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AltCONNECT® - An Innovative Structural Steel Connection Without Bolts or Welds

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ABSTRACT

A novel steel friction-only connection consisting of spigot and socket bodies was developed for modular construction in 2017 and presented at ASEC 2018. The connection transfers loads from platform beams to columns and has a unique feature of resisting tension by the presence of a bending moment. In the previous work, numerical models were developed to predict the tension-bending interaction capacity of the connection and subsequently validated as a stainless steel prototype tested in a controlled lab at Curtin University in Western Australia. In present work, a 1:6 prototype structure was modelled using Solidworks Simulation and results suggested the structure should remain structurally sound under lateral and gravity loads with minimal uplift at those joints in tension. A mild steel structure was fabricated that incorporated twelve altCONNECT® joints at beam-column junctions. This structure was load-tested to confirm the computer model results.

altCONNECT® components are ideal for manufacture using 3D printers as additive manufacturing continues to provide lower cost and larger sizes able to be produced. Neither stick-built nor modular, steel structures using primarily friction-resisting connections provide significant time savings in construction, increase safety by reducing work at height and reduce the overall cost compared with conventionally built steel structures. Ideally suited to mining structures, altCONNECT® is set to transform the construction industry.

KEYWORD(S): Friction connection, 3D Printing, Modular construction, altCONNECT®

INTRODUCTION

AltCONNECT® is a type of friction-only beam to column connection system recently developed for steel structures with the aim of reducing cost and erection time while improving safety. It has an application in moment-resisting frame structures wherein the critical loads acting on the connection are compression or tension in conjunction with bending moment.

Each friction-only connection consists of two types of components - the spigot, as shown on the right in Figure 1 and the socket, as shown on the left.

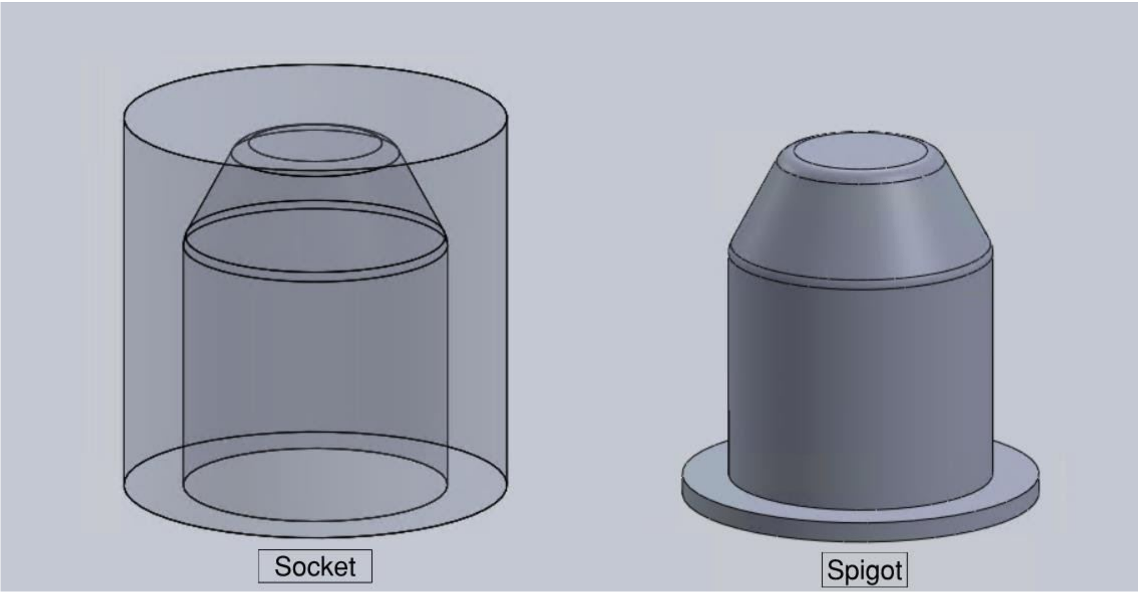

Figure 1. altCONNECT® components

These connections when in a moment-resisting structural system develop a friction bond between mating faces. The utilisation of the bending moment in the connection increases the limiting friction force between the components, providing resistance to tension forces trying to separate the connection.

Numerical studies were performed in 2017 (Boulos 2017) and a laboratory test of a single connection was carried out in 2018 (Gao 2018). The results of these studies were presented at ASEC 2018 in Adelaide.

