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TEST REPORT ON MATERIAL PROPERTIES OF TIMBER AND FASTENERS EXTRACTED FROM EXISTING BUILDINGS

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1 Introduction

This report presents the material properties of timber and fasteners specimen extracted from NAM houses. The test set-ups and testing procedures directed at determining the relevant properties of the materials are presented in [1]. The determination of the properties of these elements was an essential step because they formed the basis for the configuration and material choice of the large scale replicas of diaphragms.
In this report the number, the type and the properties of all the analysed specimens are presented.

2 Material properties of the analysed structural elements

2.1 Material properties of the timber joists and planks

As presented in [1], the material properties of the joists and planks that are of importance are:

- The wood species;
- The density (ρ);
- The modulus of elasticity (MOE);
- The moisture content.

The moisture content was determined randomly on a few pieces, assuming to be representative for the pieces from the same floor or roof samples.

2.2 Material properties of the fasteners

For the nails and screws two properties are of importance:

- The maximum tensile strength;
- The plastic bending moment.

The plastic bending moment is of importance because this determines the strength and ductility of the joist-plank connection. The maximum tensile strength is used in Eurocode 5 to calculate the plastic bending moment.
Both pulling tests and four-point bending test were performed for the connections extracted from a detached house (samples G1, G3 and G4), whereas for the remaining ones (G2, Z1, Z2) only pulling tests were performed, because of the limited amount of left over fasteners (The most of them were used in the plank-joist connection tests).

3 Experimental setup and procedures

3.1 Timber

3.1.1 Density

The density ρ in kg/m^3 was determined by weighing the test piece and dividing the weight by its volume, determined by measuring the length, width and height of the specimen.

3.1.2 Modulus of Elasticity

The modulus of elasticity (MOE) was determined by vibration measurements with a Brookhuis MTG 960. With this apparatus the first natural frequency of a timber piece can be determined and together with the density the MOE can be calculated: in this way the dynamic modulus of Elasticity E_{dyn} is obtained.
In [5] is shown that the MOE determined in this way has a very good correlation with the MOE determined in a static test according to EN 408. The static MOE is about 95% of the dynamic one.

3.1.3 Moisture content

The moisture content of the timber was determined as specified in EN 13183-1:2002 [4].
Small pieces were cut out and the moisture content was determined with the oven-dry method according to EN 13183-1.

3.2 Fasteners

3.2.1 Maximum tensile strength

EN 1383 [2] provides guidance on the performance of a pulling test, in order to determine the pull-through resistance of the nail or screw head through a timber piece. A schematization of this test according to EN 1383 is shown in figure 1(a). By omitting the timber piece on the top steel plate and adjusting the hole in the steel plate under the fastener head, the test set-up can be used to determine the tensile strength of the fastener. The test set-up which was used is shown in Figure 1(b).

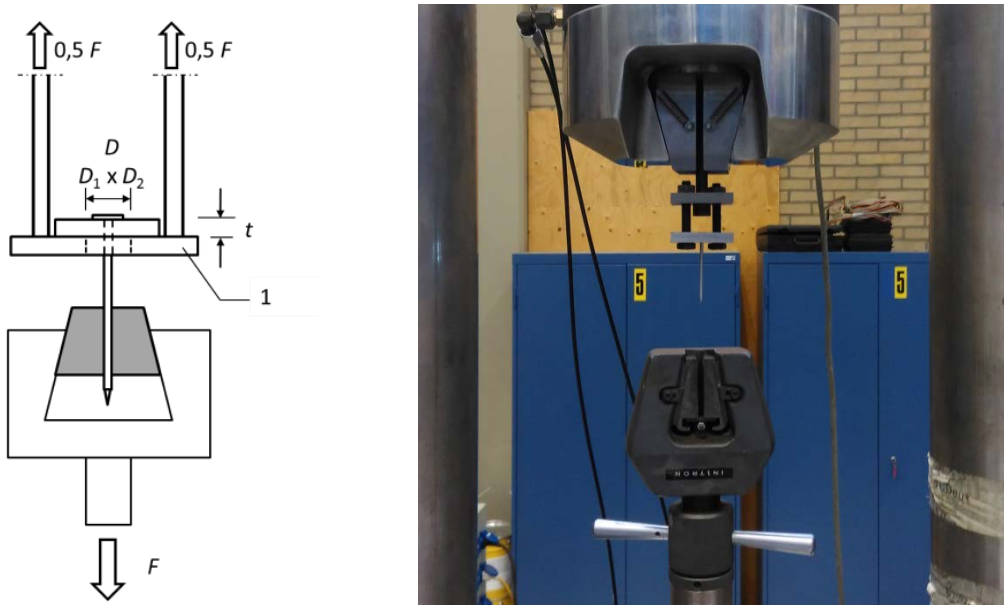

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Figure 1: Test apparatus pulling test

The loading rate is chosen in such a way that the failure load (ultimate load) is reached within 10s +- 5s. The maximum force is recorded and the tensile strength is then determined by dividing this value by the original diameter of the fastener.

3.2.2 Plastic bending moment

EN 409 [3] provides guidance to perform a four-point bending test on dowel type fasteners. The principle of the test according to EN 409 is given in figure 2(a). The rotation point A is attached to a fixed point as well as the top of element 7. Element 3 is a lever through which the forces are applied to the nail. Element 7 is attached to a load cell that registers the applied loads to the nail. From this force and the gravitational force of element 5 the yield moment can be calculated. In figures 3(a) and (b) a drawing and a picture of the actual set-up is given.
This setup fulfils the requirement that the nail has to be bent to an angle of 45°, while the forces applied on the nail stay perpendicular to the axis of the nail according to figure 2(b).

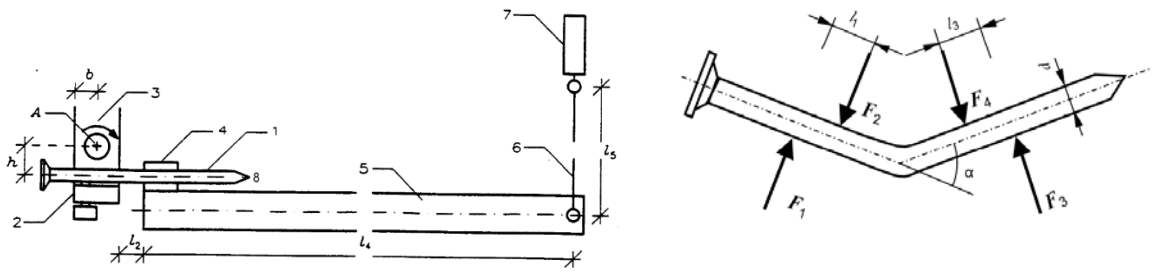
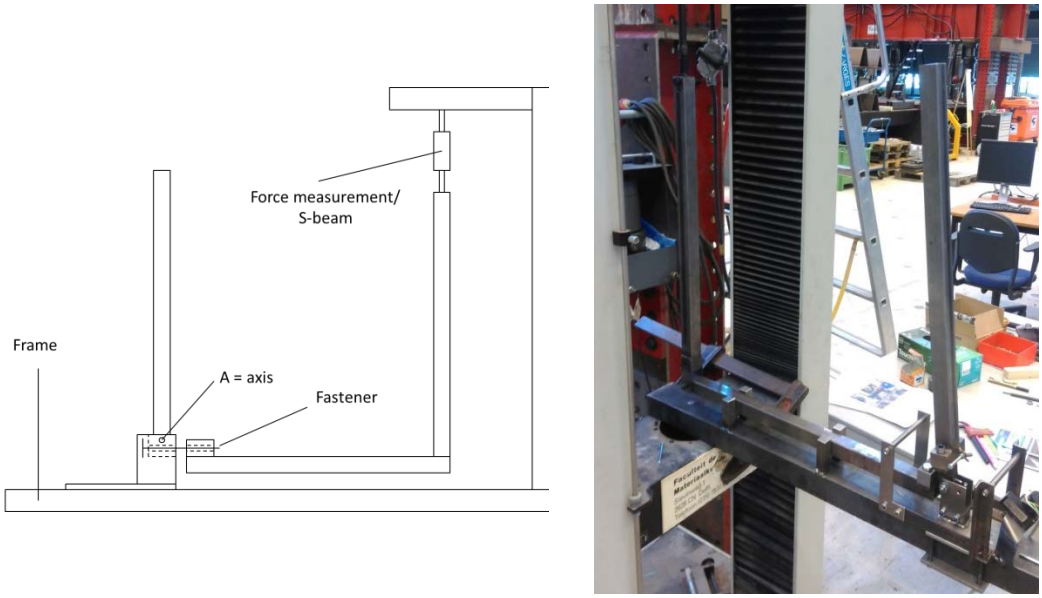


Figure 2: Test scheme (a) and required direction of loads after nail deformation (b) according to EN 409

The nail is loaded via the lever (figure 2(a), element 3), which is powered by hand. The instrument is physically limited to a bending angle of 45°.
The registered measurements are the force at the top of element 7 in figure 2 and the rotation angle around A. The force was registered with a measurement ring type load cell, while the rotation was calculated from the displacement of the lever near rotation point A measured with a linear potentiometer.



a b

Figure 3: Scheme (a) and realisation (b) of the test set-up.

4 Experimental results

4.1 Timber elements

4.1.1 Introduction

In this section the characteristics of the tested timber elements are reported: besides the material properties, also the wood species are specified for each sample. These properties were then used to replicate structural elements for the tested diaphragms representing floors and roofs.

4.1.2 Material properties of sample G1

In the following table the properties of the extracted sample G1 (ground floor of detached house) are presented: they refer both to the planks (p) and to the joists and/or beams (b). For each element also its code number is reported.

Table 1 – Characteristics of timber elements extracted from sample G1

Specimen	Species	Weight (kg)	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	Average moisture content (%)	Dynamic MOE (MPa)
G1-b01	Spruce	1,32	1478	52	36	478	9,2	11440
G1-b02	Spruce	1,41	1482	51	39	479		10870
G1-p01	Spruce	2,00	1647	162	18	416		12740
G1-p03	Spruce	2,10	1645	162	18	438		10020
G1-p05	Spruce	2,28	1645	161	18	478		15530
G1-p07	Spruce	2,04	1644	161	18	428		13130
Average values						**453**	**9,2**	**12286**

4.1.3 Material properties of sample G2

In the following table the properties of the extracted sample G2 (roof of the detached house) are presented: they refer both to the planks (p) and to the joists and/or beams (b). For each element also its code number is reported. Since for this sample a large amount of structural elements were used in the test for plank-joist connection, only a limited number of them was available to determine material properties.

Table 2 – Characteristics of timber elements extracted from sample G2

Specimen	Species	Weight (kg)	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	Average moisture content (%)	Dynamic MOE (MPa)
G2-b01	Spruce	2,61	940	100	50	555	9,4	11780
G2-b02	Spruce	2,33	915	100	50	509		13370
G2-p03	Spruce	1,18	1200	163	14	433		10730
G2-p04	Spruce	0,70	740	163	14	415		9890
Average values						**480**	**9,4**	**11440**

4.1.4 Material properties of sample G3

In the following table the properties of the extracted sample G3 (first floor of the detached house) are reported: they refer both to the planks (p) and to the joists and/or beams (b). For each element also its code number is reported.

Table 3 – Characteristics of timber elements extracted from sample G3

Specimen	Species	Weight (kg)	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	Average moisture content (%)	Dynamic MOE (MPa)
G3-p01	Pine	2,38	1396	164	23	452	9,0	12570
G3-p05	Pine	2,62	1396	164	23	498		12110
G3-p07	Pine	2,82	1394	165	23	533		16260
G3-p09	Pine	2,56	1392	164	23	488		14750
G3-b01	Spruce	1,81	1526	62	47	406		11550
G3-b02	Spruce	1,52	1129	62	40	542		17380
Average values						**486**	**9,0**	**14100**

4.1.5 Material properties of sample G4

For this sample (first floor of the detached house) more data are available because it was entirely used to determine material properties. In the following table they are therefore summarized: they refer both to the planks (p) and to the joists and/or beams (b). For each element also its code number is reported.

Table 4 – Characteristics of timber elements extracted from sample G4

Specimen	Species	Weight (kg)	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	Average moisture content (%)	Dynamic MOE (MPa)
G4-p01	Pine	2,32	1304	163	23	475	9,1	15090
G4-p02	Pine	2,36	1305	163	23	482		11900
G4-p03	Pine	2,64	1305	163	23	540		16720
G4-p04	Pine	2,48	1307	161	23	512		15130
G4-p05	Pine	2,50	1302	162	23	515		12340
G4-p06	Pine	2,18	1305	163	23	446		13490
G4-p07	Pine	2,40	1309	162	23	492		13440
G4-p08	Pine	2,34	1308	166	23	469		8020
G4-p09	Pine	2,16	1305	163	23	441		12390
G4-b01	Spruce	5,44	1535	100	60	591		17280
G4-b02	Spruce	3,79	1530	100	50	495		10820
Average values						**496**	**9,1**	**13330**

4.1.6 Material properties of sample Z1

This sample (first floor of the terraced house) is characterized by timber beams (b) and chipboard panels (p) as decking material. In this case, a panel was therefore sawn and material properties were determined in both directions for it. Direction X is orthogonal to the beams, while direction Y is parallel to them.

Table 5 – Characteristics of timber elements extracted from sample Z1

Specimen	Species	Weight (kg)	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	Average moisture content (%)	Dynamic MOE (MPa)
Z1-p01-X	Mix spruce/pine	0,455	590	60	18	714	8,6	3090
Z1-p02-X	Mix spruce/pine	0,440	590	60	18	691		2840
Z1-p03-X	Mix spruce/pine	0,445	590	60	18	698		2900
Z1-p04-X	Mix spruce/pine	0,455	590	60	18	714		3030
Z1-p05-X	Mix spruce/pine	0,450	590	60	18	706		2970
Z1-p01-Y	Mix spruce/pine	0,395	520	60	18	703		2660
Z1-p02-Y	Mix spruce/pine	0,400	520	60	18	712		2750
Z1-p03-Y	Mix spruce/pine	0,405	520	60	18	721		2800
Z1-p04-Y	Mix spruce/pine	0,410	520	60	18	730		2800
Z1-p05-Y	Mix spruce/pine	0,405	520	60	18	721		2770
Average values for chipboard panels						**711**	**8,6**	**2860**
Z1-b01	Spruce	2,670	1485	72	50	499	9,8	13970
Z1-b02	Spruce	2,275	1490	72	50	454		13230
Average values for beams						**476**	**9,8**	**13600**

4.1.7 Material properties of sample Z2

Also this sample (roof of the terraced house) is characterized by timber beams (b) and chipboard panels (p) as decking material. A panel was therefore sawn and material properties were determined in both directions for it. Direction X is orthogonal to the beams, while direction Y is parallel to them.

Table 6 – Characteristics of timber elements extracted from sample Z2

Sample	Species	Weight (kg)	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	Average moisture content (%)	Dynamic MOE (MPa)
Z2-p01-X	Mix spruce/pine	0,330	615	60	18	497	9,3	1280
Z2-p01-Y	Mix spruce/pine	0,390	710	60	18	508		1040
Average values for chipboard panels						**503**	**9,3**	**1160**
Z1-b01	Spruce	1,550	805	72	55	486	10,4	13970
Representative value for beams						**486**	**10,4**	**15440**

4.2 Fasteners

4.2.1 Introduction

In this section the main properties of the fasteners extracted from the analysed specimens are presented. Also in this case the knowledge of these values makes it possible to use quite similar fasteners for the configuration of the large scale diaphragms.
Both pulling tests and four-point bending test were performed for the connections extracted from detached house (samples G1, G3 and G4), whereas for the remaining ones (G2, Z1, Z2) only pulling tests were performed, because of the limited amount of leftover fasteners.
For sample G2, the nails were very similar to the ones found in specimens G1, G3 and G4, apart from the nails of the rafters, which were longer and thicker: therefore, only for this type of fasteners the pulling test was performed.
In the following tables each fastener is referred to the specimen from which it was extracted, specifying also the type of connection (screw, round nail or square nail) and its dimensions. These were measured and reported according to figure 4 scheme: it should be noticed that for the diameter of the screws the value of d1, i.e. the root diameter, is considered in order to calculate the ultimate traction resistance.

