



Structural Seismic Retrofits For Hawaii Single Family Residences With Post and Pier Foundations

Volume I

**Results of Study, Structural Analysis
and Retrofit Strategies**

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Executive Summary

The local seismic hazard in parts of the State of Hawaii is similar to that near the most active faults in the United States. The magnitude 6.7 and 6.0 earthquakes on October 15, 2006 resulted in considerable damage throughout the southeastern Hawaiian Islands. Houses with a “post and pier” style of foundation system were found to be particularly vulnerable, with observed damage that included: movement of piers, sliding or unseating of posts relative to piers, failure of braces and failure of plumbing or other services. Without widespread retrofit of these types of houses, the extent of damage is likely to be considerably greater after an earthquake generating larger levels of ground motion.

A survey of 53 post and pier houses on the island of Hawaii was performed to determine the typical structural characteristics and variations in structural properties of these houses in the most vulnerable areas. The survey also investigated the extent of damage of these homes during the 2006 earthquakes along with any attempts to retrofit the houses at the time of survey. Based on this survey, a number of prototypical models of post and pier houses were analyzed for different levels of ground motion. A number of aspects of the houses were found to require retrofitting for even moderate levels of ground motion.

From the analysis, three retrofit options were developed, with the applicability of each retrofit based on the location of the house and its structural properties. The retrofits are presented in a general format that can be applied to a wide range of houses without specific input from a structural engineer, except in special cases. General notes and details applicable to all retrofit options are provided in Appendix 1 in Drawing 0. Retrofit Option 1 is primarily a strengthening of connections using the existing post and pier foundation system, applicable in regions of low to moderate seismic hazard and for houses with moderate differential post heights. Details of this retrofit option are summarized in Appendix 1 in Drawing 1. Retrofit Option 2 uses additional plywood shear walls between the ground and first floor of a house to provide additional lateral strength and stiffness to the foundation system. This retrofit is applicable in all regions with most combinations of differential post height and other structural properties, with details provided in Appendix 1 in Drawings 2A and 2B. Retrofit Option 3 uses masonry shear walls to provide additional lateral strength and stiffness. This option, shown in Appendix 1 on Drawings 3A and 3B is applicable for any post and pier house, although in some extreme cases a structural engineer would need to be consulted if the properties of the house fall outside the range of properties considered in this report. An example of how to apply the different retrofit options is provided in Section IV of this report.

Appendix 2 provides statistical representations of key properties for the different houses surveyed. The basis for the structural analysis of prototypical houses is provided in Appendix 3. A summary of dimensional, structural and other properties of each of the surveyed houses is provided through plans, sections and selected photos in Appendix 4, in Volume II of this report.

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1. Seismic Hazard in the State of Hawaii

The seismic hazard and earthquake occurrence rates in Hawaii are locally as high as that near the most hazardous faults elsewhere in the United States (Klein et al, 2001; Chock and Sgambelluri, 2005). The highest hazard is on the south side of the island of Hawaii, where a number of magnitude 7.0 or greater earthquakes have been experienced since 1868.

Figure 1-1 is a representation of a number of major earthquakes that have occurred around the Island of Hawaii (relative ground shaking intensity for each) (RMS, 2006). Although the seismic hazard for the other Hawaiian Islands is less than for Hawaii, earthquakes have occurred in proximity to these other islands as shown in Figure 1-2.

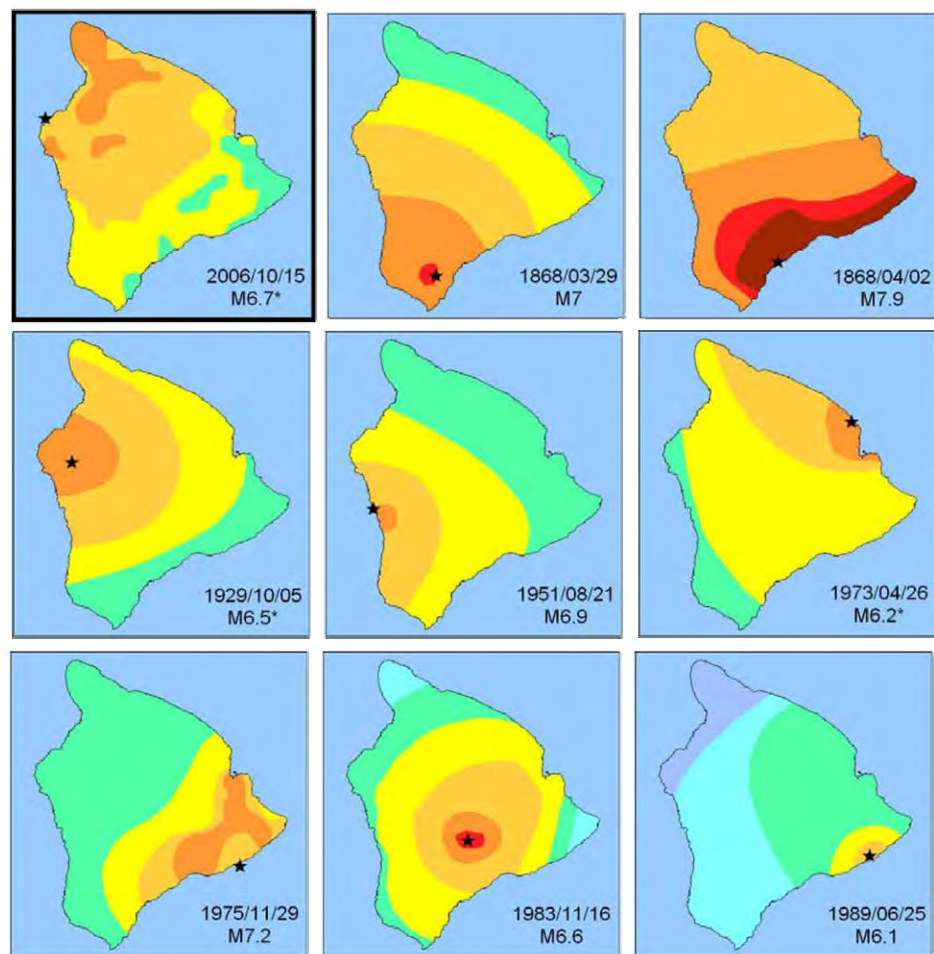


Figure 1-1. Past major seismic events around the island of Hawaii and relative ground shaking intensity (RMS, 2006, Updated from Wyss and Koyanagi, 1992 with the use of 2006 USGS Shakemap data for the Kiholo Bay earthquake)

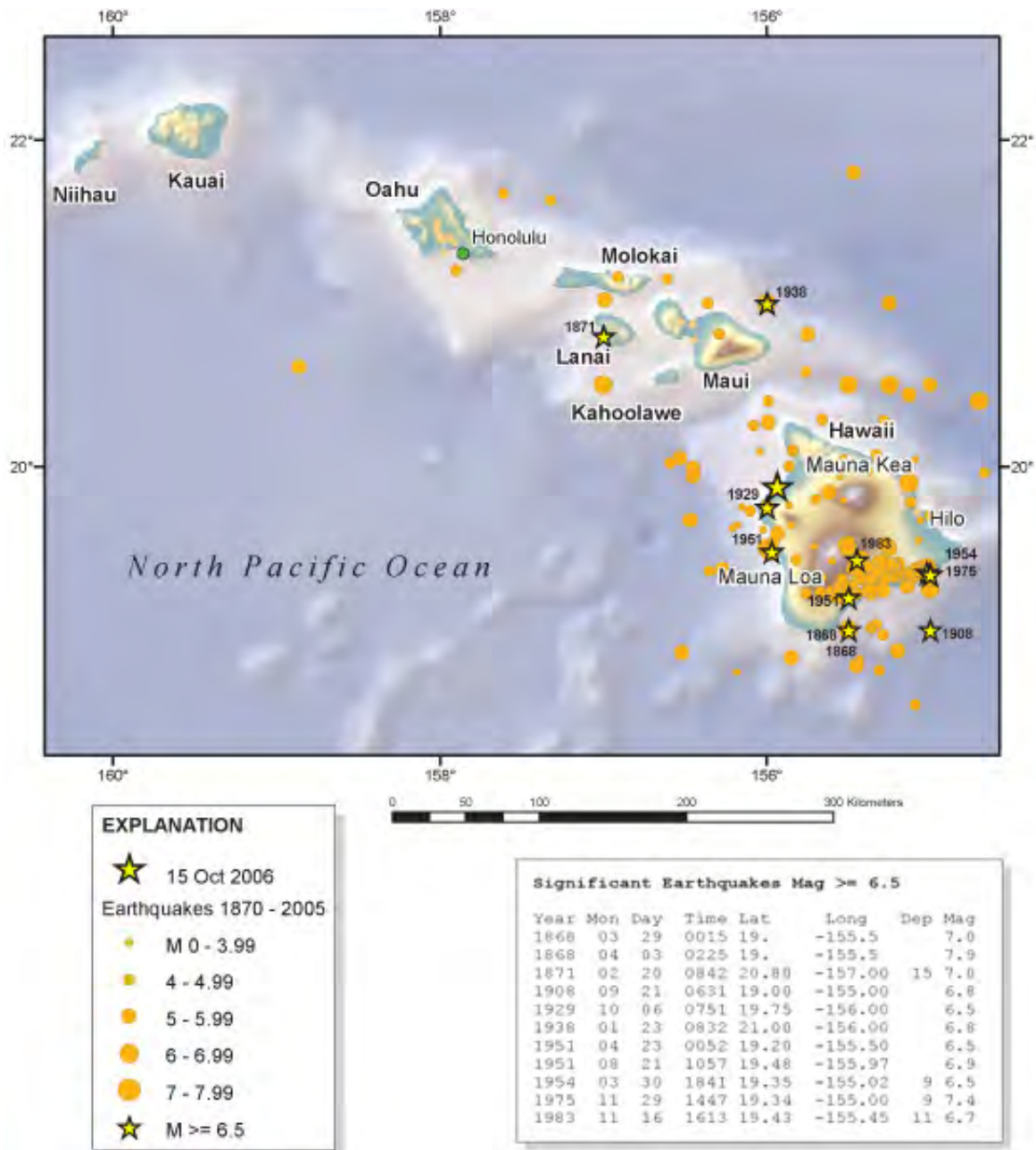


Figure 1-2. Historic earthquakes in the State of Hawaii (USGS website)

Based on the probabilities derived from historic data, the seismic hazard throughout the state, as reflected in the current building code, is represented in Figure 1-3. The design short period spectral acceleration response ranges from a maximum of 267%g at the south end of the big island to under 20%g for areas of Kauai, with a range of values in locations between these two extremes. There is a similar spread of values for the 1.0 second design spectral acceleration response.

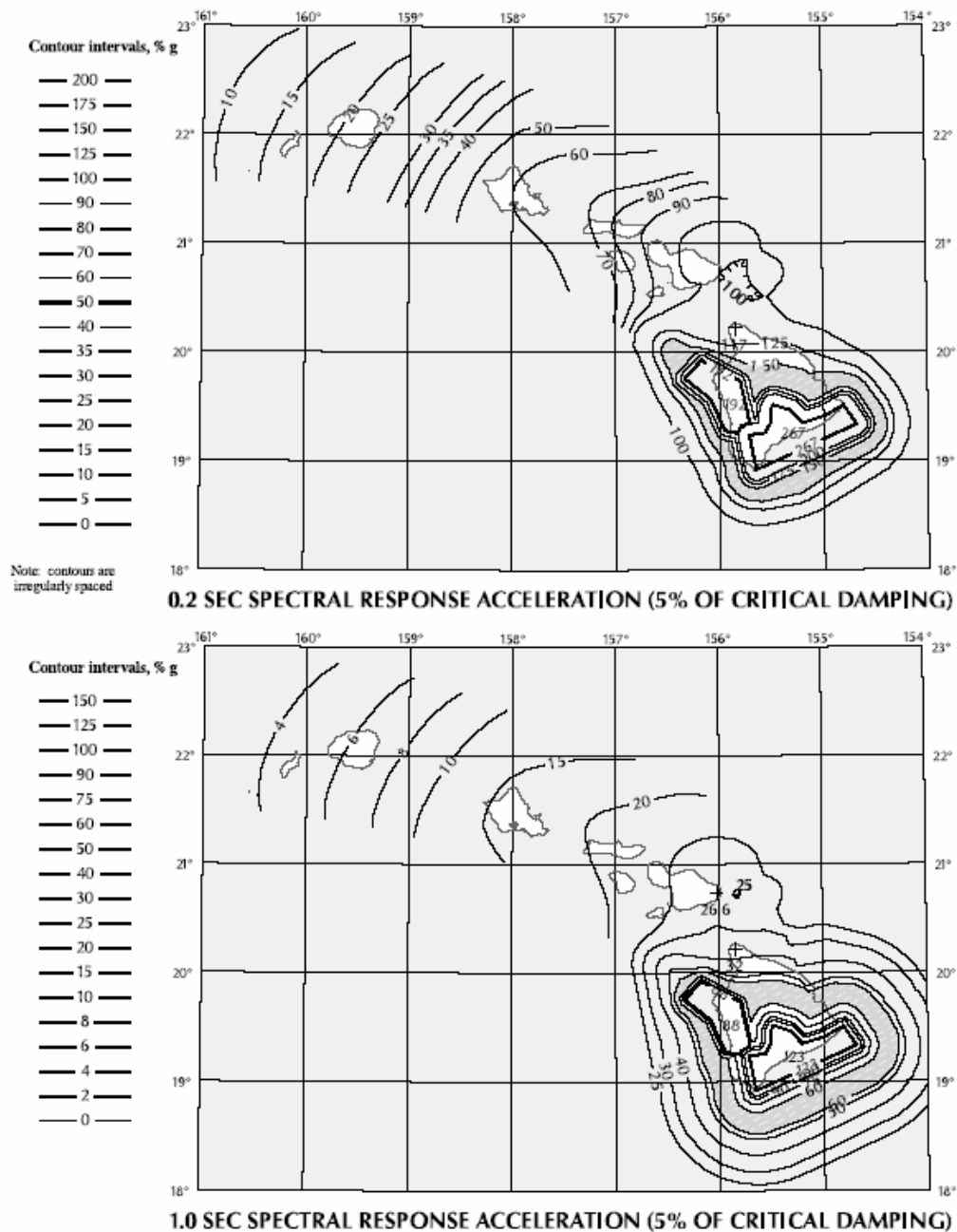


Figure 1-3. Maximum considered earthquake ground motion for the State of Hawaii of 0.2 and 1.0 second spectral accelerations (5% damping, Site Class B) (ASCE, 2005)

The most recent major earthquakes in the State of Hawaii were the Magnitude 6.7 Kiholo Bay and Magnitude 6.0 Mahukona earthquakes that occurred on October 15, 2006 at 7:07am and 7:14 am respectively (Robertson et al, 2006; EERI, 2006; EERI et al, 2006). Both earthquakes were centered near the Kona coastline of Hawaii. A map of ground shaking intensity for the island is shown in

Figure 1-4 (Adapted from USGS Shakemap downloads). The maps show that largest ground shaking for this earthquake was at the northern end of the island, but did not directly coincide with the epicenter of the earthquake. The largest ground motions were recorded at the towns of Waimea and Hawi. These areas had amplified ground motion due to softer soil conditions at these locations. A map of the buildings that were inspected and tagged immediately following the two earthquakes is shown in Figure 1-5; with a yellow tag limiting occupancy of parts of the structure, or a red tag requiring that the structure be unoccupied until repairs are completed. The map shows that the most heavily damaged buildings were concentrated in the Waimea and Hawi areas with some damage also in the Honokaa and Kona areas. There was very little damage at the south end of the island even though, historically, it is more seismically active than the north end of the island.

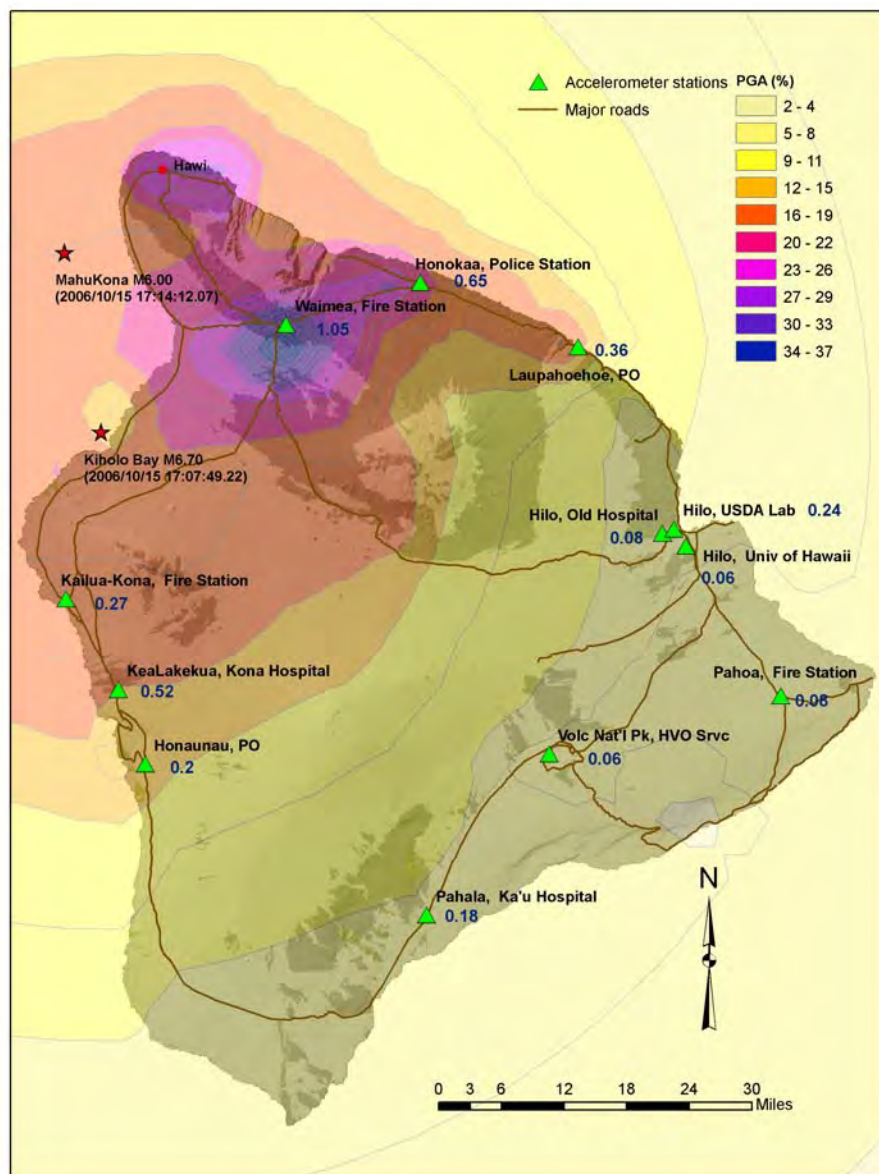


Figure 1-4. Ground shaking intensity during the October 15, 2006 Hawaii Earthquakes

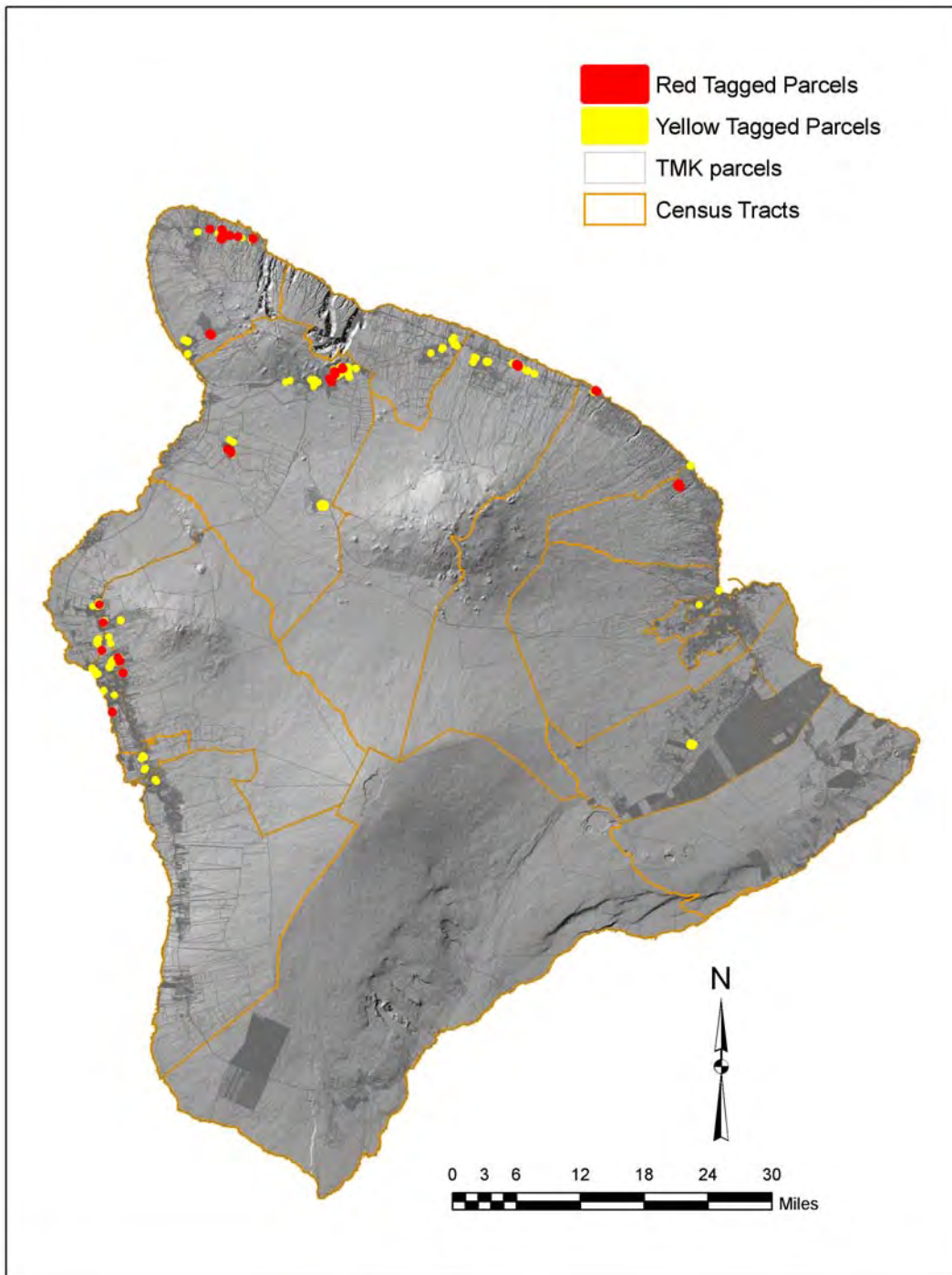


Figure 1-5. Map of inspected buildings with red or yellow tags following the October 15, 2006 earthquakes

2. Post and Pier Residences in Hawaii

2.1 Background

Historically a large percentage of single family residences in the state of Hawaii were constructed using the “post and pier” style of construction. In this type of house the first floor of the house is typically elevated by 2-3 feet above grade, or greater, as necessary to accommodate sloping sites. The elevated first floor is typically constructed with wood girders and joists overlaid with plywood or wood decking. The floor framing is supported by wood posts, typically 4x4, supported on precast concrete foundation blocks. There are usually a pair of concrete blocks with the posts bearing upon a smaller 7 x 7 x 4 inch concrete block that sits on a larger 16 x 16 x 6 inch concrete footing. The posts are typically braced with 2x4 bracing oriented at 45 degrees and toenailed to the post and girder or joists. The height above the base of the post at which the braces connect to the posts tends to vary between houses. A typical post and pier foundation system is shown in Figure 2-1.



Figure 2-1. Typical post and pier foundation

The walls of a post and pier house may be either single wall or conventional stud walls. Cross sections through typical one-story houses with both single wall and stud walls are shown in Figure 2-2. In single wall houses the walls consist of $\frac{3}{4}$ " to $1\frac{1}{8}$ " thick tongue and groove wood planks oriented vertically that form the entire thickness of the walls. At the top of the walls there are typically a single or double horizontal wood “plates” connecting the vertical wall planks together and also used for bearing of the roof trusses or rafters. At the base of the walls the planks are typically nailed to the side of the rim joists. There are typically horizontal girts around the mid-height of the wall providing additional connectivity between the vertical planks. In some cases there are additional 4x4 or similar posts at the corners and other intermediate locations along the length of the walls. The single walls are load bearing, supporting gravity

loads from the roof trusses or rafters as well as providing lateral shear resistance. The single walls were the most common method of construction for single family residences in Hawaii until around the mid 1970's when stud wall construction became more common. The roofs are typically constructed from wood trusses or wood rafters. The roofs are commonly sheathed in corrugated metal or wood planks with asphalt shingles.

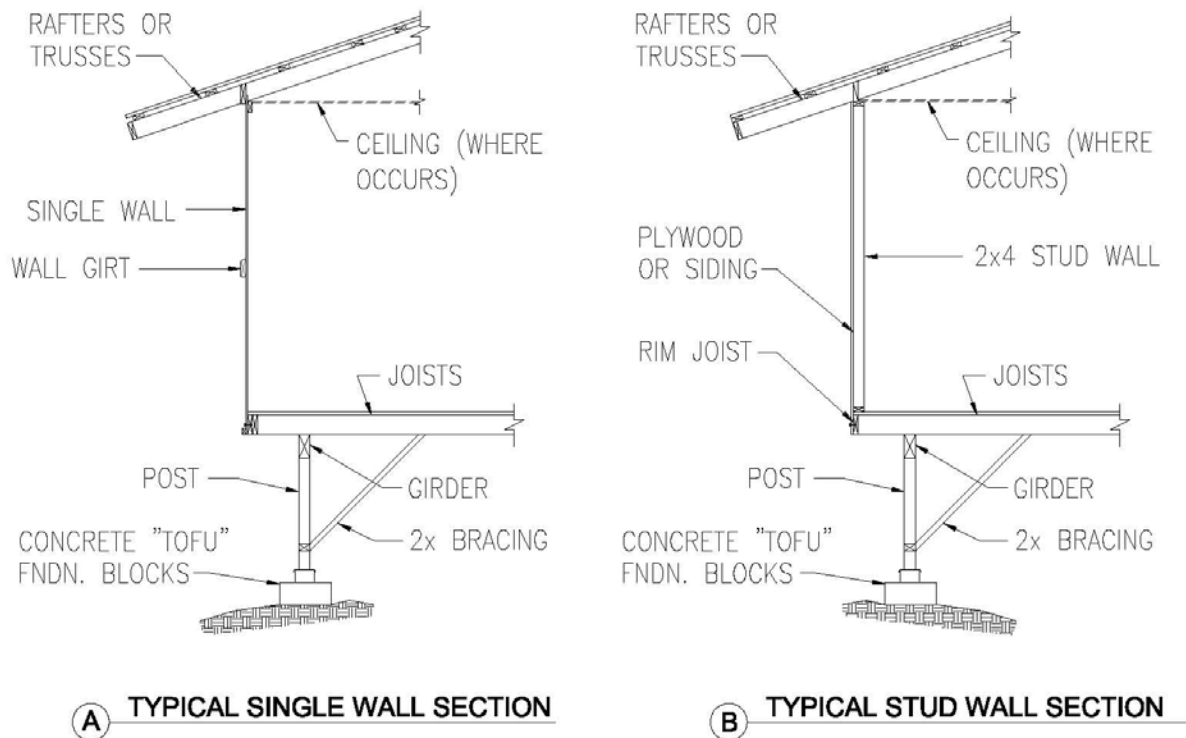


Figure 2-2. Cross sections through typical single story residences with a) single walls and b) stud walls

2.2 Seismic Vulnerabilities of Post and Pier Residences

The foundation blocks are typically seated on top of the ground surface with little or no embedment into the ground and sometimes on fill material that may not be firmly compacted. This creates a potential for sliding or toppling of the foundation blocks. This potential is exacerbated when the ground surface is sloping or irregular in nature resulting in the unstable positioning of some foundation blocks, such as that shown in Figure 2-3.



Figure 2-3. Undermined pier due to unstable soil conditions

The posts are not typically connected to either the small or large block, therefore the only resistance to sliding of the posts is the friction between the posts and the foundation blocks. This provides minimal resistance and consequently these houses have a tendency to slide off their foundations in the event of an earthquake as shown, for example, in Figure 2-4, Figure 2-5 and Figure 2-6. A sheet metal “termite barrier” is often located between the post and the upper foundation block in an attempt to prevent ground termite access to the underside of the post. This is expected to further reduce the frictional resistance between the post and foundation blocks.



Figure 2-4. Lack of post anchorage resulting in sliding of post and toppling of foundation blocks



Figure 2-5. Lack of post anchorage resulting in walking and splitting of post as it unseats from foundation blocks



Figure 2-6. Lack of post anchorage resulting in unseating and lateral displacement of posts

Braces from the posts to the girders or joists provide lateral stability to the posts and increase the stiffness of the structure. The connections of these braces, however, are usually inadequate to resist significant earthquake forces. Typically only two toenails are provided at all brace connections. These toenails have a tendency to pull out, as shown in Figure 2-7, yielding the braces ineffective for their intended purpose. Ineffective braces lead to excessive deformations and potential instabilities in the posts.



Figure 2-7. Nail pullout failure of a post brace

Bending stresses occur in a structural member when forces apply curvature to the member. The posts in a post and pier house have a finite strength to resist bending stresses. Although it is not common for posts to fail in bending before some other failure mode is observed, the susceptibility of a post to flexural failure is dependent on its unbraced length. If the braces are connected too high up the post, then the potential for flexural failure in the unbraced lower portion of the post increases. If some of the posts are taller than other posts, as is typical on a sloping site, then the differential in post height can result in torsional deformation of the structure and increased stresses and deformations in the posts. Shear stresses also occur in the posts. Very short posts may be limited by shear failure, although normally connections govern the shear strength and not the strength of the post itself. There are often only toenails between the top of the post and the girders. The lack of adequate connections, when post cap connection plates are absent, can result in the girders unseating from the top of the posts, particularly if there is a butt joint in the girder at the post location.

Houses framed with single walls are typically more vulnerable than houses framed with stud walls and sheathed with plywood. Other types of siding, such as horizontal boards are less effective than plywood for resisting lateral loads in stud wall houses, although with most types of siding, stud walls are generally stronger than single walls. During previous earthquakes racking deformation was observed in single wall houses, although the observed damage to the walls was much less severe than observed damage to the foundation system of post and pier houses.

The vulnerability of a house is also dependent on its location due to the different levels of seismic hazard at different locations. As discussed earlier, properties on the Island of Hawaii are at the greatest risk, followed by Maui, Molokai and Lanai then Oahu and Kauai, based on the relative seismic hazard shown in Figure 1-3.

2.3 Relative Severity of Hurricane and Seismic Loading

Until recently, most Hawaii single family houses were not built with adequate protection against hurricane force winds or seismic ground motions. In general, for single family houses on the northwest Hawaiian Islands of Oahu and Kauai, the lateral loads on the structural system for building code design wind loads are greater than the seismic design forces. For the Islands of Maui, Molokai, and Lanai, the overall wind and seismic building code lateral design forces on the structure are roughly equal, while on the Island of Hawaii the seismic forces will typically govern the structural load on the foundation system.

The predominant action on a building during an earthquake is lateral loading, with cyclic forces acting sideways on a building. During a hurricane forces also act sideways on a building, therefore any seismic retrofit will be beneficial during a hurricane. However, during a hurricane there are also significant vertical uplift loads on a structure. Therefore in addition to the retrofits for lateral loads, vertical retrofits will also be required for wind hazards. Often a retrofit for lateral loads, such as anchorage of the foundation posts, will also be effective for resisting vertical loads. However, other requirements may be necessary for resisting hurricane forces, such as anchorage of the roof trusses to resist uplift. For a full description of retrofits of single family houses in Hawaii for hurricane wind loads refer to the State of Hawaii Department of Commerce and Consumer Affairs, Loss Mitigation Grant Program - Wind Resistive Devices Technical Specifications (DCCA, 2007). (Although the 2008 Legislature did not re-authorize appropriation for the awarding of grants to homeowners who install these retrofits, the work is still justified by the potential benefits of loss reduction.)

3. Survey of Houses in Hawaii County

In order to study the typical properties and variations of structural parameters for post and pier houses in Hawaii, homeowners of post and pier houses were asked to complete a questionnaire. There were 172 respondents from which basic information on their houses were collected. Of these respondents, 53 physical surveys were selected and completed by structural engineers from the University of Hawaii and Martin & Chock, Inc. From these surveys, a range of dimensional, structural and other properties of the houses was collected, including: observed damage and ATC-20 tag given following the Kiholo Bay Earthquake; cost of repairs; FEMA assistance provided; floor area; number of stories; lot topography; post size, height, spacing, bracing, and connections; floor girder size, joist size and connections; floor diaphragm type; wall construction; roof framing, geometry, and connections; physical condition; and, any other observed vulnerabilities.

Statistical representations of key properties for the different houses surveyed are provided in Appendix 2. A plan, typical section and raw data sheets and selected photos for each of the houses is provided in Volume II of this report.

4. Retrofit Options for Post and Pier Houses

Prototypical houses, with properties that represent the typical range of properties observed during the surveys, were developed and a structural analysis was performed on each house in accordance with the 2006 International Building Code (ICC, 2006-1) using loads reduced by 25% as permitted by the 2006 International Existing Building Code (ICC, 2006-2) using ground motion with an average probability of exceedance of 10% in 50 years. Further details of the structural analysis and properties of the prototypical structures are provided in Appendix 3.

Results from the structural analyses showed that all typical post and pier houses in the State of Hawaii would benefit from some level of retrofit in the foundations. There are three basic options considered, which are:

1. Retrofit of the existing posts, piers and braces.
2. Addition of plywood sheathed shear walls between the ground and first floor.
3. Addition of masonry shear walls between the ground and first floor.

The applicability of each retrofit option and details of the retrofit depend on the site location, size and plan geometry of the house and slope of the site under the house. The details of the three retrofit options are discussed separately in the following sections. Drawing sheets for each retrofit are provided in Appendix 1, intended for use by homeowners to provide details to contractors, and the building department if required, for implementation of their chosen retrofit strategy at their home. An example showing how to choose between the three retrofit options is provided at the end of the section. A discussion of each of the retrofit strategies is provided in Sections 5, 6 and 7 respectively.

For the purposes of this report, areas within the State of Hawaii with a similar seismic hazard level are grouped into 5 regions given in Figure 4-1. The choice of retrofit strategy for a particular house is dependent on the region within which the house is located.

The design strength and intended corrosion resistance of all retrofit options is based upon the use of the following materials:

- *Concrete* - Compressive Strength, $F_c' = 4,000$ psi or greater.
- *Wood* - No. 1 grade Douglas Fir (or better), pressure preservative treated for exterior exposure.
- *Simpson Connectors* – Stainless steel in highly corrosive environments (close to the shoreline), Z-max triple zinc coated galvanized when exposed to weather and not stainless steel, hot dipped galvanized elsewhere.
- *Nails and Bolts* - Stainless steel when stainless steel connectors are used, galvanized in all other applications.
- *Masonry* - A.S.T.M. C 90 grade N-II concrete masonry units, normal weight, Type S mortar with a minimum compressive strength, $F_c' = 1,900$ psi.

