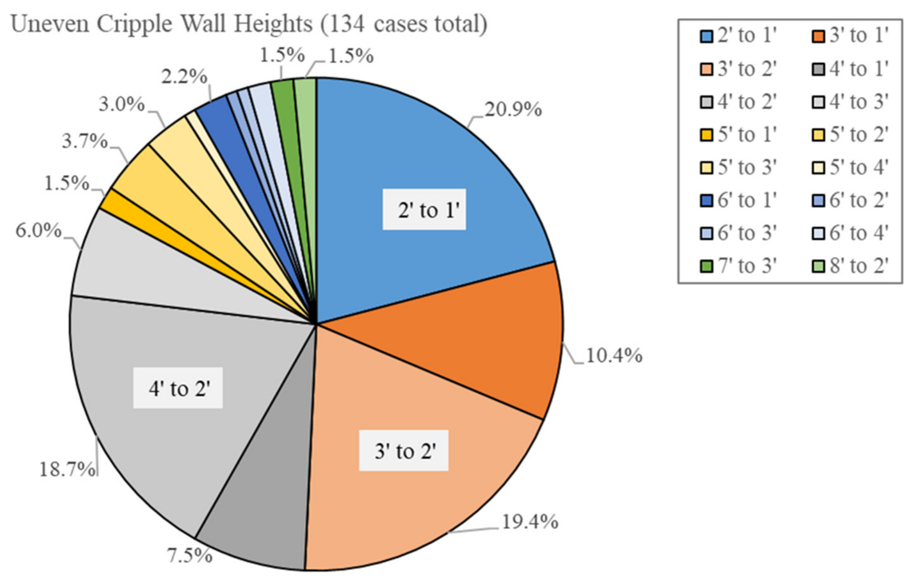


Figure 2.7 Distribution of observed uneven cripple wall heights.

Table 2.8 Data for observed uneven cripple wall heights.

Uneven cripple wall heights	No. of observations	Percent of sample
2 ft to 1 ft	28	20.9%
3 ft to 1 ft	14	10.4%
3 ft to 2 ft	26	19.4%
4 ft to 1 ft	10	7.5%
4 ft to 2 ft	25	18.7%
4 ft to 3 ft	8	6.0%
5 ft to 1 ft	2	1.5%
5 ft to 2 ft	5	3.7%
5 ft to 3 ft	4	3.0%
5 ft to 4 ft	1	0.7%
6 ft to 1 ft	3	2.2%
6 ft to 2 ft	1	0.7%
6 ft to 3 ft	1	0.7%
6 ft to 4 ft	2	1.5%
7 ft o 3 ft	2	1.5%
8 ft to 2 ft	2	1.5%
Total	**134**	**100.0%**

*Cripple wall heights estimated to nearest foot; Colors correspond to Figure 2.7.

The height distributions for cripple walls with a *"zero-height condition"* are shown in Figure 2.8 (numerical data provided in Table 2.9). Similar to observations for level cripple walls, the most commonly observed cripple wall heights (i.e., the tallest height on downhill side of home) ranged from 1-ft- to 4-ft-tall cripple walls. The most commonly observed zero-height condition was the "2-ft- to 0-ft-tall cases, which comprised 26% of the 194 cases of the "zero-height" condition. Only about 10% of the cases had cripple walls taller than 4 ft high.

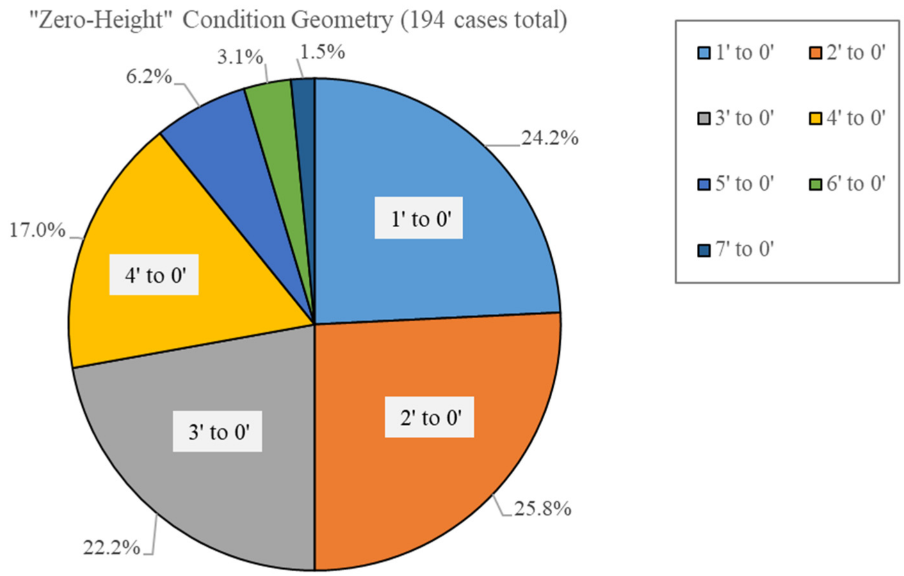


Figure 2.8 **Distribution of wall heights for cripple walls with "zero-height" condition.**

