



Determination of the Capacities of a new Composite Timber-Steel Connector System

Schreyer, Alexander¹, Bathon, Leander A.², Prion, Helmut G. L.³

ABSTRACT

An evaluation of a new end-grain heavy-timber connection system is presented. The TiSCo-system (**T**imber-**S**teel-**C**onnector) consists of a tubular steel connector that is embedded into timber using mortar to provide adhesion as well as mechanical bond. The connector allows the attachment of a variety of steel hardware by means of a threaded rod connection.

The objective of this research was to determine the strength properties and the behavior of the aforementioned connector in tension and compression. Also, its capacities in a laterally loaded situation and the required edge distances for this arrangement were examined. Additional testing was conducted to investigate the behavior of the system under changing climatic conditions.

This project consisted of testing the TiSCo-connectors in 80 x 80 x 500 (300) mm glulam specimens under tension and compression and Parallel Strand Lumber specimens in tension. The lateral tests were single connector tests using glulam members with different edge distances and member sizes. In addition, a double connector test series was performed.

Another series was arranged that exposed specimens to a changing climate over a period of 18 weeks after which they were tested in tension. This was then compared to tests on the reference specimens which were stored at a standard climate for the same amount of time.

Statistical evaluation of the tension and compression resistance as well as lateral resistance data showed a low variation in the results which can be attributed to the consistent quality of the mortar. In compression, the connection showed a ductile behavior stemming from the deformation properties of the wood. In tension, the failure was very brittle indicating the requirement of a controlled steel-element failure. In addition, the connection showed a small reduction in the maximum load after the climate cycles.

INTRODUCTION

Modern timber engineering is in need of efficient connection systems. Classical wood connectors such as bolts, dowels, nails or screws do not fulfill the demands of today's timber engineering industry. Engineered wood products make it possible to combine efficiency and reliability with minimization of material and thus cost reduction. It should be attempted to apply these aspects to the connections as well.

The classical wood connection either requires a relatively large amount of labor and machine time or does not offer high load transmission which is important for heavy-timber structures. Also, the efficiency is typically poor as many connections greatly reduce the usable cross-sectional area requiring larger and usually oversized structural members. Increasing labor cost also drives producers towards reducing manufacturing time and a tendency towards prefabrication and automatization. Time and efficiency play an important role in creating viable structural solutions.

The demand for efficient high-strength as well as stiff connections points the focus to glued connections. The materials are readily available and in most cases easy to apply. Glued connections provide high stiffness and strength and allow for low tolerances which makes them very reliable. They can also be mass produced which eases prefabrication. The main disadvantages are the sensitivity to climatic changes (especially moisture content changes, a generally required minimum temperature for the adhesive reaction itself and the loss of stability in extreme temperature ranges), limited ductility and a

¹ M.A.Sc. Candidate, University of British Columbia, Faculty of Forestry, Department of Wood Science, FSC 4041 - 2424 Main Mall, Vancouver, B.C., Canada V6T 1Z4, schreyea@interchange.ubc.ca

² Professor, University of Applied Science (Fachhochschule) Wiesbaden, Fachbereich Bauingenieurwesen, Kurt-Schumacher-Ring 18, D-65197 Wiesbaden, Germany, Bathon@t-online.de

³ Associate Professor, University of British Columbia, Departments of Civil Engineering and Wood Science, 2324 Main Mall, Vancouver, B.C., Canada V6T 1Z4, prion@civil.ubc.ca

sometimes elaborate and difficult preparation process. This is the case with most common epoxy adhesives. Glued timber connections were first used in the 1960's in Sweden. Since then, several investigations have been conducted in this field. Of the many approaches, glued-in reinforcing bars or threaded rods have provided an easy means to construct an efficient connection (Johansson, 1995). Recent research on glued-in rods is (amongst others) conducted in Europe under the GIROD program.

Generally, some identified disadvantages with glued-in rods include:

- The choice of adhesive being critical for the reliable performance of the connection, especially at high temperatures.
- Glued-in rods acting as skin connectors, only incorporating the outer portion of a timber member that is in direct contact which may lead to early failures.
- Longer connectors requiring vent holes and an elaborated filling process. Also, drilling of the hole can present problems.
- Glued-in rods usually requiring ductile elements as the glued connection itself has a brittle performance.

New developments in adhesives technology have paved the way for more efficient connector systems. This paper presents the TiSCo-system (**T**imber-**S**teel **C**onnector) which is applied using a vinyl-ester based mortar. Two main features distinguish this connector from most other glued connection systems:

- The connector has a tubular shape. This allows for a comparatively short length as it provides a larger surface area - the inner as well as the outer surface carry the load. The surface area of the 125 mm long connector would then be comparable to a rod of 650 mm length and 16 mm diameter. This makes the connection much smaller and easier to drill and handle.
- The second issue is the use of a compound mortar (Upat UPM66[®]) as adhesive which provides an easy application, a short hardening time and a general insensitivity to temperature variations during the manufacturing process and in the finished connection.

This paper presents the results of an extensive study of this connector system which was undertaken in 1998 at the University of British Columbia in Vancouver, Canada.

CONNECTION SYSTEM

The TiSCo connector system consists of three components: the steel connector itself, the mortar and the drill. The production of a connection involves three main steps: (a) the drilling of the circular-hole, including a 20 mm countersink to accommodate the connector, (b) the injection of the mortar into the hole and (c) the insertion of the connector and hardening of the mortar. After the hole has been drilled, inserting the mortar and the connector takes a few seconds and the total manufacturing time is mainly dependent on the hardening time of the mortar. This process is illustrated in Fig. 1. It is evident that the ease of fabrication makes this connection system a very practical means of construction. All stages can be performed on-site with little additional machinery required to facilitate the drilling.

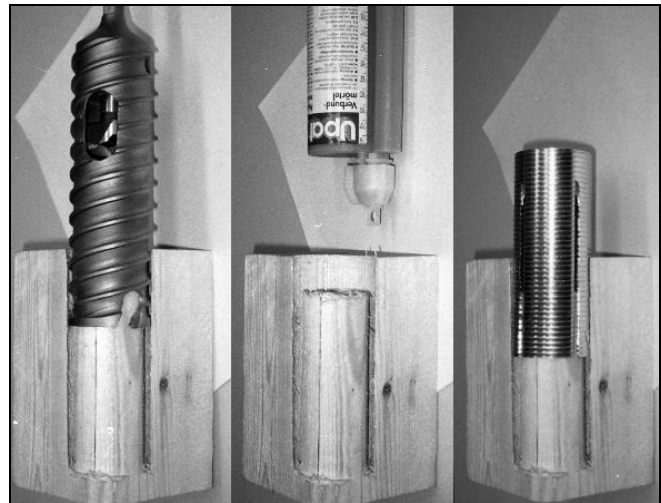


Figure 1 - Manufacturing Steps of the TiSCo Connection

The connector itself (Fig. 2) consists of a steel tube with a steel plate welded to one end. The steel strength properties are relatively low with a yield strength of approx. 235 MPa and an ultimate strength of 340 - 470 MPa. The steel tube has an outer diameter of 48 mm and 3 mm of wall thickness and is cut to a length of 125 mm. The top plate which features a centered threaded hole (M16) is welded to the tube on the outer surface. In addition, longitudinal cuts have been applied at 90° intervals to the connector over most of its length (excluding the top plate portion) which are supposed to work as assigned cracks that reduce residual stresses due to deformations of the timber. Also, they allow a uniform distribution of the mortar within the ring hole when the connector is inserted. The surface is then sandblasted which creates a coarse structure. It also receives a galvanized zinc-coating to prevent corrosion.

The 125 mm deep ring hole is produced using a tubular drill bit which had to be developed for the connector. It fits into any standard hand-held drill or drill-press and produces an accurate and clean hole into which the connector fits. All wood chips are transported to the outside of the timber by the spiral grooves. Also, an inserted drill-bit allows to simultaneously countersink the top of the central wood peg for 20 mm to accommodate the top plate of the connector. After drilling the hole, it can then be cleaned by using pressurized air. The remaining fractured fibers do not have to be removed, they can serve as additional “grip” between the wood and the adhesive

A two-component mortar, UPM66[®], a product of Upat GmbH & Co., Emmendingen, Germany was chosen as bonding agent. This mortar has several features that make it desirable for this connection. It combines ease of workability with early strength, enhanced friction capacity and temperature insensitivity. Presently, common uses of this mortar are in concrete anchoring systems.

The UPM66[®] consists of a vinyl-ester-resin dissolved in a reactive solution. Added to the mixture is a fine sand aggregate, which enhances friction. The resin and the hardener come in a 525 g (345 cm³) two-tube cartridge from which both components are pressed out manually using an injection gun. The mixing takes place within the nozzle.

Pot life of this mortar is 6 min. at 20°C, which provides a fast hardening and thus short production cycle for the entire connection. The mortar reaches a hardened state after approx. 10 min., after which the squeezed-out excess mortar can be removed from the connector (Fig. 3). Temperature tests have been conducted by the manufacturer at 100 to 200°C and have shown that no loss in strength is experienced at these temperatures.

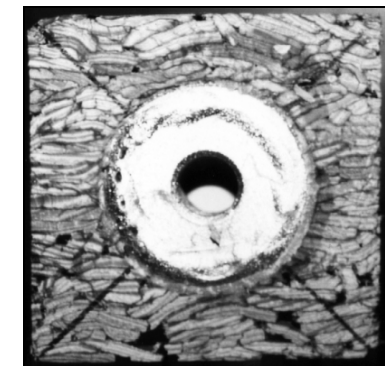


Figure 3 - Finished Connection in PSL

The mortar is applied by pumping it into the bottom of the ring-hole which allows for even distribution of the material. The insertion of the connector (with a twisting action) then pumps the viscous material all over the steel surface. Due to its short length, the connector can easily be inserted by hand without any additional machinery. It should also be noted that no vent holes are necessary. Loads can be applied one hour after the insertion.

EXPERIMENTAL PROCEDURES

The first set of twenty tests focused on the tensile capacities of the connection (**TENA-T**). Strength and stiffness values had to be found. As an evaluation of the behavior of this connection with new engineered wood products, another series of five tests was conducted. Here the connectors were inserted into PSL (Parallel Strand Lumber). The effect of the UPM66[®] mortar on voids and the general strength capacities were examined (**PARA-T**).

Compression tests (**COMA-C**) on thirty specimens were conducted after these series, followed by shear tests to determine a relationship between the edge distance and the maximum load which the connection could transmit in a lateral loading situation.

Over the entire testing period of six months, an

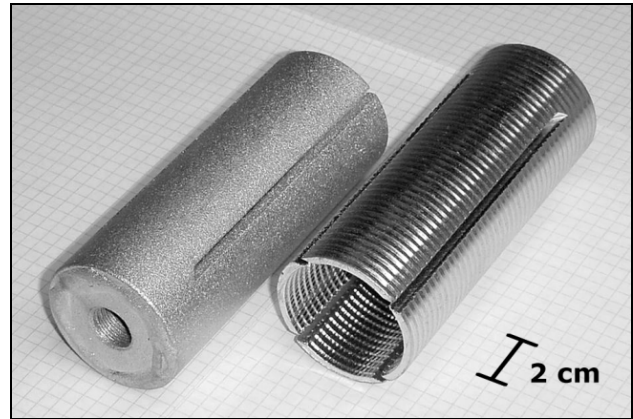


Figure 2 - The TiSCo (Sandblasted and Grooved Version)

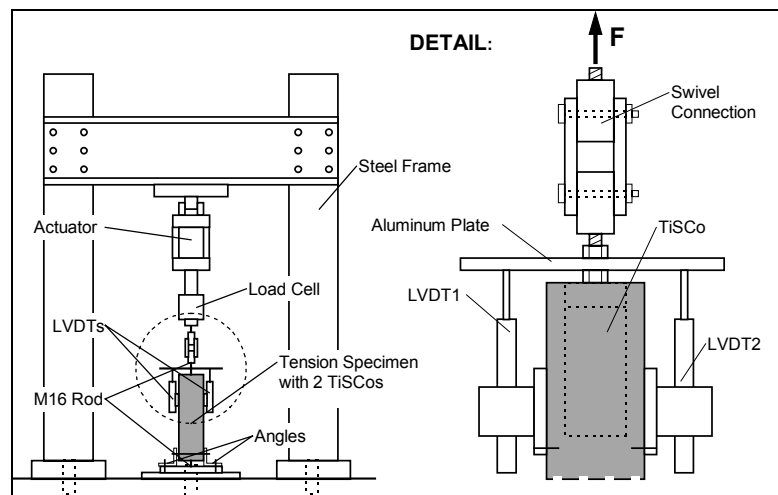


Figure 4 - Tension Test Setup

examination of the behavior under cyclic climatic conditions took place (**CLIA-T**). Ten specimens were prepared, five of which were conditioned in a reference climate of 20°C air temperature and 65% relative humidity, while the other five were subjected to cyclic climate changes.

All tests used a height-adjustable steel frame. The setup for the tension tests can be seen in Fig. 4. Mounted to the frame was a 222.41 kN load actuator capable of an overall stroke of ± 76.2 mm. The data acquisition required the monitoring of the load and the movement of the actuator as well as two LVDTs (Linear Variable Differential Transformer), which provided average displacements of the connector. The LVDTs had a range of ± 25.4 mm. The data was recorded at a frequency of 5 Hz. The accuracy of the data acquisition system was ± 0.1086 kN for the load cell and ± 0.0054 mm for the two LVDTs. Both LVDTs were used in every tension and compression test and then averaged to eliminate rotations that could occur as a result of the connector being inserted at a slight angle into the wood member. In the shear tests, where accurate displacement values were not attainable, the two LVDT readings provided information about the point of failure by comparing the relative displacements.

The tension and compression tests were performed according to DIN EN 26 891. This standard requires a loading, unloading and then reloading cycle in the range of 0.1 to 0.4 times the maximum load.

All tension and compression test specimens were produced using German glulam (BSH) of Grade I. Due to availability, all shear tests (except S1DA-S) were produced using Canadian glulam Grade B. Also, after production, the specimens were allowed to harden for at least 24 hrs. before the load was applied to ensure consistent test quality.

Tension

Due to the expectation of a relatively high load (60 kN) and the small cross-section of 80/80 mm, it would have been very difficult to clamp the specimen in the testing machine. Two connectors - one at each end of the specimen - were thus used in the tension tests. The bottom end of the specimen was reinforced with two steel angles, which forced the failure to

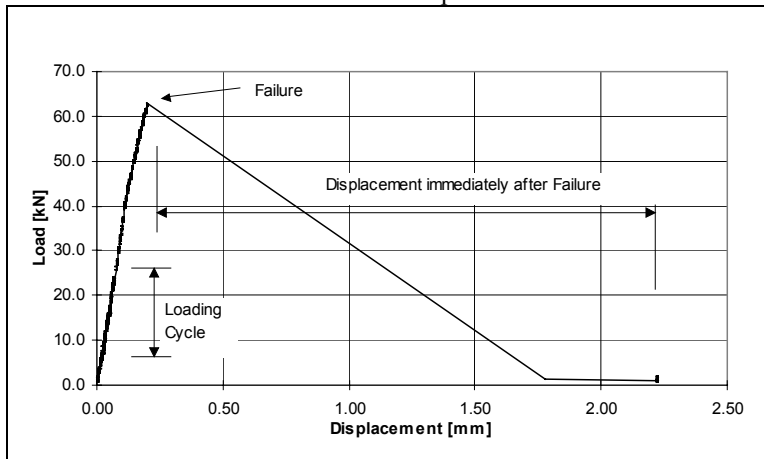


Figure 5 - Typical Tension Specimen Behavior

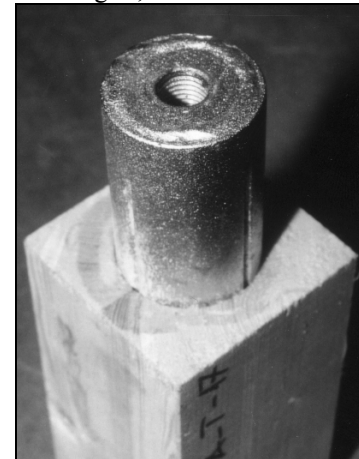


Figure 6 - Tension Failure Mode

occur at the top connector.

The tension tests resulted in an average failure load of 54.10 kN (COV: 13.8%) at a displacement of 0.214 mm (COV: 29.6%). Rupture occurred in a sudden action, when the connector sheared along the steel-mortar bond (Fig. 6) and was withdrawn from the member for about 2.00 - 2.50 mm. A cracking sound could usually be heard just prior to the actual failure but no cracks towards the outside appeared in the wood - not even after failure had taken place. In five tests, the part of the mortar that was located at the upper plate of the TiSCo broke away from the rest and stayed on the withdrawn connector, wood fibers and ruptured wood attached.

As Fig. 5 shows, no plastic deformation was evident. The connection behaved essentially linear. Although all curves show a minute reduction in stiffness starting around 40.0 to 50.0 kN it can be assumed that the elastic behavior is true over the entire loading range.

The average slip modulus k_s was calculated (using DIN EN 26 891) as 336.44 kN/mm (COV: 10.8%).

Tension Tests using Parallel Strand Lumber

This test series was intended to evaluate the applicability of the mortar with PSL material, which has somewhat large and

unevenly distributed voids. Previous tests at U.B.C. with glued-in reinforcing bars using a common epoxy showed that its low viscosity can be problematic in that the glue disappears into these voids (Malczyk, 1993).

The UPM66[®] proved to have excellent applicability with PSL. Its high viscosity prevented these problems and the voids even seem to have a positive effect on the connector strength. Voids which are located next to the connector are filled with mortar, resulting in an “anchoring” effect and providing additional strength. Generally, the average maximum load achieved was 59.69 kN (COV: 11.5%) at 0.201 mm displacement (COV: 10.5%). This represented an increase of 10% compared to the glulam tension tests.

The slip modulus k_s was comparable to the glulam tension specimens: 338.27 kN/mm (COV: 19.1%).

Compression

The compression tests did not need a bottom connector. It was thus possible to cut them to a length of 300 mm and put the bottom flush with the ground steel plate. In this setup, the angles were only used to hold the specimen in place during

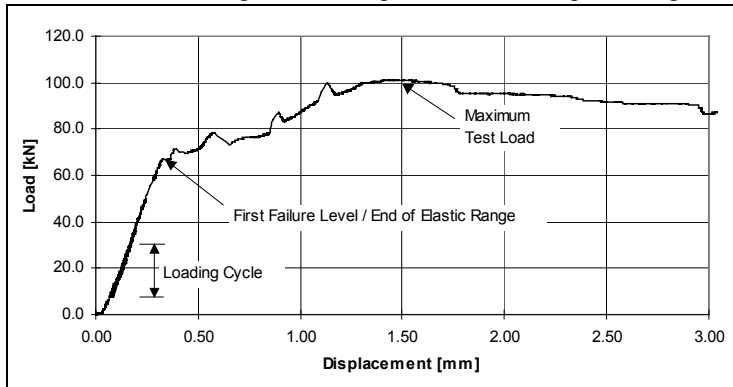


Figure 7 - Typical Compression Specimen Behavior

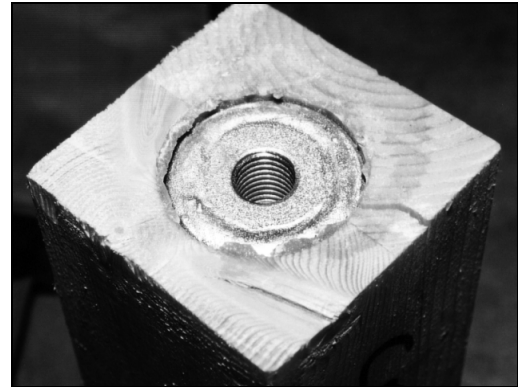


Figure 8 - Compression Failure Mode

loading.

Analyzing a typical load-displacement curve (Fig. 7), it becomes obvious that the first (linear) part is due to the mortar adhesion and friction as the behavior is similar to the tension tests which only rely on the mortar. The rise is comparable and the failure occurs at a level a bit higher than the failure level in the tension tests. The end of this elastic section was reached at an average load of 68.85 kN (COV: 8.5%) and a displacement of 0.311 mm (COV: 14.5%). The combination of shear resistance along the mortar line with the compressive reaction of the top plate pressing on the inner peg should be the explanation for the increased failure load. This combination also seems to be the cause for the relatively low variability of 8.5% as weak parts of one material can be equalized by the second material.

The maximum value of each test was reached when the wood compression of the center peg was at its maximum. This occurred at an average load of 106.15 kN (COV: 5.9%). Afterwards the wood continued to densify at lower load values.

The slip modulus value k_s was found to be comparably lower than for the tension tests 229.22 kN/mm on average (COV: 9.6%).

Shear

Although the TiSCo is primarily meant to transfer axial loads, lateral shear forces often occur in structures and it was thus important to determine a relationship between the edge distances and the shear force capacity. Several cross-sections with dimensions as presented in Figs. 9 (load direction is vertical) and 10 were tested. In all shear tests, the load was increased uniformly at a speed of 0.5 mm/min. As shown in Fig. 10, two LVDT readings were continuously made. As the exact displacement of the connection was not of interest (it would also have been difficult to measure this displacement due to the rotation of the connector), the measurements were only taken to determine failure points and approximate stiffness. This means that when the two curves in the load-displacement path diverged, a crack

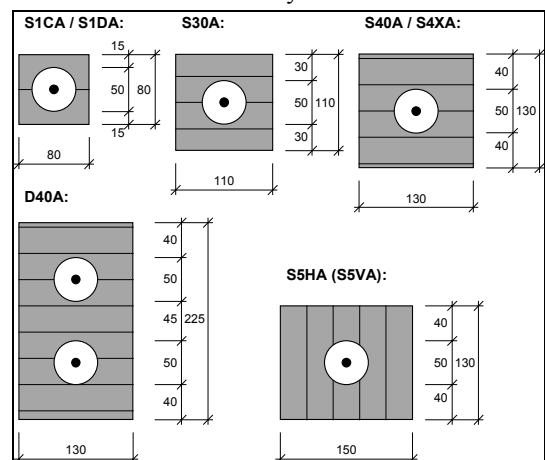


Figure 9 - Shear Specimen Geometry

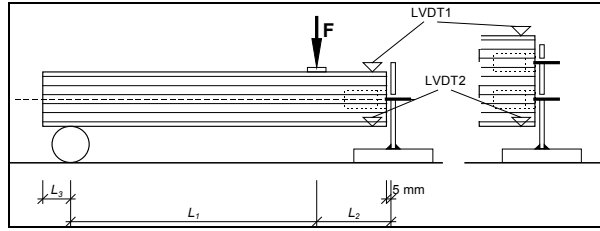


Figure 10 - Shear Test Setup

Test Series	L_1 [mm]	L_2 [mm]	L_3 [mm]
S1DA/S1CA	295	205	10
S40A/S4XA	995	260	50
S30A	815	240	250
S5VA	1175	280	50
D40A	1850	355	100

would have initiated in the member.

Results of the tests are listed in Table 1.

Test Series	Nr. of Tests	Edge Distance [mm]	First Failure Load F_1 [kN] (COV [%])	Ultim. Failure Load F_u [kN] (COV [%])	Reaction at Bearing at F_u [kN]
S1DA-S	10	15	16.16 (9.8)	18.08 (9.0)	10.67
S1CA-S	6	15	16.51 (N.A.)	18.48 (8.3)	10.90
S30A-S	5	30	12.77 (7.2)	16.68 (9.5)	12.89
S40A-S	10	40	13.37 (11.6)	20.60 (10.8)	16.33
S4XA-S	1	40	N.A. (N.A.)	16.18 (N.A.)	12.83
S5HA-S	4	50 horizontal 40 mm vertical	11.43 (5.9)	21.89 (10.3)	17.52
S5VA-S	4	40 horizontal 50 mm vertical	12.90 (10.8)	20.77 (11.0)	16.47
D40A-S	10	40 to sides 45 between c.	41.71 (9.4) (failure of first connector)	42.76 (5.6) (failure of second connector)	35.00 (at first connector failure)

Table 1 - Shear Test Results

The load-displacement graph for a single connector test (Fig. 11) typically exhibited a change of slope before the maximum point was reached. The first deviation was due to the first crack initiation and is mentioned in Table 1 as First Failure Load. A sudden displacement of 0.50 - 1.00 mm was then regarded as the final failure and the maximum load at that point was taken as the maximum capacity. A major crack was usually visible at that point.

In explaining the connector's behavior, we can assume that at first the mortar bond failed in tension at the connector bottom, which resulted in the first crack level that can be identified in the curve. After that, the wood fibres at the top were compressed until a horizontal crack in the wood material opened, which then widened from the inside to the outside (Fig. 14) and then along the entire length of the specimen.

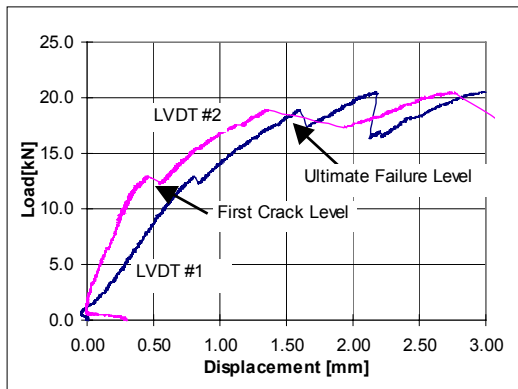


Figure 11 - Typical Single Connector Shear Test Behavior (S40A-S)

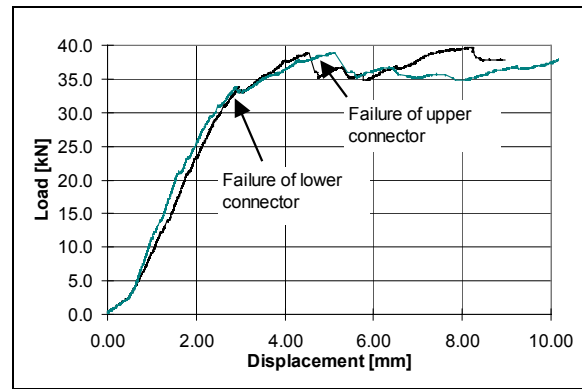


Figure 12 - Typical Double Connector Behavior (D40A-S)

Comparing the single and the double connection (S40A-S and D40A-S) it is evident that the double connection provided a more ductile response. The double connection also had a more noticeable linear section and the failure values showed that

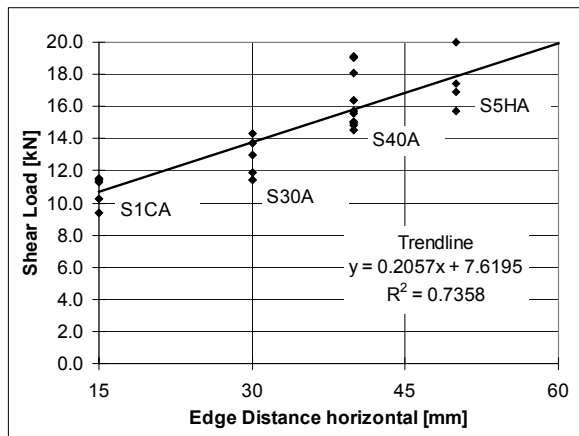


Figure 13 - Load - Edge Distance Relationship

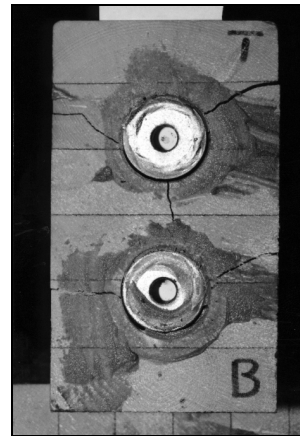


Figure 14 - Double Connector Failure

the double connection can take at least double the single connector load.

The test where no mortar was inserted (S4XA-S) showed that a relatively high load could still be transferred. However, displacements were relatively large. This “connection” failed at 10 mm displacement, whereas the ones with mortar failed at 1-2 mm. All tests show that after failure a relatively high load level could still be sustained, which illustrates that the shear resistance is not dependant on the mortar bond.

A comparison of the edge distances and maximum lateral loads is shown in Fig. 13, with a linear trendline inserted to serve as a first approach towards defining a relationship. As relatively few tests were conducted, this can be regarded as a conservative estimate. Also, the last series of tests (S5HA-S) was conducted with the glue lines vertically oriented (all others were horizontal). As almost all of these tests failed in the smaller dimensions, it can be assumed that a square cross section with 50 mm edge distance all around would have had a higher failure load.

Climate Cycles

Ten specimens were tested to determine the effect of climatic fluctuations on the strength of connections. Five of them were conditioned under constant temperature of 20°C and 65% relative humidity (R.H.) over the entire duration of the test program while the other five underwent climatic cycles as follows:

- 3°C / 90 % R.H., six weeks duration, target M.C.: 20%
- 25°C / 28 % R.H., six weeks duration, target M.C.: 7%
- 20°C / 65 % R.H., normalization until equilibrium was reached (approx. 12% M.C.)

After the third conditioning phase, the specimens were tested in tension. In all tests, failure occurred along the bond surface between the steel and the mortar. A reduction of load was detected for specimens subjected to climate cycles. The reference specimens achieved an average load of 53.84 kN (COV: 10.82%), while the climatized specimens failed at an average load of 45.55 kN (COV: 15.81%), resulting in a reduction of about 15%. Since the sample size was small, these values can only serve as estimates of the actual capacity.

CONCLUSIONS

Results from a test series on the sandblasted version of the TiSCo connector were presented. These can be summarized as follows:

- A set of tension tests exhibited an abrupt failure mode after a linear elastic performance. Failure was mostly observed as withdrawal of the steel connector along the mortar surface. This failure mode requires the application of a ductile element which can be the threaded rods or a modified version of the connector.
- Tests using PSL showed a higher failure load level as compared to the tension tests in glulam. The stiffness was comparable in both.
- The compression tests resulted in a higher failure load and a lower variability of the results. After the failure of the bond line, wood compression leads to an increase of loading capacity and a large “ductile” region was observed.

- The compression tests had a lower stiffness than the tension tests.
- Shear tests led to a failure that consisted of a rotation of the connector and then a splitting of the wood member. The load capacity was then related to the edge distance of the connector by assuming a linear relationship. Also, a double connection with comparable edge distances would provide a doubled load capacity. A test without the mortar was conducted that reached almost the same load level as a test with the mortar of similar dimensions. This shows that the capacity in shear is largely independent of the bonding agent.
- A pilot study on a limited number of specimens showed that climate cycles over a period of 18 weeks may result in a 15% reduction in tension load capacity.

OUTLOOK

Based on the results of this study, improvements of the TiSCo have since been made which resulted in a newer version. This newer and final version features two major changes (Fig. 15): (a) The surface preparation has been changed from a sandblasted to a grooved one which increases friction resistance and may provide additional safety for connections which are exposed to climatic changes. Also, the top plate thickness has been reduced from 20 mm to 8 mm which allows for a steel yielding failure in tension before the brittle failure takes place.

As this report only covers the basic properties of the first version of the TiSCo-connection, further studies should be conducted to investigate the properties of the newer version. However, some of the results, especially the shear tests, do not fully rely on the mortar adhesion and the findings can thus be extrapolated onto the newer version.

Recent preliminary tests at the Fachhochschule Wiesbaden have shown that a much higher load level can be reached using this modified version. Average tension values of 105.50 kN (COV: 6.8%) were observed.

Moment frame and column base tests are also presently being conducted at the Fachhochschule Wiesbaden.

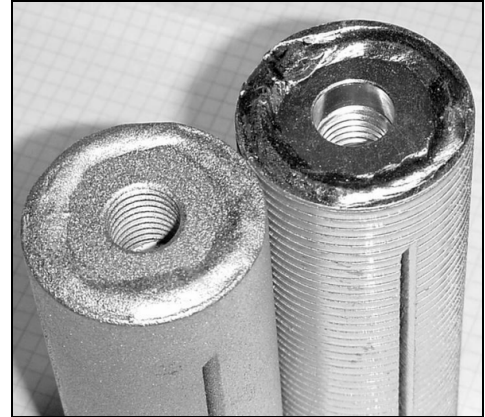


Figure 15 - Top Plate and Threaded Hole

ACKNOWLEDGEMENTS

Financial support by Forest Renewal British Columbia (FRBC) as well as financial and in-kind support by the Departments of Civil Engineering and Wood Science of the University of British Columbia is gratefully acknowledged. The authors would also like to express their gratitude for the advice and co-operation provided by Dr. Frank Lam of the Department of Wood Science University of British Columbia.

REFERENCES

- Johansson, C.J. 1995. Glued-in bolts. In: Blass, H.J., Timber Engineering STEP 1, STEP Lecture C14, Centrum Hout, The Netherlands
- Malczyk, R. 1993. Glued-in Re-bar Connection. Thesis, University of British Columbia, Department of Civil Engineering, Vancouver, Canada
- Schreyer, A. 1998. Determination of the Capacities of a new Composite Timber-Steel Connection System, the TiSCo. Part 1 - Report on the TiSCo Type A Test Series. Diplomarbeit, Fachhochschule (University of Applied Science) Wiesbaden, Germany and University of British Columbia, Vancouver, Canada