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Hidden Lateral Strength in Older Homes

Résistances latérales cachées dans les anciennes maisons

Versteckte Aussteifungen in älteren Häusern

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SUMMARY

This paper investigates the hidden lateral strength in older homes. It begins by reviewing current knowledge of residential seismic performance. A brief discussion of the United States' Uniform Building Code definition of conventional light wood-frame construction is included. This type of construction is analysed through computer modelling to determine the theoretical strength of older frame construction walls. Additional strength is identified through configuration of the home. Finally, recommendations for future code consideration are presented to improve the performance of homes in high seismic zones.

RÉSUMÉ

L'article étudie les résistances latérales présentes dans les anciennes maisons. Il passe en revue l'état des connaissances sur la performance sismique des habitations. La définition de la construction légère classique utilisant des charpentes en bois est donnée d'après le "Uniform Building Code" des États-Unis. Ce type de construction est alors étudié à l'aide d'un modèle informatique, pour déterminer la résistance théorique des murs construits avec les anciennes charpentes. L'analyse met en évidence une résistance supplémentaire, dépendant de la configuration de la maison. Des recommandations sont faites afin d'améliorer les performances des habitations dans les zones à haut risque sismique.

ZUSAMMENFASSUNG

Diese Abhandlung untersucht die versteckten Aussteifungen in älteren Häusern. Sie beginnt mit einem Rückblick auf das bisher bekannte Wissen über die Widerstandsfähigkeit von Wohnhäusern gegen erdbebenbedingte Erschütterungen. Sie beinhaltet auch eine kurze Betrachtung der Definition des Uniform Building Code der USA. für konventionelle Leicht-Holzbalkenkonstruktion. Diese Konstruktionsart wird durch Computermodelle analysiert, die den theoretischen Widerstand älterer Wände in Balkenkonstruktion bestimmt. Zusätzlich wird der Widerstand in Abhängigkeit von der Bauart der Häuser beschrieben. Abschliessend werden Empfehlungen für zukünftig zu berücksichtigende Werte gegeben, um den Widerstand von Häusern in erdbebengefährdeten Gebieten zu verbessern.

1. INTRODUCTION

Residential construction has not been a recent priority for seismic research. While studies have been done to define strength parameters for new construction, little recognition has been given to older home construction and its hidden strengths. For years, the United States' Uniform Building Code (UBC) has recognized that older homes have inherent lateral strength through the provisions of Section 2517, unofficially referred to as the "prescriptive method" of lateral analysis. This section defines code provisions for conventional light wood-frame construction. Specific definitions are given to different bracing systems and the configuration of the structure. If falling within Section 2517's provisions, the house is deemed acceptable for most seismic and wind zones. This paper will present a review of residential home performance in earthquakes, it will study how the configuration provisions of 2517 provide a stronger-than-expected home, and it will make recommendations for residential seismic code improvements.

The general public does not realize that most building codes are primarily focused on life-safety. In a disaster such as an earthquake, the UBC's primary goals are to resist collapse and allow safe exit of the building occupants. Little consideration is given to the amount of structural and non-structural damage sustained by the building. After the January 17, 1994 magnitude 6.8 Northridge, California earthquake, 15,000 homes and apartments were made uninhabitable. Tens of thousands of additional homes were sufficiently damaged to require costly repairs. Is this acceptable in a country with stringent building codes and regulations? Physical, mental, and economic damage to a community after a disaster can be devastating. We have the knowledge in our engineering community to mitigate much of this residential damage through recognition of older homes' hidden strengths. If we integrate these ideas more closely into our building codes in high seismic zone areas, the savings to homeowners, the community, insurance companies, and the government can be tremendous.

2. RESIDENTIAL SEISMIC PERFORMANCE - LITERATURE SEARCH

The Earthquake Engineering Research Institute publishes "Earthquake Spectra," one of the best sources of findings after each major earthquake. Often there is little information about the seismic performance of homes. Most often mentioned reasons for damage are:

1. The lack of a continuous load path from roof to the foundation.
   a. The lack of anchor bolts between the house and foundation.
   b. Unbraced cripple walls between the house and foundation.
   c. The lack of properly constructed shear-resisting walls.
   d. The lack of a proper method to resist shear wall overturning.
2. Lack of bracing/strapping for the hot water heater.
3. Building geometric and stiffness irregularities.
4. Precarious site conditions, such as liquefaction and steep slopes.