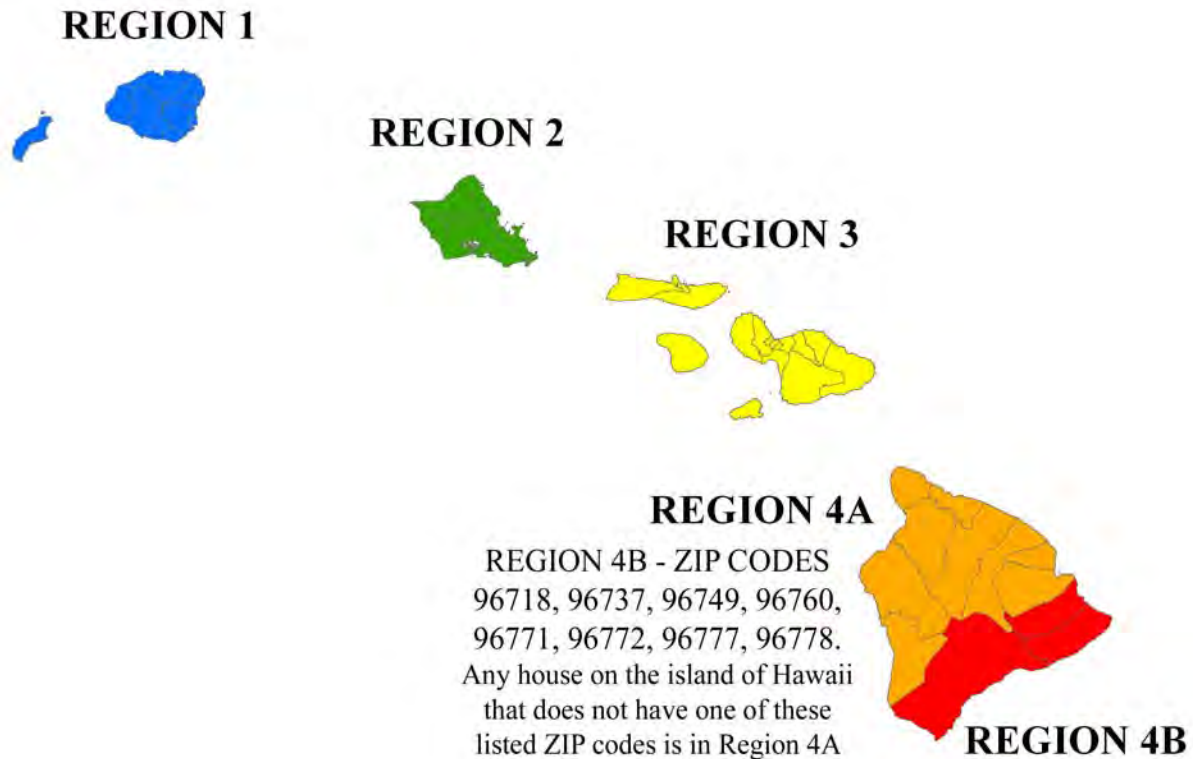


Figure 4-1. Earthquake vulnerability regions

It is important to note that the objective of the retrofits is to minimize the type of damage to a house that has a potential impact on the life safety of the occupants. Collapse of a post and pier foundation system has a high risk of serious injury to occupants and therefore retrofits to the posts and piers are of greatest importance. Minimal damage was observed in single wall houses founded on concrete slabs during the October 2006 earthquakes, despite the lack of conventional structural panel sheathed shear walls in single wall post and pier houses. The ground accelerations during these 2006 earthquakes, were less than the maximum possible accelerations and larger accelerations are expected to result in more damage in future events. However, where damage may occur in the single wall boards, there is a significantly lower probability that such damage will impact live safety compared to a failure of the post and pier foundation system. Consequently, this document does not provide recommendations for the retrofit of the walls and roofs of a post and pier house above those recommended for resisting hurricanes based on the Wind Resistive Devices Technical Specifications (DCCA, 2007). Homeowners may consult a structural engineer if they believe their single wall house is more vulnerable or if they prefer to provide additional retrofits to walls and roofs in order to achieve a higher total level of performance during an earthquake.

The focus of this report is on the frequently occupied portion of the residence. If a carport or garage is attached to the main structure, then the foundation should be retrofitted as applicable,

and the attachment should be robust enough to prevent separation of the carport or garage from the building. If the carport is detached then no retrofit is necessary, although it may be expected that the carport will suffer significant damage during an earthquake.

The retrofits recommended assume that the house has been properly maintained and is in a sound structural condition. For example, there should be no portions of exterior walls or roof in serious disrepair, missing areas of sheathing, structural supports or walls overstressed or bowed, missing wall sections or roof framing, or major cracking of any masonry walls. There should be no unrepaired structural damage due to termite, dry-rot, or wind, fire, or water damage.

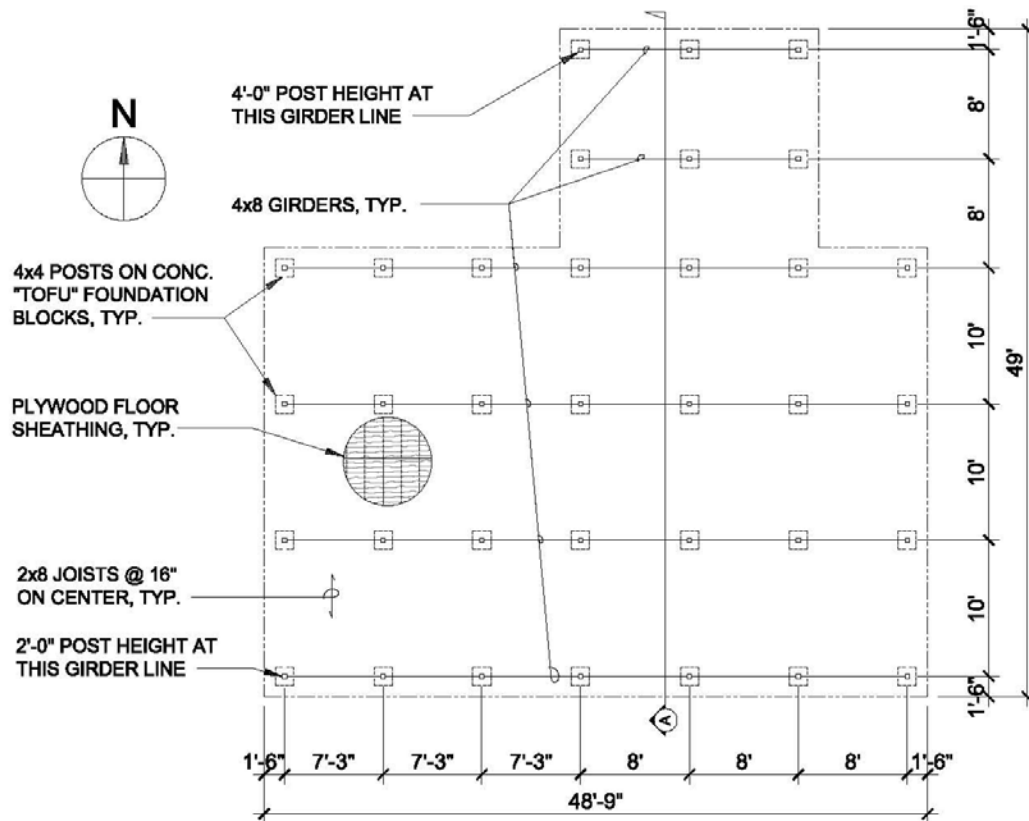
This guide indicates the use of certain types of metal connectors, straps, and ties by reference to the “Simpson” (The Simpson Strong-Tie[®] Company) trade name for the product. This is done primarily due to convenience for this publication and availability of the products. Other manufacturers produce similar products that may be used if they have equivalent allowable load value ratings in accordance with 2006 International Building Code and ASTM D1761 accepted testing procedures. The allowable load values are given in the manufacturer’s product catalogs. In general, the allowable load of a connector is the lesser of: the ultimate test load divided by a safety factor of 3; the test load at 1/8” deflection; or, the calculated capacity of the steel plates and the fasteners. If the test load governs, no increase is permitted, but if the calculation limit governs, one may increase the load by 1.6 when the connector is used to resist wind and seismic loads to allow for the short load duration. Generally it is recommended that a nail should have a distance of at least 2.5 times its diameter to the edge of wood and 10 times its diameter when the nail is loaded parallel to the grain. It is recommended to pre-drill if the nail connection would split the wood. For Douglas Fir-Larch wood members, the pre-drilled hole is not to exceed 75% of the nail diameter.

The homeowner should consult the building department for local rules and regulations to determine if a building permit is required. Some local jurisdictions allow minor voluntary improvements to a house that do not negatively impact code conformance, without any other alterations or additions, without a building permit provided that the work is performed by a contractor licensed to perform the type of work and that the value of the work is under a prescribed limit. These retrofits should not be considered alterations or additions to a house as they are being performed to remedy a preexisting structural deficiency of the house that was not addressed in the code at the original time of construction. Except in special circumstances the retrofits will probably not require specialty electrical or plumbing contractors.

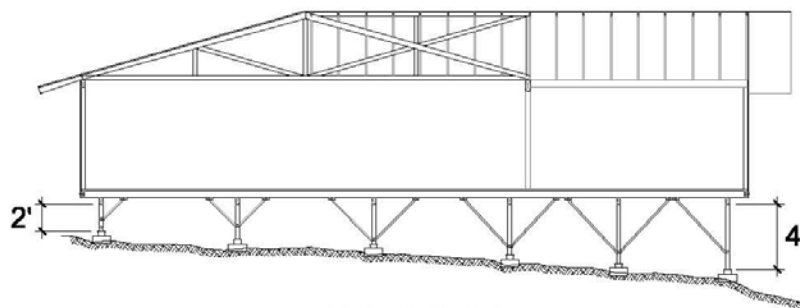
A homeowner may also choose to obtain a permit in order to have the building department provide an inspection and ensure that the work was performed acceptably. The drawings described in the follow sections are intended for use in documenting the chosen retrofit for the contractors’ use and for building permit application purposes.

Example – Choosing an Appropriate Retrofit Option for Your House

Consider the single story house with the floor foundation plan as shown below. The house is located in the Kailua-Kona area. This example presents possible retrofit options for this house based on the drawings in Appendix 1 and the descriptions provided in Sections 5 – 7.



FOUNDATION PLAN



SECTION "A"

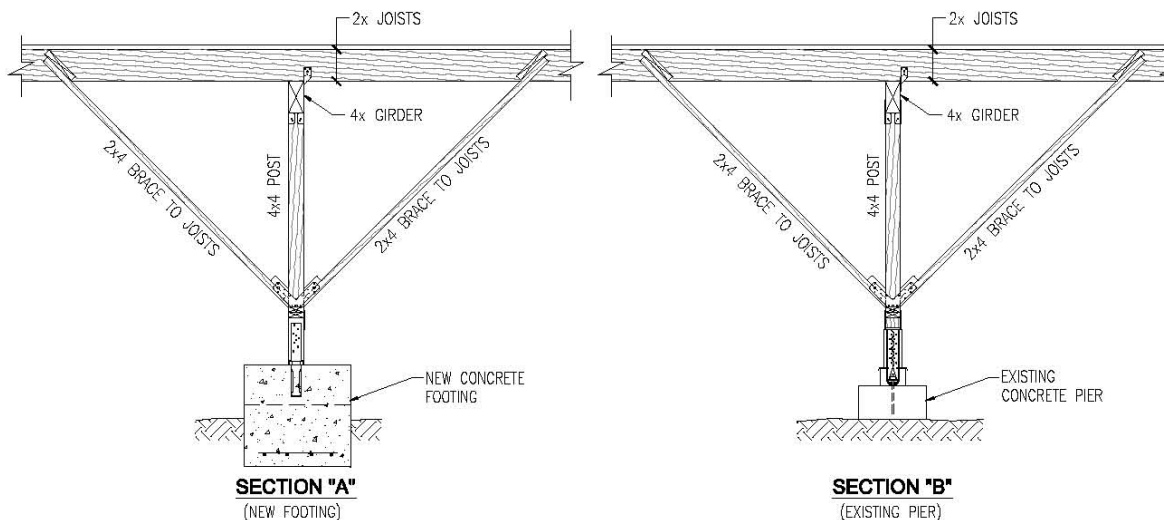
- Based on the map of seismic hazard regions on Drawing Sheet 1, the house is located in Region 4a.
- Maximum and minimum post height:
 - Maximum post height = 4.0 ft
 - Minimum post height = 2.0 ft
 - Max/Min ratio = $4.0/2.0 = 2.0$

Example – Choosing an Appropriate Retrofit Option for Your House

Retrofit Option 1

Retrofit Option 1 is first considered based on Drawing Sheet 1. From the retrofit level selection table this retrofit option is applicable with exterior and interior post retrofit levels equal to A,A. Consequently, according to the schedule associated with the retrofit selection table every exterior post must be retrofitted and every interior post must be retrofitted. The typical retrofit configuration for each post is shown in Detail 3. The steps in the retrofit are as follows:

- The concrete piers for the row of longest (4 ft) posts are considered to be unstable due to the change in slope on the down slope side of this row of posts. Therefore, it is deemed necessary to replace the piers along this row with new footings according to Detail 4 and as shown in the Section A below. The post is anchored to the new footing with a Simpson CBSQ44 column base. This house is some distance from the coast and not considered to be located in a severely corrosive environment therefore galvanized connectors and fasteners are used (if the house was located near to the coastline or in another severe environment, stainless steel connectors and fasteners should be selected).
- Other piers are considered stable therefore the posts are anchored to these piers with a pier of Simpson HTT5 connectors according to Detail 5 and Section B below.

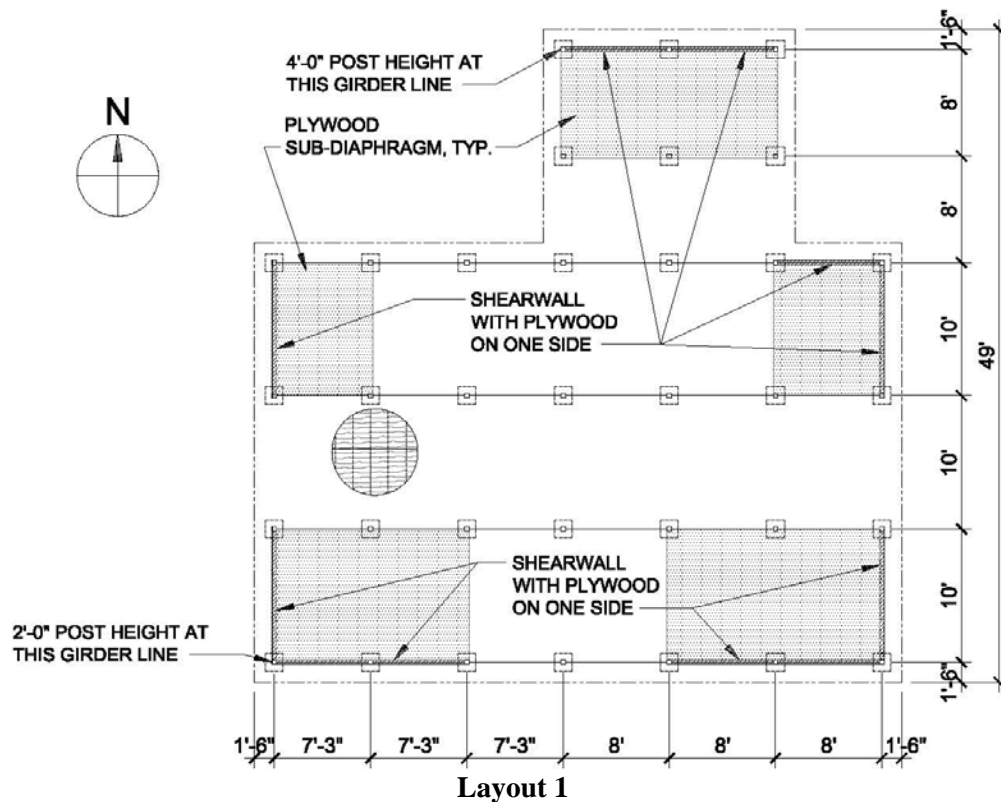


- A pair of Simpson AC4 connectors is added to connect each post to the girder above according to Detail 6.
- A Simpson H10A is installed between each joist and girder according to Detail 6 and the joist clip schedule.
- Simpson 88L angle straps are added each side of the post to connect the braces where braces extend in both directions as shown in Detail 7. At exterior posts, where braces extend in one direction only, HRS12 straps are used.
- Simpson HRS12 straps are added between the brace and girders according to detail 7. Blocking and/or straps are added to connect the braces to joists according to Detail 7.

Example – Choosing an Appropriate Retrofit Option for Your House

Retrofit Option 2

As an alternative to Retrofit Option 1, Retrofit Option 2 is considered based on Drawing Sheets 2A and 2B. The total floor area of the house is 1913 square feet. From the retrofit level selection table the retrofit levels are C, B, B, for 8, 10 or 12 ft. long wall segments respectively. Therefore a level C retrofit is required for 8 ft. long wall segments and a level B retrofit for 10 ft. and 12 ft. segments. A possible retrofit layout is shown below:



Note that there are many possible shear wall layouts for this house (as with most houses), and although several may provide sufficient strength, some may be better than others. Ideally the shear walls should be placed near the corners of the home to distribute their resistance equally throughout the structure. Layout 1 utilizes 2 -10 ft. long minimum, shear walls on each side of the house with plywood sheathing on the outside of the walls. As the post spacing is less than 10 ft in the east-west direction, the shear walls must extend over an additional bay in this direction. At the north side of the house there are two wall segments, one 16 ft. segment and one 8 ft. segment which combine for a total length of walls along this side of greater than $2 \times 10 = 20$ ft.

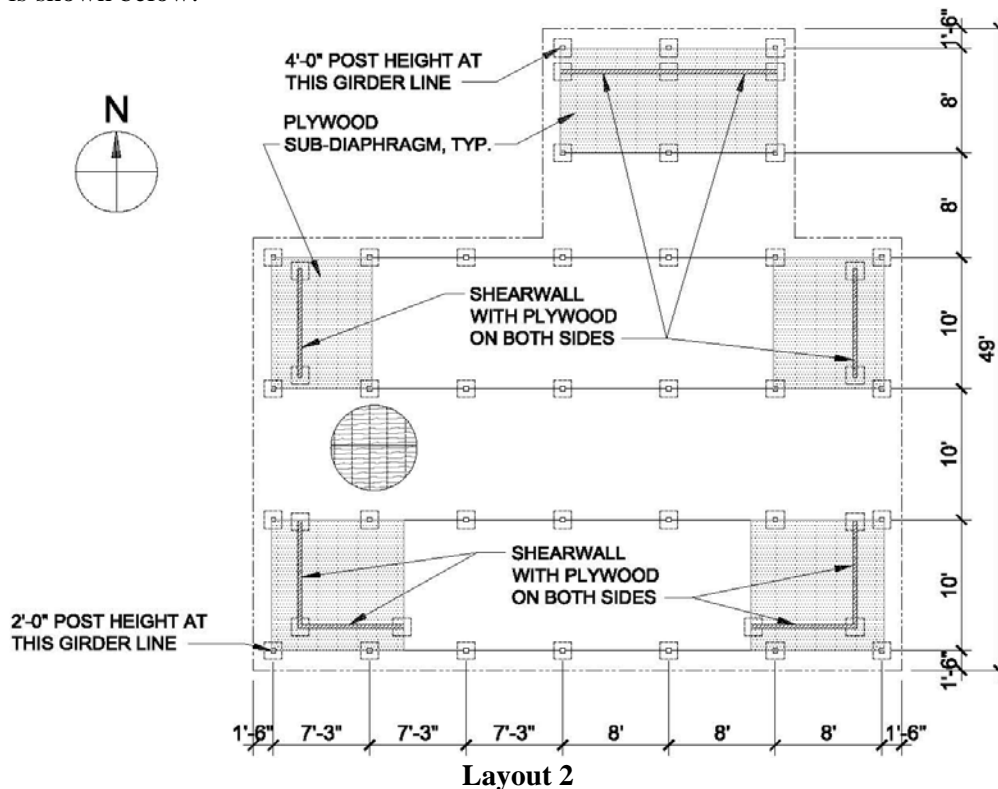
With this layout all shear walls are in line with the posts and may be constructed in accordance with Details 1, 2, 6, & 7 on Drawing Sheet 2B. This layout requires shoring (jacking) the house so that new footings may be placed. The shaded areas of the plan shown above are locations of the plywood sub-diaphragm sheathing attached to the underside of the joists, required in the framing bays adjacent to the shear walls. The steps for installing the shear walls and sub-diaphragm are as follows:

- Shore the girders where new footings are required.

Example – Choosing an Appropriate Retrofit Option for Your House

- Remove the existing tofu block foundation and place new concrete footings with embedded column bases as shown in details 1 and 2.
- After concrete has cured, place the new posts and connectors between the posts and girders and remove the shoring.
- Install blocking between the joists where the joints in the plywood sub-diaphragm sheathing under the joists will occur. Install the plywood sub-diaphragm sheathing with a pre-installed shear wall top plate connected to sheathing.
- Place the remaining shear wall framing with Simpson connectors as shown in Details 1,2, 5 and 6.
- Install the plywood wall sheathing with the nail pattern as shown.

An alternative layout for the walls, this time placed inside the existing post and girder framing lines, is shown below:

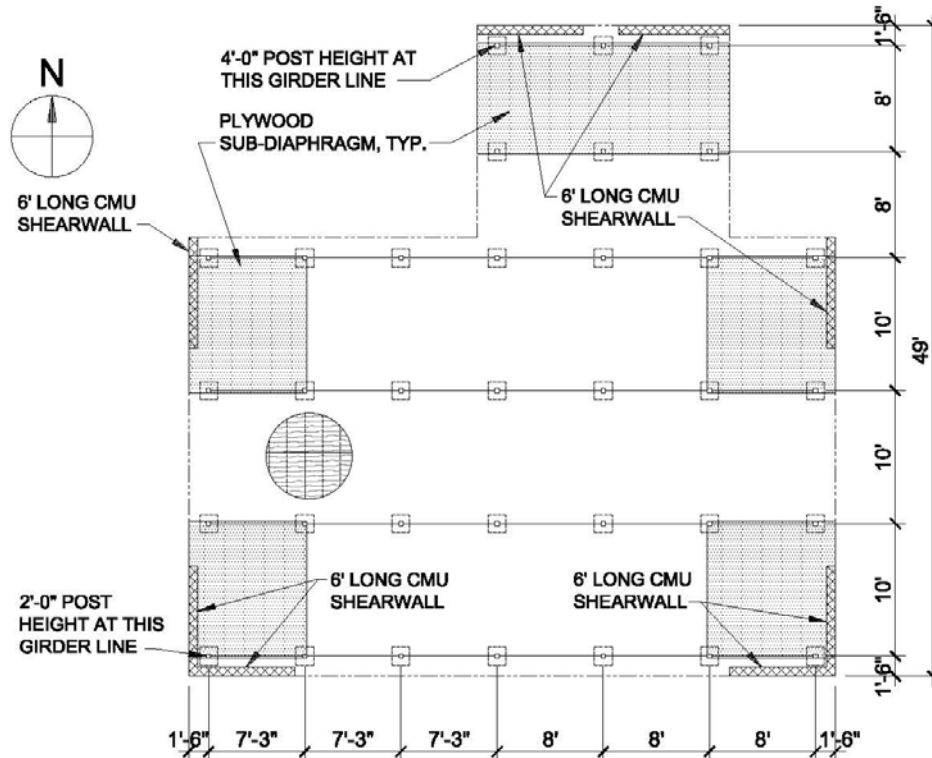


This layout uses the 8 ft long, retrofit level C shear walls with plywood sheathing on both sides of the shear wall framing (single sided 10 ft long walls could also have been used). As the new walls are offset from the existing posts, the house does not need to be jacked up and shored to place the new foundation. This layout places shear walls in a similar layout as the first; however, in this case since shorter, double sided shear walls are used, the additional walls in the east-west direction are not required. These offset shear walls can be constructed in accordance with Details 3, 4, 7A, & 8. A similar construction sequence to that described above should be used except that the girders do not need to be shored and the existing posts do not need to be removed.

Example – Choosing an Appropriate Retrofit Option for Your House

Retrofit Option 3

Although Retrofit Option 3 is the strongest option, given that both Retrofit Option 1 and 2 may be applied to this house it is less likely that Retrofit Option 3 would be utilized due to the increased cost and effort of construction. However, for illustrative purposes an example of how this option may be applied based on Drawing Sheets 3A and 3B is as follows:



The masonry shear wall layout was selected based on the same judgment described for Option 2. The required plywood sub-diaphragm is shown shaded in the framing bays adjacent to the shear walls. For this example non-load bearing walls are utilized and these are to be constructed in accordance with details 1 and 2 on Drawing Sheet 3B. This allows construction of the new masonry walls without the removal of the existing posts. The steps in the construction of each shear wall and sub-diaphragm are as follows:

- Install the post to girder and girder to joists connectors, wood blocking and plywood sub-diaphragm sheathing at the underside of the joists with the pre-installed 4x4 nailers.
- Install the new grade beam per Details 1 and 2 with reinforcing dowels extending out of the grade beam at the required spacing.
- Place the masonry blocks and horizontal reinforcing for the bottom part of the masonry wall. Place the vertical reinforcing before the wall reaches a height that makes placement impossible and construct the remainder of the wall around the reinforcing. Place the embedded anchor bolts and grout the wall solid.
- Install the prefabricated L-shaped wood top plates at top of wall connecting the wall to the sub-diaphragm.

5. Retrofit Option 1 - Post, Pier, and Brace Retrofit

5.1 General Description of Retrofit

In a typical post and pier house the posts are braced by means of 2x wood members connected between the floor framing and the posts. The purpose of these braces is to reduce the effective length of the posts and thereby decrease bending stresses and increase the stiffness of the overall structure. However, several aspects of the typical post brace design are inherently flawed. Firstly, the braces are usually connected to both the posts and the floor framing with only 2 toenails. These nails do not provide sufficient capacity to resist the magnitude of axial forces in the braces produced by even a minor earthquake. Therefore the brace end connections will typically be the first elements to fail during an earthquake. Secondly, in most post and pier houses no connection is provided between the posts and the “tofu” foundation piers. Without this connection, frictional resistance is the only mechanism that prevents the structure from sliding off its supports. Furthermore, a complete load path from the floor diaphragm to the foundation is seldom provided. Although failure of the connections between the joists and girders or girders and posts is rarely observed, primarily due to prior failure of the other elements, this connection must also be retrofitted to ensure that the forces acting on the structure can be transferred to the foundation as intended.

Retrofit Option 1 aims to address all of these issues while providing a complete load path from the floor diaphragm to the foundation and mitigating the risks of the previously described failure modes. The retrofit includes enhancing the connections between the joists and girders; the girders and posts; the braces and posts; and the brace connections to the floor framing. Holdowns are also provided to connect the posts to the foundation blocks to prevent sliding or walking of the posts. A single retrofit is detailed for both the exterior and interior posts, however due to the distribution of lateral forces resulting from an earthquake the spacing and layout of this retrofit varies between the exterior and interior. The applicability of these retrofits is dependent on the geometry of the structure (post spacing and shape), the maximum height of the posts, differential height between posts and the level of earthquake hazard in a specific region. The minimum recommended retrofit level for any region will provide a design strength that is comparable to the IBC 2006 requirements for horizontal *wind* loading (excluding required superstructure and roof framing uplift connections). This is done as a minimum because it would be undesirable for an earthquake retrofit to fail during a windstorm. For a complete summary of this retrofit option on a drawing sheet that can be reproduced for building permit application purposes refer to Appendix 1, Drawing Sheet 1 along with the general notes and details on Drawing Sheet 0.

5.2 Retrofit Option 1 Levels and Configurations

The seismic forces acting on a house, and therefore the number and location of posts requiring retrofit are affected by the length and spacing of the posts, ratio of maximum and minimum post heights (slope of the site), and the seismic hazard at the house based on the region within which the house is located from Figure 4-1. Knowing these factors the necessary minimum retrofit level can be selected from Table 5-1 and Table 5-2.

Table 5-1. Retrofit Option 1 retrofit levels and applicability for all houses

Max Post		h ≤ 4 ft					4 < h ≤ 6 ft					6 < h ≤ 9 ft					9 < h ≤ 12 ft								
Max /Min Post Height Ratio		r=1	1<r ≤1.5	1.5<r ≤2	2<r ≤3	3<r ≤4	r=1	1<r ≤1.5	1.5<r ≤2	2<r ≤3	3<r ≤4	4<r ≤6	r=1	1<r ≤1.5	1.5<r ≤2	2<r ≤3	3<r ≤4	4<r ≤6	r=1	1<r ≤1.5	1.5<r ≤2	2<r ≤3	3<r ≤4	4<r ≤6	6<r ≤9
Post Spacing ≤ 8 ft																									
Region	1	C,B	C,B	B,B	B,B	A,B	C,B	B,B	B,B	A,B	A,B	A,B	C,B	B,B	B,B	A,B	A,B	N/A	C,B	B,B	B,B	A,B	A,B	N/A	N/A
	2	C,B	B,B	B,B	A,B	A,B	C,B	B,B	B,B	A,B	A,B	A,A	C,B	B,B	B,B	A,B	A,B	N/A	C,B	B,B	B,B	A,B	A,B	N/A	N/A
	3	C,B	B,B	A,B	A,A	A,A	C,B	B,B	A,B	A,A	N/A	N/A	C,B	B,B	A,B	N/A	N/A	N/A	C,B	B,B	A,B	N/A	N/A	N/A	N/A
	4a	B,B	A,A	A,A	N/A	N/A	B,B	A,A	N/A	N/A	N/A	N/A	B,B	A,A	N/A	N/A	N/A	N/A	B,B	A,A	N/A	N/A	N/A	N/A	N/A
	4b	A,A	A,A	N/A	N/A	N/A	A,A	A,A	N/A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	N/A
8 ft < Post Spacing ≤ 10 ft																									
Region	1	C,B	B,B	B,B	A,B	A,A	C,B	B,B	B,B	A,B	A,A	N/A	C,B	B,B	B,B	A,B	A,A	N/A	C,B	B,B	A,B	A,B	N/A	N/A	N/A
	2	C,B	B,B	A,A	A,A	A,A	C,B	B,B	A,A	A,A	N/A	N/A	C,B	A,B	A,A	N/A	N/A	N/A	C,B	A,B	A,A	N/A	N/A	N/A	N/A
	3	B,B	A,A	A,A	N/A	N/A	B,B	A,A	A,A	N/A	N/A	N/A	B,B	A,A	A,A	N/A	N/A	N/A	B,B	A,A	N/A	N/A	N/A	N/A	N/A
	4a	A,A	A,A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	N/A
	4b	A,A	N/A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	N/A
10 ft < Post Spacing ≤ 12 ft																									
Region	1	C,B	B,B	B,B	A,A	A,A	C,B	B,B	A,B	A,A	A,A	N/A	C,B	B,B	A,B	A,A	N/A	N/A	C,B	B,B	A,B	A,A	N/A	N/A	N/A
	2	B,B	A,A	A,A	N/A	N/A	B,B	A,A	A,A	N/A	N/A	N/A	B,B	A,A	A,A	N/A	N/A	N/A	B,B	A,A	A,A	N/A	N/A	N/A	N/A
	3	B,A	A,A	N/A	N/A	N/A	A,A	A,A	N/A	N/A	N/A	N/A	A,A	A,A	N/A	N/A	N/A	N/A	A,A	A,A	N/A	N/A	N/A	N/A	N/A
	4a	A,A	N/A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	A,A	N/A	N/A	N/A	N/A	N/A	N/A
	4b	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 5-2. Retrofit Option 1 post installation schedule for different retrofit levels

Retrofit Level	Exterior Post Installation	Interior Post Installation
A	At Every Post	At Every Post
B	At Corners and Every Other Post	At Every Other Post
C	At Corner Posts Only	None Required

Table 5-1 two letters are given to describe the level of retrofit required. The first letter defines the retrofit level for the exterior posts while the second letter defines the retrofit level for the interior posts. Table 5-2 summarizes the number of posts that require retrofit for each retrofit level. For example, for a house located in on the island of Maui in Region 3; with a maximum post spacing of 8 ft.; a maximum post height of 6 ft.; a minimum post height of 3.5 ft. resulting in a maximum to minimum post height ratio, $r = 6 / 3.5 = 1.71$; from Table 5-1 the retrofit level is A,B. This means that retrofit level A is required for the exterior posts and retrofit level B is required for the interior posts. From Table 5-1 retrofit level A requires every exterior post to be retrofitted and retrofit level B requires every other interior post to be retrofitted.

As a second example, for a house located in on the island of Hawaii in Region 4A (the address does not have one of the ZIP codes listed for region 4B in Figure 4-1); with a maximum typical post spacing of 10 ft.; a maximum post height of 4.0 ft.; a minimum post height of 2.0 ft. resulting in a maximum to minimum post height ratio, $r = 4.0 / 2.0 = 2.0$; from Table 5-1 the retrofit level is N/A, therefore the post, pier and brace retrofit option (Retrofit Option 1) is not applicable. Hence, for this example, Retrofit Option 2 (plywood shear wall retrofit) or Retrofit Option 3 (masonry shear wall retrofit) should be used.

Figure 5-1 illustrates possible post retrofit locations for different levels of retrofit, for a typical rectangular or non-rectangular house. The figure shows that the retrofitted posts should be staggered equally about opposite sides of the house.

A summary of the elements required for the post and brace retrofit is shown in Figure 5-2.

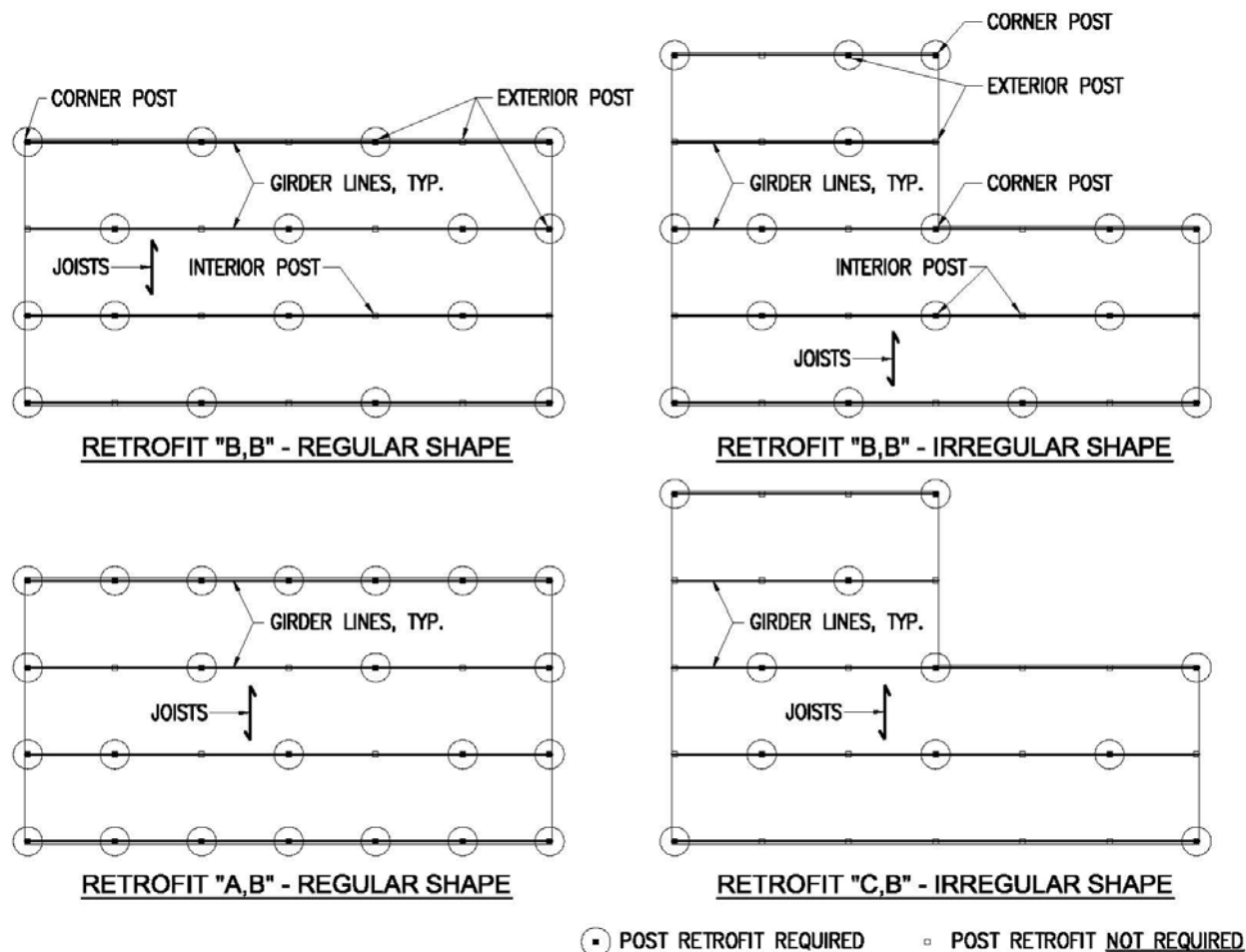


Figure 5-1. Example post retrofit layouts for retrofit Option 1

Step one of this retrofit procedure is to anchor the post to the foundation to prevent the post from sliding or walking off the foundation block. Due to the fact that the top tofu block is not large enough to place an anchor bolt with sufficient edge distance to avoid splitting of the concrete under seismic loading, the holdown should be anchored into the lower foundation block. Wood blocking should be added to the sides of the post to fill the void space between the edges of the smaller top tofu block and the post. Depending on preference, either a Simpson type HTT5 or HDU5 anchor may be used. The post anchor holdown installation is detailed in Figure 5-3.

