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# Experimental study on innovative connections for large span timber truss structures

Huifeng YANG *, Roberto CROCETTI [a], Gustaf LARSSON [a&b], Per Johan GUSTAFSSON [b]

* College of Civil Engineering, Nanjing Tech University
P.O. Box 80, NO. 30, South Puzhu Rd. Nanjing, China
yhfbloon@163.com

[a] Division of Structural Engineering, Lund University, roberto.crocetti@kstr.lth.se
[a&b] Division of Structural Engineering, and Division of Structural Mechanics, Lund University,
gustaf.larsson@construction.lth.se
[b] Division of Structural Mechanics, Lund University, per-johan.gustafsson@construction.lth.se

## Abstract

This paper summarizes an experimental investigation on several innovative reinforcing techniques for the "Single Large Diameter Dowel Connection", SLDDC in timber truss structures. Besides lateral reinforcing or prestressing, also steel plates glued on two sides of the glulam specimens were used as reinforcing measure. To study the efficiency of these techniques, 15 full-scale quasi-static tensile tests on glulam members with a SLDDC on either ends of each member were performed. It was found that the reinforcement significantly enhanced the bearing capacity of the SLDDCs. All of the reinforcing techniques showed a satisfactory efficiency, preventing splitting of wood. Moreover, most of the specimens remains showed a remarkable post failure strength.

**Keywords**: timber structure, truss, singe large-diameter dowel connection, reinforcement, improvement, experimental study

## 1. Introduction

Timber trusses are competitive for relatively large spans, typically larger than 30 m. For such span lengths, however, the magnitude of loads which have to be transferred between truss members becomes significant, often resulting in complex (and expensive) connections.

To find simpler large dowel connections for timber structures, several studies have been carried out. Haller et al. [1] produced and tested some textile reinforcements on the large dowel connections with different textile structures like biaxial weft knitted and stitch bonded. It showed significant increase on the strength, stiffness and also ductility of the connections. The plug shear and splitting failure of the wood are avoided. However, the ultimate fracture is the wood tensile failure because of the stress concentrations and the reduced net cross section. Also, multi inserted reinforcement layer will result in the relative complex and expensive production process.

Crocetti et al. [2] presented a reinforcement by means of self-tapping screws to the SLDDCs. It was found that the reinforcement can considerably increase both strength and stiffness of the connections. Also the end distance of the dowel can greatly reduced due to the reinforcing from the self-tapping screws. Furthermore, it showed a significant improvement in the ductility of the joint.

Kobel [3] conducted an experimental study on the reinforcement of large dowel connections for timber truss structures, in which the dowel has a diameter of 90mm. The study presented several reinforcement methods including reinforcing with self-tapping screws of various configurations and lateral prestressing with threaded rod. It was found that reinforcing screws can effectively impede splitting of the timber and as a result of the remarkable increase of the bearing capacity. By applying lateral prestresses, no splitting occurred and the bearing capacity is even higher.

Pavkovic´ et al. [4] investigate the bearing capacity of reinforced large diameter dowel connections loaded perpendicular to grain of timber with experimental and FEM analytical work. For the glass fiber textile layers

reinforcement glued between the timber lamellas, the result demonstrated remarkable enhancement of the strength and ductility of the connections.

The idea with introduction of a rubber layer at the bonding interface for the joints in timber structures was presented by Gustafsson [5]. Aimed to produce a more uniform distribution of the bonding shear stress and thus result in a higher bonding shear strength. The test results verified the idea and showed that most of the failure occurred in wooden parts in a high load level instead of bond fracture.

In this research, several efficient and relatively inexpensive reinforcement methods of SLDDCs were presented. By means of experimental investigations, the aim of this paper is to study the efficiency of different types of innovative reinforcing techniques for the SLDDC.

# 2. Material and methods

### 2.1. Wood materials

Spruce glulam with the strength class of GL30c was used for all of the 15 glulam specimens in the test. The characteristic tensile strength parallel to the grain of $f_{t,0,k}$ = 20 MPa. The measured average density and the moisture content was 443 kg/m$^3$ and 11.1%, respectively. These values were measured after testing on samples taken from the part of the specimen where failure had occurred (i.e. from the shear plug). These values varied in the range of 324 - 551 kg/m$^3$ for density and 8.9 - 13.4 % for MC.

