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

Annex G – Exploratory tests

Auteur, studentnr:	JJB Debije, 4309995
Datum:	06-02-2017
Bedrijf:	Technische Universiteit Delft
Adres:	Stevinweg 1
	2628 CN Delft
Afdeling:	Faculteit Civiele Techniek en Geowetenschappen
Opleiding:	Civiele Techniek
Hoofdprofiel:	Structural Engineering
Uitstroomprofiel:	Staal en houtconstructie
Begeleiders:	prof.dr.ir. J.W.G. Van de Kuilen
	ir. P.A. de Vries
	drs. W.F. Gard
	drs. W.N.J. Ursem
	ing. A. van der Vegte

Table of Contents

1 Introduction

Prior to testing the, during phase 1, designed laminated bamboo connections, it was necessary to perform several exploratory tests. The goal of these exploratory tests was mainly to confirm the expected embedment strength which was used during the connection design and to get acquainted with the testing equipment. This annex gives the results found during these exploratory tests and describes the testing method used to obtain these results.

1.1 Reading guide

After this short introduction 2 - **Exploratory testing method** will explain the testing method used and give some information on the instalment of the displacement meters. After that, the obtained results are given in 3 - **Exploratory test results**. Based on these test results, some final remarks are given in 4 - **Conclusions from exploratory tests**.

2 Exploratory testing method

To make testing of the connection variants go as smoothly as possible, all exploratory tests were done in accordance with the same testing standard as used for the connection variants. The testing standard used was (NEN-EN 1380:2009). The test protocol described in this standard is explained in **Annex B** – Testing procedure. This testing procedure prescribes tests in which the connection is first loaded to 40% of its estimated capacity, then the load is lowered to 10% and increased to 70%. After that the connection is loaded until failure.
Before testing, the capacity of the connections used for the exploratory tests needs to be estimated. The connections used for these tests were made from bamboo slats that were a remainder of the sawing process. All of these slats had a slightly varying thickness of 14.5mm. Using the expected value of the embedment strength (based upon the measured material density of 708.3kg/m³) the capacity of the connections made from these slats was estimated. The estimated capacity is shown in Table 1 - Expected capacity of exploratory tests.

	Slotted plates	Shear planes	Dowel 1 diameter	M_y	f_h	t	a	b	$F_{v,Rk}$ Mode 1	$F_{v,Rk}$ Mode 2	$F_{v,Rk}$ Mode 3
			[mm]	[Nmm]	[N/mm²]	[mm]	[mm]	[mm]	[kN]	[kN]	[kN]
Test 'X'	1	2	12	154656	63.6	14.5	28	20	22.1	31.4	43.4

Table 1 - Expected capacity of exploratory tests

In the table also the moment yield capacity of the dowel can be seen. The yield capacity shown here has been determined using the measured yield strength of the dowels. The measuring of this yield strength was done by performing tensile tests. These tests are described in **Annex E** – Dowel tensile tests.
Based on the estimated capacity, the testing protocol was established. This testing protocol is shown in Figure 1 - Testing protocol of exploratory tests.