A commonly observed type of failure in post and pier houses results from the concrete piers being undermined due to soil or slope instability. If the foundation blocks are not properly balanced on sloping soil, they are not in complete contact with the ground surface, or the stability of the soil beneath is of concern, it is recommended that the blocks be encased within a larger concrete footing embedded in the ground, or be replaced with a solid concrete footing embedded in the ground. Details of these foundation block retrofits are shown in Figure 5-4 and Figure 5-5. In questionable cases, where the soil under a number of piers might possibly be unstable, it is advisable to consult with a geotechnical and/or structural engineer for implementation of appropriate soil or slope stability measures.

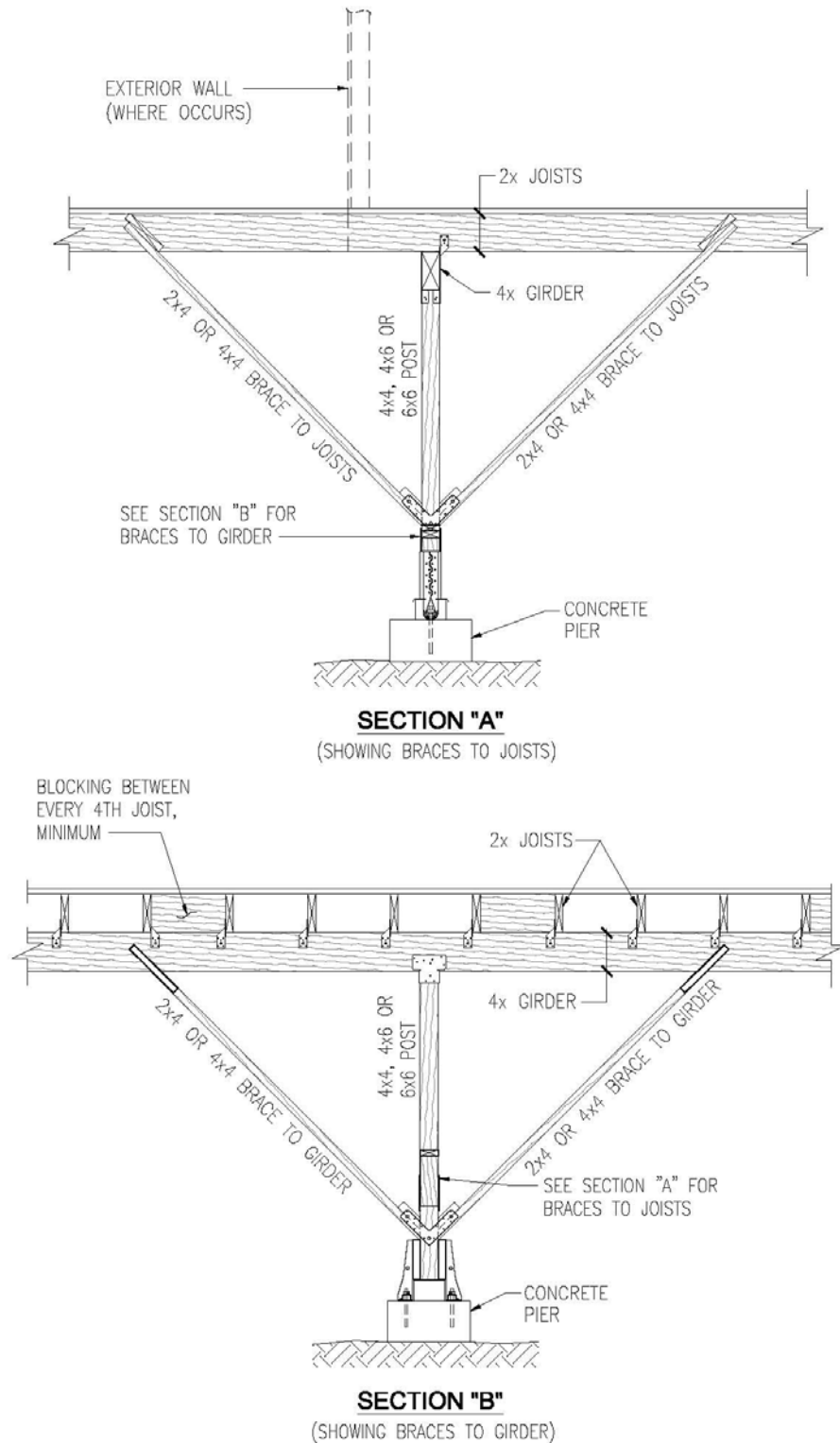


Figure 5-2. Post retrofit 1 general overview

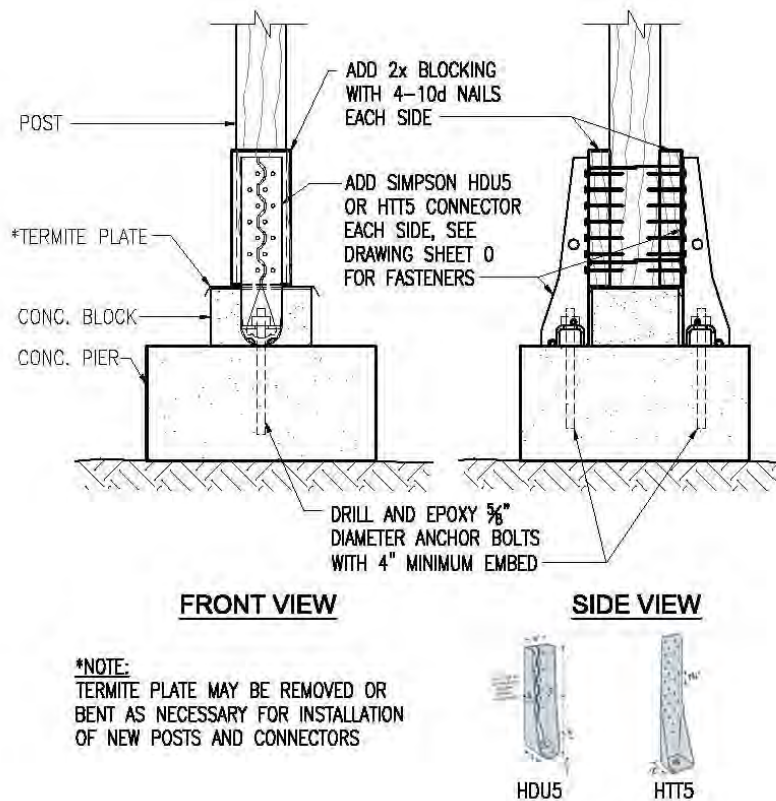


Figure 5-3. Post to foundation holdown detail

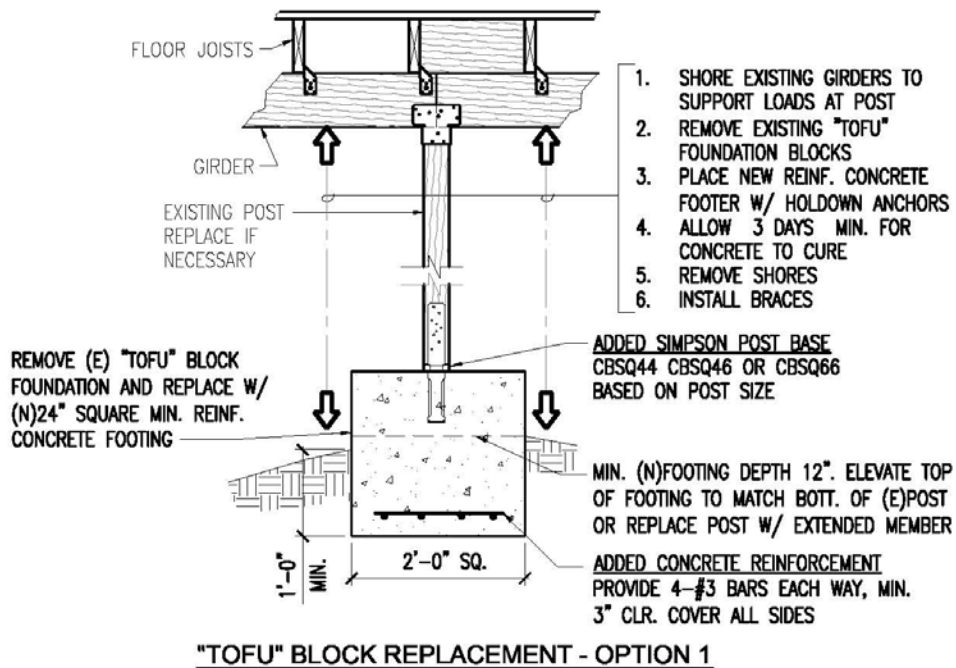


Figure 5-4. Tofu block replacement

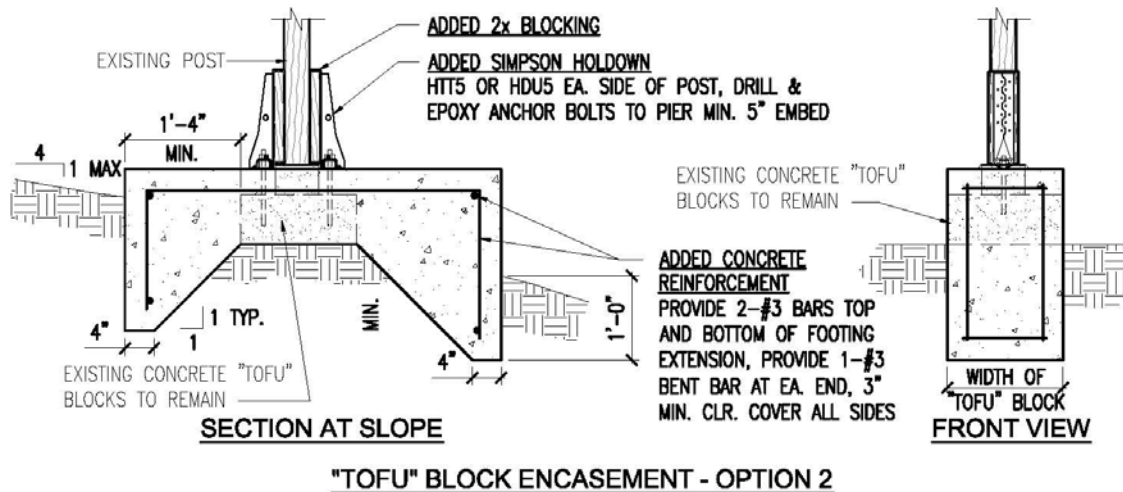


Figure 5-5. Tofu block encasement

To assure a complete load path from the floor diaphragm to the foundation, connectors must be added from the joists to girders and from the girders to the posts. These connections are detailed in Figure 5-6 with the frequency and type of a joist to girder connector provided for the different retrofit levels in the joist clip schedule.

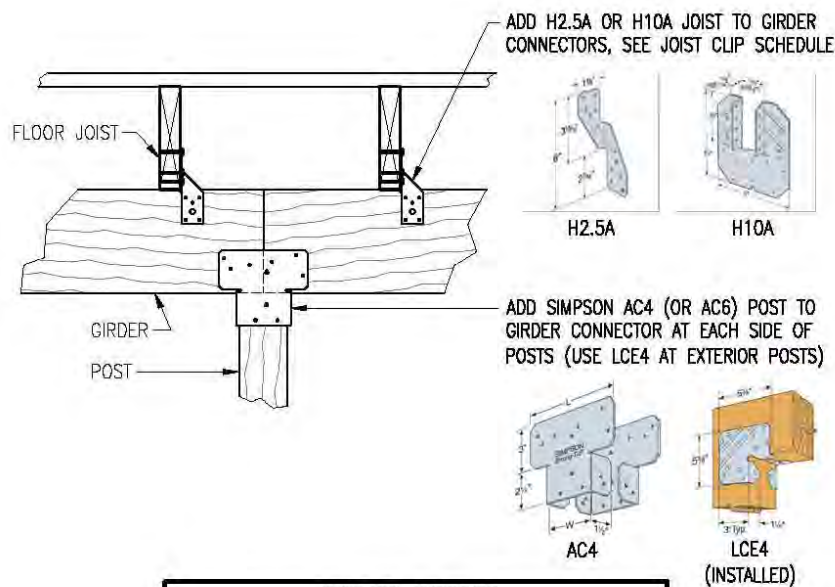


Figure 5-6. Post to girder and joist to girder connection details

After retrofit of the post connection to the foundation and girders, 2x4 post braces should be added or retrofitted. The post braces in one direction should be placed at about $\frac{1}{4}$ the post height above the base of the post, while braces in the other direction should be placed 6 to 12 inches higher or lower so that there is no conflict in the placement of the connection straps. Braces should be placed at an angle of approximately 45° . If braces currently exist with connections higher than approximately $\frac{1}{4}$ of the post height up the post, or in a substantially different configuration than described, they should be removed and replaced in the recommended position. Simpson L strap ties should be used to fasten the braces to the posts, except at exterior posts where a brace only extends in one direction towards the interior of the house, in which case HRS12 straps should be used, as shown in Figure 5-7. These straps shall be placed on both sides of each brace.

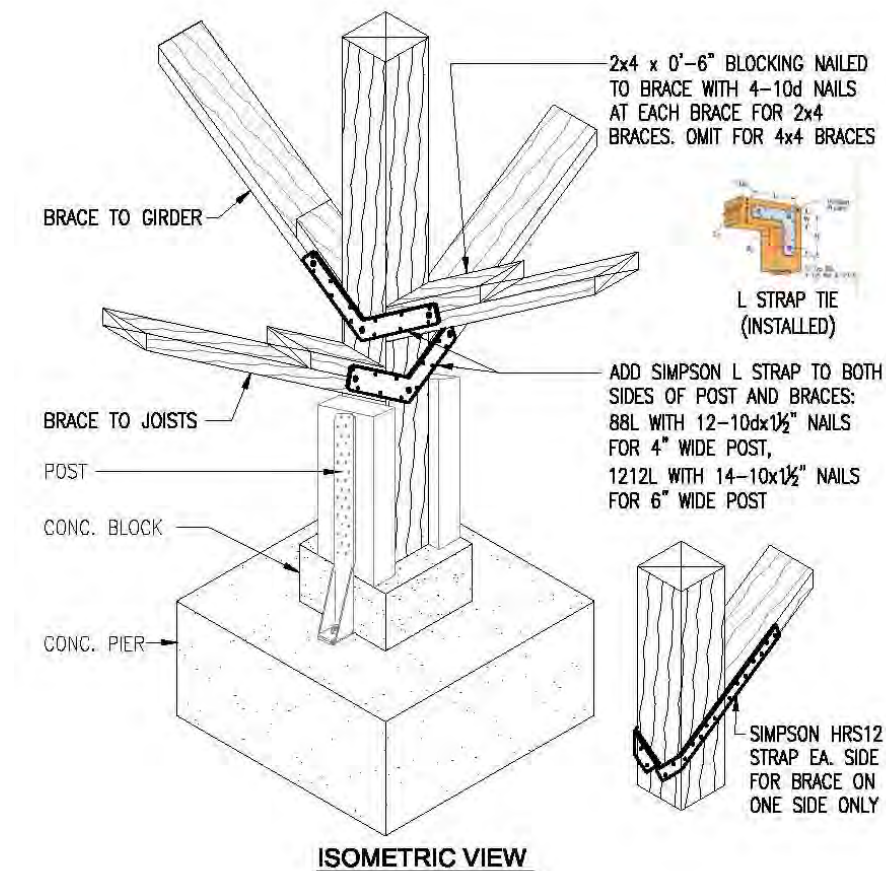


Figure 5-7. Brace to post connection detail

Once the braces are connected to the posts, they must also be fastened to the girders or joists. Since the girder lines are always along the post lines the braces oriented in the vertical plane parallel to the girder can fasten directly to the girder. This connection should also be made with an HRS12 strap (Figure 5-8). When a post is very short and not long enough to feasibly place braces between the post and the girder along with the connectors described above, the connection shown in Figure 5-9 may be used. The braces are omitted and a pair of L-straps connected directly between the post and girder just below the AC4 post to girder connector.

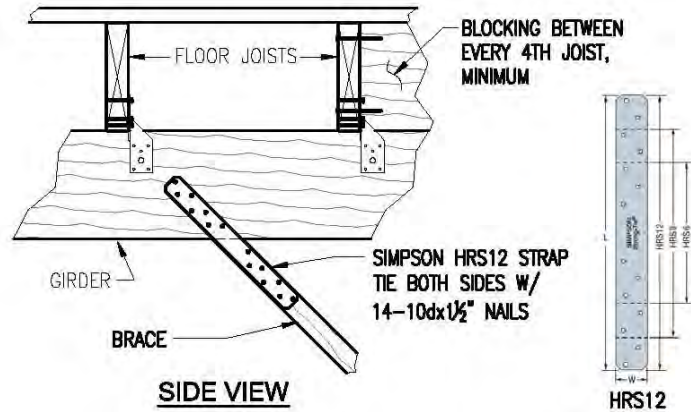


Figure 5-8. Typical brace to girder connection

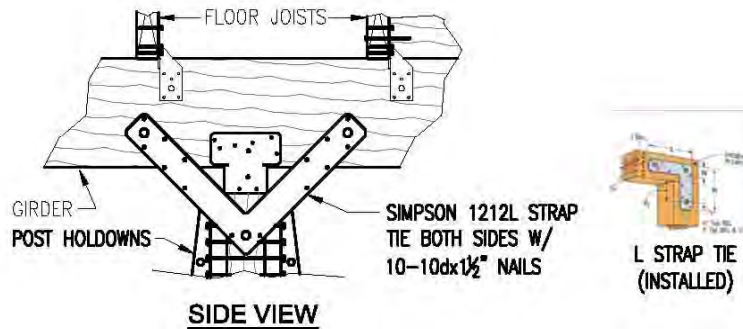


Figure 5-9. Post to girder connection for short posts where no wood braces to the girder are feasible

The braces in the plane perpendicular to the girder must fasten to the joists or blocking between the joists. Two configurations for this attachment are detailed in Figure 5-10 and Figure 5-11.

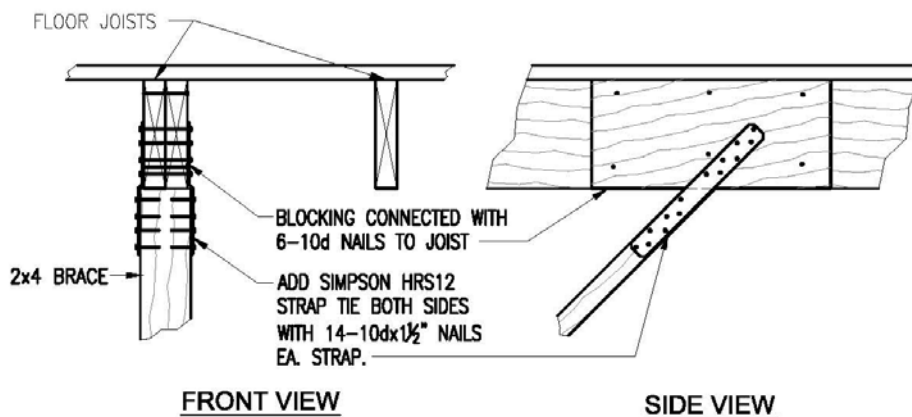


Figure 5-10. Brace to joist connection at intersection with joist

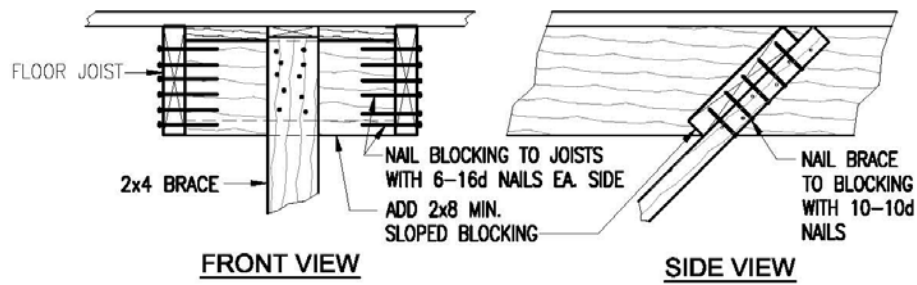


Figure 5-11. Brace to sloped blocking detail between joists

Even when posts are relatively short and the post to girder braces are not feasible, the post to joist braces are feasible if the connection to the post is made below the L-strap connecting the post and the girder. The braces and straps connecting them to the post will need to be installed before the post holdowns are installed. The straps can be sandwiched between the post and the blocking connecting to the holdowns.

6. Retrofit Option 2 – Plywood Shear Wall Retrofit

6.1 General Description of the Retrofit

The plywood shear wall retrofit option provides lateral strength and stiffness to the post and pier foundation system of a house by the addition of plywood shear walls between some of the posts, like that shown in Figure 6-1. This retrofit option is intended for use where either a post and brace retrofit (Retrofit Option 1) is not sufficient to resist the seismic forces for the location, size and/or properties of a structure, or if the retrofit of every post is undesirable or impractical due to limited access to some posts. Only select bays between posts are required to be retrofitted under this option, with the most convenient locations of the new shear walls typically located near the exterior perimeter, most commonly near the exterior corners of the building, where access is greatest. The walls may be sheathed on one or both sides. Where they are sheathed on only one side, it is preferable that the sheathing be placed on the exterior side to provide the best protection for all the wall components from the weather.

Two different installation configurations are detailed:

- The first configuration places the shear walls in line with the existing post and girder lines, therefore the original posts and foundation blocks need to be removed with the girders temporarily shored at the locations of the new walls. New posts are placed on new footings then shear walls are built between the new posts.
- The second configuration places the walls either inside or outside the existing post and girder lines with the existing posts remaining to carry the gravity loads.



Figure 6-1. Typical corner plywood shear wall providing lateral strength and stiffness to a house with a post and pier foundation system

The walls shall be placed no further in from the exterior of the building than at the first row of interior posts, with a few exceptions described later in the report.

Where new shear walls are aligned with posts, the posts that connect to the shear walls must first be retrofitted with new concrete footings and post connections. In many cases it will be most convenient to replace the posts in addition to the new footings. It is not necessary to retrofit every post for this option, but only those that connect to the shear walls, unless there are posts with unstable foundation piers. Once the posts have been retrofitted and gravity loads from the house restored on the posts, the shear walls can be constructed. Where the shear walls are not aligned with the posts, then the new walls can be constructed without the replacement of any posts, unless there are posts with unstable foundations.

For a complete summary of this retrofit option on two drawing sheets that can be reproduced for building permit application purposes refer to Appendix 1, Drawing Sheets 2A and 2B along with the general notes and details on Drawing Sheet 0.

6.2 Retrofit Option 2 Levels and Configurations

The required length of plywood shear walls, or number of bays that require shear walls to be installed on each side of a house, is based on the geometry and location of a structure. The critical properties are the floor area of the building in square feet, spacing of the posts, lengths of the posts and relative lengths of the posts based on the slope of the site and seismic hazard based on the location of the house. Depending on these factors the required shear wall retrofit level is given in Table 6-1 for houses with a maximum post height of up to 6 feet. For houses with a maximum post height of between 6 and 12 feet the retrofit level required is given in Table 6-2. This retrofit may be applied to a house with up to two stories above the post and pier foundation system. For a two-story house the floor area used in Table 6-1 and Table 6-2 should be the sum of the areas of the first and second floor.

The three letters in each cell of Table 6-1 and Table 6-2 provide the retrofit level for 8 ft. long, 10 ft. long and 12 ft. long wall segments respectively. The length of wall segments is intended to match the spacing of the posts, although this is not necessary if the walls are offset from the post lines. If the spacing of the posts is less than 8 feet then the wall segment will need to extend over two bays. Retrofit level A represents a single shear wall segment on each side of the house with plywood sheathing on one side of the wall. Retrofit level B requires that there are two wall segments along each side of the house with plywood sheathing on one side of the walls. Retrofit level C requires two wall segments at each side of the house with plywood sheathing on both sides of the wall. The shear walls shall be constructed from 2x4 stud framing sheathed on one or both sides with minimum 15/32" Structural I grade C-D plywood.

Different configurations of added plywood shear walls aligned with the existing posts and girders are shown in Figure 6-2. The drawings on the left side of the figure show different retrofit levels applied to a rectangular house, while the drawings on the right side of the figure show different retrofit levels applied to a non-rectangular shape, in this case an L-shaped house. In this figure the first rectangular and L-shaped houses at the top of the figure have walls at opposite corners of the house, which satisfy the requirements for a single segment wall on each

Table 6-1. Retrofit levels for plywood shear wall (Retrofit Option 2) for residences with a maximum post height of 6 feet

Max Post Height (ft)		<4 (ft)					4-6 (ft)					
Max /Min Post Height Ratio		r =1	1< r ≤1.5	1.5< r ≤2	2< r ≤3	3< r ≤4	r =1	1< r ≤1.5	1.5< r ≤2	2< r ≤3	3< r ≤4	4< r ≤6
Min Length of Wall Segment (ft)		8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12
Floor Area < 1000 sf												
Region	1	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	B,A,A
	2	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	B,A,A
	3	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	B,A,A
	4a	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B
	4b	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,A	B,B,B	B,B,B	C,B,B	C,B,B	C,B,B
Floor Area < 1500 sf												
Region	1	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	B,B,B
	2	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	B,B,B
	3	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	B,B,B
	4a	B,B,A	B,B,B	B,B,B	B,B,B	C,B,B	B,B,A	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B
	4b	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C
Floor Area < 2000sf												
Region	1	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	B,B,B
	2	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	B,B,B
	3	B,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	C,B,B
	4a	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C
	4b	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C
Floor Area < 2500 sf												
Region	1	B,B,A	B,B,B	B,B,B	B,B,B	C,B,B	B,B,A	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B
	2	B,B,A	B,B,B	B,B,B	B,B,B	C,B,B	B,B,A	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B
	3	B,B,A	B,B,B	B,B,B	B,B,B	C,B,B	B,B,A	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B
	4a	C,B,B	C,C,B	C,C,B	C,C,C	C,C,C	C,B,B	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C
	4b	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	C,C,C	C,C,C	N,C,C	N,N,C	N,N,C	N,N,N
Floor Area < 3000 sf												
Region	1	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	C,C,C
	2	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	C,C,C
	3	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	C,C,C
	4a	C,C,B	C,C,C	C,C,C	C,C,C	N,C,C	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	N,N,C
	4b	C,C,C	N,C,C	N,C,C	N,N,C	N,N,C	C,C,C	N,C,C	N,N,C	N,N,N	N,N,N	N,N,N
Floor Area < 4000 sf												
Region	1	C,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	N,C,C
	2	C,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	N,C,C
	3	C,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	N,C,C
	4a	C,C,C	N,C,C	N,C,C	N,N,C	N,N,C	C,C,C	N,C,C	N,N,C	N,N,N	N,N,N	N,N,N
	4b	N,C,C	N,N,C	N,N,N	N,N,N	N,N,N	N,N,C	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N

side of the house as required for Retrofit Level A. The houses in the second row have walls at each corner resulting in two wall segments along each side of the houses, satisfying the requirements of Retrofit Level B. The third configurations are the same as those in the previous row except that the wall segments are sheathed with plywood on both sides, satisfying the requirements for Retrofit Level C.

Similar configurations of walls, but offset towards the inside of the exterior row of posts are shown in Figure 6-3. For these configurations the posts do not need to be temporarily supported and as the new shear walls can be built independently of the existing posts. The new shear walls therefore only resist lateral loads and the framing inside the plywood sheathing is not required to carry the gravity loads from the house. Again the three different retrofit levels are shown in the three rows of the houses in this figure.

Table 6-2. Retrofit levels for plywood shear wall (Retrofit Option 2) for residences with a post height of 6 to 12 feet

Max Post Height (ft)		6-9 (ft)						9-12 (ft)							
Max /Min Post Height Ratio		r=1	1<r≤1.5	1.5<r≤2	2<r≤3	3<r≤4	4<r≤6	r=1	1<r≤1.5	1.5<r≤2	2<r≤3	3<r≤4	4<r≤6	6<r≤9	
Min Length of Wall Segment (ft)		8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	
Floor Area < 1000 sf															
Region	1	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,A,A	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	
	2	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,A,A	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	
	3	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,A,A	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	
	4a	B,A,A	B,B,A	B,B,A	B,B,B	B,B,B	B,B,B	A,A,A	B,B,A	B,B,B	B,B,B	B,B,B	C,B,B	C,B,B	
	4b	B,B,A	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B	B,B,A	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	C,C,B	
Floor Area < 1500 sf															
Region	1	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,B	
	2	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,B	
	3	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,B	
	4a	B,B,B	B,B,B	C,B,B	C,C,B	C,C,B	C,C,B	B,B,A	C,B,B	C,B,B	C,C,B	C,C,B	C,C,C	C,C,C	
	4b	C,B,B	C,C,B	C,C,B	C,C,C	C,C,C	C,C,C	B,B,B	C,C,B	C,C,C	C,C,C	C,C,C	N,C,C	N,C,C	
Floor Area < 2000 sf															
Region	1	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,B	
	2	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,B	
	3	B,A,A	B,B,B	B,B,B	C,B,B	C,B,B	C,B,B	B,A,A	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	
	4a	C,B,B	C,C,B	C,C,B	C,C,C	C,C,C	C,C,C	B,B,B	C,C,B	C,C,C	C,C,C	C,C,C	N,C,C	N,C,C	
	4b	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	N,N,C	C,C,B	C,C,C	N,C,C	N,C,C	N,N,C	N,N,C	N,N,C	
Floor Area < 2500 sf															
Region	1	B,B,B	B,B,B	C,B,B	C,C,B	C,C,B	C,C,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	C,C,C	C,C,C	
	2	B,B,B	B,B,B	C,B,B	C,C,B	C,C,B	C,C,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	C,C,C	C,C,C	
	3	B,B,B	B,B,B	C,B,B	C,C,B	C,C,B	C,C,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	C,C,C	C,C,C	
	4a	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C	C,B,B	C,C,C	C,C,C	N,C,C	N,C,C	N,N,C	N,N,C	
	4b	C,C,C	N,C,C	N,C,C	N,N,C	N,N,N	N,N,N	C,C,C	N,C,C	N,N,C	N,N,N	N,N,N	N,N,N	N,N,N	
Floor Area < 3000 sf															
Region	1	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	C,C,C	
	2	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	C,C,C	
	3	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	C,C,C	
	4a	C,C,C	C,C,C	N,C,C	N,N,C	N,N,C	N,N,C	C,C,B	N,C,C	N,C,C	N,N,C	N,N,C	N,N,N	N,N,N	
	4b	N,C,C	N,N,C	N,N,C	N,N,N	N,N,N	N,N,N	C,C,C	N,N,C	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	
Floor Area < 4000 sf															
Region	1	C,B,B	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	N,N,C	N,N,C	
	2	C,B,B	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	N,N,C	N,N,C	
	3	C,B,B	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	N,N,C	N,N,C	
	4a	N,C,C	N,N,C	N,N,C	N,N,N	N,N,N	N,N,N	C,C,C	N,N,C	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	
	4b	N,N,C	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,C	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	

Figure 6-4 shows similar wall layouts with the walls offset to the exterior of the outmost lines of posts. These layouts are only possible if there is sufficient overhang in the joists and girders to enable the walls to be built outside the post lines. If the overhang is sufficient, it will generally be easier to construct as there is better access for laying the foundation beam and constructing the walls.

There are a number of other possible configurations for the shear walls, depending on the plan geometry of the house. The configurations are acceptable as long as they meet the required length of the walls, are of approximately equal length on four sides of the house, and are located no more than one bay from the outside perimeter of the house on each side (except where the ratio of long to short posts is greater than 2.0 in which case a line within 4'-0" of the post line that contains the shortest posts must be used as a new shear wall line).

