COMMENTARY ON CHAPTER 3
GUIDELINES FOR SEISMIC RETROFIT OF EXISTING BUILDINGS

PRESCRIPTIVE PROVISIONS FOR SEISMIC STRENGTHENING OF CRIPPLE WALLS AND SILL PLATE ANCHORAGE OF LIGHT, WOOD-FRAME RESIDENTIAL BUILDINGS

C301 GENERAL – History has shown that light, wood-frame residential buildings with specific structural weaknesses in their original construction are susceptible to severe damage from earthquakes. The most common structural weaknesses are: 1) absence of proper connection between the exterior walls and the foundation (i.e., anchor bolts), 2) inadequate bracing of cripple walls between the foundation and first floor, and 3) discontinuous or inadequate foundations below the exterior walls. (Comerio & Levin, 1982) (Steinbrugge, 1990)

Unreinforced masonry chimneys and poorly reinforced or tied reinforced masonry chimneys are also a common source of damage, and in some cases, pose a life-safety threat. Chimneys are not included in the scope of this document, since reduction of chimney vulnerability through pointing of mortar and bracing is not typically considered cost-effective particularly if the risks to life can be controlled by other means. For example, ATC recommends adding plywood above the ceiling framing to reduce the chances of falling masonry from penetrating through the ceiling (ATC, 2002). Curtailing the occupancy and frequent use of property within the falling radius of chimneys is also an effective way of minimizing the risk of casualties. ATC recommends replacement of upper portions of damaged chimneys with light-framed construction rather than diagonal bracing. The City of Los Angeles requires the separation of chimneys from wood framing and independent bracing rather than diagonal bracing between the chimneys and wood framing because chimneys are considerably more rigid than wood framing. Otherwise masonry bearing wall chimneys should be replaced with light-frame construction with or without veneer. (LA, 2001) Generally the cost of replacing existing chimneys is comparable to the cost of repairing or replacing a damaged chimney after earthquakes, so in many cases it is best to forego chimney retrofits, but instead take steps to reduce the exposure of occupants and neighbors and to anticipate the possibility of chimney replacement after future earthquakes.

Wood-frame buildings with continuous concrete foundations in good condition, anchorages meeting the requirements of this Chapter, and sheathing (plywood, oriented strand board (OSB) or diagonal sheathing) around the entire building perimeter have performed well in past earthquakes. The provisions of this Chapter need not be applied to these buildings.

After the Loma Prieta (California) earthquake of 1989 , the average cost to repair dwellings that suffered damage due to the above stated weaknesses ranged from $25,000 to $30,000 in 1990 dollars (Gallagher, 1990) and up to $65,000 in today's dollars (SEAOSC, 2002). Some dwellings with these deficiencies have been total losses. Experience indicates that the average cost for a licensed contractor to install sill bolts and cripple wall bracing to undamaged dwellings ranges from $2500 to $5000 in 1998 dollars (CSSC, 2002). The cost varies with accessibility and increases in dwellings with limited access due to short crawl spaces, mechanical ducts or other obstructions. If dwelling owners elect to perform the strengthening work themselves, costs can be even lower. The cost effectiveness of correcting these weaknesses becomes more favorable by considering the potential costs of emergency shelters, interim housing and lost employee productivity while damaged dwellings are being repaired. (ABAG, 2000) (Comerio, 1996) Some insurance companies offer retrofit discounts that can lower earthquake insurance premiums and insured losses (CEA, 2002).

The purpose of this chapter is to provide minimum standards addressing the three structural weaknesses stated above. This chapter is intended to encourage and facilitate seismic strengthening of conventional dwellings , and to provide standardized methods for performing this work. The provisions are written in a prescriptive format to eliminate the need, in most cases, for engineering design and to encourage the direct use of the chapter by building owners.

However, there is a "disturbing aspect to the wide use of these provisions. General contractors are marketing themselves as 'seismic reinforcement' specialists who offer homeowners the promise of earthquake safety without the benefit of either specialized knowledge or the direct input of a structural engineer. Most residential seismic upgrading work is being installed without the benefit of engineering expertise. The contractors' intentions are generally honorable, and some of them have the intuitive understanding and experience to design and install effective seismic systems on existing homes. In many cases, however, homeowners pay thousands of dollars for work that provides little or no improvement in safety." (Huntington, 1991) The International Building Code and Uniform Building Code allow such retrofits provided they are no less safe than before the retrofit. Also in response to this concern, retrofit training for contractors has been periodically offered by FEMA and ABAG (FEMA, 1995). By adopting and enforcing the provisions in this chapter, jurisdictions can further help protect the interests of homeowners and establish a standard for retrofit practice.

Note that some jurisdictions (e.g., Cities of Los Angeles, San Leandro, Santa Barbara, Berkeley) have prepared drawings with approved details to further assist in retrofitting dwellings (SL, 2002). For regions outside of the Western U.S. the Institute for Building and Home Safety offers an excellent retrofit guide (IBHS, 1999).

Water heaters that are not restrained from toppling in earthquakes also pose significant risks of water and fire damage that are not addressed herein (NIST, 1997). Existing pre-manufactured restraint systems are available at many hardware stores and have been stamped as pre-approved by a government agency for limited use. They are both economical and effective for water heaters typically located adjacent to wood frame walls. (DSA 2002) However, atypical water heater bracing installations require engineered designs.

C301.1 Purpose – In contrast to other earthquake retrofit guidelines and codes, the provisions of this chapter are not strictly designed for life safety protection. These provisions are, in fact, expected to reduce property damage, reduce the number of uninhabitable dwellings after earthquakes and avoid the increased public assistance expenditures to repair damage and provide temporary housing (ABAG, 1999).

These provisions do not guarantee that strengthened structures will not be damaged. However, it is anticipated that costly damage to the vulnerable parts of dwellings below the first floor will be greatly reduced. These requirements have not been established or calibrated using Performance Based Earthquake Engineering, so there is no intent to state or imply a performance objective or range particularly since these requirements don't address vulnerabilities that might exist above the first floor of dwellings. "Cripple walls retrofitted to these provisions are generally expected to meet a Life Safety performance objective" (CUREE, 2002). However, other parts of the building may exceed or perform less than this objective requires.

Analysis and design of strengthening for other structural or nonstructural components not addressed by these provisions must be performed in accordance with Section 301.3 Alternative Design Procedures.

C301.2 Scope – "Prescriptive" means these provisions apply to specific conditions and must be used in precisely the manner described. "Prescriptive" also means determined in advance, without the need for case-specific analysis or design. Through the use of these provisions and the accompanying details, the dwelling owner or contractor can develop plans without the services of a Design Professional (Civil Engineer, Structural Engineer or Architect). However, the use of other materials, proprietary systems or methods not shown by the figures and details within this Chapter, may require the services of a Design Professional.

The provisions are intended to deal with specific earthquake weaknesses. Therefore, the work that is being done is structural in nature and requires submitting plans and obtaining a building permit. The weaknesses that these provisions address are listed in Section 303. It should be clearly understood that the application of these provisions is limited because the provisions are not suitable to use for strengthening hotels, motels or large multi-unit apartments since they are typically larger structures that require engineered retrofits by licensed design professionals. Also excluded are dwellings built with cripple walls with studs taller than 4 feet in any location, dwellings that have columns or poles embedded in the ground as their foundation system, and buildings exceeding 3 stories or any 3 story building with cripple wall studs exceeding 14 inches in height. Each of these types of buildings presents unique conditions that preclude the use of prescriptive criteria to strengthen them.

The four feet cripple wall stud height limits the amount of overturning in braced crippled walls with lengths defined in Figure A3-10. When the height of the wall studs exceeds four feet, the owner will need to have the bracing designed by an engineer or architect.