(Gao 2018) outlines the two failure types observed in the results of his prototype test, the first of which was failure of the friction connection due to a tension force larger than the friction resistance. The other failure condition occurs when the bending moment produces yielding of a connection component.

(Gao 2018) test results show a promising friction connection between two polished surfaces, initial loading induced slip before binding occurs. It is found that the experimental results closely mimic the modelled interaction curve as seen in figure 2 below, however the initial loading gradient could not be measured in the test.

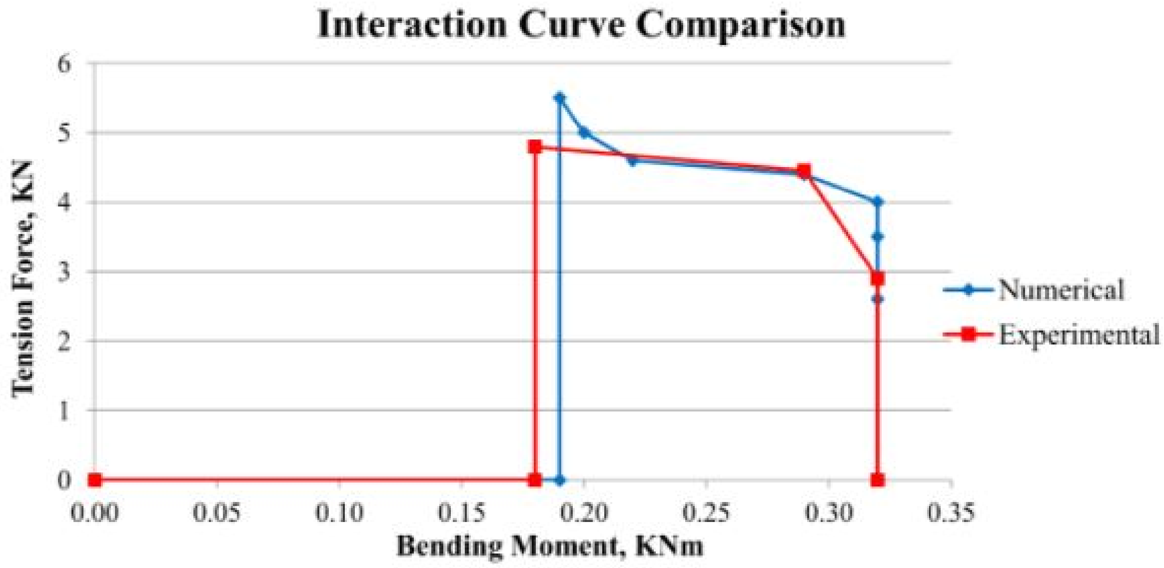

Figure 2 - Interaction Curve Comparison (Gao 2018)

The previous numerical study by (Boulos 2017) and prototype testing by (Gao 2018) show the viability of the connection for resisting tensile forces in combination with bending moment and developed interaction curves to define the connection capacity (Figure 3).

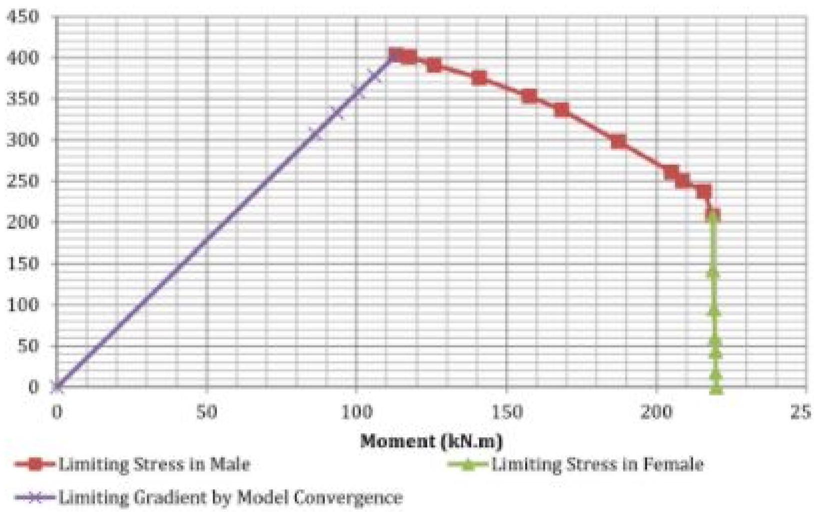

Figure 3. Interaction Curve Developed by (Boulos 2017)

As discovered in both previous studies, there are three limiting factors that define the interaction curve. These are yielding of the socket, yielding of the spigot, and failure of the friction connection observed as slippage or separation of the components.

