Built-up Column Stability in Wood Construction

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ABSTRACT

Wood construction is common for low-rise buildings, including residential and light commercial structures. For these types of structures, vertical structural members may consist of multiple wood studs, called built-up columns. As wood-framing becomes increasingly common for multi-story structures, concerns of both structural strength and stability of the wood members should be of paramount importance to the engineer. Specifically, the engineer must have knowledge of the type and extent of bracing present to properly determine the capacity of each member.

Most commonly, wood studs in low-rise buildings are braced in the weak direction by fastening wall sheathing to the face of the stud of the narrower dimension. The use of gypsum board wall finishes to brace wood stud walls (and for lateral shearwall diaphragms) has become common in the design of wood structures. However, engineers must remain aware of the limitations of gypsum board when designing heavily loaded, non-repetitive members such as columns. These limitations are particularly important for the design and detailing of built-up columns.

Design and construction defects related to wood columns in a wood-framed townhome project are presented herein. The subject three-story structures utilized built-up wood columns that depended on gypsum board for stability bracing. The columns did not satisfy the National Design Specification requirements for built-up columns. The proper design of the columns and the implications of using gypsum board for bracing will be discussed.

BACKGROUND

The case study presented herein is based on a wood-framed condominium complex located in Dallas, Texas. The complex included 17 three-story (plus attic) condominium units in three buildings of similar construction. The complex featured only four distinct floor plans; thus, the unit layouts were repeated in the three buildings. The buildings were constructed in 2000 and 2001. The 1997 Uniform Building Code (UBC) was adopted with amendments by the City of Dallas in 1999 and was the Building Code enforced at the time of the building design and construction. The 1997 UBC references the 1991 National Design Specification (NDS) for Wood Construction (AFPA 1993) for the design of wood structures.

The first floor of each building was supported by a slab-on-grade foundation with piers. The framing at the second and third floors consisted of metal plate connected wood trusses and engineered glu-laminated (glulam) and parallel strand lumber (PSL) beams. The vertical support consisted primarily of wood stud walls, with "stud packs" (groups of studs). The interior finishes were typical for residential construction and included wood floors, carpet, and gypsum board walls and ceilings. In addition to the floor loads, the framing supported some brick veneer (i.e., the veneer was not continuously supported to the foundation at some areas).

Forensic engineers investigated complaints of several of the unit owners. Such complaints included, but were not limited to, uneven floors, sloping countertops, cracks in finishes, separations in wood flooring, cracks in brick veneer, and sticking and swinging doors. Specifically, the structural design was evaluated to determine if structural deficiencies were contributing to the damage and floor levelness issues. Although the investigation encompassed several issues and causes of distress, this discussion is limited to the issues related to the design and bracing of the vertical load-resisting members, specifically built-up columns. A study of issues related to the design of the floor framing was previously presented by Verhulst and Ahuja (2008).

A relative floor elevation survey was performed for each unit type to determine the extent and pattern of floor unlevelness for each framing layout. Based on these elevation surveys and the visible distress, a pattern of deflection at some of the interior walls and/or framing support locations was apparent. The surveys ruled out foundation movement as a cause of unlevelness at the second and third floors.

DESIGN AND CONSTRUCTION

The subject condominium units required columns at the first, second, and third stories. The columns at the subject structures consisted of multiple studs (commonly called "stud packs"), typically ranging from two to five studs (although some columns with more studs were observed). The columns were not consistent throughout the project, even at repetitive units with the same framing design. It should be noted that the terms "stud pack" and "built-up columns" are not interchangeable; "stud packs" are groups of individual studs and the term "built-up column" refers to multiple studs fastened together in a specific manner so that they act together as a column. This is discussed further in the following sections.

Design

The only column specification for the subject structures was included in the framing details. "Shearwall Detail" 20 on Sheet S5.1 of the Structural Drawings is presented in Figure 1, below, and indicates that beams and truss girder supports were to consist of three 2x4 studs in a cluster or "stud pack," unless noted otherwise. The "stud packs" ranged from 8' to 10' (2.44m to 3.05m) in length. This was the only specific guidance regarding the column requirements for the project.