Conventional construction provisions in the IBC Section 2308.12.4 state that cripple walls with studs exceeding 14 inches in height are to be considered as first story walls for the purpose of determining bracing. However, the bracing layout requirements in these provisions (Figure 3-10) are provided according to the number of stories *above* the cripple wall.

Items 3 and 4 in the Exception to Section 301.2 refer to the cripple stud height. The parameter H, represented in Figure 3-7, is greater than the stud height and is not used elsewhere in these provisions.

The building official is also allowed to exclude other residential buildings to which these provisions would otherwise apply if they have vertical or horizontal irregularities or other features not considered by these prescriptive standards. Very few dwellings are rectangular in plan. U- T- or L-shaped plans aren't necessarily problems in conventional construction with wood diaphragms. However, split-level dwellings, hillside dwellings, or structures where the upper level exterior walls are horizontally offset from the line of the lower story exterior walls may be determined by the building official to be beyond the scope of these provisions. Before beginning work, it is recommended that the owner or contractor consult with the authority having jurisdiction to determine if these provisions can be applied.

Observations after past earthquakes have shown that cripple walls with substantially varying heights, such as with sloping or stepped foundations, suffer more damage than cripple walls of constant height (SEAOSC, 2002). Most of the forces are resisted by the shorter, stiffer portions of the cripple wall. For multi-story buildings with more than a 2 to 1 height ratio between the tallest and shortest cripple wall bracing panels, it is recommended that the sheathed panel lengths be engineered along the wall line(s) in question.

The provisions of this Chapter are intended for uses in high seismic regions (Section 301.2). Still, for dwellings within 10 km of major active faults ($S_s > 1.5$) it is recommended that the panel lengths be engineered to account for potentially more severe ground motions in the design earthquake, since these provisions do not account for near source ground motions.

Other structural weaknesses that may exist that are located above the first floor are also beyond the scope of this chapter. Situations that require analysis and design by a Design Professional or consultation with the Building Department prior to beginning any work include, but are not limited to, buildings with full-height stone veneer walls due to their added weight, and dwellings built on hillsides where cripple wall heights vary substantially.

Also excluded from these provisions are buildings or portions of buildings constructed on concrete slabs-on-grade. These dwellings do not have cripple stud walls and typically would not lack bracing. These buildings may have wall anchorage deficiencies, and the provisions for wall anchorage of cripple wall buildings apply equally well to these structures. However, retrofit of these structures would require removal of wall finishes and may not be as cost-effective as retrofitting buildings with crawl spaces. Also, while sliding of dwellings on slab-on-grade foundations has occasionally occurred in past earthquakes, it has not caused widespread economic and habitation losses in past earthquakes. Dwellings with stem walls (reinforced concrete or masonry foundation walls that project above the ground to the underside of the first floor framing) will experience substantial damage if the dwelling slides off the foundation. Anchorage of these structures should be considered as falling in the scope of this Chapter.

A majority of dwellings constructed in California prior to 1950 were unanchored. The Uniform Building Code did not begin to specify anchorage until its 1946 Edition (SEAOC 1995), however most local governments did not uniformly adopt such model codes promptly after their publication until the late 1970's. Furthermore, some dwellings were constructed with inadequate cripple wall bracing in the 1970s and even later particularly where model codes were not enforced.

Dwellings often used horizontal wood siding or stucco as wall sheathing material. Owners of older dwellings should examine the exterior walls from within the crawl space under the first floor to determine if the sill plates are bolted to the foundation, if the bolt size and spacing comply with the Building Code or Table 3-A and if exterior finishes have been applied over wall sheathing materials with adequate strength such as plywood, OSB or diagonal sheathing. Most dwellings constructed after 1950 were anchored to their foundations. However, even in high seismic regions, cripple wall bracing now considered inadequate was in common use in the 1970's and 1980's.

C301.3 Alternative Design Procedures –Section 301.3 purposely omits the commonly used statement that the design must comply with all the requirements of the Building Code because complete code compliance is often not feasible with respect to existing buildings. For example, Design Professionals should not be expected to rigorously address issues such as the stiffness variations in existing flooring systems due to differences in the type or thickness of the flooring. It does, however, state that any strengthening designed by the Design Professional should at least be equivalent in terms of strength, deflection and capacity to that provided by the prescriptive methods. The Building Official is allowed to require Design Professionals to provide substantiating structural calculations or test data to confirm this equivalence.

This 75 percent factor applied to Building Code design forces accounts in a general way for differences between current design criteria and the less conservative criteria that were likely in effect when the dwelling was originally designed and built. If owners prefer, they can elect to use a greater horizontal force in order to lessen potential damage from future earthquakes.

C302 DEFINITIONS – Throughout this chapter there are references to "the Building Code. " This term generally refers to the current edition of the International Building Code (IBC) or the jurisdiction's governing code. Before using this document to determine the amount of strengthening that may be required, consult with the local building department to confirm the appropriate of use of these definitions.

The definitions provided in this chapter are for terms that are not defined in the governing Building Codes. Other terms defined in the Building Code also apply to this chapter but are not repeated.

C303 STRUCTURAL WEAKNESSES – This section provides criteria that allow owners and contractors to evaluate dwellings. The structural weaknesses listed in this section might not be the only weaknesses that will lead to structural damage when the building is subjected to earthquake forces. They represent conditions that can be addressed by prescriptive, nonengineered provisions that are most common and most cost effective to strengthen.

C303 Item 1 Sill Plates or Floor Framing Without Approved Foundation System. Some older dwellings do not have a foundation system. Instead, the wall sill plate, and much of the floor framing, is supported directly on the ground. When subjected to earthquake induced lateral and vertical forces, these structures can easily move because they are not anchored. Fungus, water, and insect damage are also common in unapproved foundations. Foundation movement can result in a variety of structural and nonstructural damage including broken gas and utility lines that can lead to fires. Further, these structures are highly susceptible to fungus infection and insect infestation due to inadequate wood to earth separation. Wood deterioration caused by this inadequacy has significantly contributed to the damage from earthquakes.

C303 Item 2 Post and Pier Foundation System. Many dwellings have continuous cripple walls and foundations around their perimeter and wood posts on isolated concrete pad footings (called a "post and pier" system) under the interior of the dwelling. Such a system is not necessarily deficient. If a "post and pier" system forms the foundation for the dwelling perimeter walls, it is considered a structural weakness because of the lack of stiff walls below the first floor. This deficient foundation system is found in some older dwellings, including Victorian era structures, and buildings in areas where soil moisture is high. The posts and floor framing members of this system are usually interconnected with simple toenailed connections with no bracing between the posts. The weakness is compounded when a lack of connection occurs between the posts and the small concrete pads which act as footings. Failures in this foundation system during earthquakes occur at the underside of the floor framing, and may lead to partial collapse of the structure.

Providing diagonal bracing members between the posts does not solve the problem. Each post would then need to be adequately connected to a foundation system. Typically, the existing footing pads are too small to make the necessary connections. Simply providing bracing between the posts only moves the point of failure from the top of the post to the bottom of the post at the pad footing. For these buildings, bracing, anchorage and provision of additional footings may be required.

Some post and pier type structures may be considered as historic buildings. Care needs to be taken when performing strengthening work so the historic nature of the building is not destroyed. Many jurisdictions have adopted specific requirements for historical buildings such as those in Chapter 10 of the IEBC. If a dwelling utilizes this type of system and might be considered an historic building, consult with the building department before beginning any strengthening work.

C303 Item 3 Non-Continuous Perimeter Foundation Systems. Another deficiency is found in dwellings that do not have a continuous perimeter foundation. However, there are many variations of partial foundations, and some do not represent a significant weakness. When applying these provisions to an existing building the intent is to reduce the potential for damage to habitable portions of structures. Therefore, the standards include two exceptions to the requirement for continuous perimeter foundations.