Table 2.9 **Data for wall heights of cripple walls with "zero-height" condition.**

"Zero-height" condition geometry	No. of observations	Percent of sample
1 ft to 0 ft	47	24.2%
2 ft to 0 ft	50	25.8%
3 ft to 0 ft	43	22.2%
4 ft to 0 ft	33	17.0%
5 ft to 0 ft	12	6.2%
6 ft to 0 ft	6	3.1%
7 ft to 0 ft	3	1.5%
Total	**194**	**100.0%**

*Cripple wall heights estimated to nearest foot.

2.2.3 Exterior Sheathing Materials and Combinations

Even with the benefit of interior and exterior photographs of the cripple walls, identifying the presence (or absence) of sheathing materials behind the exterior finish material was difficult due to the presence of building paper applied directly to wall framing. In such cases, where building paper was visible on the interior of the cripple, it was difficult to determine whether there was sheathing sandwiched between the building paper and the exterior wall finish. As such, many cases had to be classified as "unknown" with respect to interior sheathing. Nevertheless, the presence/absence of sheathing was identified in a significant number of cases.

A total of nine photographs per home were considered to determine the presence or absence of exterior sheathing material. One example would be using exterior photographs of the home to distinguish between horizontal wood siding that is a different width than observable sheathing boards applied directly to studs, implying that the siding is placed over horizontal wood sheathing. Another example is the careful examination of the building paper for cases with stucco exterior. In some cases, the building paper would show tears or deteriorated areas where the underlying material attached directly to studs could be stucco (e.g., no sheathing) or some type of wood sheathing. In other cases, the line wires used as a backing material for the metal lath during stucco installation could be seen through the building paper, thus indicating that horizontal sheathing is not present between the exterior stucco and framing. It is expected that a large number of the unknown cases would be attributed to no sheathing being present since it is uncommon (but not impossible [Matteson 2019]) for building paper to be installed behind structural sheathing, as opposed to directly behind the exterior cladding layer (e.g., siding or stucco). In this review, the identification of sheathing condition only included those cases that could positively identify the presence or absence of sheathing.

The observed types of exterior sheathing materials for all cripple walls is shown in Figure 2.9 (numerical data provided in Table 2.10). The figure shows that 39% of cases had horizontal wood sheathing behind the exterior finish; this was consistent with Working Group 2's impression that this was the most common type of exterior sheathing in buildings in California for the construction era being studied [Reis 2020]. Yet, the number of "unknown" cases is also significant, comprising 36% of the cases. About 20% of the cases had no sheathing behind the exterior finish. Very few cases with diagonal sheathing were observed (< 2%, 9 out of 578 cases). The "Other" category of observed sheathing conditions included: (1) 15 cases of plywood; 2 cases of vertical tongue and groove; and 1 instance each of a combination of plywood and horizontal sheathing or plywood and diagonal sheathing.

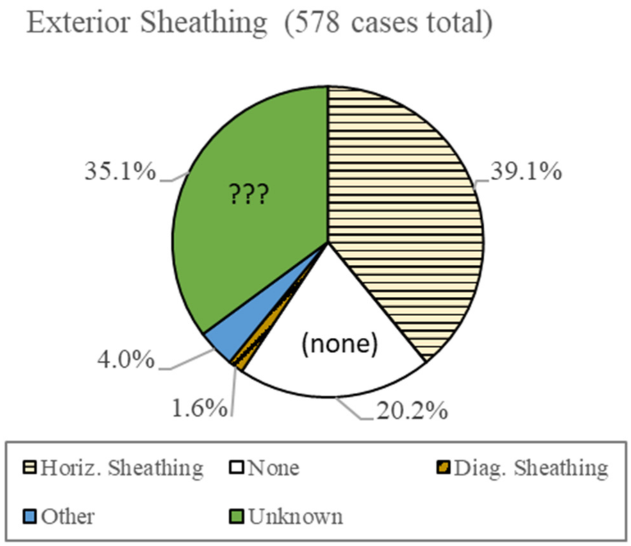


Figure 2.9 Distribution of observed exterior sheathing materials.

