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TU Delft Large-scale testing campaign 2016 – WP4

TEST REPORT ON CYCLIC BEHAVIOUR OF PLANK-JOIST CONNECTIONS OF SAMPLES EXTRACTED FROM EXISTING BUILDINGS

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Table of Contents

1 Introduction

This report presents the materials, experiment setups and testing procedures directed at determining the back-bone curves that describe the plank-joist connections of samples extracted from NAM houses. The last section contains an overview of the results obtained for the different specimens tested. The use of the outcome of these experiments are twofold:

- They provide input for FEM models to predict the mechanical behaviour of full size floors (diaphragms) made of joists with planks nailed to them.
- They provide input for the selection of materials to build up replicas of diaphragms that will be cyclically tested in a later stage, both non-strengthened and strengthened.

For the plank-joist connection a distinction is made between nailed and screwed connections. The testing started with nailed connections, which is common use in pre-war houses. The loading is applied in three ways: loading the plank perpendicular to the joist and parallel to the joist, as well as rotation of the plank relative to the joist (see figure 1). All specimens were tested under cyclic loading, according to a prescribed loading program.

The determination of the material properties is described in protocol C31B67WP4-3.

This report is structured as follows: chapter 2 presents the nomenclature that will be used in the document. Chapter 3 describes how the floor and roof samples were extracted from the NAM houses. Chapter 4 describes how the specimens for testing were cut from the extracted samples. In chapter 5 the test setup, the used machinery, the measurement instruments and the loading procedure for each of the plank-joist connections is presented. In chapter 6 the individual test results are presented. In chapter 7 a summary of all the experimental results is reported.

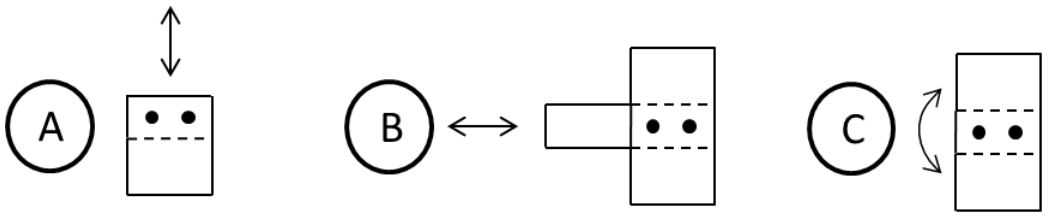


Figure 1: Specification of test specimens: A – loading perpendicular to joist, B – loading parallel to joist, C – loading in torsion

2 Nomenclature

2.1 Symbols

Below is an overview of the different symbols used in this protocol.

l_{plank}	Length of plank
h_p	Height of plank (thickness)
w_p	Width of plank
l_{beam}	Length of beam
h_b	Height of beam
w_b	Width of beam
s_2	Distance between nails in one plank in the direction of the beam
b_s	Eccentricity of nails compared to longitudinal axis of beam
v_u	Ultimate joint displacement
$F_{\max}$	Maximum vertical load

3 Selection, extraction and transport of timber samples

3.1 Introduction

NAM is in possession of a number of houses in the Groningen area, some of which had to be demolished: thus, they served as a source for the extraction of samples, which were cut into elements to be tested in the laboratory of the TU Delft to compare the material properties and test conditions of future experiments to the actual conditions.
From 2 houses, related to the timber diaphragms and their connections to the masonry, samples of the existing floors and roofs were taken: one roof sample and three floor samples – one of which was strengthened with two layers of planks – originated from Rengersweg 15, Godlinze, whereas one roof sample and one floor sample originated from Zijlvest 25, Loppersum (see figure below). Both samples from Zijlvest 25, Loppersum contained boards instead of planks as decking material.

Rengersweg 15, Godlinze **Zijlvest 25, Loppersum**

Figure 2: NAM houses from which the samples were extracted

3.2 Prescriptions given to properly collect the specimens

The extraction of samples was conducted according to [2]. A visual survey was performed prior to the selection of timber samples and the following process was performed for the selection of them:

1. Existing finishes, such as carpet, had to removed, so that the sample itself was void of anything but the structural floor: joists, planks and nails. For roofs the tiles were removed.
2. The sample location in the building was marked and identified, and a sketch or photograph from each proposed sampling location was prepared. The characteristics of desired timber samples are listed in table 1.
3. Any imperfections on the samples was marked.

The process of extracting timber samples was performed without causing damage to the samples:

4. The samples were extracted carefully from the structure.
5. The samples were removed from the construction site and set on a dry and stable horizontal surface.
6. Samples were moved to site of preparation for shipping and the specimen's condition on all exposed sides had to be documented. The samples had to be kept out of the sun to prevent drying cracks.

To prevent damage to the samples during transportation:

7. The timber samples were protected on all sides.

After that the Specimens were delivered at TU Delft Stevin II laboratory.

Table 1 – Characteristics of the extracted timber samples.

Sampling	Approximate Size	Including	Remarks
1. Sampling from floor	1.5 m x 1.5 m	- Planks, joists connected with nails or screws	- At least 2 joists in the sample. - Intact square samples, as in the original construction. - Planks at the sides at least 0.3 m outside the joists. - No decayed timber samples.
2. Sampling from roof	1.5 m x 1.5 m	- Planks, joists connected with nails or screws	- At least 2 joists in the sample. - Intact square samples, as in the original construction. - Planks at the sides at least 0.3 m outside the joists. - No decayed timber samples.

3.3 Extraction of samples from NAM houses

The aforementioned houses were visited by TU Delft and NAM on 4th of July 2016 and samples to be extracted were identified and marked. Samples from Zijlvest 25 in Loppersum were marked with the letter Z and a number, whereas the samples from Rengersweg 11 in Godlinze were marked with the letter G and a number.

3.3.1 Detached house (Rengersweg 11, Godlinze)

From this house 4 samples were extracted, one from the roof and three from the floors.

Sample G1: This is a sample from the ground floor of approximately 1.5 m by 1.5 m.

Sample G2: Sample from the roof, extracted from wall plate to top beam. The sample is approximately 2.2m by 1.5 m.

Sample G3: Sample from the first floor, an original part. The sample size is approximately 2.5 m by 1.5 m.

Sample G4: Sample from the first floor, a strengthened part. The sample size is approximately 2.5 m by 1.5 m.

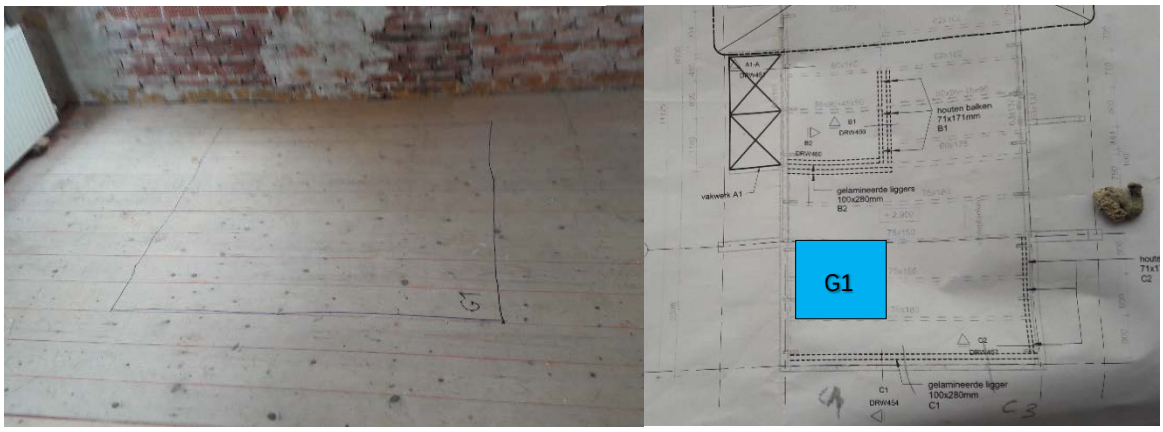


Figure 3: Floor sample G1 and its location in the house

Figure 4: Roof sample G2 and its location in the house.

Figure 5: Floor samples G3 and G4; upward and downward facings and location in the house.

3.3.2 Terraced house (Zijlvest 25, Loppersum)

From this house one floor sample, one roof sample and some connections were extracted.

Sample Z1: This was a sample from the attic floor of approximately 2.5 m by 1.5 m.

Sample Z2: Roof sample of approximately 2.5 m by 1.5 m.

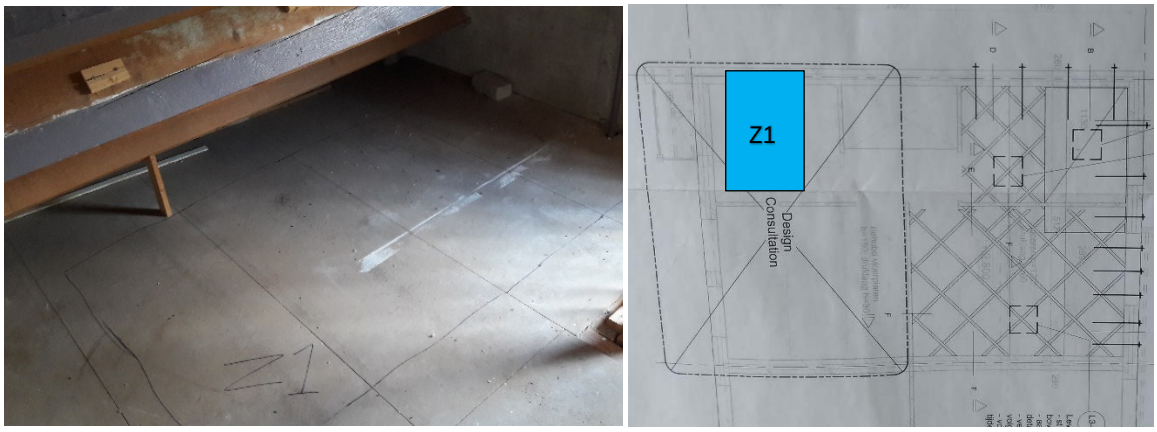


Figure 6: Floor sample Z1 and its location in the house.

Figure 7: View of Z2 roof panels and purlins (the white-coloured part is only a piece of wall paper).

4 Specimens

The coming subsection refers to the samples extracted from Rengersweg 15, Godlinze. Two of the floors (G1 and G3) were disassembled and the inner connections were tested, while the third (G4) was used to determine material properties.
The second subsection refers to the samples extracted from Zijlvest 25, Loppersum.

4.1 Specimen from detached house

Below, the plan to disassemble the samples from Rengersweg 15, Godlinze is presented. The objective was to maximize the amount of information from the samples. The plan also takes into account the materials necessary to obtain the relevant information for the materials testing. In the overview, the specimens that were extracted from the samples are denoted A, B or C, according to the type of test that they will be subjected to. Figure 8 is a copy of figure 1 with the configuration of the test specimens and the corresponding test:

- Configuration A: For cyclic loading test of the plank-joist connection perpendicular to the joist
- Configuration B: For cyclic loading test of the plank-joist connection parallel to the joist
- Configuration C: For cyclic loading test of the plank-joist connection in torsion

In Figure 9, sample G1 and its disassembly plan are presented. The heart-to-heart distance between the joists measures 788 mm.

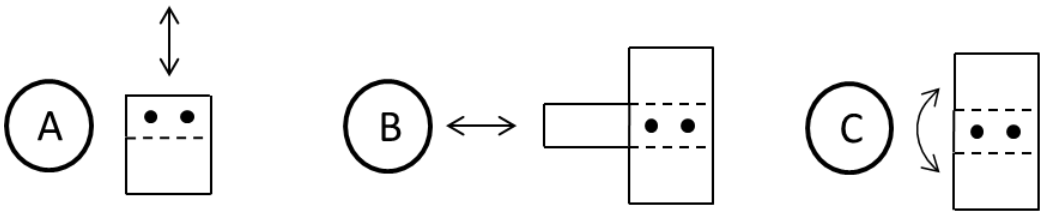
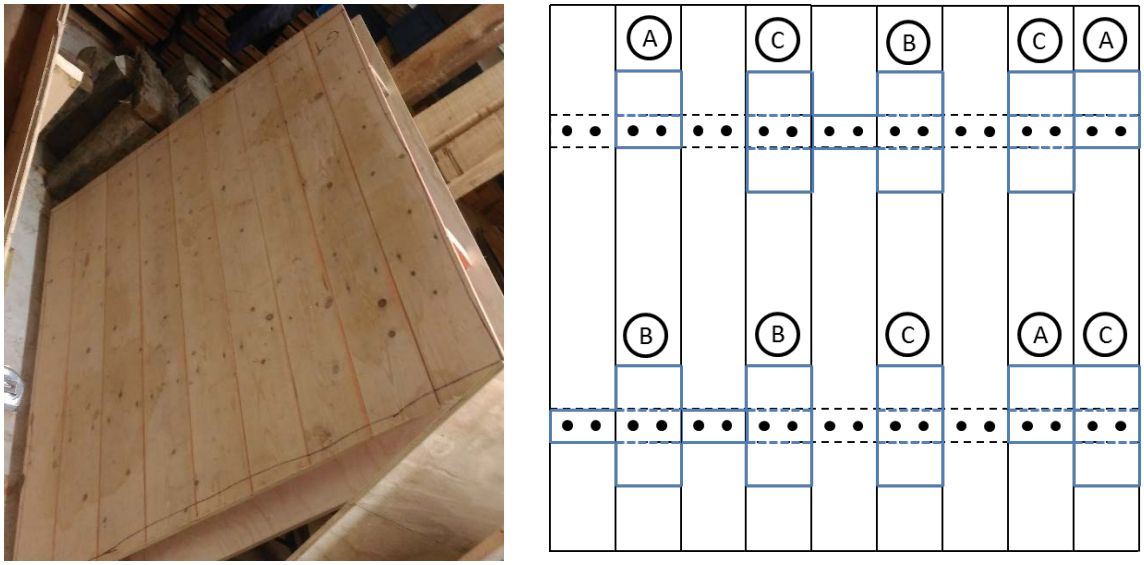


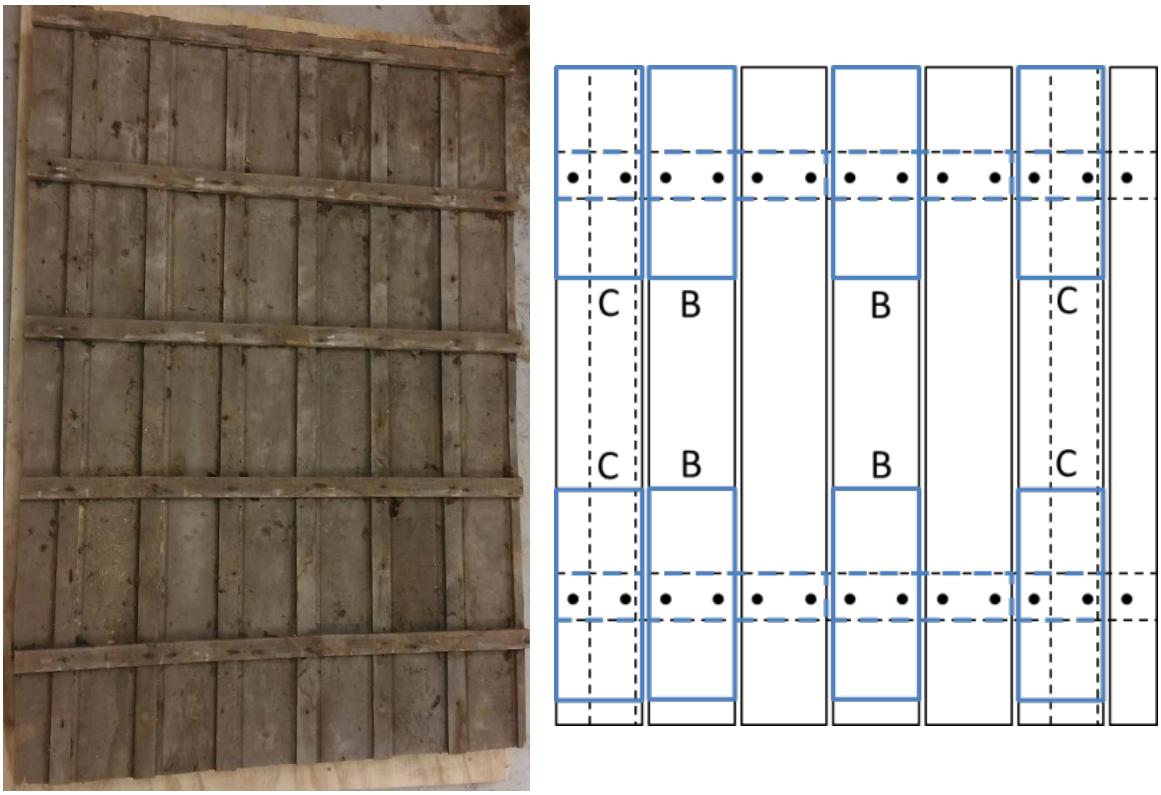
Figure 8: Specification of test specimens: A – loading perpendicular to joist, B – loading parallel to joist, C – loading in torsion



