INCORPORATING CROSS-LAMINATED TIMBER *INTO* POST-FRAME BUILDINGS

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One of the newest developments in wood structural components is cross-laminated timber. CLT has been getting a lot of press lately because of the innovations associated with it and because of its use in creating large wood buildings with skyscrapers proposed to reach 30 stories.

CLTs are composed of layers of wood *crossed*, or placed perpendicular to the previous layer, and then *laminated* when the layers are glued together. The final product is a large beam or plate, considered a *timber* (**Figure 1**). In many ways, CLT is similar to plywood (where the perpendicular layers provide strength in two directions), but on a larger scale. CLTs can range in thickness from less than 4 inches to 20 inches. Panels in Europe can be produced in 10-foot widths and up to 50-foot lengths depending upon the building needs. In the United States, *ANSI/APA PRG 320 Standard for Performance-Rated Cross Laminated Timber* (ANSI/APA, 2012) has been developed to specify the sizes, manufacturing methods and mechanical properties of CLT materials.

Currently, CLT manufacture and construction in the United States is in its infancy. Several manufacturing facilities are being planned or are in development in this country, but currently CLTs used must be imported from Canada or Europe. Current U.S. CLT construction includes a church bell tower in North Carolina, a school in West Virginia (LignaTerra, 2014), a proposed eight-story building in Minneapolis (Construction Dive, 2015) and many residential buildings.

Figure 1. Cross-laminated timber panels (Photo: Daniel Hindman)

Internationally, a nine-story CLT building, the Stadthaus, was built in London in 2008, and a 10-story building, Forte', was built in Australia in 2012. Most of the CLT construction in the world is concentrated in Europe, where the emphasis has been on large, open buildings or renovation efforts for current concrete construction. Michael Green, an architect in Vancouver, British Columbia, has proposed the development of a 30-story wood skyscraper (Green, 2012).

Particular benefits of CLTs include the following:

• **Panelized construction—**Most of the CLT elements are cut at the factory, which allows for ease of construction on site.

• **Shorter assembly time—**The Stadthaus was notable because the structure of each wood story was assembled in three days per floor, for a total time of 27 days (about 2,200 square feet per floor).

• **Self-supporting panels—**CLT construction does not require joists or internal columns for support, which lowers the building height per story and allows a high degree of design flexibility.

• **Carbon sink—**The wood used in these buildings serves to *store* carbon dioxide, rather than *producing* carbon dioxide, which occurs in the manufacture of steel and concrete materials.

• **Foundation reduction—**Because of the use of a lighter structure, less foundation support is needed. With the Stadthaus, for example, a foundation reduction of 70 percent was estimated, in comparison with the foundation in typical construction.

CLTS AND POST-FRAME

One of the particular advantages of CLT is the high in-plane shear strength and stiffness of the panels themselves. This advantage can increase the lateral design resistance (wind and seismic resistance) of CLTs. The in-plane shear stiffness is an important property in the end walls of post-frame buildings, providing load transfer from the diaphragm and decreasing the deflection of the interior frames, thereby reducing stresses on members. Could the higher shear stiffness of CLTs be a useful advantage in designing post-frame buildings?

This article examines the possible use of CLT material for end walls in post-frame buildings. A design example of a post-frame building and two thicknesses (3-layer and 5-layer) of CLT buildings illustrates the possible uses. As with all post-frame buildings, a registered design professional is required to develop a unique design considering all environmental loads and use factors of a building. As will be seen, many assumptions were used to generate the design example, which is intended for instructional purposes only.

Although in many situations CLTs may not be the best option or may present challenges, the ability to use CLTs in post-frame construction is similar to adding a tool to a tool box, and their use needs to be considered.

IN-PLANE SHEAR PROPERTIES OF CLTS

Because of the novelty of CLTs in general and the current lack of production facilities in the United States, information and test data on the shear strength and stiffness of CLT panels are somewhat limited. Most of the experimental testing has focused on dynamic testing for seismic loading. Relatively few studies have performed static loading tests (constant displacement applied until failure) for CLT panels; however, the examination of backbone curves from the cyclic data could be used.

