WHITE PAPER

MTC SOLUTIONS

INTERSTORY DRIFT STIFFNESS OF MEGANT E CONNECTOR

info@mtcsolutions.com | 1.866.899.4090 | www.mtcsolutions.com

DISCLAIMER

The information in this document is provided on an “as is” basis and for general information purposes only. While MTC Solutions aims to keep the information provided in this document complete, accurate, and in line with state-of-the-art design methods, MTC Solutions, its affiliates, employees, agents, or licensors do not make any representations or warranties of any kind, including, but not limited to, express or implied warranties of fitness for a particular purpose or regarding the content or information in this document, to the full extent permitted by applicable law.

The information in this document does not constitute engineering or other professional advice, and any reliance users place on such information is therefore strictly at their own risk. Images and drawings provided within this document are for reference only and may not apply to all possible conditions. MTC Solutions shall not be liable for any loss or damage of any kind, including indirect, direct, incidental, punitive, or consequential loss or damage arising out of, or in connection with, the information, content, materials referenced, or the use of any of the systems described in this document. Users may derive other applications which are beyond MTC Solutions’ control. The inclusion of the systems or the implied use of this document for other applications is beyond the scope of MTC Solutions’ responsibility.

ABSTRACT

In this white paper (WP), a series of pushover experiments were conducted to observe the drift capacity of three different connections, including one pre-engineered MEGANT E connector and two widely used custom connections. The findings of the experimental testing suggest that MEGANT E connectors display superior overall performance when compared to the custom connections. Specifically, MEGANT E connectors exhibited a low initial stiffness while also demonstrating the largest remaining secant stiffness towards the end of the loading protocol. Greater energy dissipation and larger average yield forces were observed when compared to the custom connectors.

Keywords: Mass timber, pre-engineered connector, MEGANT E, initial stiffness, secant stiffness, energy dissipation, damping, residual displacement

INTRODUCTION

Carbon 12 - Portland, Oregon
Photo Courtesy of Andrew Pogue Pictures

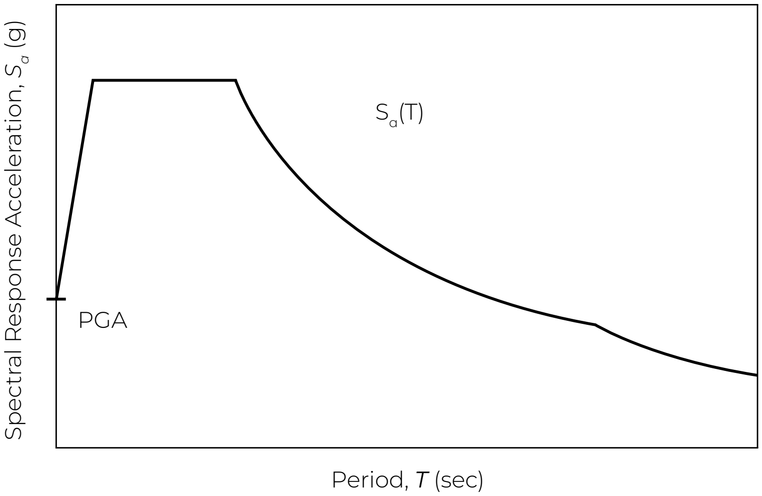
This WP is a supplement to a previously published WP by MTC, by referencing both monotonic and cyclic testing data obtained from Oregon State University (OSU) to evaluate the behavior of pre-engineered MEGANT E and custom glulam beam-to-column connections.

Beam-to-column connectors are primarily intended to withstand gravity shear forces. Nevertheless, during an earthquake, the connector needs to endure significant lateral deformations and rotations while supporting the gravity forces. These connectors can either be pre-engineered or custom-designed, but it is necessary to understand and obtain accurate information about their behavior to ensure proper engineering design. Engineers should ensure that their widespread use in mass timber buildings is appropriate, regardless of the connector type employed.

In seismic design, the primary structural features that are of utmost importance include the natural period, stiffness, damping, and ductility. It is imperative to determine a structure's fundamental period in advance, as it enables structural engineers to estimate the seismic design base shear force and acceleration response of the structure, which are crucial factors in ensuring the safety and resilience of the structure.

An increase in connection stiffness leads to higher design base shear forces for the same ground motion, while the corresponding reduction in lateral drift does not occur in the same proportion. Furthermore, an increase in connection stiffness leads to a higher acceleration response of the structure, which can result in further structural and non-structural damage. Thus, a highly stiff connection may not be the best solution in mitigating dynamic loading since an optimal structure design should aim to minimize the acceleration response and associated base shear forces while maintaining an acceptable amount of lateral deformations.

The impact of a structure's initial stiffness on its period and the load it attracts during ground motions is shown in Figure 1.



Stiffness = Force/Displacement

Period = $2\pi\sqrt{Weight/(g\times Stiffness)}$

Figure 1. Typical Response Spectrum Curve for Seismic Design

The primary goals of this paper are to examine the behavior of glulam beam-to-column connectors when subjected to monotonic and cyclic loading, and to assess and compare the performance of pre-engineered MEGANT E and custom connectors in terms of initial stiffness, secant stiffness, and energy dissipation capacity. An experimental testing program was conducted on six glulam beam-to-column connector specimens, representing three different connection types to accomplish these objectives. Two connections were custom designed, with the third being the MEGANT E beam hanger.