(a) (b)

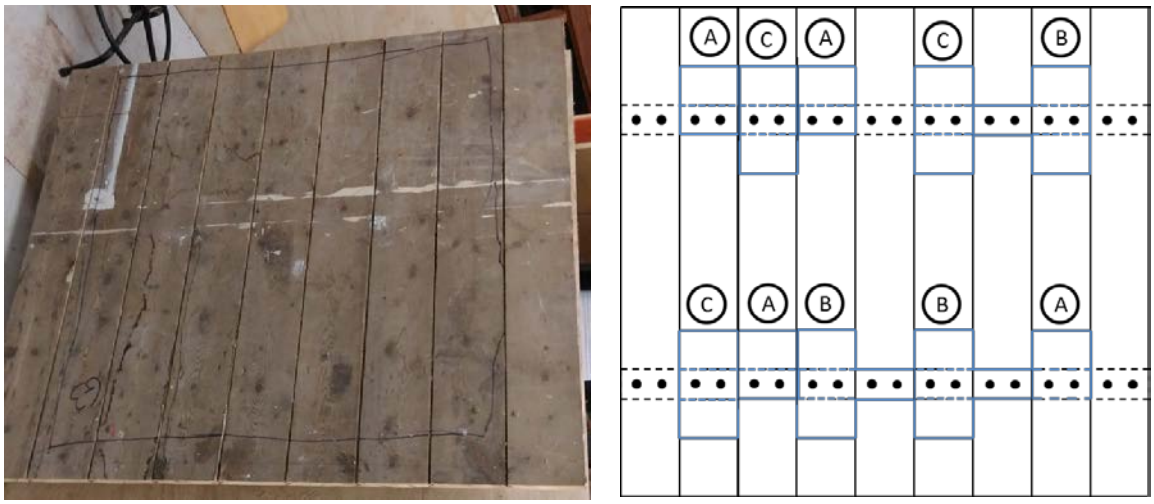
Figure 9: (a) Ground floor sample G1 with planks from Rengersweg 15, Godlinze [2], (b) overview of the test specimens that were extracted for the plank-joist connection test.

For sample G2, a picture and a plan of disassembly can be found in Figure 10. Sample G2 is a roof sample and consists of six and a half planks nailed to two beams (which will be called purlins) with two nails per connection. In addition, the two beams are nailed to two rafters, most likely with one nail for each connection. Also, each plank had a spacing batten on which 5 tile battens are nailed. The heart-to-heart distance between the rafters measures 912 mm.
The two upper layers of battens do not serve a structural function in the in-plane stiffness and were therefore removed. The disassembly plan as shown in Figure 10 takes into account the remaining layers. A limited number of tests could be conducted, as two types of tests needed to be performed and also some materials needed to be extracted to perform tests on.
This roof is loaded horizontally parallel to the beams, so test type B was performed. In addition, the pairs of fasteners that are used to connect the planks to the beams can produce a moment, so tests of type C was performed as well. Lastly, the beams are connected to the rafters which are connected to the ridge and the roof plate, and this connection would be of interest as well.
To leave enough elements for the materials testing, four specimens for type B testing and four specimens for type C testing were extracted. The location of extraction of type C specimens was chosen such that part of the rafters could be sawn off as well without hindering the type C testing. Then, after the type C testing is finished, the connection between the beams and the rafters could be tested.
In figure 11, the disassembly plan is shown for sample G3 from the first floor from Rengersweg 15 in Godlinze; the heart-to-heart distance between the joists measures 736 mm.



(a) (b)

Figure 10: (a) Roof sample G2, Rengersweg 15, Godlinze from top, (b) extracted test specimens (tile battens and spacers not shown).



(a) (b)

Figure 11: (a) First floor sample G3 with planks from Rengersweg 15, Godlinze [2], (b) overview of the test specimens that were extracted for the plank-joist connection test.

In accordance with ISO 16670 [1] 6 specimens are obtained for each test, while leaving sufficient elements (planks, fasteners and beam parts) for the materials testing. In addition, a static-monotonic test is performed on a type A and a type C specimen to determine the ultimate joint displacement, necessary for the cyclic tests.
The disassembly procedure of the floor samples was as follows:

1. A strip of the lower part of the beams (furthest away from the planks) was sawn off, in order to use it for the materials testing. Sufficient distance was kept between the 'new' bottom of the beam and the tip of the nail not to disturb the connection.
2. The fasteners were removed from the planks that were not part of a test specimen for the plank-joist connection.
3. The free planks could be removed and tested for their mechanical and physical properties.
4. The remaining part of the sample was sawn into pieces of the correct dimensions for the plank-joist connection tests to be performed.

The properties of the materials (timber and fasteners) in these tests are determined according to the protocol materials testing [2].
Measurements of samples G1 and G3 (representative of typical floors) can be found in Figure 12, while the dimensions of the test specimens for the plank-joist connection tests are given in table 2.

	G1	**G3**
l_{plank}	1644	1395
h_p	18	23
w_p	162	163
l_{beam}	1482	1533
h_b	112	165
w_b	51	61
$s_{2,min}$	66	98
$s_{2,max}$	113	130
$b_{s,min}$	11	18

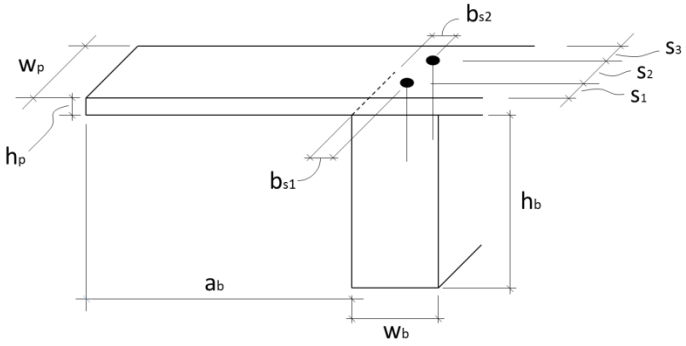


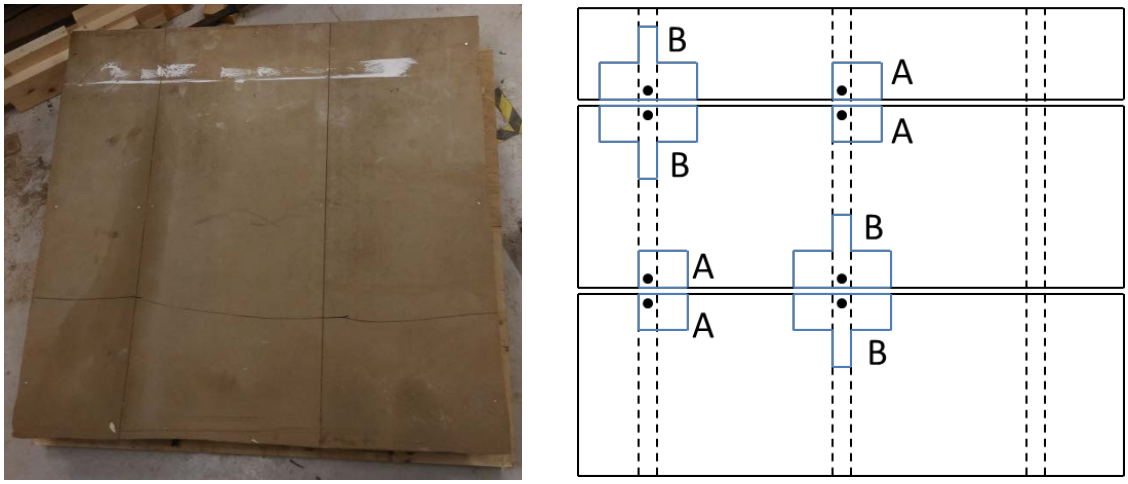
Figure 12: Measurements of samples G1 and G3

Table 2: Dimensions of the specimens.

Sample name	Number	Joist			Plank			Rafter		
		H	L	W	H	L	W	H	L	W
		mm	mm	mm	mm	mm	mm	mm	mm	mm
PJC-G1-A-x (x = 1,2,3)	3	80	162	51	18	140	162	-	-	-
PJC-G1-B-x (x = 1,2,3)	3	80	324	51	18	300	162	-	-	-
PJC-G1-C-x (x = 1,...,4)	4	80	162	51	18	400	162	-	-	-
PJC-G3-A-x (x = 1,...,5)	4	130	163	61	23	150	163	-	-	-
PJC-G3-B-x (x = 1,...,5)	3	130	326	61	23	300	163	-	-	-
PJC-G3-C-x (x = 1,...,5)	3	130	163	61	23	400	163	-	-	-
G2-b1-x-B (x=2,4)	2	35	328	62	15	300	164	-	-	-
G2-b2-x-B (x=2,4)	2	35	328	62	15	300	164	-	-	-
G2-b1-x-C (x=1,6)	2	35	164	62	15	400	164	105	400	52
G2-b2-x-C (x=1,6)	2	35	164	62	15	400	164	105	400	52

4.2 Terraced house

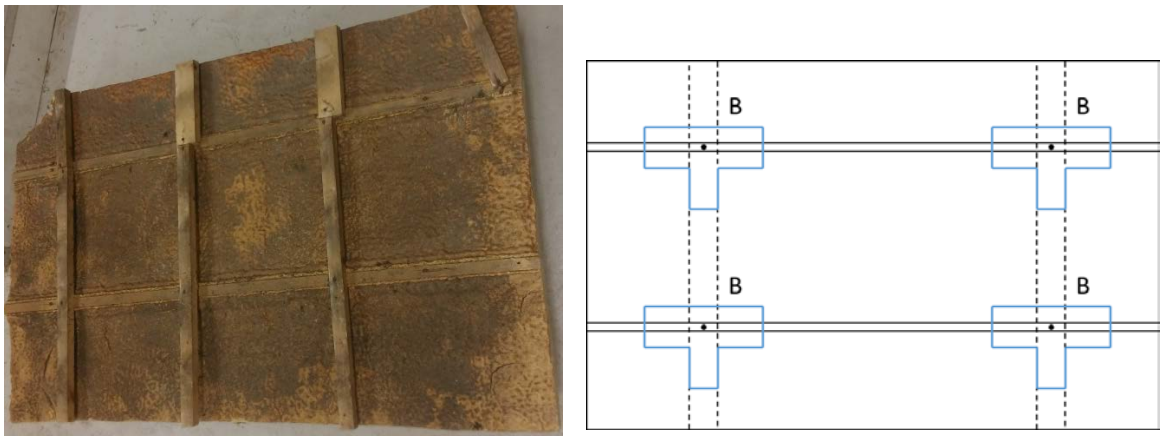
The second phase of testing concerned the floor and roof samples from Zijlvest 25, Loppersum. The performed tests took into account the way in which loading can occur in reality. For each diaphragm sample this will be explained in each respective description. The tests that were performed on these specimens were however in principle the same as the ones on the specimens in phase one (see Figure 8).
A picture and the plan of disassembly of sample Z1 can be found in Figure 13. Sample Z1 was a floor sample from Zijlweg 25, Loppersum and consists of two and a half chipboard panels screwed to three joists. Most likely due to an error during construction, only two of the joists were used to fasten the plates. The number of fasteners available was thus 8. For this type of plate-joist connection it was therefore not possible to perform 6 reversed cyclic tests for directions of loading parallel and 6 perpendicular to the joist. In addition, performing 8 tests on the connections, would leave no fasteners to be tested in a bend or pull test. As there are no double fastener connections, there are no pairs of fasteners to generate a moment connection and a rotational test is therefore not relevant.
As a compromise, 4 tests were appointed to each test direction and the remainder of the fasteners were used in a pulling test to determine the material properties. As was done in the case of samples G1 and G3 a strip of beam is sawn from the bottom of the joists in order to determine the modulus of elasticity of the joists. A strip of the chipboard panels can be sawn off, also to determine the modulus of elasticity.
The heart-to-heart distance between the joists measures 595 mm.



(a) (b)

Figure 13: (a) Floor sample Z1, Zijlvest 25, Loppersum, (b) extracted test specimens.

For sample Z2, a picture and the plan of disassembly can be found in Figure 14. Sample Z2 is a roof sample from Zijlweg 25, Loppersum and consists of one chipboard panel nailed to two joists. On the panels there were two small size rafters that were glued to the chipboard panels. The nails to the joists go through the rafters and the chipboard panel. There were also 4 tile battens, nailed to the rafters, but as these did not contribute structurally to the in-plane stiffness of the roof diaphragm, they were removed. The nails that connect the plates to the beams run through the rafters, so these cannot be removed.
As was the case with sample Z1, sample Z2 also deals with a limited number of fasteners, namely 4. Considering the manner in which the roof would be loaded horizontally in practice (perpendicular to the gable, parallel to the joist direction), the tests that were performed are those with the loading parallel to the beam (type B).
Regarding the materials testing, after testing the connection the remainder of the fasteners was again used for a pull test. A strip was sawn off of the bottom of the beams and a strip of the chipboard material was sawn off to determine the moduli of elasticity of both materials.
The dimensions of the test specimens for the plank-joist connection tests are given in table 3.
The heart-to-heart distance between the purlins measures 962 mm.



(a) (b)

Figure 14: (a) Roof sample Z2, Zijlvest 25, Loppersum, (b) extracted test specimen (tile battens not shown).

Table 3: Dimensions of the specimens

Sample name	Number	Joist			Plank / panel			Rafter		
		H	L	W	H	L	W	H	L	W
		mm	mm	mm	mm	mm	mm	mm	mm	mm
Z1-b1-x-A (x = 1,2)	2	192	160	75	20	140	160	-	-	-
Z1-b1-x-B (x = 2,3)	2	192	320	75	20	300	160	-	-	-
Z1-b2-x-A (x = 2,3)	2	192	160	75	20	140	160	-	-	-
Z1-b2-x-B (x = 1,2)	2	192	320	75	20	300	160	-	-	-
Z2-b1-x-B (x = 1,2)	2	212	320	70	20	300	160	30	300	21
Z2-b2-x-B (x = 1,2)	2	212	320	70	20	300	160	30	300	21

5 Plank-joist connection

5.1 Loading procedure

The specimens were loaded quasi-static reversed-cyclic in accordance with ISO 16670 [1], which requires that the test is carried out at a constant rate of slip between 0,1 mm/s and 10 mm/s.
A static monotonic test was performed on 1 specimen with configuration A and on 1 specimen with configuration C to determine the ultimate displacement v_u. The result of the test on configuration A was also used for configuration B.
The cyclic loading scheme is based on the measured value in the static-monotonic test of the ultimate joint displacement v_u that is graphically shown in figure 15. v_u is either the displacement at failure or the displacement at $0.8F_{max}$ at the descending part of the load-displacement curve.
For the tests in which the loading is perpendicular or parallel to the joist, the displacement is measured in millimetres, whereas the test in which the loading is torsional, the displacement is measured in millimetres and then converted to radians.