C303 Item 3 Exception No. 1. Observations after past earthquakes have shown that failures of relatively small enclosed spaces tend to be localized and may not result in the undamaged portion of the remainder of the dwelling to be uninhabitable. This exception is not intended to imply that these existing appendages should not be strengthened if they do not have a continuous foundation. Exception No. 1 only means that such a condition will not automatically require a new perimeter foundation. The point is that additions tend to act separately, especially if they have separate foundations, so other parts of the dwelling should not necessarily be penalized as "weak."

C303 Item 3 Exception No. 2 Addresses non-habitable spaces such as porches, storage rooms and other similar areas. The failure of porches is common during earthquakes. Such failures rarely impact the habitability of the structure although they may temporarily limit access or egress. Storage rooms, in this exception, include those areas adjacent to the dwelling and accessible from the outside of the building only and storage buildings or areas that are separate from the main structure. As with porches, failure of these storage areas seldom affects the habitability of the main structure. Attached rooms with water heaters or furnaces are singled out because damage to these areas could result in fires. This provision thus implies a nonstructural performance objective somewhat beyond the "risk reduction" stated in Section 301.1. Again, this exception is not intended to imply that such structures should be strengthened only if they contain fuel-burning appliances. Serious consideration should be given to strengthening any weak parts of the dwelling. There is no "typical " method of construction for these portions of existing buildings. Consequently, it is difficult to develop prescriptive standards to address them. Considering that this

Chapter is intended to reduce the potential for damage that would make dwellings uninhabitable, these small areas have been given exemptions to the general requirement for a continuous perimeter foundation.

C303 Item 4 Unreinforced Masonry Perimeter Foundation. A perimeter foundation constructed of unreinforced masonry is assumed to lack the necessary strength to resist earthquake forces. These systems are common in many older dwellings built before codes were adopted in high seismic regions and may also exist in newer dwellings where codes have not been enforced. When subjected to earthquakes these systems are easily damaged, allowing the building to shift off foundations. Section 304.2.2 requires analysis of unreinforced masonry foundations by either an architect or an engineer.

C303 Item 5 Inadequate Sill Plate Anchorage. While sliding between an unanchored sill plate and the foundation can occur, it is actually one of the more rare sources of damage. However, it is still important that sill plate anchorage be present in order to complete the lateral force path. Bracing cripple walls without bolting the sill plate to the foundation simply moves the weak link to the interface of the sill and foundation. Compliance with either Tables 3-A and B or the Building Code is deemed acceptable.

C303 Item 5 Exception No. 1 Because details common in new construction are often impractical in retrofits, the provisions recognize alternative means of anchorage, including proprietary products. These proprietary products are especially useful in conditions where limited clearance prevents installation of bolts through the sill plate in the traditional fashion. Generally, one needs cripple wall studs to be 24 inches or taller to install anchor bolts with a normal drill. Drills with right-angle attachments can be used in more confined spaces in some cases.

C303 Item 6 Inadequate Cripple Wall Bracing. Past earthquakes have shown that the most common cause of major damage in dwellings is due to poorly braced cripple walls. (LA, 1994)

Only wood structural panels and diagonal wood sheathing are acceptable for cripple walls in IBC Seismic Design Categories D, E, and F and in all Seismic Zones regulated by the UBC. Gypsum board, fiberboard, particleboard, lath and plaster, and gypsum sheathing boards are no longer acceptable methods for cripple wall bracing except in Seismic Design Categories A,B, and C. For additional information and connection requirements for these materials, refer to IBC Tables 2308.9.3(1) and 2308.12.4 and referenced sections.

A common and very weak type of cripple wall can be found in older buildings constructed with horizontal, exterior-wood siding. This type of siding, and it's nailing, is not adequate to resist earthquake forces associated with nearby moderate or major earthquakes.

Recent earthquakes have also shown that "let-in" diagonal bracing does not adequately brace cripple walls. (LA, 1994) Let-in braces are usually nominal 1" thick and placed in a notch cut into the face of the stud. Let-in braces are no longer permitted as an acceptable bracing method in IBC for buildings located in regions where strong earthquakes are expected to occur.

Let-in braces should not be confused with diagonal wood sheathing. Diagonal wood sheathing, which is acceptable by these provisions, is composed of individual boards nominally 1" thick, laid diagonally across the face of the stud wall. These boards are laid next to one another covering the entire width and length of the wall extending from the top plate to the sill plate. If the cripple walls are covered with diagonal sheathing, the wall is adequately braced, provided the boards are nailed to each stud they cross and to the top and bottom plates. Adequate nailing consists of three 8-penny nails at each stud and the ends. If the boards or the studs are split, or if the end nails are too close to the ends of the sheathing, this system can be deficient.

The most effective cripple wall bracing system that significantly reduces the risk of damage is wood structural panel sheathing (plywood, OSB) fully nailed around the sheet perimeters, to each stud and especially to the top and bottom plates.

Disturbingly, modern structures are also being found with inadequate cripple wall bracing. These dwellings have been constructed with various forms of plywood siding that was not nailed along the sill plates. Because of this lack of nailing, the cripple wall studs are free to rotate about their base until they collapse. If the dwelling has plywood sheathing as an exterior finish check for nails spaced no more than 6 inches apart along all the edges of each sheet. If adequate nailing is not present, comply with the nailing requirements of this Chapter.

Exterior plywood siding with vertical grooves (referred to as T1-11) can have another serious deficiency. At the edges where two adjacent panels adjoin, each panel must be nailed to the wall stud with a separate row of nails. These sheets have “lips” so that they overlap at the joints. A common, improper construction practice is providing only one row of nails through both sheets (at the overlap). This creates a weakness as the plywood thickness is only one-half of its normal thickness at the overlap, and only half the number of nails is provided. Such practice led to failures in the 1984 Morgan Hill (California) Earthquake. In all cases where nailing is exposed to the elements, it is recommended that hot-dip galvanized nails be used.

A dwelling with existing Portland cement plaster (stucco) as the exterior finish might not have its cripple walls adequately braced by this material. Stucco has been a recognized bracing material for a number of years but it is only as good as the connection of the lath to the studs and plates. Many dwellings with stucco applied directly over the studs without plywood or diagonal sheathing under the stucco experienced serious damage in the 1994 Northridge Earthquake (LA, 1994)(NAHB, 1994). In high seismic regions, most often this failure was due to inadequate attachment of the lath to the bottom sill plate (LA, 1994).

Through the years there have been various lath systems used for installing stucco. Stucco is normally applied in three coats (7/8 inch total thickness). When subjected to high loads it can fail in diagonal tension represented by diagonal cracks. To increase the tension capacity, stucco is reinforced with wire lath. This reinforcing does not keep the stucco from cracking but helps prevent cracks from opening.

C304 STRENGTHENING REQUIREMENTS

C304.1 General

C304.1.1 Scope – Use of materials, proprietary systems or methods not shown by the figures and details within this chapter requires the services of a Design Professional.

Where a dwelling has an unusual or irregular configuration or unusual features, the services of an engineer or architect to design a strengthening program utilizing the alternate procedures of Section 301.3 is required. The Building Official may require a pre-design special inspection as described in A304.5 and C304.5 to determine which portions of the work require the services of a Design Professional.

CUREE recommends a number of enhancements to these provisions that are currently under consideration by the SEAOC Existing Buildings Committee, the East Bay Chapter of the International Code Council and others. (CUREE, 2002)

C304.1.2 Condition of Existing Wood Materials – Damage commonly known as “dry rot” can occur to wood framing exposed to dampness or to water leakage. Termite infestation is another cause of damage to wood members. All buildings being strengthened where damage is suspected should have a thorough inspection but only those elements affected by retrofit need to be checked. If not repaired, “dry rot” and pest damage can weaken sill plates, studs, and wood siding and have a substantial adverse effect on a building’s response to earthquakes.