METHODOLOGY

Materials and Testing Setup

The construction of the test setup involved the use of Douglas Fir (DF) 24F-V4 glulam columns and beams. On top of the beams, a deck composed of 5-ply spruce-pine-fir (SPF) cross laminated timber (CLT) was attached. Table 1 provides the details and dimensions of the beams and columns for each specimen. Figure 2 shows the schematic of the test setup, including the placement and dimensions of the test specimen. Data was measured using a combination of load cells, linear variable differential transformers, and string potentiometers. Table 2 provides an overview of the magnitude and location of the applied gravity loading. In the monotonic test, identified as M, a hydraulic actuator was used to apply a maximum lateral displacement of 10-7/8" *[275.6mm]*, which corresponds to a 7.2% story drift. In addition, two reversed cyclic tests, denoted as Cyl, were conducted following the ordinary ground motions protocol of the Consortium of Universities for Research in Earthquake Engineering (CUREE), which is illustrated in Figure 3.

Table 1. Specimen Details

Connection Type	Description	Specimen Designation	Reinforcing Screw	Column Dimensions			Beam Dimensions			CLT Dimensions		
				Width	**Depth**	**Height**	**Width**	**Depth**	**Length**	**Thickness**	**Width**	**Length**
				in. *[mm]*	**in.** *[mm]*	**ft.** *[m]*	**in.** *[mm]*	**in.** *[mm]*	**ft.** *[m]*	**in.** *[mm]*	**ft.** *[m]*	**ft.** *[m]*
Custom Designed	Knife Plate	C1-KP	3 x [3/8” x 11”] ASSY VG CSK	**12-1/4** *[311]*	**16** *[406.4]*	**12** *[3.7]*	**12-1/4** *[311]*	**24** *[610]*	**14** *[4.27]*	**6-7/8** *[175]*	**4** *[122]*	**14** *[4.27]*
	Notched Column	C2-N	2 x [3/8” x 11”] ASSY VG CSK		**22.5** *[571.5]*				**14.5** *[4.4]*			
Pre-Engineered	MEGANT E	C3-MEG	N/A		**16** *[406.4]*				**14** *[4.27]*			

Notes:

1. The specimen designations utilized in this paper are established on the basis of the connection number, connection description, and applied load.
2. Sacrificial blocks of glulam were glued to the C1-KP and C2-N specimens to represent fire blocking.