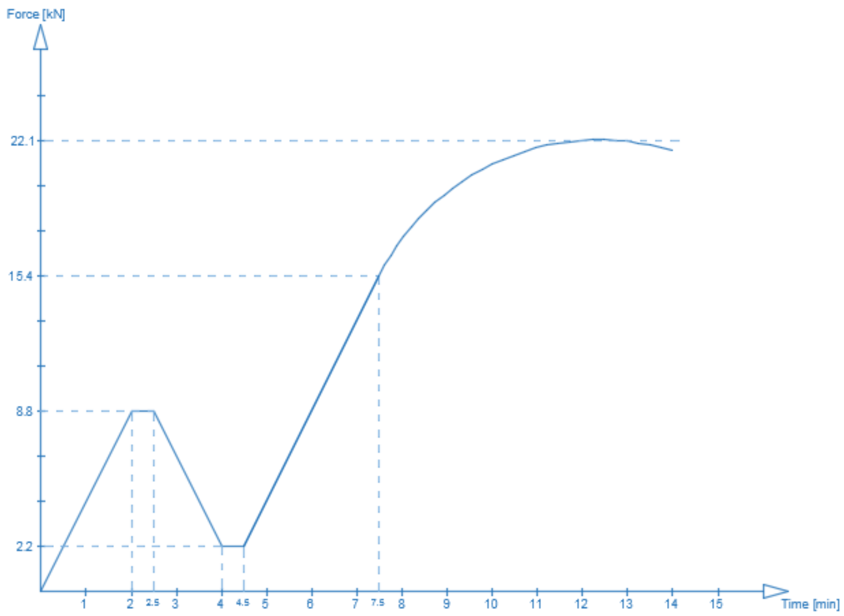


Figure 1 - Testing protocol of exploratory tests

In the figure the values for 10%, 40% and 70% of F_{est} are shown. Also the time in which this load has to be applied to the connection is specified. From these two values the loading rate was determined to be 0.2*F_{est} per minute, which corresponds to 0.0733kN/s.
When the load controlled portion of the test is finished and 70% of F_{est} is reached, the test continues on a displacement controlled setting. The speed in which the pulling bench should impose this displacement should be such that the test specimen will reach its ultimate capacity within a total testing time of 10 to 15 minutes. Since the displacement at ultimate load should be known to determine this displacement speed precisely, an initial estimate was made based on the displacement speed during the last part of the load controlled stage up until 70% of F_{est}. Based upon that speed the rate of displacement was set at 0.01 mm/s. This rate of displacement proved to be enough to get a connection failure between 600 and 900 seconds of testing time (10 to 15 minutes). A total of six exploratory tests were done.
To examine the effects of a different testing speed during the displacement controlled stage the fifth test was done at half speed (0.005 mm/s).
Since the displacement given by the pulling bench will not be equal to the displacement of the laminated bamboo connections (due to the displacement of the steel used to secure the test pieces to the testing equipment), displacement meters were installed with which the displacement of each connection could be accurately measured. A schematic drawing of the placement of these displacement meters is given in Figure 2 - Displacement meters at the front of a connection.

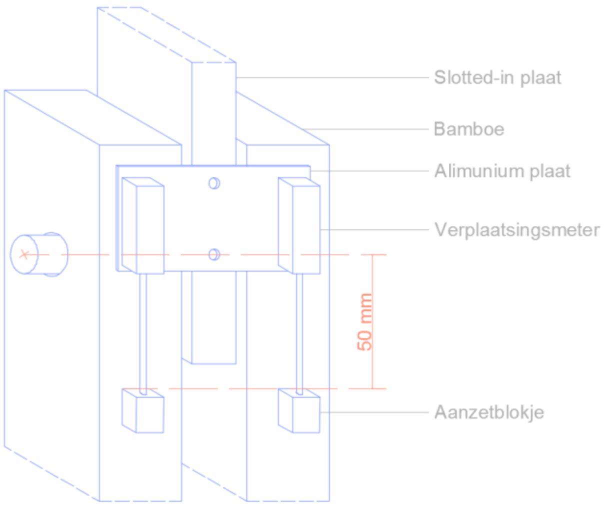


Figure 2 - Displacement meters at the front of a connection

In the above figure two displacement meters are shown. They are placed at each side of the slotted-in steel plate. The displacement meters were connected to the slotted-in plate by use of a small aluminium plate that was screwed onto the slotted-in plate. The first screw was located at the height of the dowel. The tip of the displacement meters was placed against a small metal cube that was glued onto the laminated bamboo at a distance of about 50 mm from the dowel. To glue these cubes a glue gun was used. The displacement meters were placed at the front and the back of each connection. So for each test piece consisting of two connections a total of 8 displacement meters was used. The results obtained from the tests are given in the upcoming chapters.

3 Exploratory test results

3.1 Test 1

Notes:

Test 1

Material thickness left: 14.5mm

Material thickness right: 14.5mm

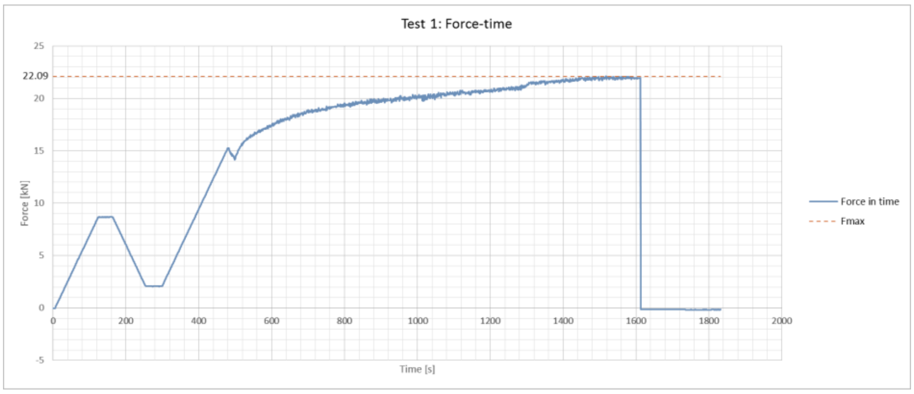
F_{est} 22.10kN

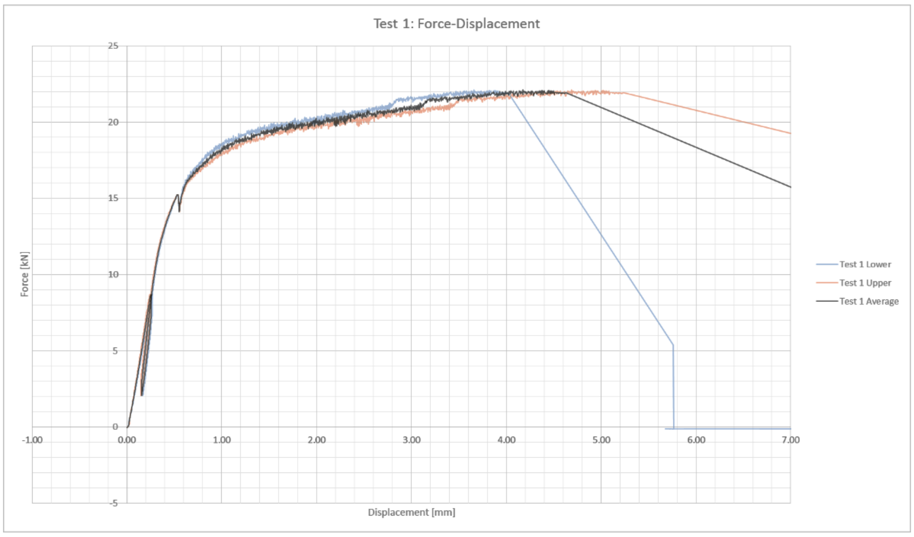
F_{max} 22.09kN

F_{max}/F_{est} 0.99

Failure: Shear + splitting

Brittle





3.2 Test 2

Notes:

Test 2

Material thickness left: 14.5mm

Material thickness right: 14.5mm

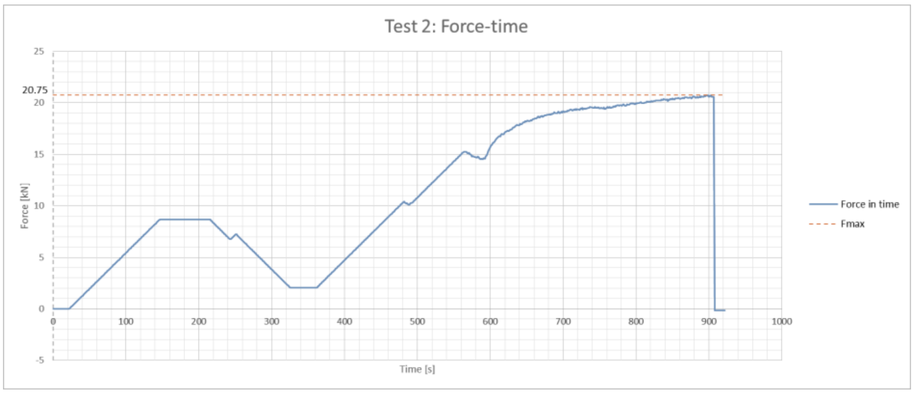
F_{est} 22.10kN

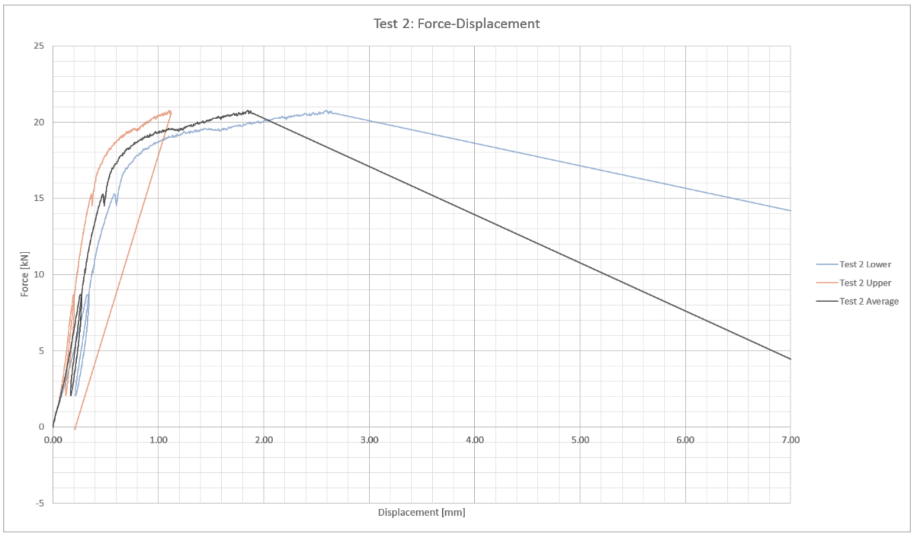
F_{max} 20.75kN

F_{max}/F_{est} 0.94

Failure: Shear + splitting

Brittle





3.3 Test 3

'

Notes:

Test 3

Material thickness left: 14.5mm

Material thickness right: 14.5mm

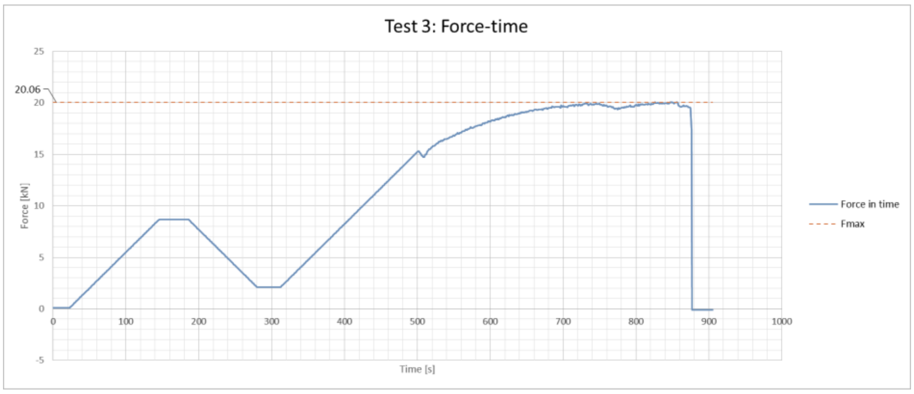
F_{est} 22.10kN

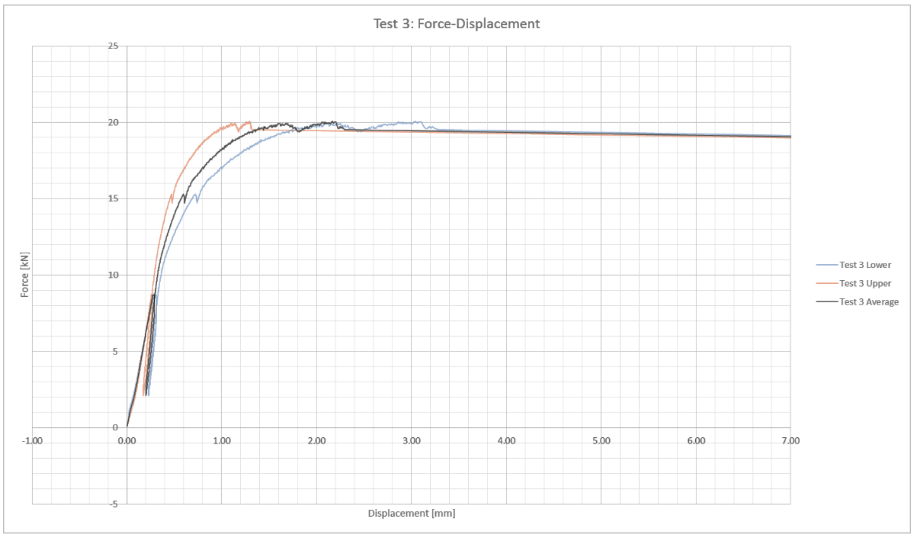
F_{max} 20.06kN

F_{max}/F_{est} 0.91

Failure: Shear + splitting

Brittle





3.4 Test 4

Notes:

Test 4

Material thickness left: 14.5mm

Material thickness right: 14.5mm

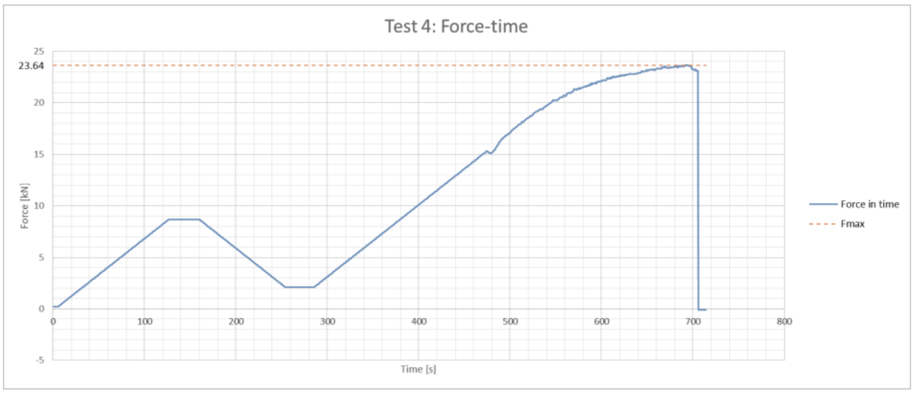
F_{est} 22.10kN

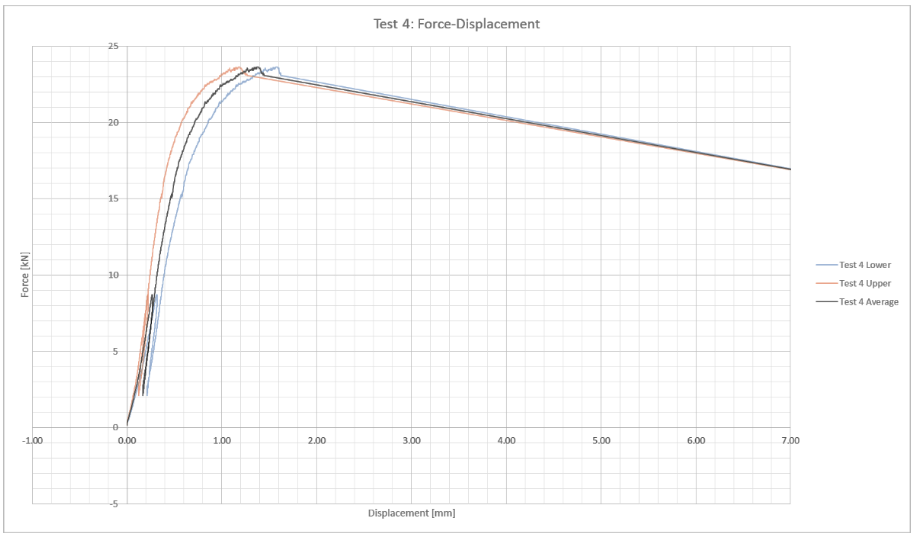
F_{max} 23.64kN

F_{max}/F_{est} 1.07

Failure: Shear + splitting

Brittle



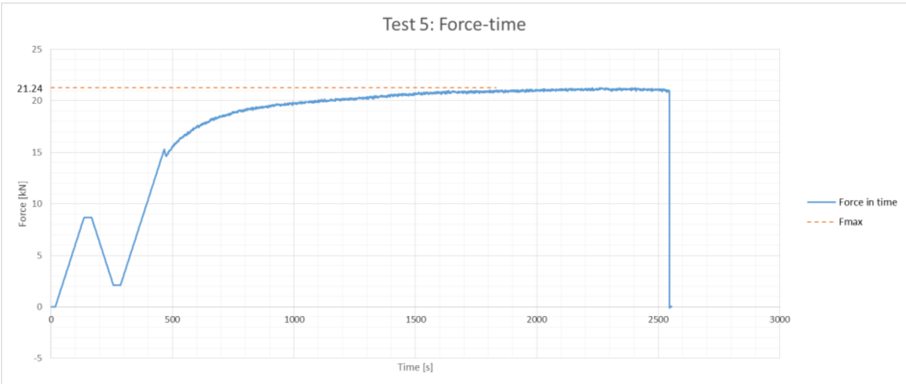


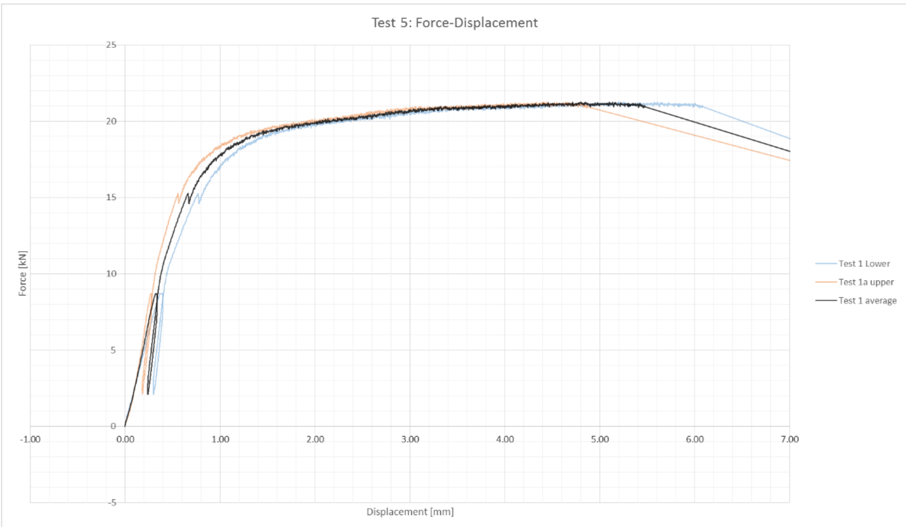
3.5 Test 5

Notes:

Test 5

Material thickness left:	14.5mm