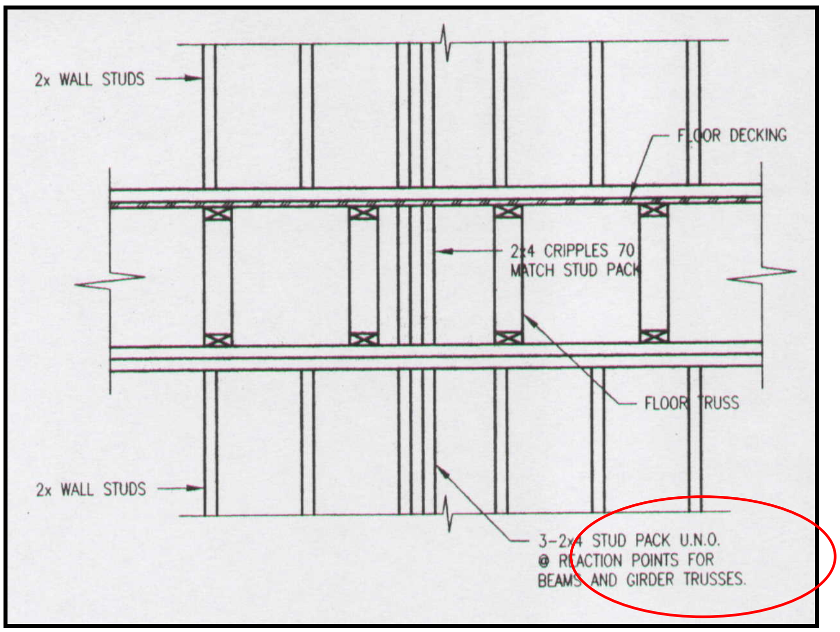

Figure 1. "Shearwall Detail" specifying columns (Detail 20/S5.1)

Based on an engineering review of the structures and the loading conditions, the columns were intended to behave as if continually braced, thus requiring the design of column bracing. However, the Structural Drawings did not include any design guidance regarding the bracing requirements of the studs/columns and no schedule for nailing the sheathing to the columns was included.

In addition, for the columns at the subject structures to be considered as built-up columns, the multiple studs must have been attached per the 1991 NDS (AFPA 1993). Studs which are not attached as indicated in the NDS act as individual studs, and do not gain additional design capacity from grouping. Compounding the structural deficiencies, even continually braced or "built-up" columns consisting of three 2x4 studs would not have been sufficient for the design loading conditions at many locations.

No attachment schedule for the studs/columns was included on the drawings. A "Nailing Schedule" indicated that "Double Studs" required 16d nails spaced at 16" (40.64cm) on-center and "Built-Up Corner Studs" required 16d nails spaced at 24" (60.96cm) on-center. These guidelines did not apply to the columns located in the walls nor did they conform to the NDS specifications for built-up columns.

It is the authors' opinion that the column design provided by the Structural Engineer was insufficient to support the design loads.

Construction

Excessive compressive load on a slender column will cause it to deflect or "bow" perpendicular to the weak axis (Breyer 1993). This deflection causes gaps between the studs of a stud grouping. Such gaps were observed between the studs at heavily-loaded "stud packs" at the subject structures. Column bowing of up to 7/8" (2.22cm) was observed at the subject structures, as measured by the distance between studs at mid-height in comparison with the distance between the studs at the top and bottom, as presented in Figures 2 - 4, below, and on the next page.

Figure 2. Bottom of two adjacent stud groups. The left group exhibits perceptible bowing. Measurement between columns was 1 1/16" at the bottom.

Figure 3. Measurement at mid-height of columns is 3/16".
The studs have displaced laterally and are also separated individually.

Figure 4. Top of columns. Distance between columns same as at base.

In addition, bowing studs were observed during the construction of the structures by a firm monitoring the overall construction. The Structural Engineer was notified.

Evidence of downward column deflection was observed due to bowing of the column under load. At one attic space, a heavily-loaded beam had separated more than 1" (2.54cm) from the framing at the attic, as shown in Figure 5, below. Despite the observed column failures, it should be noted that the structure had likely not been subjected to the full design load at the time that these conditions were observed.

Figure 5. Separation of framing at attic level above a heavily-loaded column.

Considering the significant amounts of overstress on the columns at the site, several factors prevented a collapse or catastrophic column failure. The actual loads at the time of the authors' observations did not approach the design loads, and load sharing with other structural elements such as adjacent wall studs provided many degrees of structural redundancy. Additionally, some bracing was provided by non-structural elements. Finally, the inherent factor of safety in the design capacities of the columns prevented catastrophic failure. Factors of safety may provide additional capacity but cannot be counted on by a designer for long-term load-carrying capacity. Building codes do not allow the designer to reduce these factors to increase the load-carrying capacity (UBC 1997; Breyer 1993; and Salmon 1996). Furthermore, the capacity provided by non-structural elements cannot be considered when determining the design capacity of the columns.

The unsafe conditions created by the insufficient column design necessitated significant column repairs at the subject structures. Inadequate columns were repaired or replaced with "built-up" stud columns (conforming to NDS specifications) or with glulam members. These repairs were necessarily invasive, and required relocation of the unit owners. Significant shoring was required to perform the column repairs. Additionally, some of the columns proved difficult to access and required the removal of architectural features. **The cost of the repair work far exceeded the cost of providing proper column support during construction.**

REQUIREMENTS FOR STUDS AS BUILT UP COLUMNS

Groups of studs, commonly called “stud packs”, are frequently used to support large concentrated loads, such as reactions from beams. In such applications, the studs are generally nailed together in a random manner, if at all. To be effective as a column, however, the individual laminations must be connected in the proper manner to function as a built-up column.