Table 2.10 Data for observed exterior sheathing materials.

Exterior sheathing	No. of observations	Percent of sample
Horizontal Sheathing	226	39.1%
None	117	20.2%
Diag. Sheathing	9	1.6%
Other	23	4.0%
Unknown	203	35.1%
Total	**578**	**100.0%**

More pertinent to the Working Group 2 building variant list is the actual combinations of exterior material with underlying sheathing. The "known" combinations of exterior material and sheathing are presented in Figure 2.10 (numerical data provided in Table 2.11). The two most commonly observed sheathing combinations are stucco with horizontal sheathing (52%) and stucco without sheathing (21%), followed by horizontal wood siding without (13%) and with (12%) sheathing. Very few cases with diagonal sheathing were observed, with only seven instances combined with stucco and none observed in combination with horizontal wood siding. Two other diagonal sheathing cases were observed in combination with either wood shake siding or brick veneer.

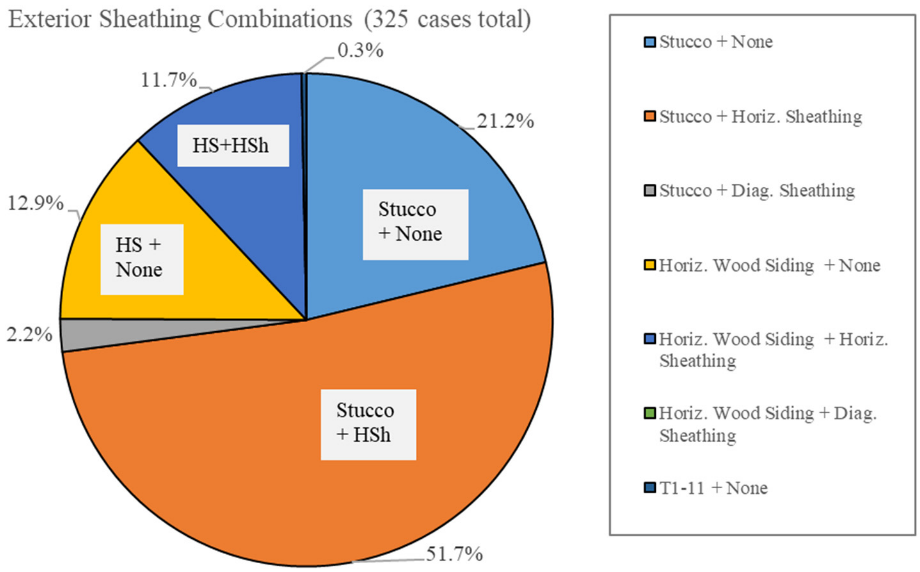


Figure 2.10 Distribution of observed exterior material and sheathing combinations.

Table 2.11 Data for observed exterior material and sheathing combinations.

Exterior combinations	No. of observations	Percent of Sample
Stucco + None	69	21.2%
Stucco + Horizontal Sheathing	168	51.7%
Stucco + Diagonal Sheathing	7	2.2%
Horizontal Wood Siding + None	42	12.9%
Horizontal Wood Siding + Horizontal Sheathing	38	11.7%
Horizontal Wood Siding + Diagonal Sheathing	0	0.0%
T1-11 + None	1	0.3%
Total	**325**	**100.0%**

2.3 OBSERVATIONS OF CRIPPLE WALL FRAMING BRACING FROM PHOTO REVIEW

The presence of wooden bracing within the framing of cripple walls is an important detail that can influence seismic response. In this regard, the bracing relates to the existing construction details, which is distinct from the wood structural panel (e.g., plywood) sections that are commonly used for bracing in seismic retrofitting. Initially, Working Group 2 did not originally consider variants regarding bracing, but it became obvious during the course of the Project that variants in bracing was key to better understanding of the likely strength ranges in existing cripple walls. The photographic review documents when various types of bracing were observed and have been classified into the following five categories:

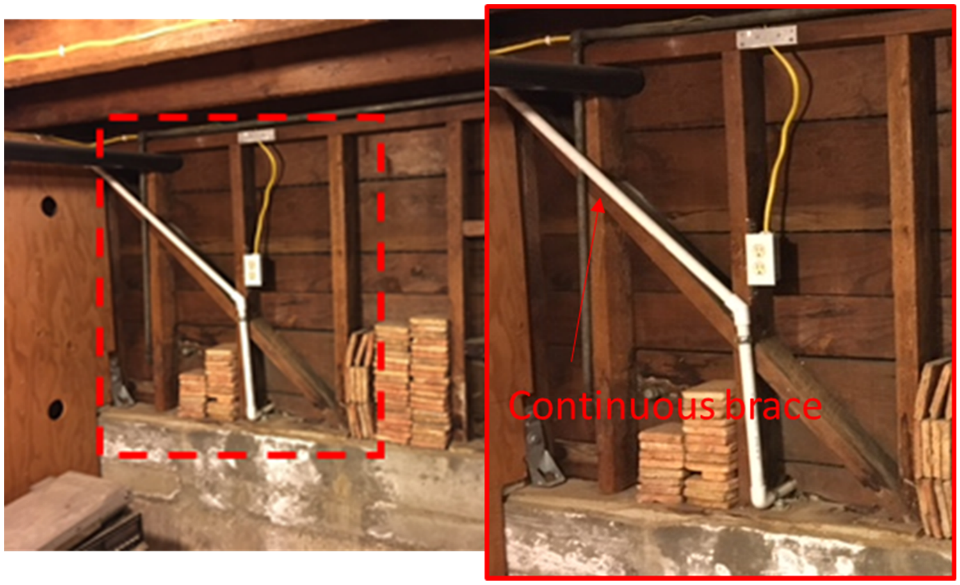
- Cut-in Bracing (CI) – Diagonal bracing between studs that are installed as individual pieces, commonly fastened to vertical studs by toe-nails. Short cripple walls have single-brace elements, and taller cripple walls have multiple-bracing pieces (see Figure 2.11);
- Continuous Braced Framing (BF) – Diagonal bracing element is continuous. Stud ends are cut at angles and toe-nailed to bracing elements to maintain vertical load path (Figure 2.12);
- Retained Block Bracing (RBB) – Bracing is "cut-in" between studs and supported in the compression direction by additional blocks face nailed to studs. Additional blocking to support vertical stud connections is commonly placed in stud bays adjacent to braced area (Figure 2.13);
- "Weak" Bracing (WB) – Bracing is only face-nailed to the studs. No axial loading of the brace elements possible (the only resistance is provided by face nail connections). Often used as temporary bracing used during construction (Figure 2.14(a); and
- Let-in Bracing (LIB) – Brace member is "let-in" to vertical studs in notches in studs (or brace and studs). Brace is typically placed on the exterior side of vertical framing prior to applying exterior sheathing or siding [Figure 2.14(b)].

Example photographs for each bracing type are provided in Figure 2.11 through Figure 2.14.

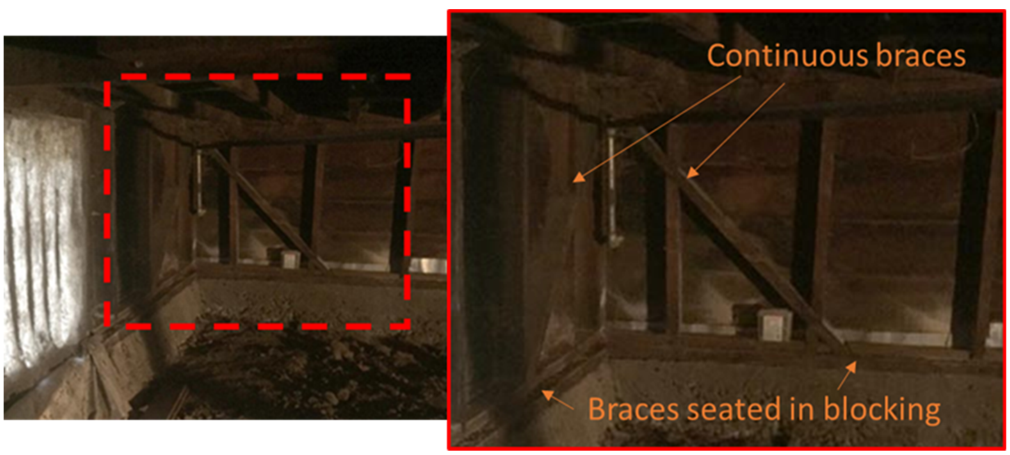
(a)

(b)

Figure 2.11 Example photographs of cut-in bracing: (a) cut-in bracing (multiple pieces); and (b) cut-in bracing (single piece).



(a)



(b)

Figure 2.12 Example photographs of continuous braced framing: (a) continuous-braced framing example dwelling 1; and (b) continuous braced framing example dwelling 2.

(a)

(b)

Figure 2.13 Example photographs of retained block bracing: (a) retained block bracing example dwelling; and (b) retained block bracing example dwelling 2.