Provided that the combination of bending moment and tensile force in the connection is under the interaction curve, the connection is capable of resisting the load combination.

Given that for conventional structures tension exists in columns due to a lateral force (e.g. from wind) and in a moment-resisting frame the column-beam joint carries a corresponding bending moment, there is an application for this type of connection in various steel structures and so further development and testing was extended to a whole structure to investigate strength and serviceability.

OPTIMISING THE CONNECTION

Since the test results validated the computer model, the connection geometry was further refined using the computer model.

The mating faces consist of two geometries, the truncated cone and the cylindrical body. The truncated cone allows for ease of alignment during assembly while the cylindrical portion provides greatest resistance to the applied forces (larger surface area and lower stresses). Analysis with Solidworks determined the best ratio between constructability and connection capacity (Figure 4). Once this geometry was achieved, the connection was scaled down to a 1:6 geometrically scaled model of the original.

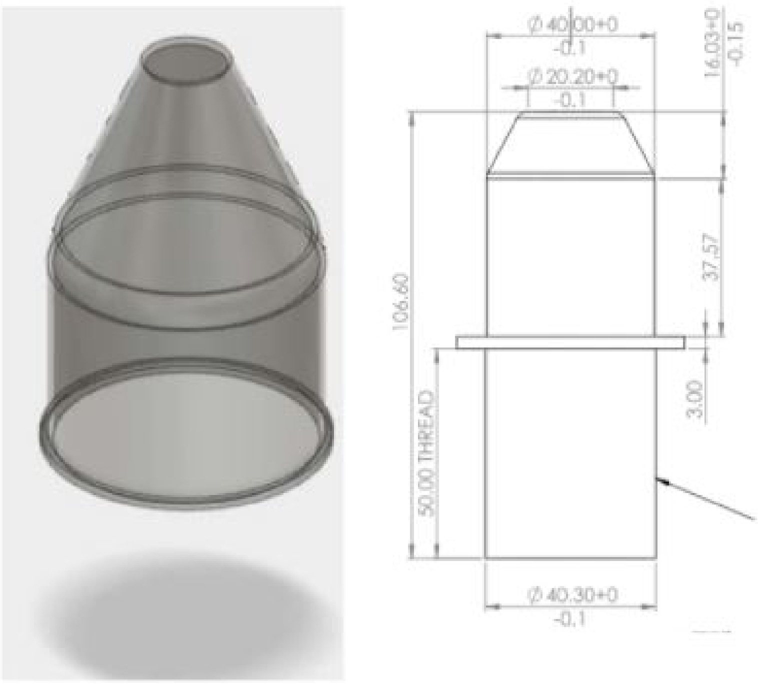

Figure 4 - Comparison of the original tested geometry and the revised geometry

The connections were designed in Solidworks using nonlinear analysis to model the friction contact between components where the mating surfaces were in compression (in contact). The connection was loaded with combinations of bending and axial tension to create an interaction curve (Figure 5) similar to that described above for comparison with test results.

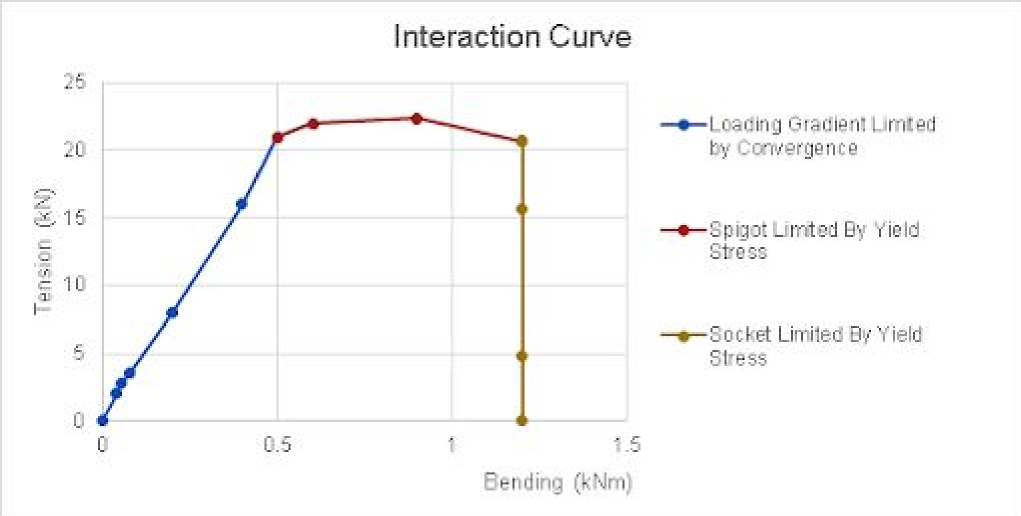

Figure 5 - Bending-Tension Interaction Curve 1:6 Scale Component

THE TEST STRUCTURE

(Gao 2018) test was of a single component, and this was compared with results from a computer model of a simplified conveyor transfer tower (Figure 6). This study now extends to the whole of the simplifi ed transfer tower, using the optimised altCONNECT® connection.