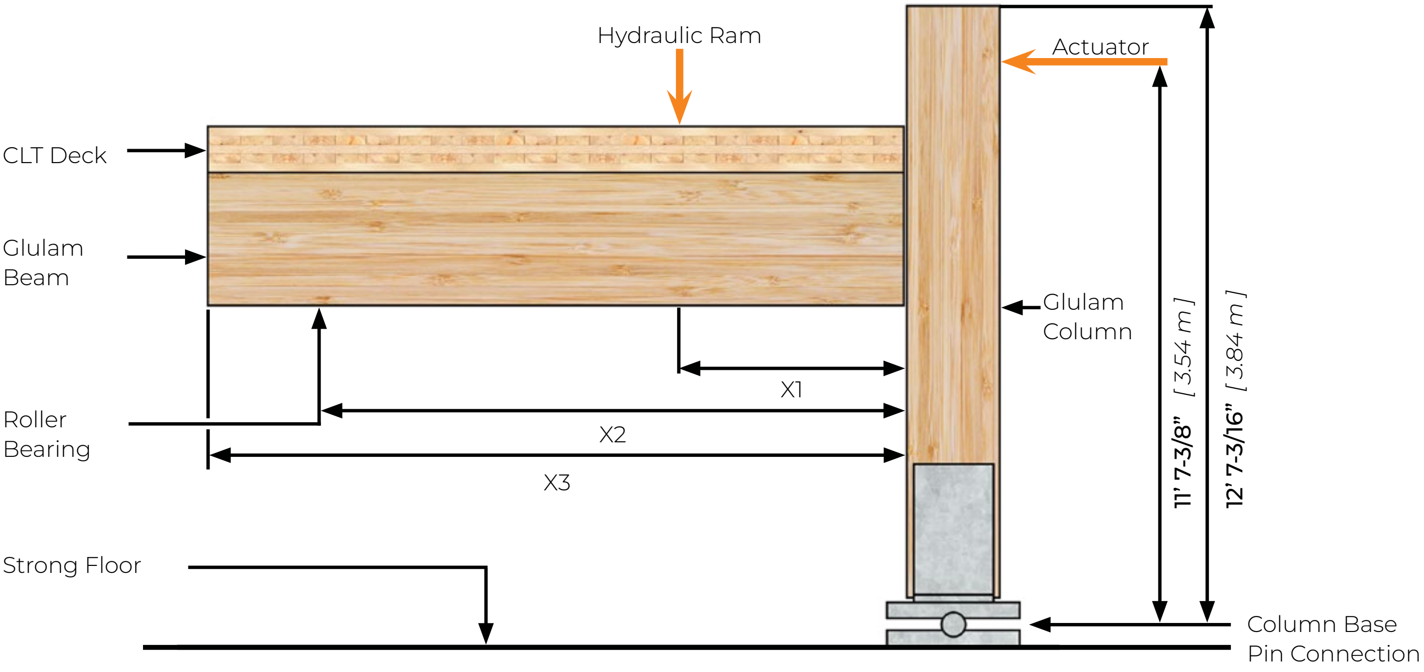


Figure 2. Overall Testing Schematic

Table 2. Applied Gravity Loading Magnitude and Location

Connection Designation	X1	X2	X3	Gravity Shear Loading
	ft. *[m]*	ft. *[m]*	ft. *[m]*	kip. *[kN]*
C1-KP	**5.77** *[1.76]*	**13.75** *[4.19]*	**14.00** *[4.27]*	**17.20** *[76.51]*
C2-N	**5.76** *[1.76]*	**13.79** *[4.20]*	**14.24** *[4.34]*	**17.24** *[76.69]*
C3-MEG	**5.77** *[1.76]*	**13.75** *[4.19]*	**14.00** *[4.27]*	**36.14** *[160.80]*

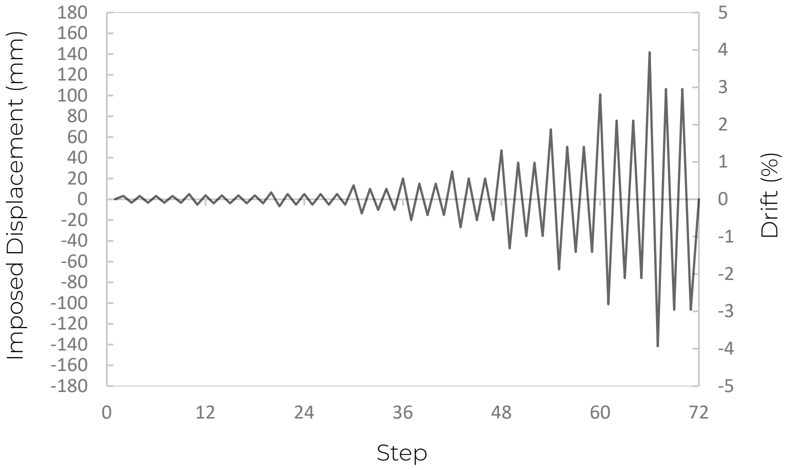
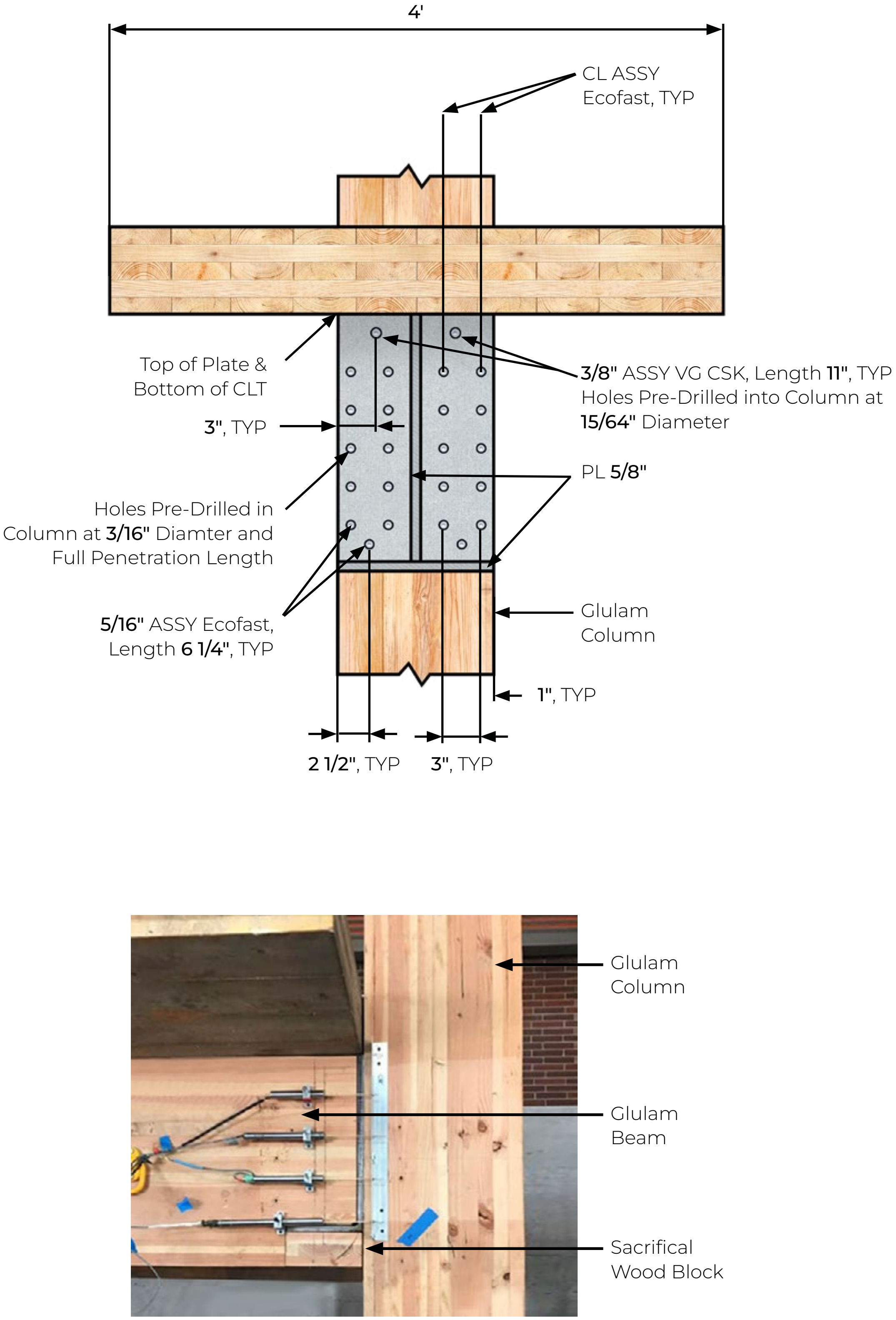


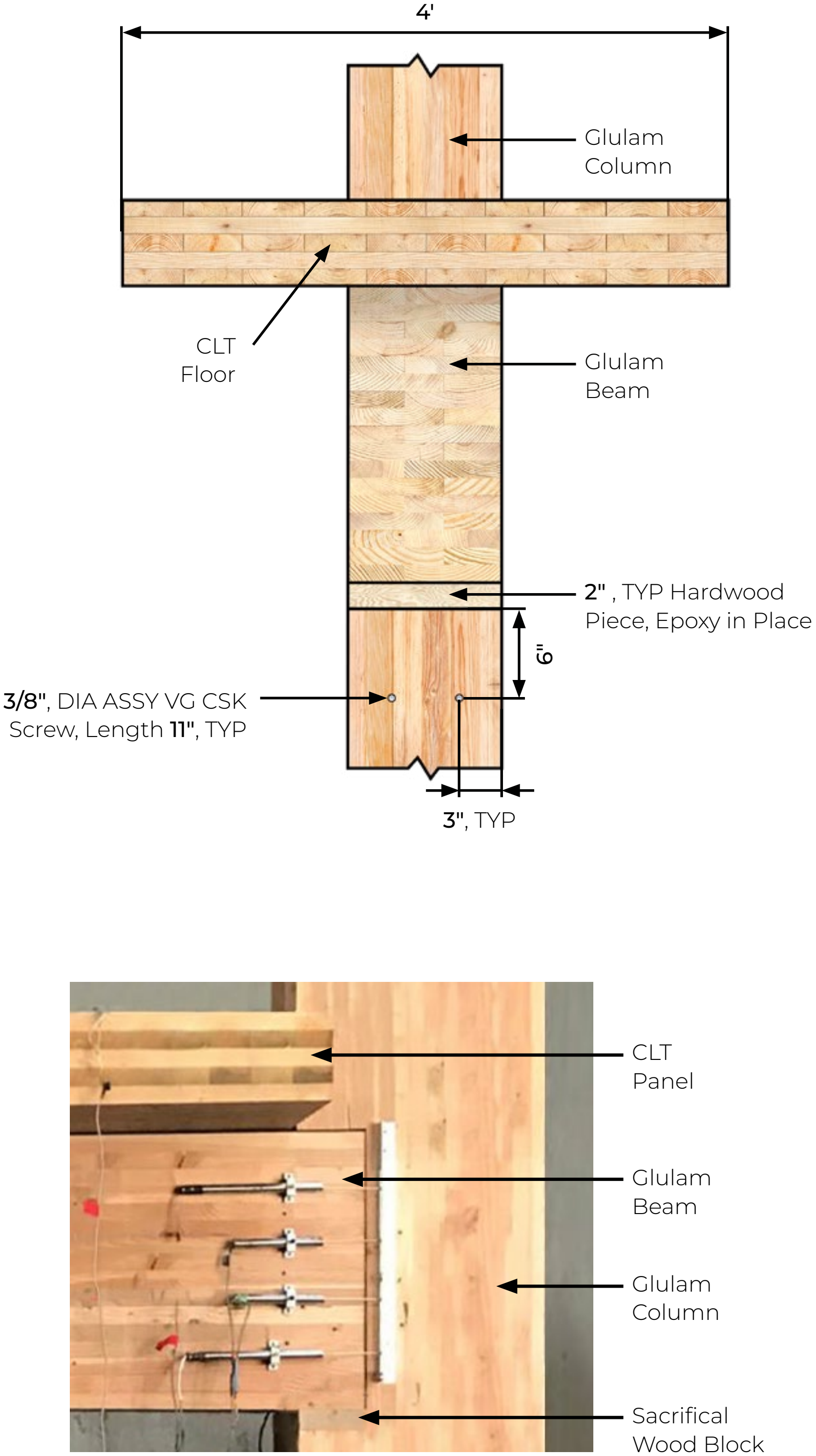
Figure 3. CUREE Cyclic Loading Protocol

Connection Types

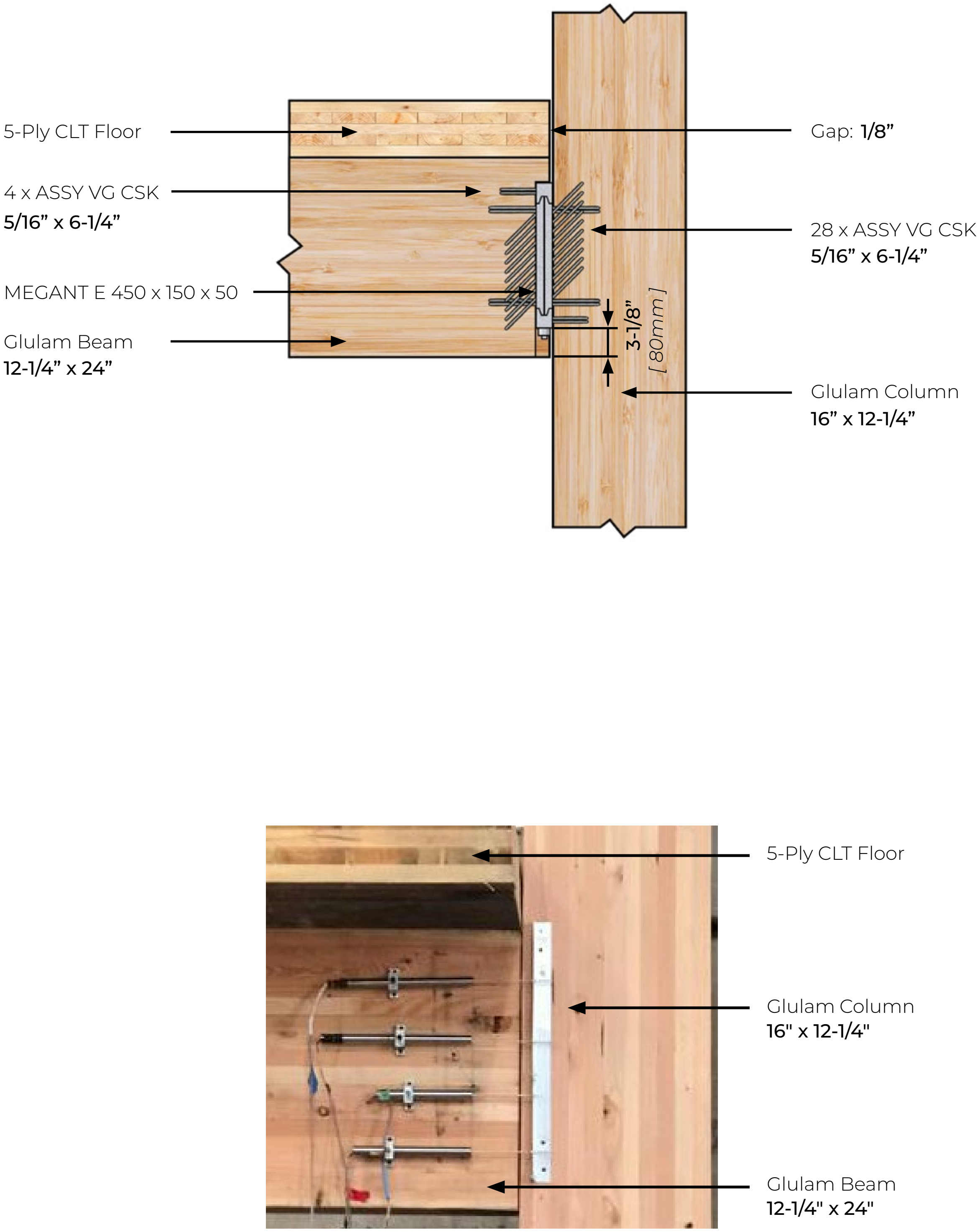
In this experimental testing program, three different connections were considered. These included a pre-engineered connector called MEGANT E 450×150×50, as well as two custom-designed connections consisting of a knife plate connector and notched column connector (designed by OSU). These connections are shown in Figure 4. Engineers can refer to the WP on the Interstory Drift Performance of MEGANT E Connector and the Beam Hanger Design Guide for more details on the MEGANT E connection, including its housing details, screw types, and arrangement.



(a) Knife Plate



(b) Notched Column



(c) MEGANT E

Figure 4. Configurations of Connectors

CARBON 12

Portland, Oregon

Photo Courtesy of Andrew Pogue Pictures

RESULTS

Monotonic Test Result Analysis

Table 3 presents the yield displacement, yield load, initial stiffness, secant stiffness, and maximum load, which were obtained from the monotonic force-displacement response of the specimens shown in Figure 5.

The residual drift, which refers to the permanent deformation sustained by a structure after a seismic event, is a critical performance criterion for assessing the effectiveness of connectors in terms of building functionality, occupant comfort, rehabilitation cost, and structural safety. Residual drift was measured after the actuator was pulled back to the zero-displacement position.

The monotonic results revealed that the MEGANT E connectors had the lowest residual displacement, measuring only 5/16", while the custom-designed connectors had a wide range of residual displacements, between 3/4" and 4-1/16". These findings indicate that the MEGANT E connectors are more effective in limiting the permanent deformation of the connection, which can lead to lower rehabilitation costs and improved occupant safety and comfort.