Figure 1 - Typical Early 1900's Home

While "Earthquake Spectra" reports damage findings, few reports have studied what types of homes have performed well in earthquakes. Good design, construction, and inspection practices can address all of the above deficiencies, except for site limitations. With the techniques identified in this paper, additional strength can be designed into homes without increasing construction costs. To understand the importance of configuration in residential lateral design, it is important to first understand some of the conventional light wood-frame provisions in the UBC's Section 2517. Figure 1 shows a typical older home conforming to these provisions.

3. CONVENTIONAL LIGHT WOOD FRAME CONSTRUCTION - UBC LATERAL DESIGN GUIDELINES

Conventional light wood-frame construction is the typical type of construction employed in the timber framing of most homes in the United States. The 1991 Uniform Building Code, Chapter 25, Section 2517, Conventional Construction Provisions, defines design guidelines for conventional light wood-frame construction. This section also refers to a Table No. 25-V - Wall Bracing. This table presents acceptable wall bracing provisions for the four seismic zones, and is referred to as the "prescriptive method of lateral design". From a code interpretation in the Building Standards magazine, Section 2517 and Table 25-V are limited "to regular, or conventional, structures... In general, regular structures have no significant discontinuous elements in plan or elevation and the lateral force-resisting system is positioned parallel to the major orthogonal axes. Regular structures in plan are without reentrant corners associated with "L"- or "T"-shaped systems; roof and floor diaphragms are without abrupt discontinuities or large openings; there are no out-of-plane offsets in vertical bracing elements; and bracing elements are uniformly distributed parallel to the major axes of the structure. Regular structures in elevation are without structural discontinuities such as in-plane offsets of bracing elements and large mass or geometric differences between stories or levels. If the framing member sizes of a light-frame structure are selected in accordance with Section 2517 and the bracing system is without offsets in both the horizontal and vertical planes, the conventional construction provisions are applicable in Seismic Zones Nos. 2, 3, 4."[2] Figure 4 shows Table 25-V as presented in the 1991 Uniform Building Code.

The historical significance to this section is important because it is the nearest the UBC comes to recognizing the hidden lateral strength of older homes. The Handbook To The Uniform Building Code gives some explanation as to the origin of these prescriptive provisions. The last modification to the wall bracing requirements in Section 2517 and Table 25-V came after the 1971 San Fernando earthquake. As the Handbook explains, "The provisions of Section 2517 are based on experience gained over the last 60 years or more."[3] Though the Handbook doesn't elaborate, most likely this experience was based upon observations of older homes (early 1900's), among others. Examining Figure 5 (25-36 from the Handbook), the sketches look conspicuously like many of the popular older home styles. The blank areas between the cross-hatching would typically represent windows or doors. Among others, homes from the French architecture (Second Empire, French Eclectic), the English architecture (Georgian, Adam, Colonial Revival), and Italian architecture (Italianate, Italian Renaissance) falls into the 25-V category. All of these styles are prevalent in older American cities throughout the United States, as well as throughout Europe. One can surmise that this style of regularly spaced walls defined in 25-V occurred because glass was scarce and expensive in early homes. Therefore, windows were located at the center of rooms to maximize natural lighting. The window positioning typically happened to leave 4 foot (1.2 m) wide walls in the corners and regularly spaced 4 foot (1.2 m) panels throughout the home.

Figure 2 - A Typical Prescriptive One-Story Home

Figure 3 - A Typical Two-Story Prescriptive Home

TABLE NO. 25-V—WALL BRACING

SEISMIC ZONE	CONDITION	TYPE OF BRACE[1] A	B	C	D	E	F	G	H	AMOUNT OF BRACING[2]
0, 1 and 2	One Story Top of Two or Three Story	X	X	X	X	X	X	X	X	Each end and each 25′ of wall
	First Story of Two Story or Second Story of Three Story	X	X	X	X	X	X	X	X	
	First Story of Three Story		X	X	X	X[3]	X	X	X	
3 and 4	One Story Top of Two or Three Story	X	X	X	X	X	X	X	X	Each end and each 25′ of wall
	First Story of Two Story or Second Story of Three Story		X	X	X	X[3]	X	X	X	Each end. 25% of wall length to be sheathed
	First Story of Three Story		X	X	X	X[3]	X	X	X	Each end. 40% of wall length to be sheathed

