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Cross-Laminated Timber Diaphragms	Date: November 15, 2019
ABSTRACT: This white paper is intended to establish a rational approach for designing Cross-Laminated Timber diaphragms to resist wind and seismic loads.	**Task Force Group Members:** *Alex Legé, P.E., S.E., Chair* *Dennis Pradere, P.E., S.E.* *Violeta Tihova, P.E., S.E.* *Scott Breneman, PhD., P.E., S.E.* *Hans-Erik Blomgren, P.E., S.E.* *Clayton Binkley, P.E., S.E.* *Patrick Lindblom, P.E., S.E.* *Leif Johnson, P.E., S.E.* *Jacqueline Rock*

I. INTRODUCTION:

Cross-Laminated Timber (CLT) is recognized as a structural material in the International Building Code and can be used for floors and roofs. However, the ability of CLT to be used as a diaphragm is limited by lack of a design method in the current ANSI/AWC SPDWS standard. This leaves the design approach up to engineering judgment with a variety of analysis and design method approaches. The intent of this white paper is not to exclude any rational design method, but to provide design professionals and building officials with a rational approach and guidance to utilize this construction material.

II. RECOMMENDATIONS:

CLT floor and roof diaphragms may be designed for seismic forces using the Alternative Design Provisions for Diaphragms in ASCE 7-16 Section 12.10.3. Some ductility in the connections between panels should be provided. CLT diaphragms with a structural concrete topping may be designed utilizing the provisions of ACI 318 Section 18.12.5 for cast-in-place noncomposite topping slab diaphragms.

CLT diaphragms without structural concrete topping may be designed using the following approach:

- The diaphragm should conform to AWC SDPWS Section 4.2.5, except as modified below.
- CLT Panels should be manufactured and identified in accordance with ANSI/APA PRG 320-18. Products should have a tested and published in-plane (edge wise) shear capacity.
- Capacity of the diaphragm should be checked including shear, moment, and axial forces.
- Plywood or CLT spline joint connections should not be used to transfer tension forces.
- Diaphragm seismic forces should be determined per ASCE 7 Section 12.10.3 with a Diaphragm Design Force Reduction Factor, R_s = 1.0 in place of other values from Table 12.10-1.
- The connection capacity should be governed by dowel fastener yield modes III_S or IV in accordance with NDS Section 12.3.1 to achieve ductility in the panel-to-panel connections.

For CLT diaphragms cantilevered beyond the last support, SDPWS Section 4.2.5.2.4 may be modified to allow for any cantilevered diaphragm length provided all other requirements of AWC SDPWS Section 4.2.5.2 are met. Story drift should be checked utilizing a method which accounts for torsion, accidental torsion, and diaphragm deformation.

All references are from the ASCE 7-2016 Edition, ACI 318 2014 Edition, AWC Special Design Provisions for Wind and Seismic 2015 Edition (AWC SPDWS), AWC National Design Specification for Wood Construction 2015 Edition, and the 2018 International Building Code.

III. COMMENTARY:

Although some jurisdictions have required the use of separate diaphragm assemblies such as a continuous plywood sheathing layer or structural concrete topping, CLT itself with added interconnections at panel edges and diaphragm chords has considerable capacity to function as a diaphragm. There is also limited CLT diaphragm testing from which engineers can extrapolate design methodology. However, several shear wall tests have been conducted with diaphragm assemblies included but not specifically studied. Shear wall testing has shown that the panels tend to perform as elastic rigid bodies where the deformation behavior and ultimate strength of the system is determined by the connections at panels and chords. Until additional testing is conducted on diaphragms and their connections, the alternative design provisions in ASCE 7 Table 12.10-1 with the modified reduction factor could be used and are deemed to be conservative. As part of the shake table testing, a preliminary design was conducted which utilized the ASCE 7-16 alternate diaphragm provisions with a Rs = 1.0 and had some correlating test results (see reference C). The task force therefore judged that this approach could be utilized until additional testing and research is performed. This design method is deemed to provide an adequate level of conservatism at this time and no further increases in forces are recommended.

The basis for eliminating the cantilever limitation is that CLT diaphragms are significantly stiffer than a typical light framed wood diaphragm. Long span cantilevered CLT diaphragms are not expected to exhibit the extremely high drift differentials between the supported and free edge of that are a concern with long span cantilevered light framed wood diaphragms. It should be noted that the Canadian code does not include a span limit for CLT diaphragms, and that recent proposals for the 2021 AWC SDPWS include a separate section for CLT diaphragms which do not include a span limit. Some analysis by the Task Group was undertaken through a parametric study comparing a 30-foot cantilever to a 50-foot cantilever for both an un-topped CLT and typical ¾" plywood light frame diaphragm. The following assumptions were used for this analysis:

- ¾" plywood spline with 10d nails or proprietary screws
- Panel widths of 4 feet, 6 feet, 8 feet, 10 feet
- Panel length of 30 feet minimum
- (5) Ply CLT panels
- The aspect ratio was maintained in conformance to AWC SDPWS section 4.2.5.2 at 0.67:1
- An updated cantilevered diaphragm deformation equation is currently in development. The following equation was adapted from reference C and made specific to CLT diaphragms as noted in reference A used for the study:

$$\delta_{dia} = \frac{3vL'^3}{E_{ch}A_{ch}W'} + \frac{vL'}{2G_v t_v} + 2CLe_n + \frac{\sum(x\Delta_c)}{W'}$$

The following observations from the task force are based on analysis of this equation informed by the parametric study and their own engineering experience:

- Panel length was judged to not be a critical criterion for deformation analysis.
- The number of plys in the CLT panel is not critical to diaphragm design.
- The aspect ratio limitation of AWC SDPWS may be very conservative for CLT diaphragms.
- Panel orientation is a significant factor in diaphragm deformation, with the length of the panels conservatively assumed to be parallel to load.
- The results showed the flexural term of the cantilever equation (term 1) does not significantly contribute to the deformation of the diaphragm with the aspect ratio limitation. Therefore, increasing the cantilever length of the diaphragm generally results in only a linear increase of the diaphragm deformation.

Additional references used in the design of Cross Laminated Timber Diaphragms:

A. Cross Laminated Timber Horizontal Diaphragm Design Example (2015):
https://www.structurlam.com/wp-content/uploads/2016/10/Structurlam-CrossLam-CLT-White-Paper-on-Diaphragms-SLP-Oct-2015.pdf

B. A. Barbosa, et al Numerical Modeling of CLT Diaphragms tested on a shake-Table Experiment. In: World Conference on Timber Engineering, WCTE 2018

C. A Design Example of a Cantilever Wood Diaphragm (2019):
https://www.woodworks.org/wp-content/uploads/design_examle-Design-Example-of-a-Cantilever-Wood-Diaphragm.pdf