IMPACTS OF BEAM HANGER ROTATIONAL STIFFNESS ON COLUMN RESISTANCE OF POST-AND-BEAM FRAMES

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ABSTRACT: Mass timber frames with deep beams are being increasingly adopted. At beam-to-column joints, pre-engineered beam hangers provide shear capacity and allow for fast installation. In current design practice, a pinned condition is typically assumed for such shear connections, permitting columns to be designed as axially-loaded members. However, when frames undergo lateral drift, beam hangers may exhibit rotational stiffness due to various interlocking mechanisms, inducing bending moments to columns. When subjected to combined moments and axial forces, columns may provide a lower resistance than designed for. In this project, beam-hanger-induced moments and their impacts on column design are investigated through full-scale experimental tests and finite element analysis of a single storey, two-bay frame. The tests showed that despite undergoing multiple reversed cycles with a 3.0% drift, no structural instability or connection failure was observed. The numerical findings indicate that beam hangers introduce significant bending moments in interior columns, exceeding 100% of their bending moment capacity, suggesting that such connections should be considered semi-rigid rather than pinned. The study highlights the need for revised design assumptions to account for these moments and prevent underestimating column demands.

KEYWORDS: Rotational stiffness, Finite element modelling, Experimental tests, Parametric analyses

1 – INTRODUCTION

1.1 MASS TIMBER CONSTRUCTION

Mass timber buildings are increasingly constructed using post-and-beam configuration. To allow for large open spaces, deep glulam beams are adopted to meet serviceability requirements. For beam-to-column joints, pre-engineered beam hangers are widely used and typically assumed to provide a shear connection, allowing columns to be designed for axial forces only [1]. However, as the gravity load-bearing frames sway with the lateral-force-resisting system under lateral loads, moments can develop at beam-to-column connections given the configuration of beam hangers. As a result, columns can be subjected to combined moments and axial loads, a load case for which they are not designed for.

To address this research need, this project aimed to provide a better understanding of the impacts of beam-hanger-induced moments on the resistance of columns and the lateral stiffness of post-and-beam frames. To achieve these objectives, finite element analyses and full-scale experimental tests on a one-storey two-bay glulam frame were conducted.

1.2 BEAM HANGER CONNECTIONS

Advancements in materials and connector technology have shaped beam hanger design. Early methods of connecting beams to columns relied on traditional carpentry, which were replaced by steel connectors. The the rise of engineered wood products promoted further evolution in beam hangers to meet modern building codes. Today, pre-engineered beam hangers are widely used in tall timber structures, typically featuring pre-installed plates on beams and columns connected with self-tapping screws (STS) [2]. These hangers are often concealed for fire resistance and must comply with design codes such as the Canadian Standard for Engineering Design in Wood CSA O86 [3].

The MEGANT beam system is a pre-engineered, aluminium alloy post-to-beam connector, consisting of two identical plates, clamping jaws, and up to three threaded rids with washers and nuts for tightening, as shown in Fig. 1 [4]. The plates and clamps attach to primary and secondary members using a combination of 45° and 90° fully threaded screws. On-site assembly involves sliding the components together and tightening the nuts, which provide tension to counteract uplift forces. Fully concealable, MEGANT hangers achieve a 60-minute fire resistance rating [4]. The MEGANT E (450×150×50) is the largest in the series, offering a factored shear capacity of 166 kN under standard loading. It was specifically tested for seismic applications, demonstrating high yield displacement, ductility, and sustained inter-storey drift levels [5].

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https://doi.org/10.52202/080513-0484

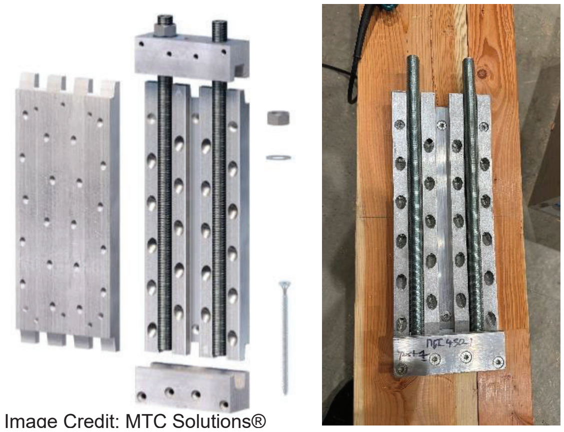

Figure 1. MEGANT connector [6]