### 2.2. Steel

The steel plates and the large diameter dowel were all made of steel quality Q345B, with a nominal yield stress of 345 MPa. The threaded rods, with a diameter of 24 mm, had a nominal yield stress of higher than 800 MPa. The large diameter dowels had a hollow cross section with the outer diameter of 89 mm and the inner one of 38 mm, with a strength grade of S355 and a nominal yield stress of 355 MPa. The yield strength was 320 MPa for the hexagon head wood screws with 6 mm in diameter and 70 mm in length.

### 2.3. Rubber

The rubber was a mix of natural rubber and SBR (styrene-butadien), with density is 1220 kg/m$^3$, hardness 62°, shear modulus G≈1.2 MPa, tensile strength is 22.4 MPa, shear strength 9.4 MPa and the elongation at break is 595 %. The thickness of the rubber layer vulcanized to steel plates was 1.0-1.2 mm. The outer surface of the vulcanized rubber layer was treated by the sulfuric acid in order to get a satisfactory bonding between the timber and rubber layer.

### 2.4. Glue

The glue used in vulcanized steel – glulam interface was Purbond CR 421 (glue+hardener). The glue used in smooth steel – glulam interface was epoxy (glue+hardener).

### 2.5. Layout of the reinforcement

The test series were divided into five groups of three specimens each, Fig. 1.

The specimens of the group "Non-Pre" and "Pre" had dowel holes with 92 mm diameter in both end of the glulam specimens. Thus the hole diameter was 3 mm larger than diameter of the dowel. The area between the dowel and the loaded end was reinforced using a threaded rod (See Fig. 1(a) and Fig. 1(b)). Meanwhile for the load transmission from the threaded rods to the glulam, a 30 mm thick steel plate was also used. The prestress in the threaded rods of group "Pre" was surrounding 3.8 MPa at the time when the specimens were prestressed, i.e. approximately three month before the test. As to group "Non-Pre", it had no prestress in the threaded rods. The threaded rods acted as the reinforcement of the timber perpendicular to the grain.

The specimens of the group "S2" and "S2+R" presented reinforcement by bonding steel plates to the glulam surfaces around the large dowel holes. The hole diameter of glulam and steel plates was 102 mm and 92 mm respectively. It means a 5 mm gap between the dowels and the glulam specimens aimed to transfer the applied loads from dowel to timber by bond shear stress of the vulcanized steel – glulam interface. The major difference between these two groups was that the bonding surface of group "S2" was smooth steel, while group "S2+R" was vulcanized rubber layer onto the steel plates (See Fig. 1(c) and Fig. 1(d)).

The specimens in the group named "S1+R" were also reinforced by bonding steel plates but with a doubled glulam elements (See Fig. 1(e)). Furthermore, in all of the bonding steel plates reinforced specimens, each steel plate was anchored by 34 wood screws in order to bear the normal stress at the bonding interface as well as give the pressure while gluing.