Even dwellings without dry rot or termite damage may have weaknesses due to poor construction quality. For example, insufficient nailing of plywood, OSB or diagonal sheathing will result in a structure that is unable to resist the forces imposed during earthquakes. Simply repairing the weaknesses will not be adequate if the condition of the existing wood framing members to be utilized is in doubt. It is recommended that the exposed wood be thoroughly inspected to ensure that all wood that is “part of the strengthening work” is in good condition. Members that contain splits, checks (cracks) or knots affecting the ability of the member to resist earthquake forces must be strengthened or replaced.

Existing wood members showing evidence of fungus infection, commonly referred to as dry rot, or evidence of insect infestation must be removed and replaced. Fungus remains active even after the affected area is treated. Fungus infection can be found by probing the wood members with a sharp object like a knife or awl. If the probe easily penetrates the wood, the member might have fungus infection. Sound wood will be difficult to probe. In some cases the fungus infection will be found only inside the member because rot may affect the wood from the inside and progress outward. By the time it is noticeable on the surface as staining or softening, the wood’s strength may already be significantly degraded. Thus it is important to perform probing and visual observations prior to and during construction. In these cases, probing with a sharp tool will not always locate the infection (see Figure 2.). This concealed condition may be encountered when drilling for new sill anchors. If the drill suddenly moves through the wood, a pocket of fungus infection is likely to have been encountered. The portion of the sill plate containing the infection will need to be cut out and replaced with a new piece of sill plate. The new sill plate must be anchored in accordance with Tables 3-A and 3-B. When replacing pieces of sill plate, pressure treated lumber will need to be used to protect the new member from fungus infection.

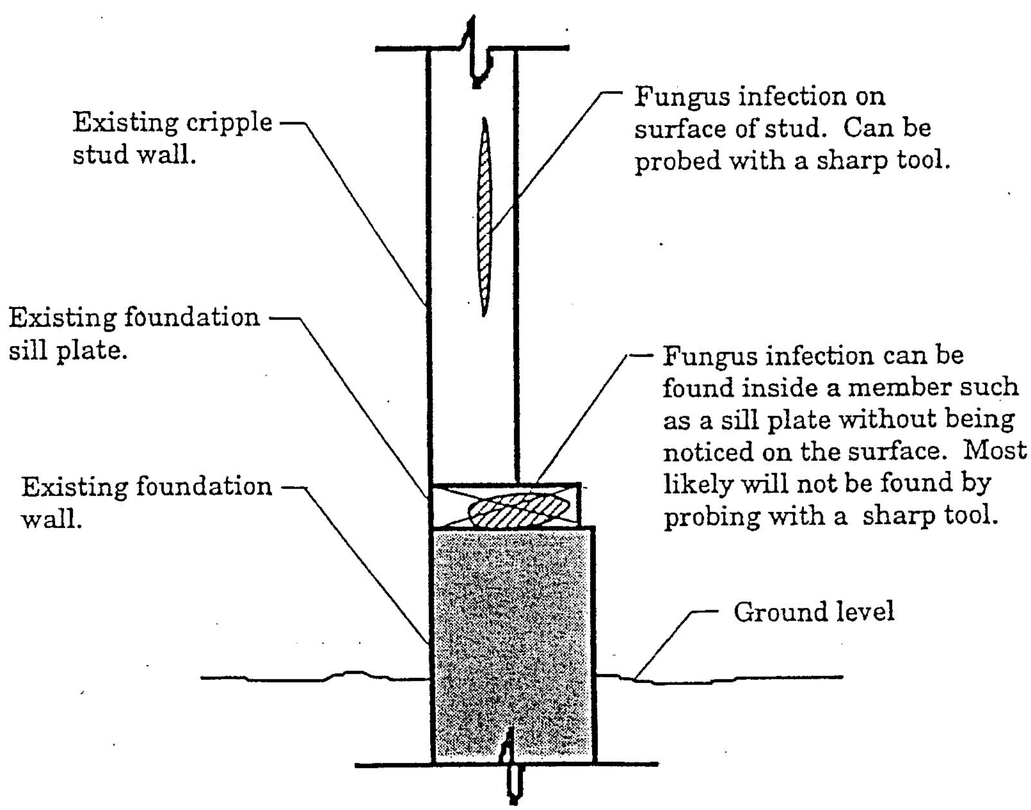

FIGURE NO. 2 - LOCATING FUNGUS INFECTION

- Renumber as “Figure C3-1.”cite reference.

Fungus growth occurs where wood is made continually or repeatedly damp, by a leaking plumbing pipe, or by repeated saturation and drying from an exterior wall that leaks during rains. Simply removing and replacing infected wood will not necessarily prevent the fungus infection from recurring. It is important to find the cause of the leak, repair it, and allow the remaining wood to dry. Repairs will involve tracing a water stain or the actual water to a leaky pipe or fitting or other source. It is usually more difficult to trace a leak in the exterior wall covering. Hand held moisture detectors could be used to locate moisture intrusion. Spraying the exterior of the residence with a high-pressure hose and then using the moisture detector on the inside surface of exterior walls can locate defective flashing or torn paper backing behind the stucco. A common area to check for leaks through the wall is at building corners. Evidence of the infection may be found in other members that are not involved in the strengthening work. It is recommended that other members should also be replaced and the source of the wetness eliminated by appropriate repairs.

Insect infestation, on the other hand, stops damaging the wood once the infestation has been stopped. Consequently, a member that has been significantly damaged by insects does not need to be removed if it can be strengthened. The easiest method of strengthening is to add a new member next to the damaged member. Unfortunately, there are no clear guidelines to indicate when insect damage requires strengthening. This determination must be based on judgment gained through experience.

Prior to removing sill plates or studs for repair due to fungal or infestation damage, temporary shoring must be installed. The design of this shoring must be carefully planned by a qualified Design Professional with shoring design experience and installed by a contractor with shoring experience.

C304.1.3 Floor Joists Not Parallel To Foundations – For these strengthening procedures to be effective there must be a continuous horizontal load path from the exterior walls to the foundation. Where floor joists are perpendicular to a cripple wall, or frame into the cripple wall at an angle, existing rim joists (or blocking) need to be connected to either the foundation sill plate (if there are no cripple stud walls) or the top plate of the cripple wall. When reviewing existing construction, if there is a connection between the rim joist and the plate that meets the nailing requirements of this section, such a connection may be considered adequate for this link in the load path. Where these connections do not exist, new connections must be made. Rim joists will need to be toe-nailed with 8 penny 2-1/2" long common nails, spaced 6 inches apart, through the joist into the plate. Blocking will need to be toe nailed. Use of proprietary products for these connections might be easier than toenailing. When approved by the building official, these connections may be made by using products with current Evaluation Reports by an independent testing authority.

Because the forces in a single-story structure are relatively small, it is not necessary to verify these connections if the blocking or rim joists are present. In multi-story buildings, the connections between the foundation and the blocking or rim joists must be verified. When these requirements are not met or cannot be verified, the provisions of this Chapter apply.

In some cases, existing construction might not include a rim joist or blocking. In other cases the members are smaller in width than a nominal 2 inches (1-1/2 inches). In these cases, either a new nominal 2-inch wide full-depth joist or blocking, or one of the methods described in the Chapter may be used to provide the load path from the floor to the sill plate or cripple wall (Figure 3-8). In addition to providing a load path link, the rim joist or blocking provides rotational restraint for the ends of the floor joists.