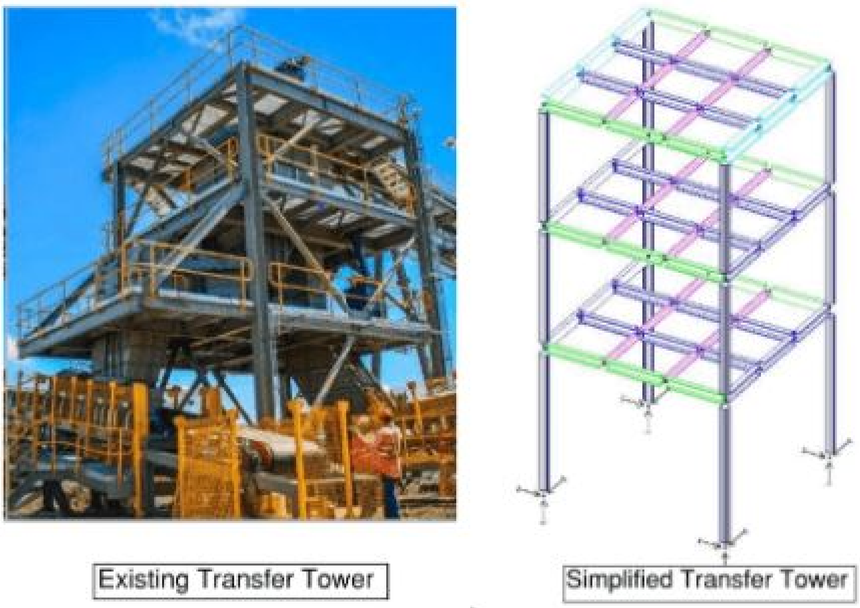

Figure 6 - Transfer Towers Used for Design of Scale Structure

The transfer tower (left) is a braced frame structure designed and constructed using conventional methods in 2015. To enable the use of altCONNECT® connections, it was first re-designed as a moment-resisting structure - braces were removed, columns and beams then designed for the combined bending and axial effects, and then the columns replaced with Circular Hollow Sections (CHS) to facilitate the use of altCONNECT® connections. The resulting structure was of similar mass and the deflections under serviceability loads within acceptable limits.

The model was then further simplified to create a conventional moment-resisting structure (right). Th is provided a computer model with typical design actions that an altCONNECT® connection would be required to resist whilst also lending itself to prototyping.

The test structure was based on this simplified structure, reduced in geometry to 1/6th of the full size. It was nominally 1040(W) x 1040(D) x 2275(H). Columns were 48.3 CHS and beams typically 50 mm channel sections. Loads were suitably factored in order to produce design actions that could be replicated in the laboratory.

The test structure was modelled with conventional connections in Microstran to determine the actions (tension and bending) that the connections would be expected to endure when a lateral load was applied to its top. These were plotted against the interaction curve in Figure 5 to ensure they fell below the cur ve. Figure 7 shows the computer model of the test structure and the subject design actions at the critical connections.