Madland et al. [5, 7] tested the MEGANT E beam hanger alongside four other beam-to-column connections to assess deformation compatibility of custom and pre-engineered glulam connection. The setup included a 3.7 m Douglas-fir larch 24F-V4 glulam column and a 4.3 m glulam beam. A 1.2 m wide five-ply spruce-pine-fir (SPF) cross-laminated timber (CLT) deck was attached to the top of the beam to simulate the floor. The column was pinned at the base, allowing free rotation, while the beam was supported with a roller-type condition, restricting vertical movement but permitting horizontal displacement. A force-controlled hydraulic ram applied a constant gravity load to the beam, and a hydraulic actuator provided lateral loading using a displacement-controlled loading protocol at 0.51 mm/s. The test reached 7.2% drift without connection failure. Based on its moment-rotation behaviour, the MEGANT E connection was classified as flexible, as it resisted less than 20% of the moment of a fully fixed connection.

2 – EXPERIMENTAL INVESTIGATION

2.1 MATERIALS

A one-storey post-and-beam Glulam frame, consisting of two bays, was tested at the Wood Innovation and Research Laboratory at the University of Northern British Columbia. A total of eight pre-engineered beam hangers, type MEGANT 430×150, were used to connect the frame.

The glulam frame measured 6.04 m by 1.08 m in plan and had a height of 3.0 m, as shown in Fig. 2. The beams were Douglas Fir 24F-EX with dimensions 265 mm × 646 mm, and the columns were Douglas Fir 16C-E, measuring 265 mm × 380 mm.

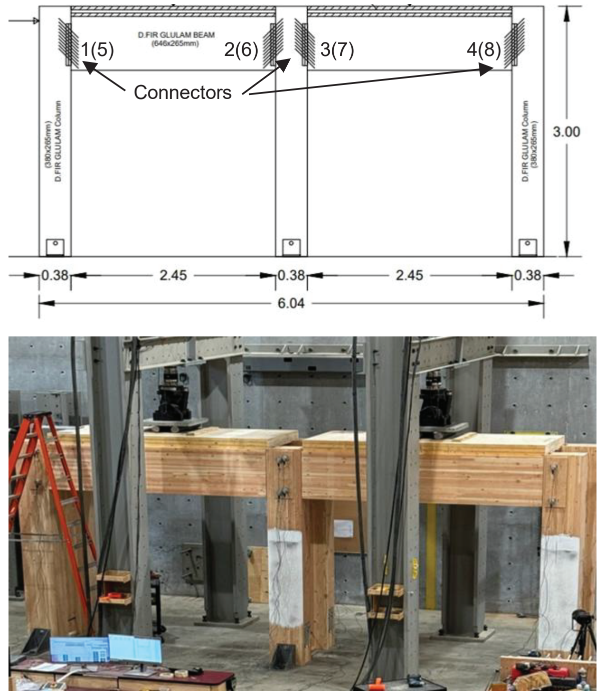

Figure 2. Glulam frame

The moisture content of columns and beams was measured using an electric resistance meter, with an average value of 11%. Each bay consisted of two 5-ply CLT panels as a deck, 139 mm thick and 2450 mm × 1000 mm, with a strength grade of V2. The CLT panels were connected to the beams using six Ø8 mm × 300 mm partially threaded STS on each side and connected to each other using tension straps. There was no overlap between the CLT panels and columns.

2.2 METHODS

Gravity loads of 480 kN and 96 kN were applied to the left and right bays respectively. The gravity load was controlled throughout testing and maintained constant while the frame was displaced laterally. The lateral displacement was applied using a 350 KN hydraulic actuator. Target lateral drifts were set to 0.6%, 1.2%, 1.8%, 2.4%, and 3.0%.

The lateral displacement was recorded by the calibrated actuator. To calculate the connection rotation, string potentiometers were located at top and bottom of beam to column connection to measure the horizontal displacements between the beam and the column. These measurements were then used to calculate the connection rotation, see Fig. 3.

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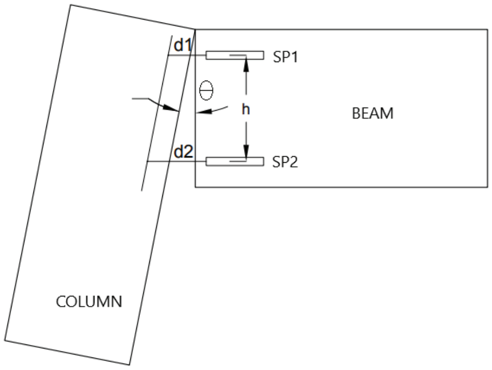

Figure 3. Connection rotation measurement

2.4 EXPERIMENTAL RESULTS

The horizontal force–displacement and the resisted forces at each drift are presented in Figs 4 and 5, respectively. The behaviour up to 1.2% drift was within the elastic limits. Positive (push) and negative (pull) loadings were similar; however, the resisted load at negative cycles was consistently smaller. Starting at 1.8% drifts, residual resistance when the frames were pushed through the neutral position increased, indicating the connectors were deformed beyond their elastic limit. This postulation is supported by strength degradation between the three cycles within 1.8%, 2.4% and 3.0% drifts. A further indication was the increase of resistance in the negative cycles compared to the positive cycles.