Ceccotti and colleagues (Ceccotti, Lauriola, Pinna, & Sandhaas, 2006) tested a series of spruce CLT panels 3.35 in (85 mm) thick as a shear wall (horizontal load applied at top of wall, support provided along bottom edge). The panel size was 9.7 feet by 9.7 feet. A shear stiffness of 38,000 lb/in was found based on the secant modulus, which was the slope of the load-displacement curve from 10 percent to 40 percent of the ultimate load. This is slightly different from the test procedures used for post-frame shear walls outlined in EP 558.1 (American Society of Agricultural and Biological Engineers, 2014), which states that the stiffness is composed of 40 percent of the ultimate load divided by the displacement at 40 percent of the ultimate load. For the purpose of this design example, this value will be used as the equivalent of the effective shear modulus, *G*.

According to ANSI/APA PRG-320, standard sizes for CLTs in the United States are 3-layer (4.125 in) and 5-layer (6.875 in). Linearly adjusting the shear stiffness found by Ceccotti et al. (2006) for the panel thickness, one determines that the effective shear modulus of a 3-layer CLT is 46,800 lb/in, and for a 5-layer CLT, 78,000 lb/in.

COMPARISON OF CLT AND POST-FRAME END WALLS

The building characteristics of the example structure are based on work by Mill (2012), who created a similar example for shear-wall deflection calculation investigation.

The model building is 112 feet long and 56 feet wide, with a 16-foot wall height. Posts are 4¼ inches wide by 7¼ inches deep and are spaced every 8 feet for a total of 14 bays. The roof has a 3.5:12 pitch (16.3 degrees) with a 2-foot overhang. The interior frame stiffness was calculated as 163.4 lb/in using Visual Analysis (Mill, 2012).

For the sheathing, diaphragm assembly #9 from the *Post-Frame Building Design Manual* (National Frame Building Association, 2015) was chosen. This is a regular-leg, 29-gauge steel with a 9-inch rib spacing and major rib height of 0.62 inches. The effective shear modulus, *G*, of the panel was 4,700 lb/in. For the roof, the calculated diaphragm shear stiffness was 33,840 lb/in.

Loading of the structure consisted of a windward roof pressure of 5.5 psf and a leeward roof pressure of -4.4 psf.

For the assumptions on post-frame end-wall stiffness, test configurations from Ross et al. (2009) were used for pressure-preservative-treated skirtboards placed on edge. The average apparent shear stiffness value recorded was 20,800 lb/in. Adjusting this value to the size of the example shear wall (multiplying by building width and dividing by wall height) produced a shear-wall stiffness of 72,800 lb/in.

For the assumptions on CLT end-wall stiffness, the shear stiffness values from Ceccotti et al. (2006) were used as the apparent shear stiffness. Adjusting these values to the size of the example shear wall produced shear stiffness values of 163,800 lb/in for the 3-layer CLT and 273,000 lb/in for the 5-layer CLT. These stiffness values were, respectively, approximately two and four times the post-frame end-wall stiffness, from Ross et al. (2009).

To examine the effect of end-wall shear stiffness on the performance of the building, the Diaphragm and Frame Interaction (DAFI) calculator was used. DAFI uses the inputs of number of building bays, diaphragm shear stiffness, end-wall stiffness, interior frame stiffness and eave load on the interior frame to calculate the horizontal displacement, the load resisted, the diaphragm displacement and the shear load within the diaphragm for each individual frame. The DAFI input values for the different materials are shown in **Table 1**. Only the default value for end-wall stiffness was changed for the post-frame and CLT end walls.

The horizontal displacement of the

Table 1. DAFI Input Values Used for End-Wall Comparison

Name	Value
Number of building bays	14
Default value for diaphragm shear stiffness	33,840 lb/in
Default value for end-wall stiffness	72,800 lb/in for post-frame 163,800 lb/in for 3-layer CLT 273,000 lb/in for 5-layer CLT
Default value for interior frame stiffness	163.4 lb/in
Default value for eave load on an interior frame	498 lb

