Dowel type connections in laminated bamboo with multiple slotted-in steel plates

Annex E – Dowel tensile tests

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1 Introduction

In order to calculate the expected capacity of a connection several parameters are necessary. One of these parameters is the moment capacity of the used dowels. To determine this moment capacity one can make use of the formula provided by Eurocode 5, which has a correction factor for large diameter dowels, or a more theoretical formula such as the one proposed by (Jorissen, A., Leijten, A., 2005). This last formula is shown here.

$$M_{y,Rk} = \frac{1}{6} * f_y * d^3 \approx \frac{1}{6} * 0{,}8 * f_{u,k} * d^3$$

To determine the yield moment of the dowel, the above formula makes use of either the yield stress or the ultimate tensile stress of the dowel. It follows that, for an accurate estimate of the expected capacity of a timber connection, the tensile strength of the dowel has to be determined.
The laminated bamboo connections in this research were designed using dowels of steel grade S355. In this design already a margin of error of 20% was anticipated. According to Eurocode 3, a dowel with a yield stress of 355N/mm² has an ultimate tensile strength of about 510 N/mm². For the design of the connections an ultimate strength of 1.2*510 = 612N/mm² was anticipated. By using the approximation $f_y \approx 0.8*f_{u,k}$ (Jorissen, A., Blaß, H., 1998) the M_y was then calculated.
To verify that the expected capacity of the connections was correct and potentially adjust this expectation an extra length of dowels (grade S355) was ordered. This extra length will be used for tensile tests in which the actual yield stress and ultimate tensile stress of the dowels will be determined.

1.1 Goal

The goal of this annex is to perform tensile tests on the delivered dowels so that the actual tensile strength of the dowels is known.

1.2 Plan of action

First the extra length of dowel will be cut into pieces so that several monsters can be made to perform tensile tests on. After that, the individual dowels shall be equipped with displacement meters and attached to a pulling bench. By measuring the force needed to pull apart the dowels (the diameter of the dowels is the same 12mm as used in the design of the laminated bamboo connections) the ultimate tensile strength of the dowels could be determined. The placement of the displacement meters gives some insight in the ductility of the dowels.

1.3 Reading guide

The procedure followed during the tensile testing of the dowels used in this research and the results that followed from these tests are given in 2 - **Dowel tensile tests**. In 3 - **Comparison between delivered steel grades** a comparison is made between dowels of different steel grades ordered from the same supplier.

2 Dowel tensile tests

First, the extra length of steel rod was cut into pieces of approximately 380 mm in length. The length of the cut pieces is shown in Figure 1 - Dowel test pieces.

Figure 1 - Dowel test pieces

After length cutting of the dowels a device to hold the displacement meters was attached to the dowels. A picture of this device can be seen in Figure 2 - Device to hold the displacement meters.

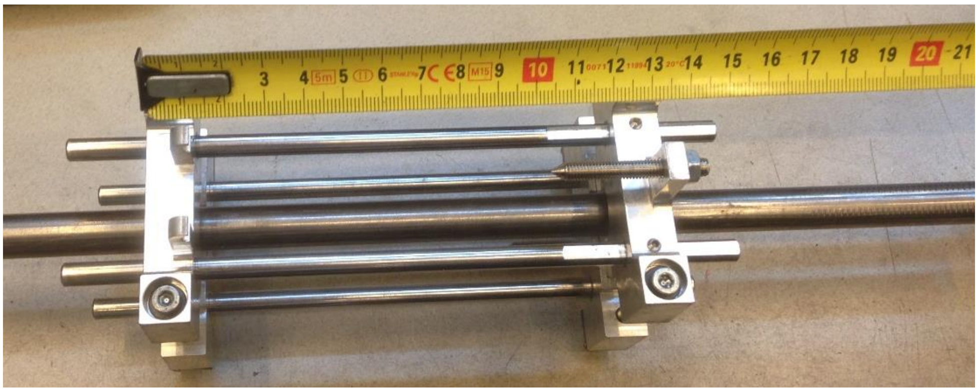

Figure 2 - Device to hold the displacement meters

In the picture is shown that the displacement of the dowel during the tensile tests is measured over 120mm. By keeping this measuring distance constant for all dowels an easy comparison could be made between the test pieces and the occurring strain could be easily calculated.
Next, the dowels were placed into the pulling bench. The pulling bench made use of wedge grips to grab on to the dowels. Some pictures of the used pulling bench and wedge grips can be seen in Figure 3 - Pulling bench for dowel tensile tests.

