The Evolution of Lateral Load Design in Residential Construction

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Summary

This paper summarizes the changes in lateral load design of residential construction over the last decade that have resulted from the architectural desire to build structures with larger windows, without compromising their structural safety. In addition to this retrospective, and more important, is a forward-look into current efforts to make the prescriptive code more comprehensive and consistent. The development of the international family of codes is discussed as a possible driving force for the current evolution in the prescriptive bracing provisions of the 2006 International Residential Code[1] (IRC).

1. Introduction

For lateral load design, the United States currently has two parallel tracks for ensuring the safety of new residential construction. The first track is through the complete engineering design of the structure where lateral loads are resisted through the use of shear walls and diaphragms. Today such design is normally carried out by way of the International Building Code[2] (IBC) (latest edition referenced, local jurisdictions may use other versions) through the design of an engineered load path that includes shear walls, diaphragms, collectors and tie downs. While suitable for more expensive, commercial, and public buildings, the cost associated with a complete engineering design makes this a very unpopular option for most residential structures. That said, in many parts of the country – the West coast for seismic and the Southeast for high wind reasons – even residential structures must be designed due to the magnitude of the loads to which they are subjected.

The most popular and cost effective track for residential construction, and the subject of this paper, is through the use of prescriptive provisions as found in the International Residential Code (IRC). The prescriptive approach has been bolstered by years of successful in-field performance as well as, recently, a significant amount of testing. The IRC uses a "cookbook" approach to the construction of a structure within a specific set of parameters. This approach essentially hides the engineering within the prescriptive guidelines of the structure. In these structures, lateral loads are accommodated by the use of bracing panels, and the prescribed floor and roof decks resist the diaphragm forces.

As the prescriptive bracing in the IRC is the most visible manifestation of this "hidden engineering", in its traditional form, bracing has often been at odds with the architectural imperatives of the home designer. As a result, there has been pressure by the building and design communities on the building regulatory community to provide bracing alternatives that are not in conflict with the wants and needs of the home-buying public, while maintaining the longevity and safety the public demands. A very good example of this conflict is the garage, attached or freestanding. For many years the codes required a 1220-mm- (48-inch-) bracing unit on each side of a wide garage door. The builders, designers and homeowners, on the other hand, expected to see something more on the order of 305 to 508 mm (12 to 20 inches).

2. Lateral Load Design and Conventional Construction

As mentioned previously, the great majority of structures built in the US today are residential and residential-type structures. The International Residential Code (IRC) and the 1998 International One-and Two-Family Dwelling Code[3] (IO&TFDC) it replaced were developed to provide an adequate measure of structural safety for small dwellings **without** requiring a full structural design. This was accomplished by very carefully defining an envelope of physical parameters (not too tall, too large or too irregular) and limiting the scope to environments for which these targeted structures can be safely constructed utilizing a simplified set of guidelines, tables and figures. Today, this set of guidelines, tables and figures is in the IRC and this "cookbook" approach has been codified and used successfully for over 30 years and probably accounts for the majority of habitable structures in the US. (Actually, the history of successful residential wood framed construction goes back over a century and for generations relied on transfer of “technology” from master to apprentice. This has been loosely described as ”industry practice” and was highly regional in nature. The standardization of practices into the codes is a relatively recent development.)

Similar, but far less comprehensive, prescriptive material is located in the International Building Code (IBC), again targeting smaller (residential–type structures). In the IBC Section 2308, these are the Conventional Construction provisions. Much of the following discussion is appropriate for the IBC Conventional Construction provisions as well.

Most of the “engineering” in the prescriptive provisions/requirements in the current IRC are actually invisible to the homeowner. The “engineering” is hidden in the text, figures and tables of the IRC. The homeowner never sees the grade of lumber in the walls, the thickness of the gypsum board, the size of the header, type of weatherproofing used or roof framing in the home, nor do they usually care. The majority of the requirements do not noticeably impact the *look* of the house.