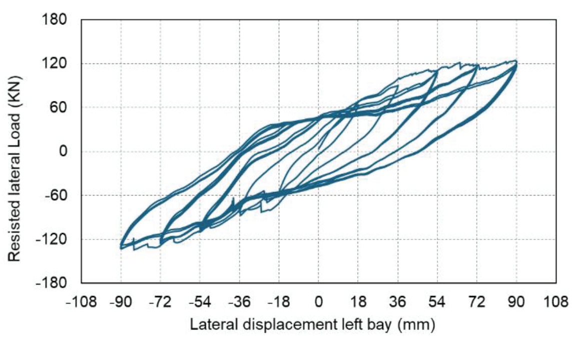

Figure 4. Load-displacement curve

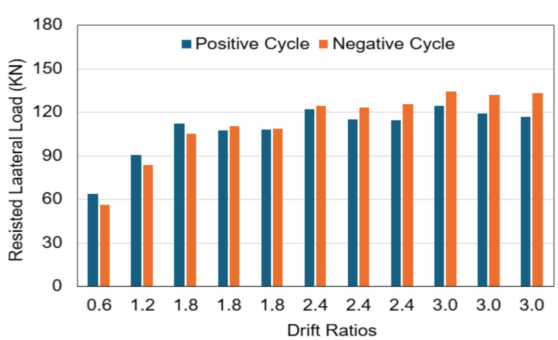

Figure 5. Resisted lateral load

The rotations of eight connections at the target drifts are presented in Fig. 6, with the connection numbers shown. A linear increase of connection rotation with frame drift can be seen in the figures. However, larger rotations of the connectors of the outside columns (#1, #4, #5, and #8) than those of the inside columns (#2, #3, #6, and #7) were observed during the drifts beyond 1.2%. This phenomenon was caused by the insufficient translational restraint of the centre columns.

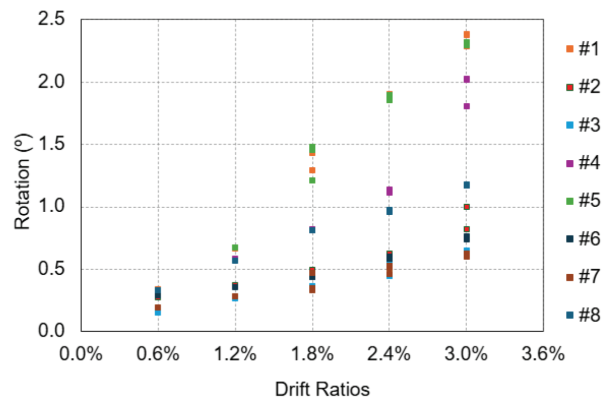

Figure 6. Connection rotation at pushing cycles

The typical damages to the MEGANT connectors on columns and beams are shown in Figs. 7 and 8, respectively. The connector plate yielded causing up to five of the screws per connector to break.

Figure 7. Typical damage to column connectors

Figure 8. Typical damage to beam connectors

3 – NUMERICAL INVESTIGATION

3.1 MODEL DEVELOPMENT

A 3D finite element (FE) model of the MEGANT E connection was created in RFEM, a structural analysis software suited for timber modelling [8]. The frame tested by Madland et al. [7] was used as a reference. Fig. 9 illustrates the geometric configuration, which replicates the experimental setup with glulam members and beam hanger elements modelled as 3D solid elements. Member dimensions, material properties, and boundary conditions were defined to match the test conditions. A dead load of 161 kN was applied to the CLT panel, while the column was subjected to an incrementally increasing load.