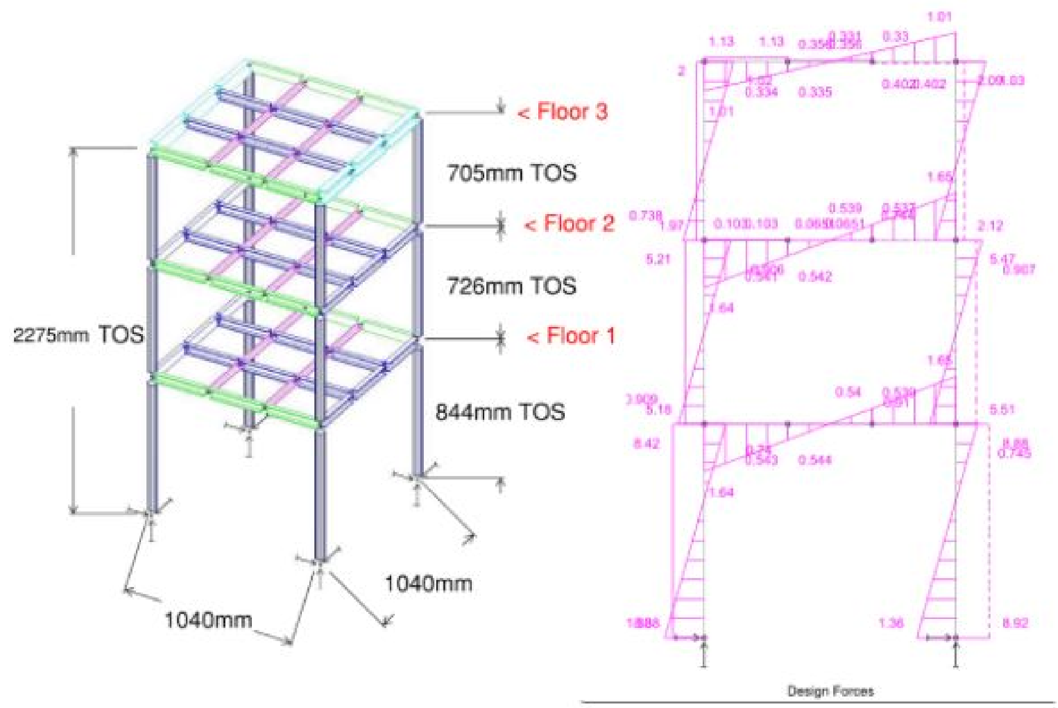

Figure 7 - Microstran Model of the Test Structure

The test structure was fabricated using mild steel sections and the altCONNECT® components were manufactured using CNC. There is potential to produce the spigot and socket using additive manufacturing (3D printing) to achieve a lighter, optimised design.

Figure 8 - altCONNECT® Connection

The connection was provided with minimum clearance between the spigot and the socket to ensure surfaces would mate with minimal movement. Beam stubs welded to the socket contained end plates to conventionally connect with floor beams. Tolerances in fabrication were accommodated at the end plates using shims. The spigots were threaded into the CHS columns.

Testing of the subject structure was conducted in March 2020 at Curtin University in Perth, Western Australia. Each platform was constructed complete with altCONNECT® connections and lifted onto the columns below. A hydraulic jack provided a lateral load to the structure at the top, central on the platform. Lateral displacement and slip were measured using linear variable displacement transducers *(LVDT)*.

Figure 9 - Test Structure in the Curtin Lab

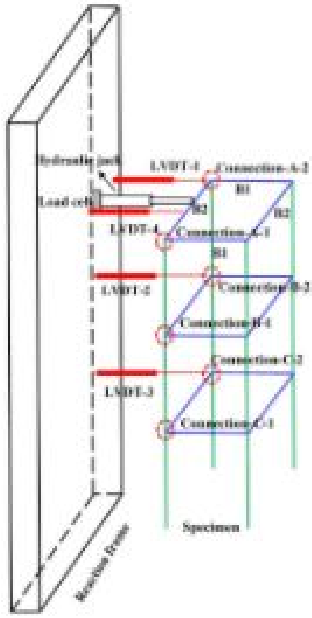

Figure 10 - Layout of LVDT and Load Cells

TEST 1 – 10.2 KN LATERAL LOAD

The first test was a 10.2 kN lateral load applied at the top floor of the structure. This test was used to validate altCONNECT® in a whole structure, ensuring the structure would not yield. The model predicted a maximum lateral load of 12 kN to remain elastic.

Test 1 showed the structure including components resisted 10.2kN load under elastic conditions, returning to zero deflection once the load was released. Under load, a maximum displacement of 49 mm was recorded at the top of the structure as seen in figure 11, compared with 27 mm predicted from the Microstran model. The difference was due to small slip measurements recorded at each level. 50% of the slip occurred at the initial stage of loading from 0-3 kN (less than 2 mm) and 50% over the following 3-10.2 kN as shown in figure 12. It should be noted that the slip would have a much less significant effect on the full-size structure. In the scaled connection, a 0.5 mm gap represents a slope of 1:100 over the 50 mm embedded length. In a full size component, the gap would represent a slope of only 1:600.