C304.1.4 Floor Joists Parallel To Foundations – Where floor joists are parallel to a cripple wall, the same load path concept applies as with joists perpendicular to foundations. In this condition, the end floor joist must occur over the foundation wall or cripple wall and be connected. If this member is not connected to the plate, it will need to be toe nailed with 8 penny common nails spaces at 6" apart or with equivalent approved hardware. This connection need only be verified for multi-story building, for which seismic forces are larger. If an end joist in a multi-story building is not connected to the sill plate on top of the foundation, or this connection cannot be determined, the end joist may be connected to the sill plate with sheet metal angles (proprietary hardware is available). Where clearances do not permit installation of this angle, an alternate method using ¾-inch plywood attached to the foundation plate or cripple wall top plate and to the underside of the flooring as shown in Figure 3-9 may be used.

C304.2 Foundations

C304.2.1 New perimeter Foundations – No Commentary.

C304.2.2 Foundation Evaluation By An Engineer or Architect - It might not be economical to replace existing partial perimeter foundations or unreinforced masonry foundations. In order to determine if existing foundation systems are adequate, an engineer or an architect would evaluate both the condition of the system as well as its ability to resist the prescribed forces. This analysis would be limited to the foundation system only. If other strengthening is to be performed, it must comply with the prescriptive provisions of this chapter.

C304.2.3 Details For New Perimeter Foundations – The first three weaknesses listed in Section 303 involve buildings without complete foundation systems. These conditions will be resolved by installing a new concrete or masonry foundation system around the perimeter of the dwelling. It is the intent of these provisions that all new foundations meet the current minimum standards of the Building Code. Although the Building Code sometimes allows plain concrete foundations for one- and two-family dwellings, standard construction practice is to provide nominal horizontal reinforcing. Reinforcing is often required where the soil is expansive. These provisions, therefore, require reinforcing of all new concrete foundations with a minimum of one No. 4 reinforcing bar in the top and bottom.

The Building Code has specific provisions for minimum clearance under the structure for both access and ventilation. Occasionally, older construction did not provide the clearances that are required today. It is not the intent of these provisions to require current code clearance when a new foundation must be installed. To require excavation or raising the building would be extremely difficult and costly and will not improve its resistance to earthquakes. If substantial fungal or insect infestation has occurred in the past, the owner may want to consider measures to prevent future damage. In some cases, remedial work will be required per Section 304.1.2.

An existing partial concrete foundation (weakness type 3 in Section 303) may be replaced or it may be evaluated by a Design Professional to determine if it can perform in a manner equivalent to a continuous foundation. An existing unreinforced masonry or stone foundation (weakness type 4) may be replaced with a new foundation that complies with the Building Code or it may be evaluated per Section 304.2.2. Replacement might be uneconomical or aesthetically displeasing. A well maintained unreinforced masonry foundation might be adequate to support a building for normal vertical loads, but its strength and ability to brace the building during earthquakes should be evaluated. If the existing unreinforced masonry foundation is not used to resist earthquake forces, a new foundation bracing system may be provided that is independent of the existing foundation. Examples include foundation capping and providing concrete plugs (alternate segments) in the existing foundation. Both fixes require partial removal of the existing foundation as well as shoring and/or jacking of the wood superstructure. The new system must be designed to resist all the earthquake forces from the building occurring at the foundation level. In this case, unreinforced masonry foundations do not require analysis and strengthening when an alternate foundation system is used.

Concrete foundations are typically not reinforced and commonly have cracks due to shrinkage or long-term differential settlement. Even new footings have shrinkage cracks. Common locations for these cracks are at corners and near changes in footing height or thickness. Typical shrinkage cracks in footings are straight and vertical and have uniform narrow width. Isolated cracks less than 1/8-inch in width can be assumed not to significantly diminish the strength of the foundation. (ATC, 2002)

C304.3 Foundation Sill Plate Anchorage

C304.3.1 Existing Perimeter Foundations – The provisions for connecting existing sill plates to existing foundations maintain the traditional code requirements for 1/2-inch diameter bolts spaced a maximum of 6 feet apart for one story buildings. Two and three story buildings need progressively more bolts because their height and added weight result in larger forces to be resisted.

Expansion bolts and chemical anchors are acceptable for connecting to existing concrete. These connectors, due to their shorter length of embedment into the concrete, have lower capacity in concrete than anchor bolts that are cast-in-place when the foundation is poured. However, even with the required 4-inch embedment, these connectors will have the same capacity in the wood sill plate, which is the weakest link in this connection. Consequently, properly installed expansion bolts or chemical anchors can provide the same resistance against sliding as cast-in-place bolts.

An expansion bolt is effective when the hole is drilled the correct size, the hole is relatively clean, and the bolt is properly tightened to set the expanding portion of the assembly in accordance with manufacturer's specifications. For expansion bolts to be fully effective the foundation material must be able to engage the expansion portion without cracking. Where cracking indicates conditions of poor quality concrete or masonry during installation, expansion anchors may not be used. If cracks are observed during installation, installation should be stopped, and a bolt should be installed at a new location at least 1 foot away. If the problem continues, chemical anchors or screw type should be used instead. All anchors must be installed away from the edge of the sill plate in order to be effective.

The chemical anchor is a threaded rod that uses "epoxy" type adhesive to set the anchor. Chemical anchors are effective when the hole is the correct size and the hole is completely clean. Concrete dust must be removed in accordance with manufacturer's specifications. A clean hole is more critical for chemical anchors than for expansion bolts. Chemical anchors are allowed for all types of foundations, but are required where existing concrete is in poor condition or when the installation of expansion bolts causes cracking of the concrete.

Some adhesives are viscous enough for use in horizontal holes but others are too thin and tend to drain out of the holes before setting. To avoid this problem, consult with current ICC Evaluation Services reports on anchor systems as well as manufacturers' instructions before purchasing.

The provisions require square plate washers between the nuts and the sill plate. Because the holes that must be drilled to insert the connectors are larger than the connector diameters, the resulting holes in the sill plate are too large to provide proper bearing against the bolts. Consequently, the plate washer is installed so that the nut can be tightened sufficiently to develop the required clamping action between the sill plate and the top of the foundation wall. The use of plate washers is also intended to minimize the potential for crushing and splitting of the sill plate as the bolt is tightened. Due to the oversized hole in the wood sill a standard round washer does not engage enough of the wood around the hole. The use of the larger plate washer will eliminate the problem of the nut recessing into the drilled hole as it is tightened. Table 3-A provides the size of the plate washers required.

The provisions call for the nut to be tightened to a "snug-tight condition" *after* epoxy curing is complete or *after* the nut has been tightened to set an expansion bolt. Tightening the nut to set the expansion bolt and tightening the nut to connect the sill plate to the foundation are separate operations. The setting requirements of expansion bolts vary according to the bolt used. The specific bolt manufacturer's procedures must be closely followed to assure that the bolt is properly set and is capable of transmitting forces into the foundation. Because these procedures vary, the provisions only address how tight the nut should be after an expansion bolt has been properly set or the adhesive of a chemical anchor has set. If the nuts are not tight against the washer plates, there will not be sufficient clamping action between the sill plate and the foundation wall. The nut should be tightened to the point at which the full surface of the plate washer is in contact with the wood member and slightly indents the wood surface. Over-tightening beyond this "snug-tight" condition will cause crushing of the wood sill that will reduce the capacity of the connection. This section also gives the Building Official the authority to spot test the nut tightness during the required inspection.

Figures 3-4A, 3-4B or 3-4C show side plates with chemical anchors or expansion bolts into the foundation and lag bolts into the narrow face of the existing wood sill plate. Proprietary systems with ICC-ES reports or other independent test reports may be used with Building Official approval in lieu of the connections shown if they provide an equal or greater capacity.