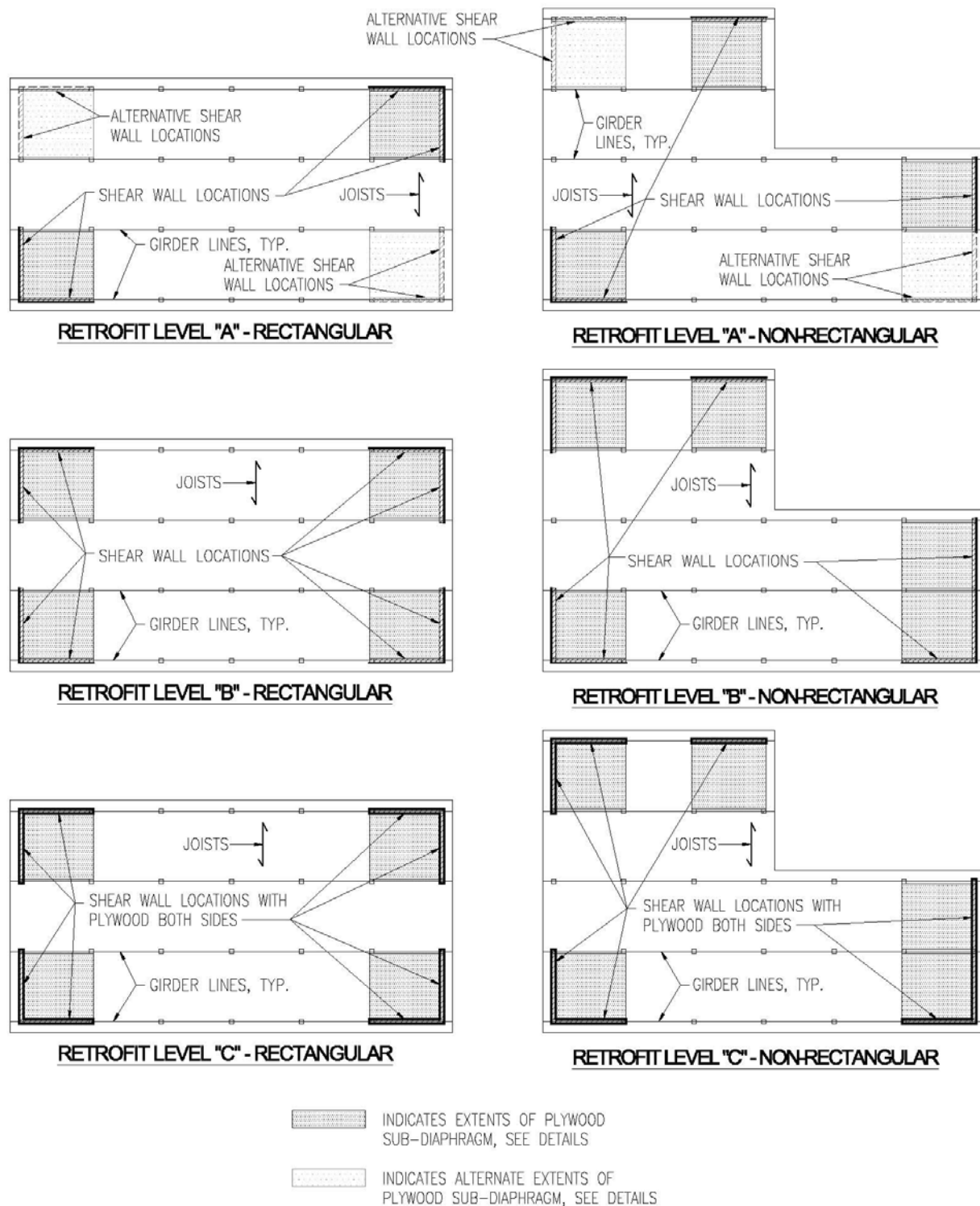


Figure 6-2. Plan views of possible configurations of shear walls having walls aligned with existing posts

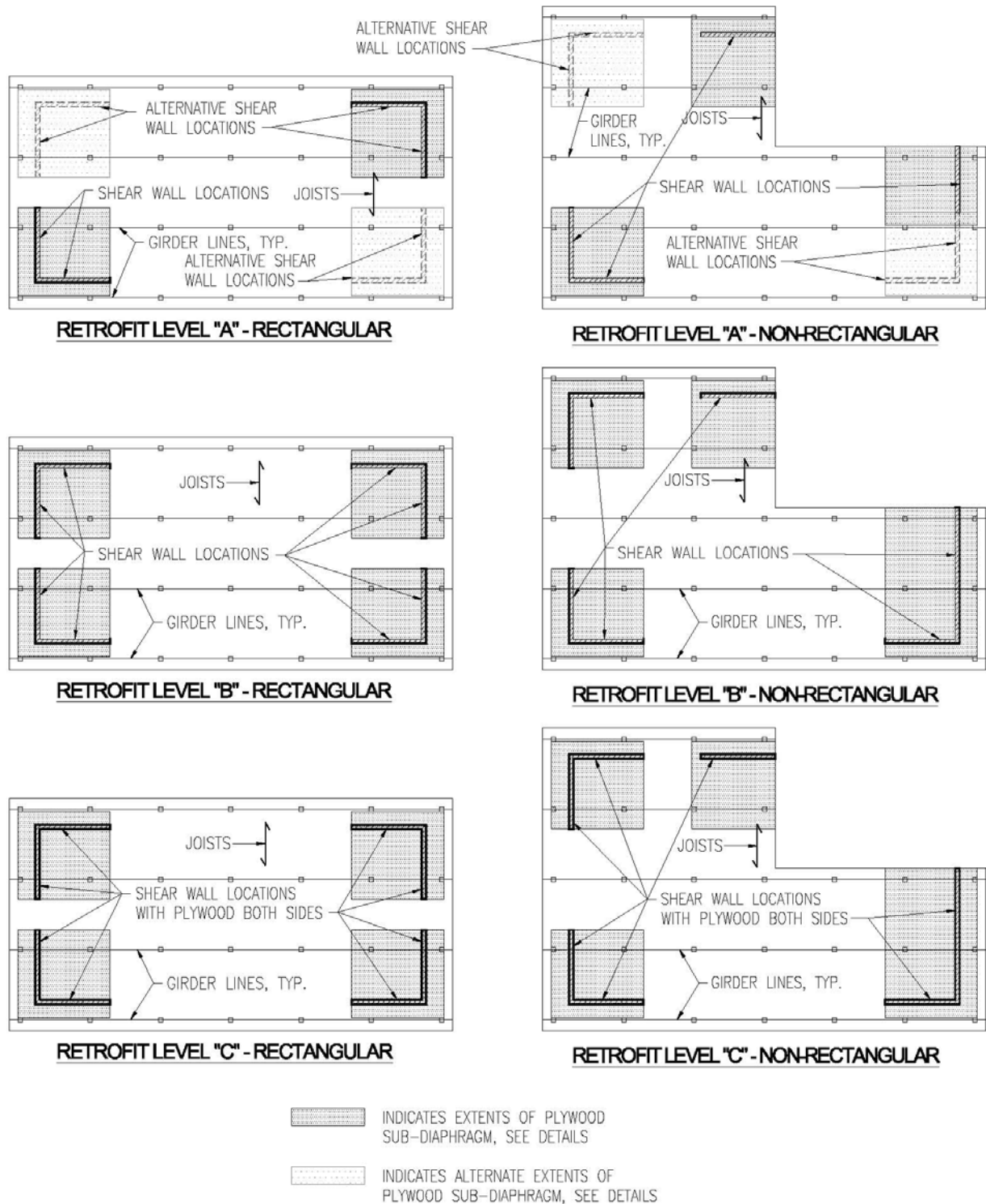


Figure 6-3. Plan views of possible configurations of shear walls with walls offset inside existing posts

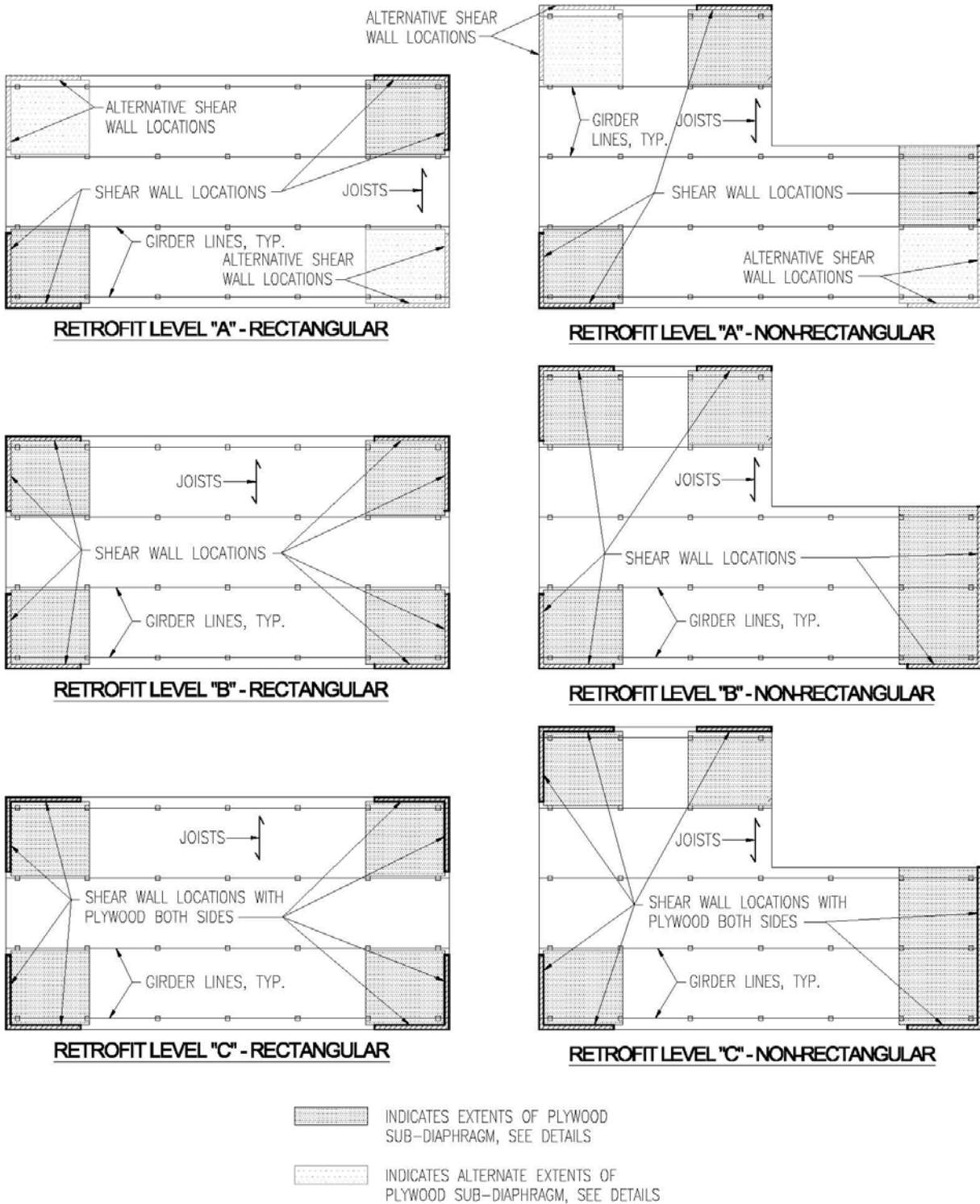


Figure 6-4. Plan views of possible configurations of shear walls with walls offset outside existing posts

6.3 *Retrofit Option 2 Details*

A side view drawing and cross section of a shear wall retrofit installed at the corner of a house is shown in Figure 6-5. This figure provides details for a wall installed between existing posts parallel to an exterior girder line. Figure 6-6 shows a similar shear wall assembly installed parallel to the joists. Figure 6-7 and Figure 6-8 show shear walls offset from the existing post lines installed parallel to the girders and joists respectively.

In Figure 6-5, where the walls are aligned with the posts and parallel to the girders, the girders must be temporarily jacked up at either side of the existing posts. The existing posts and piers can then be removed. New footings, with embedded post bases, can be poured as shown in the drawing. Once the concrete has cured for at least three days, new posts can be installed between the footings and girders with the connectors shown. The temporary jacks can then be removed allowing the gravity loads to be carried by the new posts. Simpson H10A ties should then be used to connect each of the joists to the girders along the entire length of the girders in lines of the new shear walls. Simpson MSTC straps should be installed on both sides of the girders at butt joints in the girders that occur above some of the posts. The plywood sub-diaphragm can then be installed at the underside of the joists with blocking installed between the joists at all of the joints in the sub-diaphragm. If not already present, blocking should also be placed between the joists on top of the girders, between every joist over the length of the shear wall and every fourth joist between wall segments. The new shear walls can then be constructed with a new 4x4 bottom chord spanning between the posts, just above the post base connectors. This member should be tied to the posts using Simpson MSTA straps that wrap around the posts. Vertical wood studs can then be inserted between the bottom chord and the girder and sheathing placed on one or both sides of the wall, as required, based on the retrofit level.

In Figure 6-6 the new walls are aligned with the existing posts and the joists. The existing posts and piers must be removed in the same manner as previously described with temporary shoring of the girders as required. The new posts must be installed and Simpson connectors and straps installed to connect the posts to the girders, girders to the joists and joist segments together where the butt joints occur. The shear walls can then be constructed. This figure shows the sheathing of the wall aligning with the face of the joist, allowing the vertical plywood sheathing to be connected directly to the joist. If the sheathing is not aligned with the joist, but is almost aligned, then the sheathing can be nailed to a 2x4 top plate which is already nailed to the joist. Where the offset between the wall sheathing and joists is too large to be accommodated by a 2x4 top plate alone then the 2x4 top plate can be preinstalled to the plywood sub-diaphragm that, once in place, can be connected to the shear wall, as shown in Figure 6-8.

When the walls are offset from the post lines by more than 2 feet, then the existing posts do not need to be retrofitted except for Simpson AC or LCE connectors that must be installed at all of the post to girder connections. The nearest girders and joists to the shear wall additions must be retrofitted with MTSC28 straps to ensure a continuous load path from one end of the building to the other. As shown in Figure 6-7 and Figure 6-8 the plywood sheathing must be attached to the underside of the joists to transfer the forces from the wall to the nearest girder or joists respectively as shown in Figure 6-7 and Figure 6-8. The wall can then be built with the same steps as previously described.

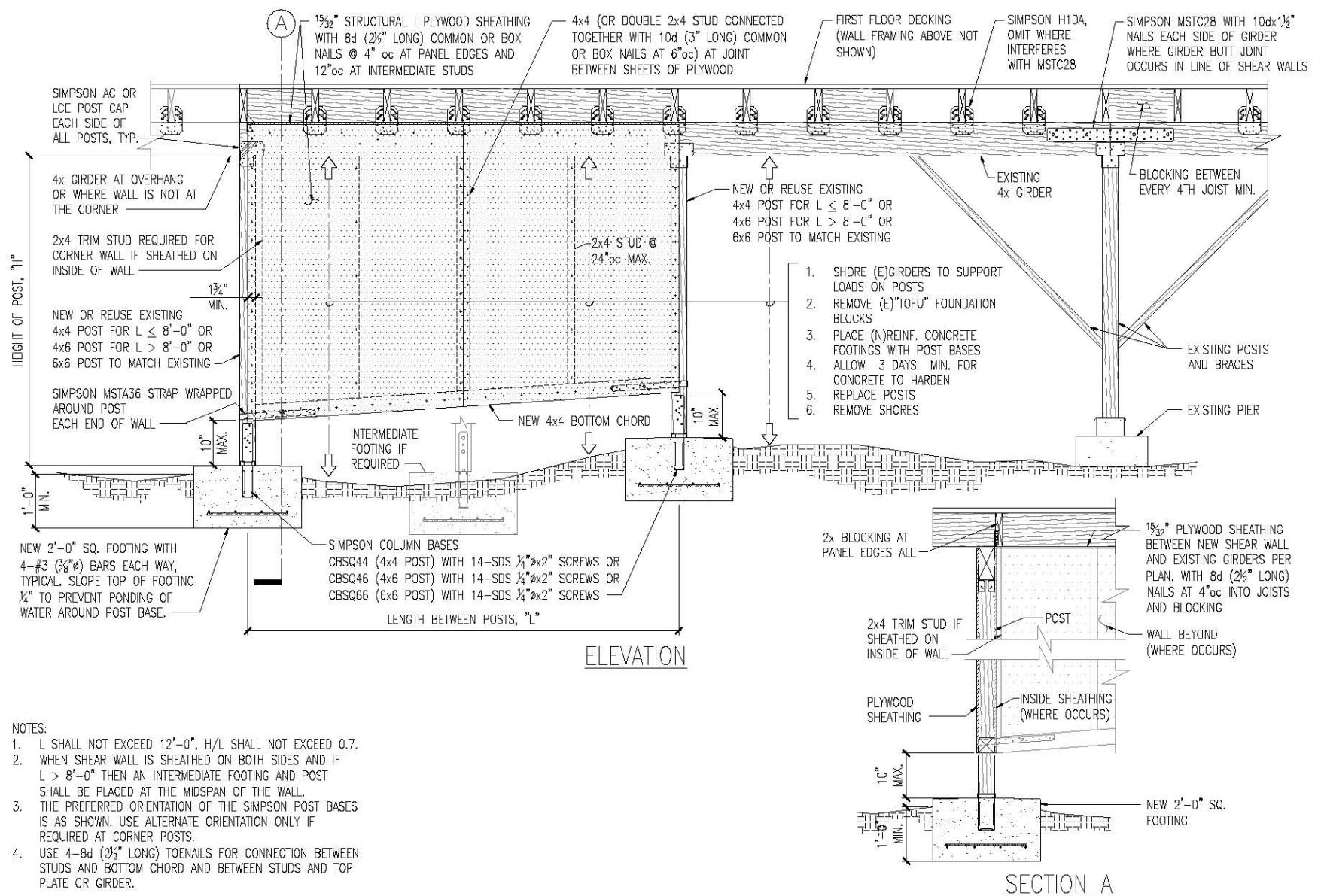


Figure 6-5. Shear wall retrofit (Retrofit 2) elevation and section when wall is in line with the posts and parallel to the girders

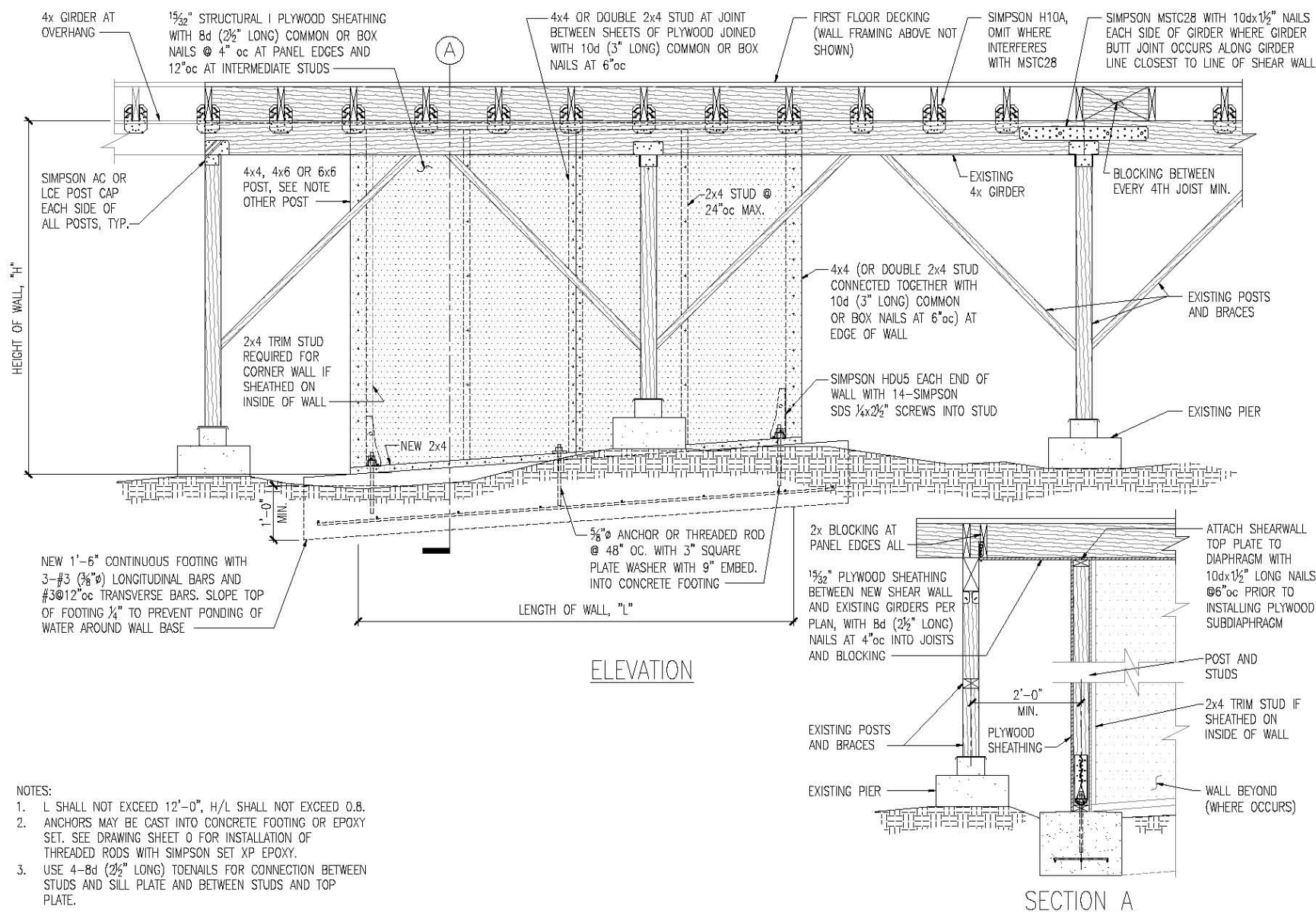


Figure 6-7. Shear wall retrofit (Retrofit 2) elevation and section when wall is offset from the existing posts and parallel to the girders

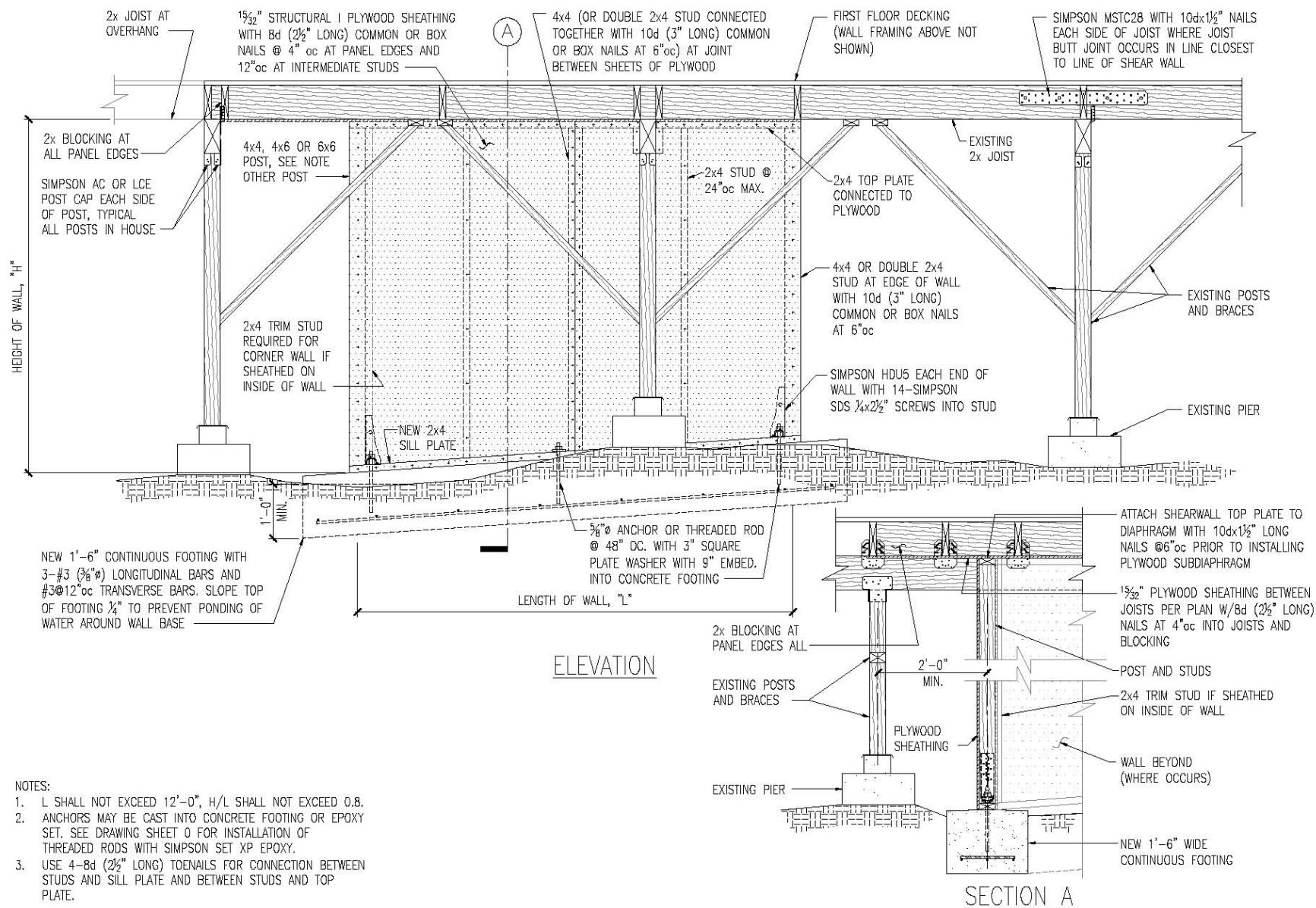


Figure 6-8. Shear wall retrofit (Retrofit 2) elevation and section when wall is offset from the existing posts and parallel to the joists

7. Retrofit Option 3 - Masonry Shear Wall Retrofit

7.1 *General description of retrofit*

This retrofit option provides masonry shear walls at four corners of a house. While it is likely to be the most costly of the retrofit options, it is the most widely applicable and reliable option since it can resist higher levels of earthquake forces. This retrofit is designed for a single level of protection to encompass the extreme cases of post height, height ratio, post spacing, and earthquake ground motions.

As with the plywood shear wall retrofit, two different installation configurations for the masonry wall retrofit are detailed:

- The first configuration places the walls either inside or outside the existing post and girder lines with the existing posts remaining to carry the gravity loads. In this option the new masonry walls are non-gravity load bearing.
- The second configuration places the walls in line with the existing post and girder lines, therefore the original posts and foundation blocks will need to be removed with the girders temporarily shored. The new masonry walls and foundations therefore become gravity load bearing.

The second configuration is more robust structurally but requires additional effort in jacking and temporarily shoring the house and if the load transfer from the old posts to the new walls is not performed carefully, there is potential for damage particularly to non-structural components within the house.

The same basic design is used for all masonry shear wall retrofit options. All walls shall be 6 feet long in each direction placed in two locations on each side of the house (typically at the exterior corners). The masonry walls shall be constructed up to the underside of the girders and connected to the girders or sub-diaphragms above using prefabricated L-shaped wood top plates. The walls are reinforced and fully grouted on a reinforced concrete footing.

Due to its complexity, unless the homeowner has some experience laying masonry block and with concrete work, it is generally recommended that a contractor be hired to perform this retrofit. For a summary of this retrofit option on Drawing Sheets that can be reproduced for building permit application purposes refer to Appendix 1, Drawings Sheets 3A and 3B along with the general notes and details on Drawing Sheet 0.

7.2 *Retrofit Option 3 Applicability and Configurations*

This retrofit will provide earthquake protection to most typical houses throughout the state, including the southern regions of the Island of Hawaii where the highest earthquake forces are expected. If the floor area of a house is greater than 4000 sf, maximum post height is greater than 12 ft or the maximum post spacing is greater than 12 ft then an engineer should be consulted prior to implementing this retrofit.

Figure 7-1 illustrates the location and configuration of the masonry shear wall retrofit on regular (rectangular) and irregular (for example, L-shaped) houses with and without joist overhangs along the exterior girders. As shown in this figure, walls located in each corner of the house are required.

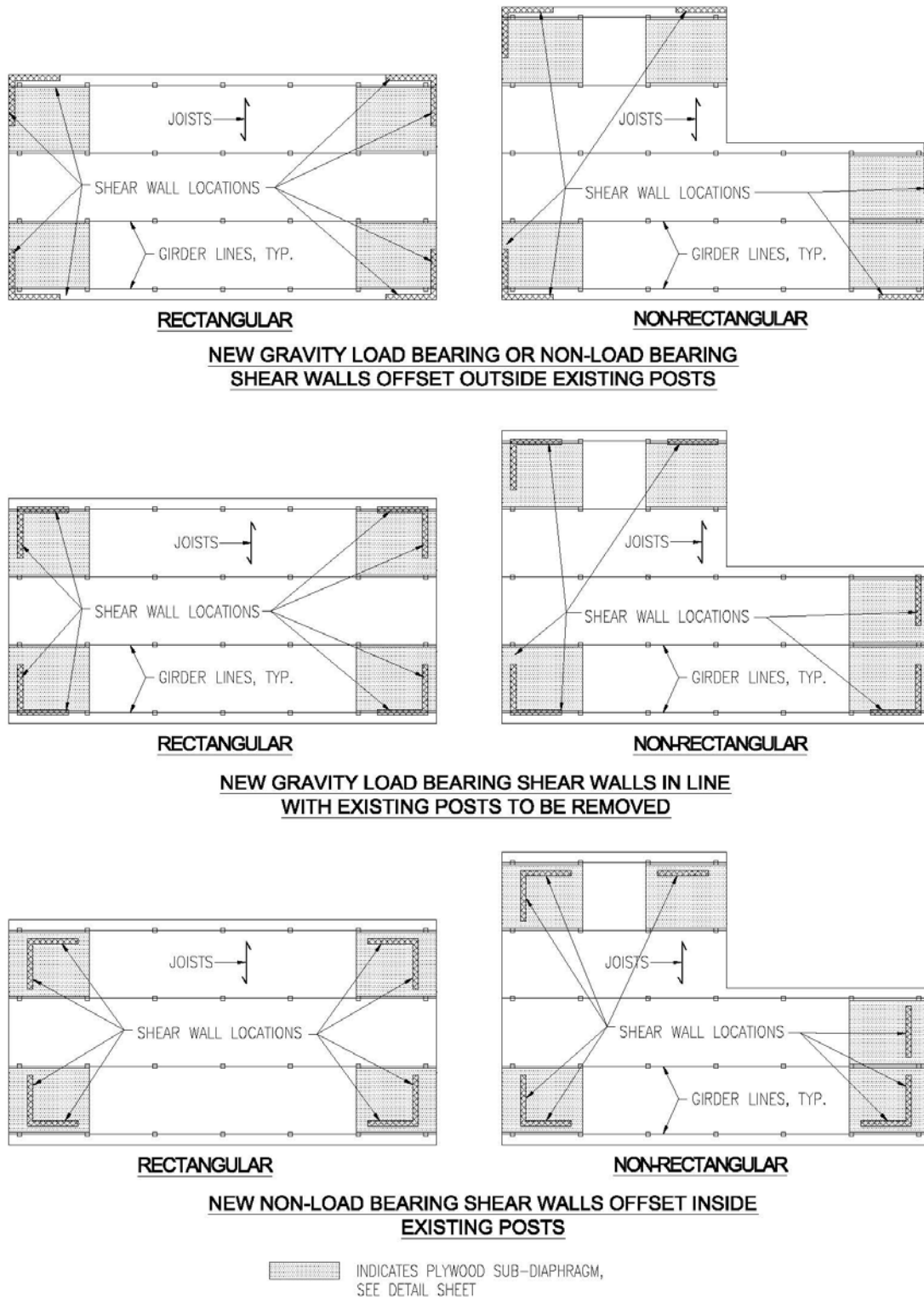


Figure 7-1. Location of retrofits in plan

7.3 *Retrofit Option 3 Details*

Construction details for Retrofit Option 3 are shown in Figure 7-2 to Figure 7-5. These details provide the general schemes for walls offset from existing post and girder lines or aligned with existing post and girder lines respectively. The option which best suites the site conditions at a particular house should be applied.

When the walls are offset from the post lines by more than 16 in., then the existing posts do not need to be retrofitted except for Simpson AC or LCE connectors that must be installed at all of the post to girder connections. Simpson H10A ties should be used to connect each of the joists to the girders along the entire length of the girders for girder lines closest to the new shear walls. The nearest girder and joist lines must also be retrofitted with PCT23 tie rods to ensure a continuous load path from one end of the building to the other. The plywood sub-diaphragms can then be installed at the underside of the joists with blocking installed between each joists at all of the joints in the sub-diaphragms. Blocking should also be placed between every fourth joist outside the areas of the sub-diaphragms. The 4x4 wood members located parallel to the walls at the top of the walls must be preinstalled to the sub-diaphragm before the sub-diaphragm is installed. New wall footings, with reinforcing dowels extending out of the footings can then be placed alongside the existing concrete piers. The new masonry walls can then be constructed. Due to the way in which the walls must be placed under an existing floor, which is not typically the case when building a masonry wall, care must be taken in the sequencing of the wall construction to ensure that all the reinforcing can be placed in the walls. This will require starting the walls, placing the horizontal reinforcing as the height of the walls increase, then placing the vertical reinforcing before the walls reach a height at which point the vertical reinforcing becomes impossible to place. The remaining height of the walls must then be completed by threading the concrete blocks over the vertical reinforcing bars. The anchor bolts can then be placed and the walls grouted solid. Finally the walls are connected to the subdiaphragms using the prefabricated L-shaped top plates with the connectors shown.

The sequence is essentially the same when the walls are aligned with the existing posts, except that the girders must be temporarily shored and existing posts removed. The walls perpendicular to the girders can then be built and the girder supported on top of these walls, then the shoring can be removed and the walls parallel to the girder completed. The details at the top of the load bearing walls are slightly different than the non-load bearing walls as the girders are seated on top of the walls.

It is recommended to consult a structural engineer if these retrofit details cannot be applied directly to a particular house.