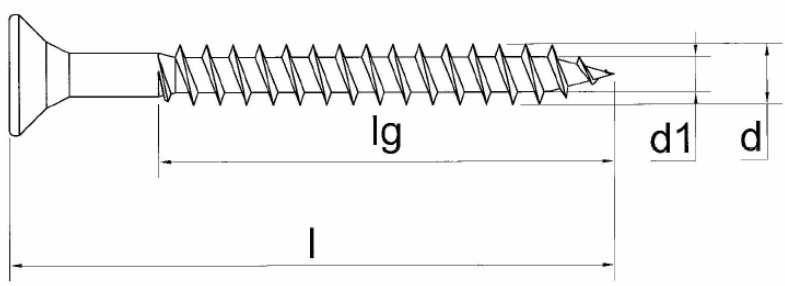


Figure 4: Dimensions and terminology used to report the characteristics of fasteners.

4.2.2 Pulling test (detached house)

In the following table the ultimate traction obtained by pulling test is reported for each tested connection extracted by samples G1, G2, G3 and G4, retrieved from samples extracted from a detached house.

Table 7 – Results of pulling test on fasteners extracted from samples G1, G2, G3 and G4

Element number	Diameter/Side (mm)	Type of nail	Length (mm)	F_u (kN)	σ_u (MPa)
G1-01	3,05	Round	65,0	4,9	665
G1-02	3,10	Round	64,8	4,1	545
G1-03	3,10	Round	64,6	4,4	582
G1-04	3,10	Round	65,8	4,6	612
G1-05	3,00	Round	65,2	5,5	775
G1-06	3,00	Round	65,3	5,6	788
G1-07	3,00	Round	65,0	5,3	753
Average values for G1				**4,9**	**674**

G2-01	4,00	Square	88,0	11,4	715
G2-02	4,00	Square	86,0	11,0	688
Average values for G2				**11,2**	**701**
G3-01	2,65	Square	56,0	4,2	598
G3-02	2,50	Square	55,3	5,2	838
G3-03	2,90	Square	56,2	3,8	447
G3-04	2,65	Square	55,6	4,1	587
G3-05	2,65	Square	55,4	4,1	578
G3-06	2,60	Square	56,0	3,2	474
G3-07	2,60	Round	61,1	4,0	753
G3-08	2,65	Square	55,8	4,8	681
Average values for G3				**4,2**	**620**
G4-01	2,60	Square	55,5	4,5	669
G4-02	2,65	Square	56,6	4,5	645
G4-03	2,65	Square	55	4,8	687
G4-04	2,55	Square	55,7	4,3	654
G4-05	2,65	Square	55,9	4,8	685
G4-06	2,90	Square	55,4	4,8	574
G4-07	2,85	Square	56	4,2	560
Average values for G4				**4,6**	**639**

4.2.3 Pulling test (terraced house)

In the following table the ultimate traction obtained by pulling test is reported for each tested connection extracted by samples Z1 and Z2, retrieved from samples extracted from a terraced house. In these case the analysed fasteners were screws instead of nails, and only pulling tests were performed due to the scarcity of connections available.

Table 8 – Results of pulling test on fasteners extracted from samples Z1 and Z2

Element number	Diameter/Side (mm)	Type of screw	Length (mm)	F_u (kN)	σ_u (MPa)
Z1-01	3,00	Round	40	6,35	899
Z1-02	3,00	Round	40	6,00	849
Z1-03	3,00	Round	40	6,35	899
Average values for Z1				**6,23**	**882**
Element number	Diameter/Side (mm)	Type of fastener	Length (mm)	F_u (kN)	σ_u (MPa)
Z2-01	2,50	Round screw	30	3,80	774
Z2-02	3,00	Round nail	56	4,48	634
Z2-03	3,00	Round nail	55	4,22	597
Z2-04	3,50	Round nail	80	7,01	729
Z2-05	3,50	Round nail	80	7,87	818
Average values for Z2				**5,48**	**710**

4.2.4 Four-point bending test (detached house)

In the following table the plastic bending moment obtained by the four-point bending test is reported for each tested connection extracted by samples G1, G3 and G4. Because the fasteners are very similar to each other, the average value is calculated from the whole amount of data available.

Table 9 – Results of pulling test on fasteners extracted from samples Z1 and Z2

Element number	Diameter/Side (mm)	Type of nail	Length (mm)	$\lvert M_u \rvert$ (Nmm)
G1-01	3,0	Round	66	3438
G1-02	3,0	Round	66	3610
G1-03	3,0	Round	66	3198
G1-04	3,0	Round	66	3562
G1-05	3,0	Round	66	3540
G1-06	3,0	Round	66	3228
G1-07	3,0	Round	66	3250
G3-01	3,0	Square	56	3207
G3-02	3,0	Square	56	3309
G3-03	3,0	Square	56	2409
G3-04	3,0	Square	56	2375
G3-05	3,0	Square	56	3028
G3-06	3,0	Square	56	3543
G3-07	3,0	Square	56	3408
G3-08	3,0	Square	56	3138
G4-01	3,0	Square	56	3006
G4-02	3,0	Square	56	3260
G4-03	3,0	Square	56	3187
G4-04	3,0	Square	56	2999
G4-05	3,0	Square	56	3424
G4-06	3,0	Round	66	3057
G4-07	3,0	Square	56	2904
G4-08	3,0	Square	56	3005
Average				**3178**

5 Conclusions

In this report the tests conducted in order to determine material properties of the typical structural elements of timber floors in Groningen area are presented. With these results, it is possible to replicate the studied floors and roofs in large scale diaphragms.
In the following two tables, the test results are summarized: all the mean material properties for timber and fasteners from each extracted sample are presented, together with the corresponding standard deviations and coefficients of variation.

Table 10 – Summary of the properties of timber elements

Extracted sample	Element(s)	Density (kg/m^3)			Modulus of Elasticity (MPa)			Moisture content
		Mean	St. dev.	C.of Var. (%)	Mean	St. dev.	C. of Var. (%)	Mean (%)
G1	Joists and planks	453	29	6,3	12286	1965	16,0	9,2
G2	Joists and planks	480	57	11,8	11440	1299	11,3	9,4
G3	Joists and planks	486	51	10,5	14100	2394	17,0	9,0
G4	Joists and planks	496	43	8,7	13330	2681	20,1	9,1
Z1	Joists	476	32	6,7	13600	523	3,8	9,8
Z1	Panels	711	12	1,6	2860	135	4,7	8,6
Z2	Purlin*	486	-	-	15440	-	-	10,4
Z2	Panels	503	8	1,5	1160	170	14,6	9,3

*The purlin of sample Z2 was the only one left over for the testing of material properties, so only one value is available.

Table 11 – Summary of the properties of fasteners

Extracted sample	Type of fasteners	Ultimate tensile strength (MPa)			Plastic bending moment* (Nmm)		
		Mean	St. dev.	C.of Var. (%)	Av.	St. dev.	C.of Var. (%)
G1	Nails	674	99	14,6	3404	175	5,1
G2	Nails	701	19	2,7	-	-	-
G3	Nails	620	133	21,4	3052	437	14,3
G4	Nails	639	52	8,1	3105	172	5,5
Z1	Screws	882	29	3,3	-	-	-
Z2	Nails and screws	710	93	13,1	-	-	-

*The plastic bending moment was measured only for fasteners extracted from samples G1, G3 and G4.

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