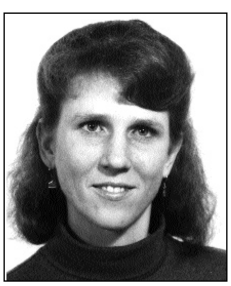
Conventional Construction for Today's Buildings

by Robert J. Bossi, P.E.
Senior Engineering Consultant
Thomas Anderson and Company
Sonoma, California

and

Kelly E. Cobeen, S.E.
Principal
GFDS Engineers
San Francisco, California

Robert J. Bossi, P.E., *is a senior engineering consultant with Thomas Anderson and Company in Sonoma, California, specializing in investigation of construction claims. Mr. Bossi previously operated his own design and consulting practice in San Francisco, California, for 12 years and was employed as a senior building inspector/plans examiner for the City of South San Francisco. He chaired the Conventional Construction Task Force from 1991 to 1993, served on ICBO's Ad Hoc Committee on Adoption of Standards and was the Structural Engineers Association of California's (SEAOC) representative to ICBO from 1987 to 1989. A graduate of San Jose State University, San Jose, California, with a bachelor's degree in civil engineering, Mr. Bossi is a registered civil engineer in California and holds ICBO certification as a building inspector, combination dwelling inspector and plans examiner.*



A principal with GFDS Engineers in San Francisco, ***Kelly Cobeen, S.E.,*** *received her bachelor's and master's degrees in civil engineering from the University of California, Berkeley, and is a registered civil and structural engineer in California. Ms. Cobeen's 11 years of consulting engineering experience include the design of timber, concrete and steel structures, with a particular emphasis on seismic restraint design and seismic upgrade of existing structures. In addition to serving as a member of the Conventional Construction Task Force, she has participated in drafting the American Society of Civil Engineers LRFD Specification and is currently a member of the Building Seismic Safety Council NEHRP TS7 wood subcommittee. She has taught timber design at the University of California, Berkeley, and has been actively involved in the ICBO code development process as a representative of the SEAOC Code Committee.*

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INTRODUCTION

The conventional light-frame construction provisions of 1994 *Uniform Building Code*™ (U.B.C.) Section 2326 contain prescriptive provisions permitting the construction of wood-frame structures without requiring an engineered design for gravity, wind or earthquake loading. Prior to the 1994 U.B.C. provisions, the appropriate uses and limitations of the conventional construction provisions had long been a subject of considerable discussion and disagreement.

In areas with strong wind or earthquake forces, buildings designed and constructed using the U.B.C. engineering provisions are materially different from similar buildings constructed using pre-1994 conventional construction bracing provisions. This anomaly, the subjectivity involved in interpreting conventional construction requirements, and varying local building department interpretations and amendments led to much frustration among users and building officials. It also raised questions regarding the appropriateness of the bracing provisions because of the tremendous variation in the wind and earthquake resistance provided in buildings constructed under the conventional construction provisions.

In the fall of 1990, the Conventional Construction Task Force (CCTF) was formed with the goal of reviewing the conventional construction provisions in light of current building types and construction practices and developing modifications that would allow more rational and uniformly enforceable provisions. This article discusses the development of the resulting conventional construction provisions (adopted into the 1994 U.B.C.) and the intent of these provisions.

Identification of a Problem

For the most part, the conventional construction provisions pertaining to framing members that carry gravity loads are adequate, largely because the framing member tables are based on engineering calculations. That is not the case with the lateral (wind and earthquake) bracing provisions. For a number of reasons, the lateral bracing resistance provided by pre-1994 U.B.C. provisions was considerably less than that required to resist wind and earthquake loads, based on an engineering analysis. There are at least two significant reasons.

First, while earlier codes were quite specific as to the type and length of bracing material to be provided in any given wall, limits on spacing between those walls were not provided. Very different performance will result if walls are spaced close together rather than far apart. To some extent, the span tables for joists and rafters placed limits in the 25- to 30-foot-span (7620 to 9144 mm) range, but only in the direction of joist and rafter spans. Further, there was no prohibition against the use of post-and-beam construction at the interior, in some cases making the exterior walls the only lateral bracing elements.

Second, over the last 40 years, buildings have become larger, and the quantity of interior partitions has declined as a result of more “open” floor plans. Additionally, more complex plan layouts with jogging exterior walls and offset floor and roof planes have significantly broken up the continuity of the lateral bracing system. If a comparison is made between a post-World War II Federal Housing Administration tract house and a single-family dwelling built today, it is obvious that today’s building offers inherently less capacity to resist lateral forces. In addition to the reduction in quantity and increase in spacing of the bracing walls, there has been little attention paid to collecting and delivering wind and earthquake loads to the bracing walls. This becomes increasingly important as walls are spaced farther apart.

The pre-1994 conventional construction provisions were adequate for simple “boxes” but not for large, open buildings of complex geometries. Unfortunately, very few simple boxes are being built today. Thus, the pre-1994 U.B.C. conventional construction provisions required modification to keep up with the buildings being regulated. Three major areas of modification developed: the first addressed the great disparity between the lateral bracing resistance provided under conventional versus engineered provisions, the second addressed the large variations in interpretation of unusual size and unusual shape, and the third modified framing connections to reasonably match the bracing wall capacities. There were also other minor miscellaneous modifications.

Lateral Bracing Solutions Considered

Two approaches were considered in addressing the disparity in lateral force resistance. The first approach was to maintain the existing bracing wall capacities and limit the lateral forces resisted by the walls by limiting the wind, seismic tributary area and building weight. This introduced a new concept of mandating the maximum spacing between lines of bracing walls and limiting offsets between walls in a bracing line. Additionally, the building occupancy would be specifically limited to those residential occupancies permitted when conventional construction was originally developed, with the addition of single-story, slab-on-grade, Occupancy Category IV buildings and miscellaneous buildings. The intent was to limit occupancies to those that inherently rely on the conventional construction provisions for the redundant bracing.

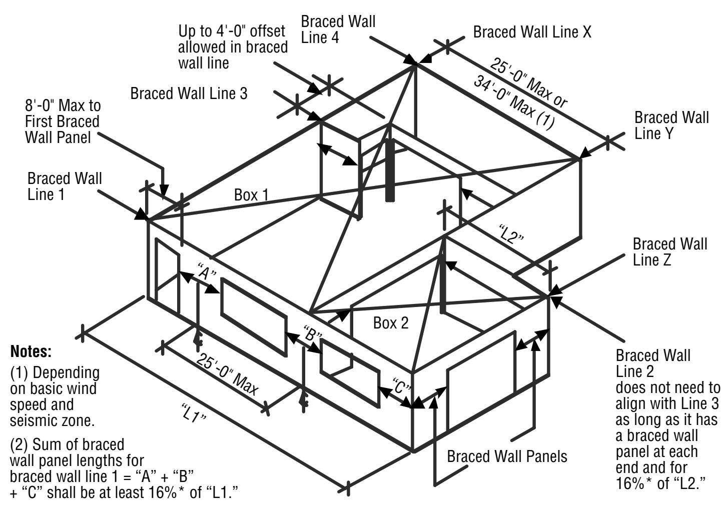
The second approach considered was to increase the capacity of bracing walls (plywood thickness, nail size and quantity) or increase the length of bracing wall required. If wall length were to remain as previously required and capacity were increased, overturning would soon become a problem, and it was thought necessary to develop minimum overturning resistance (hold down) requirements. The 1994 U.B.C. provides many materials for use as bracing wall sheathing (see Table 23-I-W). At a base level, all these materials–with the exception of let-in braces and gypsum wallboard–offer relatively equal resistance. If capacities were required to be increased, however, some of the permitted bracing materials, such as stucco, would no longer be considered adequate. Additionally, as more force is delivered to a bracing wall, the connections become highly stressed, quickly exceeding the capacities found in U.B.C. Table 23-I-Q.

After considerable debate, the first method was selected to avoid making the lateral bracing system overly complex. With the approach chosen, there remains only one standard method of constructing conventional bracing in all buildings. The only variable is the total length of bracing, based on the seismic zone and the story being considered.

Lateral Bracing Concept

It was considered important that conventional construction have its own unique vocabulary. Definitions of the terms “braced wall line” and “braced wall panel” were included in U.B.C. Section 2302.1 to differentiate between engineered shear walls and bracing selected in accordance with the conventional construction provisions. Figures 1 and 2 illustrate the basic concept of the lateral bracing system. A series of braced wall panels comprise a braced wall line; spacing of the braced wall panels within the line is prescribed in U.B.C. Section 2326.11.3. A two-dimensional grid of interior- and exterior-braced wall lines breaks up buildings into a series of boxes. The size of a box is limited to either 25 feet (7620 mm) or 34 feet (10 363 mm), depending on seismic zone and basic wind speed (U.B.C. Sections 2326.4.1 and 2326.5.1). Figure 3 demonstrates how T- and L-shaped buildings, which might previously have been considered of unusual shape, use added braced wall lines to develop a conventional construction box system.

In Figure 1, Box 1 is bounded by braced wall lines X, Y, 1 and 4. Box 2 is bounded by braced wall lines Y, Z, 1 and 2. Because the distance between lines 1 and 4 exceeds the permitted box dimension, braced wall line 3 is required. While braced wall lines 1 and Y are common to both boxes, this has no effect on the braced wall panel requirements for these lines. Braced wall line 2 does not need to align with braced wall line 3 because they occur in separate boxes, and each box individually meets the bracing requirements. As shown by line 3, out-of-plane offsets of up to 4 feet (1219 mm) can occur between braced wall panels in a single braced wall line. If more than one offset occurs in a braced wall line, then the sum of offsets cannot exceed 4 feet (1219 mm) (U.B.C. Section 2326.11.3). The closest end of the braced wall panel can be moved up to 8 feet (2438 mm) from the end of a braced wall line, as shown by panel A in line 1. There are no requirements for top plates or other collector members to



*Subject to minimum panel width requirements.

Figure 1–Acceptable bracing example–one-story building.

tie the braced wall panels together. It is believed that for interior braced wall panels, the emphasis should be placed on adequate connection to the ceiling or roof instead of to a collector.

Figure 2 depicts a two-story building of conventional construction. In Seismic Zones 2B, 3 and 4, the length of the braced wall panels at the lower story must total 25 percent of the building length (U.B.C. Table 23-I-W). The length requirement for the upper story is at least 16 percent, but not less than 4 feet (1219 mm) in each 25 feet (7620 mm) of building length, subject to minimum panel widths. In Seismic Zones 0, 1 and 2A, the required total length of braced wall panels does not increase in lower stories of multistory buildings.

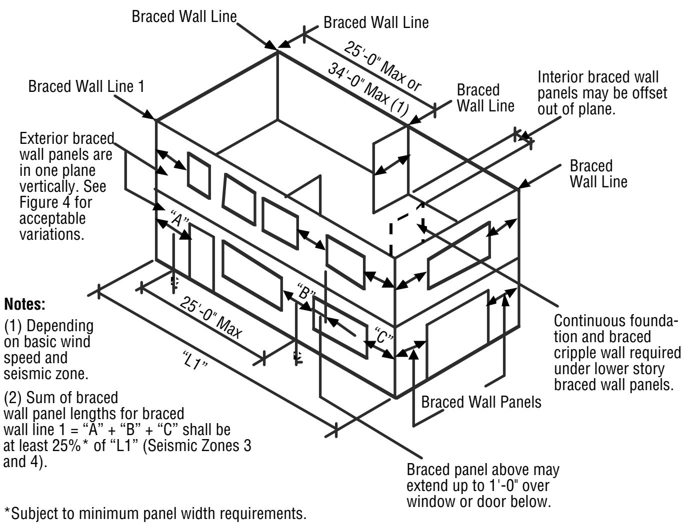


Figure 2–Acceptable bracing example–two-story building.

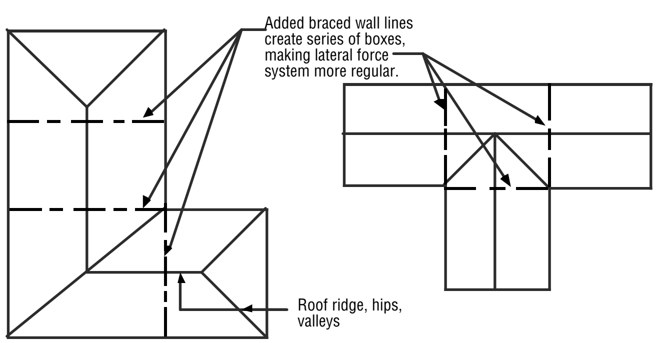


Figure 3–T- and L-shaped buildings. Added braced wall lines provide conventional "box" bracing system.

Exterior-braced wall panels in upper stories of multistory buildings are expected to be in the same plane as the braced wall panels at floors below, except for some permitted setback and cantilever conditions. Although panels ideally should fall at the same horizontal location so that they "stack," stacking is not required. As illustrated in Figure 2, line 1, upper-floor exterior-braced wall panels in Seismic Zones 3 and 4 are permitted to extend up to 1 foot (305 mm) over an opening in the wall below (U.B.C. Section 2326.5.4.3). Interior-braced wall panels are not required to be in the same plane or to stack. While it would be desirable for them to stack, this was seen as a severe constraint on architectural layout and not structurally imperative.

In buildings of more than one story, interior-braced wall panels at the lowest level are required to be supported on continuous foundations (U.B.C. Section 2326.5.6). In one-story buildings, interior-braced wall lines are required to be supported on continuous foundations at intervals not exceeding 50 feet (15 240 mm). If there is a foundation crawl space, braced wall panels in the lowest floor are also required to have cripple walls below, braced in accordance with U.B.C. Section 2326.11.5. It is intended that continuous perimeter foundations be provided in accordance with Table 18-I-D, unless another foundation system is approved by the building official.

Unusual Size and Shape Limitations

The requirement that buildings of unusual size or shape or those with split levels have an engineered design was added in the 1979 U.B.C. in response to damage incurred in the 1971 San Fernando, California, earthquake. Although this provision was helpful because it gave the building official authority to require engineered design, it was not very specific and created a variety of interpretations. The most challenging task for CCTF was defining the term "unusual shape" for use in higher seismic zones.

The structural irregularities of U.B.C. Tables 16-L and 16-M, although intended for engineered structures, lent guidance in developing limits. The various irregularities were reviewed, and those that were applicable were studied to see how they apply to typical wood-frame buildings. These included out-of-plane bracing wall offsets (setbacks and cantilevers), diaphragm re-entrant corners (T, L and more complex shapes, overhangs), diaphragm discontinuities, vertical diaphragm offsets (split levels) and non-parallel systems (braced wall lines not at 90 degrees to each other). Limits on some of these conditions were developed based on reasonable levels of calculated stress in the various components. In this way, such architectural details as overhanging stories, cantilevered porches, bay windows and setbacks, as well as T- and L-shaped buildings, can reasonably be constructed using conventional construction.

The term "split-level" generally applies to buildings with an offset in the floor system of about one-half story. The principal

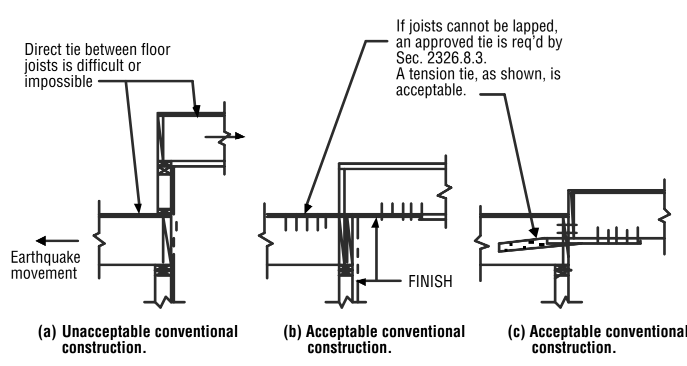


Figure 4–Split-level floors.

problem with this form of construction is the inability to transfer lateral forces across the offset. This condition is illustrated in Figure 4 (a) for Seismic Zones 3 and 4. If the floors on either side of the offset move in opposite directions because of wind or earthquake loading, the short bearing wall in the middle becomes unstable, and vertical support for the upper joists can be lost, causing a collapse. If the vertical offset is limited to a vertical dimension equal to or less than the joist depth, however, then a simple strap tie directly connecting joists on different levels can be provided, as shown in Figures 4 (b) and 4 (c). This will allow

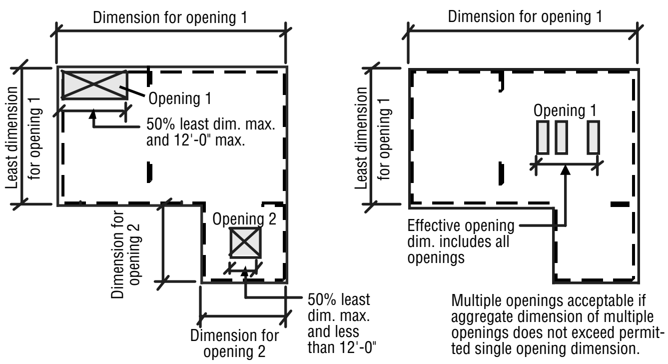


Figure 5–Acceptable floor and roof openings.

popular architectural design features such as step-down living rooms to be constructed using the conventional construction provisions.

Conventional construction permits a variety of sheathing materials for floor or roof diaphragms (sheathed floor and roof systems). Despite the resulting variation in diaphragm strength, it was realized that large openings in the roof or floor sheathing system could significantly affect performance. The resulting limitations on openings for Seismic Zones 3 and 4 are illustrated in Figure 5. These set a balance between overstresses seen in engineering calculations and the need to have a reasonable allowance for stairs and other openings. Figure 5 also illustrates a suggested approach toward applying these limitations to multiple, closely spaced openings.

Unusual size was much easier to address. Once it was decided to place a limit on the maximum spacing between parallel-braced wall lines, it was realized that the size of a building was actually of little importance because the building could always be reduced to a series of compliant smaller boxes. The term "unusual size" thus was deleted from the code.

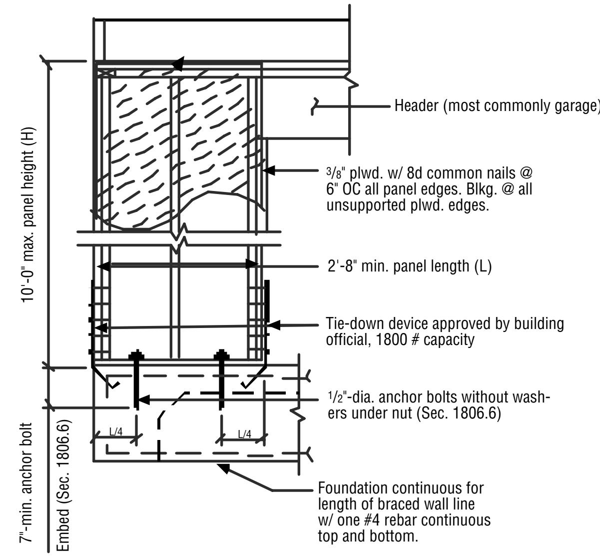


Figure 6–Alternate braced wall panel, one-story building.

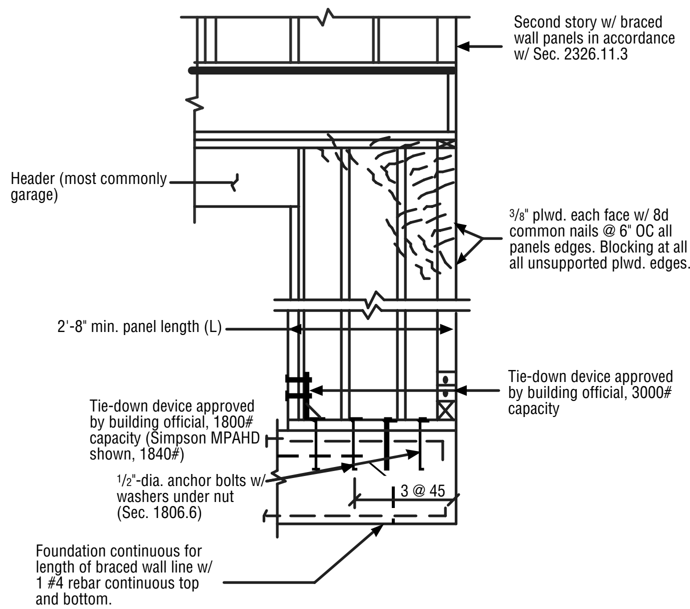


Figure 7–Alternate braced wall panel, first story of two-story building.

Other Conventional Construction Modifications

Except for the concept of spacing between braced panel lines and the definition of unusual shape, the 1994 U.B.C. provisions actually contain little in the way of significant new requirements or limitations. As discussed previously, the intent was to rely on the traditional bracing materials already specified in the code. This results in about 200-pounds-per-linear-foot (420 kN/m) capacity for the bracing walls. There were, however, two exceptions. First, a 1x4 let-in brace has significantly less capacity than any of the other bracing materials and is frequently either installed improperly or damaged after installation and inspection. It was eliminated as a bracing method in Seismic Zones 2B, 3 and 4, but is still available in all wind speed areas in the lower seismic zones. The elimination of this type of brace will not be an undue burden because it is rare for it to be used without one of the other acceptable bracing materials being present. In Seismic Zones 2B, 3 and 4, the amount of gypsum wallboard required has been doubled when applied to only one side of a wall. This is to compensate for the fact that gypsum board has always had one-half of the bracing capacity of other materials, not including an additional 50 percent reduction in high seismic zones. *(continued)*

Provisions have been added to U.B.C. Section 2326.11.4 for braced wall panels adjacent to garage doors. At the front of most garages, it is rare to have the luxury of providing two 4-foot-wide (1219 mm) bracing panels. Specific alternate construction provisions have been developed that compensate for narrower panels by adding overturning resistance. These are illustrated in Figures 6 and 7. This approach is similar to that taken by ATC-4 (Applied Technology Council 1976).

The connections that deliver the lateral forces to the bracing panels are provided in U.B.C. Table 23-I-Q. Existing connection requirements were found adequate with a few exceptions. Prior to the 1994 edition, the U.B.C. did not differentiate between top plate splices and general top plate nailing. A splice nailing requirement was added to the table as Item 6 to address this concern. Similarly, a requirement to provide minimum nailing of parallel rim joists and joist blocking to top plates was added as Item 11. The code has long required a metal strap where top plates are interrupted by piping. The strap previously specified was not generally available, and the requirement in U.B.C. Section 2326.11.7 has been revised to permit a commercially available strap. The nailing has been matched to that of the top plate splice.

The Conventional Construction Task Force wanted to make it very clear where requirements for high seismic zones (i.e., unusual shape) were triggered. As a result, an organizational change was made indicating where additional design provisions are applicable; U.B.C. Section 2326.3 provides additional requirements for high-wind areas; U.B.C. Section 2326.4 for Seismic Zones 0, 1, 2 and 3; and U.B.C. Section 2326.5 for Seismic Zone 4.F

Comparison to Engineered Design

The 1994 U.B.C. provisions provide a rational bracing system that can be applied and enforced much more uniformly than previous code provisions. If the conventional bracing system is checked against the engineered design procedures of Chapters 16 and 23, however, significant overstresses still are likely to be calculated.

In the shear capacity of the bracing material, overstresses in excess of 300 percent can occur for seismic loading in Seismic Zone 4 and 400 percent for wind loading in Seismic Zones 3 and 4, based on 70 mile-per-hour (112.6 km/h) basic wind speeds. In Seismic Zones 0, 1 and 2, even greater overstresses for wind load can be calculated due to less bracing being required. When evaluated with engineering design procedures, the 1994 U.B.C. conventional bracing system also would likely have calculated inadequacies in braced-wall-panel overturning resistance, in chords and collectors, in floor and roof diaphragms, etc.

There are several reasons to justify calculated overstress in conventional construction systems. The redundancy inherent in the conventional construction system makes it nearly impossible to calculate the time capacity available. Additionally, the wind and earthquake performance of residential buildings constructed in accordance with these provisions has generally been good. Exceptions are split-level buildings, irregularly shaped buildings and buildings that were not constructed in complete accordance with the provisions. In recent earthquakes, buildings without code-required cripple wall bracing and bolting to the foundations have sustained considerable damage. The generally good performance of existing buildings, however, has led some to question the level of wind and seismic forces to which these buildings are being subjected. It is possible that the design forces specified in U.B.C. Chapter 16 are very conservative for this type and size of building; this will not be understood until testing of these building types is performed. These reasons may not be adequate to explain the very large wind overstresses that can be calculated in the lower seismic zones.

Through creation of a system of boxes, the 1994 U.B.C. provisions attempt to provide a conceptually complete lateral-force-resisting system. Because there is little evidence that properly constructed box-type conventional construction systems perform inadequately, modification of bracing provisions to eliminate overstress was not believed necessary. In the future, as the performance of these buildings is better understood because of observation of wind and seismic performance or testing programs, the conventional construction provisions may need to be reviewed and modified.

Design of Nonconforming Elements

There has been considerable debate in the engineering community regarding the design of nonconforming bracing elements that are part of otherwise conventional buildings. Such a concept already was specifically allowed by U.B.C. Section 1603.1, exception (1991 Section 2301 (a), exception), as well as many state professional practice laws. The provisions in Sections 1603.3 and 2326.2 now require code-compliant design using the provisions of Chapters 16 and 23 for these nonconforming elements. This will standardize the various approaches currently in use. It will remain incumbent on the designer and building official, however, to determine the extent of engineered design required based on the effects of the nonconforming element on the behavior of the overall lateral bracing system.

CONCLUSION

The 1994 U.B.C. conventional construction provisions require the construction of buildings with significantly more complete and consistent lateral bracing systems. The result will be safer buildings with more reliable performance when subjected to high winds and earthquakes. The provisions now have explicit, rather than subjective, limitations, allowing greater uniformity of application and enforcement. It is hoped that interpretations and amendments will no longer vary greatly among jurisdictions.

If creatively used, the specific limitations of the 1994 U.B.C. provisions can result in greater opportunities for the use of conventional construction. Because of greater clarity, these provisions will result in less complex design, plan check and inspection and reduced housing costs. With specific uniform requirements and limitations in place, the ability to develop training materials also will be enhanced. ■

ACKNOWLEDGMENTS

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