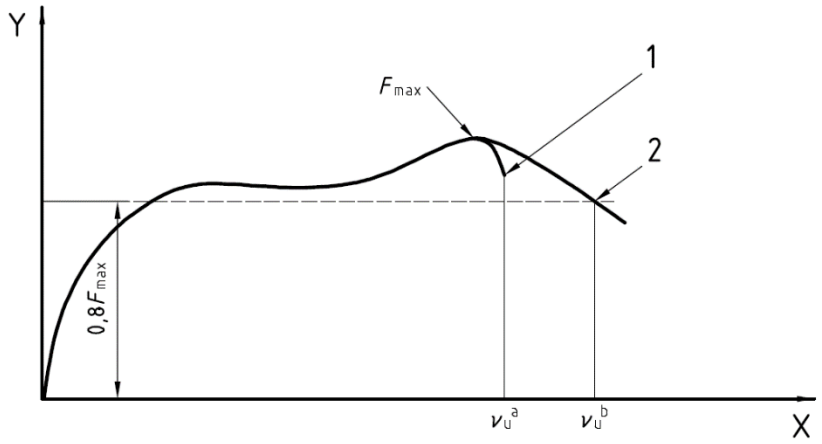


Figure 15: Load-displacement curve of a joint with mechanical fasteners [1]

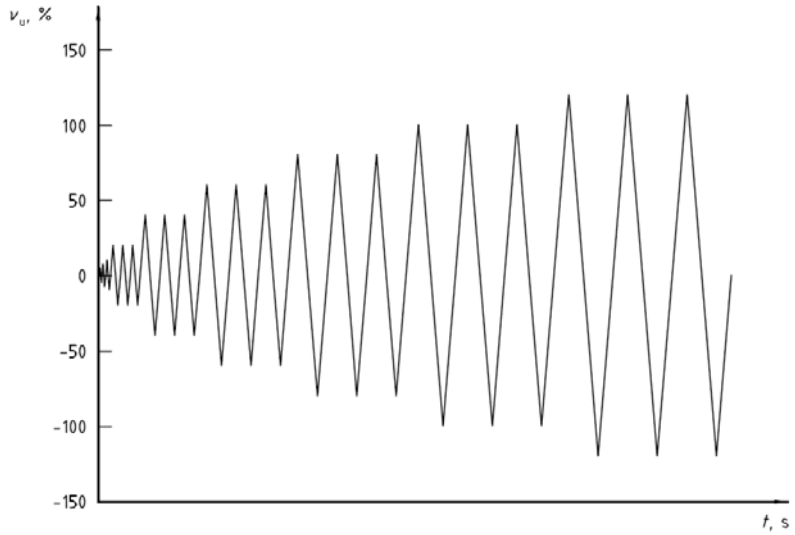


Figure 16: Loading scheme - plank-joist connection [1]

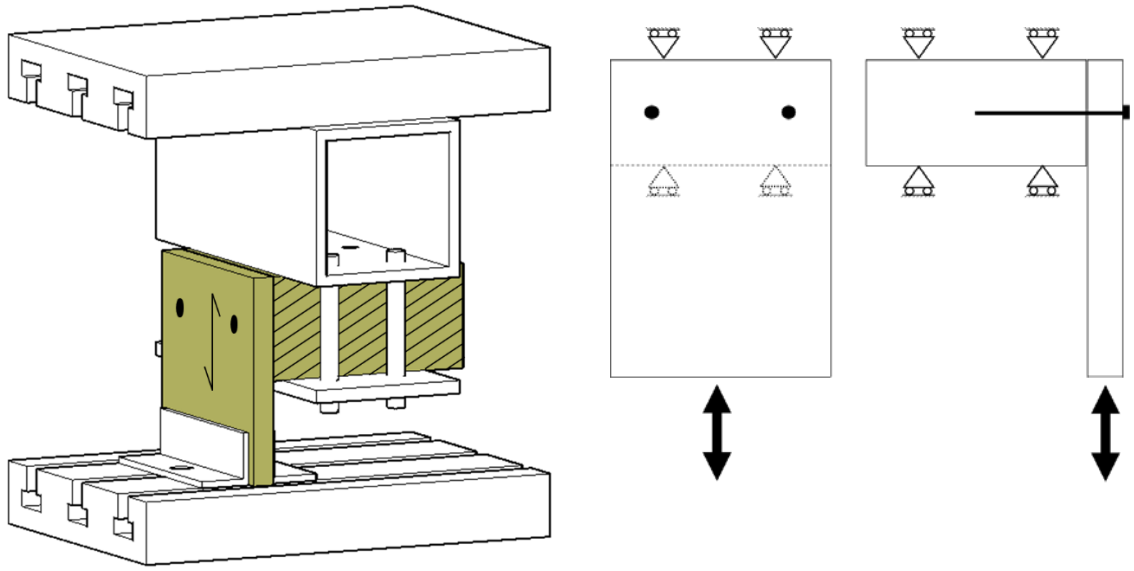
A graph of the reversed-cyclic loading scheme is displayed in figure 16. A table with the values of the amplitudes of the different cycles in the loading scheme that will be applied according to ISO 16670 is also presented.

Table 4: amplitudes in loading scheme as a function of v_u [1]

Step	No. of cycles	Amplitude
1	1	1,25 % of v_u
2	1	2,5 % of v_u
3	1	5 % of v_u
4	1	7,5 % of v_u
5	1	10 % of v_u
6	3	20 % of v_u
7	3	40 % of v_u
8	3	60 % of v_u
9	3	80 % of v_u
10	3	100 % of v_u
11	3	increments of 20 % of v_u
NOTE Some of the initial steps (1,25 % to 10 % v_u) may be omitted or repeated (or new steps may be added) depending on the stiffness of the joint or accuracy of the measurement system, as long as the principles given in 6.2 are satisfied. Clause A.2 identifies cases where modification of the standard cyclic displacement schedule may be warranted.		

5.2 Test set-up loading perpendicular to joist (configuration A)

The test set-up and the forces that were exerted on the specimens loaded perpendicular to the joist (configuration A) are shown in figure 17. The joist was clamped to the steel tube. The plank was glued to the 2 steel angles. The large bottom plate could displace vertically up and down. The deformation between joist and plank was measured.

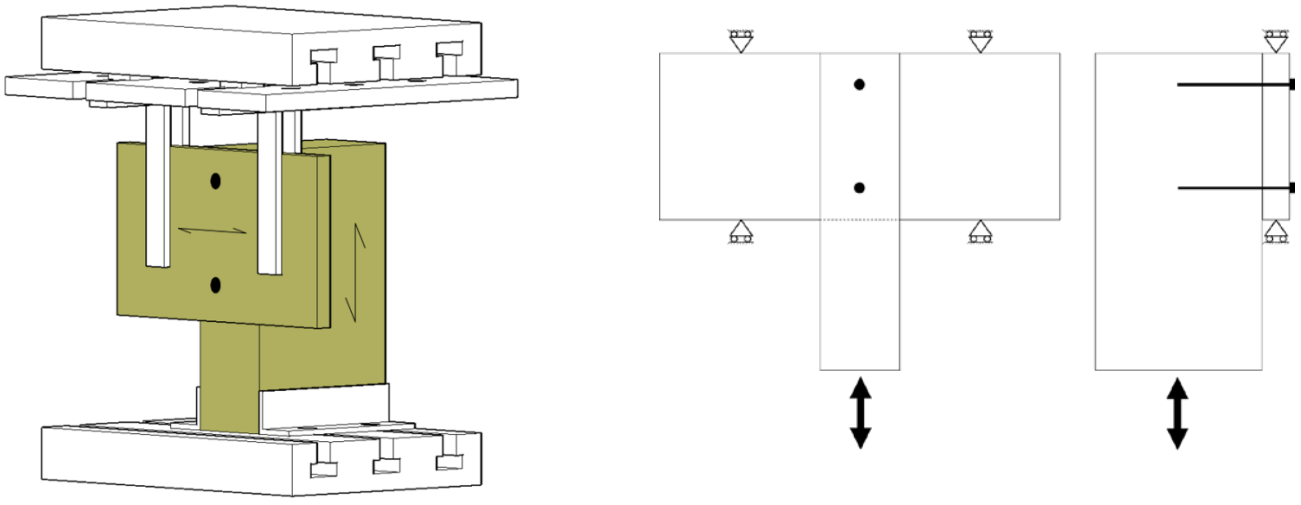


(a) (b)

Figure 17: Test set-up (a) and forces acting on the specimens (b) for loading perpendicular to joist (configuration A)

5.3 Test set-up loading parallel to joist (configuration B)

The test set-up apparatus and the forces that were exerted on the specimens loaded parallel to the joist (configuration B) are shown in figure 18. The joist was glued to the two steel angles that are connected to the bottom plate. The planks are glued to two pairs of steel strips that are mounted to the top large steel plate. The large bottom plate can displace vertically up and down. The deformation between joist and plank was measured.

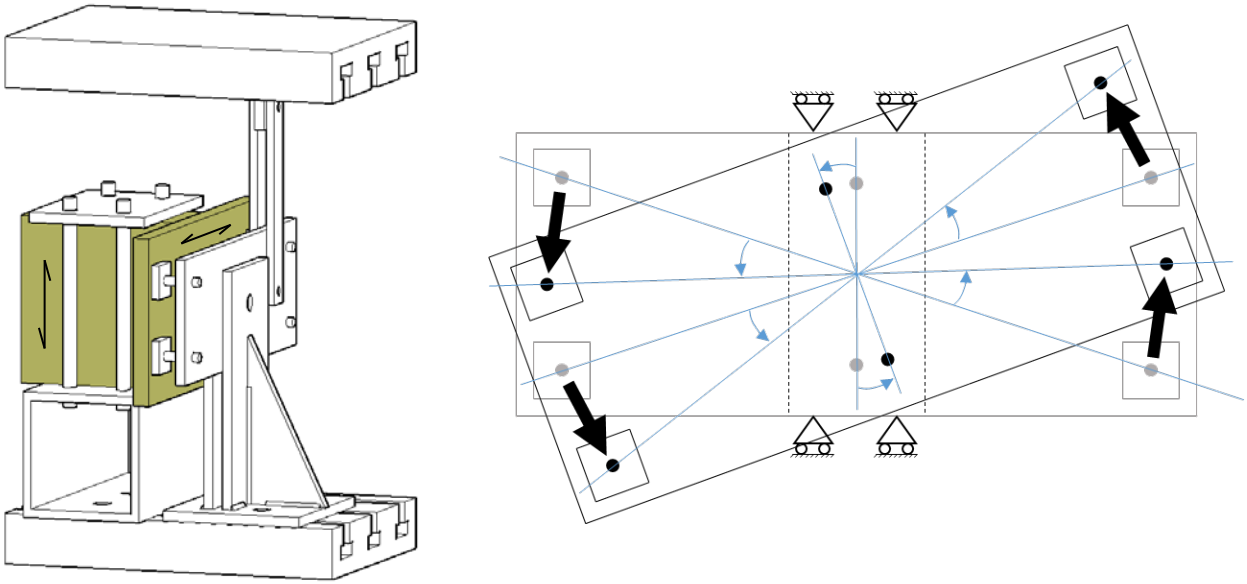


(a) (b)

Figure 18: Test set-up (a) and forces acting on specimen (b) for loading parallel to joist (configuration B)

5.4 Test set-up loading in torsion (configuration C)

The test set-up and the forces that were exerted on the specimens loaded in torsion are given in figure 19. The joist is clamped to the steel tube. 4 steel plates are glued on the planks. They were bolted to a steel plate that is able to rotate around its central point. The rotation is introduced by the application of a vertical displacement on this steel plate. The deformations between joist and plank to calculate the rotation was measured.



(a) (b)

Figure 19: Conceptual test apparatus (a) and forces acting on specimen (b) for loading in torsion (configuration C)

6 Experimental results

6.1 Overview on the tested specimen

6.1.1 Characteristics of the tested specimens

In the following tables all the properties of the tested specimen are summarized.
(*) = static monotonic test.

Table 5 – Characteristics of the tested specimens for tests A and B

Specimen	Test type	Fastener(s)	Fastener stiffness (ISO 16670) [N/mm]		F_{max} [kN]	d_{max} [mm]	Failure type
			1 fastener	2 fasteners			
G1-b1-8-A	A	2 nails		565.5	-3.76	-9.02	Bending failure of both nails
G1-b2-2-A	A	2 nails		660.0	-3.28	-14.91	Bending failure of both nails
G1-b2-9-A	A	2 nails		610.0	-3.44	-11.92	Bending failure of both nails
G2-b1-6-A	A	2 nails		304.3	0.56	5.08	Pull out failure of the nails
G2-b1-R1-A*	A	1 nail	260		6.65	26.35	Bending failure of nail
G2-b2-3-A	A	2 nails		739.1	-1.26	-5.27	Bending failure of both nails
G3-b1-3-A*	A	2 nails		565.5	2.60	13.38	Failure of beam
G3-b1-8-A	A	2 nails		932.2	2.31	11.78	Bending failure of both nails
G3-b2-2-A	A	2 nails		792.0	1.90	11.97	Bending failure of both nails
G3-b2-4-A	A	2 nails		911.3	2.75	12.06	Bending failure of both nails
Z1-b2-1-A	A	1 screw	740.1		1.95	5.61	Double bending failure of screw
Z1-b2-2-A	A	1 screw	595.7		1.91	5.42	Double bending failure of screw
Z1-b3-2-A	A	1 screw	394.7		1.26	8.58	Rupture of screw
Z1-b3-3-A*	A	1 screw	497.4		1.29	6.37	Failure of beam
Z2-b1-3-A	A	1 nail	494.7		-1.21	-10.17	Bending failure of nail
Z2-b2-1-A	A	1 nail	298.6		-1.72	-19.43	Bending failure of nail
G1-b1-2-B	B	2 nails		916.5	-4.95	-11.73	Crack of plank, failure of a nail
G1-b1-4-B	B	2 nails		1696.3	-3.84	-11.89	Crack of plank, failure of a nail
G1-b2-6-B	B	2 nails		916.6	-3.18	-8.97	Rupture of both nails
G2-b1-2-B	B	2 nails		206.3	-0.89	-8.93	Bending failure of both nails
G2-b1-4-B	B	2 nails		186.2	-1.01	-5.95	Rupture of both nails
G2-b2-4-B	B	2 nails		259.4	0.89	5.61	Bending failure of both nails
G2-b2-6-B	B	2 nails		352.5	0.82	2.87	Rupture of both nails
G3-b1-4-B	B	2 nails		741.2	-2.57	-8.69	Rupture of both nails
G3-b1-6-B	B	2 nails		5432.6	2.18	8.87	Rupture of both nails
G3-b2-8-B	B	2 nails		4135.7	-3.50	-9.12	Rupture of both nails
Z1-b2-2-B	B	1 screw	833.8		-1.50	-4.01	Rupture of screw
Z1-b2-3-B*	B	1 screw	576.4		-1.16	-6.15	Tear out failure of plate
Z1-b3-2-B	B	1 screw	1260.3		1.24	4.14	Tear out failure of plate and bending failure of screw
Z2-b2-2-B	B	1 nail	540.5		0.7	3.95	Pull out failure of the nail

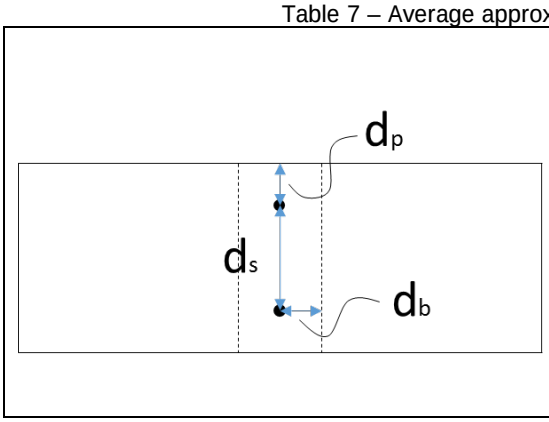
Table 6 - Characteristics of the tested specimens for test C

Specimen	Test type	Fastener(s)	Fastener stiffness (ISO 16670) [Nmm/rad]	M_{max} [Nmm]	θ_{max} [rad]	Failure type
G1-b1-6-C*	C	2 nails	1622600	175700	0.16	Crack in the timber
G1-b1-9-C	C	2 nails	2648800	202820	0.14	Rupture of both nails
G1-b2-4-C	C	2 nails	2573800	-161240	-0.28	Rupture of both nails
G1-b2-8-C	C	2 nails	2582400	144070	0.42	Failure of one of the nails
G2-b1-2-C	C	2 nails	14264500	38930	0.15	Bending failure of both nails
G2-b1-7-C	C	2 nails	15049600	-49130	-0.14	Bending failure of both nails
G2-b2-7-C	C	2 nails	4226700	-32190	-0.07	Bending failure of both nails
G3-b1-2-C	C	2 nails	3350600	125620	0.18	Rupture of both nails
G3-b2-3-C	C	2 nails	5372000	146020	0.15	Rupture of both nails
G1-b2-6-C	C	2 nails	3257000	-115350	-0.17	Rupture of both nails

6.1.2 Approximate position of the fasteners in the specimens

In the following table the average approximate position of the fasteners in the specimens is reported.