The lamellae thickness was 45 mm for glulam specimens. The specimens in the group named "S1+R" (See Fig. 1(e)) had a doubled glulam elements each with a cross section of 61 mm × 405 mm. The other groups of specimens had a single cross section of 140 mm × 405 mm. All the glulam specimens were 2, 00 m in length.
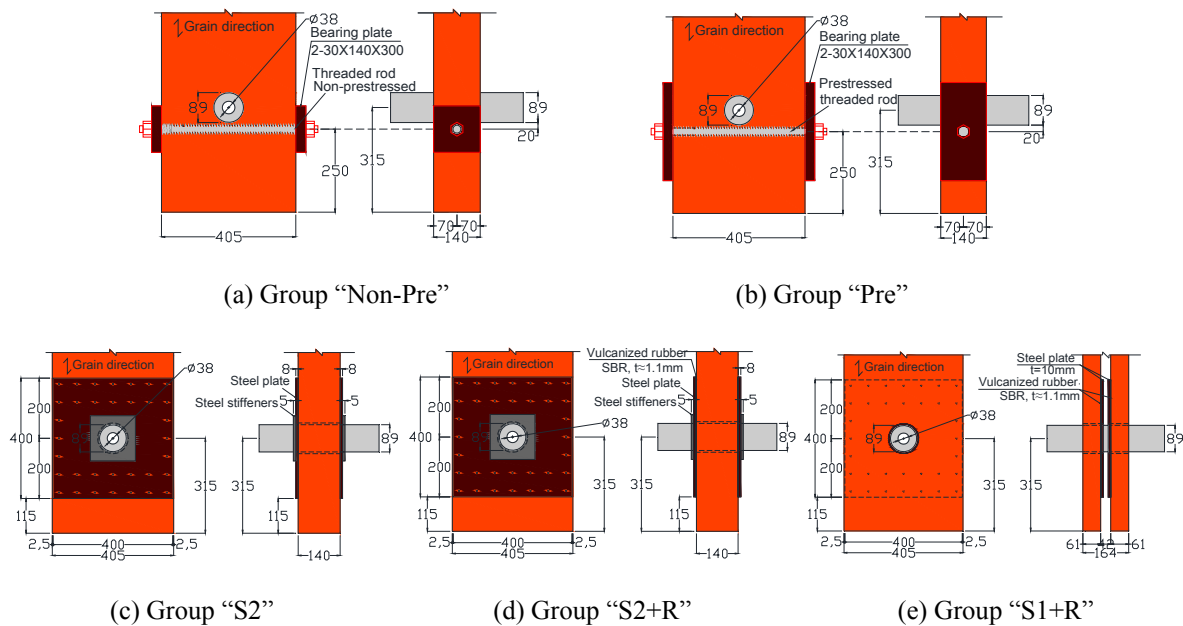
|  |  |
|---|---|
| (a) Group "Non-Pre" | (b) Group "Pre" |

|  |  |  |
|---|---|---|
| (c) Group "S2" | (d) Group "S2+R" | (e) Group "S1+R" |

Figure 1: Configuration of test specimens. Units: [mm]

## 2.6. Test setup

All tests were conducted at the Jiangsu Key Laboratory of Civil Engineering, Disaster Prevention and Mitigation, Nanjing Tech University. The general setup for all of the specimens is illustrated in Fig. 2. The tests were quasi-static tensile tests under displacement control and the actuator speed was 0.5 mm/min. Each specimen was equipped with an identical design of reinforced SLDDC on both ends. The loads were applied by the loading rods or loading plates between the dowels and the hydraulic device.

The dowel slip as well as the lateral deformation was continuously measured in both end of the specimens for group "Non-Pre" and "Pre". As to the other three groups, only the steel plate slip was measured.
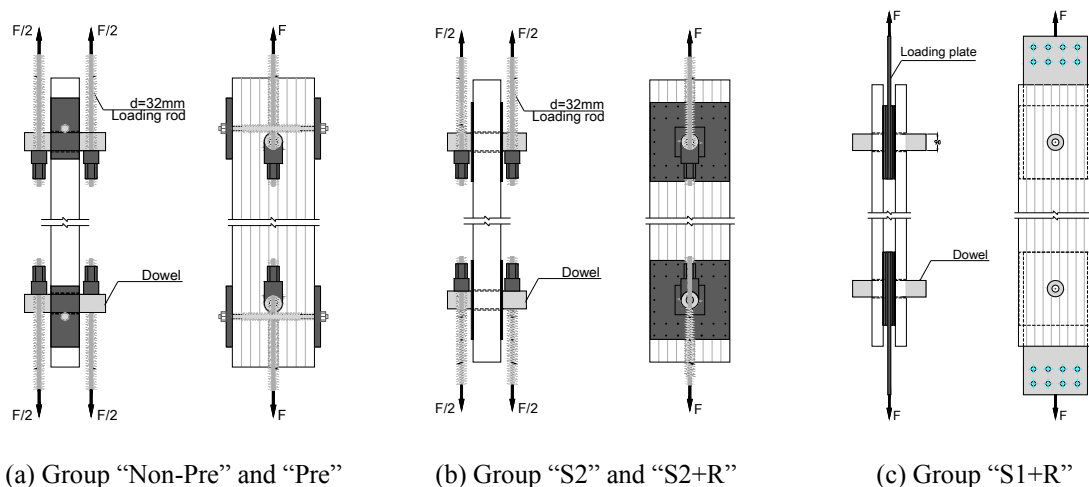
|  |  |  |
|---|---|---|
| (a) Group "Non-Pre" and "Pre" | (b) Group "S2" and "S2+R" | (c) Group "S1+R" |

Figure 2: General test setup.

## 3. Results and discussions

### 3.1. Bearing capacity

Table 1 displays average values of the test results for the specimens. And Fig. 3 gives a comparison on the bearing capacities and the residual strength of different groups. For a comparison, some of the test results of Kobel [3] are also presented here. From Table 1 and Fig. 3 it can be seen that the bearing capacity of the SLDDCs were significantly increased due to the reinforcements. And the gains in bearing capacity range from 46% to 639%.

For the reinforcement by bonding steel plate with vulcanized rubber layer, e.g. for the specimens in group "S1+R" and "S2+R", the bearing capacities were most greatly improved. The reason of such an improvement in strength is that the introduction of the rubber layer lead to a big decrease of the stress concentration at the bonding interfaces.

Lateral non-prestressing or prestressing is also effective way to improve the load bearing capacities of the SLDDCs. The bearing capacities were 46% and 122% higher than those of non-reinforced "Basic" specimens. As compared to Group "Dywidag" in Kobel [3] (See Fig. 4) with a prestress of about 3.1 MPa, the bearing strength of group "Pre" had no obvious difference. In other words, it can not be seen the notable effects on the bearing capacity by the location of the prestressed rods and the magnitude of the prestress values.

Table 1: Summary statistics of the test results

| Specimen group and no. | Bearing capacity $F_{max}$ Mean (Individual value) [kN] | Residual Strength $F_{res}$ Mean (Individual value) [kN] | $(\frac{F_{res}}{F_{max}})_{mean}$ [%] | Density $\rho$ [kg/m$^3$] | Moisture content MC [%] |
|---|---|---|---|---|---|
| Basic[1] | 134 (139, 127, 135) | 0 (0, 0, 0) | 0 | 523 | 12.1 |
| Non-Pre | 195 (188, 194, 204) | 95 (95, 41, 149) | 49 | 433 | 11.0 |
| Pre | 298 (276, 290, 327) | 47 (35, 60, 46) | 16 | 456 | 10.9 |
| S2 | 220 (281, 209, 170) | 112 (178, 71, 88) | 51 | 423 | 11.5 |
| S2+R | 990 (843, 1076, 1052) | 57 (0, 38, 132) | 6 | 457 | 11.4 |
| S1+R | 755 (800, 781, 683) | 347 (475, 334, 233) | 46 | 443 | 10.9 |
| Dywidag[1] | 306 (297, 342, 280) | 90 (40, 103, 126) | 29 | 392 | 9.2 |

Note: 1. From Kobel [3].
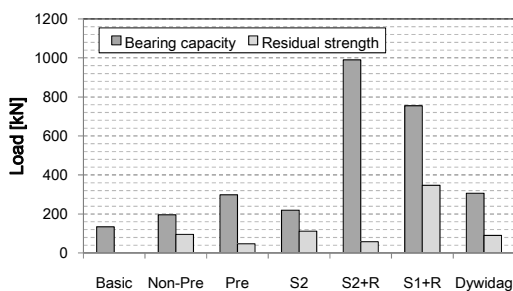


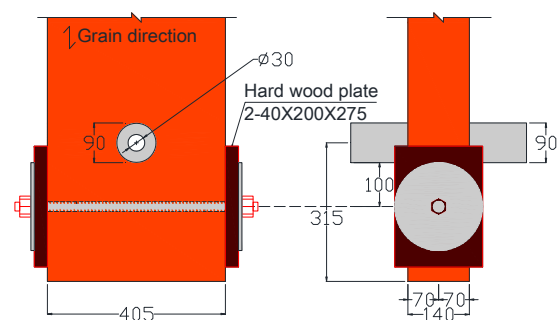Figure 3: Bearing capacities and residual strength



Figure 4: Configuration of "Dywidag" from Kobel [3]

The post failure strength was defined here as the residual load capacity just after the first failure of the specimen. The values of the residual strength for group "Non-Pre", "S2" and "S1+R" were about 50% of the maximum load. For group "S2+R" and "Pre" the value was only 6% and 16%, respectively. The maximum residual strength of 347kN was recorded by group "S1+R" and it was due to the failure just occurred in one side of the specimen (It is considered of the effect of the loading eccentricity by the test arrangement). After this first failure,

another side was also able to bear a high load. For group "S2+R", $F_{res}$ to $F_{max}$ ratio was only 6% because of the high load and the sudden failure. And the specimen would bear a high impact load from the fracture and thus result to a very small residual strength.

Another interesting phenomenon occurred in the load-displacement curves recorded by the test machine for group "S2". After the first failure and the recorded residual strength, the load increased to a higher level compared to the $F_{max}$. And then the load dropped and again increased to a high level, so back and forth several times (See Fig. 5). This observation indicates that this kind of specimen failed gradually in the last load stage. This may due to the fracture of the bonding surface near the load end caused by the stress concentration, and then some load was transferred to the wood screws nearby. While the second bonding fracture occurred with the increasing load, growing number of wood screws participated in the work. As a result, the ultimate load was usually higher than that at the first failure.
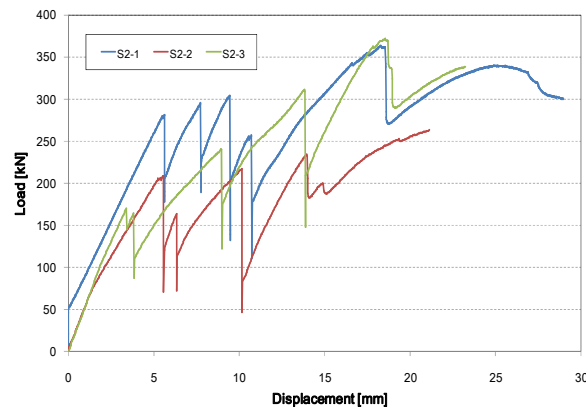


Figure 5: Load-displacement curves of group "S2"

## 3.2. Failure mode

For the SLDDCs with lateral reinforcement, the ultimate failure mode was a shear plug fracture (See Fig. 6). For a comparison, giving a prestress in the lateral reinforcement would generally lead to a larger shear plug and so as to reach a higher bearing capacity. It showed that even when there was no prestress in the rods, not any splitting appeared in the glulam specimen.



(a) Group "Non-Pre"                    (b) Group "Pre"

Figure 6: Failure modes of SLDDCs with lateral reinforcement

For the bonding smooth steel plate reinforced specimens, failure occurred due to bonding shear fracture between the steel plate and the glulam. Then the rest of the bonding layer combined with some of the wood screws worked together to bear the applied load, till to the failure of the whole bonding surfaces (See Fig. 7(a)). While for the group "S2+R", with a rubber layer, the ultimate failure showed a fully wood shear failure around the bonding area (See Fig. 7(b)). The average value of the shear stress at ultimate load reached to 3.1 MPa. As to

group "S1+R", with a double glulam specimens, the failure mode was combined the wood shear failure and tensile failure (caused by the load eccentricity for the glulam), see Fig. 7(c).

Another observation was that there was also the shear plug failure for the SLDDCs reinforced with bonding steel plates. However, it did not mean that it is a failure mode of this kind of specimens, since this shear plug was just caused by the high impact load due to the wood shear failure, i.e. the shear plug occurred just after the first failure.



| (a) Group "S2" | (b) Group "S2+R" | (c) Group "S1+R" |

Figure 7: Failure modes of SLDDCs reinforced with bonding steel plates

### 3.3. Stiffness

The load-slip stiffness is steel plate slip for the group "S2", "S2+R" and "S1+R". While it is dowel slip for the other groups, groups in Kobel [3] is also included. And it was determined as the rate of dowel or steel plate slip in load direction between $0.4 F_{max}$ and $0.7 F_{max}$.