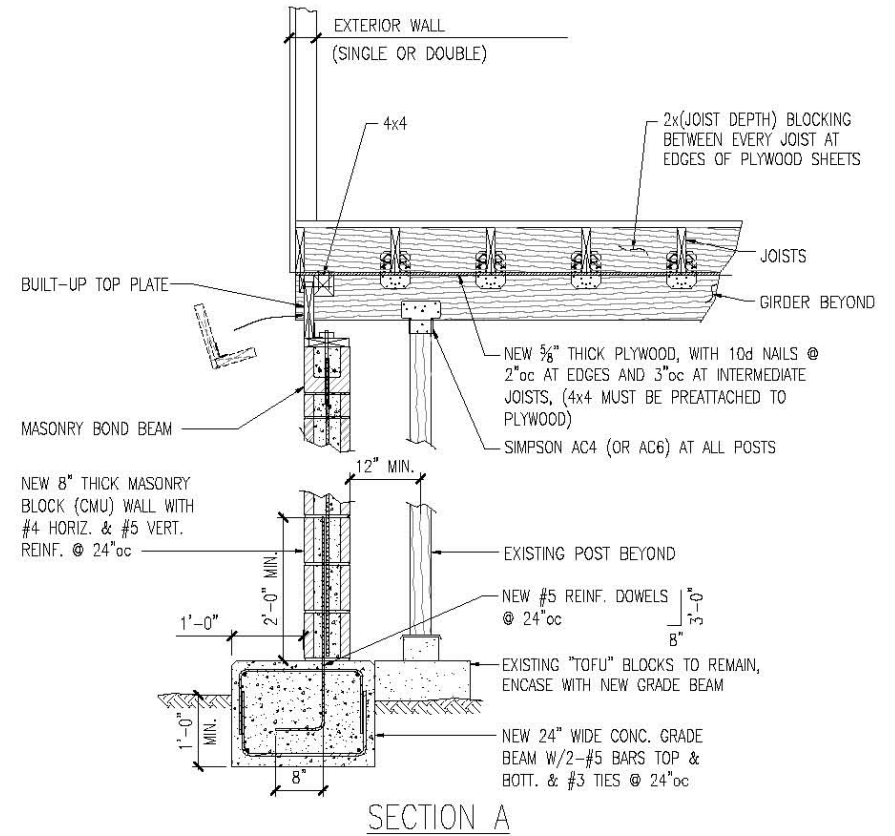
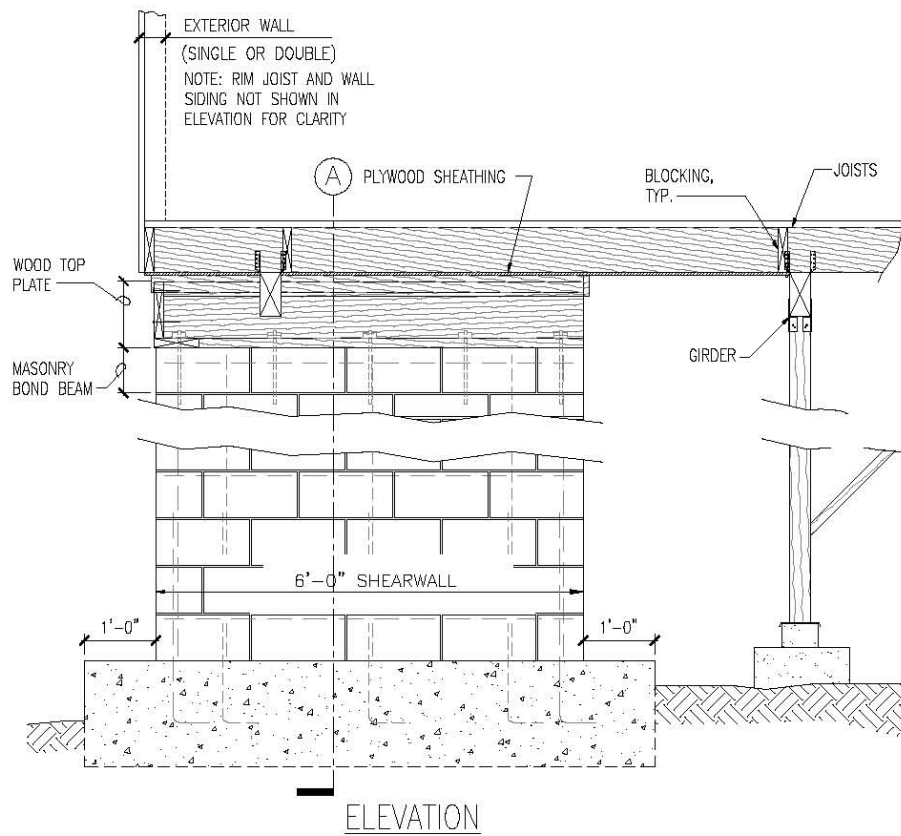


Figure 7-2. Non-load bearing masonry wall retrofit, shear wall parallel to joists

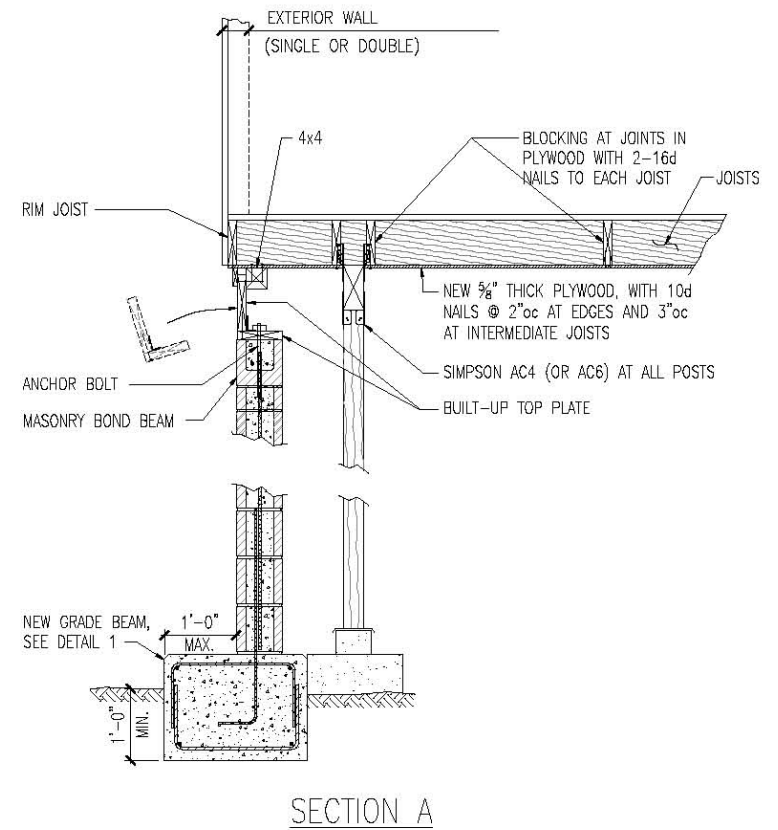
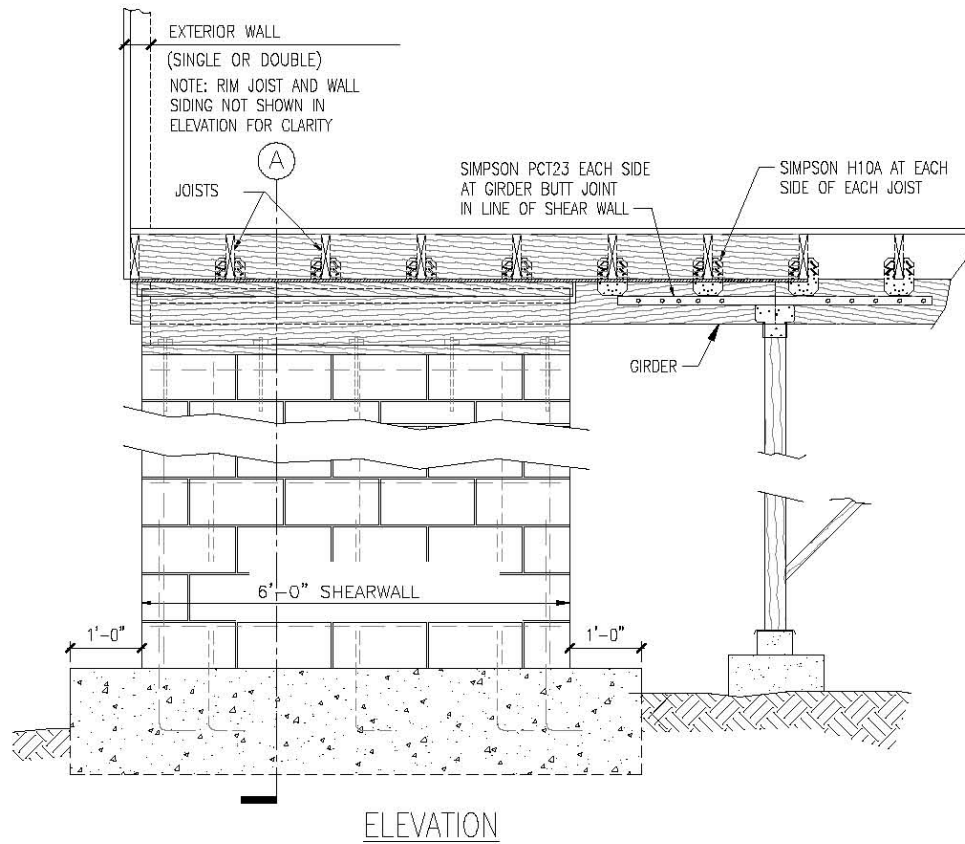


Figure 7-3. Non-load bearing masonry wall retrofit, shear wall parallel to girder

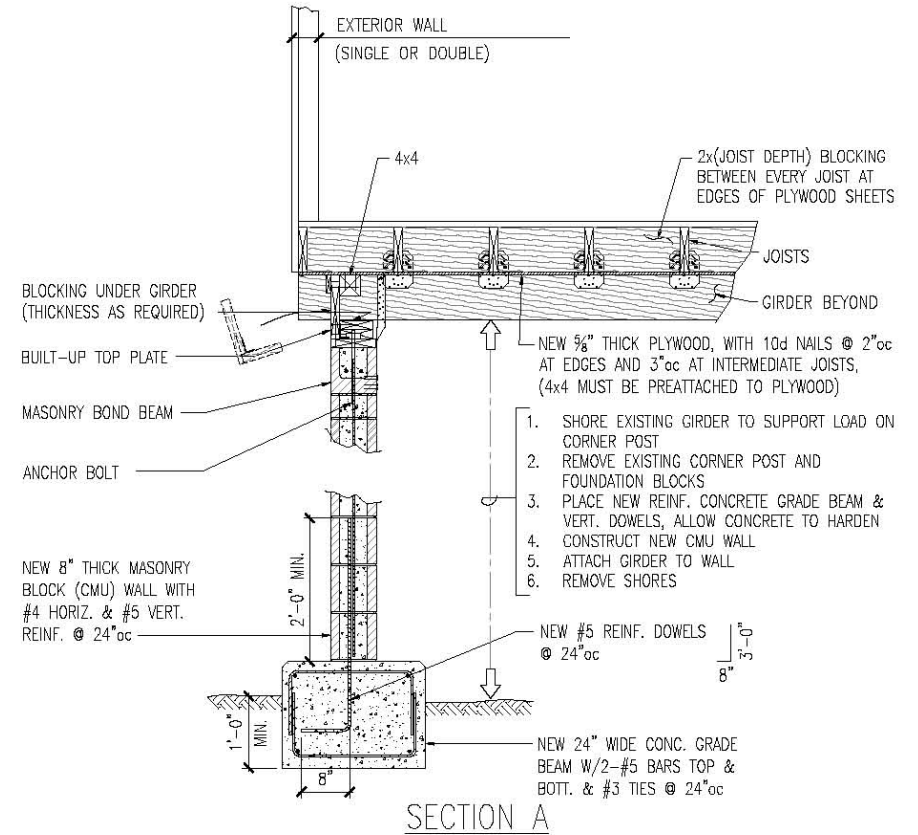
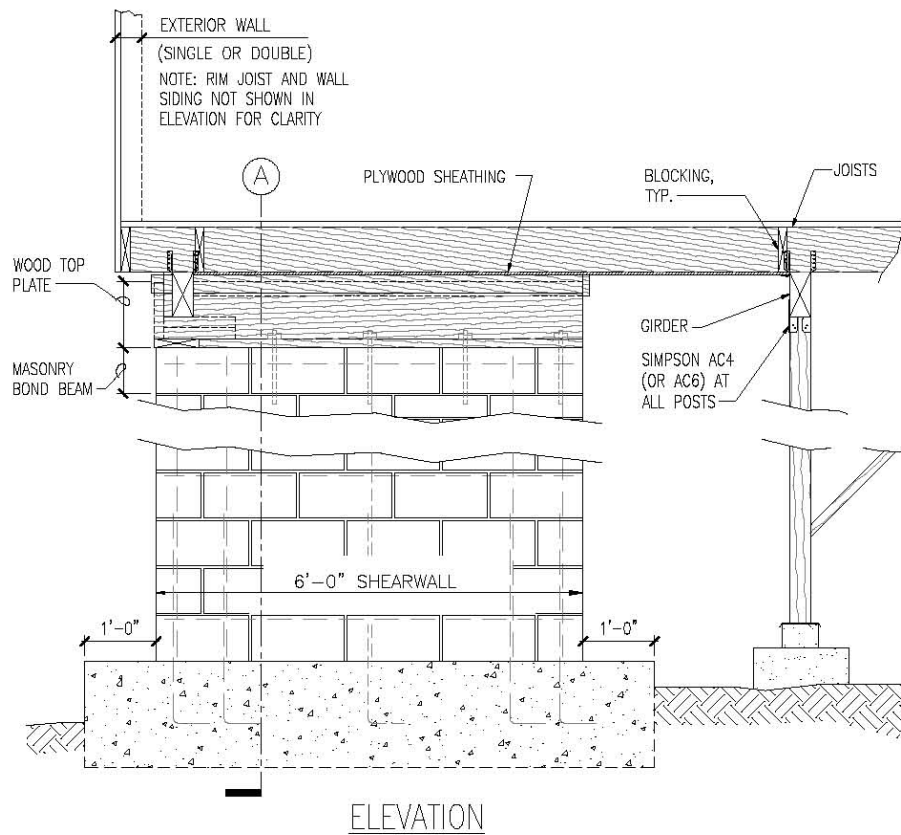


Figure 7-4. Load bearing masonry wall retrofit, shear wall parallel to joists

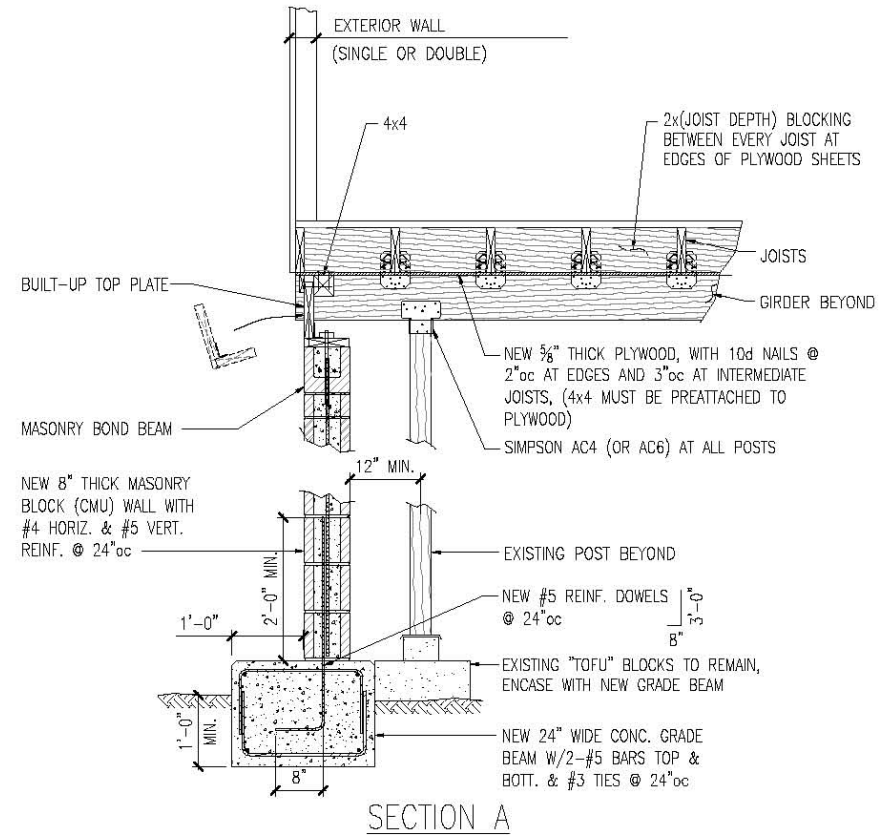
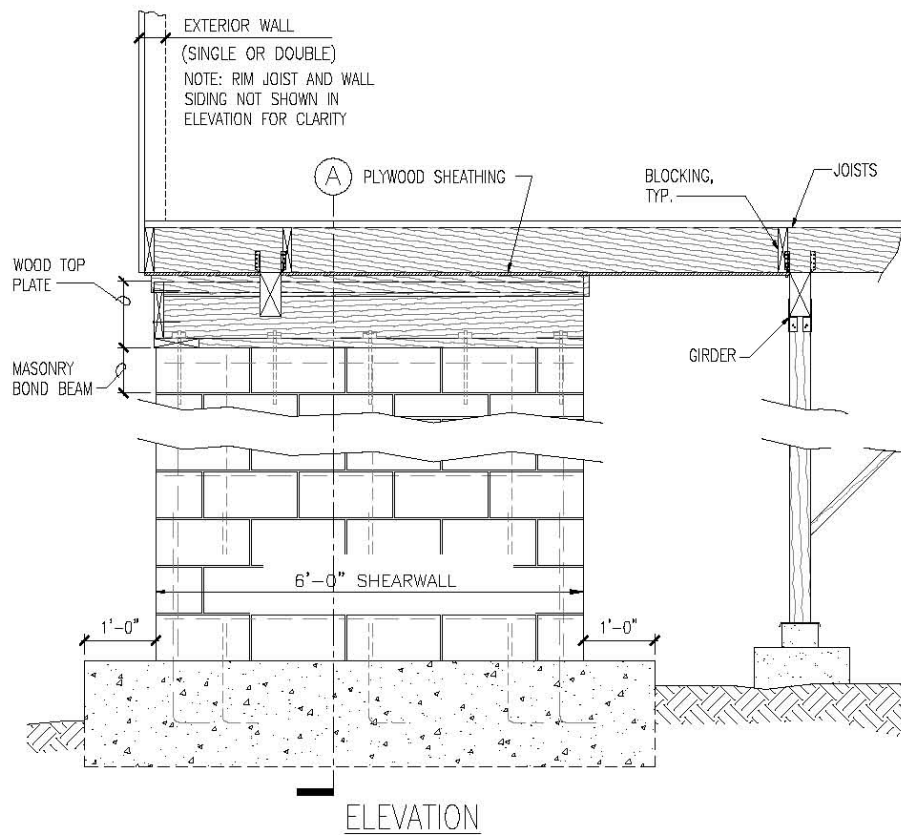


Figure 7-5. Load bearing masonry wall retrofit, shear wall parallel to girder

8. Retrofit of Plumbing and Services

In even a structurally sound house, extensive and costly damage can occur to the contents and non-structural elements in the event of an earthquake. In fact the contents of a house may represent even more of a hazard than the building itself. An effort should be made to secure all large plumbing, mechanical and electrical systems to prevent flooding, fire, and electric shock. Water heaters, furnaces, washers, dryers, and refrigerators should be bolted or strapped in place. Bookshelves, china cabinets, and other furniture should also be secured in high seismic areas. Heavy or breakable items should not be stored on high shelves where they may fall and cause damage or injury. Fire resulting from broken gas lines may be prevented by installing an automatic safety valve at the gas meter, which will shut off the gas during a major earthquake.

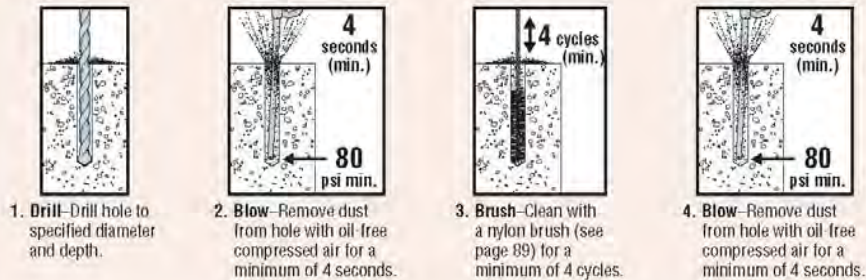
9. References

- American Society of Civil Engineers / Structural Engineering Institute, 2005. *ASCE7 - Minimum Design Loads for Buildings and Other Structures*. ASCE, Reston, Virginia.
- Department of Commerce and Consumer Affairs - State of Hawaii, June 1, 2007. *Loss Mitigation Grant Program – Wind Resistive Devices Technical Specifications – Version 2.1*. DCCA, Honolulu, Hawaii.
http://hawaii.gov/dcca/areas/ins/consumer/consumer_information/hrt
- Earthquake Engineering Research Institute, December, 2006. *Preliminary Observations on the Hawaii Earthquakes on October 15, 2006*. EERI, Oakland, California.
- Earthquake Engineering Research Institute, Structural Engineers Association of Hawaii, University of Hawaii, December 31, 2006. *Compilation of Observations of the October 15, 2006 Kiholo Bay (Mw 6.7) and Mahukona (Mw 6.0) Earthquakes, Hawaii*. Joint Report EERI/SEAOH/UH.
- Chock, G. and Sgambelluri, M., February 2005. *Earthquake Hazards and Estimated Losses in the County of Hawaii*. Department of Civil Defense, State of Hawaii.
- International Code Council, 2006. *International Building Code*. ICC, Country Club Hills, Illinois.
- International Code Council, 2006. *International Existing Building Code*. ICC, Country Club Hills, Illinois.
- Klein, F.W., Frankel, A.D., Mueller, C.S., Wesson, R.L. and Okubo, P.G., 2001. *Seismic hazard in Hawaii: high rate of large earthquakes and probabilistic ground motion maps*. Bulletin of the Seismological Society of America, 91: 479-498.
- Risk Management Solutions, 2006. *2006 Kiholo Bay, Hawaii Earthquake*. RMS Event Report. Newark, California.
- Robertson, I.N., Nicholson, P.G. and Brandes, H.G., October 2006. *Reconnaissance following the October 15, 2006, Earthquakes on the Island of Hawaii*. Research Report UHM/CEE/06-07, University of Hawaii College of Engineering, Department of Civil and Environmental Engineering.
- Wyss M and Koyanagi R (1992). *Isoseismal Maps, Macroseismic Epicenters, and Estimated Magnitudes of Historical Earthquakes in the Hawaiian Islands*. (U.S. Geological Survey Bulletin, 2006

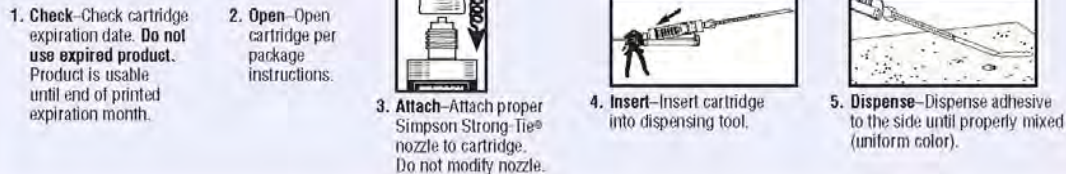
Appendix 1 – Summary Sheets for Three Post and Pier Retrofit Options

1 HOLE PREPARATION: Concrete, Brick, Hollow and Grout-Filled CMU

For horizontal, vertical and overhead applications.



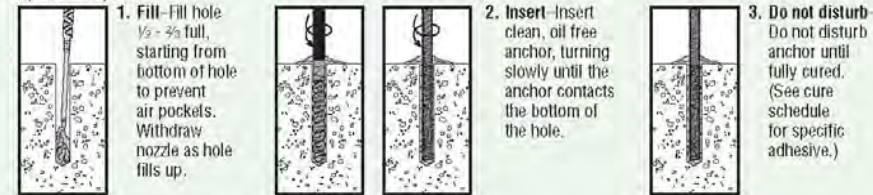
2 CARTRIDGE PREPARATION: For AT, ET, SET and SET-XP™ adhesives



3 FILLING THE HOLE: Vertical Anchorage

Prepare the hole per instructions "Hole Preparation".

Dry and Damp Holes:



Water Filled Holes: (SET or AT only)



- DUAL CARTRIDGE TYPE SIMPSON SET-XP EPOXY (OR EQUAL) SHALL BE USED FOR DRILL AND EPOXY BOLT INSTALLATIONS.
- MINIMUM EMBED DEPTH FOR ALL DRILL AND EPOXY BOLTS IS 4" UNLESS NOTED OTHERWISE

4 DRILL AND EPOXY ANCHOR BOLT INSTALLATION PROCEDURE

NO SCALE

PREFERRED SIMPSON PRODUCT		ALTERNATIVE SIMPSON PRODUCT	
CONNECTOR	FASTENERS	CONNECTOR	FASTENERS
A35	12-8d $\frac{1}{2}$ " NAILS	-	-
AC4 PAIR	28-16d NAILS	-	-
AC6 PAIR	28-16d NAILS	-	-
LCE4 PAIR	24-16d NAILS	-	-
CB5044	14-SDS $\frac{1}{2}$ "x2" SCREWS	CB44	2- $\frac{3}{8}$ "# BOLTS
CB5046	14-SDS $\frac{1}{2}$ "x2" SCREWS	CB46	2- $\frac{3}{8}$ "# BOLTS
CB5066	14-SDS $\frac{1}{2}$ "x2" SCREWS	CB66	2- $\frac{3}{8}$ "# BOLTS
H0U5	14-SDS $\frac{1}{2}$ "x2" SCREWS	-	-
HTT4	18-10d $\frac{1}{2}$ " NAILS	HTT16	18-10d $\frac{1}{2}$ " NAILS
HTT5	26-10d $\frac{1}{2}$ " NAILS	HTT22	32-10d NAILS
H2.5A	10-8d $\frac{1}{2}$ " NAILS	H2.5	10-8d $\frac{1}{2}$ " NAILS
H10A	18-8d $\frac{1}{2}$ " NAILS	H10	16-8d $\frac{1}{2}$ " NAILS
HRS12	14-10d $\frac{1}{2}$ " NAILS	-	-

PREFERRED SIMPSON PRODUCT		ALTERNATIVE SIMPSON PRODUCT	
CONNECTOR	FASTENERS	CONNECTOR	FASTENERS
L90	10-10dx1½" NAILS	-	-
MSTA36	26-10dx1½" NAILS	-	-
MSTC28	36-10dx1½" NAILS	-	-
88L	12-10dx1½" NAILS	-	-
1212L	14-10dx1½" NAILS	-	-
PS723	10-¾" Ø A307 BOLTS	-	-

NOTES:
THE CONNECTORS LISTED ON THE LEFT SIDE OF EACH TABLE ARE THE PREFERRED CONNECTORS AND ARE TYPICALLY REFERENCED IN THE DRAWINGS. THE CONNECTORS LISTED ON THE RIGHT SIDE OF EACH TABLE WHERE APPLICABLE ARE ALTERNATIVE CONNECTORS THAT MAY BE USED IF PREFERRED, BUT GENERALLY HAVE LOWER STRENGTHS AND/OR ARE MORE DIFFICULT TO INSTALL.

5 SIMPSON CONNECTOR SCHEDULE

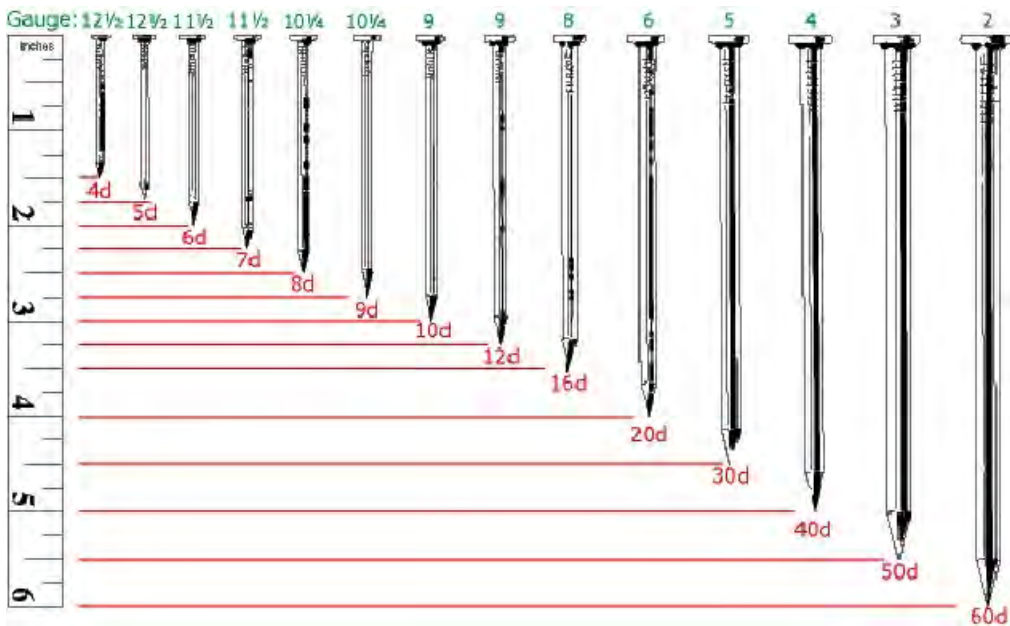
NO SCALE

A.B.	ANCHOR BOLT	FNDN.	FOUNDATION	SCHED.	SCHEDULE
ALT.	ALTERNATE	FL.	FLOOR	SECT.	SECTION
APPROX.	APPROXIMATE	F.O.C.	FACE OF CONCRETE	SHT.	SHEET
ARCH.	ARCHITECTURAL	FIN.	FINISH	SIM.	SIMILAR
(B), BOT.	BOTTOM	FTG.	FOOTING	SL.	SLOPE
BLDG.	BUILDING	GA.	GAUGE	S.O.G.	SLAB-ON-GRADE
BM.	BEAM	GALV.	GALVANIZED	SPECS.	SPECIFICATIONS
BTWN.	BETWEEN	(H),HORIZ.	HORIZONTAL	SQ.	SQUARE
C.I.P.	CAST-IN-PLACE	H.P.	HIGH POINT	S.S.	STAINLESS STEEL
C.J.	CONSTRUCTION JOINT	I.D.	INSIDE DIAMETER	STD.	STANDARD
CL	CENTERLINE	INFO.	INFORMATION	STIFF.	STIFFENER
CLR.	CLEAR(ANCE)	INTERM.	INTERMEDIATE	STRUCT.	STRUCTURAL
CMU	CONCRETE MASONRY UNIT	JT.	JOINT	SYM.	SYMMETRICAL
COL.	COLUMN	LLH	LONG LEG HORIZONTAL	(T)	TOP
CONC.	CONCRETE	LLV	LONG LEG VERTICAL	T&B	TOP & BOTTOM
CONN.	CONNECTION	LONG.	LONGITUDINAL	T.F.	TOP FLANGE
CONST.	CONSTRUCTION	MAX.	MAXIMUM	THRU	THROUGH
CONT.	CONTINUOUS	M.B.	MACHINE BOLT	T.O.F.	TOP OF FOOTING
DBL.	DOUBLE	MECH.	MECHANICAL	T.O.S.	TOP OF SLAB, TOP OF STEEL
DET.	DETAIL	MFR.	MANUFACTURER	T.O.W.	TOP OF WALL
DIA., Ø	DIAMETER	MIN.	MINIMUM	TYP.	TYPICAL
DIM.	DIMENSION	MISC.	MISCELLANEOUS	U.O.N.	UNLESS OTHERWISE NOTED
DWG.	DRAWING	N.T.S.	NOT TO SCALE	(V),VERT.	VERTICAL
EA.	EACH	O.C.	ON CENTER	V.I.F.	VERIFY IN FIELD
E.F.	EACH FACE	O.D.	OUTSIDE DIAMETER	W/	WITH
E.J.	EXPANSION JOINT	O.F.	OPPOSITE FACE		
EL.	ELEVATION	O.H.	OPPOSITE HAND		
ELEV.	ELEVATION, ELEVATOR	OPG.,OPG.	OPENING		
EQ.	EQUAL	OPP.	OPPOSITE		
E.S.	EACH SIDE	PART.	PARTIAL, PARTITION		
E.W.	EACH WAY	PL., R	PLATE		
EXP.	EXPANSION	PT.	POINT		
EXT.	EXTERIOR	R.O.	ROUGH OPENING		
		REINF.	REINFORCED, REINFORCEMENT		
		REQD.	REQUIRED		

2 STRUCTURAL ABBREVIATIONS

NO SCALE

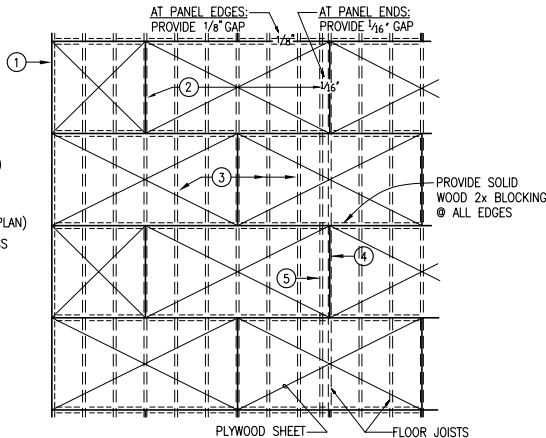
NAIL SIZE CHART



NOTE: NAIL SIZE CHART INDICATES STANDARD COMMON WIRE NAIL SIZE. IN SOME CASES SHORTER NAILS WITH THE SAME DIAMETER MAY BE SPECIFIED. FOR EXAMPLE 10d $\frac{1}{2}$ " NAILS ARE THE SAME DIAMETER AS STANDARD 10d NAILS BUT ONLY $\frac{1}{2}$ " LONG.

NOTES:

- INDICATES BOUNDARY NAILING (SEE PLAN)
- INDICATES EDGE NAILING (SEE PLAN)
- INDICATES INTERMEDIATE NAILING (SEE PLAN)
- INDICATES ADDED 2x JOIST @ PLYWOOD EDGE (SEE PLAN)
- UNEVENLY SPACED TRUSS OR RAFTER (SEE PLAN)
- LONG DIMENSION OF PLYWOOD SHALL RUN ACROSS JOISTS OR RAFTERS
- 2'-0"x4'-0" MIN. SIZE OF PLYWOOD SHEET
- NAILS SHALL HAVE MIN. 3/8" EDGE DISTANCE & SHALL NOT BE OVER-DRIVEN THRU OUTER FACE
- SEE PLANS FOR PLYWOOD THICKNESS AND TYPE
- STAGGER PLYWOOD END JOINTS



3 PLYWOOD SHEATHING LAYOUT & NAILING

NO SCALE

GENERAL

- THESE DRAWINGS AND DETAILS ARE INTENDED FOR USE BY A PERSON EXPERIENCED IN THIS FORM OF CONSTRUCTION WITHOUT THE GENERAL NEED FOR A STRUCTURAL ENGINEER. CONSULT A STRUCTURAL ENGINEER, IF SPECIFIC SITE CONDITIONS ARE SIGNIFICANTLY DIFFERENT FROM THOSE SHOWN IN THESE DRAWINGS OR IF THE CHARACTERISTICS OF THE STRUCTURE ARE OUTSIDE THE RANGE CONSIDERED.

CONCRETE

- ALL CONCRETE UNLESS OTHERWISE NOTED SHALL BE REGULAR WEIGHT HARD ROCK TYPE (150#/CU.FT.).
- ALL NEW CONCRETE SHALL HAVE A 28-DAY COMPRESSIVE STRENGTH OF 4,000 PSI
- MINIMUM CLEAR COVERAGE OF CONCRETE OVER OUTER REINFORCING BARS SHALL BE AS FOLLOWS:
A. CONCRETE POURED DIRECTLY AGAINST EARTH..... 3"
B. FORMED CONCRETE EXPOSED TO EARTH OR WEATHER..... 2"
- ALL REINFORCING BARS, ANCHOR BOLTS AND OTHER CONCRETE INSERTS SHALL BE WELL SECURED IN POSITION PRIOR TO PLACING CONCRETE.
- SOIL AND OTHER FILL MATERIAL BELOW NEW CONCRETE FOOTINGS SHALL BE COMPACTED.

WOOD

- ALL LUMBER FOR POSTS AND FRAMING MEMBERS SHALL BE STRUCTURAL GRADE NO. 1 & BETTER DOUGLAS FIR.
- ALL NAILS SHALL BE GALVANIZED COMMON WIRE NAILS UNLESS OTHERWISE NOTED. BOX OR SINKER NAILS SHALL NOT BE USED UNLESS APPROVED ALTERNATIVES ARE PROVIDED.
- ALL BOLTS SHALL BE GALVANIZED. BOLT HOLES SHALL BE 1/16" LARGER DIAMETER THAN NOMINAL SIZE OF BOLT USED. RETIGHTEN ALL NUTS PRIOR TO CLOSING IN. STANDARD CUT WASHERS SHALL BE USED UNDER BOLT HEADS AND NUTS AGAINST WOOD.
- ALL CONNECTOR REFERENCES ARE FROM "SIMPSON STRONG-TIE COMPANY" CATALOG. ALL CONNECTORS AND THEIR FASTENERS SHALL BE HOT DIPPED GALVANIZED. ALL CONNECTORS EXPOSED TO WEATHER SHALL BE Z-MAX TRIPLE ZINC COATED GALVANIZED.
- STAINLESS STEEL CONNECTORS AND NAILS OR OTHER FASTENERS MAY BE USED AND SHOULD BE USED IN HIGHLY CORROSIVE ENVIRONMENTS SUCH AS IN EXPOSED REGIONS NEAR THE SHORELINE. IF STAINLESS STEEL CONNECTORS ARE USED THEN STAINLESS STEEL FASTENERS MUST ALSO BE USED.
- ALL WOOD AND PLYWOOD PRODUCTS SHALL BE PRESSURE PRESERVATIVE TREATED FOR EXTERIOR EXPOSURE.

CONCRETE MASONRY (CMU)

- CONCRETE BLOCK SHALL BE HOLLOW LOAD-BEARING CONCRETE MASONRY UNITS CONFORMING TO A.S.T.M. C 90 GRADE N-II UNITS, NORMAL WEIGHT.
- REINFORCING BARS - SEE NOTES UNDER 'REINFORCING STEEL' FOR REQUIREMENTS.
- ALL WALLS SHALL BE CONSTRUCTED WITH TYPE S MORTAR. MORTAR MIX SHALL CONFORM TO THE REQUIREMENTS OF TABLE 2103.7(1) OF THE IBC-2003. MORTAR SHALL ATTAIN A MINIMUM COMPRESSIVE STRENGTH OF 1,900 PSI AT 28 DAYS.
- GROUT SHALL CONFORM TO REQUIREMENTS OF TABLE 2103.10 OF THE IBC-2003 FOR FINE GROUT. USE SUFFICIENT WATER FOR GROUT TO FLOW INTO ALL JOINTS OF THE MASONRY WITHOUT SEGREGATION. GROUT SHALL ATTAIN A MINIMUM COMPRESSIVE STRENGTH OF 2,500 PSI AT 28 DAYS.

REINFORCING STEEL

- ALL REINFORCING STEEL SHALL BE PLACED IN CONFORMANCE WITH THE "BUILDING CODE REQUIREMENTS FOR STRUCTURAL CONCRETE" (ACI 318), THE CRSI "MANUAL OF STANDARD PRACTICE," AND THE "ACI DETAILING MANUAL" (SP-66)
- REINFORCING BARS SHALL CONFORM TO ASTM A-615 GRADE 60 REQUIREMENTS.
- ALL REINFORCING BAR BENDS SHALL BE MADE COLD.
- DOWELS BETWEEN FOOTING AND WALL SHALL BE THE SAME GRADE, SIZE AND SPACING OR NUMBER AS THE VERTICAL REINFORCING.
- WELDING OF REINFORCING STEEL IS NOT PERMITTED
- REINFORCING BARS SHALL BE AS LONG AS PRACTICABLE AND AS DETAILED AND SHALL BE LAPPED AT SPLICES AND CORNERS NOT LESS THAN 32 BAR DIAMETER (24" MINIMUM). STAGGER HORIZONTAL WALL BAR SPLICES. IN GENERAL, BAR SPLICES SHALL BE MADE AT POINTS OF MINIMUM STRESS.