Table 7 – Average approximate position of the fasteners



G1	d_b (mm)	d_p (mm)	d_s (mm)
Nail 1	25	28	100
Nail 2	23	32	
G2	d_b (mm)	d_p (mm)	d_s (mm)
Nail 1	28	33	90
Nail 2	27	39	
G3	d_b (mm)	d_p (mm)	d_s (mm)
Nail 1	25	19	110
Nail 2	25	17	
Z1	d_b (mm)	d_p (mm)	d_s (mm)
Screw 1	37	85	-
Z2	d_b (mm)	d_p (mm)	d_s (mm)
Nail 1	35	80	-

6.2 Test type A (loading perpendicular to joists)

6.2.1 Test configuration

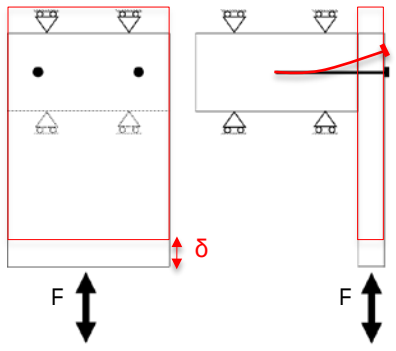


Figure 20: Test configuration A

In the reported figure the test configuration A is presented. In the following sections, descriptions of the tests and the obtained hysteresis diagrams can be found, as well as their backbone curves. Since every specimen is loaded to each level of displacement three times, a backbone curve is given for each set of cycles. All hysteretic plots show the measured force F against the applied deformation δ according to figure 20.

6.2.2 Test results G1-b1-8-A

Description of test

The test was performed according to the protocol with a yield slip of 15mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

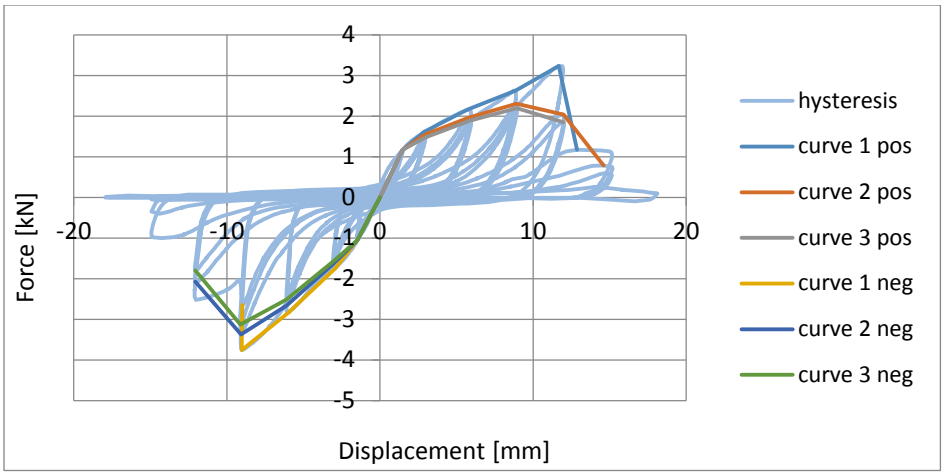


Figure 21: Hysteresis diagram and backbone curves

6.2.3 Test results G1-b2-2-A

Description of test

The test was performed according to protocol with a yield slip of 15mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

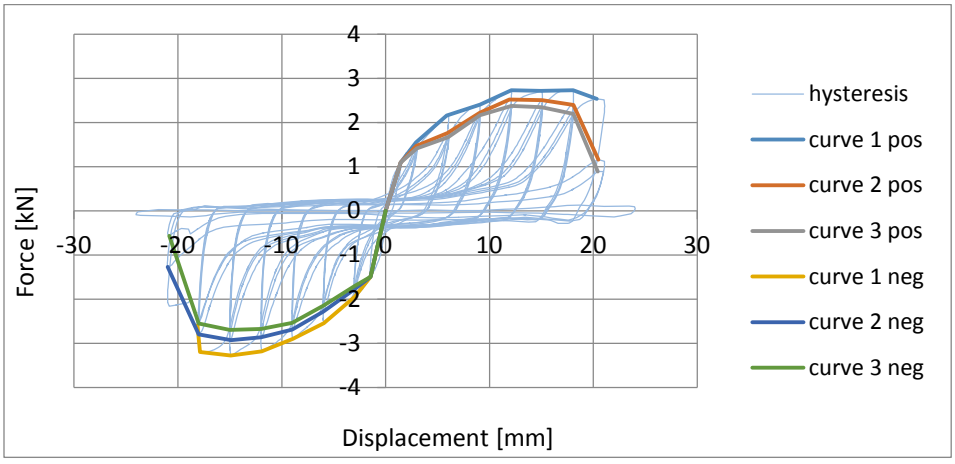


Figure 22: Hysteresis diagram and backbone curves

6.2.4 Test results G1-b2-9-A

Description of test

The test was performed according to protocol with a yield slip of 15mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

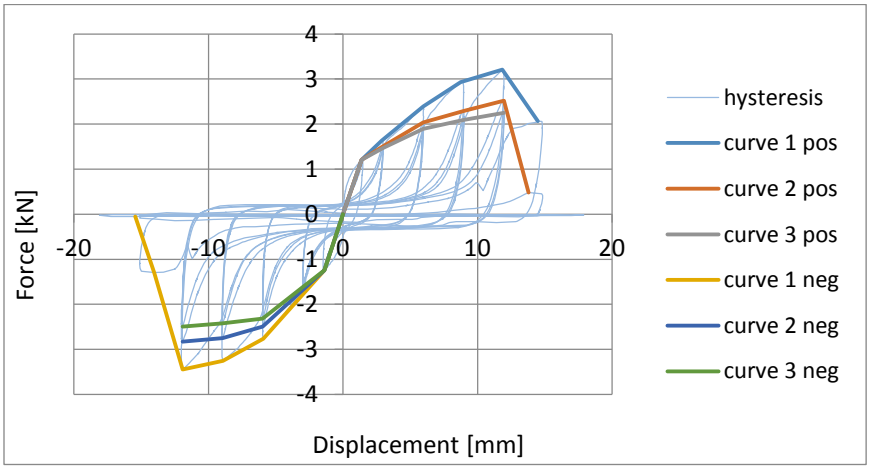


Figure 23: Hysteresis diagram and backbone curves

6.2.5 Test results G2-b1-6-A

Description of test

Loading according to ISO 16670 with an applied yield slip of 14mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

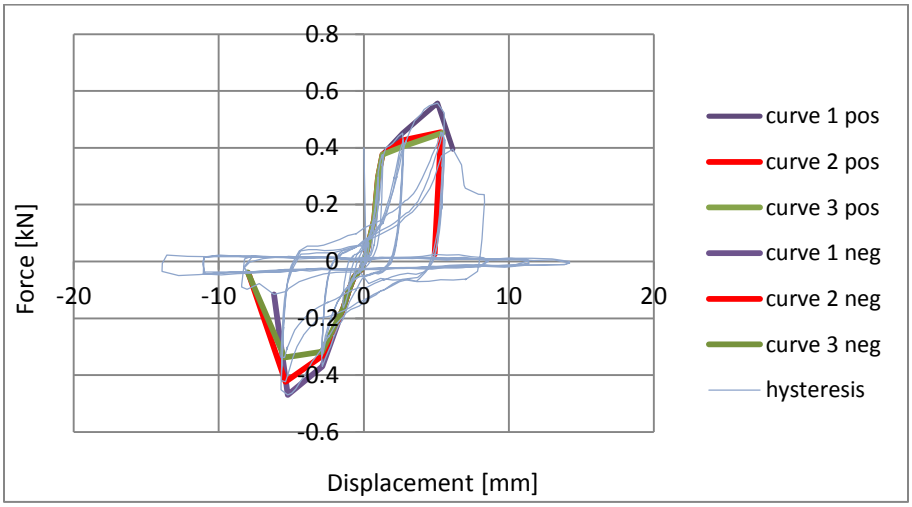


Figure 24: Hysteresis diagram and backbone curves

6.2.6 Test results G2-b1-R1-A

Description of test

Rate of deformation of 0.1mm/s. There is a malformation of the timber, so the test is decided to be performed in compression, as this would probably be the weakest direction. The specimen had dimensions that did not work well with the original idea of the setup, so it was slightly modified.

Hysteretic cycle

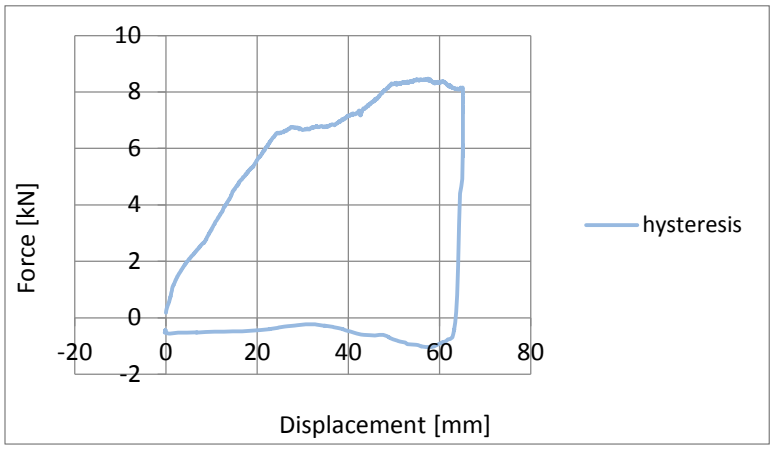


Figure 25: Hysteresis diagram and backbone curves

6.2.7 Test results G2-b2-3-A

Description of test

Loading according to ISO 16670 with an applied yield slip of 14mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

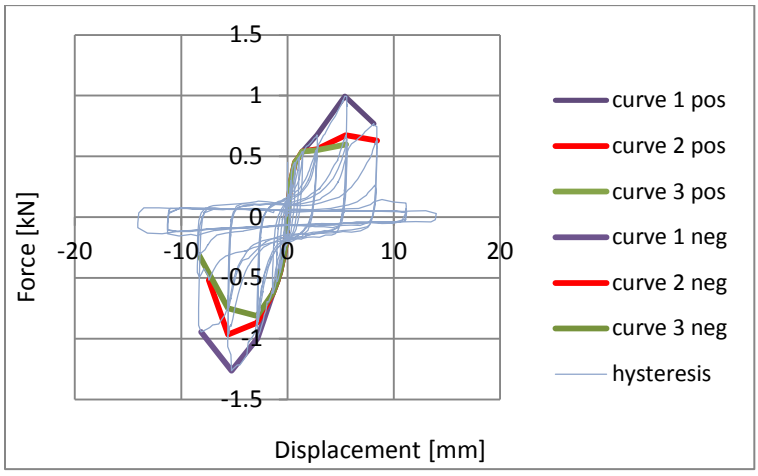


Figure 26: Hysteresis diagram and backbone curves

6.2.8 Test results G3-b1-3-A

Description of test

The test was performed monotonically according to protocol. The rate of displacement of the loading cell was chosen at a constant rate of 0.1mm/s in accordance with EN 16670, which prescribes a deformation rate between 0.1mm/s and 10mm/s.

Hysteretic cycle

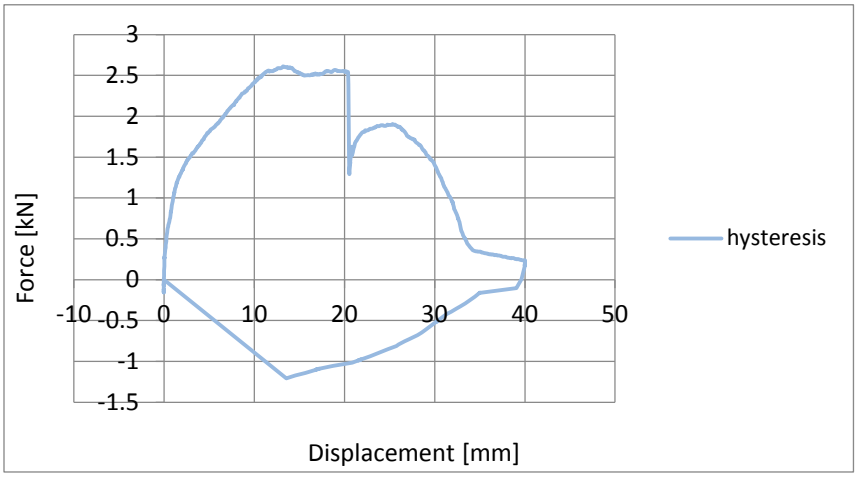


Figure 27: Force-displacement diagram

6.2.9 Test results G3-b1-8-A

Description of test

The test was performed according to protocol with a yield slip of 15mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

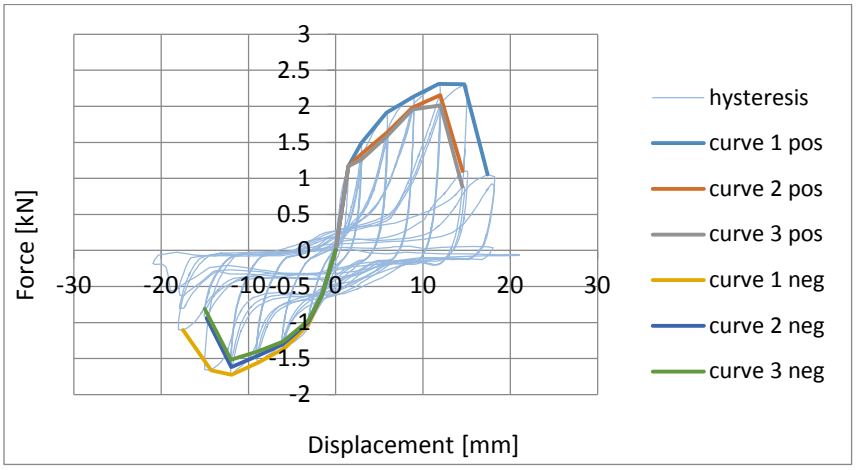


Figure 28: Hysteresis diagram and backbone curves

6.2.10 Test results G3-b2-2-A

Description of test

The test was performed according to protocol with a yield slip of 15mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

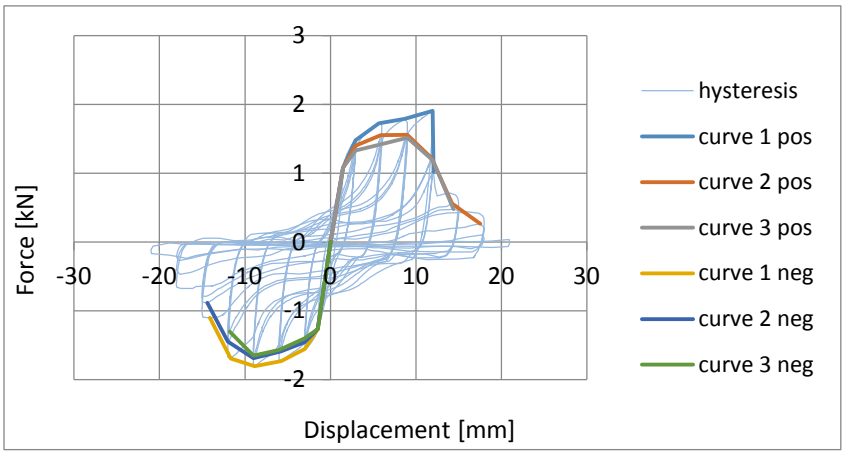


Figure 29: Hysteresis diagram and backbone curves

6.2.11 Test results G3-b2-4-A

Description of test

The test was performed according to protocol with a yield slip of 15mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.
Pieces of paper were added to remove any spaces between the clamping steel parts and the joist.

Hysteretic cycle

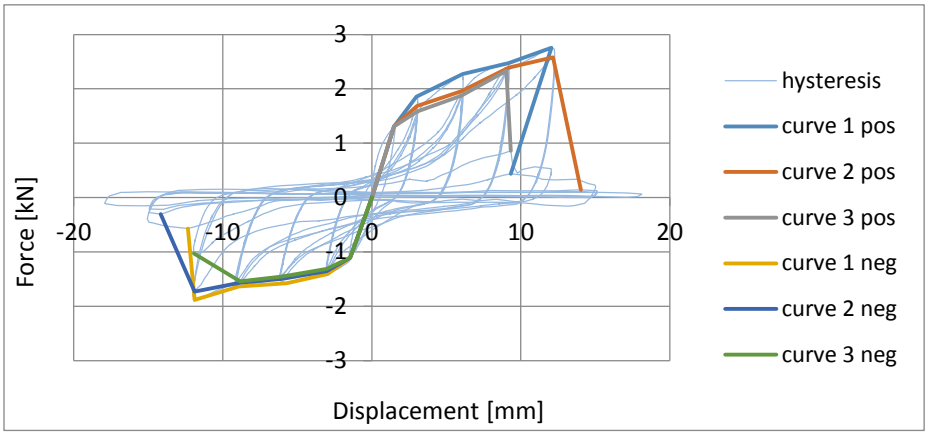


Figure 30: Hysteresis diagram and backbone curves

6.2.12 Test results Z1-b2-1-A

Description of test

The test was performed according to protocol with a yield slip of 14mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

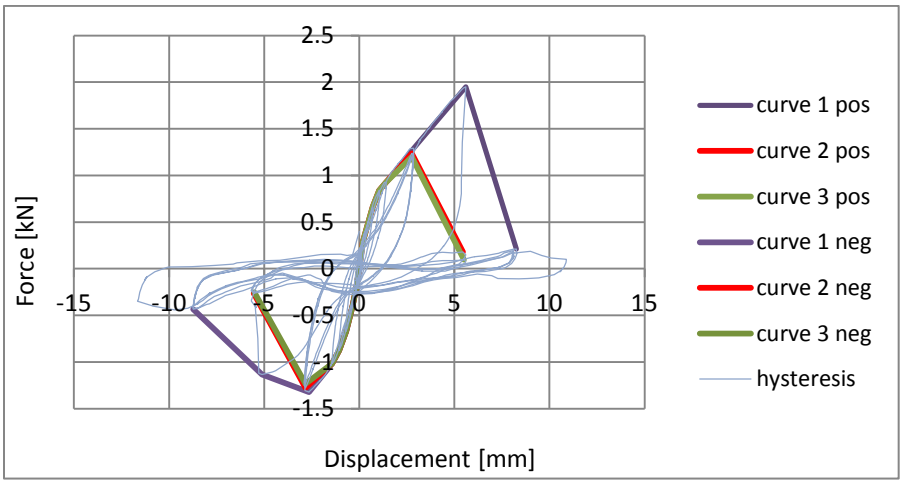


Figure 31: Hysteresis diagram and backbone curves

6.2.13 Test results Z1-b2-2-A

Description of test

The test was performed according to protocol with a yield slip of 14mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

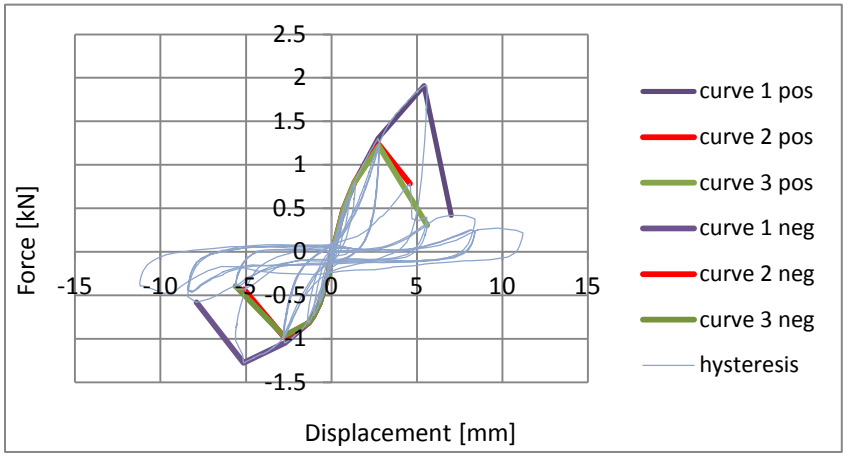


Figure 32: Hysteresis diagram and backbone curves

6.2.14 Test results Z1-b3-2-A

Description of test

The test was performed according to protocol with a yield slip of 14mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

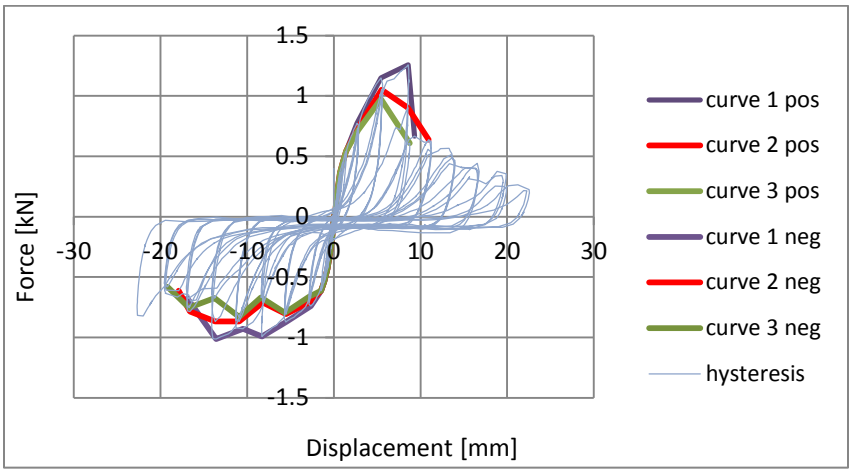


Figure 33: Hysteresis diagram and backbone curves

6.2.15 Test results Z1-b3-3-A

Description of test

The test was performed according to protocol. The rate of displacement of the loading cell was chosen at a constant rate of 0.1mm/s in accordance with EN 16670, which prescribes a deformation rate between 0.1mm/s and 10mm/s. The direction of loading was in 'tension', as the screw seemed to be fastened under an angle and therefore the specimen seemed weakest in the 'tensile' direction. Loading was continued until the measured force was about 30% of F_{max}.

Hysteretic cycle

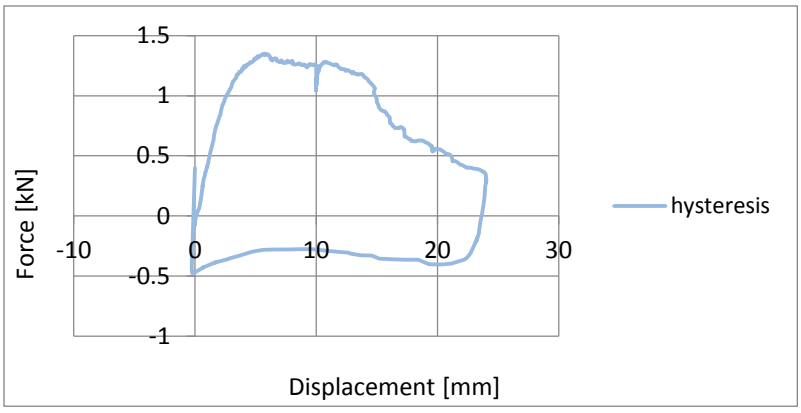


Figure 34: Hysteresis diagram and backbone curves

6.2.16 Test results Z2-b1-3-A

Description of test

The test was performed according to protocol with a yield slip of 14mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

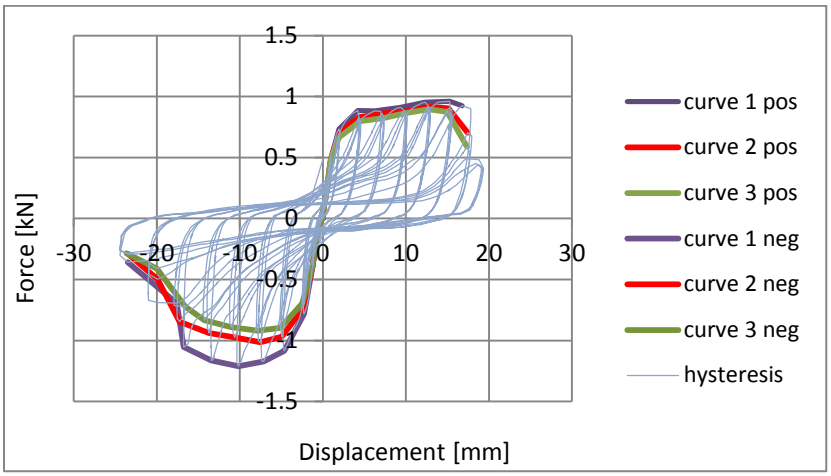


Figure 35: Hysteresis diagram and backbone curves

6.2.17 Test results Z2-b2-1-A

Description of test

The test was performed according to protocol with a yield slip of 14mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

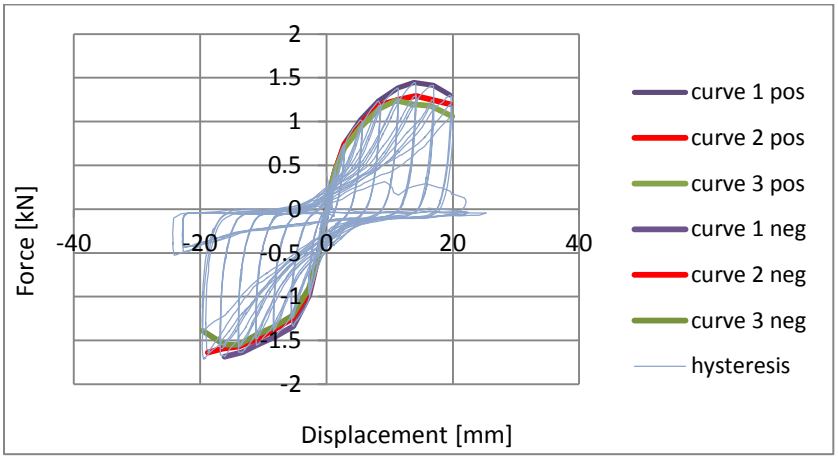


Figure 36: Hysteresis diagram and backbone curves

6.3 Test type B (loading parallel to joists)

6.3.1 Test configuration

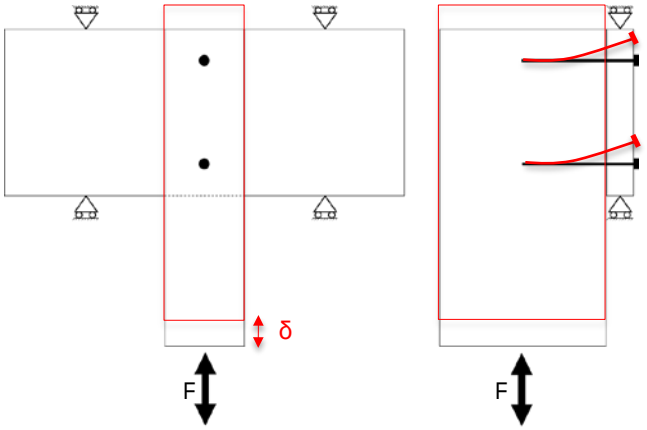


Figure 37: Test configuration B

In the reported figure the test configuration B is presented. In the following sections, descriptions of the tests and the obtained hysteresis diagrams can be found, as well as their backbone curves. Since every specimen is loaded to each level of displacement three times, a backbone curve is given for each set of cycles. All hysteretic plots show the measured force F against the applied deformation δ according to figure 38.

6.3.2 Test results G1-b1-2-B

Description of test

The test was performed according to protocol and yield slip was set at 15mm.

Hysteretic cycle

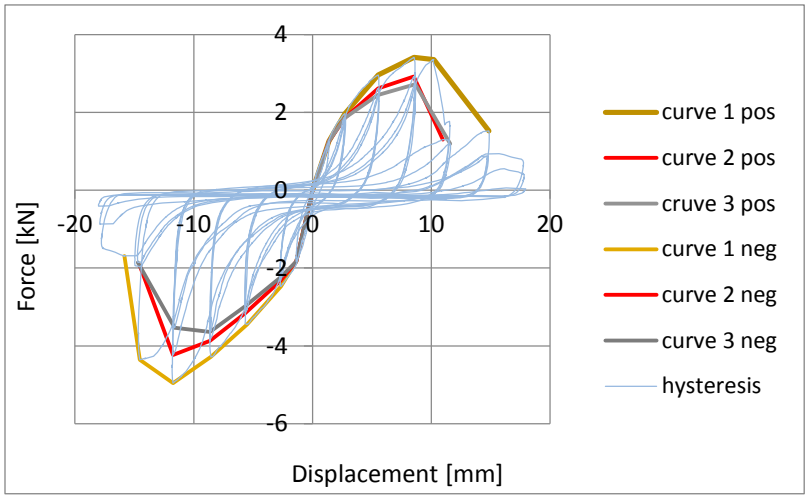


Figure 38: Hysteresis diagram and backbone curves

6.3.3 Test results G1-b1-4-B

Description of test

The test was performed according to protocol and the yield slip chosen was 15mm.

Hysteretic cycle

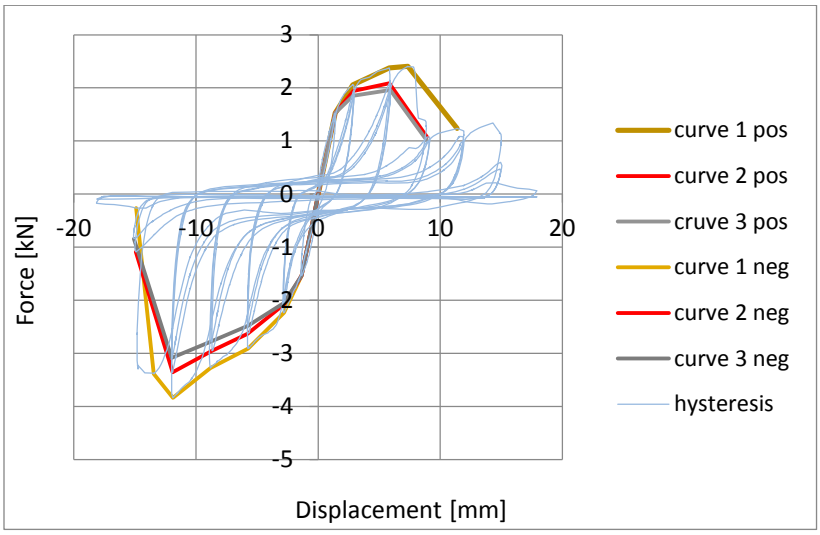


Figure 39: Hysteresis diagram and backbone curves

6.3.4 Test results G1-b2-6-B

Description of test

The test was performed according to protocol. Yield slip was set at 15mm.

Hysteretic cycle

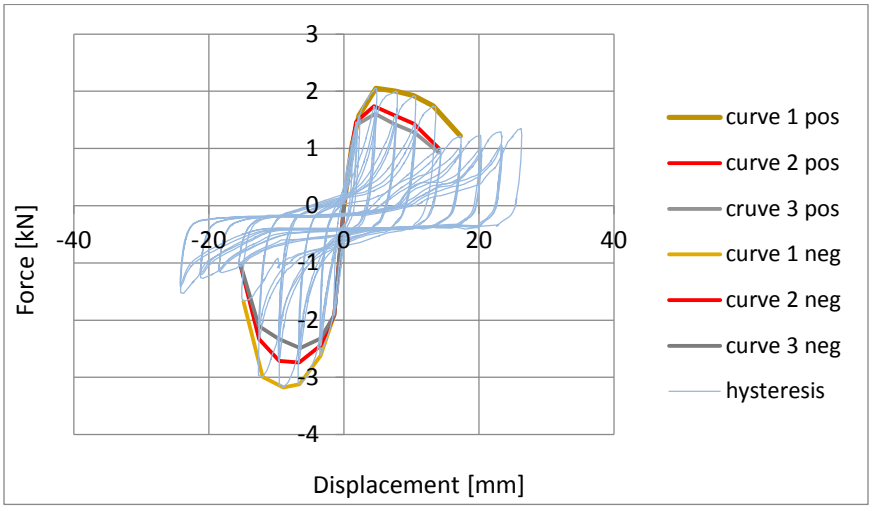


Figure 40: Hysteresis diagram and backbone curves

6.3.5 Test results G2-b1-2-B

Description of test

The test was performed according to protocol with a yield slip of 15mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s. Both nails were without head.

Hysteretic cycle

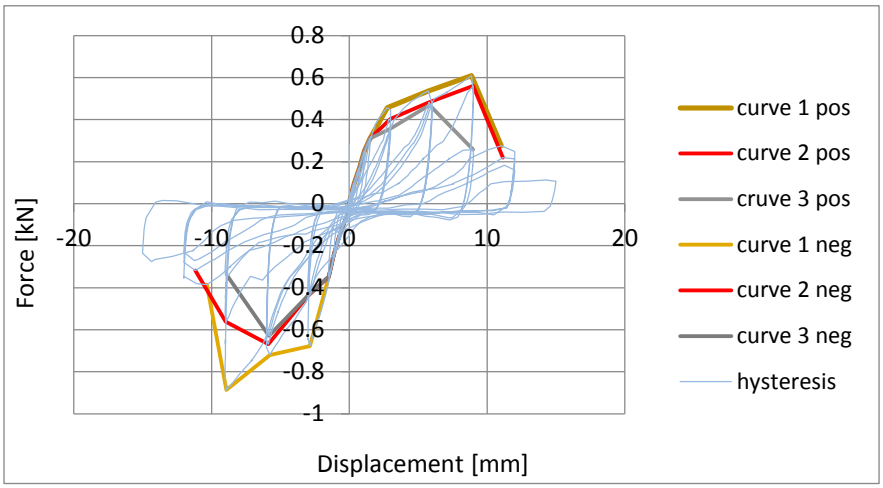


Figure 41: Hysteresis diagram and backbone curves

6.3.6 Test results G2-b1-4-B

Description of test

The test was performed according to protocol with a yield slip of 15mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s. Both fasteners in the specimen were without heads.

Hysteretic cycle

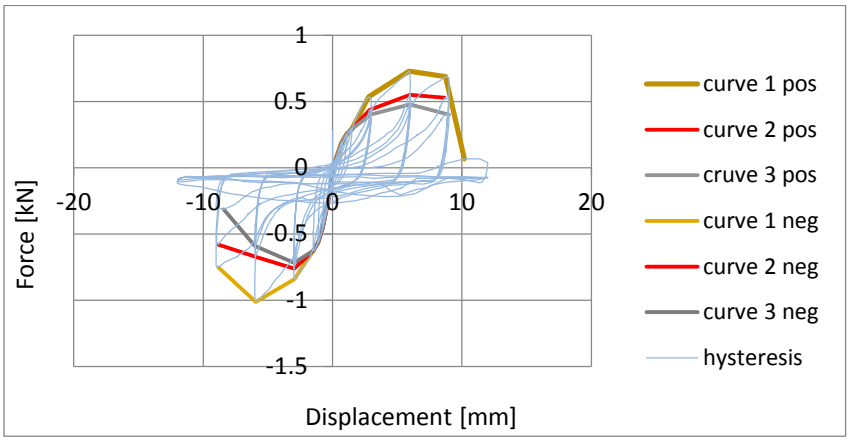


Figure 42: Hysteresis diagram and backbone curves

6.3.7 Test results G2-b2-4-B

Description of test

The test was performed according to protocol with a yield slip of 15mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

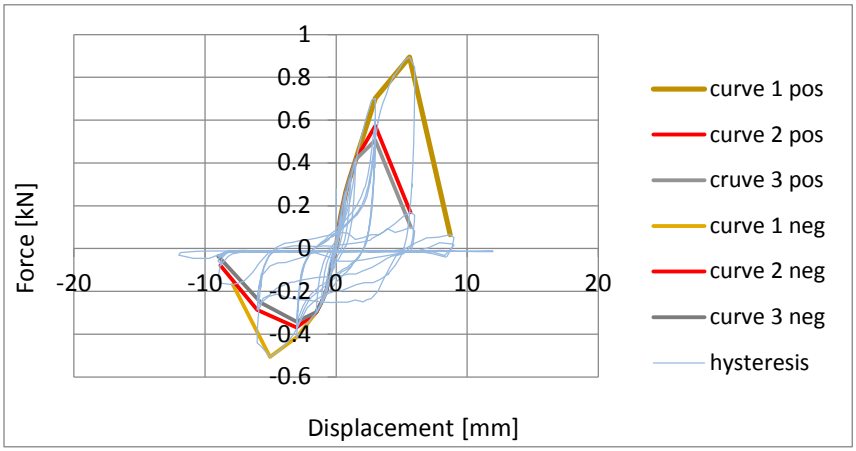


Figure 43: Hysteresis diagram and backbone curves

6.3.8 Test results G2-b2-6-B

Description of test

The test was performed according to protocol with a yield slip of 15mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

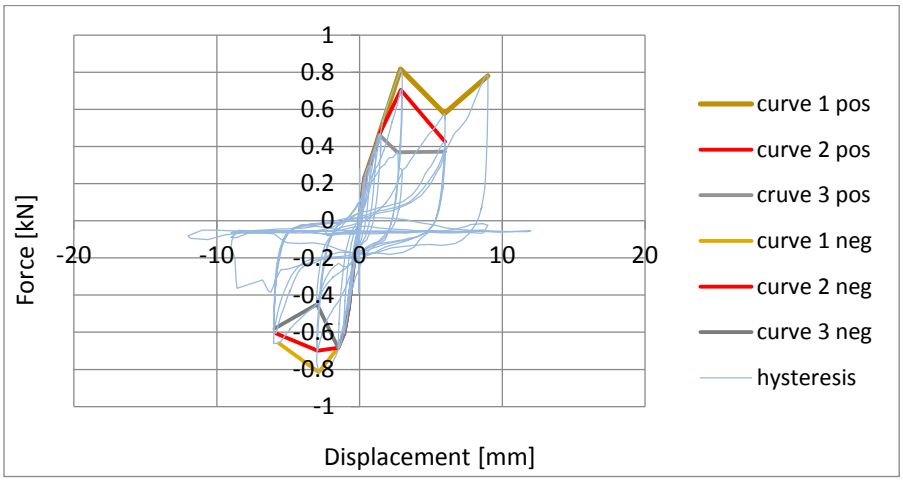


Figure 44: Hysteresis diagram and backbone curves

6.3.9 Test results G3-b1-4-B

Description of test

The test was performed according to protocol with a yield slip of 15mm.

Hysteretic cycle

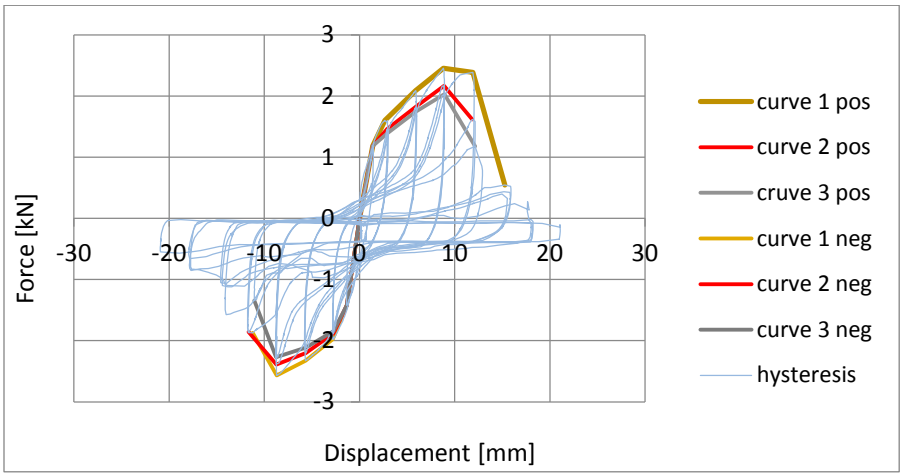


Figure 45: Hysteresis diagram and backbone curves

6.3.10 Test results G3-b1-6-B

Description of test

The test was performed according to protocol with a yield slip of 15mm. At the beginning of the test there was a force of 0.40kN on the specimen. It was noted that if there is no specimen placed in testing position the registered force is -0.28kN, so correction is performed in data-analysis. During preparation a small line of paint was filed off in order to be able to clamp the joist well.

Hysteretic cycle

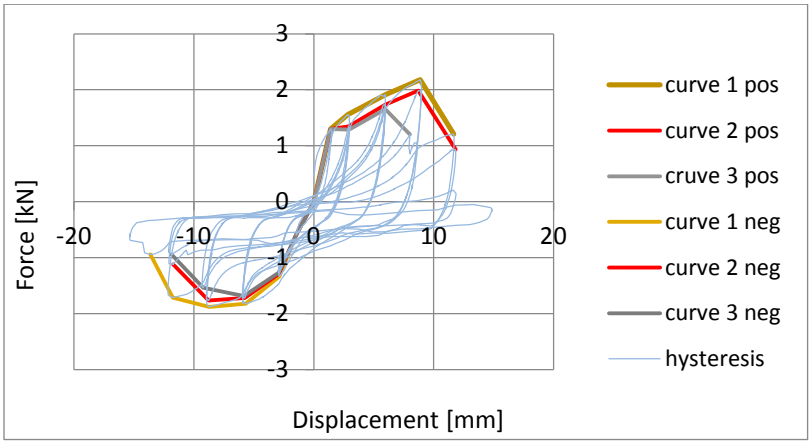


Figure 46: Hysteresis diagram and backbone curves

6.3.11 Test results G3-b2-8-B

Description of test

The test was performed according to protocol with a yield slip of 15mm. Without any specimen, there is a force of -0.28kN, so correction for this force is performed in the data-analysis. During preparation a small line of paint was filed off in order to be able to clamp the joist well.

Hysteretic cycle

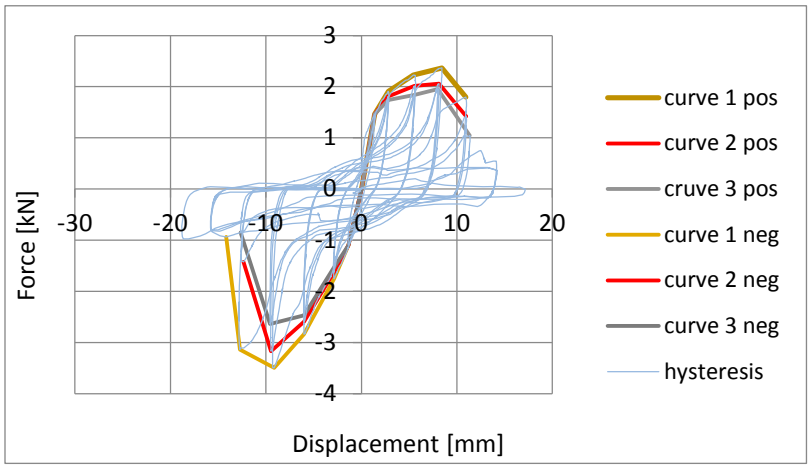


Figure 47: Hysteresis diagram and backbone curves

6.3.12 Test results Z1-b2-2-B

Description of test

The test was performed according to protocol with a yield slip of 7.0mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

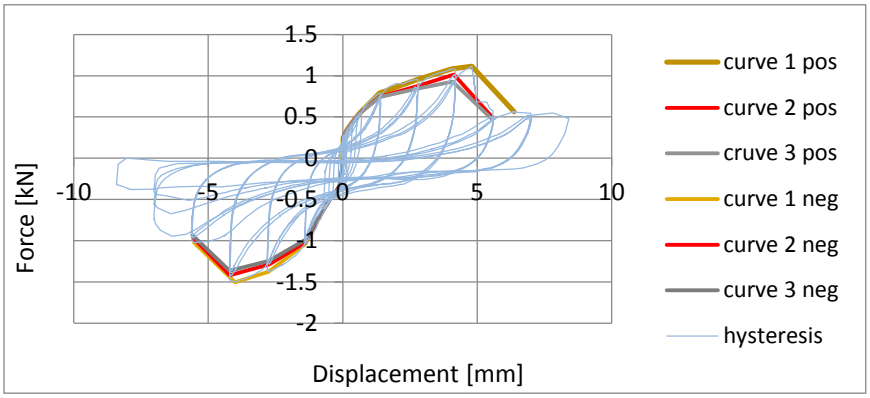


Figure 48: Hysteresis diagram and backbone curves

6.3.13 Test results Z1-b2-3-B

Description of test

The test was performed according to protocol with a rate of displacement of 0.1mm/s in order to determine the yield slip of this type of sample: a plate connected to a beam with a screw.
The 4 specimens of this type differed from each other in the sense that the distance from the fastener to the edge differed. Also, two of the four are tongue specimens and two are groove specimens. The decision was made to select the specimen with presumably the lowest yield slip, as this specimen will be governing. As the test finishes with increments of 20% until failure is reached, the other specimens will reach failure nonetheless. The specimen is pushed in the weakest direction, namely in 'compression' of the load cell.