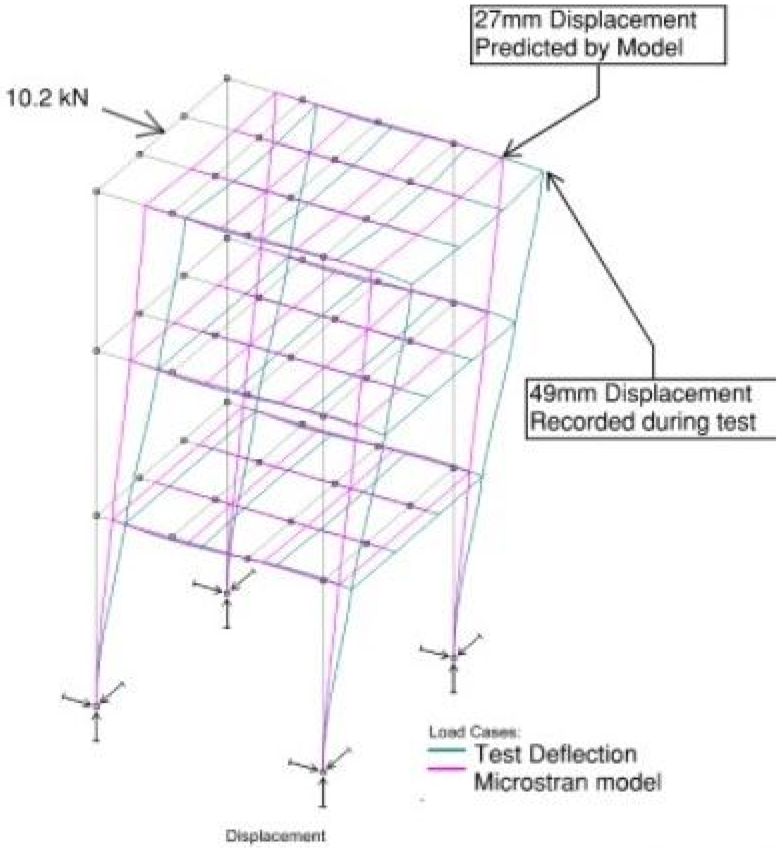

Figure 11 - Deflection Comparison Between Test and Model Data

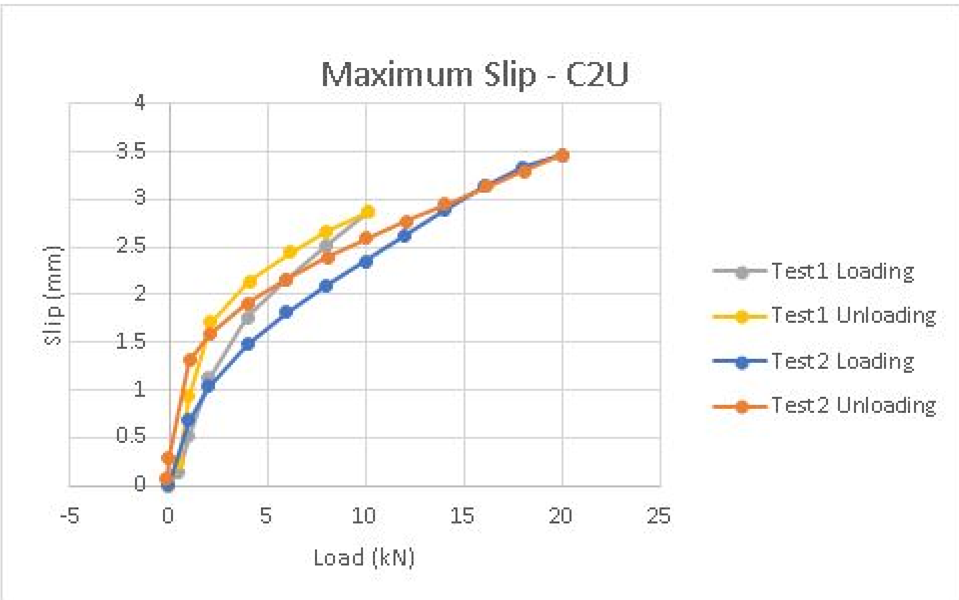

Figure 12 - Slip at Location C2U (First Floor upper socket)