The one aspect of the structure of the house that is visible is the lateral bracing system. In the IRC, the lateral bracing system is made up of braced walls and braced wall lines. These are the solid walls of the structure. These systems are the reason that a homeowner cannot have a 100% window wall no matter how good the view is from his or her residence based on the IRC. In some parts of the country, (high wind or seismic areas) this requirement for lateral bracing can put severe limitations on the home designer and can often prevent a home from having a “conventional” appearance. A good example is the wall adjacent to a garage door. Prior to 1995, the One and Two Family Dwelling Code would not permit a width less than 1219 mm (48 inches) on each side of a garage door no matter where the building was located in the country. This is not what is traditionally seen in a dwelling in the US.

Such limitations have often not been enforced in some parts of the country. This has been due to lack of knowledge of the existing code provisions or even from lack of a building code in some jurisdictions and preceded good performance of existing structures as compared with the perceived risk. With the adoption of a single family of codes throughout the US, this is less likely to be the case. With everybody using the same code, “They don’t build ‘em that way around here” is becoming less of a valid point. APA staff has witnessed a dramatic increase in awareness of prescriptive bracing provisions, particularly in areas outside of traditional earthquake and hurricane wind zones.

Much of this increase can be attributed to builders noticing a difference between what is permitted in one jurisdiction and what is not in the next, while both are using the same “code.” The consolidation of smaller contractors into ever-bigger companies means more in-house engineering and architectural capabilities. These design professionals logically feel that the same code should yield the same designs in similar regions. When locales interpret differently or do not enforce the code, builders will want to know why.

State building official organizations made up of officials from differing local jurisdictions are also promoting a better understanding of what the bracing provisions are in the code.

As can be expected, the bracing requirements are not the same for all parts of the country. In areas with minimal risk of seismic or high wind activity, the bracing requirements are minimal. As the risk increases, so do the minimum requirements for bracing. Table R602.10.1 of the 2006 IRC recognizes the increased risk of Seismic Design Categories (SDC) as they go from SDC A – D_2 and wind speeds up to less than 110 mph. These two categories of load define the scope of the IRC for lateral design. As the load increases, the bracing requirement also increases from 16% to 75% of each exterior wall. The difficulty in meeting the aesthetic requirements of the residence, while not permitting doors or windows in 75% of all exterior wall lines, is another good example of the "visibility" of the bracing requirements in residences constructed in accordance with the IRC.

2.1 The Evolution of Bracing

In reviewing the history of the bracing requirements in the IRC and its predecessor, the 1998 International One- and Two-Family Dwelling Code (IO&TFDC), it is interesting in that it first showed the increase in bracing requirements as an awareness of the actual lateral load requirements increased. It also showed how the academic, industry and regulatory groups within the building industry have worked together over the last decade to make the bracing requirements more flexible and useable, as an understanding of the impact of these bracing requirements on the building aesthetics grew. A brief review of the evolution of the residential bracing requirements follows:

- Prior to 1971, homes were built following industry practice and local codes, if any, which did not provide minimum requirements for bracing. Homes of this era were generally smaller, and had many interior walls, relatively small window openings, simple roof lines and few plan irregularities.
- (1971 O&TFDC)[4] Sheathing or let-in bracing required at each end of the exterior walls. This is accomplished by a simple annotation on a figure.
- (1986 O&TFDC)[5] Bracing requirement is moved form the figure to the text of the code. Sheathing is defined as plywood, particleboard or other approved material. In recognition of the fact that more bracing is needed in some parts of the country than others, a bracing table is added with different requirements for Seismic Zones 0, 1, and 2 – a single entry – and another single entry for Seismic Zones 3 and 4. In this table the requirement for bracing panels at 7620 mm (25 ft) intervals along a wall line is present as well as the additional requirements for percent bracing. The bracing percents range from 25–40% and only for Seismic Zones 3 and 4. The code recognized a 1219 mm (48 inch) <u>minimum</u> panel width for sheathing when used as bracing.
- (1995 O&TFDC)[6] Structural sheathing requirements for plywood were replaced with wood structural panel. This was done as a direct result of the code adoption of the consensus standard PS 2 (Voluntary Product Standard, Performance Standard for Wood-Based Structural-Use Panels)[7]. This standard, for the first

time, permitted the use of the term “oriented strand board’ in the body of the code. Also included was a greater discussion of bracing in text, and the first introduction of 813mm (32 inches) wide bracing alternative to 1219 mm (48 inch) structural sheathing option.

- (1998 IO&TFDC) Six options (3 new options) for bracing were introduced – let-in bracing, wood structural panel, particleboard, gypsum sheathing (2438 mm (96 inches) required), fiberboard, and Portland cement plaster over metal lath.
- (2000 IRC) Two additional options were added to options list (hardboard siding and diagonal board), percent bracing requirements rose to present levels, four Seismic Design Categories replaced the two Seismic Zone categories, and winds less than 110 mph were added to bracing table. A fully sheathed option was added to the permitted bracing methods, which reduced the percent bracing required when used with Method 3 (wood structural panels) bracing. The fully sheathed method also permitted bracing panel widths as small as 610 mm (24 inches) in a 2438 mm (8 ft) wall.
- (2004 Supplement to the 2003 IRC)[8] In fully sheathed structures, 406 mm (16 inch) wide corner bracing was permitted under specific conditions, and site built braced frame with 6:1 aspect ratios were recognized for a wide range of single story applications. For all single story applications, a 406mm (16 inch) site-built portal frame with holddowns was permitted to replace 1219 mm (4 ft) of any bracing method for walls up to 3048 mm (10 ft) high. For first of two story applications adjacent to a garage door opening, a 610 mm (24 inch) site-built portal frame with holddowns was permitted to replace 1219 mm (4 ft) of any bracing method for walls up to 3048 mm (10 ft) high.
- (2006 IRC) Alternate bracing provisions are linked to aspect ratio for heights over 3048 mm (10 ft), and additional text is added to clarify attachment of braced wall lines to rest of structure in SDCs D_0 through D_2.

2.2 The Debate over Bracing - Today

As can be seen from the above, lateral load resistance in building design has continued to grow in scope and sophistication over the last few decades at an ever-increasing rate. This rapid growth can be in part attributed to the adoption of a single family of codes. The process of adopting a single code from the best parts of the three existing model codes seems to have opened the eyes of many people within the building regulatory industry to new ideas. In addition, the single code reality also made it easier for researchers to bring their ideas before a single body instead of three.

2.2.1 The formation of the IRC Bracing Committee

The evolution of the bracing provisions in the IRC is not developing without its share of growing pains. The actual direction of this evolution is currently being debated in a number of venues and as can be expected, there are a number of different “sides”. This growing debate came to a head at the 2005 ICC Final Action Hearing held in Detroit. At this time, it became evident that there was no consensus as to the direction this evolution in bracing was to proceed. As a direct result of the confusion caused by all of the discordant voices, a number of code change proposals were either pulled or denied, and, even more importantly, a committee was formed for participation of all interested parties in an attempt to come to grips with the numerous differing “visions” for the future of prescriptive bracing.

This committee – called the IRC Bracing Committee – is not affiliated with the International Code Conference (ICC). It is voluntary and is being headed up by Dr. J. Daniel Dolan, Professor, Civil & Environmental Engineering, Washington State University. It was formed in an attempt to bring together the disparate sides on a number of issues and try to come to a rational consensus on as many of these issues as possible. A list of the issues discussed by this committee include:

2.2.1.1 A non-technical rewrite of the existing bracing provisions of the 2006 IRC

There was almost complete agreement that the bracing sections of the IRC had been tweaked over the last six years to the point where they were very difficult, if not impossible, to use. Many of the provisions necessary to properly use the bracing sections in Chapter 6 were essentially hidden in other chapters of the code. Keeping in mind that some of the new users of this material have had no prior experience with prescriptive bracing. It was evident that a rewrite with no technical changes was absolutely necessary.

<u>Committee Action</u> - As a result of this committee’s work, a non-technical rewrite of the bracing provisions has been completed and has been submitted as a code change proposal to the 2006 IRC.

2.2.1.2 Analysis procedures for future evaluation of IRC bracing and alternatives

There are currently no widely-recognized analytical procedures or even agreement on how to analyze IRC bracing. This lack of foundation makes support for the introduction of new, alternative bracing systems difficult. The following issues appear to frame much of the discussion:

- Definition of current design parameters.
- What boundary conditions apply?
- Qualification criteria.
- Impact of out-of-plane loads on bracing performance.
- Define missing design parameters.
- Which bracing methods are sufficient and which are strongest?
- Definition of the “box” for analysis.
- Use of dissimilar bracing types within a common wall line, floor or in the whole structure.
- Corner anchorage required to anchor a continuously sheathed braced wall line.
- Combination of frame systems and wall systems.

<u>Committee Action</u> – Pending further study.

2.2.1.3 Testing protocol

The actual testing protocol was also an area of disagreement between the academics and industries, and between the testing laboratories. Esoteric subjects like the stiffness of the load head or the tightness of the anchor bolts caused vehement disagreement between interested parties. Subsequent surveys after the first meeting of the committee found that of the 6-8 national and international laboratories conducting such testing, no two were doing it the same. As a result, the test data from one laboratory is not comparable to that from the others. The following is a list of the parameters that must be considered:

- Load/displacement regime
- Boundary conditions
- Instrumentation
- Conversion of test results to design values/prescriptive requirements

<u>Committee Action</u> – Pending further study.

In a parallel track, a task group under ASTM E06.11 has been formed to revise ASTM E2126[9] to modify the consensus standard by which future testing should follow. The revised standard can be expected in the next few years.

Once approved, the Dolan committee is interested in reevaluating all of the bracing methods and alternates currently in the IRC (and in conventional construction section of the IBC). This will provide current bracing provisions with a rational foundation and permit the evaluation of future alternate systems on a similar basis.

2.2.1.4 Conversion of two-dimensional tests (typical wall tests) to three-dimensional application recommendations

The majority of testing conducted to date to develop design recommendations for engineered shearwalls and prescriptive bracing has been done using two-dimensional (single wall) testing. It has always been assumed that this data could be conservatively used for actual, three dimensional structures. (In real terms, this assumption is predicated on the belief that the adjacent wall adequately anchors the braced wall line receiving the in-line forces, effectively providing hold-down anchorage for the adjacent loaded wall.) The boundary conditions are much more than just a return wall. Dead load, finishes, additional wall lengths in line with test wall, 3-D shell effects, etc, are all important. Of specific consideration is the current practice of permitting isolated 1210-mm (4-foot) sections as far as 3810 mm(12.5 feet) away from a corner. This may have a profound impact on the performance of the adjacent wall. Another consideration that comes from the evaluation of a structure in 3-D is the impact of forces at an angle to a corner.

Recent CUREE (Consortium of Universities for Research in Earthquake Engineering) testing appears to support this contention as long as the applied forces (seismic - shake table- forces in the case of the CUREE testing) are acting in the direction of the walls. A question remaining unresolved is what happens when the force is applied simultaneously to both walls, such as a wind force, acting at 45 degrees to both walls? In this case, how can one wall provide uplift resistance to its neighbor when it is being uplifted itself, or, if it is not even placed in the corner? Is a hold down required at every building corner even in areas with minimal high wind and seismic potential? Such a conclusion can have a relatively large impact on the cost of housing in areas of low lateral load. Such a provision would also have ramifications in some areas of the country concerning the wisdom of adopting a code that has the appearance of fixing something that hasn't been broken. Hold downs are generally considered extraordinary when and where they have never been *perceived* to be needed, nor used in the past.

Committee Action – Pending further study.

Action by Others - In response to this need for testing, APA – The Engineered Wood Association is committed to testing full size structures with both in-plane and out-of-plane loads. Square, rectangular, "L", and "T" shaped structures can be tested in an effort to answer some of the 2-D - to - 3-D questions.

APA is not alone in this effort. Other organizations, such as the Network for Earthquake Engineering Simulation (NEES) sponsored by the National Science Foundation, have engaged in similar efforts. APA is hoping to partner with those of other testing facilities to future the fundamental understanding of prescriptive bracing in the US codes.