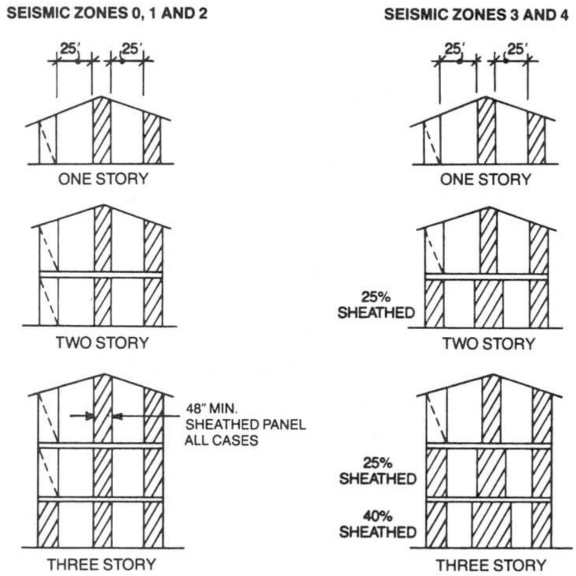
[1]See Section 2517 (g) 3 for full description.

[2]Bracing at ends shall be near thereto as possible. Braces shall be installed so that there is no unbraced section along the wall exceeding 25 feet.

[3]Gypsum wallboard applied to supports at 16 inches on center.

A - 1"x4" Let-In Braces
B - 5/8" Minimum Diagonal Sheathing
C - 3/8" Minimum Plywood Sheathing
D - 1/2" Minimum Fiberboard, 4'x8' Sheets
E - 1/2" Minimum Gypsum Wall Board
F - Particle Board Wall Sheathing Panels
G - Portland Cement Plaster
H - Hardboard Panel Siding

Figure 4 UBC Table 25-V [4]



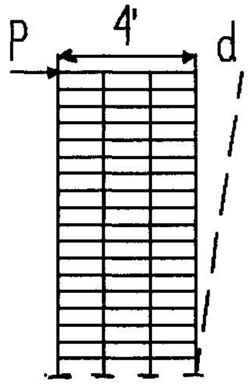
WALL BRACING

Figure No. 25-36

Figure 5 Handbook to the UBC Figure 2 5-36 [3]

4. ANALYTICAL STUDY OF TRADITIONAL HOME DESIGNS

The 4'(1.2m) wide wall panels are identified as key to the UBC prescriptive method. These can easily be seen in the pictures, UBC Table 25-V, and the UBC Handbook 25-36. These 4'(1.2m) panels were typically thought to act in shear. Apparently ignored was the approximately 2'(0.6m)-4'(1.2m) wide beams connecting the 4'(1.2m) panels. Since these panels are typically skip-sheathed, this investigation focused on the whole wall acting more flexibly as a portal frame. First, the strength of a typical skip-sheathed 4'(1.2m) wall panel had to be quantified. A finite element frame model was created as shown in Figure 6. The model is a 4 foot (1.2 m) wide wall, with heights varying between 7 feet (2.4 m) and 10 feet (3.0m) high. The verticals are 2"(5 cm)x4"(10 cm) Douglas Fir members, spaced at 16" (40 cm) on center. The horizontals are 1"(2.5 cm)x6"(15 cm) tongue-in-groove skip sheathing on both the inside and outside walls. The horizontals are connected to the verticals with 2-8d nails spaced 5"(13 cm) apart. The limiting factor for loading this frame is the nail connection. The maximum nail allowable shear is 129 pounds (574 nt). The maximum beam connection moment for the element, then, is figured using a 5"(13 cm) moment arm, per side. The maximum panel shear load was iterated until the first element connection reached its maximum allowable moment. The resultant loads and corresponding deflections are shown in Figure 6 below. In this case, a linear elastic analysis is valid because loads and deflections are so low.