CONCRETE REINFORCING DOWEL NOTES

- AT INTERFACE BETWEEN NEW AND EXISTING CONCRETE, PROVIDE THE FOLLOWING MINIMUM DOWELING:
A. NEW FOUNDATION TO EXISTING FOUNDATION: DRILL AND EPOXY #4x2'-0" LONG DOWELS @18"o.c. MAX. (2 DOWELS MIN.), U.O.N. DO NOT UNDERMINE EXISTING FOOTING.
- EPOXIED REBAR DOWELS SHALL CONFORM TO THE FOLLOWING:
A. UNLESS OTHERWISE NOTED, THE DIAMETER OF THE HOLE RECEIVING THE DOWELS SHALL BE $\frac{1}{4}$ " LARGER THAN THE DIAMETER OF THE REBAR DOWEL.
B. ALL HOLES SHALL BE COMPLETELY FREE OF CONCRETE DUST, DIRT, WATER, ETC., PRIOR TO EPOXY GROUTING REBAR.
C. DUAL CARTRIDGE TYPE SIMPSON SET-XP™ HIGH STRENGTH EPOXY IS REQUIRED.

1 TECHNICAL NOTES



STRUCTURAL SEISMIC RETROFITS FOR HAWAII SINGLE FAMILY RESIDENCES WITH POST AND PIER FOUNDATIONS

TYPICAL DETAIL SHEET

The original size of this drawing is 22"x34". It can be reproduced at 1/2 size on 11"x17" paper

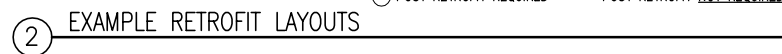
GENERAL NOTES FOR ALL RETROFIT OPTIONS

DATE

05/15/09

SHEET NO.

0



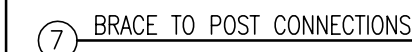
RETROFIT SCHEDULE TABLE (EXTERIOR POST, INTERIOR POST)		
LEVEL	EXTERIOR POST	INTERIOR POST
A	EVERY POST	EVERY POST
B	CORNERS AND EVERY OTHER POST	EVERY OTHER POST
C	CORNER POSTS ONLY	NONE

IF THE TABLE READS "N/A" FOR THE ATTRIBUTES OF A GIVEN HOUSE THIS RETROFIT OPTION CANNOT PROVIDE THE REQUIRED LATERAL RESISTANCE AGAINST EARTHQUAKE FORCES. CONSIDER APPLYING RETROFIT OPTION 2 OR 3.



DETERMINE THE RETROFIT LEVEL REQUIRED FOR YOUR HOME.
EXTERIOR POST RETROFIT LEVEL: _____, INTERIOR POST RETROFIT LEVEL: _____ (A, B, C OR N/A)

6. DETERMINE A RETROFIT LAYOUT FOR YOUR HOME SIMILAR TO ONE OF THOSE SHOWN IN DETAIL ②.



FEMA

STRUCTURAL SEISMIC REINFORCEMENT FOR HAWAII SINGLE FAMILY RESIDENCES WITH POST AND PIER FOUNDATIONS

116

The original size of this drawing is 22"x34". It can be reproduced at 1/2 size on 11"x17" paper

REINFORCEMENT - POST, PIER, AND BRACE RETROFIT

15/09

ET NO.



GENERAL INSTRUCTIONS

TO DETERMINE IF YOUR HOME QUALIFIES FOR THIS RETROFIT OPTION PLEASE FOLLOW THE FOLLOWING PROCEDURES:

1. DETERMINE THE REGION IN WHICH YOUR HOME EXISTS.



REGION: _____ .

2. DETERMINE THE TOTAL FLOOR AREA, THE MAXIMUM AND MINIMUM POSTS HEIGHTS AND FIND THE RATIO OF THE MAXIMUM HEIGHT DIVIDED BY THE MINIMUM HEIGHT.

TOTAL FLOOR AREA: _____ (FT²)
 MAX POST HEIGHT: _____ (FT)
 MIN POST HEIGHT: _____ (FT)
 MAX/MIN POST HEIGHT: _____
 MAX TYPICAL POST SPACING: _____ (FT)
3. DETERMINE THE MAXIMUM TYPICAL POST SPACING (EXCLUDE ODD OR IRREGULAR SPACINGS).
4. ENTER THE RETROFIT LEVEL SELECTION TABLE ② WITH THIS INFORMATION.
5. DETERMINE THE RETROFIT LEVEL REQUIRED FOR YOUR HOME FOR A SELECTED LENGTH OF WALL SEGMENT.


RETROFIT LEVEL: _____ (A, B, C OR N)


IF THE TABLE READS "N" FOR THE ATTRIBUTES OF A GIVEN HOUSE, THIS RETROFIT CAN NOT PROVIDE THE REQUIRED LATERAL RESISTANCE AGAINST EARTHQUAKE FORCES, GO TO DRAWING SHEET 3 TO DETERMINE IF THE MASONRY SHEARWALL RETROFIT IS APPLICABLE.
6. DETERMINE A RETROFIT LAYOUT FOR YOUR HOME SIMILAR TO ONE OF THOSE SHOWN IN DETAIL 1. FOR RETROFIT LEVEL A USE A WALL WITH SHEATHING ON ONE SIDE (TYPICALLY THE OUTSIDE) BETWEEN ONE PAIR OF POSTS ON EACH OF THE FOUR SIDES OF HOUSE. FOR RETROFIT LEVEL B USE A WALL SHEATHED ON ONE SIDE (TYPICALLY THE OUTSIDE) BETWEEN POSTS IN TWO LOCATIONS ON EACH SIDE OF THE HOUSE (TYPICALLY AT THE TWO CORNERS). FOR RETROFIT LEVEL C USE THE SAME WALL CONFIGURATION AT FOR RETROFIT LEVEL B BUT USE PLYWOOD SHEATHING ON BOTH SIDES OF THE WALL.
7. DETERMINE WHETHER THE SHEAR WALLS ARE TO BE LINE WITH THE POSTS OR OFFSET FROM THE POSTS. IF THE WALLS ARE IN LINE WITH THE POSTS USE DETAILS 1 AND 2 ON SHEET 2B. IF THE WALLS ARE TO BE OFFSET FROM THE POSTS USE DETAILS 3 AND 4 ON SHEET 2B.

NOTES:

- A. THE APPLICATION OF THIS RETROFIT IS LIMITED TO HOUSES OF TWO STORIES OR LESS. WHEN GREATER THAN TWO STORIES THE RETROFIT OF A HOUSE SHOULD BE EVALUATED BY A STRUCTURAL ENGINEER.
- B. SEE DRAWING SHEET 0 FOR ADDITIONAL NOTES AND TYPICAL DETAILS AND DRAWING SHEET 2B FOR OTHER DETAILS.



 INDICATES EXTENTS OF PLYWOOD SUB-DIAPHRAGM, SEE DETAILS

 INDICATES ALTERNATE EXTENTS OF PLYWOOD SUB-DIAPHRAGM, SEE DETAILS

NOTES:

1. IN THE TABLE THREE LETTERS ARE GIVEN IN EACH CELL. THESE LETTERS REPRESENT THE RETROFIT LEVEL FOR THE LENGTH OF NEW SHEAR WALLS:

- THE 1ST LETTER GIVES THE RETROFIT LEVEL FOR 8 FT SHEAR WALL SEGMENTS,
- THE 2ND LETTER GIVES THE RETROFIT LEVEL FOR 10 FT SHEAR WALL SEGMENTS,
- THE 3RD LETTER GIVES THE RETROFIT LEVEL FOR 12 FT SHEAR WALL SEGMENTS.

2. RETROFIT LEVELS:
- A - SHEAR WALL WITH PLYWOOD SHEATHING ON 1 SIDE OF THE WALL IN 1 BAY ON EACH SIDE OF A HOUSE.
- B - SHEAR WALL WITH PLYWOOD SHEATHING ON 1 SIDE OF THE WALL IN 2 BAYS ON EACH SIDE OF A HOUSE.

- C - SHEAR WALL WITH PLYWOOD SHEATHING ON BOTH SIDES OF THE WALL IN 2 BAYS ON EACH SIDE OF A HOUSE.

- N - RETROFIT IS NOT APPLICABLE FOR A GIVEN LENGTH OF WALL. CONSIDER EITHER LONGER PLYWOOD SHEAR WALLS OR MASONRY SHEAR WALLS (RETROFIT OPTION 3)

3. FOR A TWO-STORY STRUCTURE THE FLOOR AREA SHALL BE THE SUM OF THE FLOOR AREAS OF THE FIRST AND SECOND STORIES.

Max Post Height (ft)		h ≤ 4 (ft)						4 < h ≤ 6 (ft)						6 < h ≤ 9 (ft)						9 < h ≤ 12 (ft)						
Max/Min Post Height Ratio		r=1	1<r≤1.5	1.5<r≤2	2<r≤3	3<r≤4	r=1	1<r≤1.5	1.5<r≤2	2<r≤3	3<r≤4	4<r≤6	r=1	1<r≤1.5	1.5<r≤2	2<r≤3	3<r≤4	4<r≤6	r=1	1<r≤1.5	1.5<r≤2	2<r≤3	3<r≤4	4<r≤6	6<r≤9	
Min Length of Wall Segment (ft)		8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	8,10,12	
Floor Area ≤ 1000 sf																										
Region	1	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	B,A,A	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,A,A	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A
	2	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	B,A,A	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,A,A	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A
	3	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	A,A,A	B,A,A	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,A,A	A,A,A	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A
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	4b	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,A	B,B,A	B,B,B	C,B,B	C,B,B	C,B,B	C,B,B	B,B,A	B,B,B	B,B,A	C,B,B	C,B,B	C,B,B	C,C,B	B,B,A	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B
1000 sf < Floor Area ≤ 1500 sf																										
Region	1	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,B	B,B,B	B,B,B	B,B,B	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,B
	2	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,B	B,B,B	B,B,B	B,B,B	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,B
	3	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	B,B,B	A,A,A	B,A,A	B,A,A	B,B,B	B,B,B	B,B,B	B,B,B	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,B
	4a	B,B,A	B,B,B	B,B,B	B,B,B	C,B,B	B,B,A	B,B,B	B,B,B	C,B,B	C,B,B	C,B,B	B,B,B	B,B,B	B,B,A	C,C,B	C,C,B	C,C,B	C,C,B	B,B,A	C,B,B	C,C,B	C,C,B	C,C,C	C,C,C	C,C,C
	4b	B,B,A	C,B,B	C,B,B	C,C,B	C,C,B	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	C,C,B	C,C,B	C,C,B	C,C,C	C,C,C	C,C,C	C,C,C	C,C,B	C,B,B	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C
1500 sf < Floor Area ≤ 2000 sf																										
Region	1	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	B,B,B	A,A,A	B,A,A	B,A,A	B,B,B	B,B,B	B,B,B	B,B,B	A,A,A	C,B,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,B
	2	A,A,A	A,A,A	B,A,A	B,A,A	B,B,A	A,A,A	B,A,A	B,A,A	B,B,A	B,B,A	B,B,B	A,A,A	B,A,A	B,A,A	B,B,B	B,B,B	B,B,B	B,B,B	A,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	B,B,B
	3	B,A,A	B,A,A	B,B,A	B,B,B	B,B,B	B,A,A	B,B,A	B,B,B	B,B,B	B,B,B	C,B,B	B,A,A	B,B,B	B,B,B	C,B,B	C,B,B	C,B,B	C,B,B	B,A,A	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B
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2000 sf < Floor Area ≤ 2500 sf																										
Region	1	B,B,A	B,B,B	B,B,B	B,B,B	C,B,B	B,B,A	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B	B,B,B	B,B,B	C,B,B	C,C,B	C,C,B	C,C,B	C,C,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	C,C,C	C,C,C
	2	B,B,A	B,B,B	B,B,B	B,B,B	C,B,B	B,B,A	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	B,B,B	B,B,B	C,C,B	C,C,B	C,C,B	C,C,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	C,C,C	C,C,C
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2500 sf < Floor Area ≤ 3000 sf																										
Region	1	B,B,B	B,B,B	C,B,B	C,B,B	C,C,B	B,B,B	C,B,B	C,B,B	C,C,B	C,C,B	C,C,C	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	C,C,C	B,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	C,C,C
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	4a	C,C,B	C,C,C	C,C,C	C,C,C	N,C,C	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C	N,C,C	N,C,C	C,C,B	N,C,C	N,C,C	N,C,C	N,C,C	N,C,C	N,C,C
	4b	C,C,C	N,C,C	N,C,C	N,N,C	N,N,C	C,C,C	N,C,C	N,N,C	N,N,N	N,N,N	N,N,N	N,C,C	N,N,C	N,N,C	N,N,N	N,N,N	N,N,N	N,N,N	C,C,C	N,N,C	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N
3000 sf < Floor Area ≤ 4000 sf																										
Region	1	C,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	C,C,C	C,B,B	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C	N,N,C	N,N,C
	2	C,B,B	C,B,B	C,C,B	C,C,C	C,C,C	C,B,B	C,C,B	C,C,C	C,C,C	C,C,C	C,C,C	C,B,B	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C	C,C,B	C,C,C	C,C,C	N,C,C	N,C,C	N,C,C	N,N,C	N,N,C
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	4b	N,C,C	N,N,C	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,C	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N	N,N,N



STRUCTURAL SEISMIC RETROFITS FOR HAWAII SINGLE
FAMILY RESIDENCES WITH POST AND PIER FOUNDATIONS

TYPICAL DETAIL SHEET

The original size of this drawing is 22"x34". It can be reproduced at 1/2 size on 11"x17" paper

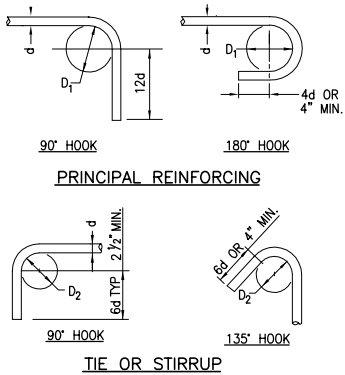
RETROFIT 2 - PLYWOOD SHEAR WALL RETROFIT NOTES AND LAYOUTS

DATE _____

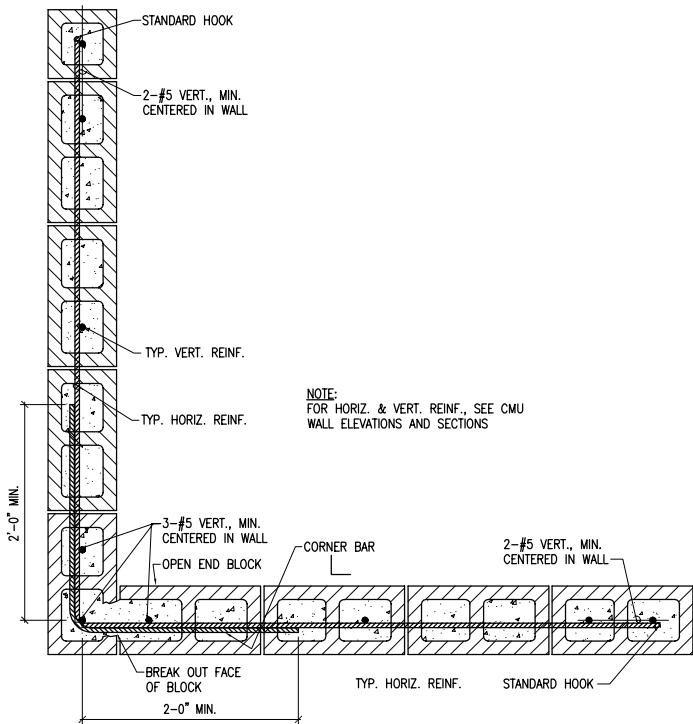
05/15/09

SHEET NO.

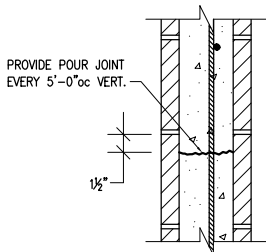
2A



2 TYPICAL REINFORCING BAR BEND DETAILS



3 TYPICAL CMU WALL REINFORCING END DETAILS



4 TYPICAL VERTICAL CONSTRUCTION JOINT IN MASONRY WALL

GENERAL INSTRUCTIONS

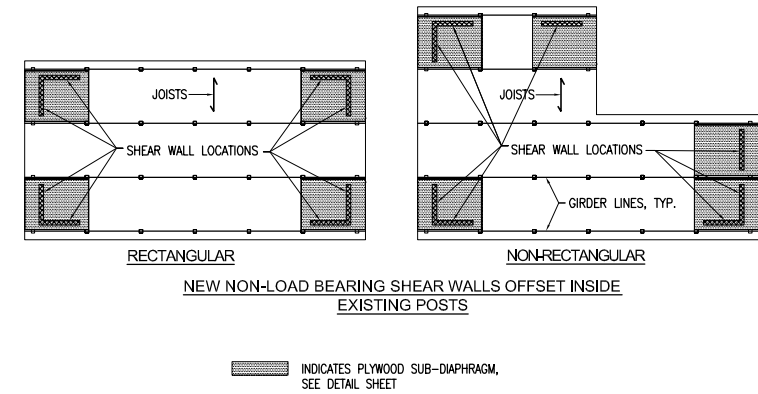
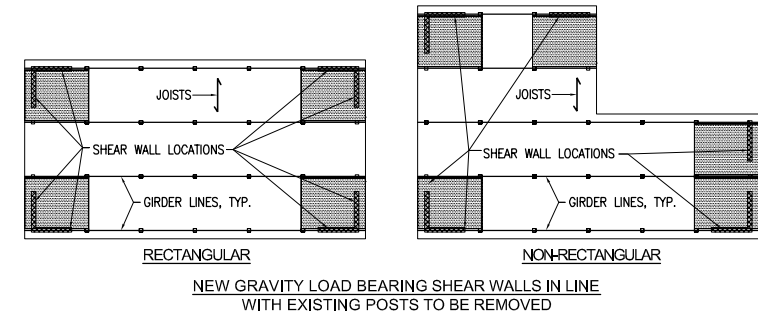
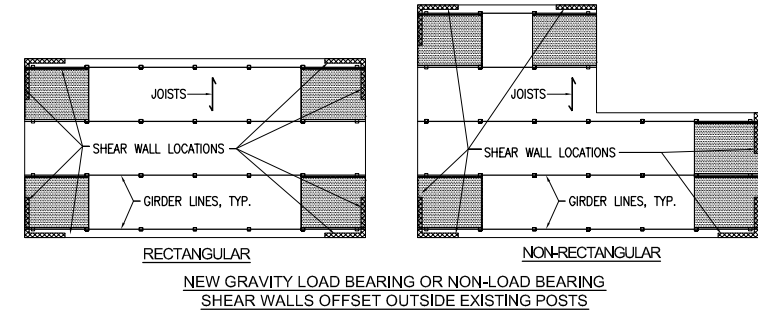
THIS RETROFIT OPTION MAY BE USED FOR ANY EXISTING POST AND PIER HOUSE, IN ANY REGION OF HAWAII PROVIDED THAT THE TOTAL FLOOR AREA IS LESS THAN 4000 FT², THE MAXIMUM POST HEIGHT IS LESS THAN 12 FT, THE MAXIMUM TYPICAL POST SPACING IS LESS THAN 12 FT, AND THE HOUSE HAS NO MORE THAN TWO STORIES. IF THE ATTRIBUTES OF A HOUSE FALL OUTSIDE THESE LIMITS A STRUCTURAL ENGINEER SHOULD BE CONSULTED TO DETERMINE IF THIS RETROFIT OPTION WILL PROVIDE ADEQUATE LATERAL RESISTANCE FOR THE DESIGN EARTHQUAKE FORCES.

ALTERNATIVES FOR THIS RETROFIT ARE PROVIDED BASED ON THE CONDITIONS OF EITHER JOISTS WITH OR WITHOUT OVERHANGS BEYOND THE EXTERIOR GIRDERS. FOR THESE ALTERNATIVES EITHER THE EXISTING CORNER POSTS CAN BE REMOVED OR THE CORNER POSTS REMAIN. IF THE CORNER POSTS ARE REMOVED THE LOAD BEARING WALL DETAILS MUST BE USED.

IT IS RECOMMENDED THAT A LICENSED CONTRACTOR BE HIRED TO ADVISE THE ALTERNATIVE BEST SUITED FOR A PARTICULAR HOME BASED ON THE SITE CONDITIONS, AND TO CONSTRUCT THIS RETROFIT.

ANY EXISTING MASONRY SHEAR WALLS SHOULD BE FULLY GROUTED WITH A COMPLETE LOAD PATH PRESENT, AND MADE TO COMPLY WITH THE DETAILS OF THIS RETROFIT.

ROCK WALLS GENERALLY HAVE NO RELIABLE LATERAL LOAD RESISTING CAPACITY DURING EARTHQUAKES, AND SHOULD NOT BE UTILIZED AS SHEARWALLS.



1 HOUSE FOUNDATION PLANS SHOWING EXAMPLE RETROFIT LAYOUTS



STRUCTURAL SEISMIC RETROFITS FOR HAWAII SINGLE FAMILY RESIDENCES WITH POST AND PIER FOUNDATIONS

TYPICAL DETAIL SHEET

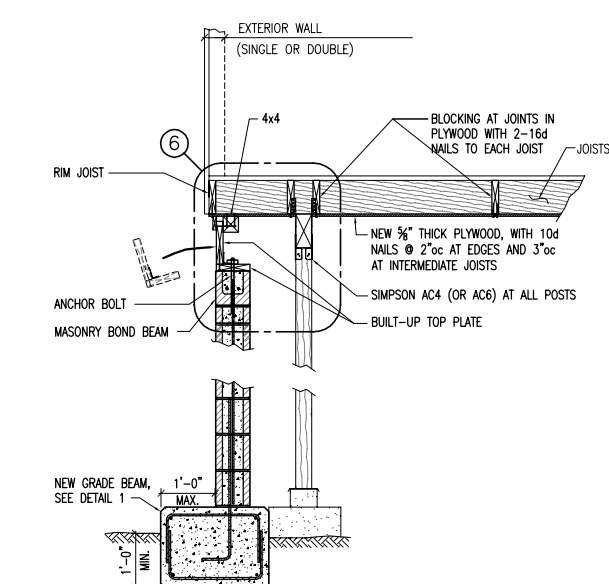
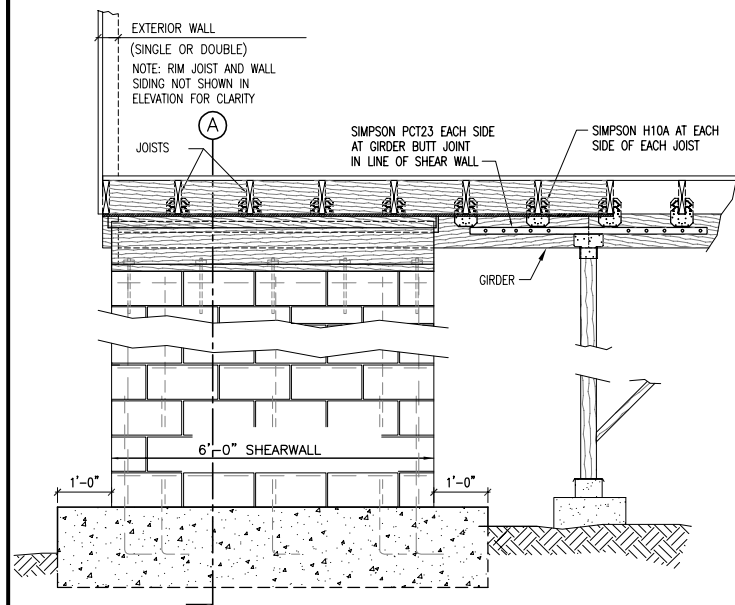
The original size of this drawing is 22"x34". It can be reproduced at 1/2 size on 11"x17" paper

RETROFIT 3 - MASONRY SHEAR WALL RETROFIT

DATE
05/15/09

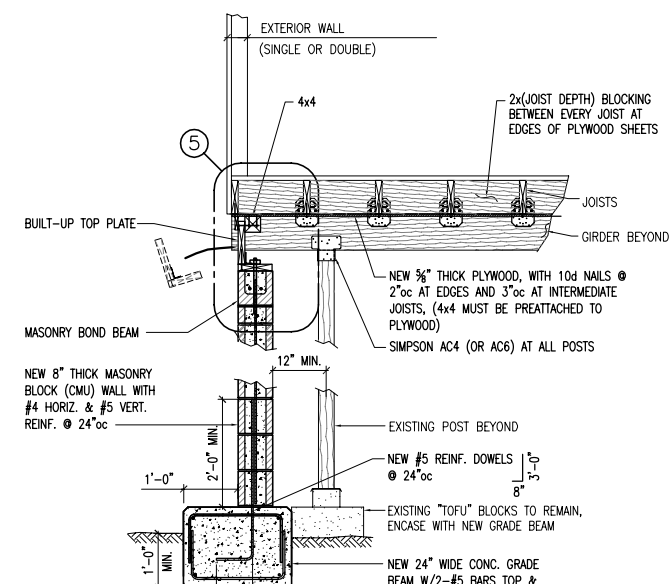
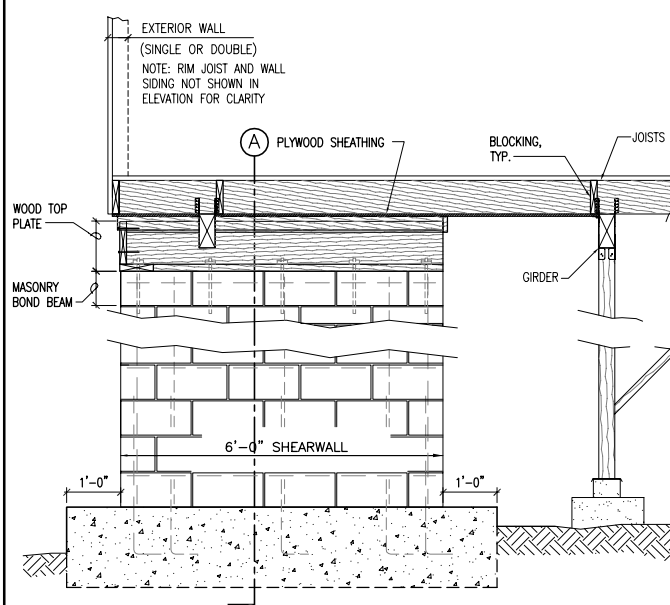
SHEET NO.

3A



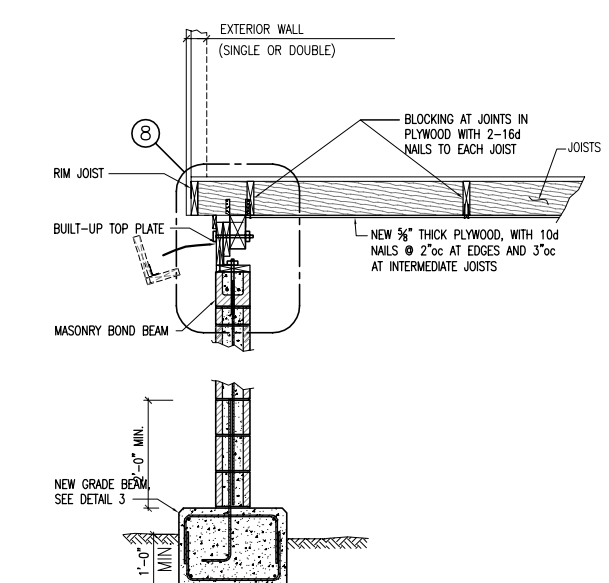
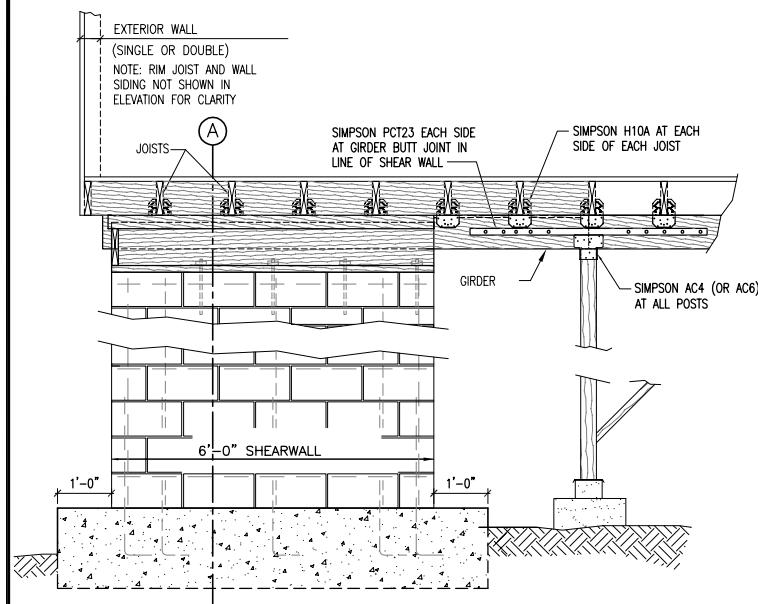
SECTION

2 MASONRY SHEAR WALL ELEVATION FOR WALL PARALLEL TO JOISTS (NOT GRAVITY LOAD BEARING - WALL OFFSET FROM POSTS)



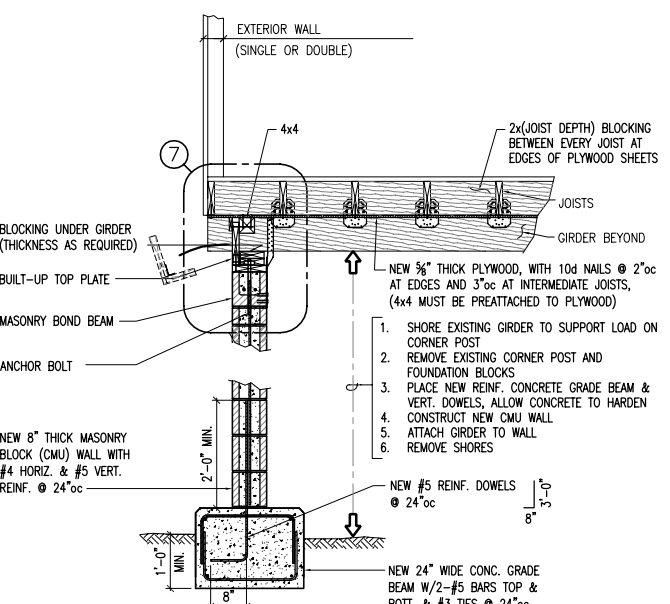
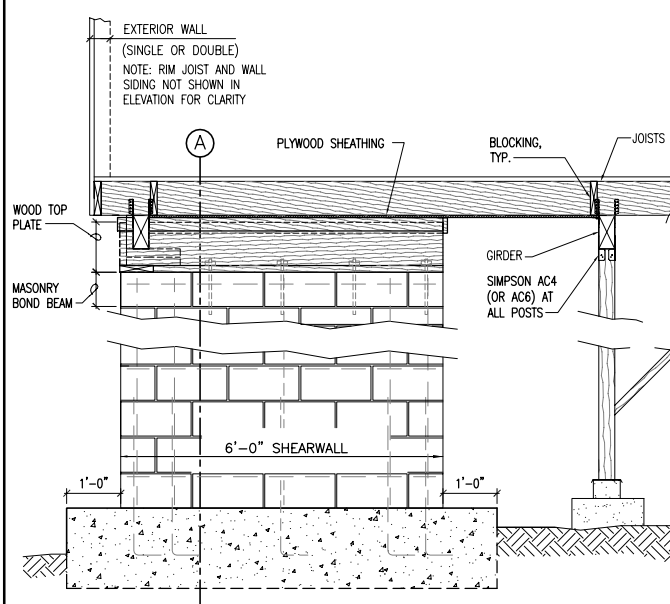
SECTION

1 MASONRY SHEAR WALL ELEVATION FOR WALL PARALLEL TO GIRDERS (NOT GRAVITY LOAD BEARING)



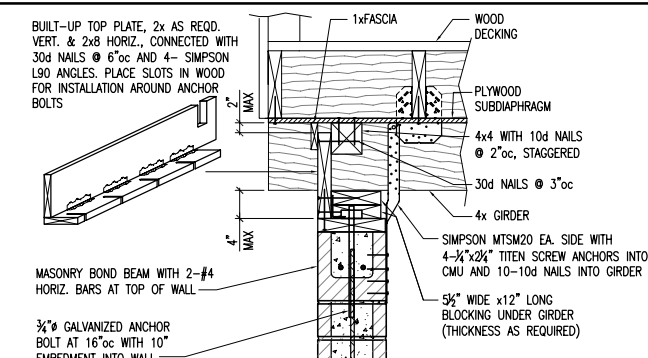
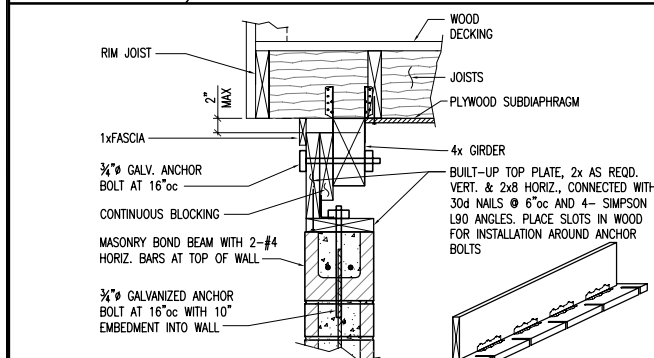
SECTION

4 GRAVITY LOAD BEARING MASONRY SHEAR WALL ELEVATION FOR WALL PARALLEL TO JOISTS (WALL ALIGNED WITH EXISTING POSTS)

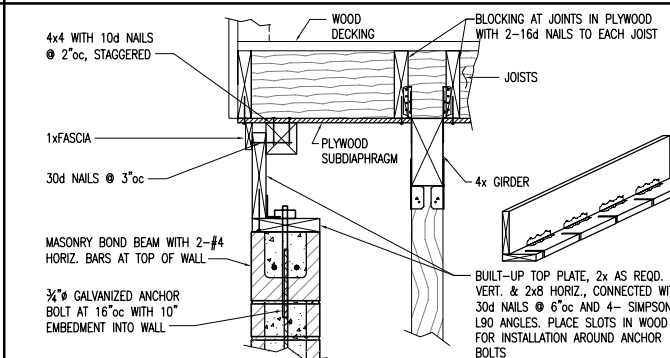


SECTION

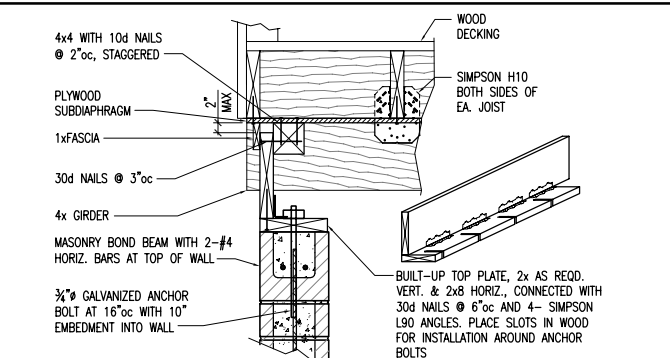
3 LOAD BEARING MASONRY SHEAR WALL ELEVATION FOR WALL PARALLEL TO GIRDERS



7 LOAD BEARING WALL TO FLOOR CONNECTION DETAIL



6 WALL TO FLOOR SUB-DIAPHRAGM CONNECTION DETAIL



5 WALL TO FLOOR SUB-DIAPHRAGM CONNECTION DETAIL

8 LOADING BEARING WALL TO GIRDER CONNECTION DETAIL



STRUCTURAL SEISMIC RETROFITS FOR HAWAII SINGLE FAMILY RESIDENCES WITH POST AND PIER FOUNDATIONS

TYPICAL DETAIL SHEET

The original size of this drawing is 22"x34". It can be reproduced at 1/2 size on 11"x17" paper

RETROFIT 3 - MASONRY SHEAR WALL RETROFIT

DATE

05/15/09

SHEET NO.