(a)

(b)

Figure 2.14 (a) Example photographs of "weak" bracing; and (b) let-in bracing.

Among the 578 cases with cripple walls, 197 cases (34%) were observed to have bracing. Note that this does not necessarily imply that the remaining 66% did not have bracing since it may have been present in the houses, but there was no photographic evidence of interior cripple walls. A summary of the bracing observations is provided in Figure 2.15 with data summarized in Table 2.12. The most observed type of cripple wall framing braces were cut-in braces, comprising 61% of all observed cases. The next most common case was the continuous braced framing with a total of 37 out of 197 cases (19% of sample). Similarly, the "weak" bracing cases were observed in 32 out of 197 (16% of sample). The retained block bracing detail was only observed in six cases (3% of sample), and there was a single observation of let-in bracing.

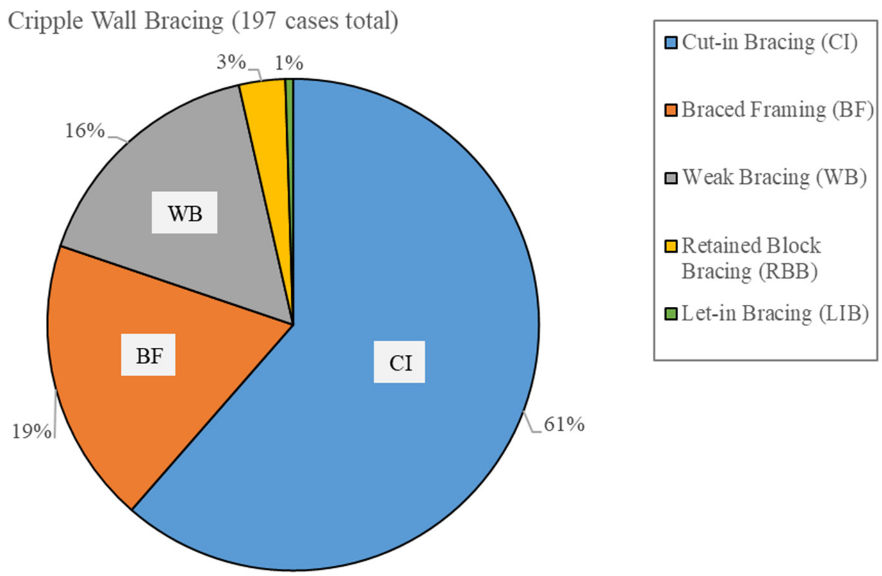


Figure 2.15 Different types of framing braces observed for cripple wall dwellings.

Table 2.12 Data for cripple wall braces observed in framing.

Cripple wall classification	No. of observations	Percent of sample
Cut-in Bracing (CI)	121	61.4%
Braced Framing (BF)	37	18.8%
Weak Bracing (WB)	32	16.2%
Retained Block Bracing (RBB)	6	3.0%
Let-in Bracing (LIB)	1	0.5%
Total	**197**	**100.0%**

REFERENCES

Bhattacharjee G. (2017). *Summary of Single-Family Home Information from CoreLogic® Tax Roll Database*, Unpublished summary report working in collaboration with PEER-CEA Working Group 2, Stanford University, Stanford, CA.

EBB [2019] "Earthquake Brace + Bolt Program: Rules for Participation," Earthquake Brace + Bolt – Funds to Strengthen Your Foundation, October 30, 2019, *www.earthquakebracebolt.com/Content/ProgramRules*, California Earthquake Authority, Sacramento, CA.

FEMA (2015). *Performance of Buildings and Nonstructural Components in the 2014 South Napa Earthquake*, *FEMA P-1024*, Prepared by the Applied Technology Council for the Federal Emergency Management Agency, Washington, DC.

HUD (1994). *Assessment of Damage to Residential Buildings Caused by the Northridge Earthquake*, U.S. Department of Housing and Urban Development, *http://www.aresconsulting.biz/publications*.

ICC (2016). *2016 California Existing Building Code*, California Building Standards Commission, International Code Council, Washington, D.C.

Matteson T. (2019). Discussion of older wood-frame construction practices, *Personal Communication*, April 8, 2019.

Rabinovici S., Ofodire N. (2017). *California Earthquake Authority South Napa Home Impact Study: Phases I and II Integrated Findings Report*," California Earthquake Authority, Sacramento, CA.

Reis E. (2020). Development of Index Buildings, A Report for the "Quantifying the Performance of Retrofit of Cripple Walls and Sill Anchorage in Single-Family Wood-Frame Buildings" Project, *PEER Report*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA.