WHITE PAPER

INTERSTORY DRIFT PERFORMANCE OF MEGANT E CONNECTOR

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ABSTRACT

This paper investigates the drift capacity of MEGANT E 450×150×50 connectors observed through a series of pushover experiments. The test results revealed that the MEGANT E connectors exhibited ductile behavior and were able to sustain interstory drifts of up to 4% and 7.2% in cyclic and monotonic tests, respectively, and successfully maintained their intended design shear load-carrying capacity throughout the duration of the tests.

INTRODUCTION

The significance of the response of mass timber connections to loading conditions such as seismic or high wind events grows over time with the increase in maximum height now permitted for mass timber buildings under the 2021 IBC updates. This is of rising importance knowing that the Cascadia subduction zone, located on the west coast of the North American continent, is a 600-mile-long fault capable of generating an earthquake magnitude of 9.0 or higher [1]*. In addition to the lateral force resisting system being designed to withstand lateral forces generated by earthquakes or winds, every building component, including connections, needs to withstand the deformation demands as well. As such, in order to maintain the expected deformations during a seismic event, the post and beam framing system needs to behave in a ductile manner.

One of the seismic design lessons learned from the Northridge earthquake in 1994 was the importance of meeting the deformation compatibility criteria. Deformation compatibility is the capacity of framing elements and connections not part of the lateral force resisting system to withstand seismic displacements without failing. The load-carrying capacity of beam-to-column connections could be lost during a seismic event. Loss of connection capacity can cause a collapse of the supporting beam structure with a subsequent structural integrity decline. The frame displacements and force redistribution during a severe seismic event is affected by the connections' ability to deform. This paper presents an overview of the findings of full-scale monotonic and quasi-static cyclic testing of pre-engineered MEGANT E 450×150×50 connectors that involved combined gravity and lateral loading conducted at Oregon State University [2]*.

Keywords: Mass timber, connector, monotonic, cyclic, interstory drift, residual displacement, pre-engineered beam hanger, MEGANT

**All references on page 23*
Above Photo Courtesy of Swinerton Pictures

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METHODOLOGY

Material

D.fir 24F-V4 glue laminated (glulam) columns and beams were used for the construction of the test set-up and a 5-ply spruce-pine-fir (SPF) cross laminated timber (CLT) deck was fastened on top of the beam.The Megant E is a modified version of the common Megant system; however, strengthened clamping jaws are deployed. The connectors were fastened with ICC-ES approved ASSY VG CSKs 5/16” x 6-1/4” *[8mm x 160mm]*.

Testing Setup

The dimensions of the beams and columns were consistently maintained throughout the experiments, as summarized in Table 1. The vertical movement was restrained at the end of the beam, where a roller connection was used to support the beam which was free to move in the longitudinal direction during all tests. Figure 1 illustrates the locations of the beam end reaction, the applied lateral actuator force, and the applied gravity load from the face of the column. Data related to the connection behaviour was collected using linear variable differential transformers (LVDTs) and load cells, shown in Figure 2. LVDTs 1 through 4 were used to calculate the rotation between the beam and column, and LVDTs 5 and 6 were used to calculate rotation at the column base. The measured rotation at the connection and column base was identical for all 3 tests, which indicates minimal bending had occurred at the columns. A mostly constant shear force at the connection was applied with a hydraulic ram.

Table 1. Specimen Dimensions

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]*
12-1/4" *[311]*	**16"** *[406.4]*	**12'** *[3.7]*	**12-1/4"** *[311]*	**24"** *[610]*	**14'** *[4.3]*	**6-7/8"** *[175]*	**4'** *[1.22]*	**14'** *[4.27]*

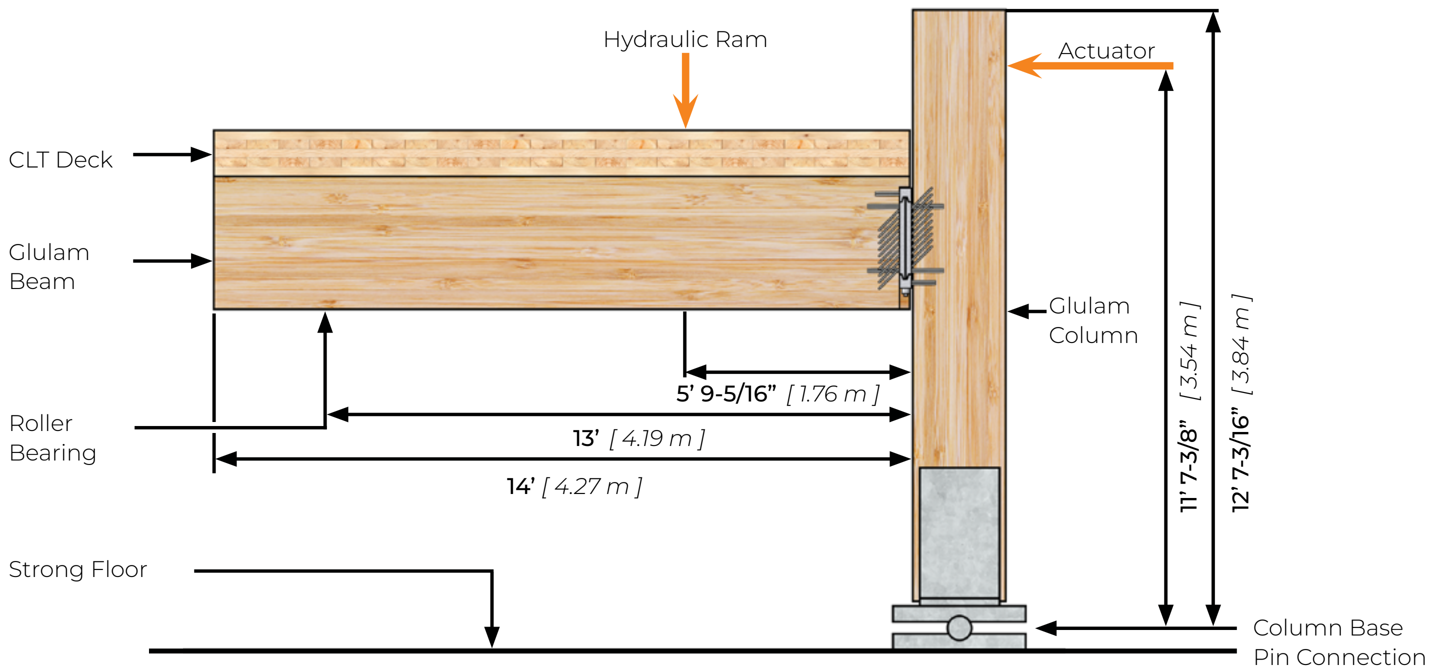


Figure 1. Schematic of Test Setup

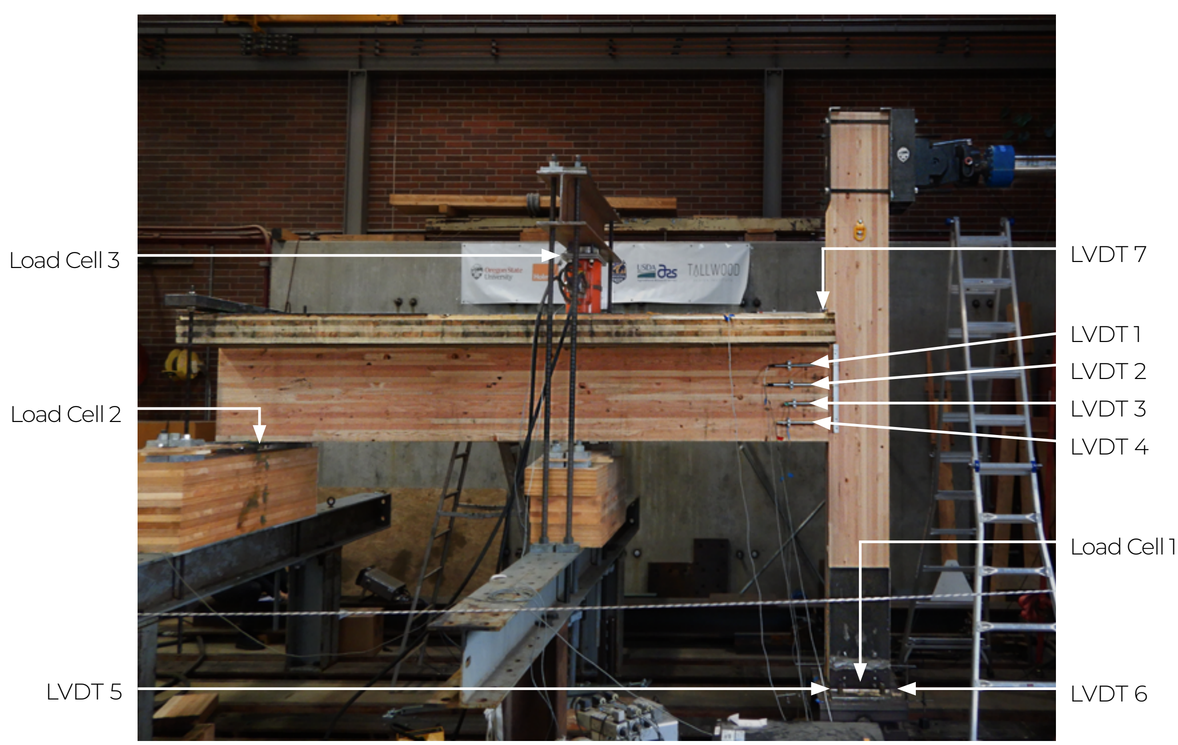
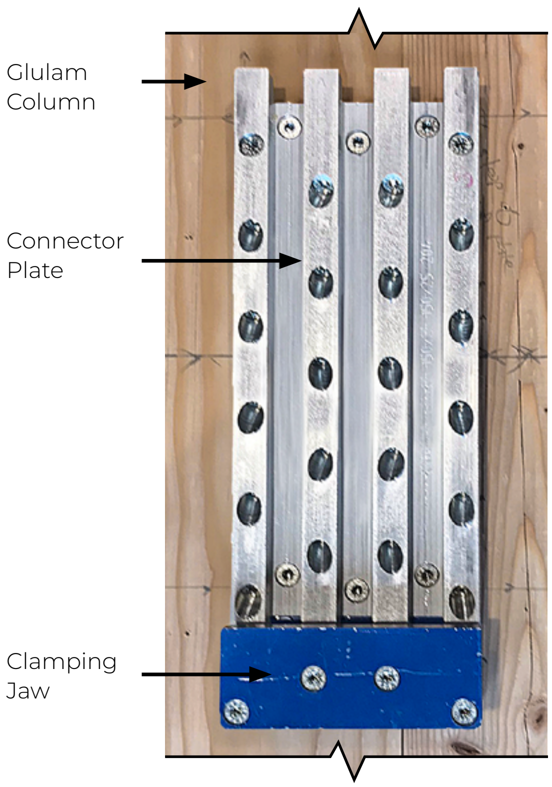


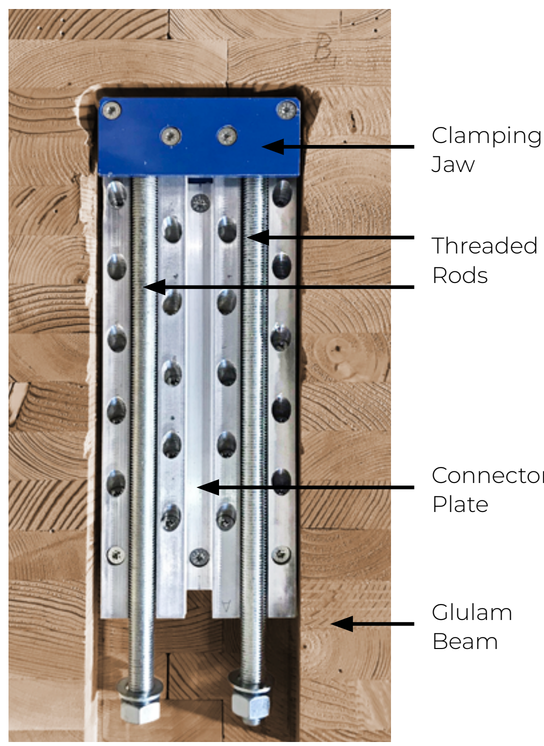
Figure 2. Specimen Sensor Layout

Connector Details

The MEGANT E 450×150×50 with an allowable load of 22.67kip [*100.8kN]*, is a modified version of the MEGANT 430×150×50 with 3/8" *[10mm]* deeper clamping jaws. This connector, shown in Figure 3, includes two aluminum connection plates identical to the MEGANT 430×150×50: one connected to the primary member and one connected to the secondary member. The top clamping jaw is connected to the bottom clamping jaw via two threaded rods with washers and nuts along the bottom of the connector.



(a) Primary Member



(b) Secondary Member

Figure 3. MEGANT E Connection Details

Housing Details

MEGANT E connectors can be concealed for architectural and Fire Resistance Rating (FRR) purposes by routing into either the main or the side member. For this study, the housing was routed into the beam end (also known as secondary member) to conceal the connector. Figure 4 demonstrates the detail of the connector assembly housed in the beam end. For housing details, the designer should refer to the **Beam Hanger Design Guide**.

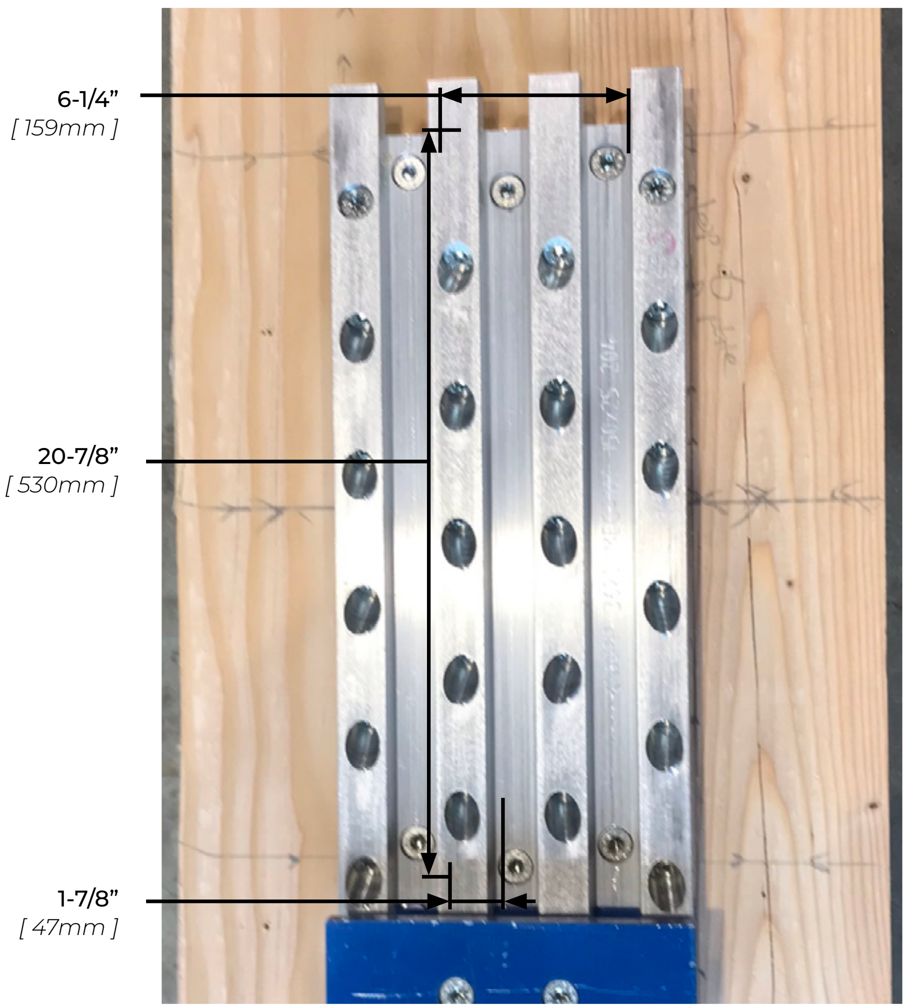


Figure 4. Beam End Housing Details

Connection Detail

Each aluminum connector plate was fastened to glulam using 28 pieces of 5/16" x 6-1/4" *[8mm x 160mm]* ASSY VG CSK fully threaded screws. The reinforcing clamping jaws were fastened to the glulam with four additional screws of the same type and dimension. The beam connector plate is set into the end of the beam in a housing with a depth of 1-7/8" *[47mm]*, a width of 6-1/4" *[160mm]*, and a height of 20-7/8" *[530mm]*. The gap between the CLT floor and the column was 1/8" *[3mm]*, as well as between the beam end and the column face. The connection detail is presented in Figure 5, and more details on the MEGANT E connector can be found on **MTC's website** [3]*.

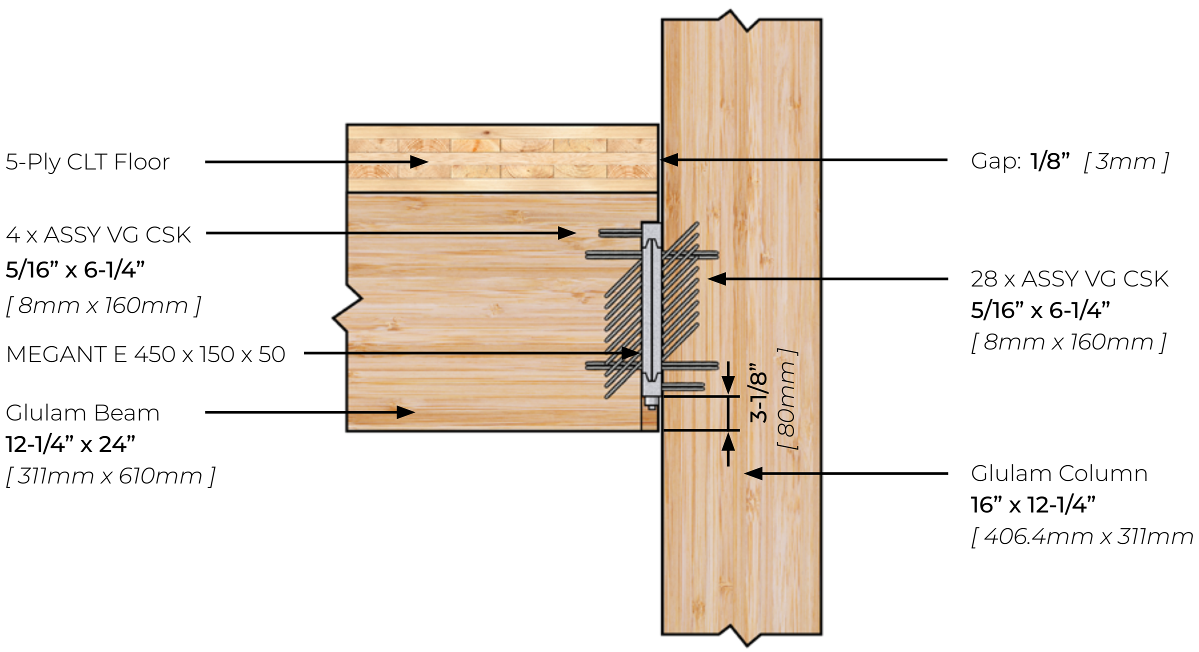


Figure. 5. Specimen Configuration and Connection Assembly Details

*All references on page 23

LOADING PROTOCOL

Monotonic Loading

In the monotonic test, labeled as MEG-M, the lateral displacement was imposed with a hydraulic actuator connected to a strong wall via a displacement-controlled loading protocol with a loading rate of 0.02in./sec. *[0.51mm/sec.].* The maximum imposed displacement at the top of the column was 10-7/8" *[275.6mm],* which was the maximum stroke of the actuator and corresponded to a story drift of 7.2%.

Cyclic Loading

The two reversed cyclic tests, labeled as MEG-CyI, were performed based on the Consortium of Universities for Research in Earthquake Engineering (CUREE) ordinary ground motions protocol with a constant loading rate of 0.01in/sec. *[0.254mm/sec.]* [4]*. Figure 6 displays the typical trailing and primary cycles of the CUREE procedure. MEG-Cyc1 was subjected to 5-5/16" *[135mm]*, corresponding to a 3.8% drift, while the second test specimen MEG-Cyc2 was subjected to a maximum deformation of 5-1/2" *[140mm]*, corresponding to a drift of 4%. All specimens were loaded with a gravity shear load of 22.67kips *[100.8kN]* at the interface between the beam and the column face. A summary of the input parameters is presented in Table 2.

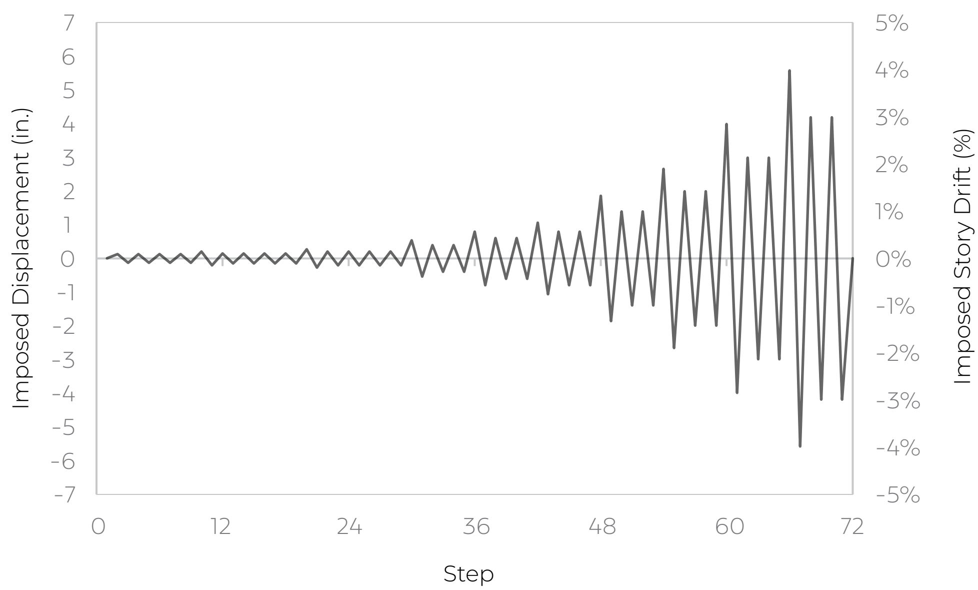


Figure 6. CUREE Cyclic Loading Protocol

Table 2. Summary of Input Parameters

Test	Maximum Lateral Displacement	Maximum Drift	Applied Gravity Load on the Connector	Connection Allowable Load
	in. *[mm]*	%	kip *[kN]*	kip *[kN]*
MEG-M	**10-7/8"** *[275.6]*	**7.2**	**22.67** *[100.8]*	**22.67** *[100.8]*
MEG-Cyc1	**5-5/16"** *[135]*	**3.8**		
MEG-Cyc2	**5-1/2"** *[140]*	**4**		

*All references on page 23

RESULTS

Monotonic Test Observations

Specimen MEG-M required an actuator stroke adjustment at 4-7/16” *[113mm]* displacement, which corresponded to a 3.2% drift. The adjustment required unloading and reloading to the specified load. Currently, American design requirements are satisfied in codes and standards at a 1.5% drift assumption for mass timber buildings [5]*. As shown in Figure 7, the MEGANT E in specimen MEG-M demonstrated the ability to sustain load-carrying capacity throughout the duration of the test, with measured drifts exceeding 7%.

For the purpose of determining residual displacement, a basic measure to asses post-disaster damage on buildings, the actuator was pulled back into the zero displacement position. The measured residual displacement of 5/16” *[8mm]* reemphasizes the resiliency of the MEGANT E connectors in alignment with the assumptions of minimal plastic deformation.

All references on page 23

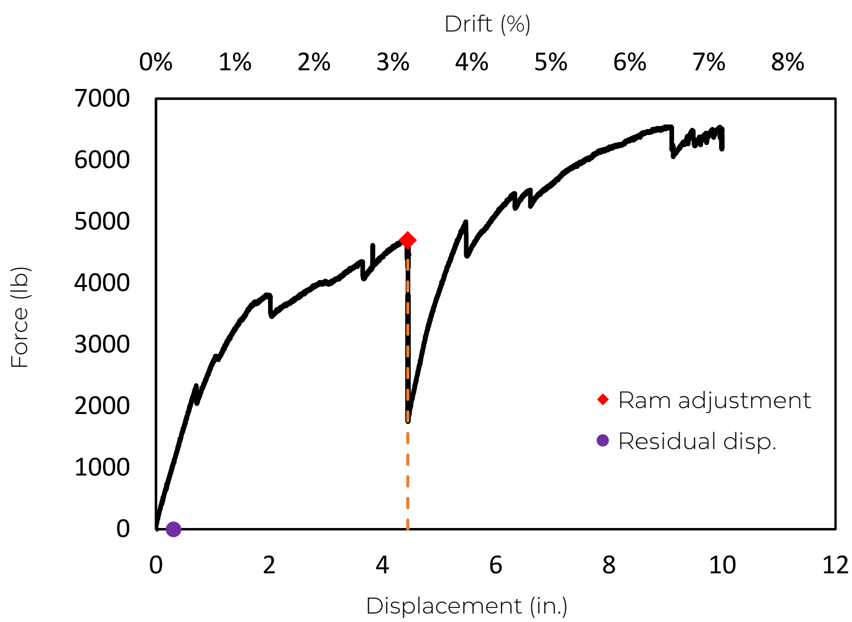


Figure 7. Actuator Force Versus Actuator Displacement for Monotonic (MEG-M) Test

After testing, specimen MEG-M was disassembled and components were visually evaluated. Figure 8 shows typical observed performance and connector deformations after specimen disassembly. A permanent deformation of 9/16” *[14mm]* due to bending was measured at the connector plate bottom, which was mounted to the column. Early signs of withdrawal resistance failure of fasteners near the deformation extremity of the connection were noticed, and screw tensile failure occurred, as indicated in Figure 9. The beam member was assembled with a full-sized CLT panel attached via screws to simulate a typical floor panel-to-beam assembly. Given that the CLT panel was fastened to the beam below, resistance against lateral deformation was present, and the CLT produced clear indentations due to compression into the column member. Figure 10 highlights this clearly, indicating that the pivot point of the connection is influenced by the prying of the CLT panel against the column members. From this observation, the conclusion can be drawn that columns in buildings under lateral loading events may experience column bending moments which need to be addressed during design.

(a) Close Up of Specimen MEG-M at Approximately 7% Drift

(b) Typical Connector Plate Bending Failure Under Monotonic Test

Figure 8. Components During and After Testing

Figure 9. Typical Locations of Screw Withdrawal and Screw Tensile Failure

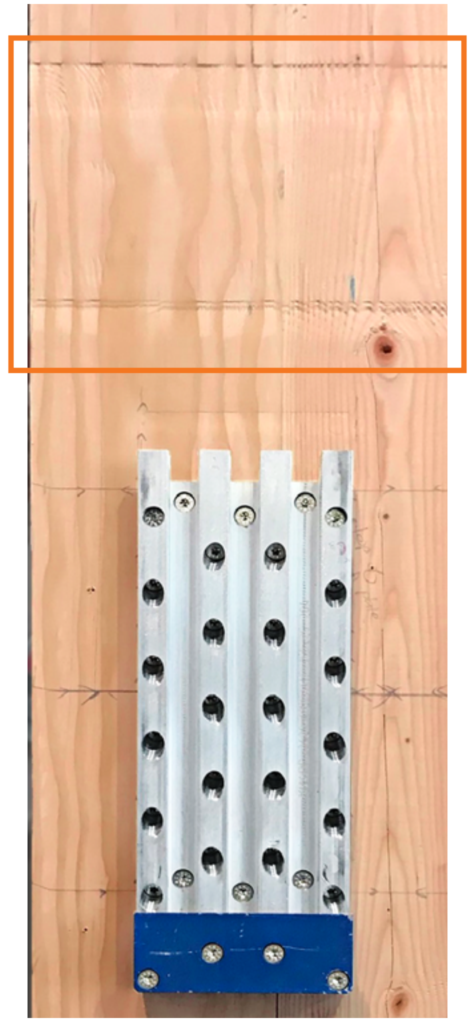


Figure 10. Column Crushing at Location of CLT Bearing

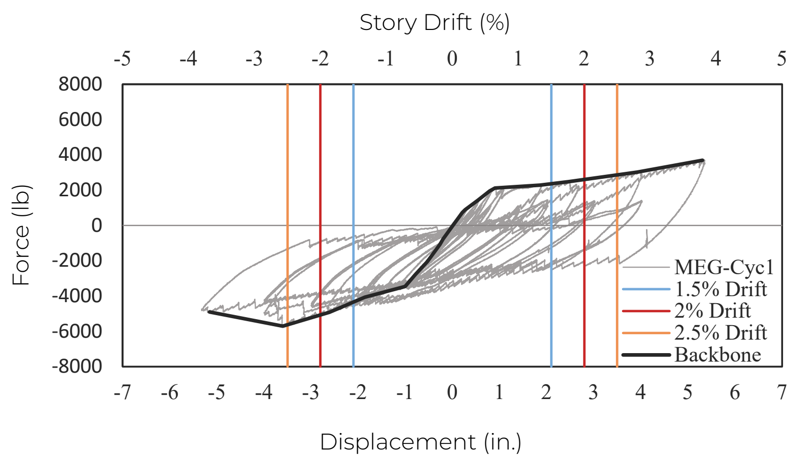
Cyclic Test Observations

Initial stiffness (K_i) and yield force (F_y) were obtained for the pushing (K_{i+} and F_{y+}) and pulling (K_{i-} and F_{y-}) envelope curves for all test specimens, as presented in Table 3. Data recorded from the MEG-Cyc specimen series was sufficient for deriving hysteresis loops, and subsequently backbone envelope curves. The derived curves are shown in Figure 11, from which the conclusion can be drawn that the MEGANT E connector is able to sustain its load-carrying ability with minimal stiffness degradation through the course of the destructive testing. A ductile response without significant damage, yielding, or complete connection failure can be assumed.

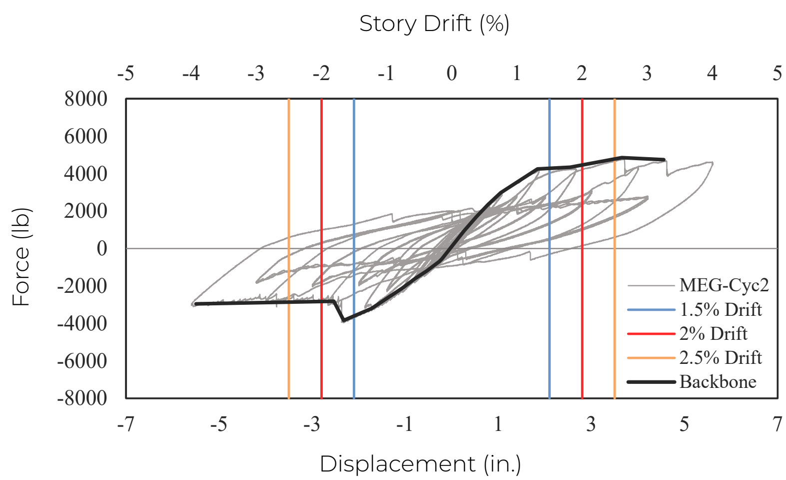
Table 3. Initial Stiffness and Yield Properties

Test	Pushing (+)					Pulling (-)				
	d_y	F_{y+}	F_{y+_avg}	K_{i+}	K_{i+_avg}	d_y	F_{y-}	F_{y-_avg}	K_{i-}	K_{i-_avg}
	in. [mm]	lb [kN]	lb [kN]	lb/in. [N/mm]	lb/in. [N/mm]	in. [mm]	lb [kN]	lb [kN]	lb/in. [N/mm]	lb/in. [N/mm]
MEG-Cyc1	0.8 [20.3]	2078 [9.2]	3051 [13.6]	2573 [451]	2773 [486]	1.12 [28.4]	-4185 [-18.6]	-3931 [-17.5]	3725 [652]	2860 [501]
MEG-Cyc2	1.35 [34.3]	4023 [17.9]		2973 [521]		1.84 [46.7]	-3677 [-16.4]		1995 [349]	

1. The yield displacement (d_y) represents the displacement corresponding to the yield force (F_y)
2. The initial stiffness (K_i) affects the structure's period and the load it attracts during strong ground shaking
3. Initial stiffness (K_i) was calculated as the ratio of the yield force (F_y) over yield displacement (d_y)