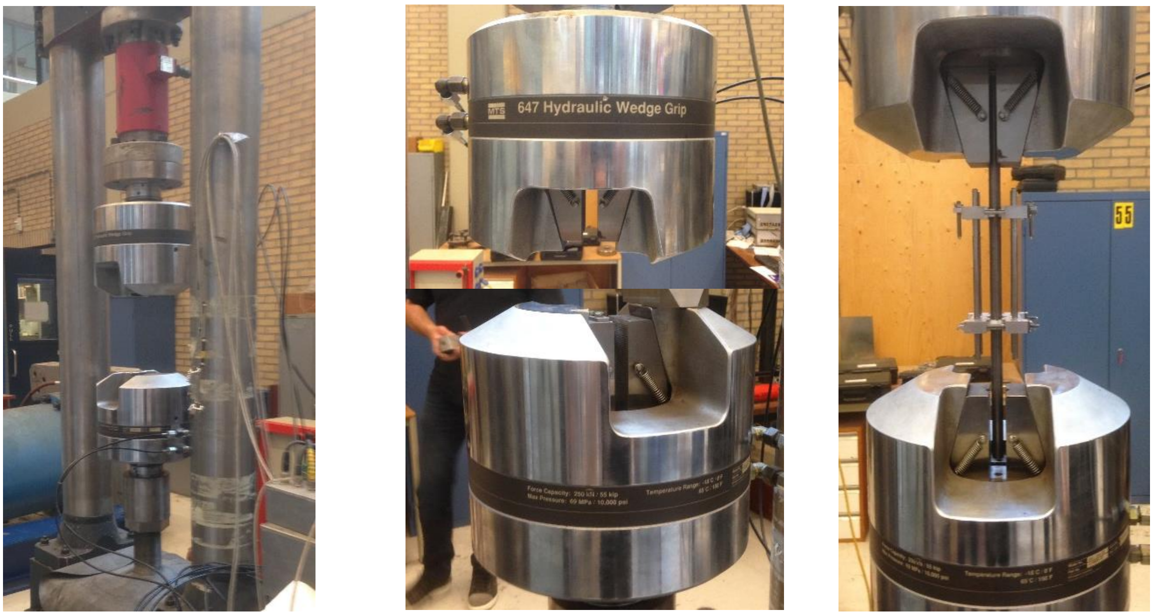

Figure 3 - Pulling bench for dowel tensile tests

After the instalment of the dowels, the pulling bench was activated and the dowels were loaded until failure using a constantly increasing displacement. From the measurements made by the displacement meters the elongation in the steel rod was calculated ($\varepsilon = \frac{\Delta l}{L}$). A picture of one of the ruptured rods is shown in Figure 4 - Ruptured rod.

Figure 4 - Ruptured rod

From the force exerted by the pulling bench also the stress acting on the dowel was calculated. By combining the calculated elongation and stresses, a σ-ε diagram was made in which the yield stress of the dowel and its ultimate stress can be easily read. This diagram is shown in Figure 5 – σ-ε diagram of steel grade S355.

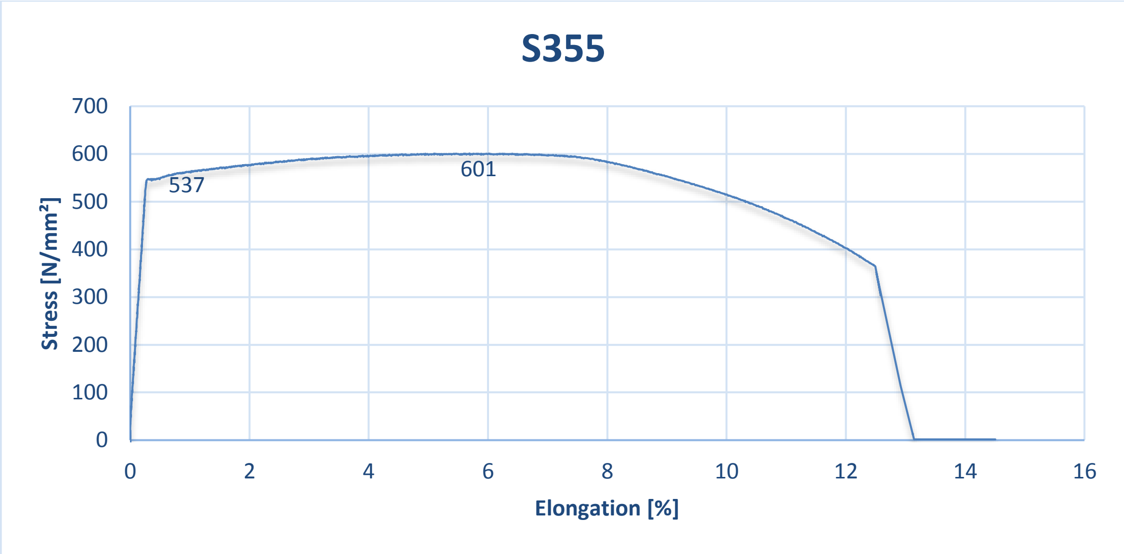

Figure 5 – σ-ε diagram of steel grade S355

This diagram shows a measured yield stress of 537N/mm² and a measured ultimate stress of 601N/mm². Clearly the measured stresses are much higher than could be expected from an ordered steel grade S355. However, during test piece design this was already anticipated and the design was based on the 510N/mm² ultimate stress prescribed by Eurocode 3, with an additional 20% to account for differences between ordered and delivered steel. Concluding, the test pieces were designed using an ultimate tensile strength of 612N/mm² and the delivered steel dowel had a tested ultimate tensile strength of 601N/mm².
Prior to testing the laminated bamboo connections, this measured tensile strength was used to determine the expectancy of the connection capacity.