MEGANT E connectors exhibited low initial stiffness, gentler stiffness degradation, and stable/steady behavior while accommodating increasing force with increasing displacement. In addition, they have the highest capacity and secant stiffness among all tested connectors, which is crucial when the structure reaches its maximum drift limit. These features make the MEGANT E connectors a feasible option for seismic design since they can effectively contribute to minimizing base shear forces and acceleration response due to their low initial stiffness, while still allowing for acceptable lateral deformations and providing the highest capacity and secant stiffness when the structure is at its maximum drift limit. This greatly improves the safety and resilience of the structure under seismic loading, making the MEGANT E connectors a preferred choice for mass timber structures.

Table 3. Yield and Stiffness Properties of Specimens

Specimen Designation	**Yield Displacement d_y**	**Yield Load F_y**	**Initial Stiffness K_i**	**Secant Stiffness K_{sec}**	**Maximum Load F_{Max}**
	in. *[mm]*	**lb** *[kN]*	**lb/in.** *[N/mm]*	**kip-in./rad** *[kN-m/rad]*	**kip.** *[kN]*
C1-KP-M	**0.43** *[10.9]*	**1088** *[4.84]*	**2549** *[446]*	**19002** *[2147]*	**1.96** *[8.72]*
C2-N-M	**0.59** *[15]*	**1993** *[8.87]*	**3396** *[595]*	**21887** *[2473]*	**2.69** *[11.97]*
C3-MEG-M	**1.33** *[33.8]*	**3557** *[15.82]*	**2667** *[467]*	**22790** *[2575]*	**6.55** *[29.17]*

Notes:

1. Yield displacement refers to the displacement at which the connector elements start to yield or deform plastically, typically corresponding to the yield load of the material.
2. The secant stiffness refers to the ratio of the absolute value of the maximum moment (Mi+) and minimum moment (Mi-) experienced during a primary cycle, to the absolute value of the corresponding rotations (Δi+ and Δi-).

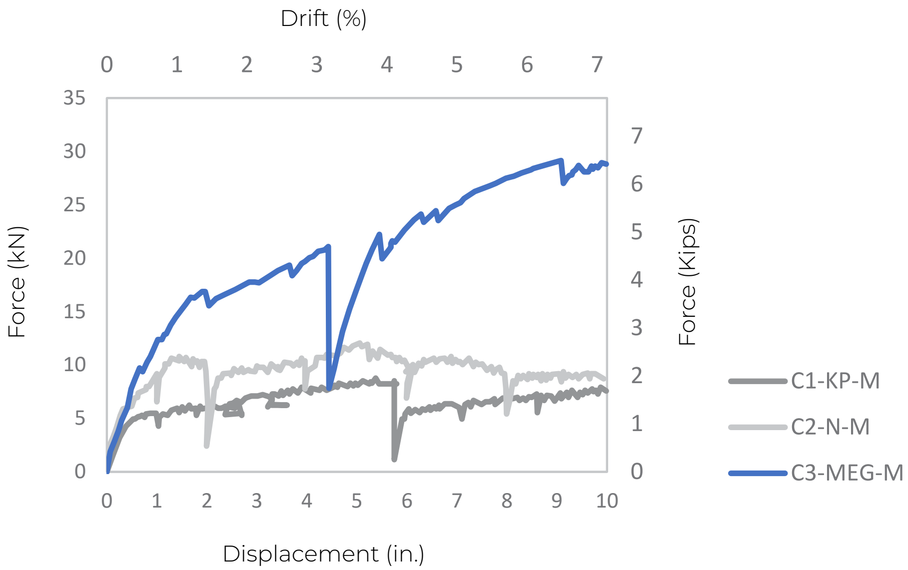
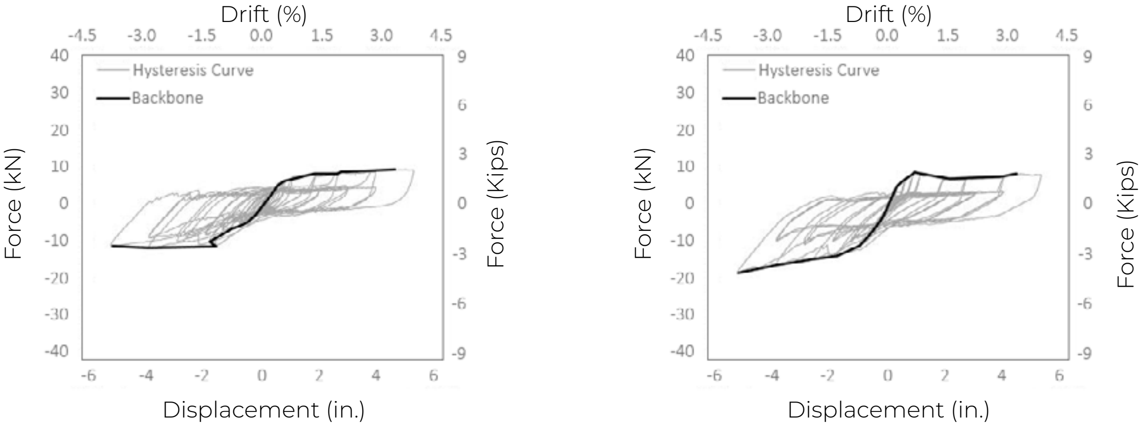