(a) MEG-Cyc1

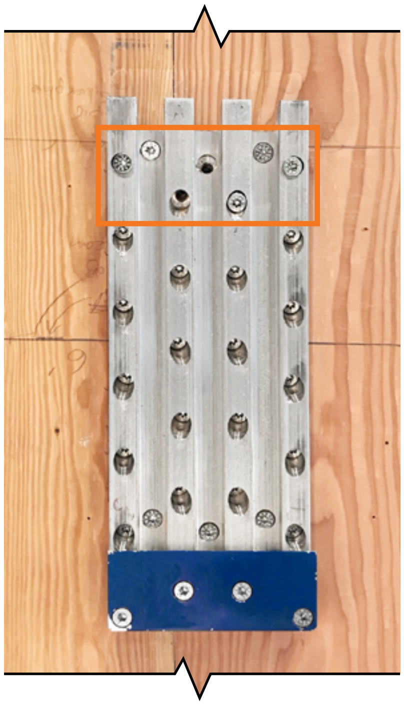


(b) MEG-Cyc2

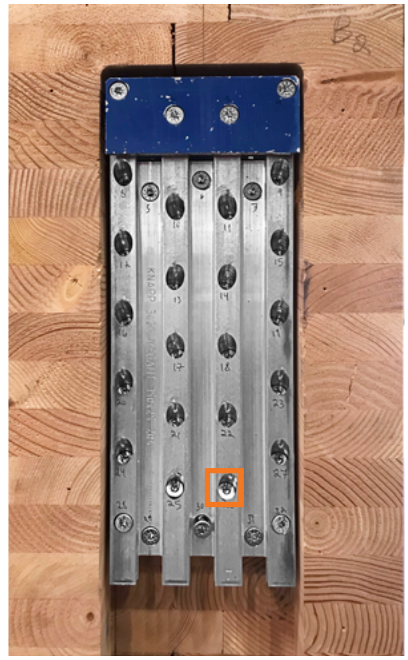
Figure 11. Derived Hysteresis Loops and Backbone Envelope Curves

After testing, specimens MEG-Cyc were disassembled and components were visually evaluated. Similar to the MEG-M specimen, permanent deformation due to bending at the connector plates' extremity is evident. Due to the cyclic nature of this testing series and the associated pivot point shifting as a result of the CLT panel prying against the column of the connection in a cycle, an asymmetrical deformation occurs. It appears that certain portions of the connection are subjected to higher stresses. This conclusion is supported by the observation of increased screw withdrawal and tensile failure spreading over a larger area of the connector plate, as seen in Figure 12, Figure 13, and Figure 14.

Figure 12. Typical Connector Plate Bending Failure Under Cyclic Test

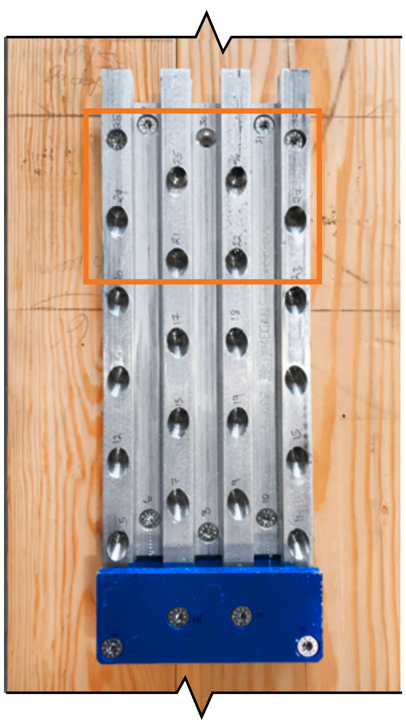


(a) Primary Member

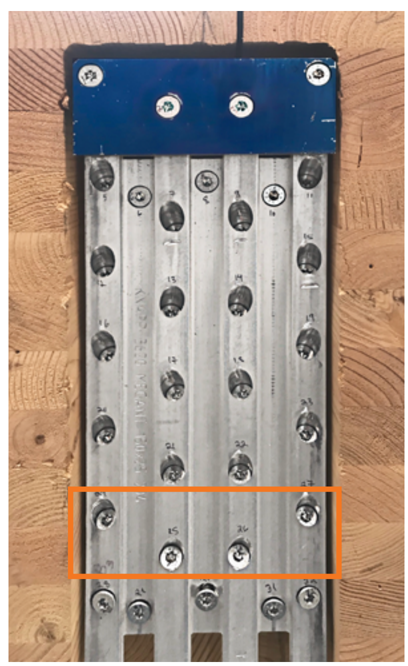


(b) Secondary Member

Figure 13. Typical Screw Fracture Area
Specimen MEG-Cyc1



(a) Primary Member



(b) Secondary Member

Figure 14 Typical Screw Fracture Area
Specimen MEG-Cyc2

CONCLUSION

A total of three sets of full-scale specimens were experimentally tested, one subjected to monotonic and two subjected to cyclic lateral displacement under the CUREE loading protocol. The obtained results indicate the ability of the MEGANT E connector to sustain its full intended load-carrying ability to drift levels of up to 4% under cyclic loading and 7% under monotonic loading. Small residual deformations after specimen disassembly suggest a generally ductile connection performance; withdrawal and tension failure of load-transmitting screws during testing did not sacrifice the structural integrity of the connector system. Note that additional information such as damping parameters can be obtained from this test data set, but this is outside the scope of this white paper.

Shifting connection pivot points due to prying of the CLT floor panel against the column and associated induced bending moment onto the column was noted to be a consideration for future testing projects.

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