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Structural Design

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ABSTRACT

In order to analyse the stiffness and the strength of joints used for battens in bracing of trusses 70 tests have been made. The joint was made by a single nail or screw located perpendicular to or at an angle to the grain direction. The single fastener joints did not fulfill the requirements for edge distances and the number of nails according to the standard.

Three different nails and one screw were tested in 7 different series. The fasteners, test series and the test arrangement are presented. The failure loads and the load-displacements curves are given and the results are compared to the standard.

The expressions for the strength and the stiffness given in the standard can be used for the unspliced joints.

INTRODUCTION

Battens applied to trusses in Denmark have several purposes for example transfering the load from the roof to the trusses, lateral bracing of compression elements in the truss, see figure 1, and a load transfering element in the 3D stability of the truss system.

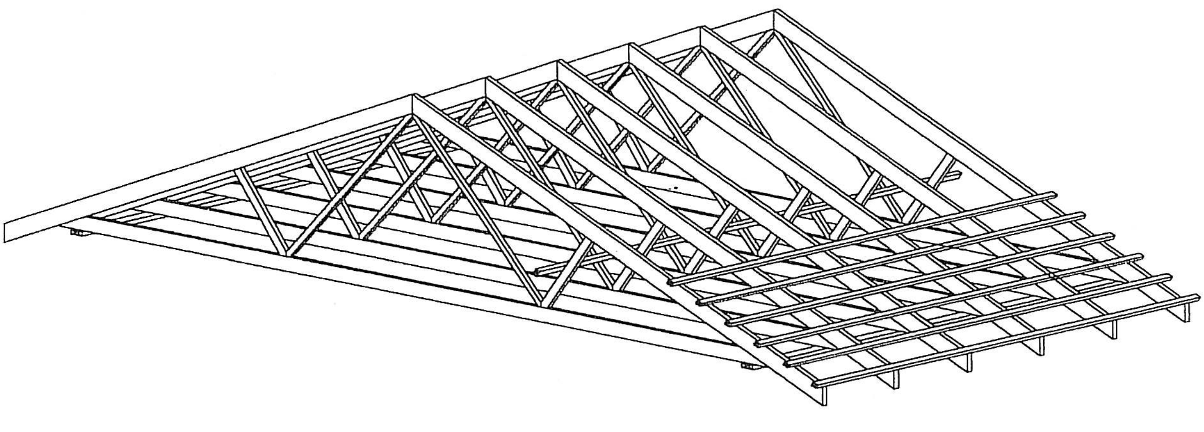

Figure 1: Battens used for bracing and load-bearing material for the roof on W-trusses.

According to the Danish national standard DS 413, the joint between the compression element and the bracing shall be able to transfer a force of $N_d/80$, where N_d is the average design force in the compression element. There are also requirements for the stiffness of the bracing.

In traditional Danish buildings the thickness of the trusses and the dimension of the battens are 45 mm and 38x56 mm, respectively. The joint is normally made by a single nail without predrilling. However, according to the above standard it is only allowed to transfer forces in this joint if the edge distance is larger than 10 d, where d is the diameter of the fastener. The fastener normally used has a diameter of 3-4 mm, which means an edge distance of only 6-7 d.

In order to analyse the strength of the above single nail joint some tests have been made. The tests and the test results are described in this paper.

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TEST SERIES

The test programme is divided into 7 different series as shown in table 1 and figure 2. Each series consists of 10 tests.

Table 1: Test programme with 7 different series.

Series no.	Fastener		Edge distance mm	Squeeze strip mm×mm
S1	34/90	nail	100	-
S2	38/100	nail	100	-
S3	38/100	nail	100	25x50
S4	3.1x90	ringed nail	100	-
S5	4.5x80	screw	100	-
S6	3.1x90	ringed nail	~33	-
S7	4.5x80	screw	~33	-