Due to the test arrangement error, the dowel slip values were unfortunately not valid. But it can be seen from the test result of Kobel [3] that the lateral reinforcement has no contribution to the stiffness. For group "S2", there was quite little slip before the first failure, implying quite high slip stiffness. And due to the load eccentricity of the glulam in group "S1+R", the load-slip curves showed an irregular. So only the slip value of group "S2+R" was recorded. According to the sip value of this group, the stiffness (484 kN/mm) was obtained and gave a comparison with group "Basic" (308 kN/mm) and "Dywidag" (311 kN/mm) from Kobel [3]. So the gains of the stiffness was about 57% for group "S2+R" to group "Basic" and "Dywidag".

The load-slip behaviour of group "S2+R" was given in Fig. 8. There was a quite small variation in the stiffness and the bearing capacity. The relative smaller bearing capacity of S2+R-1 was due to the eccentricity caused by the high load to the test equipment. And then an update was provided to the other two specimens in this group. It could also be observed from Fig. 8 that there was an increasing stiffness during the late loading stage due to the strain hardening of the rubber layer.
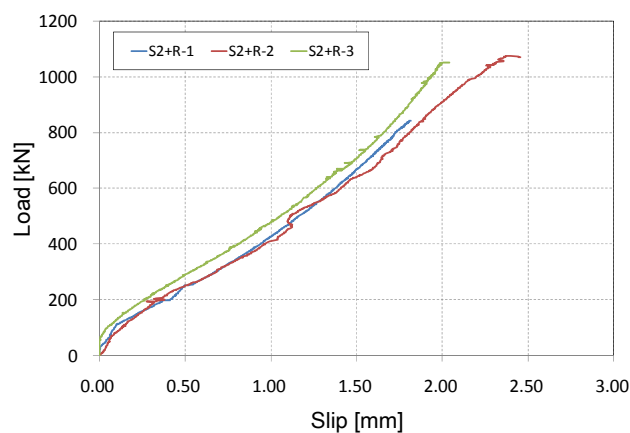


Figure 8: Load-slip behaviour in group "S2+R"

## 4. Conclusions and future work

From the results of the full-scale test series for SLDDCs the following conclusions can be drawn:

- Lateral reinforcing or prestressing are both able to prevent the splitting, and lateral prestressing will lead to a larger bearing capacity.

- The location of the prestressed rods around the dowel hole in glulam specimen appears to have little effect on the bearing capacity.

- The high prestress in this showed no improvement in strength as compared to the test results of the earlier research.

- The reinforcement with bonding steel plates to the glulam is a very efficient way to the SLDDCs, especially with a rubber layer vulcanized to the steel plates. The bearing capacity was 990kN, implying an increase of 639% in bearing capacity. The main reason is the considerably reduced stress concentration and therefore come into a quite uniform shear stress distribution on the bonding surfaces.

- The slip stiffness of the group with a rubber layer on the steel plate can also be increased into a high level compared to the control "Basic" group.

- For a bonding smooth steel plate reinforcing, the gains in bearing capacity was much less than that had a rubber layer. But even so, its gains reached to 64%.

From the test and the observation, further studies should be carried out including:

- The lateral prestressing with a lower level should be taken into consideration.

- In order to further improve the efficiency of the bonding steel plate reinforcement, different kinds of shapes and placement of steel plate need to be studied.

- Since the wood screws can prevent the sudden fracture of the bonding smooth steel plate reinforcement, it is noteworthy that the arrangement of the wood screws should also an important factor on the bearing capacity as well as the slip stiffness.

- It is strongly recommended that ductile glue should be used between steel plates and glulam so as to decrease the stress concentration on the bond surface.

- For the group with bonding steel plate vulcanized a rubber layer, some measures should be taken so as to endure the sudden impact load on the glulam specimen caused by the fracture at a very high load level.

- Numerical model is a more efficient and economical way to carry out some parametric analysis and also the stress distribution study.

## Acknowledgement

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