Figure 5. Monotonic Pushover Curves

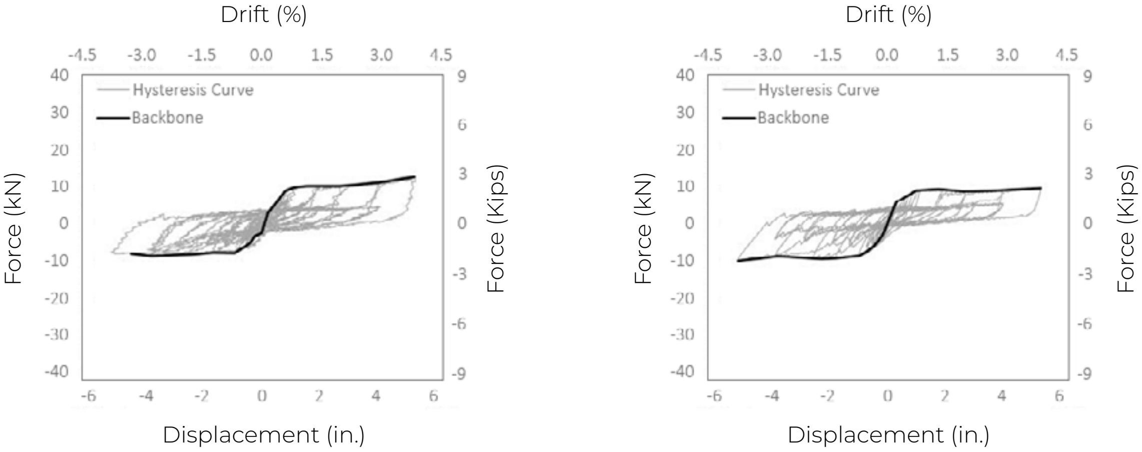
Cyclic Test Result Analysis

The amount of energy dissipated through hysteresis in systems undergoing quasi-static loading is commonly regarded as a useful indicator of their performance during earthquake excitation. Generally, a fuller hysteresis loop indicates a higher level of seismic energy dissipation by the structure, which is technically regarded as better performance when compared to systems of similar strength. The results of the cyclic tests on the six specimens, along with their corresponding backbone curves, are presented in Figure 6. To determine the amount of energy dissipated during the testing process, the total area enclosed by the hysteresis loops was calculated for each cycle and then added up over the entire test duration. The relationship between the cumulative energy dissipated at each primary cycle and the average of the absolute values of the maximum and minimum rotations achieved during each cycle is depicted in Figure 7(a), while Figure 7(b) presents a comparison of the total energy dissipated. Overall, the specimens equipped with MEGANT Es (C3-MEG-Cyc1 and C3-MEG-Cyc2) exhibited greater energy dissipation than the custom designed connectors.