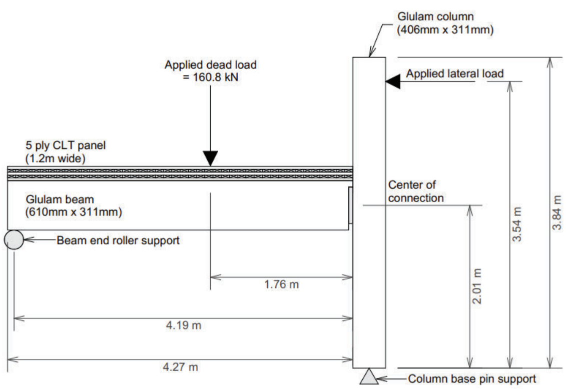

Figure 9. Modelled test specimen (adapted from [5])

The FE model of the MEGANT beam hanger accurately represented its geometry, as shown in Fig. 10. Surface releases were applied to contact areas, allowing free movement in shear and detachment under tension while preventing element penetration. Instead of modelling individual screws, releases were assigned to the plate-to-member contact surfaces, with properties selected to reflect the two primary failure modes: screw withdrawal and tensile fracture. Screw shear failure was omitted based on experimental findings [7]. Unfactored screw withdrawal resistance was determined using CSA O86 [3] for screws installed at 90°, 45°, and 0° to the grain, alongside their unfactored tensile resistance. Surface release values were calculated by distributing the total screw strength over the contact area.

3.2 Model Validation

The force-displacement relationship from the FE model and the experimental results of Madland et al. [7] are shown in Fig. 11. The discrepancy between the numerical and experimental curves, representing dissipated energy, is 1.4% up to a 3% drift. This represents the model's high accuracy and suitability for further numerical analysis.

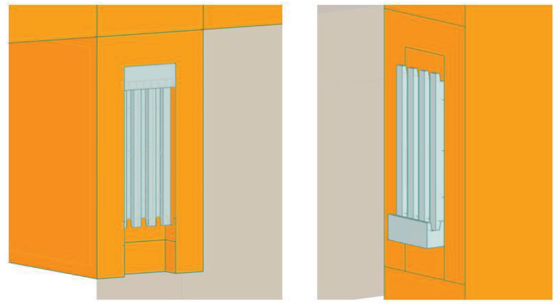

Figure 10. MEGANT E connector modelled in RFEM

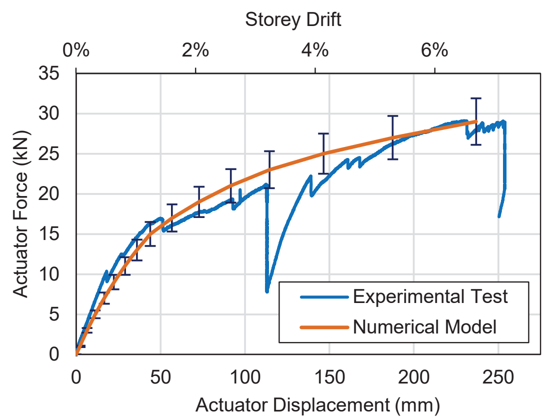

Figure 11. Numerical model validation

3.3 NUMERICAL RESULTS

This connection model of the MEGANT E beam hanger was implemented in a single storey, two-bay frame model to replicate the experimental frame tested in this study. The numerical frame followed the same configuration as the experimental setup, shown in Fig. 2. A gravity load of 240 kN was applied to each bay, while a monotonic lateral load was applied until a 3% storey drift was reached. Fig. 12. shows the bending moment utilization in each column at four drift levels (0% to 3%). Column C1 is located farthest from the applied lateral load, C2 is the interior column, and C3 is the column directly subjected to the lateral load. The interior column (C2) has zero bending moment under dead load only and exceeds 100% bending utilization by 2% storey drift.

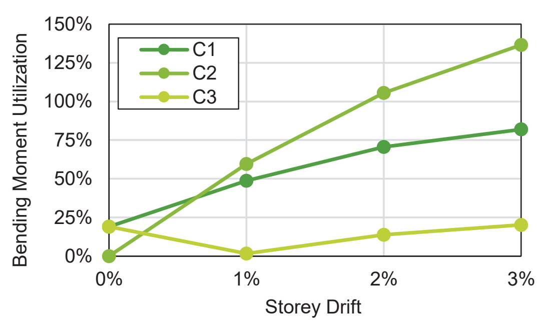

Figure 12. Bending moment utilization in columns

https://doi.org/10.52202/080513-0484

The interior column develops the largest bending moment compared to the exterior columns because both sides of the column are rotationally restrained by a beam and beam hanger. The bending moments that arise in the columns under lateral loading as a result of the beam hanger connections are significant and contribute to additional compressive stresses in columns.

The design check for combined bending and axial load for the interior column, calculated using the interaction equation given in Clause 7.5.12 of CSA O86 [3], is shown in Fig. 13. Under gravity load only, there is no bending demand, so the compressive utilization is given. The interior column was designed for 30% compressive utilization, however it fails the combined loading design check by 2% storey drift. This highlights the importance of considering both axial compression and bending moment to avoid under designed columns.