Figure 3-4C also shows the condition of a battered footing. This type of slanted face footing will require that the wood shim installed between the steel plate and the wood sill plate must be shaped so the steel plate will have full contact against the shim when the lag screws are tightened. Further, a beveled washer under the head of the lag screw is needed to ensure that it bears fully on the steel plate. It is recommended that the shim be nailed to the sill plate (in addition to the lag screws), but the nailing must not split the shim. Pre-drilling of holes may be necessary. Alternative details may be easier and faster to install and should be acceptable in principle to the Building Official. Discuss potential alternatives with the building department or consider hiring a licensed design professional to prepare an alternative for unique conditions.

C304.3.2 Placement of Chemical Anchors and Expansion Bolts – Careful attention needs to be given to the proper location and spacing of sill bolts. In order to assure that the sills are properly connected, this Section not only specifies the minimum spacing, but also limits the placement of bolts at the ends of pieces of sill plate. These provisions differ from those in the Building Code in requiring the bolts be placed no closer than 9 inches from the end of the sill plate. When bolts are placed closer than 9 inches to the end of a plate, there is a potential for that bolt to split the sill from the bolt hole to the end of the plate as the bolt is loaded from earthquake forces. When the bolt is placed more than 12 inches from the end of the piece there is a tendency for the end of the plate to lift due to overturning forces on the wall (CUREE, 2002). Placing the bolt between 9 and 12 inches from the end will minimize both tendencies.

These provisions also address the realities that existing sill plates may be installed in short pieces either where the foundation wall steps or where new pieces of a sill plate must be installed to replace sections damaged by fungus infection or insect infestation. Therefore, the provisions specify a minimum number of bolts for various lengths of sill plate.

It will not always be possible to install sill bolts at the exact spacing. There are many existing elements that can interfere with their placement, such as a fireplace, plumbing or mechanical ducts. The provisions of this chapter have taken these field situations into account and allowed that where physical obstructions exist, the bolts may be omitted. However, the spacing of the remaining bolts needs to be adjusted so that the same total number of bolts is installed as though the obstruction did not exist. It is recommended that if possible, the bolts with close spacing should coincide with the sheathing locations.

C304.4 Cripple Wall Bracing

C304.4.1 General – When bracing a cripple wall, consideration must be given to providing adequate resistance to both the horizontal forces and the tendency for uplifting one of the ends of the wall. Any wall panel that is subject to earthquake forces has a tendency to want to lift up at one end as well as slide. This uplift can be resisted by one of two methods. In new construction a "holddown" anchor consisting of a heavy gauge metal angle is bolted to a stud and also anchored into the concrete foundation. Because this would be impractical to install in existing construction the method used in this chapter is based on the proper proportioning of the length and height of the cripple wall bracing panels. By making the panels longer, more weight from the walls and floor above can be engaged to resist the uplift force. The basic proportion required is a minimum length of braced cripple wall panel at least two times its height. (RRR, 1992) In addition, longer panels are needed as the number of stories above the wall increases. This is simply because a taller building imposes larger horizontal forces on the braced cripple wall panel.

Nonbearing walls, where floor joists run parallel to the wall, will not engage substantial weight, so holddowns at the ends of the walls may be prudent for multi-story buildings. Where cripple wall bracing panels can be connected at corners of buildings and installed in combined panel lengths longer than the minima defined in Figure A3-10, the potential for wall overturning can be reduced. In addition, continuity provided by rim joists, plates, and floor framing tends to create appreciable fixity at the tops of the cripple walls that offsets wall overturning.

To stay within the limits of these prescriptive methods, a maximum of 4 feet for the height of the cripple wall was established to limit overturning effects. When the height of the cripple wall exceeds 4 feet, the dwelling owner will need to have the bracing designed by a Design Professional.

C304.4.1.1 Sheathing Installation Requirements **–**15/32 inch thick (5 ply) plywood is prescribed as the required sheathing because of observations of ruptured 3/8" thick (3 ply) plywood panels documented in the Modified Mercalli Intensity (MMI) VIII and IX intensity areas caused by the Northridge Earthquake (LA, 1994).

Let-in braces have been observed to perform poorly in past earthquakes without some other form of bracing (LA, 1992). Let-in braces are no longer accepted by the 2003 IBC for Seismic Design Category D, E, and F. Therefore, walls braced only with let-in braces are considered a structural weakness requiring supplemental bracing.

Even though the provisions accept existing diagonal wood sheathing to be acceptable (see Section C303), diagonal wood sheathing is no longer cost-effective for strengthening weak cripple walls. The omission of this material was not based on its ability to resist lateral forces, as it has performed well in past earthquakes and high winds (LA, 1992). Instead it was based on cost considerations and practicality, since this type of sheathing is more time consuming to install and more expensive than wood structural panels. Proprietary bracing methods may also be used when approved by the building official.

The most important component of wood structural sheathing is proper nailing. To prevent splitting of existing wood framing 8d nails are considered optimum for 2x material. If splitting of studs is observed, predrilling of holes is recommended. Predrilled holes should have a diameter of about 3/4 of the diameter of the nail. Nail guns tend to produce less splitting than hand nailing. Minimum edge distance for nails should be maintained for plywood and the wood studs and top and sill plates to prevent splitting or premature nail failure. With this size nail, 4 inch spacing provides adequate capacity with the minimum bracing length permitted by Table 3-A and Figure 3-10. Further, using larger nails or closer spacing would, by comparison of capacity, require larger diameter sill bolts or closer spacing of the bolts than specified in Section 304.3.2.

When plywood is installed on the inside face of cripple walls with an exterior surface of stucco, care must be used to prevent damage to the stucco. In this situation, it is recommended that 3-inch long #6 wood screws may be used instead of nails. The 3-inch length is needed to ensure that the shank (unthreaded) portion of the screw will have at least 5/8” penetration into the studs and plates. If the threaded portion of the screws exists at the plywood-stud interface, the screws can fail in a brittle manner when the earthquake occurs.

If a nail gun is used, the operator must make sure that the nail heads do not fracture the surface of the plywood. Local variations in the density of the backing (new or existing wood framing members) can create situations where it will be difficult to maintain consistent nail penetration. The use of a flush head attachment on a nailing gun will usually prevent overdriving. When a nail head fractures the plywood surface, the amount of force that this particular connection is capable of resisting is reduced significantly. It becomes much easier for the nail head to pull through the sheathing material. Whenever a nail head fractures the surface of the sheathing, the nail must be discounted. When a nail is discounted, it must be left in place. Removing the nail will further damage the sheathing material and could result in the rejection of the whole sheet of sheathing by the inspector. (Shepherd, 1991)

When purchasing structural sheathing, one of the structural grades must be stamped on the sheets used. The correct grade of structural sheathing is important. Refer to the Building Code for more information.

C304.4.2 Distribution and Amount of Bracing – Table 3-A and Figure 3-10 note the location and distribution of bracing panels based on the number of stories and cripple stud height. The amount of bracing described is for *each* wall line.

Figure C3-2 shows where cripple wall bracing should be installed in conditions where the building floor plan is not a simple rectangle. While the interpretation in Figure C3-2 tends to penalize dwellings with reentrant corners, compared to rectangular buildings, and require more wall length in one direction compared to the other, the code rules are intentionally kept simple so that homeowners and contractors can readily apply them. If owners desire to install fewer walls, they should consider hiring a Design Professional.

Bracing panels are required at or near each end of each wall line . Although not required, it is beneficial if the cripple wall bracing panels align with the panels above the first floor to provide a more direct load path. Thus, cripple wall bracing panels should be located under windows only when necessary. Performance can also be enhanced if all panels along a single wall line are of similar lengths rather than having one very long panel and other shorter panels. This prevents concentration of forces in one location. The existence of a small number of studs over 14 inches in heights should not trigger this requirement.