The NDS (AFPA 1993) provides requirements for built-up columns. Built-up columns may be either bolted or nailed and contain two to five laminations. The NDS requires that:

- Each lamination must be at least 1-1/2" (3.81cm) thick;
- All laminations must have the same depth (face width);
- The faces of adjacent laminations are to be in contact;
- All laminations must be full column length; and
- Specified connection requirements must be met.

The nailing and bolting requirements of the NDS are very specific. When nails are used, the following provisions must be met:

- Adjacent nails are driven from opposite sides of the column;
- All nails must penetrate at least 75% of the thickness of the last lamination [A 30d nail, for example, has a length of 4-1/2" (11.43cm), and the column thickness would be limited to three 1-1/2" (3.81cm) laminations]; and
- Nail spacing and end and edge distances are specified [For example, for 30d nails the minimum end distance is 3-1/2" (8.89cm), the minimum edge distance is 1-1/2" (3.81cm), and the maximum spacing in the parallel to grain direction is 9" (22.86cm)].

When bolted columns are used, the NDS requires that:

- Two or more longitudinal rows of bolts are required when more than three laminations are used;
- Metal washers or plates are required beneath the bolt head and the nut; and
- Typical bolt locations for 1/2" (1.27cm) diameter bolts are 3-1/2" (8.89cm) end distance, 2" (5.08cm) edge distance, and 8" (20.32cm) longitudinal spacing.

The built-up column is designed as a solid wood column, except that in the direction perpendicular to the face grain, the allowable axial load based on stability equals the load permitted for a solid column multiplied by K_f, where $K_f = 0.6$ for a built-up column nailed in accordance with NDS Section 15.3, and $K_f = 0.75$ when bolted in accordance with NDS Section 15.3. In effect, the allowable load (considering the designated axis) is reduced by 40% when the column is nailed and 25% when the column is bolted compared to a solid wood column having the same size. The reduction in load is due to the fact that the contact faces of the laminations are not fully restrained from slipping, and as a result the column does not fully behave as a solid column.

If the provisions of the NDS 15.3 are not met for built-up columns, the members cannot be considered to act as an integral unit; each stud must be considered as an individual column. Since the maximum L/D = 50 for a wood column, a non-braced stud with an unsupported length of 50 x 1.5 = 75" (190.5cm) or greater (as encountered at the previously-mentioned structures) would have an allowable load, P = 0. Typically, gypsum board is used to brace individual studs, but if gypsum board is nailed to one of the members in the stud pack, the other members would not be considered as braced in the direction of the least dimension. Only the nailed member could be considered as braced, but **only if the bracing were adequate**.

In the opinion of the authors, nailed gypsum board or paneling should **never** be assumed to provide bracing for a stud pack to function as a composite column for the following reasons:

- Neither gypsum board nor paneling is a permanent brace. During future remodeling either could be removed, and the column would then have no allowable axial load capacity. That is not a risk that either the design engineer or the owner should accept.
- If gypsum board were to become water saturated, perhaps due to a roof or plumbing leak, the gypsum board would have little or no bracing capacity.
- It is very difficult to verify during construction that the nailing into the individual laminations was in accordance with the design, e.g. some nails might be driven into the interface or nearer to the edge of the lumber than permitted by the NDS. For example, Figure 6, on the next page, shows nails

at the edge of one of the studs at the subject condominium project when only a single line of nails was used.

Verification of correct nailing would require much greater levels of inspection than is practical. With the studs covered by gypsum board, it would be very difficult for the drywall contractor to ensure that the gypsum board was nailed adequately and for the engineer to inspect the nailing.

Figure 6. Nails attached near the edge of a stud in a "stud pack".

Individual studs can be braced using nailed gypsum board or paneling; however, individual studs carry a relatively small axial load, and if one or two studs were rendered unbraced, adjacent studs would provide support. When stud packs are required to carry large loads, e.g. 5 kips to 10 kips (2268kg to 4536kg) or more, no such adequate nearby support is generally available.

RECOMMENDATIONS

The issues discussed herein deal with column design capacities, which is an issue of public safety. The limitations of multiple wood studs used as columns and of gypsum board as a bracing material were discussed. The authors recommend that building codes and the applicable standards be revised to reflect these limitations. Structural

Engineers should be aware of the above-noted limitations when performing wood design.

The authors recommend that applicable codes be changed to reflect the following:

1. Two or more studs that are required to carry a greater load than permissible using a single stud should be designed as a built-up column.
2. Gypsum board or other wall paneling is not to be considered as bracing for more than one stud in a group. Also, these materials should not be considered as bracing for columns (solid or built-up) with a design load greater than the capacity of one stud.
3. Built-up columns should be called out on Structural Drawings and be detailed in accordance with NDS requirements.

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