Material thickness right:	14.5mm
F_{est}	22.10kN
F_{max}	21.24kN
F_{max}/F_{est}	0.96
Failure:	Shear + splitting
	Brittle



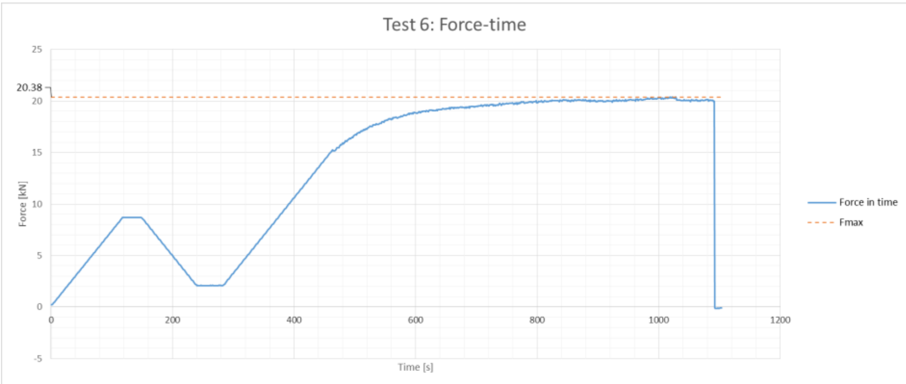


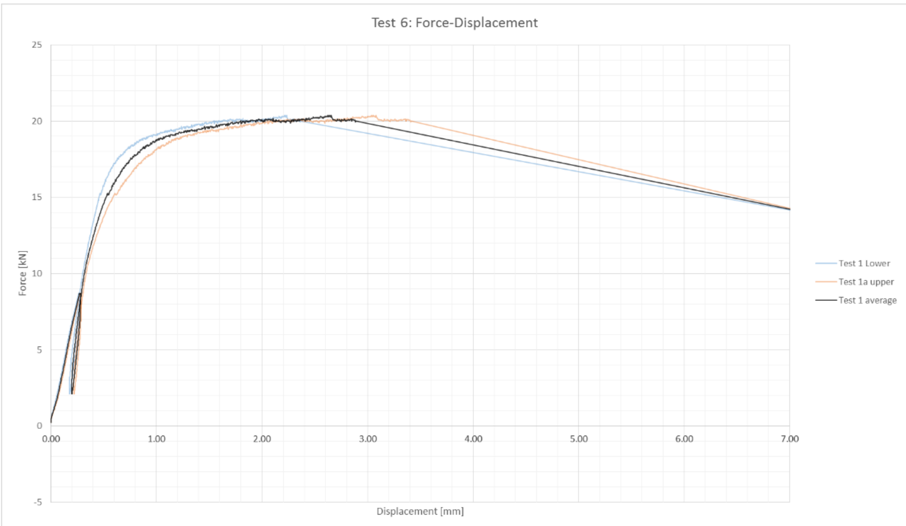
3.6 Test 6

Notes:

Test 6

Material thickness left:	14.5mm
Material thickness right:	14.5mm
F_{est}	22.10kN
F_{max}	20.38kN
F_{max}/F_{est}	0.922
Failure:	Shear + splitting Brittle