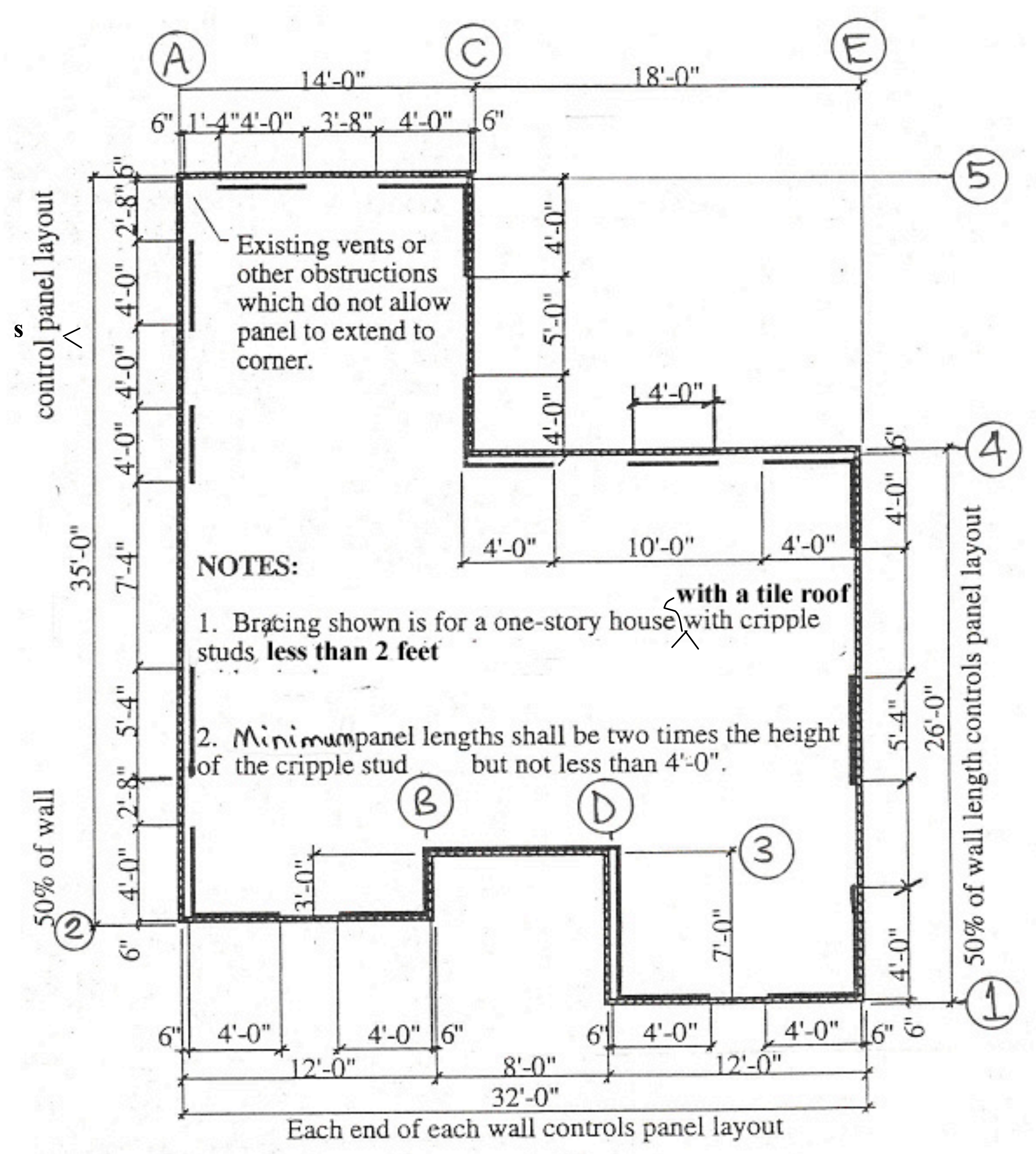

FIGURE NO. - CRIPPLE WALL BRACING PANEL LAYOUT

Renumber to Figure C3-2.

***C304.4.3 Stud Space Ventilation* –** The most common form of cripple wall bracing will be to add sheathing to the interior face of the cripple wall from within the crawl space. When this is done, a closed space is created between each stud that does not allow natural ventilation. This can result in a build up of moisture that will lead to fungus infection. In order to protect these concealed spaces from fungus infection, 2” to 3” diameter (3” recommended) ventilation holes must be provided (See Figure 3-7). These ventilation holes will allow the free movement of air within the stud space thereby minimizing the risk of fungus infection. When 2x horizontal blocking is needed in the stud space to provide backing for panel joint nailing, it must be installed with the wide face oriented vertically, flush with the face of the stud on which the sheathing is being installed. This can be easily accomplished using commercially available fence rail hardware at each end to attach the block to the studs. This will eliminate blockage of ventilation inside the stud space.

Ventilation holes should be cut or drilled as close to round as possible. Hole cutting tools are available to cut the required size hole. Square holes, or other shapes with sharp corners or notches can result in high concentrations of stress when the panel is loaded.

***C304.4.4 Existing Underfloor Ventilation* –**Air circulation under the floor protects the framing from fungus infection. Vents by themselves do not provide all the solutions to underfloor ventilation. It is imperative that there be cross ventilation. In order to have cross ventilation, the vents must be located in opposite walls, approximately opposite each other. In many cases, heating units have been added to the dwelling and the ducts are installed within the crawl space. When this is done, the ducts block the cross ventilation and significantly reduce the efficiency of the vents. Consequently, a dwelling with vents that meet existing code might not be adequate if there are obstructions to the cross ventilation. If this condition exists, consideration should be given to providing additional vents in order to obtain the necessary cross ventilation.

***C304.5 Quality Control* –** Strengthening work is only as good as the quality of the construction. In most jurisdictions the strengthening work required by this chapter will require building permits and inspections. Prior to requesting a permit the owner or contractor should survey and determine all existing conditions, dimensions, and other considerations significant to the retrofit or repair work. A plan should be prepared (11x17 inch paper with 1/8” = 1 foot scale is adequate) showing the location of proposed sheathing and spacing of anchor bolts. The drawings should differentiate between new and existing components. Because of the nature of the work being performed and the materials being used, there are some additional inspections that need to be performed that are not specified in the Building Code for new construction.

C304.5 Item 1 Placement and Installation of New Chemical Anchors or Expansion Bolts. The Building Official must approve the use of expansion bolts or chemical anchors. Building officials often use Evaluation Reports from the International Code Council Evaluation Services (ICC-ES) as guidance in the products they approve. These reports set allowable design values based on testing and specify requirements for construction quality control. They often call for special inspection, especially for bolts that might be subject to tension forces. (Special inspection generally involves inspection of the work while it is being performed, as opposed to when it is complete. It is performed by qualified individuals retained by the owner.)

For the purposes of GSREB Chapter 3, special inspection is not required because the bolts in question are intended to act primarily in shear, not in tension. Even if these bolts are not set exactly as noted in the evaluation report they will still work to resist the shear forces from earthquakes. The waiving of special inspection thus represents a justifiable cost savings. While special inspection is not typically required, the building official may still require verification of proper installation per Section 304.3.1.

In lieu of special inspection, it is recommended that a post-installation torque test for expansion anchors be done together with inspection for bolt spacing, end distance and a spot check to make sure the nuts are properly tightened. Usually this inspection would be performed after the bolts were installed and before the cripple wall sheathing is placed. However, the building official may elect to perform this inspection at the same time they inspect the installation of the cripple wall sheathing. Vent holes in each stud space should be located and sized to allow inspectors to reach in and torque the bolts.

Both expansion bolts and chemical anchors must be approved, as stated in the Section 302 definitions. This means that they generally must have a valid evaluation report from the International Code Council Evaluation Service (ICC-ES) or an approved equivalent independent test report. Normally chemical anchors require continuous inspection during their installation as a part of their approval for use. Continuous inspection checks that the hole is the correct depth and is sufficiently clean prior to placing the epoxy material. Its purpose is to ensure that each bolt will attain the tension strength allowed by its evaluation report.

Since sill bolts are not subject primarily to tension, however, the provisions make an exception to this rigorous special inspection requirement. However, it is recommended that a less expensive torque test of expansion anchors in lieu of tension tests is an appropriate substitute for special inspection. Torque tests must be performed on at least 25 percent of the total number of installed expansion bolts and must be done in the presence of a building inspector or a deputy inspector employed by a testing agency hired by the owner and approved by the authority having jurisdiction.

C304.5 Item 2 Installation and Nailing of New Cripple Wall Bracing. The final required inspection is to make sure that the connections of the wall bracing panels are installed correctly and completely. The bracing serves no purpose if the connections do not engage the proper framing members, or, in the case of wood sheathing, are overdriven.

C304.5 Item 3 Work Subject to Special Inspection - The building official may require special inspection where conditions on a particular job site make inspections difficult . Retrofit and strengthening work often involves unusual conditions or proprietary components that require additional levels of quality control. In order to address these problems, the building official is allowed to require that a special inspector verify work.

Most dwellings have some features that will not conform to the conditions and strengthening provisions used in this Chapter. To avoid situations where those existing conditions either preclude the use of these prescriptive provisions or where other complications may occur that would make their application to a specific building difficult, the Building Official is encouraged to perform a pre-design inspection. The cost of this inspection, however, may be in addition to the normal permit fee . Such an inspection might not be necessary if the owner provides adequate drawings supplemented by photographs to permit adequate review by the building official.

The purpose of a pre-design inspection is to notify the owner or contractor of problems that may need the services of Design Professionals. It is not intended to be a consulting service to the owner. Typically, this inspection should focus on the following issues:

- Areas where obstructions in the crawl space along exterior walls might prevent installation of adequate lengths of bracing;
- Areas that may be questionable with respect to insect or fungal damage to wood members to be used in the strengthening;
- Foundations that may be questionable or clearly too weak to be effectively used for anchoring sill plates;
- Tests of nut snug-tightness on sill bolts;
- Inadequate rim joist or blocking conditions along exterior wall lines;
- Other concerns that the owner or contractor believes will preclude the use of the prescriptive details or methods described in this Chapter.

C304.6 Phasing of Strengthening Work – The phasing of the strengthening work can occur when approved by the building official. A new permit will be required for each phase before beginning the additional work. Phasing may benefit owners with limited budgets or scheduling conflicts with other planned alterations.

The strengthening work in any phase requires that the work be performed on at least two parallel sides and never on one side alone. This is meant to prevent rotation of the foundation anchorage, in plan, from seismic horizontal forces.

References

(ATC, 2002)
ATC 50 Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings; ATC 50-1 Seismic Retrofit Guidelines for Detached, Single-Family Wood-Frame Dwellings; ATC 50-2 Safer at Home in Earthquakes a Proposed Earthquake Safety Program, Applied Technology Council, www.atcouncil.org , 2002.

(ABAG, 1999)
Preventing the Nightmare – Designing a Model Program to Encourage Owners of Homes and Apartments to Do Earthquake Retrofits, Association of Bay Area Governments, 1999.

(ABAG, 2000)
Preventing the Nightmare – Post-Earthquake Housing Issue Papers, Association of Bay Area Governments, 2000.

(CEA, 2002)
Earthquake Insurance Retrofit Premium Discounts, Rates and Premiums, Policy Information, California Earthquake Authority, http://www.earthquakeauthority.com/rates/rates_premiums.html#top , 2002.

(CRERF, 1992)
Damaging Residential Earthquakes Since 1960 , California Residential Earthquake Recovery Fund, 1992.

(CSSC, 1998)
Homeowner's Guide to Earthquake Safety, CA Seismic Safety Commission, www.seismic.ca.gov, 2002.

(Comerio, 1982)
Earthquake Hazards and Wood Frame Houses – What You should Know and Can Do, College of Environmental Design, U.C. Berkeley, Mary C. Comerio, Levin, 1982.

(Comerio, 1996)
Residential Earthquake Recovery – Improving California's Post-Disaster Rebuilting Policies and Programs, Mary C. Comerio, John D. Landis, Catherine J. Firpo, Juan Pablo Monzon, California Policy Seminar, Berkeley, 1996.

(CUREE, 2002)
Recommendations for Earthquake Resistance in the Design and Construction of Woodframe Buildings, Consortium of Universities for Research in Earthquake Engineering, 2002 Final Review Draft.

(DSA, 2002)
Guidelines for Earthquake Bracing of Residential Water Heaters, DSA Review and Acceptance Procedures – Manufactured Earthquake Bracing Systems for Residential Water Heaters, Division of the State Architect, Department of General Services, State of California, www.dsa.gov , 2002.

(FEMA, 1995)
Seismic Retrofit Training for Building Contractors and Building Inspectors - Participant Handbook, Wiss Janney, Elstner Assoc. , EMW-92-C3852, 1995.

(IBHS, 1999)
Is your Home Protected from Earthquake Disaster? – A Homeowner's Guide to Earthquake Retrofit, Institute for Building and Home Safety, www.ibhs.org ,1999.

(Gallagher, 1990)

Mitigation of Principal Earthquake Hazards in Wood Frame Dwellings and Mobile Dwellings, Ron Gallagher, S.E., CA Department of Insurance, June 1990

(Huntington, 1991)
Taking the Lead on Earthquake Safety, Craig G. Huntington, Civil Engineering Magazine, Pg. 6, June 1991.

(LA, 2001)
Reconstruction and Replacement of Earthquake Damaged Masonry Chimneys, City of Los Angeles, Department of Building & Safety, http://www.ladbs.org/Reports_and_Publications/Information_Bulletin/information_bulletin.htm ,2001.

(LA, 1994)
Prescriptive Provisions for Seismic Strengthening of Light, Wood Frame, Residential Buildings, City of Los Angeles, Department of Building and Safety, Joint City of Los Angeles/SEAOSC Subcommittee on Cripple Wall Buildings, 1994.

(NAHB, 1994)
Assessment of Damage to Residential Buildings Caused by the Northridge Earthquake, National Association of Home Builders, http://www.nahbrc.org , 1994.

(NIST, 1997)
Fire Hazards and Mitigation Measures Associated with Seismic Damage of Water Heaters, Mroz and Soong, National Institute of Standards and Technology, 1997.

(RRR, 1992)
Prescriptive Provisions for Voluntary Seismic Strengthening of Light, Wood-frame Residential Buildings, (with Commentary), Residential Retrofit and Repair Committee jointly sponsored by CA Office of Emergency Services, California Building Officials, American Institute of Architects – CA Council, Structural Engineers Association of CA, State Historical Building Safety Board, available from CA Seismic Safety Commission, 1994.

(SL, 2002)
City of San Leandro, CA Retrofit Plan Set, http://www.ci.san-leandro.ca.us/program.html , 2002.

(Shepherd, 1991)
An Experimental Investigation of Retrofitted Cripple Walls, R. Shepherd and E.O. Delos-Santos, Bulletin of the Seismological Society of America, Vol 81, No. 5, pp. 2111-2126, October 1991.

(Steinbrugge, 1990)
Earthquake Losses to Single-Family Dwellings: California Experience, Karl V. Steinbrugge and S.T. “Ted” Algermissen, US Geological Survey Bulletin 1939-A.

(SEAOC, 1995)
History of Conventional Construction, Structural Engineers Association of California, 1995.

(SEAOSC, 2002)
Seismic Retrofit of Existing Buildings – Retrofit of Hillside Dwellings, Seminar Notes, Nels Roselund, Prescriptive Provisions for Seismic Strengthening of Cripple Walls, Ben Schmid, June 2002.