3B

Appendix 2 – Statistical Data from Surveys of Post and Pier Houses in Hawaii County

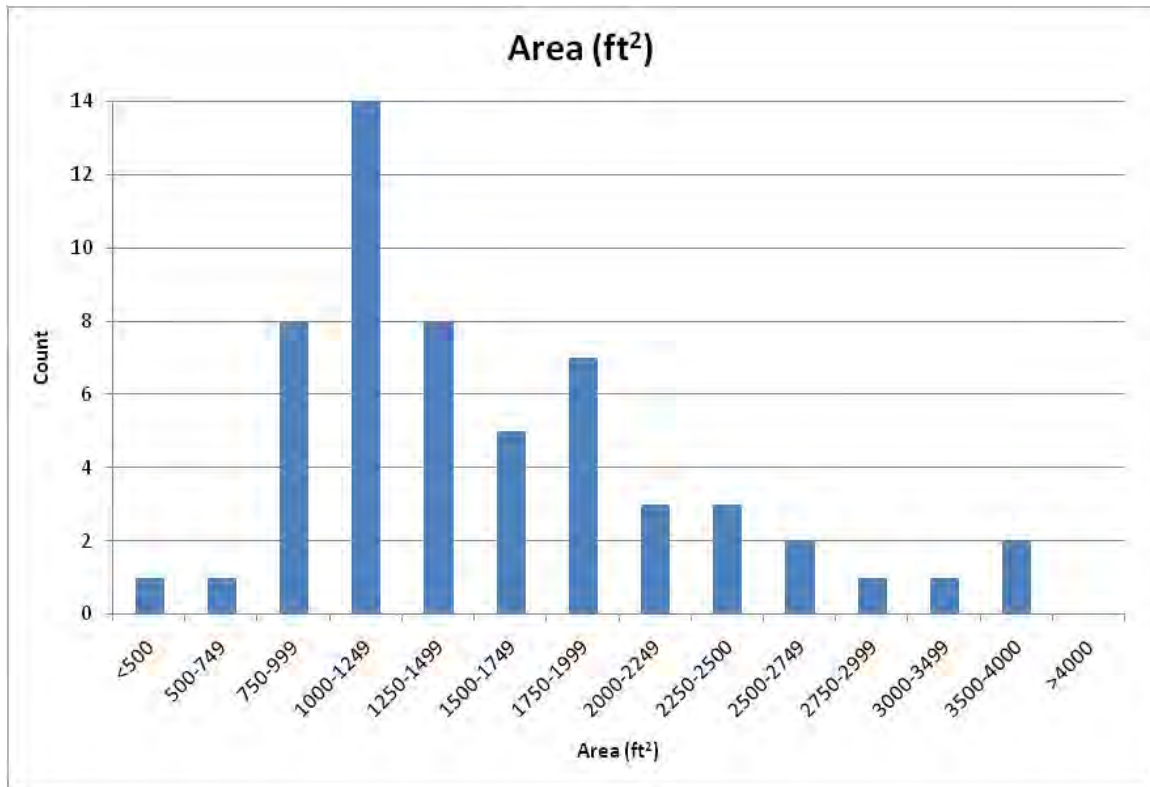


Figure A2-0-1 – Total gross area of homes surveyed

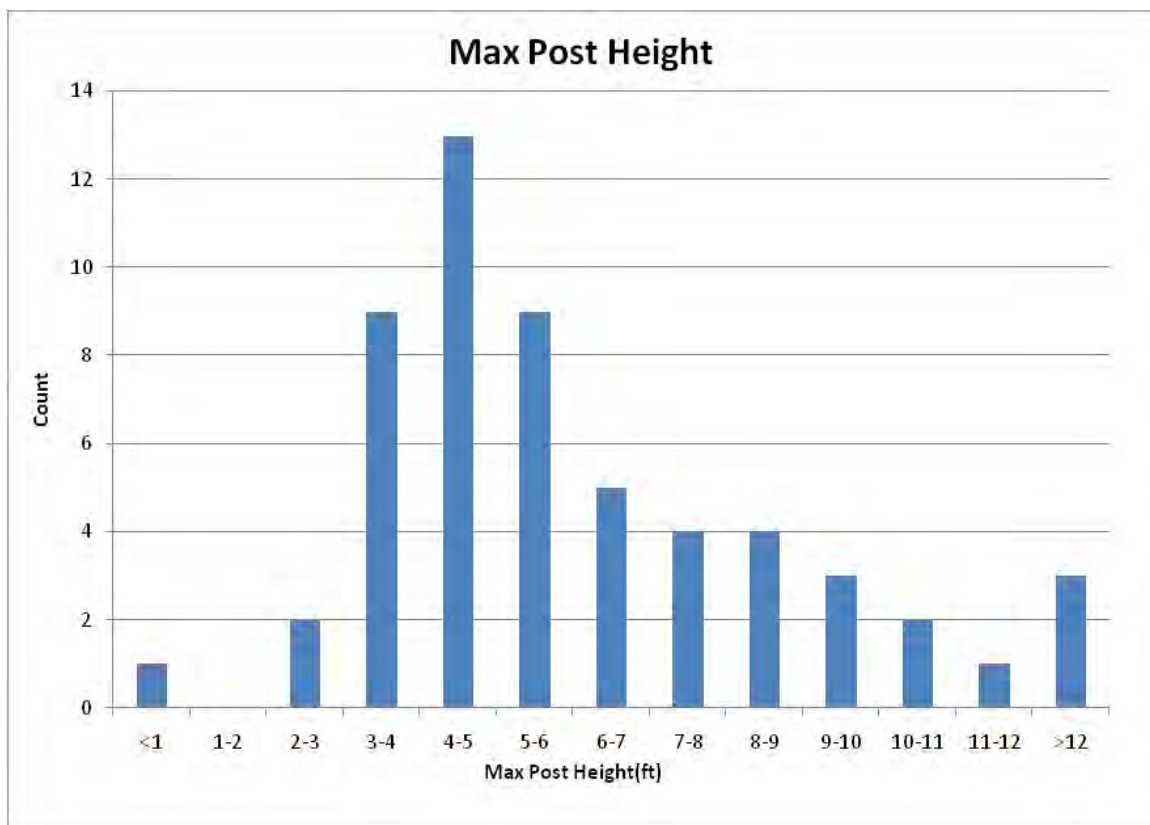


Figure A2-0-2 – Maximum post heights of homes surveyed

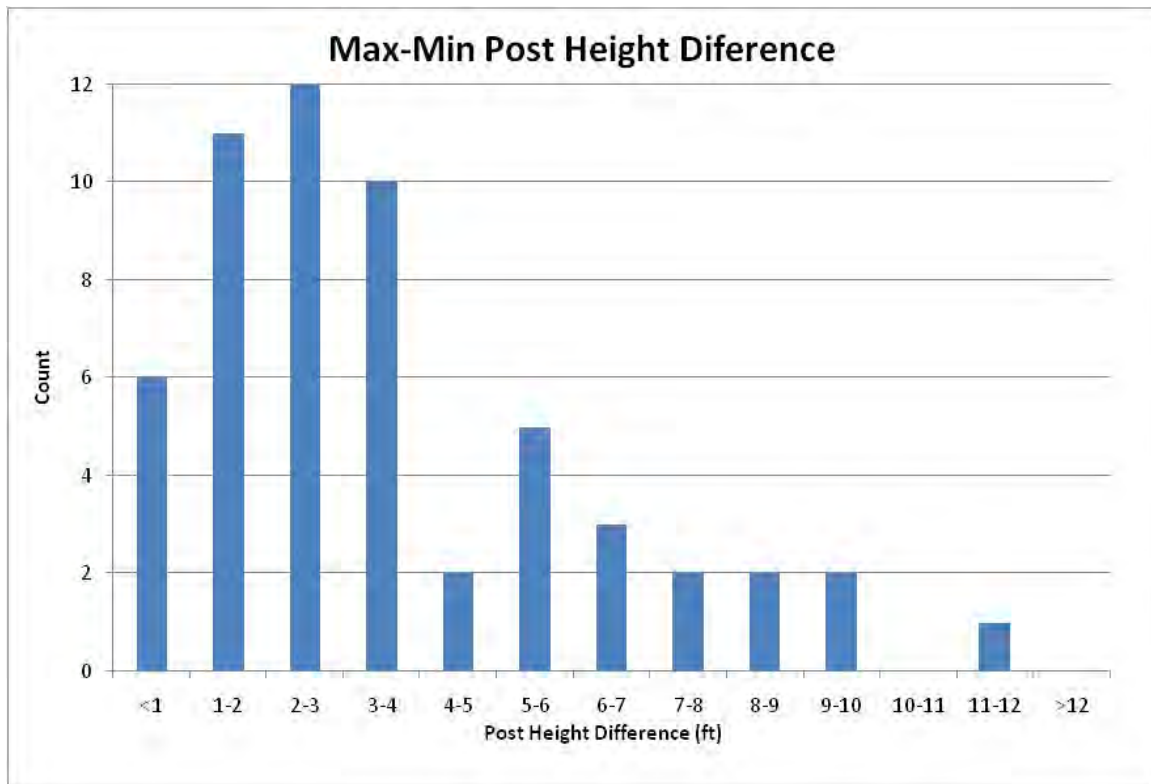


Figure A2-0-3 – Difference between maximum and minimum post heights in surveyed homes

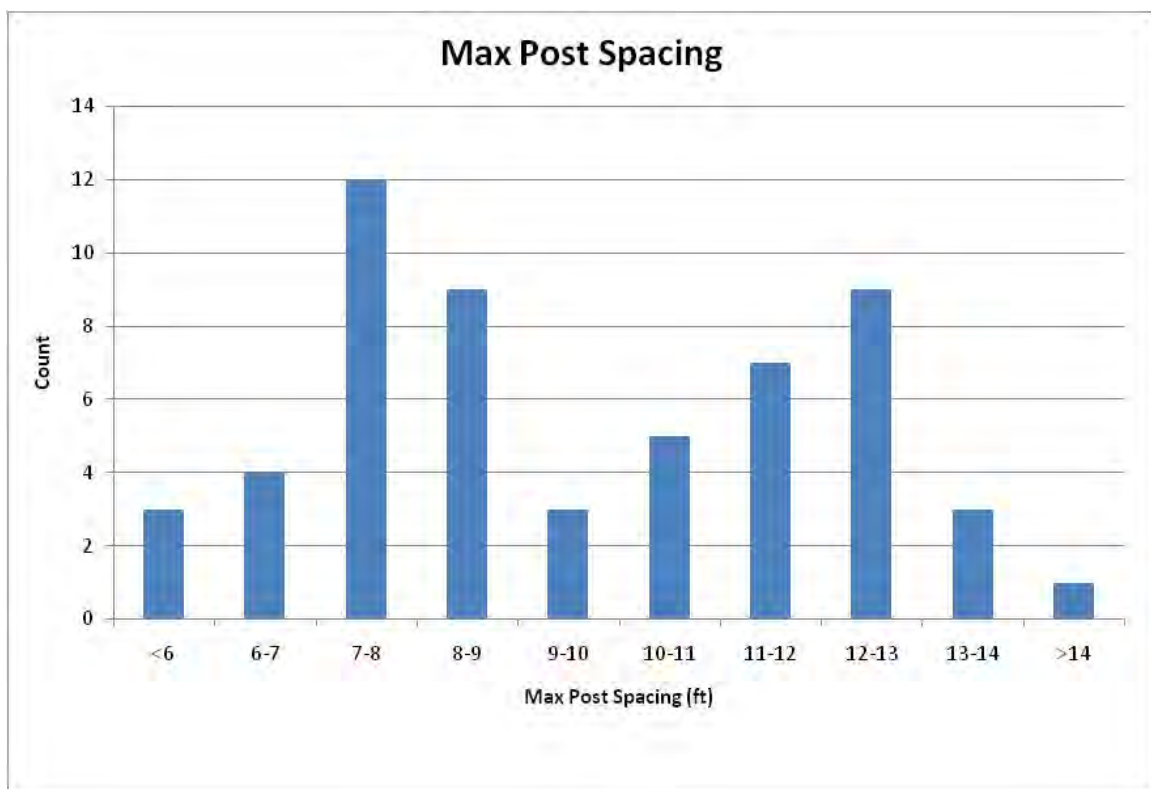


Figure A2-0-4 – Maximum typical spacing of foundation posts in surveyed homes

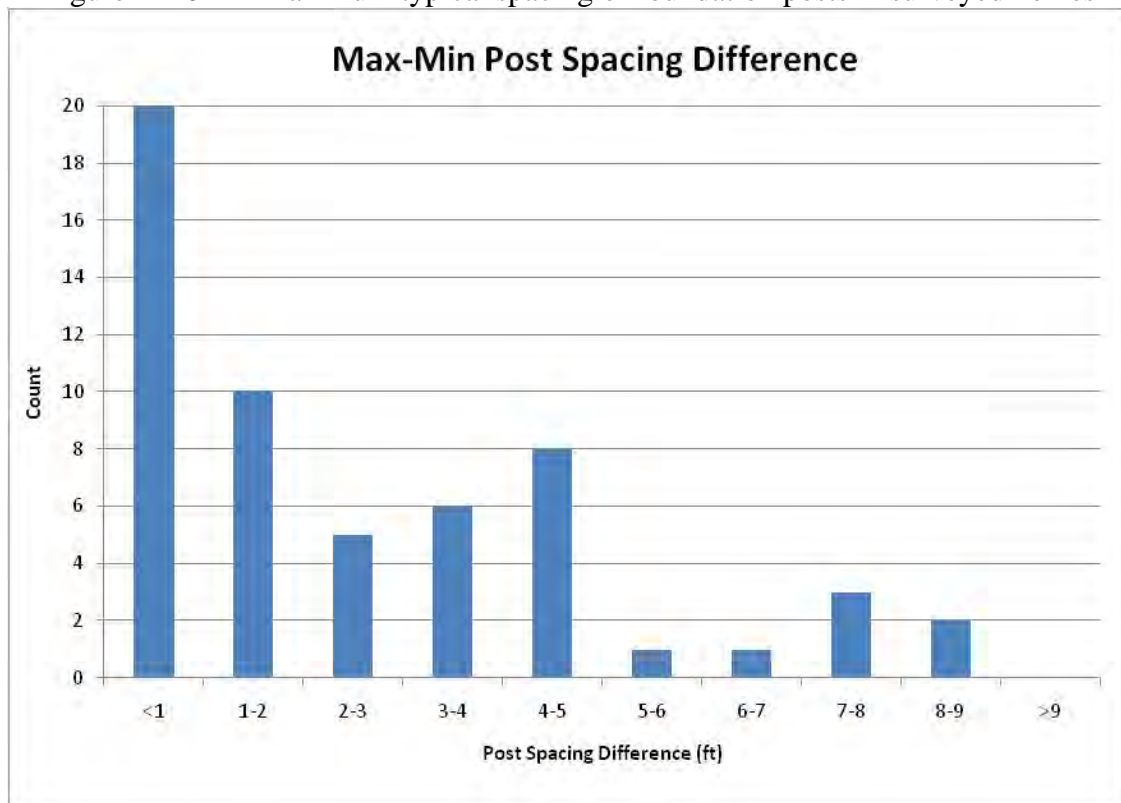


Figure A2-0-5 – Difference between maximum and minimum typical foundation post spacing in surveyed homes

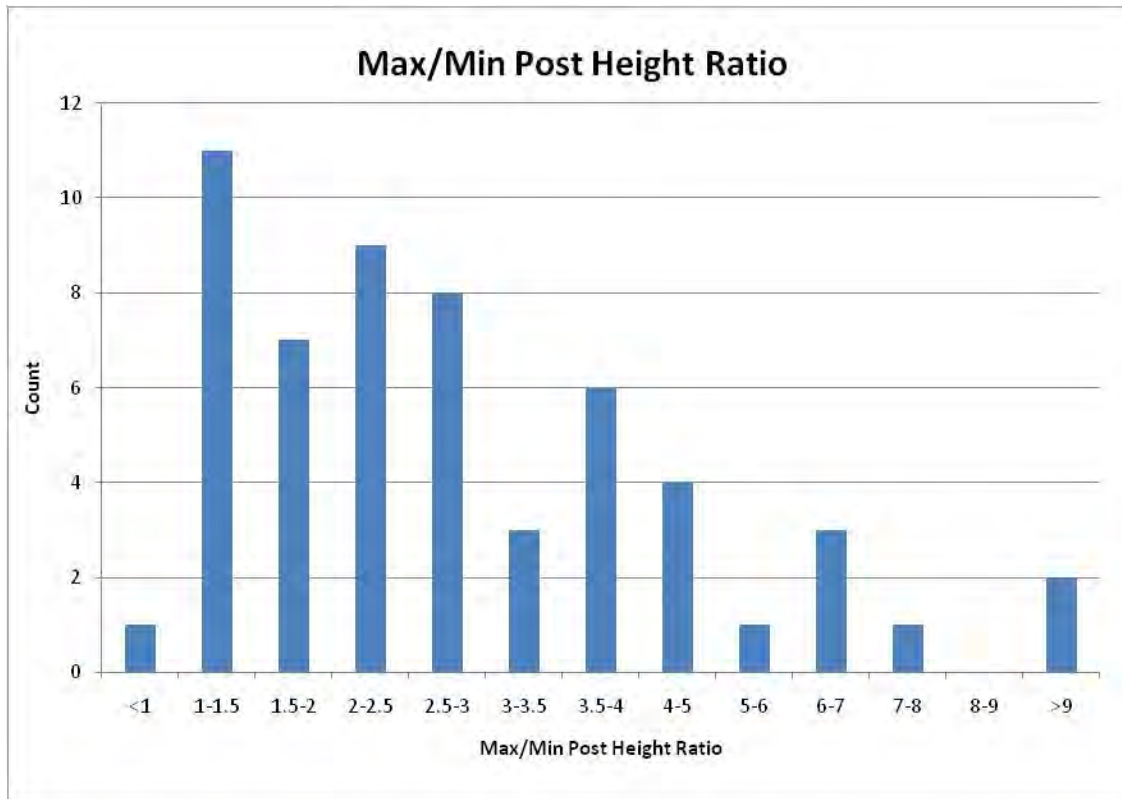


Figure A2-0-6 – Ratio of the maximum post height divided by the minimum post height

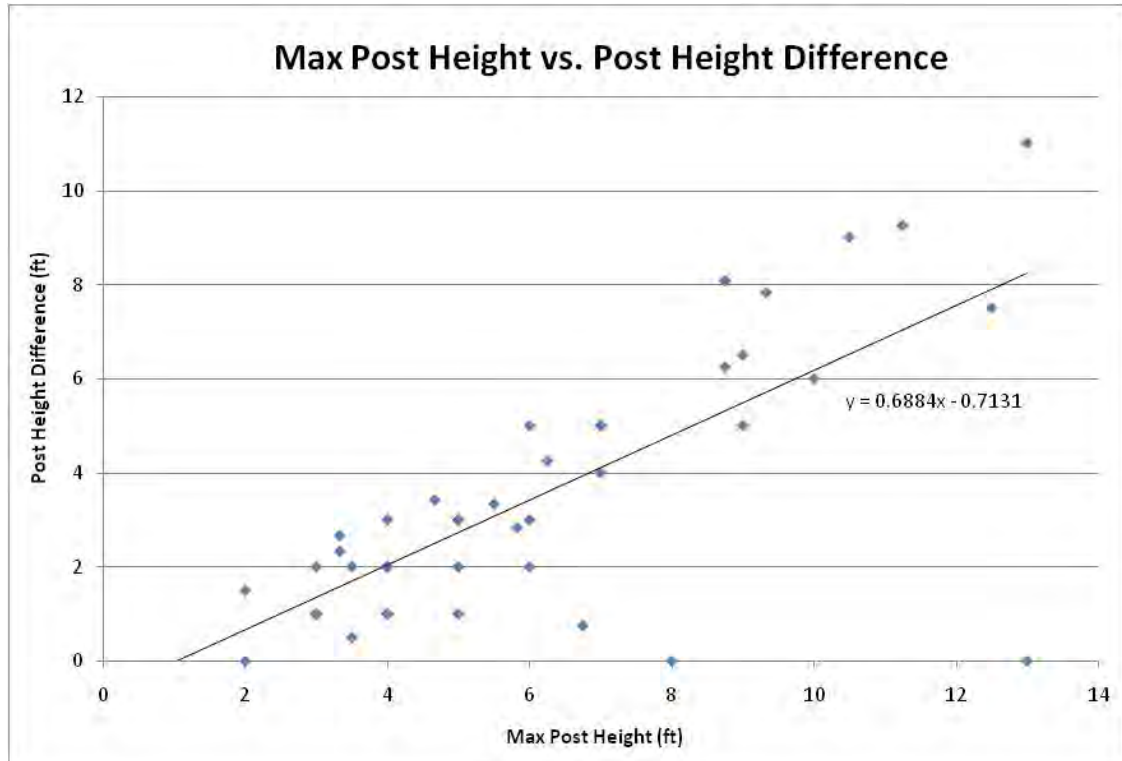


Figure A2-7 - Scatter plot of the maximum post versus the difference between the maximum and minimum post heights

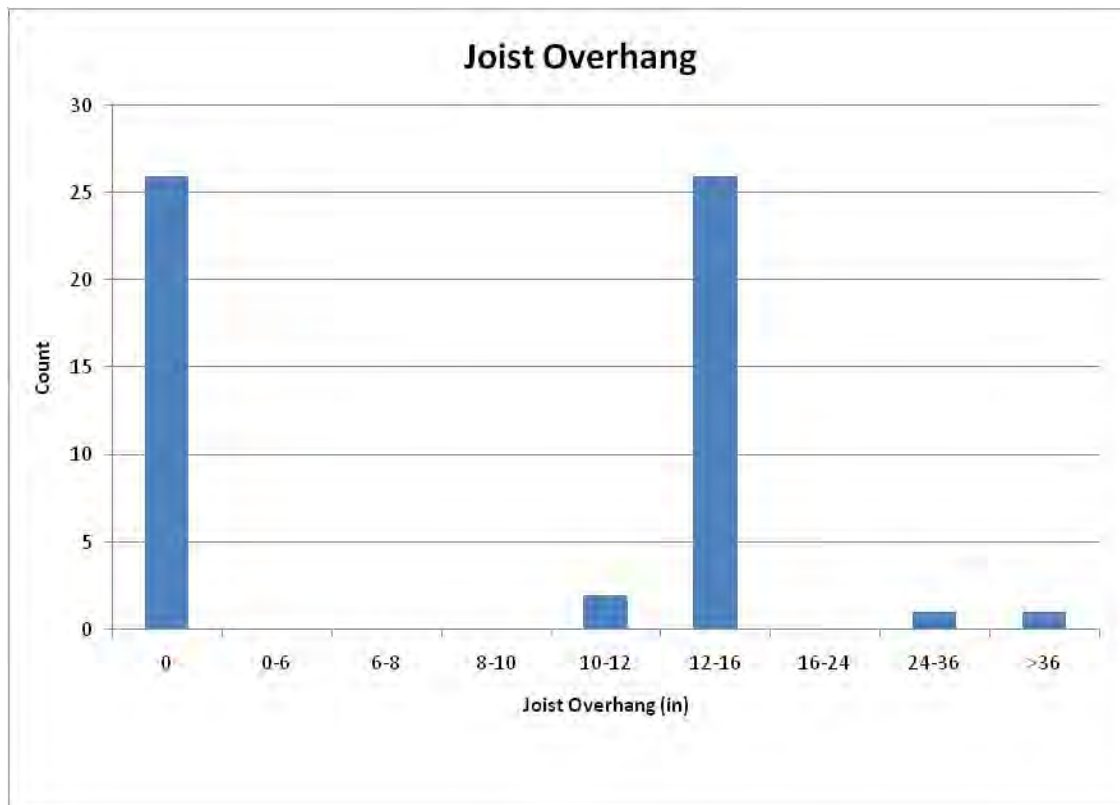


Figure A2-0-7 – Maximum overhang of floor joists in the homes surveyed

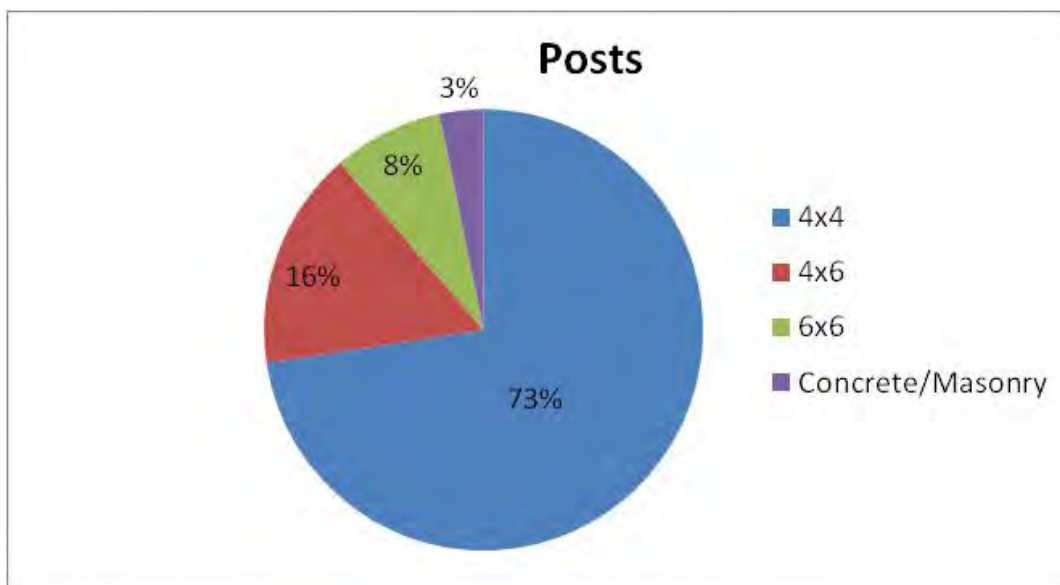


Figure A1-0-8 – Post size distribution in surveyed homes

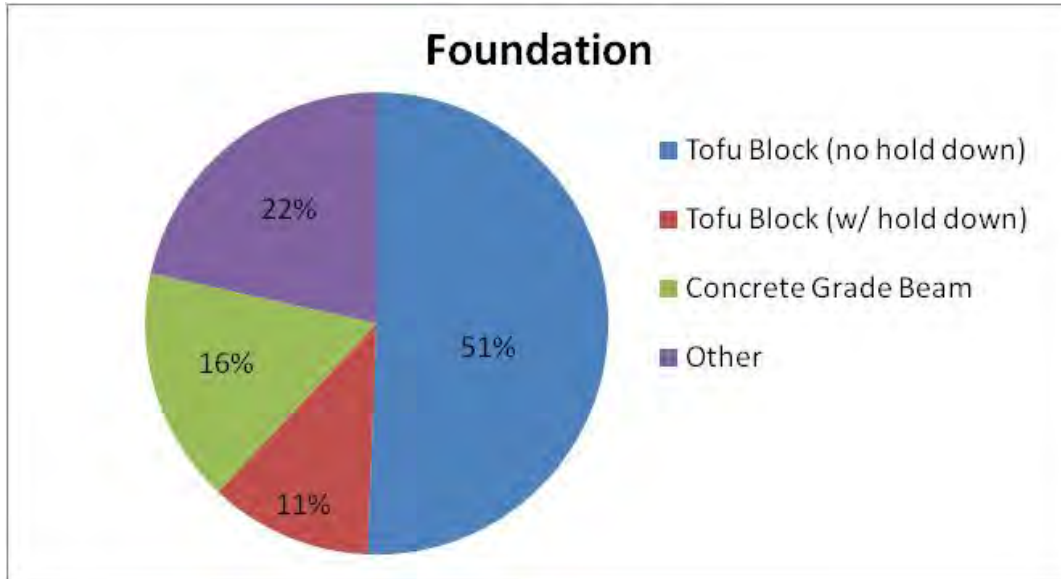


Figure A1-0-9 – Surveyed distribution of foundation types

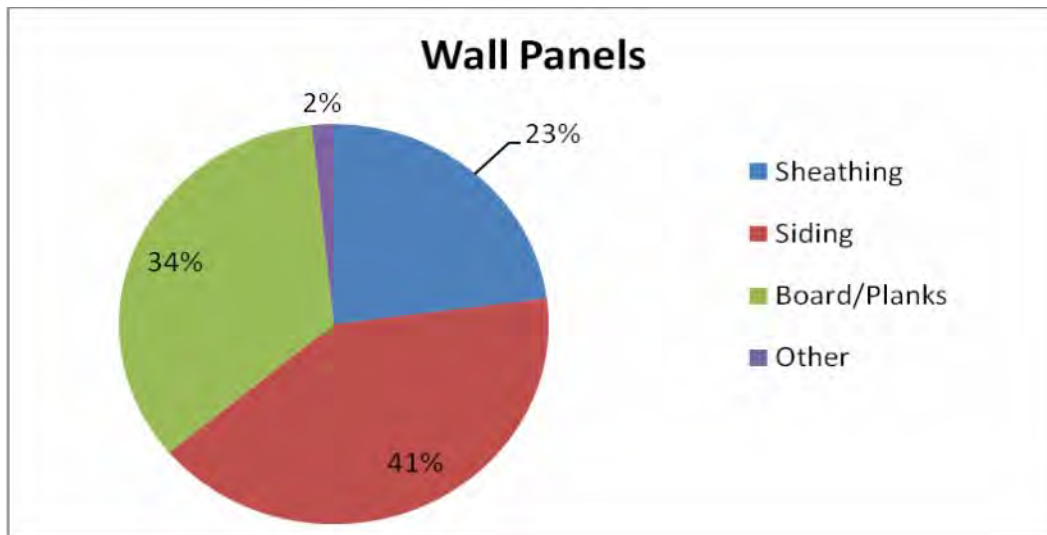


Figure A1-0-10 – Distribution of wall panel types

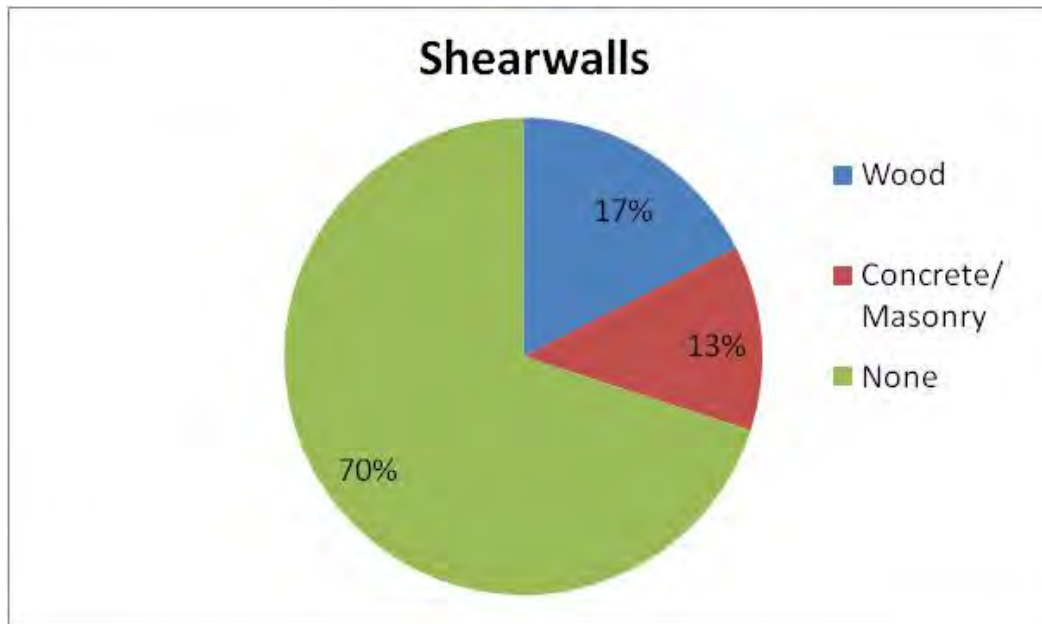


Figure A1-0-11 – Type of shear wall in surveyed homes

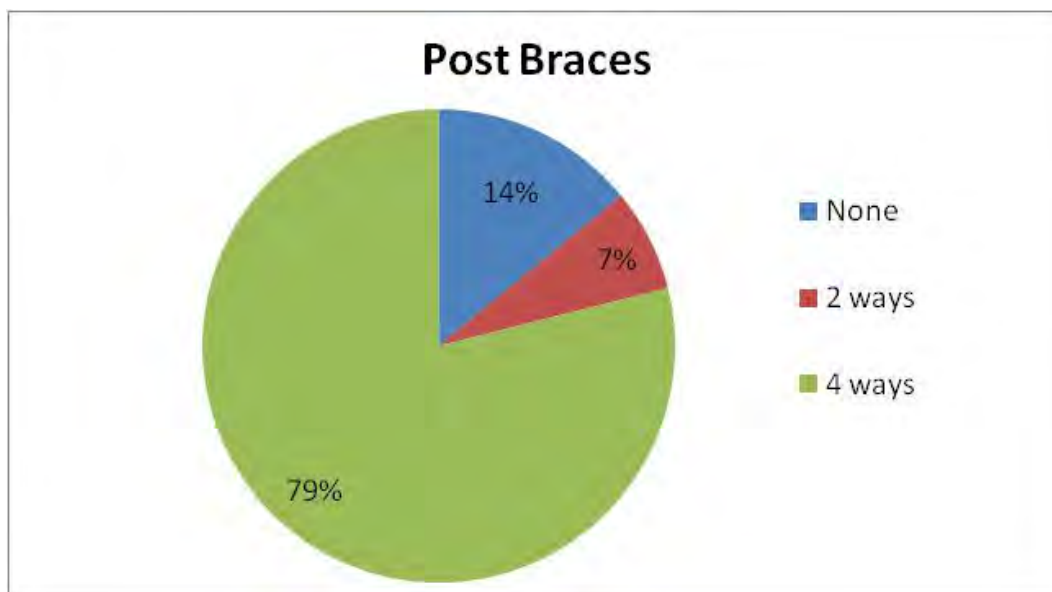


Figure A1-0-12 – Distribution of diagonal braces between the foundation posts and girders or joists