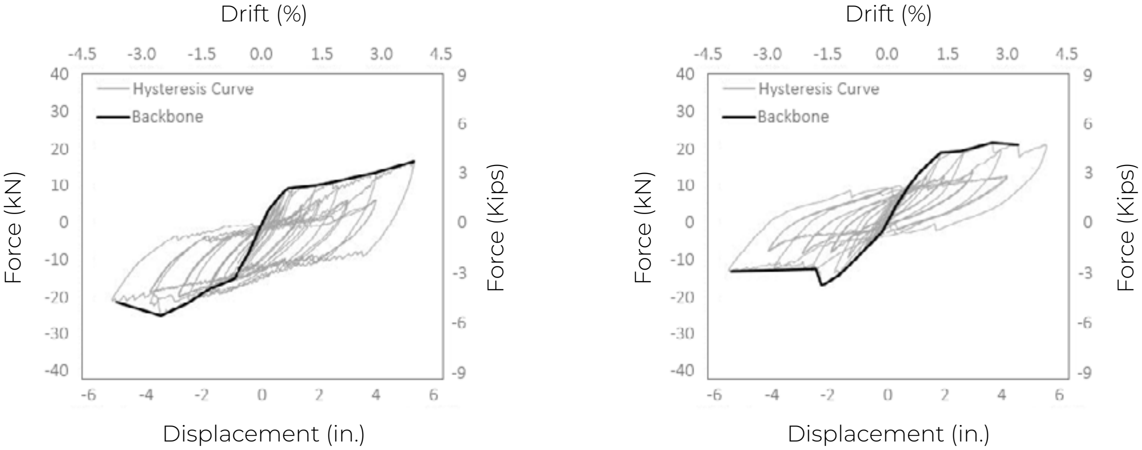
(a) C1-KP-Cyc1

(b) C1-KP-Cyc2



(c) C2-N-Cyc1

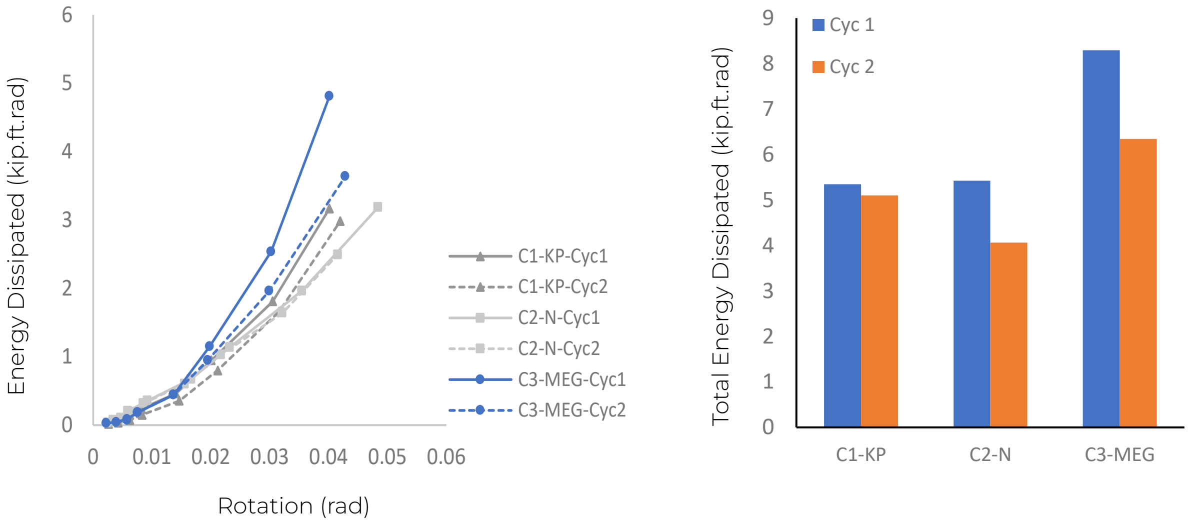
(d) C2-N-Cyc2



(e) C3-MEG-Cyc1

(f) C3-MEG-Cyc2

Figure 6. Cyclic Hysteresis Curves of Specimens



(a) Computed Cumulative Energy Dissipation

(b) Total Energy Dissipated

Figure 7. Energy Dissipation

The equivalent viscous damping ratio (EVDR) is another option to measure a connection's energy dissipation. It provides a per-cycle metric to evaluate energy dissipation, compared to total energy dissipation. When the EVDR increases sharply, it suggests an increase in energy dissipation between cycles, which could be an indication of damage. Figure 8 suggests that (given the small number of tests conducted) the MEGANTE connectors exhibit the most consistent and stable behavior with minimal performance fluctuations. Moreover, C3-MEG specimens display a general trend of increasing EVDR as the connection rotation increases, while the EVDR of custom-designed connectors generally tends to plateau or decrease during the final primary cycles.

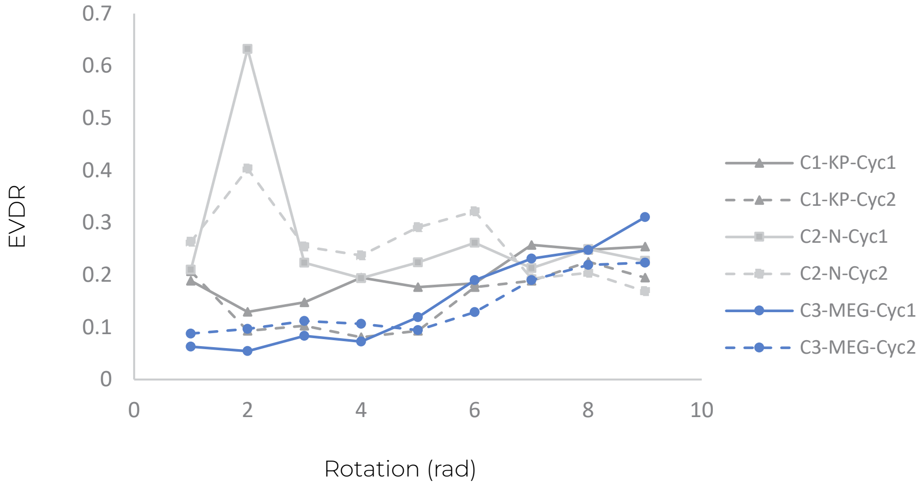


Figure 8. EVDR for all Specimens

CONCLUSION

This white paper aimed to compare the deformation compatibility behavior of gravity glulam beam-to-column connections under monotonic and cyclic lateral loading. Three full-scale connection types were tested, including two custom-designed and one pre-engineered connection. The connections were evaluated based on initial stiffness, secant stiffness, equivalent damping ratio, energy dissipation, and residual displacements. Results showed that the MEGANT E pre-engineered connectors had the lowest residual displacement and highest capacity and secant stiffness after the final primary cycles. They also exhibited larger total energy dissipation during testing and continuously increasing EVDR values throughout. These findings suggest that the MEGANT E connectors have better energy dissipation compared to the two custom-designed connections. Further testing of glulam beam-to-column connections is recommended to better understand and quantify post-peak load behavior. Beyond the scope of this WP, it was noted that shifting connection pivot points induced bending moment onto the column due to prying of the CLT floor panels against the columns. This should be a consideration for future research projects as the data would be valuable to the engineering industry.

CARBON 12

Portland, Oregon

Photo Courtesy of Andrew Pogue Pictures

MTC
SOLUTIONS