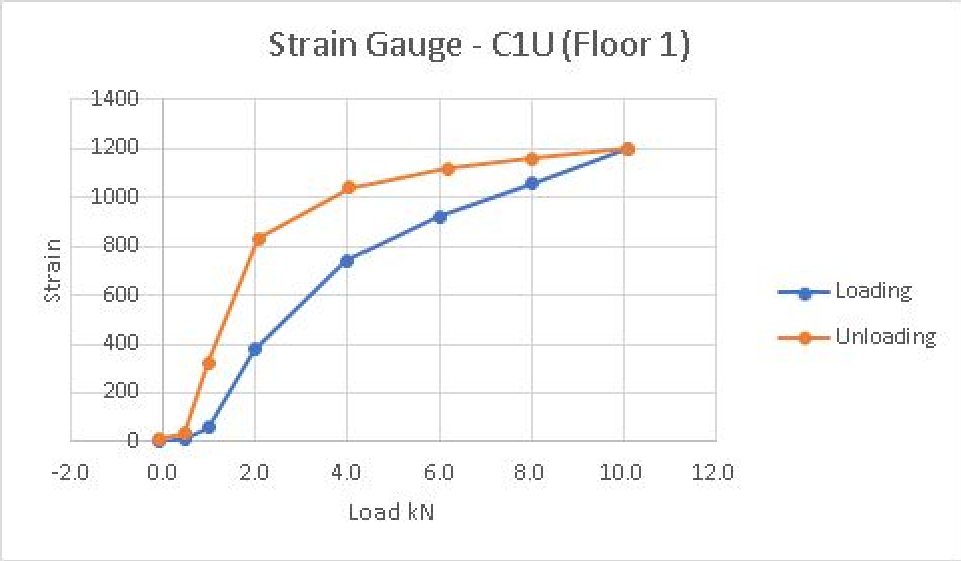

Figure 13 - Strain at location C1U (First floor upper socket)

The largest strain measured during the first test occurred at level 1 shown in Figure 13. The mild steel connections developed only 50% yield stress under a 10.2kN lateral load. With the load removal, the strain gauge shows the structure remained in the linear elastic range.

Test 2

This lead to an impromptu test 2, applying load until yielding occurs. Test 2 results show no altCONNECT® components yielded under the 20kN loading, with a maximum strain reading of 1660um, equal to about 70% of yield stress (Figure 14). There was minimal separation between components of only friction connections, the upper Connection at C2 showing 3.5mm at 20kN, a third of which occurs during loading to 2kN as seen in figure 15. Yielding occurred at the base of the structure where columns developed beyond yield stress, permanently deflecting the structure leaving ~1.03 degrees rotation to the column members at their bases.