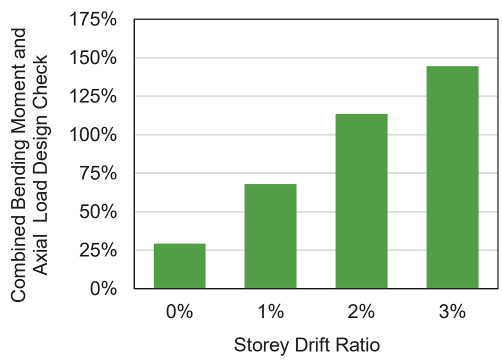

Figure 13. Combined bending moment and axial load design check for interior column (C2)

To examine the behaviour of the beam hanger connection relative to a fixed connection, the numerical beam hanger frame was compared against a moment resisting frame (MRF) with simplified line element members and fully rigid connections. The ratio of bending moments that develop in the beam hanger frame columns to those that develop in the MRF is shown in Fig. 14.

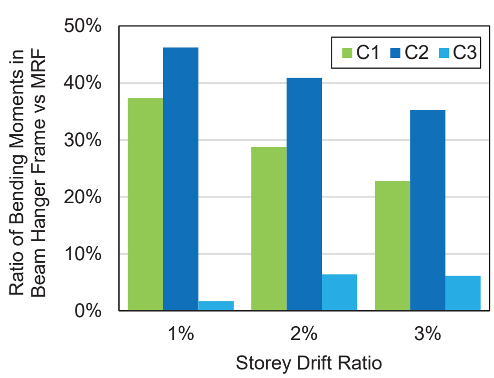

Figure 14. Ratio of bending moments in beam hanger frame to MRF

In the interior column, the bending moment ratio is 46% at 1% storey drift (i.e., the bending moment that develops in a column with beam hanger connections on either side is 46% of the bending moment in a column with fixed connections on either side). These are significant levels of bending moment considering this type of connection is assumed to be pinned in current design practice. The bending moment ratio decreases as the drift level increases because as the beam hanger connection yields, it becomes more flexible and relatively less bending moment is transferred through the joint.

Examining column C3, the bending moment due to the beam hanger is less than 10% of that of a fixed connection. This aligns with the results from a previous study, which classified the MEGANT E connection as flexible [5], as the study examined a partial frame with a connection on one side of a column and a lateral ‘push’ force applied to the opposite side. However, when examining the beam hanger in a more typical application (i.e., connected to either side of an interior column) the bending moment exceeded 20% of the moment of a fixed connection. This suggests that MEGANT E beam hangers should not be considered pinned connections, but rather semi-rigid.

5 – CONCLUSION

The influence of beam-hanger-induced moments on the behaviour of glulam columns was investigated. Experimental testing and numerical analysis were conducted on a single storey, two-bay post and beam frame, connected with a commercially available beam hanger. The results can be summarized as follows:

1. Despite undergoing multiple reversed cycles with a 3.0% drift, which exceeds the design drift limit of 2.5%, no significant structural instability or connection failure was observed.

2. The frames’ behaviour up to 1.2% drift was within the elastic limits. Beyond 1.2%, there was an increasing residual resistance when the frames were pushed through the neutral position, and strength degradation was observed between cycles within the same drifts.

3. Typical damage to connectors was characterized by plate yielding followed by screw failure.

4. The interior column exceeded 100% bending moment utilization by 2% storey drift.

5. The MEGANT beam hanger connection should be considered semi-rigid as it contributes to the development of bending moments that exceed 20% of that of a fixed connection.

This study was limited to a single storey, two-bay frame, which may not fully capture the behaviour of multi-storey configurations. Future research should consider various frame parameters including beam sizes, bay spans, and connection styles.

ACKNOWLEDGEMENTS

The project was funded by the government of British Columbia through a Forest Innovation Investment (FII) grant (24/25-UNBC-SRB-W25-043) and by the Natural Sciences and Engineering Research Council of Canada (NSERC) through an Alliance grant (ALLRP 583429 – 23) in collaboration with MTC Solutions.

MTC Solutions and Kalesnikoff Lumber Co. Ltd. provided in-kind contributions in form of connectors and screws, and CLT supplied at reduced price. Aspect Structural Engineers and FPInnovations supported the funding application. The support in developing and conducting the tests provided by Dr. Tyler A Davis (MTC Solutions), UNBC lab lead Maik Gehloff, UNBC technicians Nathan Downie, James Andal and Ryan Stern is greatly appreciated.

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https://doi.org/10.52202/080513-0484