2.2.1.5 Evaluation of the basis for the existing bracing provisions.

While this may prove to be an academic issue in the future as all of the existing bracing provisions are reevaluated, for now, it is important to understand where the existing permissible percentages, found in Table R602.10.1 of the 2006 IRC, came from.
The validity of these initial assumptions needs to be reevaluated as they were adopted into the code with little peer review. In addition, some of the basic assumptions made in the late '90s during the development of the IRC may not be relevant today. A couple of the issues concerning the preliminary work that need to be reevaluated are as follows:

- The preliminary bracing percentages were based on the use of gypsum board applied to the inside of the bracing unit. Over the last decade, to prevent cracking in corners, Gypsum installers have gotten away from attaching the gypsum to the top and bottom plates and at corners. As this would have a serious impact on the shear capacity of the assembly, the assumption of its use must be reevaluated. The fact that there would potentially be two different gypsum installation schedules – one for bracing walls and one for other applications – is also subject for concern.

- During the development of the IRC, an assumption was made that non-structural gypsum walls would resist a certain percentage of the applied load. These are walls other than the gypsum bracing walls, including interior finishes between exterior bracing walls. This assumption was predicated a nailing-only schedule existing at the time (various nails and screws attached to framing at 102 mm (4inches) on center at panel perimeters and at 203 mm (8 inches) on center over intermediate supports). These assumptions did not include adhesives with screws at 610 mm (24 inches) on centers, nor did they include not attaching the gypsum to top or bottom plate and at corners.

- As mentioned above, the decisions to rely on gypsum on the inside of bracing units and in non-structural walls may be applicable to the wind load case. The cyclic nature of earthquake loads greatly degrades the capacity of gypsum walls after the first few cycles. Therefore, the contribution of gypsum board to any bracing system for use in areas of seismic loads and relatively monotonic wind loads cannot be considered equal and must be further evaluated. Note that ICC-ES Acceptance Criteria AC269 – *Racking Shear Evaluation of Proprietary Shear Materials Used as Braced Wall Panels*[10] specifies that panels be tested without gypsum wall panels on the inside.

- During the development of the 2000 IRC bracing percentages, a value for the capacity of 1219 mm (4 feet) of Method 3 bracing (wood structural panel) of 2 kN/m (137 plf) was used. This value is higher than could be expected for shearwalls with essentially fixed end restraint. Depending on the location within the structure, bracing panel end restraint varies from very little (single story gable end) to very great (first of 3 stories). The majority of applications could not be expected to reach the design levels used during the development of the IRC bracing provisions.

- One final point of discussion was that residential structures are not being built today in the same way they were even two decades ago. Today's structures are generally larger with more open floor plans, and, consequently, have fewer redundant interior walls. Windows are larger, walls and rooflines are more irregular, and two-story atrium entrances are not uncommon on even moderately priced homes. This, coupled with the fact that the current bracing provisions were developed based on structures built in the1950s, 60s and 70s, is cause for concern among many academics, engineers, researchers and code officials.

<u>Committee Action</u> - As a result of the factors discussed above, the general consensus of the committee was to use a four-foot wood structural panel (Method 3 bracing) with no gypsum board on the backside as the standard for bracing re-evaluation. All other bracing methods and alternates will be compared to this standard as a first step in the redevelopment of the bracing tables.

2.2.2 ICC Ad Hoc Committee on Wall Bracing

As a measure of the importance of this subject, the ICC has decided to form an Ad Hoc committee whose expressed purpose is to review and make recommendations on the code change proposals made for the IBC and IRC on issues related to bracing. At the time of writing this paper, this committee is not yet formed. The scope of this committee is very limited and will work in parallel with the IRC Bracing committee, chaired by Dan Dolan.

3. Discussion, Conclusions and Acknowledgments

As can be seen by the above, the subject of lateral load resistance – bracing – in residential structures has been in a process of evolutionary changes for several decades. The formation of the ICC and the development of a single family of model codes heralded in a new era of increased activity in this subject and shows great promise for the development of rational prescriptive bracing recommendations, while opening the door for future innovation. Resolution of the issues discussed above will in the future permit greater latitude for designers, homeowners and builders, while providing stronger and safer structures.

This paper is a snapshot of a rapidly moving target and like every evolutionary process there is no conclusion. It is only hope that with continued cooperation from all parties involved, we can direct the evolution of our family of codes into producing safer, more useable and more flexible structures.

4. References

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