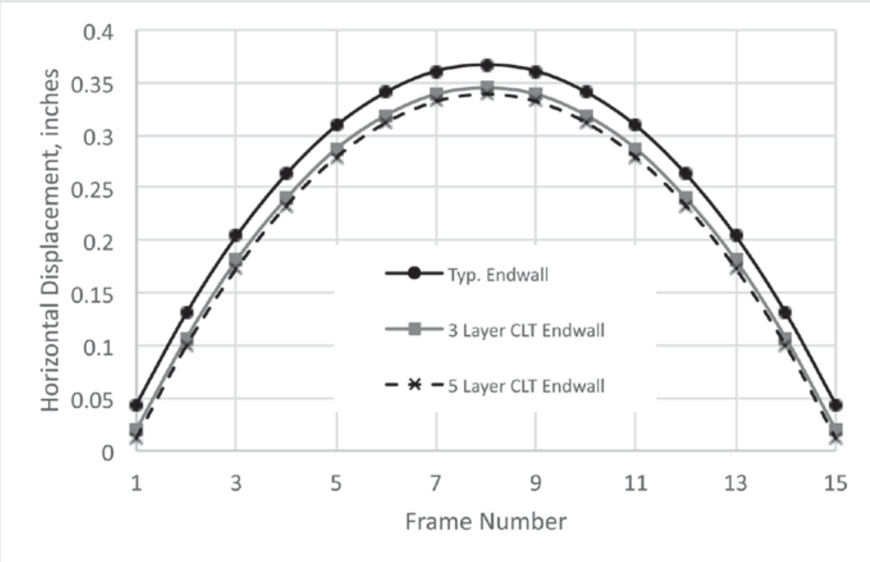

Figure 2. Comparison of DAFI results for typical post-frame and CLT end walls

individual frames for the post-frame, 3-layer CLT and 5-layer CLT are shown in **Figure 2**. Overall, the displacement profile of the fifteen frames in the building is very similar for all three end walls. The curves for the displacements seem to have been shifted slightly from the post-frame displacement, with the 3-layer CLT displacement curve 0.023 inches less and the 5-layer CLT displacement curve 0.028 inches less than the post-frame end wall, respectively. Overall, the change in interior frame deflection between the post-frame and CLT materials is minimal.

COMPARISON OF CLT END WALLS WITH OPENINGS

Although there appears to be little advantage to changing the end walls to CLT panels for a fully closed end wall, some authors have proposed the use of CLTs for large end-wall openings where the shear stiffness of post-frame end walls is reduced. The great shear stiffness of CLTs may be an advantage as a portion of the shear wall is removed.

The opening considered is symmetrical from the center line of the wall to prevent any torsion or additional moment forces developing. No changes in post-frame or CLT construction were assumed, so the reduction in shear stiffness was proportional to the remainder of end-wall section available to resist the lateral load.

The comparison of the maximum interior frame deflection from DAFI is shown in **Table 2** for the post-frame, 3-layer CLT and 5-layer CLT with various opening sizes. Table 2 highlights an interesting comparison: the maximum interior frame deflection of the solid post-frame wall with a 0 percent opening is approximately equivalent to a 3-layer CLT end wall with a 60 percent opening and a 5-layer CLT end wall with an 80 percent opening.

This simple design example demonstrates that CLT materials may be an option when large end-wall openings of the building are required. This example did not consider any changes in construction methods for post-frame end walls, which can be made to increase end-wall stiffness for openings (Wirt, Woeste, Kline, & McLain, 1992), such as additional strapping. More research and understanding of the design process for post-frame end walls may be helpful.

An advantage of the shear stiffness for CLT materials is the simplification of panel stiffness calculations versus those for post-frame materials. Although post-frame panels require an intimate knowledge of fasteners location, type of metal panel connections and other details, CLTs can be treated as a homogenous material with a single shear stiffness term.

Table 2. Maximum Interior Frame Deflection from DAFI for Different End-Wall Stiffnesses

% Opening	Post-Frame End Wall	3-Layer CLT End Wall	5-Layer CLT End Wall
0%	0.367	0.345	0.339
20%	0.377	0.350	0.341
40%	0.393	0.357	0.346
60%	0.424	0.371	0.354
80%	0.514	0.414	0.380

CHALLENGES IN USING CLTS

The use of CLTs in post frame, as mentioned before, can be viewed as an additional tool in the tool box used by designers and engineers to create efficient structures. But CLTs are not without challenges, some of which may be difficult to overcome. These challenges include the following:

- **Lack of production in the United States**—Currently, no commercial CLT manufacturing facilities for construction exist in the United States. Several facilities are located in Canada and Austria, but these present challenges in transportation. However, the APA is currently in the process of trademarking a company for CLT production in Oregon.
- **Cost**—Because no CLTs are produced in the United States, the cost is unknown. The hope is that as U.S. production occurs and the panels are used for certain applications, lower costs will prove to be an advantage.
- **The requirement of exterior cladding**—One advantage of post-frame design is the incorporation of the building envelope and structural elements. However, CLTs are produced only from nontreated wood sources and therefore require exterior cladding. CLTs are easier to clad than many other building systems because nails and screws can be readily placed almost anywhere within the panel. Specific detailing of the CLT connection to posts would have to be made, and attention to cladding tolerances and appearance is needed to ensure that the building does not have a discontinuous or unfinished look.
- **Attachment of CLTs to the post structure**—CLTs are currently connected by a variety of small-diameter (1/4 inch and less) lag screws. Attachment to

the posts is also an issue; Ceccotti et al. (2006) and other researchers have found that the strength and stiffness of the CLT panels are highly dependent upon the behavior of the fasteners and connections. In fact, the panels themselves are usually not the element that fails in CLT shear tests, but rather the connections.

• **Ground contact—**CLT materials are constructed from untreated lumber only. The use of CLT in post frame would be limited to situations where ground contact of the walls is avoided, such as with a floating slab.

CONCLUSIONS

This article presents a short design example illustrating the use of cross-laminated timber in a post-frame end wall. Comparisons of the interior frame deflection values in CLT end walls and solid post-frame end walls demonstrated little change. When CLTs are used for end walls with a symmetric opening, the interior frame deflection of a solid post-frame end wall was similar to that of a 3-layer CLT with a 60 percent opening and a 5-layer CLT with an 80 percent opening. These estimates were developed considering only the capacity of the CLT itself and not any contributions to stiffness made by fasteners.

CLTs may therefore be a viable option for post-frame buildings with large end-wall openings. CLTs may be an option for use in other buildings if needed. However, significant challenges need to be addressed before the material can be used more widely.

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REFERENCES

American Society of Agricultural and Biological Engineers. 2014. *ASAE EP 558.1. Load Tests for Metal-Clad Wood-Frame Diaphragms.* St. Joseph, Mich.: ASABE.

ANSI/APA. 2012. *ANSI/APA PRG 320 Standard for Performance-Rated Cross-Laminated Timber.* Tacoma, Wash.: APA—The Engineered Wood Association.

Ceccotti, A., Lauriola, M. P., Pinna, M., & Sandhaas, C. 2006. SOFIE project—Cyclic tests on cross-laminated wooden panels. Paper presented at World Conference on Timber Engineering, August 6–10, 2006, Portland, Ore.

Construction Dive. 2015. First all-timber commercial structure in U.S. breaks ground in Minneapolis. Retrieved from www.constructiondive.com/news/1st-all-timber-commercial-structure-in-us-breaks-ground-in-minneapolis/403135/

Green, M. 2012. The Case for Tall Wood Buildings: How Mass Timber Offers a Safe, Economical, and Environmentally Friendly Alternative for Tall Building Structures. Retrieved from http://cwc.ca/wp-content/uploads/publications-Tall-Wood.pdf

LignaTerra. 2014. Franklin Elementary School. Retrieved from www.lignaterra.com/work/franklin-elementary-school/

Mill, D. P. 2012. Simplified Lateral Design of Post-Frame Buildings—Comparison of Design Methodologies and Underlying Assumptions. M.S. thesis. Washington State University.

National Frame Building Association. 2015. *Post-Frame Building Design Manual,* 2nd ed. Chicago, Ill.: NFBA.

Ross, L. A., Bender, D. A., & Carradine, D. M. 2009. Performance of post-frame shear walls with wood plastic composite skirtboards subjected to monotonic racking loads. *Transactions of the American Society of Agricultural and Biological Engineers,* 52(2): 583–589.

Wirt, D. L., Woeste, F. E., Kline, D. E., & McLain, T. E. 1992. Design procedures for post-frame end walls. *Applied Engineering in Agriculture,* 8(1): 97–105.