7'(2.1m) Wall Height, P = 1,160#(5,162nt), d = 0.026"(0.07cm)

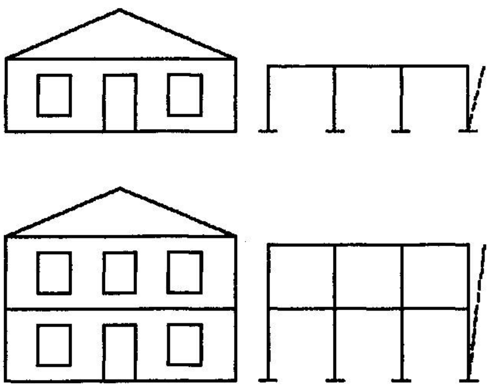
8'(2.4m) Wall Height, P = 1,148#(5,109nt), d = 0.030"(0.08cm)

9'(2.7m) Wall Height, P = 1,140#(5,073nt), d = 0.036"(0.09cm)

10'(3.0m) Wall Height, P = 1,136#(5,055nt), d = 0.042"(0.10cm)

Figure 6 - Frame Analysis Results For 4' Panel

After the frame panel analysis was complete, equivalent wall properties were determined to model a simple frame for a side of both a one-story and two-story house of varying wall heights. A typical house configuration was selected as shown in Figure 7. The house is 28'(8.5 m) square in plan, with a 6'(1.8) high roof. The model is shown in Figure 7with each member modeled as a skip-sheathed panel from the first analysis. Note the difference between our model and the 25-36 sketches of Figure 5. The portion crucial to our model, and ignored in the prescriptive method, is the beam section of the portal frame. To ensure that compatibility was maintained with the results of the single 4'(1.2 m) panel, story drift was limited to the deflection of the single 4'(1.2 m) panel, 0.031"(0.8 mm). The resultant loadings are shown in Figure 7. These loads are commensurate with Zone 4 seismic loads as defined in the UBC.



	7'(2.1m)	8'(2.4m)	9'(2.7m)	10'(3.0m)
P	4400#	4400#	4400#	4400#
d	0.026"	0.030"	0.036"	0.042"
P2	2600#	2700#	2800#	2900#
d2	0.052"	0.060"	0.072"	0.084"
P1	1300#	1200#	1100#	1000#
d1	0.026"	0.030"	0.036"	0.042

Figure 7 One- and Two- Story Frame Model Results

5. CONFIGURATION: THE ADDITIONAL HIDDEN STRENGTH OF OLDER HOMES

Though limited, the above analysis shows that older homes are significantly stronger than previously thought. The prescriptive 4'(1.2 m) panels spaced at regular intervals are very strong. But there are other hidden and unquantified areas within older homes that contribute further strength. Those areas we lump into the term configuration:

1. Redundant load paths. Beyond the regularly spaced 4'(1.2 m) panels, most older homes hae small rooms and many interior walls. These interior walls form secondary (redundant) load paths, providing extra strength
2. A lightweight structure, resulting in lower seismic loads.
3. Stronger framing lumber. The structure is composed of old growth, strong, full-dimensional lumber.
4. A symmetric structure, symmetric about both axes.
5. A continuous load path. Load paths are continuous from roof to foundation. Structure/foundation attachment, while not mechanical, often had an of embedded the bottom sill into the concrete foundation wall.
6. A flexible structure with high damping characteristics, due to the many nailed connections and friction of the tongue-in-groove skip sheathing.
7. Secondary strength contributors, such as the interior sheetrock or plaster and exterior siding on older homes.

With properly connected interior walls, 50% redundant capacity can be easily shown. The author estimates that these configuration factors can contribute 50%-100% additional lateral load capacity.

6. RECOMMENDATIONS FOR RESIDENTIAL CODE IMPROVEMENTS

Residential prescriptive codes should be improved to include the importance of configuration, including:

1. A continuous load path.
2. A symmetric structure, without geometric or stiffness discontinuities.
3. A relatively lightweight, flexible structural system with high damping.
4. A prescriptive approach to lateral design.
5. A secondary/redundant load path.

Home designers, engineers, architects, and building officials should recognize the importance of the UBC Section 2517 provisions for prescriptive lateral design, and the importance of configuration. Building codes should mandate that home designs in seismic Zones 3 and 4 fulfill the intent of these characteristics. Proper designs can implement all of these characteristics without increasing construction costs. Additional research beyond this paper is needed, but the importance of the prescriptive approach, along with thoughtful configuration design, has been demonstrated.

7. REFERENCES

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