3 Comparison between delivered steel grades

In this chapter a comparison will be made between tensile tests done on dowels of two different ordered steel grades. Another research was done at TU Delft at the same time this research took place. For this other research dowels of steel grade S235 were ordered from the same supplier. Both of these types of dowels were placed in the same order and the only difference was the ordered steel grade (S235 for the other research and S355 for this research).
From both types of dowels lengths of 380 mm were cut and tested in the way that is described in 2 - **Dowel tensile tests**. A photograph of both tested dowels of the two steel grades can be seen in Figure 6 - Tested dowels (left: S235, right: S355).

Figure 6 - Tested dowels (left: S235, right: S355)

For both steel grades σ-ε diagrams were made. To compare the yield stress and ultimate tensile strength of both steel grades the diagrams were overlaid. The resulting graph is shown in Figure 7 – Overlaid σ-ε diagrams for S235 and S355.

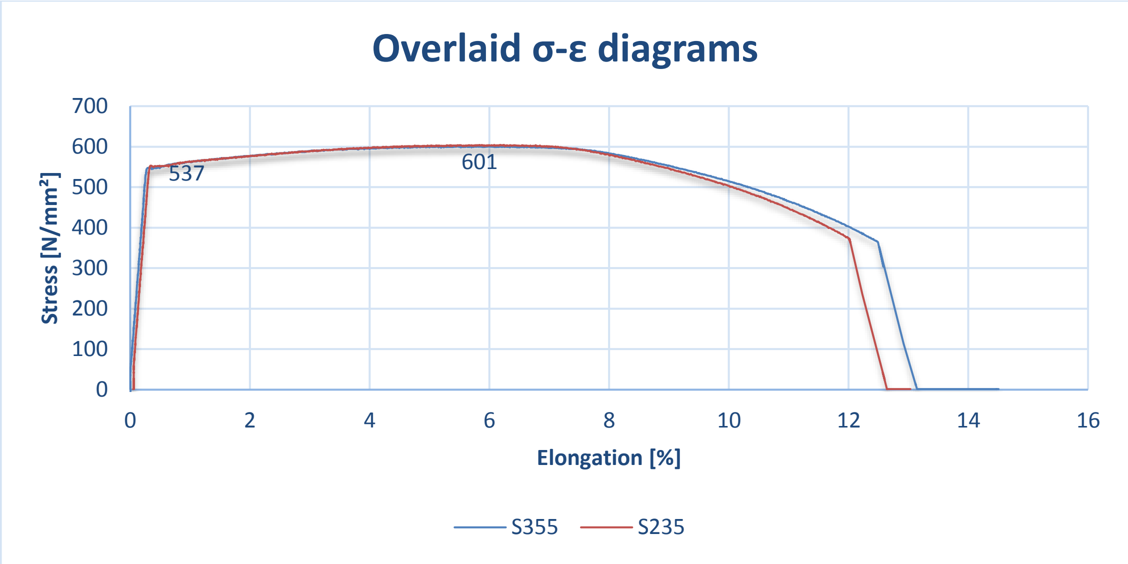

Figure 7 – Overlaid σ-ε diagrams for S235 and S355

In the graph can be seen that the behaviour of the ordered steel grades S235 and S355 is very similar, if not exactly the same. The most probable explanation for this behaviour is of course that the delivered steel grades were, in fact, one and the same steel grade. However, due to a lack of a similar yield stress as one of the ordered steel grades it could not be determined which steel grade had been delivered. It could, of course, be speculated that the found ultimate value of 601N/mm² is within the range for the ultimate stress of S355 and the increased yield stress is a result of some cold forming process. This would also explain the limited deformation capacity of only 13%.

The comparison made in this chapter and the results found are shown here as a reminder that, when ordering a certain steel grade, the supplier of the steel only has an obligation to supply a steel that has a strength of at least the required value. So when ordering a certain steel grade a supplier is within his rights to deliver a steel of a much higher strength then asked for if he pleases. Normally this would never be a problem, in fact, usually this would mean that a construction will only be stronger. For research purposes however, it is always advisable to test the delivered dowels and determine their actual capacity, preferably even before making the actual connection design.

4 References

Jorissen, A., Blaß, H. (1998). *The fastener yield strength in bending.* Working commision CIB W18 - timber structures, paper 31-7-6.

Jorissen, A., Leijten, A. (2005). *The yield capacity of dowel type fasteners.* Karlsruhe, Germany: CIB-W18/38-7-5.