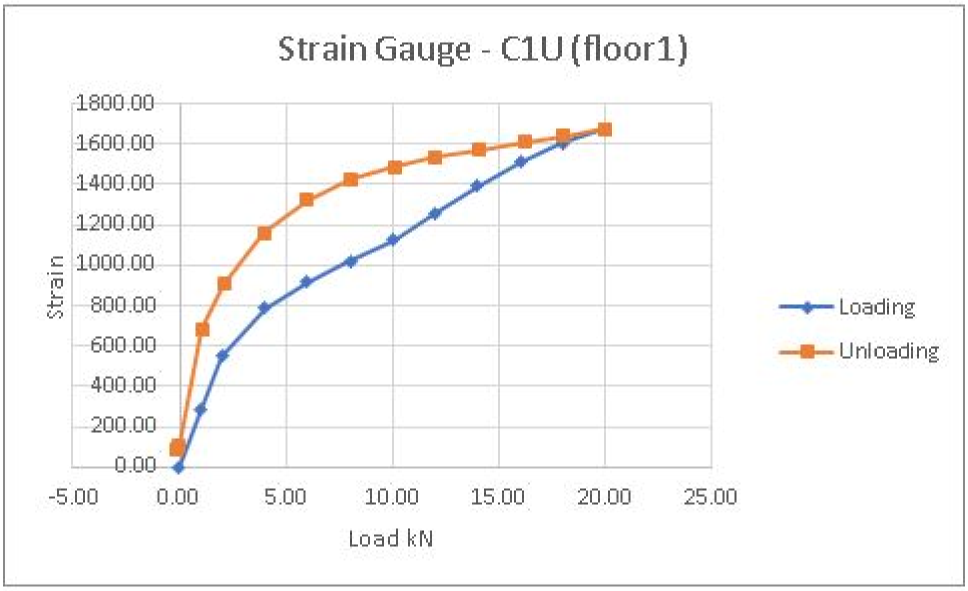

Figure 14 - Strain gauge plot for Test 2, floor 1 upper altCONNECT® connection

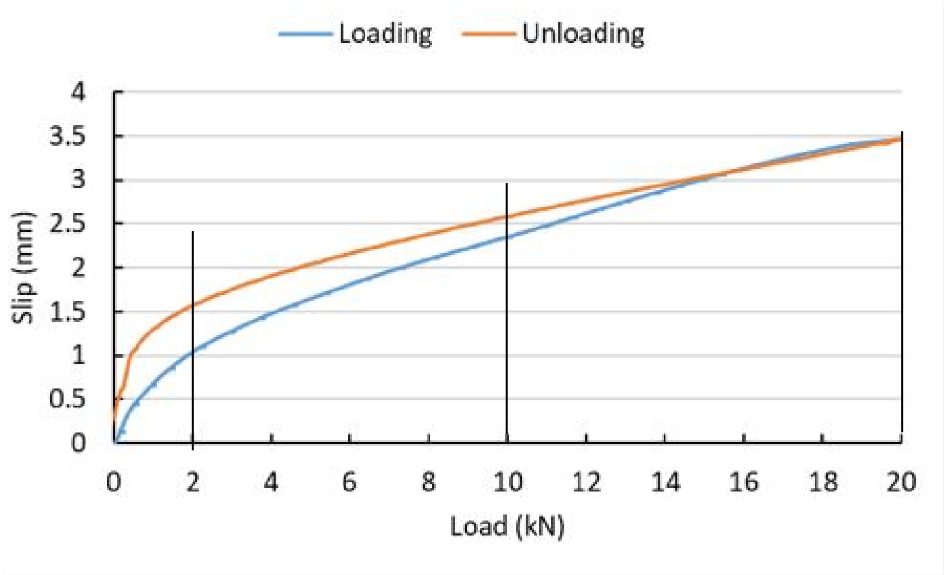

Figure 15 - Slip at the upper part of connection C2 (first floor)

In reality, the structure was not designed for loads more than 12 kN, making the 20 kN results better than expected with 70% higher loading than the design limit. The failure at the base columns (yielding) indicated a ductile structure with non-catastrophic failure in the event of overloading.

The tests confirm the strength and stability limit states as required by AS 4100 Steel Structures code are satsified and the expected results equal or exceed that of a conventionally assembled frame of similar di mensions.

The serviceability limit state assesses the structure under a reduced, unfactored load to ensure deflection is not excessive. On this structure, a serviceability limit state load would be 6.8 kN (10.2 kN ULS divided by 1.5). Lateral deflection at this load, whilst greater than a bolted or welded structure due to the small slip in the connections, is still acceptable for a steel structure that does not contain rigid cladding or glazing.

The results of Test 1 and 2 show that under the worst case scenario with minimal floor weight, the lateral load produces enough bending in the beams for the friction capacity of the connections to overcome the tension loads presented. In reality there would be more load on the floor, including floor plate and secondary members that would aid in the connection resistance.

CONCLUSION

As a result of testing, the modelled data now has a valid benchmark for comparison. Using the results gained from the two rounds of testing, further development of the connection and interaction curve can be made using numerical modelling with confidence in the results. A range of interaction curves can be prepared for various sizes of spigot and socket components compatible with commercially available circular hollow section columns elimnating the need for structural engineers to design the connection components but rather specify them as a product.

The testing to date consists of static load tests of the connection components both individually and within a complete structure. Further testing could include cyclic load testing to validate the fatigue performance of the connection. Additionally, a dynamic load test could be carried out to evaluate the performance of a structure containing altCONNECT® components under vibrating loads or seismic loading.

The testing has confirmed that the altCONNECT® connection system works, providing a safe and fast method of assemblings moment-resisting steel framed structures. It has immediate application in industrial structures supporting equipment and lateral loads from conveyors and the like.

Adoption of the connections in such structures will likely result in other strucrures being considered for and benefiting from the altCONNECT® system.

RECOMMENDATIONS

Structures used in the mining industry are generally subjected to dust, moisture and vibration-induced fatigue. Further work could be carried out to ensure the connections resist these effects during their required design life.

altCONNECT® makes site erection of a steel structure significantly faster than conventional methods of erection and also eliminates scaffolding and potentially unsafe work at height by not requiring access to the connections. However, the gap between the spigot and socket needs to be minimal to ensure friction contact without significant structure movement, and so tolerance of plan dimensions is critical. The test structure used end plate connections between the sockets and grid beams, and utilised shims to achieve correct plan dimensions. Discussions with fabricators is necessary to ensure the manufacture of the connection components and the structure members are such that the befenifits of fast erection are realised.

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BIOGRAPHY

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