Hysteretic cycle

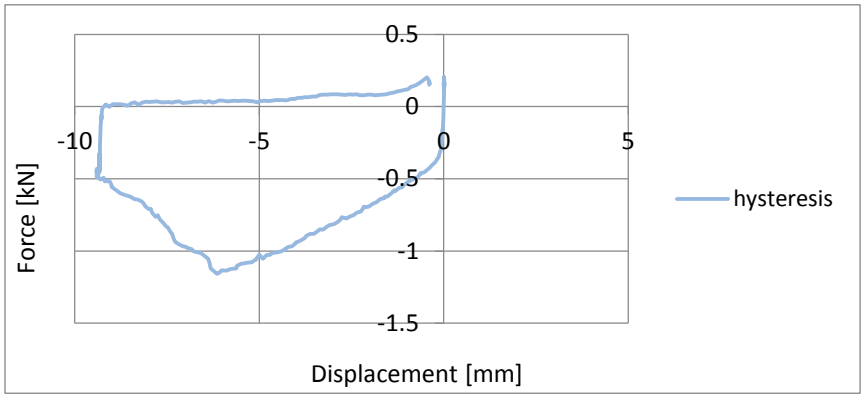


Figure 49: Hysteresis diagram and backbone curves

6.3.14 Test results Z1-b3-2-B

Description of test

The test was performed according to protocol with a yield slip of 7mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.

Hysteretic cycle

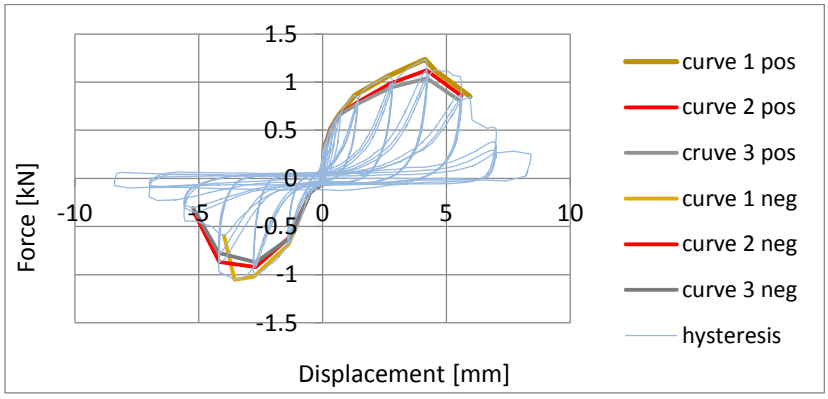


Figure 50: Hysteresis diagram and backbone curves

6.3.15 Test results Z2-b2-2-B

Description of test

The test was performed according to protocol with a yield slip of 7mm. The displacement rate was set such that time between zero displacement and maximum displacement of cycle took 10 seconds with a minimum displacement rate of 0.1mm/s.
During preparation, part of the rafter had to be removed in order to be able to place the L-profiles to clamp the plate part of the specimen. This was done by first clamping the plate to the beam with a clamp, clamping the rafter to the plate and beam, and after this by carefully sawing with a handsaw. However, a small crack already present grew larger in the rafter during placement of the specimen in the test setup.
At the beginning of the test, the plate part was not connected tightly to the beam part, as it already was not as part of the roof sample.

Hysteretic cycle

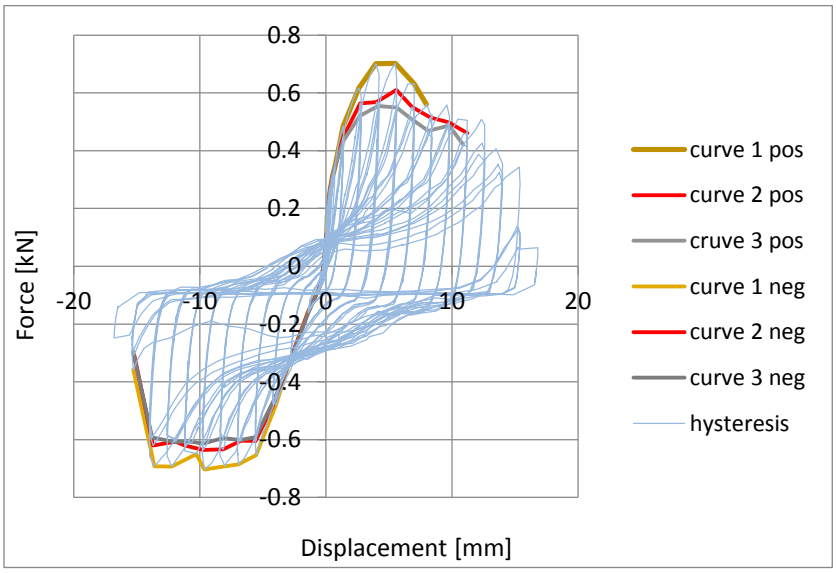


Figure 51: Hysteresis diagram and backbone curves

6.4 Test type C (loading in torsion)

6.4.1 Test configuration

In figure 53 the test configuration C is presented. In this test, like in previous cases, the force and the displacement were measured, but then they were converted in a moment and a rotation through geometrical considerations, hereby shown.

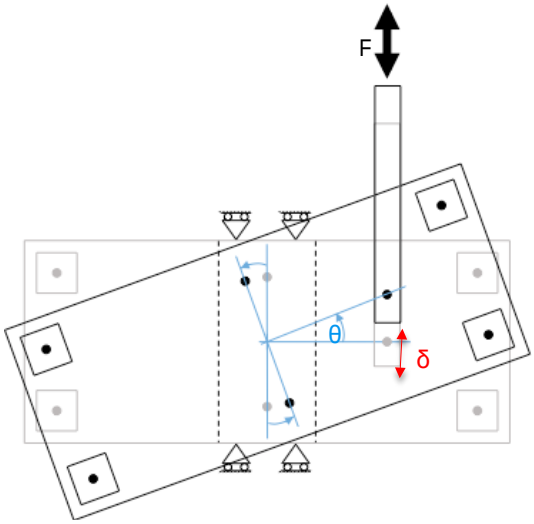


Figure 52: Test configuration C

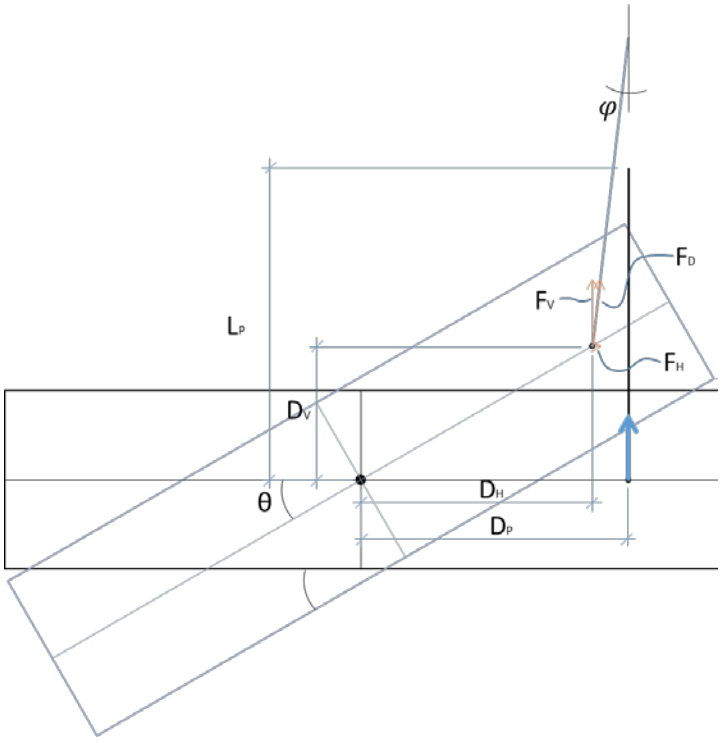


Figure 54: Configuration to determine the moment acting on the specimen (D_P = 110 mm).

The moment M acting on the specimen an the corresponding rotation angle θ can be determined with the following equations:

$$M = F_v \cos\theta \; D_p - F_v \tan\varphi \;\; \sin\theta \;\; D_p$$

$$\theta = \text{atan}(\,\delta / D_p)$$

In the following sections, descriptions of the tests and the obtained hysteresis diagrams can be found, as well as their backbone curves. Since every specimen is loaded to each level of displacement three times, a backbone curve is given for each set of cycles.

6.4.2 Test results G1-b1-6-C

Description of test

This test was a monotonic static test with the goal of determining the yield slip, on which the loading scheme of the reverse cyclic test was based. The rate of displacement of the loading cell was chosen to be 0.2mm/s in accordance with EN 16670.

Hysteretic cycle

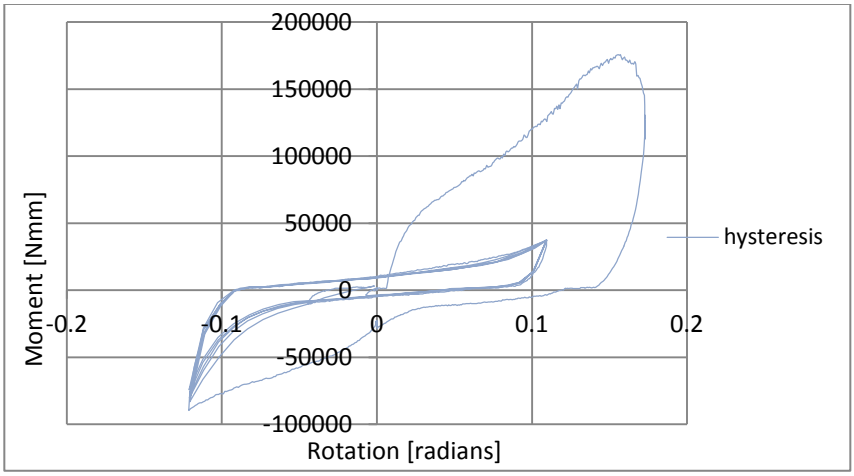


Figure 55: Load-displacement diagram

6.4.3 Test results G1-b1-9-C

Description of test

The test was performed according to protocol. Compared to previous test (G3-b2-3-C) loading was updated to take 10 seconds between peak deformation and zero deformation.

Hysteretic cycle

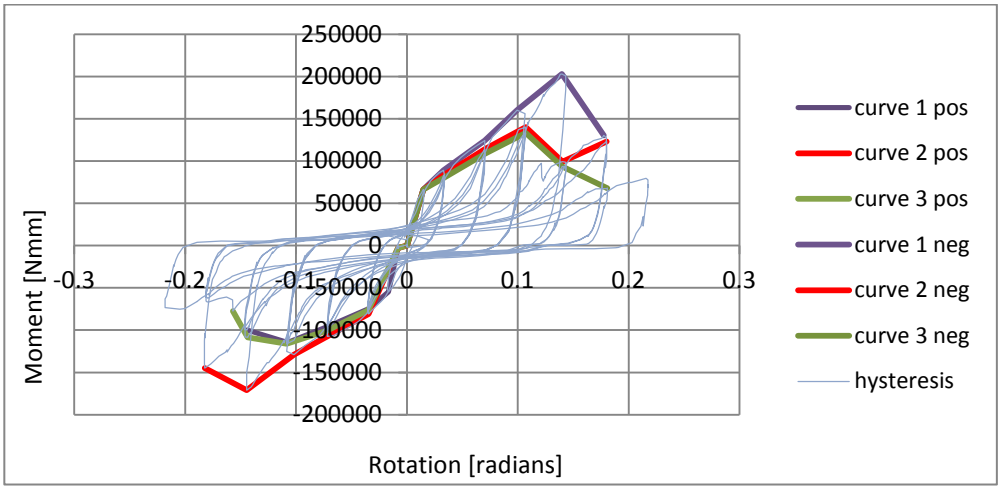


Figure 56: Hysteresis diagram and backbone curves

6.4.4 Test results G1-b2-4-C

Description of test

The test was performed according to protocol with a yield slip of 20 mm

Hysteretic cycle

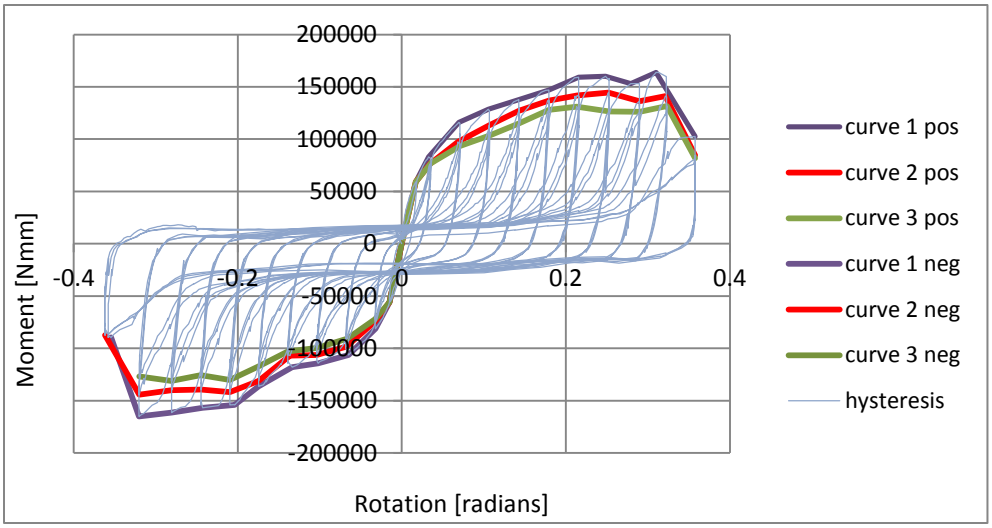


Figure 57: Hysteresis diagram and backbone curves

6.4.5 Test results G1-b2-8-C

Description test

The test was performed according to protocol with a yield slip of 20 mm.

Hysteretic cycle

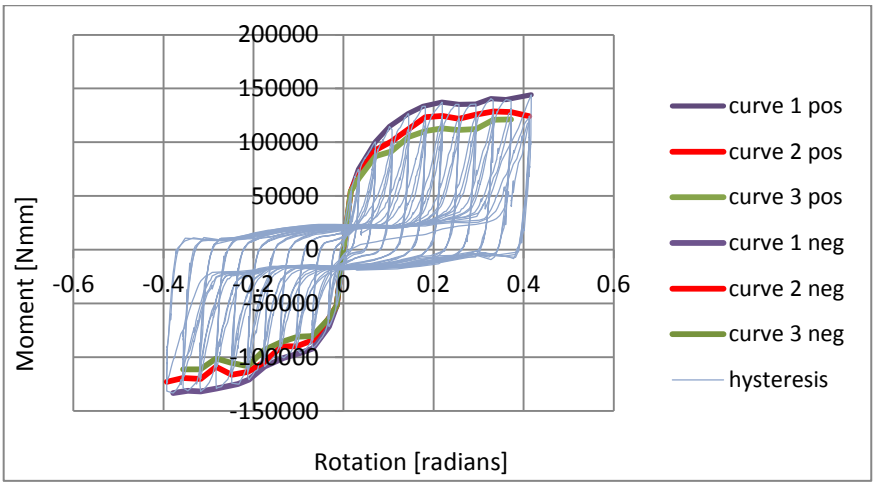


Figure 58: Hysteresis diagram and backbone curves

6.4.6 Test results G2-b1-2-C

Description test

Loading occurred according to protocol. A yield slip of 10mm was applied. No static-monotonic test was done due to a shortage on specimens. Instead it was reasoned that the yield slip should be slightly higher than specimens with screws, but definitely lower than the specimens from the floor samples, as the nails seemed to be of poorer quality and beams in the earlier specimens had larger height so probably longer nails. A minimum displacement rate of 0.1mm/s was kept at the location of the nails (minimum displacement rate of loading cell was therefore 0.3mm/s).