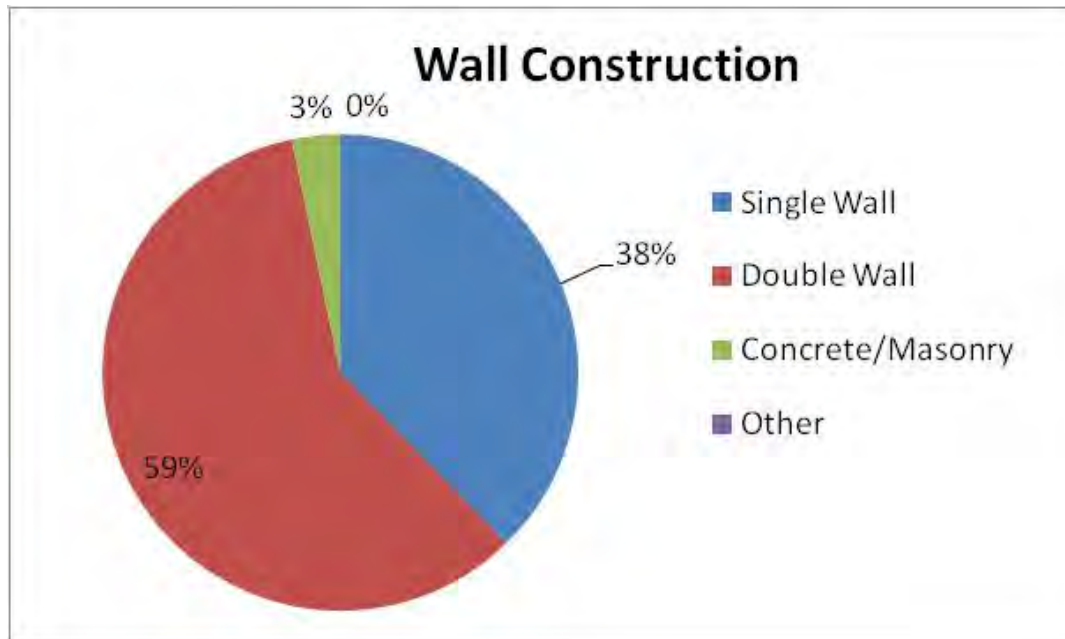


Figure A1-0-13 – Wall construction type distribution

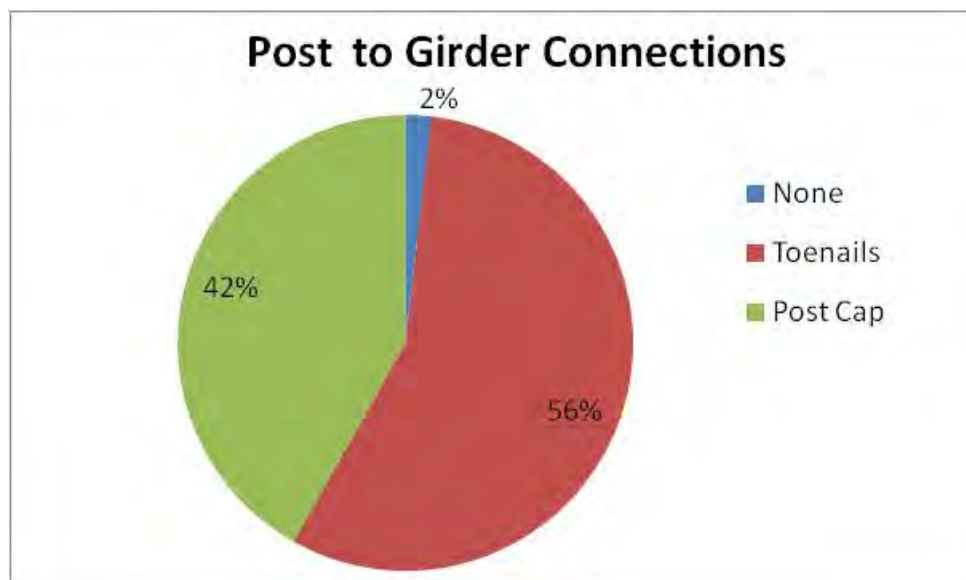


Figure A1-0-14 – Distribution of post to girder connections

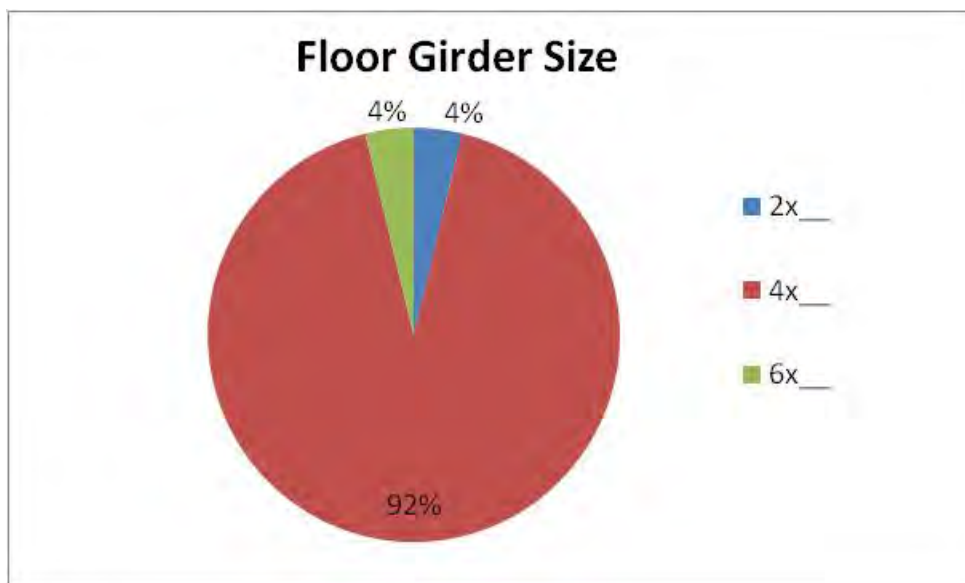


Figure A1-0-15 – Sizes of floor girders in surveyed homes

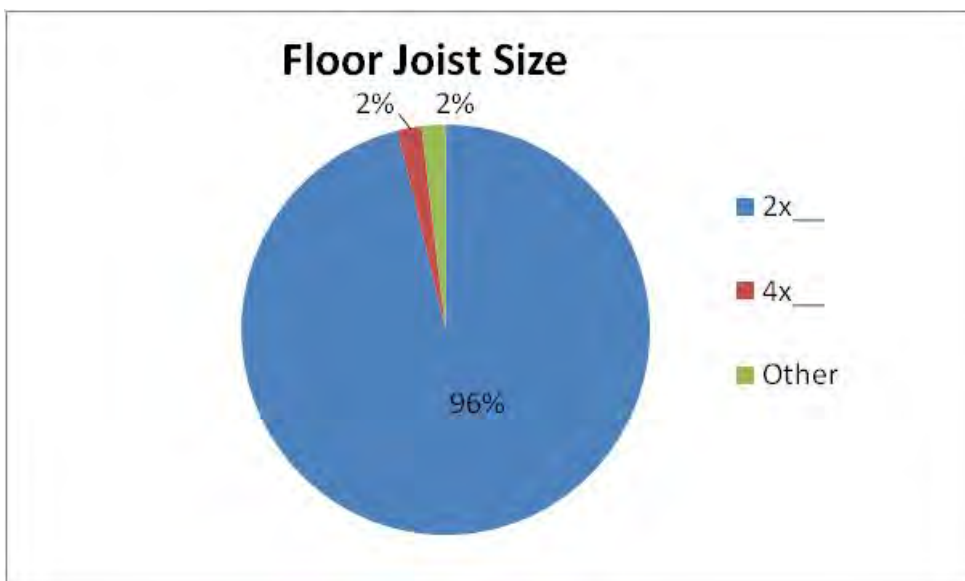


Figure A1-0-16 – Floor joist size distribution

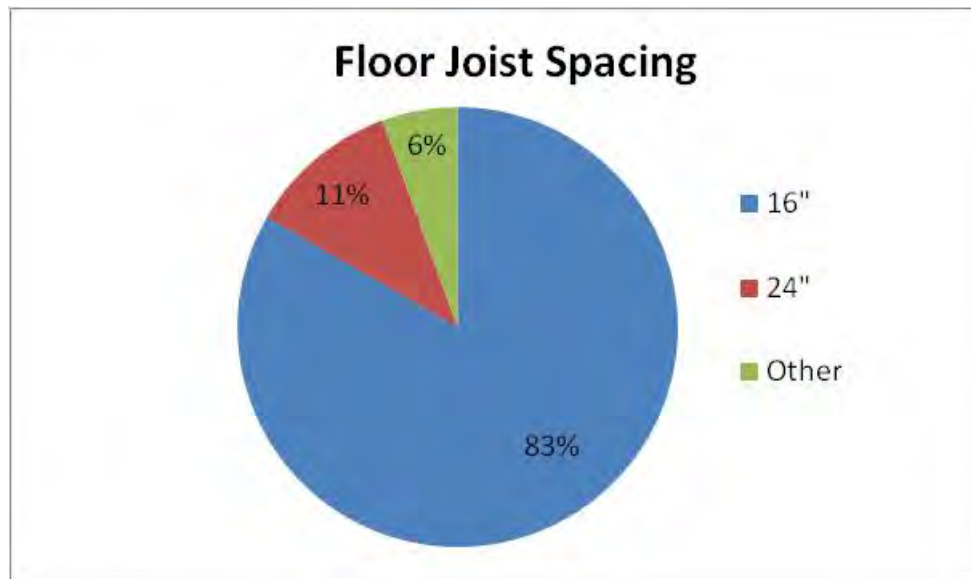


Figure A1-0-17 – Typical spacing of floor joists

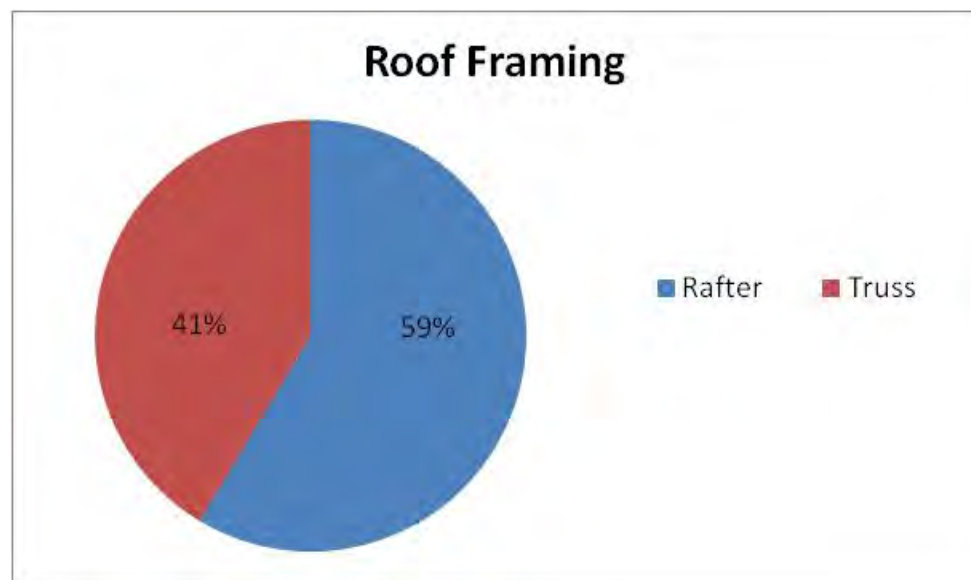


Figure A1-0-18 – Roof framing type distribution

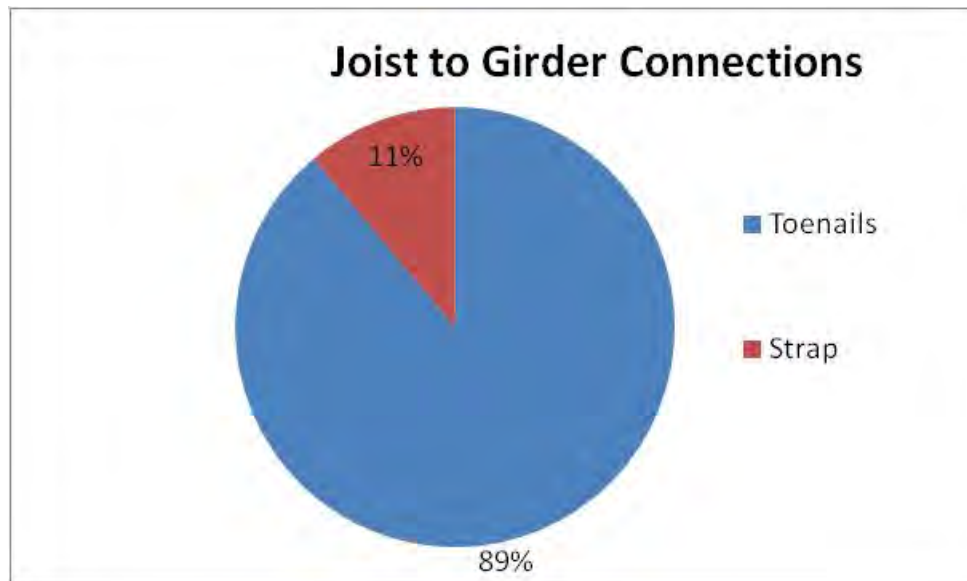


Figure A1-0-19 – Floor joist to floor girder connection types

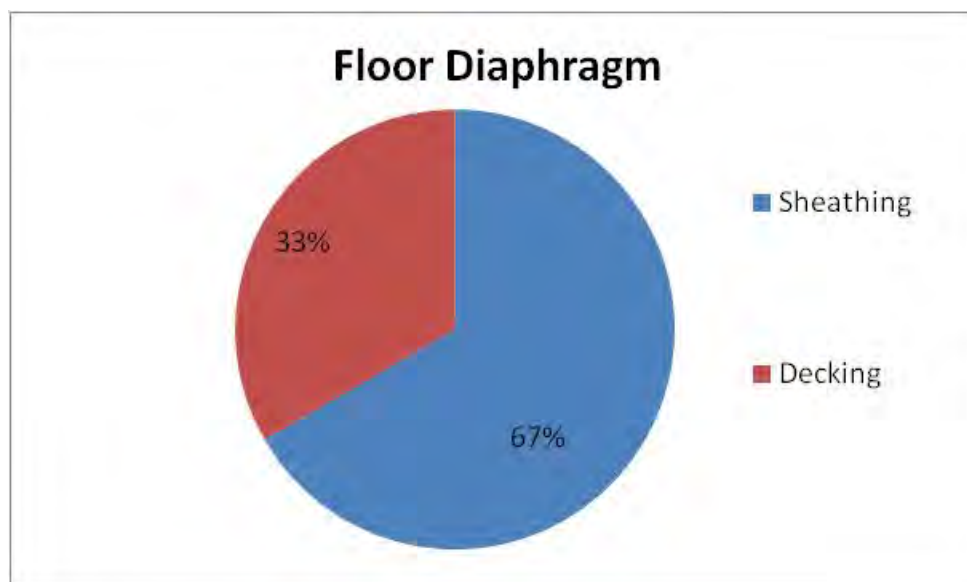


Figure A1-0-20 – Floor diaphragm type distribution

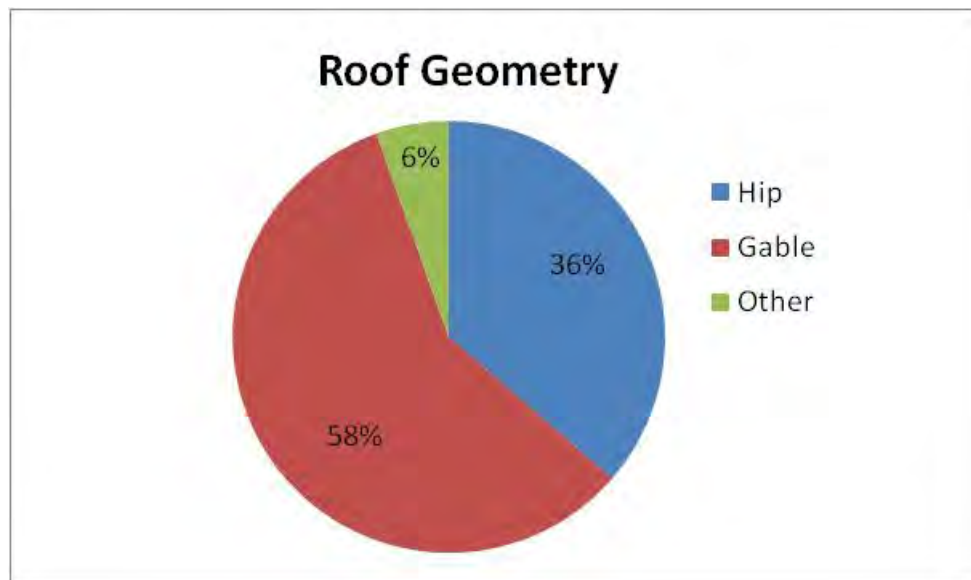


Figure A1-0-21 – Roof geometry distribution

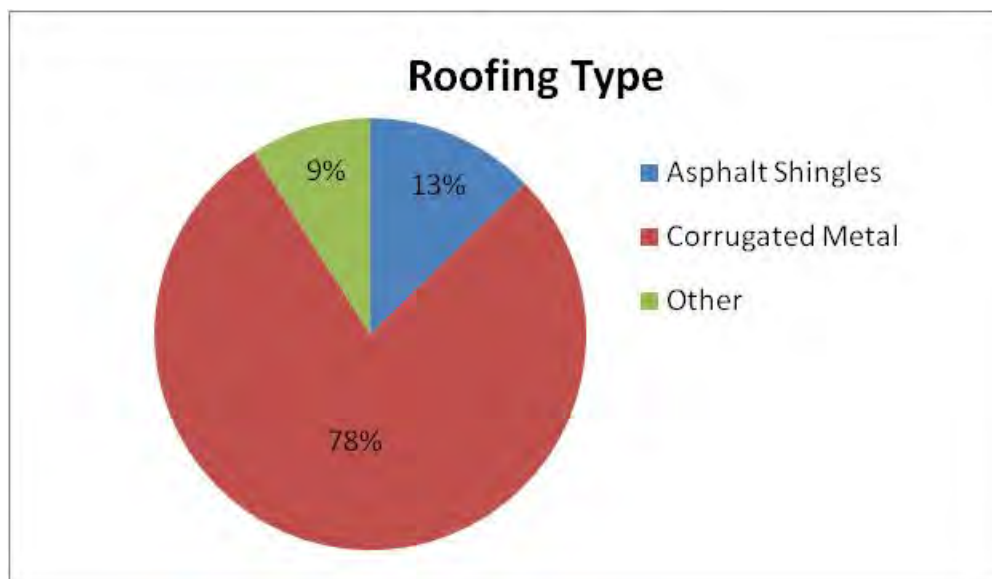


Figure A1-0-22 –Roofing type distribution

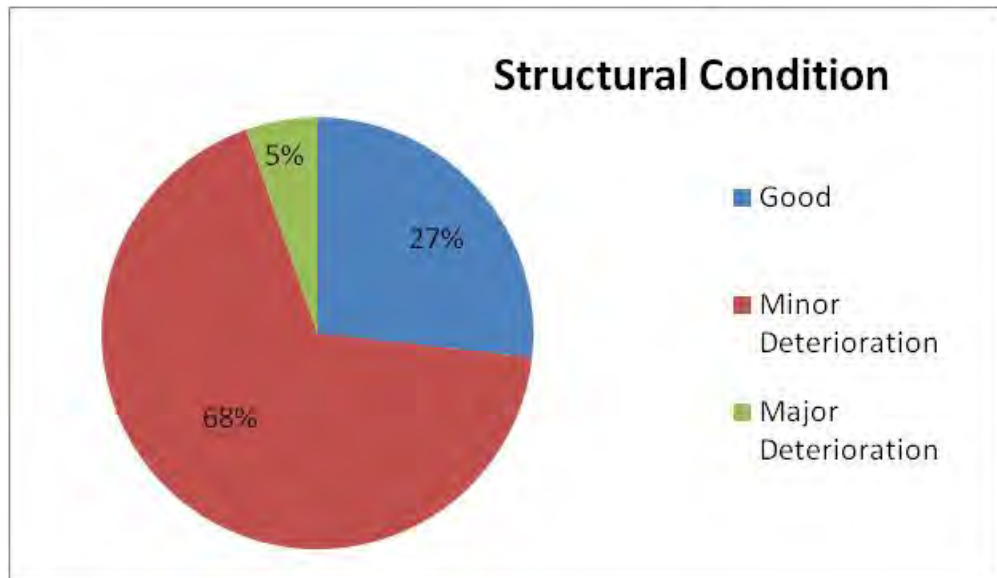


Figure A1-0-23 – Assessed structural condition distribution of surveyed homes

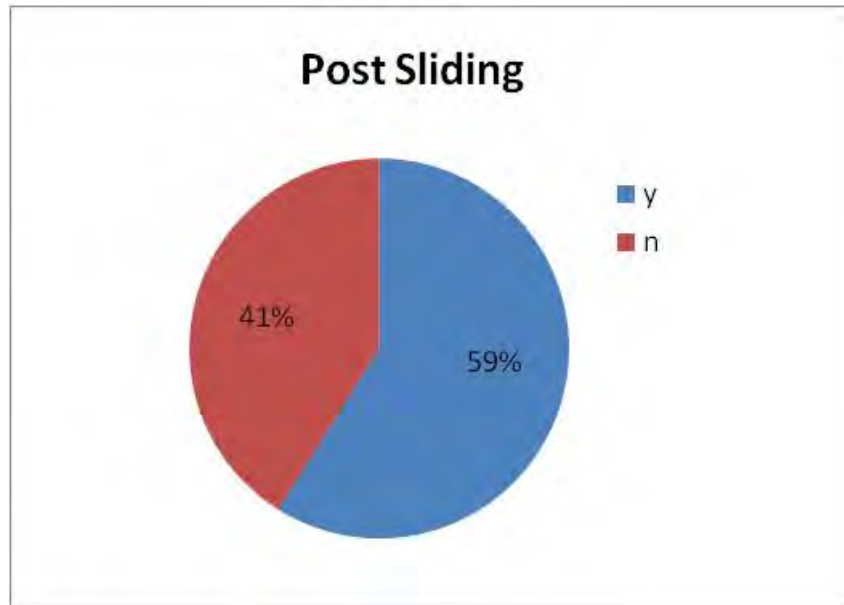


Figure A1-0-24 – Percentage of homes that exhibited sliding during the October 2006 earthquakes

Appendix 3 – Basis for Performing Structural Analysis and Determining Retrofit Criteria for Houses

Prototypical Structures

A structural analysis was performed using prototypical houses based on two single-story house plan configurations, considered representative of the range of structural properties of the surveyed houses. These two configurations were considered with a range of dimensional variations in the spacing between the posts and the differential post heights. The first configuration was a rectangular structure with plan dimensions ranging from 24 ft x 48 ft to 36 ft x 72 ft. This corresponds to 4 post lines in one direction and 7 post lines in the other direction with a spacing of the posts ranging from 8 ft to 12 ft as shown in Figure A3.1. The second configuration was an L-shaped house as shown in Figure A3.2, with overall dimensions ranging from 48 ft x 56 ft to 72 ft x 84 ft. This corresponds to post spacing between 8 ft and 12 ft.

The length of the posts was assumed to vary from 1 ft to 12 ft. The longest post was assumed to be up to 9 times longer than the shortest post. Where there was assumed to be a variation in post height, one side of the house had the minimum post height while the other side of the house had the maximum post height, with a linear variation between the minimum and maximum post heights for the intermediate posts. This was assumed to simulate a constant slope underneath the house. A slope was considered in each orthogonal direction parallel to the sides of the house with the direction resulting in the largest variation in post shears considered the critical direction.

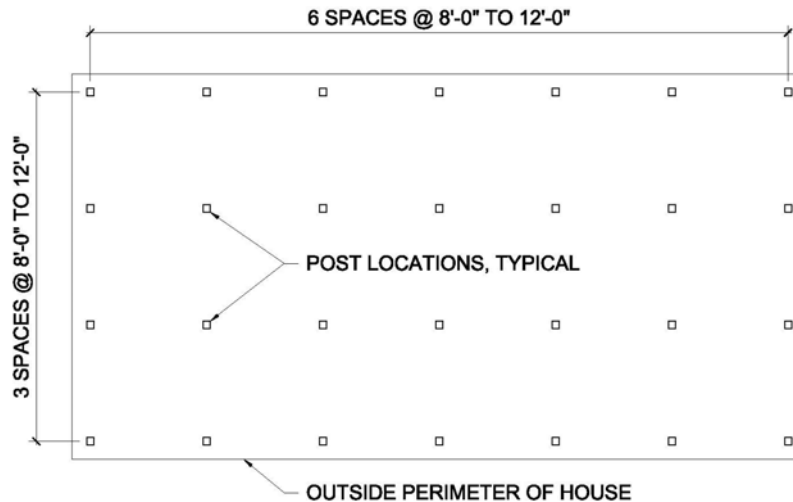


Figure A3.1. Plan layout of rectangular prototypical house

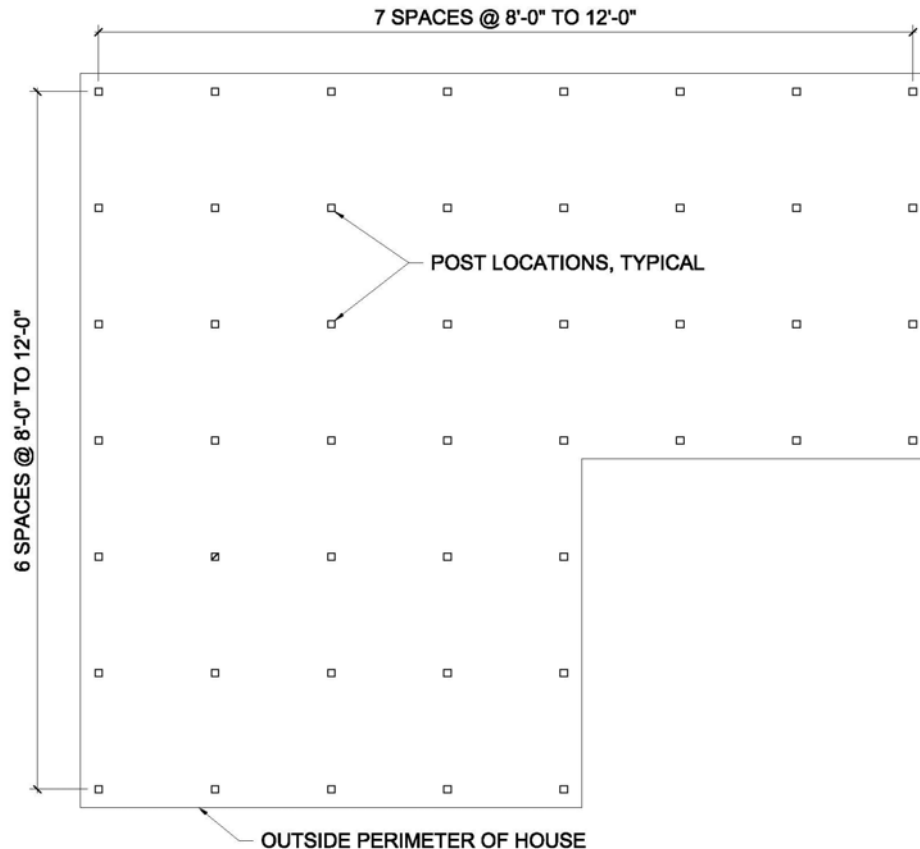


Figure A3.2. Plan layout of rectangular prototypical house

The posts were assumed to be 4x4 posts which is the minimum and predominant size observed during the surveys. The posts were assumed to be braced by 2x4 braces in each of the four directions except the corner and other exterior posts that were not braced on the exterior sides. The braces were assumed to be oriented at 45% degrees to the horizontal. An initial investigation was conducted to determine the impact that the height of the connection between the braces and the posts had on the response of the house. It was found to have a significant effect when the braces were attached more than approximately $\frac{1}{4}$ of the height of the post above the base of the post. For braces connected higher up the posts, the lateral deformation of the house is largely dependent on bending in the post, while for braces connected near the base of the post, deformation is largely dependent on axial deformations in the braces. Therefore, it was found to be necessary to connect the braces at or below the $\frac{1}{4}$ height of the post. This is used as the assumption in the prototypes on the basis that braces in any house connected higher than this level should be replaced in the retrofit of the house, even if this means increasing the slope of the braces.

Each prototype was assumed to have a seismic floor weight of 21.6 psf to allow for the floor framing, decking, partitions and miscellaneous permanent fixtures. It was assumed to have an exterior wall weight of 1.6 psf with a wall height of 9 ft totaling 14.4 plf

around the perimeter of the house. The roof was assumed to have a weight of 8.0 psf for framing and sheathing of a typical lightweight roof system.

Seismic Design Criteria

The criteria used for calculating the seismic loading are provided in Table 1. From structural analyses, the houses were found to have natural periods in the short period (constant acceleration) range of the acceleration spectrum, therefore this portion of the spectrum was used to define seismic hazard, making the seismic loading on each of the buildings constant. The seismic design criteria are based on the 2006 International Building Code (ICC, 2006) multiplied by 0.75 as applicable for the retrofit of existing buildings in accordance with the 2006 International Existing Building Code (ICC, 2006).

Table A3.1. Seismic Design Criteria for Houses in Different Retrofit Zones

Seismic Retrofit Zone		4b	4a	3	2	1
Importance Factor	I	1.0	1.0	1.0	1.0	1.0
Short Period Spectral Acceleration	S_s	2.67	2.00	1.00	0.62	0.24
Reduction for Existing Building	$0.75 S_s$	2.00	1.50	0.75	0.47	0.18
Site Class	Site Class	D	D	D	D	D
Short Period Site Coefficient	F_a	1.00	1.00	1.20	1.43	1.60
MCE Spectral Response Acceleration	S_{MS}	2.00	1.50	0.90	0.66	0.29
Design Spectral Response Acceleration	S_{DS}	1.34	1.00	0.60	0.44	0.19
Response Modification Coefficient	R	2.0	2.0	2.0	2.0	2.0
Deflection Amplification Factor	C_d	2.0	2.0	2.0	2.0	2.0
Base Shear / Weight	C_s	0.668	0.500	0.300	0.221	0.097

Wind Design Criteria

A lower bound lateral load was also determined based on wind criteria, which is defined with a constant basic wind speed for the entire State of Hawaii. The houses were assumed to be in an Exposure Category B corresponding to locations in urban, suburban or wooded areas. This is consistent with most of the single family houses in the state with the exception of those located within 600 ft of the coastline and other special regions. To provide the maximum practical lower bound lateral load based on wind loading, extreme cases were assumed for regional topography factors and directionality factors based on the amendments to the International Building Code in the State Building Code. The wind design criteria are summarized in Table A3.2 for a typical house with a

roof pitch of 3:12. For the prototypical houses this resulted in a lateral load of between 25% and 33% of the weight of the structure, approximately equivalent to a lateral seismic load of Seismic Retrofit Zones 2 or 3 depending on the geometry of the building. In all cases the lateral wind force was less than the seismic force in Zones 4a or 4b.

Table A3.2. Wind Design Criteria for Houses in the State of Hawaii

Basic Wind Speed	V (mph)	105	mph
Importance Factor for Wind	I	1.0	
Exposure Category		B	
Mean Roof Height	H	15.0	ft
Directionality Factor	K_d	0.7	
Topography Factor	K_{zt}	1.6	
Velocity Pressure Coefficient	K_z, K_h	0.58	
Velocity Pressure	q	18.2	psf
Gust Effect Factor	G	0.85	
Windward Wall Pressure Coefficient	C_p	0.80	
Windward Wall Pressure Coefficient	C_p	-0.50	
Windward Roof Pressure Coefficient	C_p	-0.18	
Leeward Roof Pressure Coefficient	C_p	-0.50	

Post and Pier Model

Three dimensional finite element models of a number of post and pier prototype configurations were developed in SAP2000. These were used to calibrate an analytical model of the structure. The model shown in Figure A3.3 represents the components that were found to significantly affect the stiffness and strength of the post and pier foundation system. This model neglects the stiffness of the girders and joists in the lateral response as the finite element model showed that these typically only contributed 5 to 10% to the lateral flexibility. The effect of the girders and joists on the relative stiffness of the posts, which determines the distribution of lateral forces, is less than 5%.

From this model expressions for the applied actions and stiffness of each braced post were developed. As the exterior walls and floor and roof diaphragms were rigid relative to the stiffness of the braced posts, a model that captured the distributed stiffness of each post was able to capture the overall response of the building. Thus a matrix representing each post location was used to determine the lateral and torsional properties of each of the prototypical houses. From each of the models the maximum forces in the posts were determined.

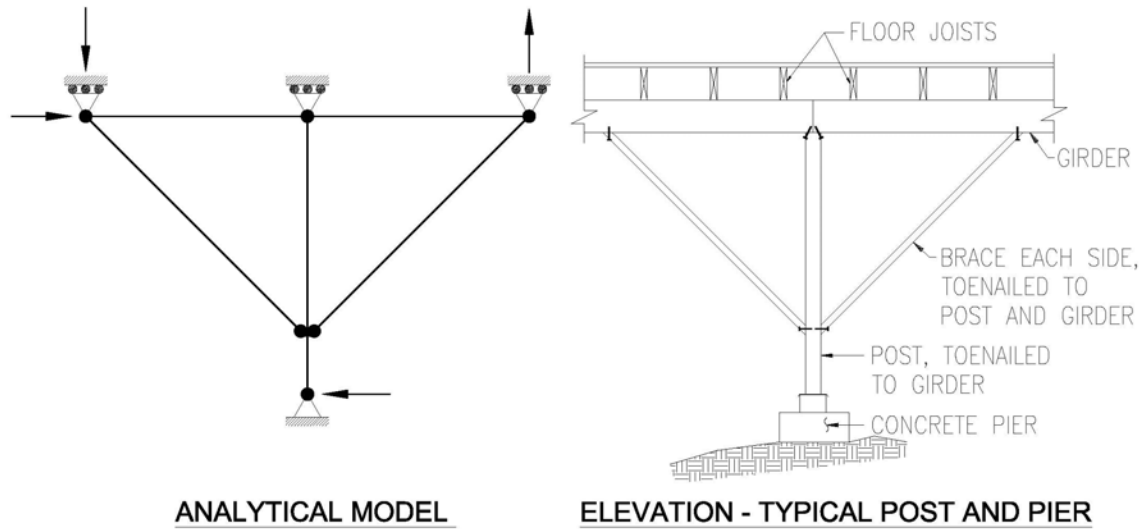


Figure A3.3. Analytical model of braced post and pier

Capacity of the Post and Pier Foundation System

A number of failure modes, or limit states, for the braces, posts and piers were considered, from which the governing failure mode for each prototypical house was determined. Due to variations in axial loads and shear forces in the posts, it was calculated that some posts or braces are likely to fail before other posts or braces. However, it was assumed that a post or brace will not fail until all of the posts or braces along a given row, parallel to the direction of load, fail. This is based on the assumption that if one post or brace starts to fail then it will redistribute its load into the other posts along a given row. Therefore complete failure of the house will not occur until all of the posts along a given row fail. This assumption requires that the girders or joists along a row of posts are able to act as collector elements and distribute loads longitudinally between posts as required. Each of the failure modes is discussed below.

- Brace Connections – The brace connections typically consist of two toenails between the brace and post and brace and girder or joist. These were calculated as the governing failure mode in all prototype models, based on the NDS Wood Design Specifications (2005) for nails in shear and withdrawal. The connections are expected to fail at relatively low shear forces, well below the design shear forces.
- Post Sliding – It was assumed that the friction coefficient between the base of the post and the concrete piers was equal to 0.62. The level of shear required for the post to slide relative to the piers was determined based on the axial load. This tended to govern the capacity after the connections between the posts and the braces were strengthened.

- Brace Axial Compression and Tension – Axial compression buckling capacity, determined using the NDS Wood Design Specifications (2005), tends to be the governing failure mode for the retrofitted posts and braces when adequate capacity is achieved in the retrofitted brace connections. The compression buckling failure mode is dependent on the length of the braces and therefore imposes limitations on the height of the posts that can be retrofitted without the use of shear walls.
- Post Flexure - The maximum bending moment occurs in the post where the post is connected to the braces and is dependent on the height of the connection to the braces. The flexural capacity of the post was determined using the NDS Wood Design Specifications (2005). The flexural capacity of the post did not govern when the braces were connected at a height no greater than $\frac{1}{4}$ of the height of the post.
- Post Shear – The maximum post shear force is in the same region as the maximum bending moment. This did not govern the capacity of the system as sliding occurred before the shear capacity of the post was reached.
- Pier Overturning – This failure mode is dependent on the soil conditions and slope of the site, therefore it was not evaluated for each prototypical structure. If the stability of the piers at a house is questionable, the retrofit strategies recommend that the piers be replaced or encapsulated with footings that are embedded into the soil.