3.7 Test 1 to 6 combined

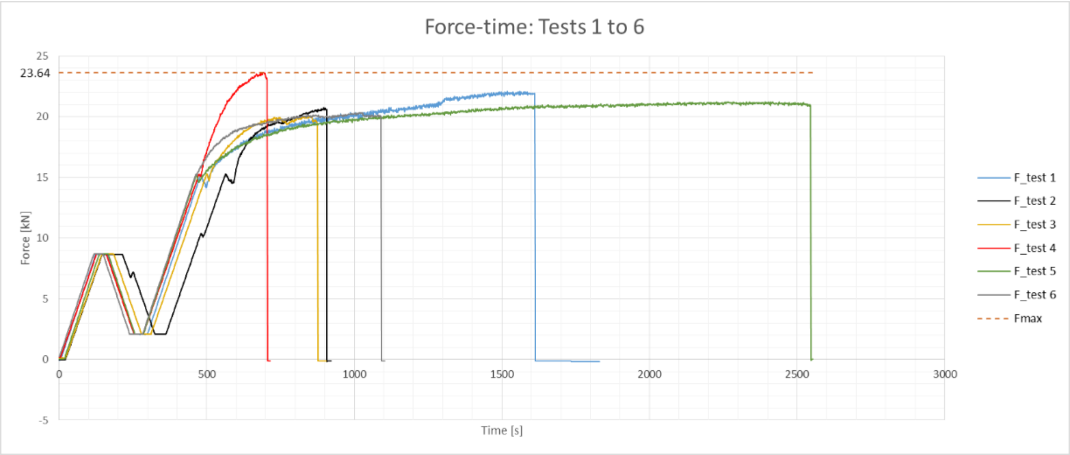
Notes:

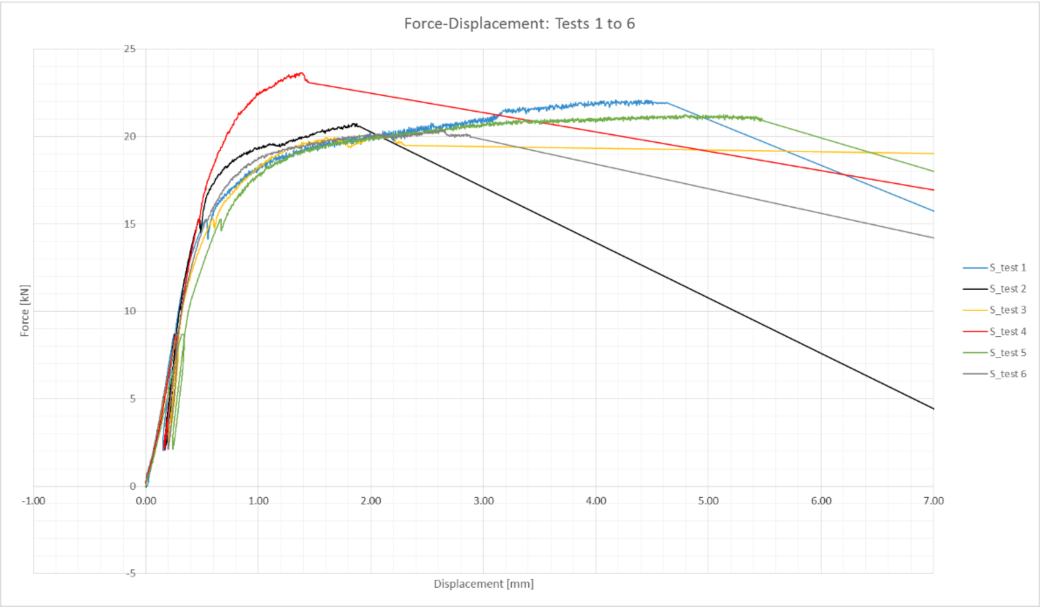
Tests 1 to 6

Material thickness left: 14.5mm

Material thickness right: 14.5mm

F_{est} 22.10kN





3.8 Test 1 to 6 normal distribution

Combined test results

Faverage [kN]	S.Dev [kN]	COV	5-Perc
21.36	1.33	0.06	18.10

Adjusted test results

Faverage [kN]	S.Dev [kN]	COV	5-Perc
22.26	1.61	0.06	18.32

Notes:

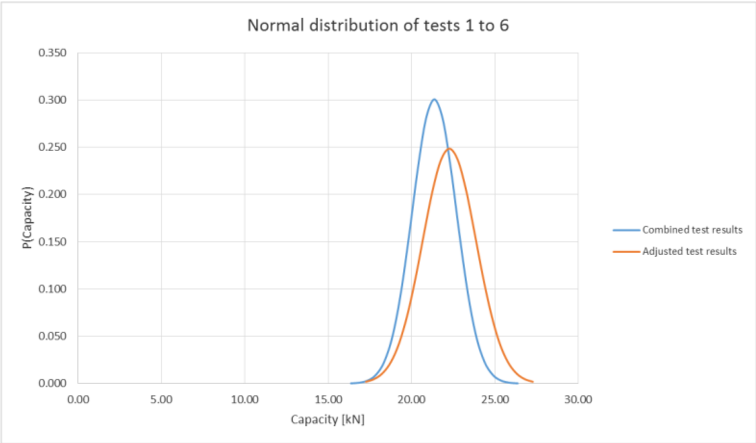
Tests 1 to 6

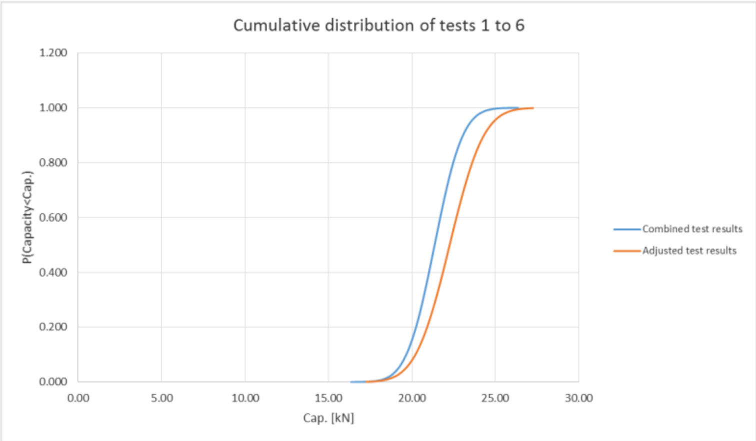
Material thickness left: 14.5mm

Material thickness right: 14.5mm

F_{est} 22.10kN

$F_{adjusted}/F_{est}$ 1.0072





- The resistance $F_{adjusted}$ given here is the average of the measured capacities that has been adjusted by use of the findings in 'Annex F – Probabilistic analysis of test data'. The formula found in this annex makes it possible to approximate the actual average capacity and standard deviation.

4 Conclusions from exploratory tests

In the previous chapter the results from all 6 exploratory tests are given. In that chapter graphs are shown that describe the behaviour of the test specimens during the loading process. Also the obtained normal distribution graphs are shown together with the determined values for the standard deviation and the COV.
Since all test pieces were loaded until failure, the F_{max} of every (failed) connection was measured and recorded. Since these failed connections only make up for the weaker half of all connections the measured maximum capacities needed to be modified to get a realistic value for the maximum average capacity for all connections.
The way in which this modification is done was explained in **Annex F** – Probabilistic analysis of test data.

The F_{max} was determined to be 22.26kN. Through a comparison with the estimated value F_{est} of 22.1kN it can be seen that the measured value for the capacity only deviates from the expected value by 0.72%. This already indicates that the embedment strength used to calculate the expected capacity is close to the real value.
The embedment strength displayed by the laminated bamboo during these exploratory tests is calculated below.

$$f_{h,tested} = \frac{F_{max,all}}{2 * t * d_1} = \frac{22.26 * 1000}{2 * 14.5 * 12} = 63.97\ N/mm^2$$

$$f_{h,est} = 63.6\ N/mm^2$$

$$\frac{f_{h,tested}}{f_{h,est}} = 1.0057$$

The calculation above shows that there is only a 0.57% difference between the measured embedment strength and the estimated embedment strength of the laminated bamboo. Although these are not actual embedment strength tests, this clearly suggests that the formula used for the estimation of the embedment strength may be as well suited for laminated bamboo as it is for timber.
It must be noted, that during these exploratory tests, the displacements measured at the moment of failure were all in between 1 and 5 mm and shear failure combined with splitting behaviour was observed in all test specimens. This phenomenon is less likely to occur in an actual embedment test (at least at these displacement values) due to an embedment test having a supported instead of a free end. For a number of test specimens the loading was still increasing at the moment the specimen failed. The measured embedment strength will thus most likely be an underestimation.

5 References

NEN-EN 1380:2009, e. (n.d.). *Houtconstructies - Beproevingsmethoden - dragende nagels, schroeven, stiften en bouten.*