Hysteretic cycle

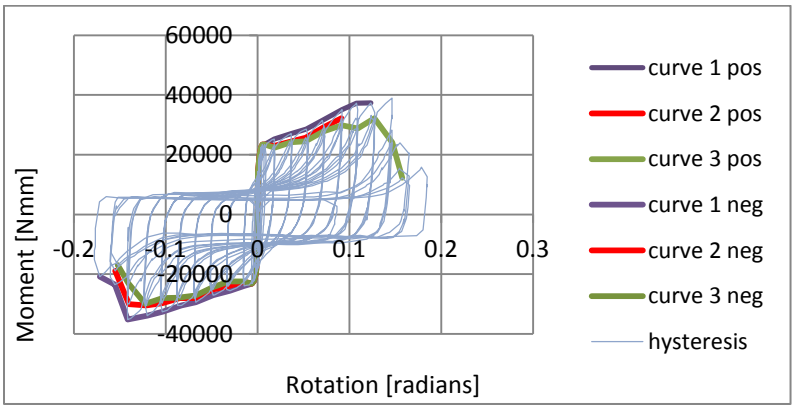


Figure 59: Hysteresis diagram and backbone curves

6.4.7 Test results G2-b1-7-C

Description of test

Loading occurred according to protocol. A yield slip of 10mm was applied.
The specimen had dimensions that did not work well with the original idea of the setup, thus was slightly modified.

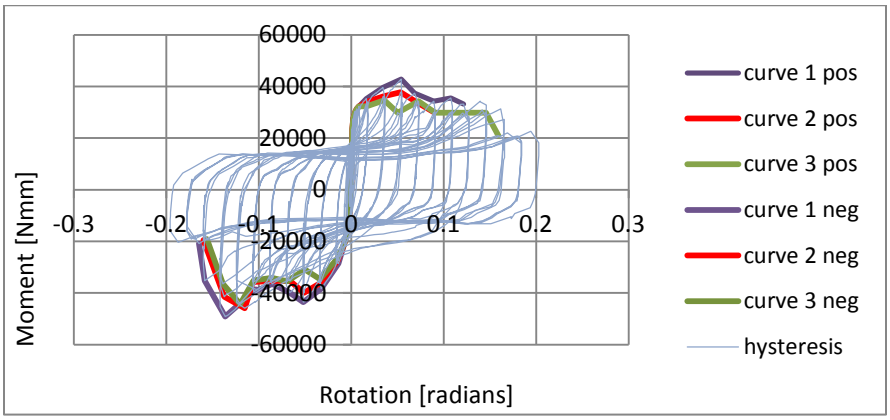


Figure 530: Hysteresis diagram and backbone curves

6.4.8 Test results G2-b2-7-C

Description of test

Loading occurred according to protocol. A yield slip of 10mm was applied. No static-monotonic test was done due to a shortage on specimens. Instead it was reasoned that the yield slip should be slightly higher than specimens with screws, but definitely lower than the specimens from the floor samples, as the nails seem to be of poorer quality and beams in the earlier specimens had larger height so probably longer nails. A minimum displacement rate of 0.1mm/s was kept at the location of the nails (minimum displacement rate of loading cell was therefore 0.3mm/s).

Hysteretic cycle

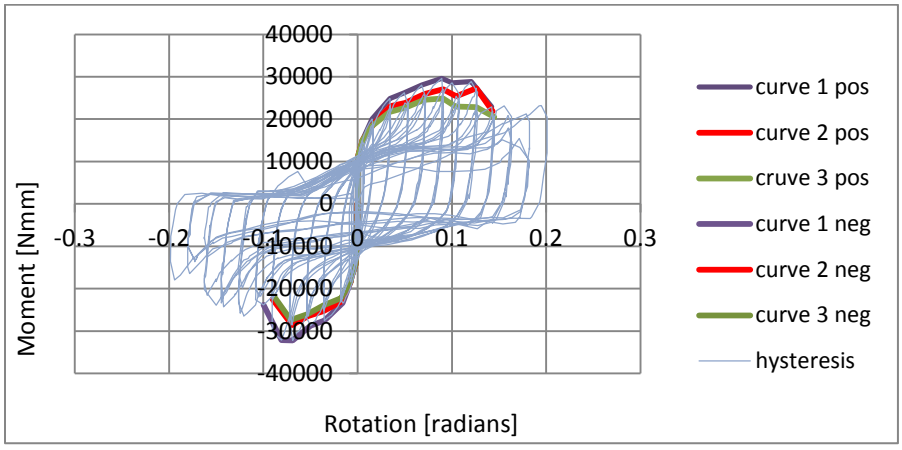


Figure 61: Hysteresis diagram and backbone curves

6.4.9 Test results G3-b1-2-C

Description test

The test was performed according to protocol.

Hysteretic cycle

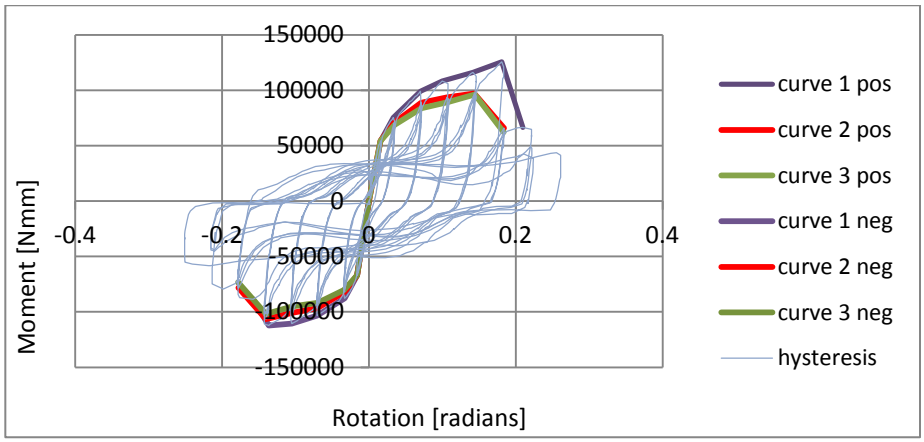


Figure 62: Hysteresis diagram and backbone curves

6.4.10 Test results G3-b2-3-C

Description of test

The test was performed according to protocol. The rate of displacement of the loading cell was chosen to be 0.2mm/s in accordance with EN 16670, which prescribes a deformation rate between 0.1mm/s and 10mm/s.

Hysteretic cycle

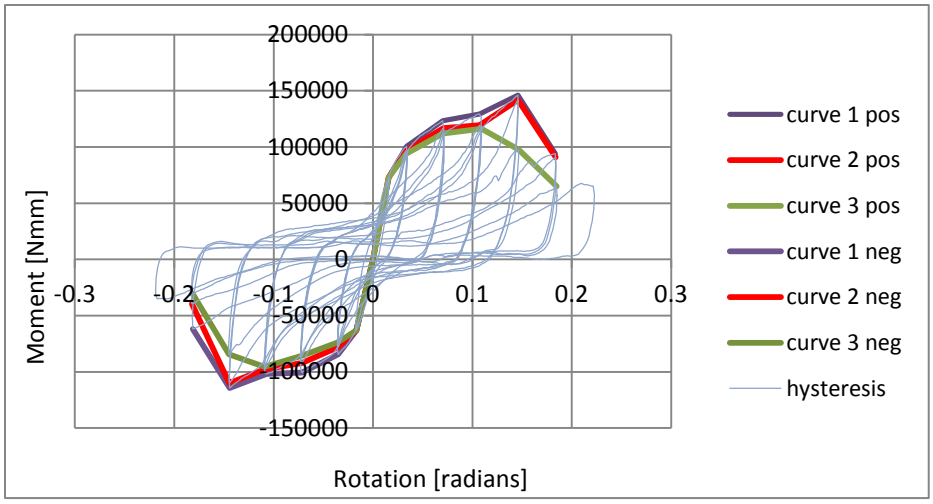


Figure 63: Hysteresis diagram and backbone curves

6.4.11 Test results G3-b2-6-C

Description of test

The test was performed according to protocol. The position of the laser was a bit closer to the rotation centre in order to keep the measurements within range of the laser.

Hysteretic cycle

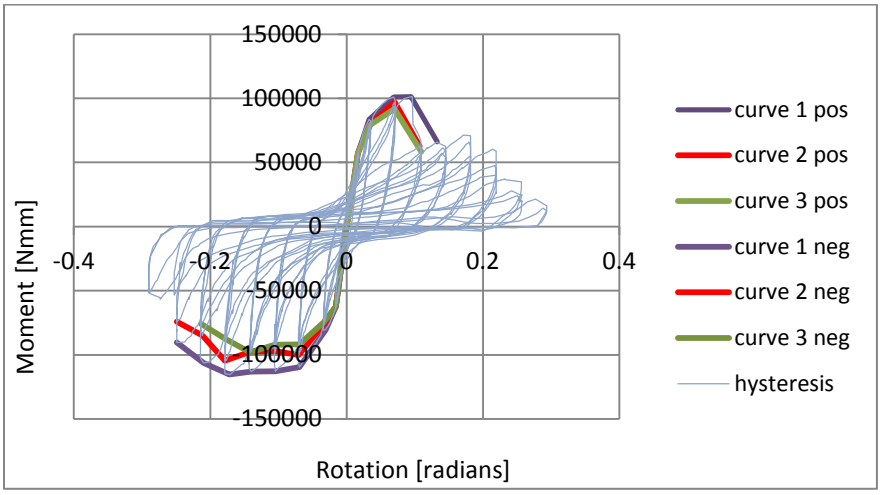


Figure 64: Hysteresis diagram and backbone curves

7 Conclusions

In this report the test performed on several plank-joist connections specimen were presented. These results are useful to understand better the dissipative behaviour of timber floors and to provide input data for FEM models.

According to the possible load directions, the specimens were tested with three different configuration: A (perpendicular to the joist), B (parallel to the joist) and C (loading in torsion).

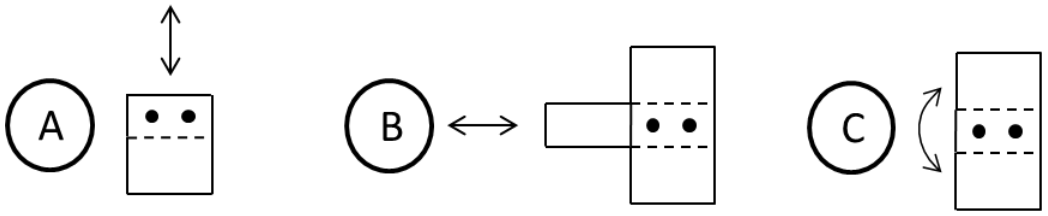


Figure 65: Specification of test specimens: A – loading perpendicular to joist, B – loading parallel to joist, C – loading in torsion

Results show a good dissipative behaviour of the connections, with nonlinearities appearing even for very low applied forces. A summary of these results for the whole amount of the tested specimens is reported in the following tables.

Table 8 – Properties of the specimens for test A (* means that a static monotonic test was performed)

Specimen	Test type	Fastener(s)	Fastener stiffness (ISO 16670) [N/mm]		F_{max} [kN]	d_{max} [mm]	Failure type
			1 fastener	2 fasteners			
G1-b1-8-A	A	2 nails		565.5	-3.76	-9.02	Bending failure of both nails
G1-b2-2-A	A	2 nails		660.0	-3.28	-14.91	Bending failure of both nails
G1-b2-9-A	A	2 nails		610.0	-3.44	-11.92	Bending failure of both nails
G2-b1-6-A	A	2 nails		304.3	0.56	5.08	Pull out failure of the nails
G2-b1-R1-A*	A	1 nail	260		6.65	26.35	Bending failure of nail
G2-b2-3-A	A	2 nails		739.1	-1.26	-5.27	Bending failure of both nails
G3-b1-3-A*	A	2 nails		565.5	2.60	13.38	Failure of beam
G3-b1-8-A	A	2 nails		932.2	2.31	11.78	Bending failure of both nails
G3-b2-2-A	A	2 nails		792.0	1.90	11.97	Bending failure of both nails
G3-b2-4-A	A	2 nails		911.3	2.75	12.06	Bending failure of both nails
Z1-b2-1-A	A	1 screw	740.1		1.95	5.61	Double bending failure of screw
Z1-b2-2-A	A	1 screw	595.7		1.91	5.42	Double bending failure of screw
Z1-b3-2-A	A	1 screw	394.7		1.26	8.58	Rupture of screw
Z1-b3-3-A*	A	1 screw	497.4		1.29	6.37	Failure of beam
Z2-b1-3-A	A	1 nail	494.7		-1.21	-10.17	Bending failure of nail
Z2-b2-1-A	A	1 nail	298.6		-1.72	-19.43	Bending failure of nail

Table 9 – Properties of the specimens for test B (* means that a static monotonic test was performed)

Specimen	Test type	Fastener(s)	Fastener stiffness (ISO 16670) [N/mm]		F_{max} [kN]	d_{max} [mm]	Failure type
			1 fastener	2 fasteners			
G1-b1-2-B	B	2 nails		916.5	-4.95	-11.73	Crack of plank, failure of a nail
G1-b1-4-B	B	2 nails		1696.3	-3.84	-11.89	Crack of plank, failure of a nail
G1-b2-6-B	B	2 nails		916.6	-3.18	-8.97	Rupture of both nails
G2-b1-2-B	B	2 nails		206.3	-0.89	-8.93	Bending failure of both nails
G2-b1-4-B	B	2 nails		186.2	-1.01	-5.95	Rupture of both nails
G2-b2-4-B	B	2 nails		259.4	0.89	5.61	Bending failure of both nails
G2-b2-6-B	B	2 nails		352.5	0.82	2.87	Rupture of both nails
G3-b1-4-B	B	2 nails		741.2	-2.57	-8.69	Rupture of both nails
G3-b1-6-B	B	2 nails		5432.6	2.18	8.87	Rupture of both nails
G3-b2-8-B	B	2 nails		4135.7	-3.50	-9.12	Rupture of both nails
Z1-b2-2-B	B	1 screw	833.8		-1.50	-4.01	Rupture of screw
Z1-b2-3-B*	B	1 screw	576.4		-1.16	-6.15	Tear out failure of plate
Z1-b3-2-B	B	1 screw	1260.3		1.24	4.14	Tear out failure of plate and bending failure of screw
Z2-b2-2-B	B	1 nail	540.5		0.7	3.95	Pull out failure of the nail

Table 10 - Properties of the specimens for test C (* means that a static monotonic test was performed)

Specimen	Test type	Fastener(s)	Fastener stiffness (ISO 16670) [Nmm/rad]	M_{max} [Nmm]	θ_{max} [rad]	Failure type
G1-b1-6-C*	C	2 nails	1622600	175700	0.16	Crack in the timber
G1-b1-9-C	C	2 nails	2648800	202820	0.14	Rupture of both nails
G1-b2-4-C	C	2 nails	2573800	-161240	-0.28	Rupture of both nails
G1-b2-8-C	C	2 nails	2582400	144070	0.42	Failure of one of the nails
G2-b1-2-C	C	2 nails	14264500	38930	0.15	Bending failure of both nails
G2-b1-7-C	C	2 nails	15049600	-49130	-0.14	Bending failure of both nails
G2-b2-7-C	C	2 nails	4226700	-32190	-0.07	Bending failure of both nails
G3-b1-2-C	C	2 nails	3350600	125620	0.18	Rupture of both nails
G3-b2-3-C	C	2 nails	5372000	146020	0.15	Rupture of both nails
G1-b2-6-C	C	2 nails	3257000	-115350	-0.17	Rupture of both nails

References

[1] ISO 16670:2003. Timber structures – Joints made with mechanical fasteners – Quasi-static reversed-cyclic test method. International Organization for Standardization (ISO).

[2] Ravenshorst G. J. P. & D. P. Kroon (2016). Protocol for the selection, extraction and transportation of timber samples. Delft University of Technology. Report C31B67WP4-1, version 1, 6-07-2016.