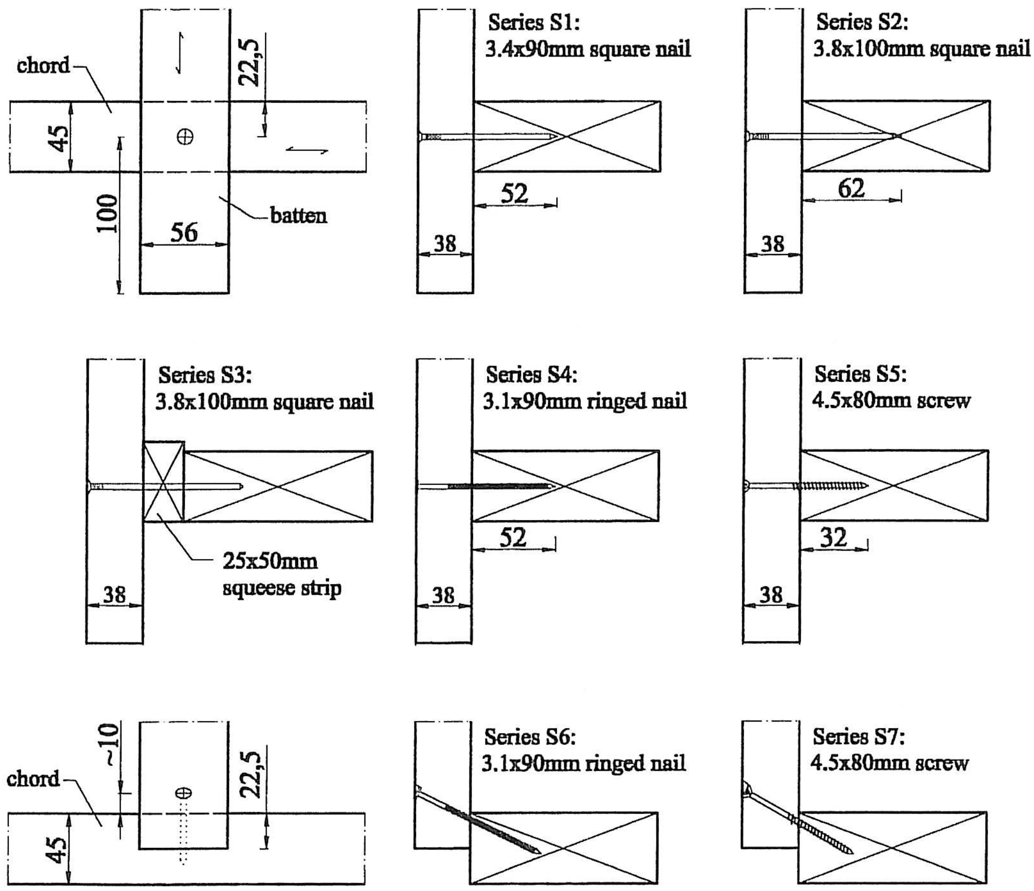


Figure 2: The 7 different tests series. Dimensions in mm.

In series S1 to S5 the distance from the centre of the nail to the end of batten is taken as 100 mm. At this distance splitting in the batten should be avoided. The fastener is located perpendicular to the grain direction.
Further, in series S3 a 25×50 mm squeeze strip is located between the batten and the chord. In practice, these strips are used to fix a sub roof between the chord and the strip. The sub-roof is normally made from reinforced

plastic or fibre sheet. In series S3 the squeeze strip is fixed to the chord with 2 galvanized 28/65 square nails located ~100 mm from the analysed fastener. During the test the strip is further supported by I-beams, see figure 4.

In series S6 and S7 the end of the batten is located at the centre of the chord (timber with 45 mm thickness). Series S6 and S7 are used to analyse a situation where the battens are spliced on the chord. There is a risk of splitting in the batten, and to reduce this risk the fastener is inserted at an angle approximately 33 mm from the edge of the batten, see figure 2.

The timber with 45 mm thickness is Swedish spruce, grade K24 [2]. The timber was selected and graded by the truss plant. The battens are Swedish spruce graded to K18. The 25×50 mm squeeze strips are ungraded Swedish pine treated with impregnation. All the timber is conditioned according to DS/EN 26891 and the moisture content during testing is found as ~12%.

Four different mechanical fasteners are tested:

38/100 nail:	Bright square nail. Thickness 3.8 mm. Length 100 mm. Produced by NKT, Denmark.
34/90 nail:	Bright square nail. Thickness 3.4 mm. Lenght 90 mm. Produced by NKT, Denmark.
45×80 screw:	Zink galvanized screw. Diameter 4.5(3.2) mm. Length 80 mm Distributed by Arvid Nilsson.
3.1×90 ringed nail:	Bright ringed shank strip nail. Thickness 3.1 mm. Length 90 mm. Produced by Paslode.

No tests have been made to analyse the properties of the fasteners.

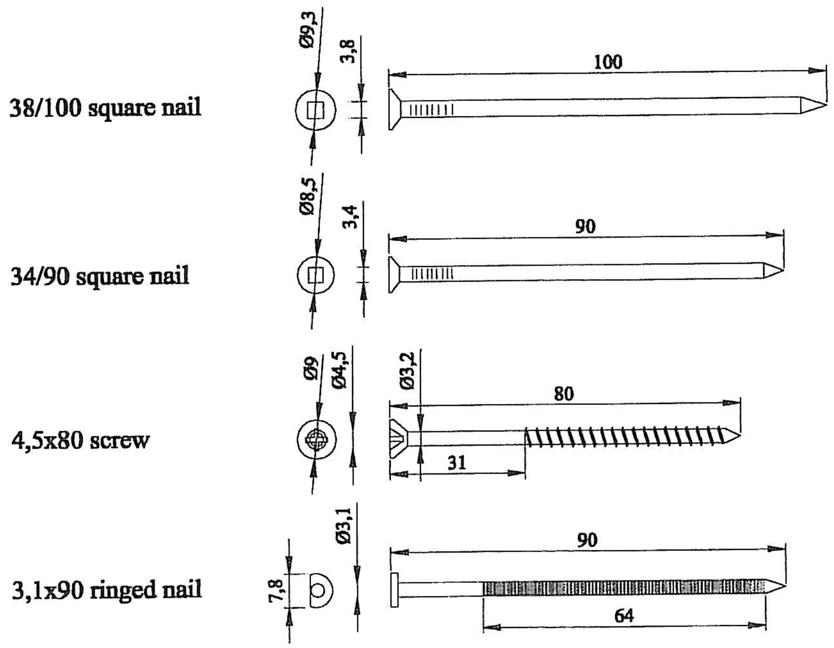


Figure 3: The 4 different mechanical fasteners. Dimensions in mm.

The time between collecting each test specimen and testing is below one day.
All specimens are loaded with a compression load parallel to the batten, see figure 4. The load is applied at the lower edge of the batten, see figure 4 right. Each specimen is loaded according to DS/EN 26891.
The relative displacement between the batten and the chord is measured by one HBM displacement transducer of type W10TK(± 10 mm).
A storage program from HBM, (UG6IEBE, 15/9-89), is used to store the data from the forces and the displacement measurings through an HBM data acquisition system (HBM UGR 60). The recording frequency is 1 Hz. The data are saved on disk.

[2]Strength classes K18 and K24 can be transmitted to S8 and S10, according to ECE Timber Committee.

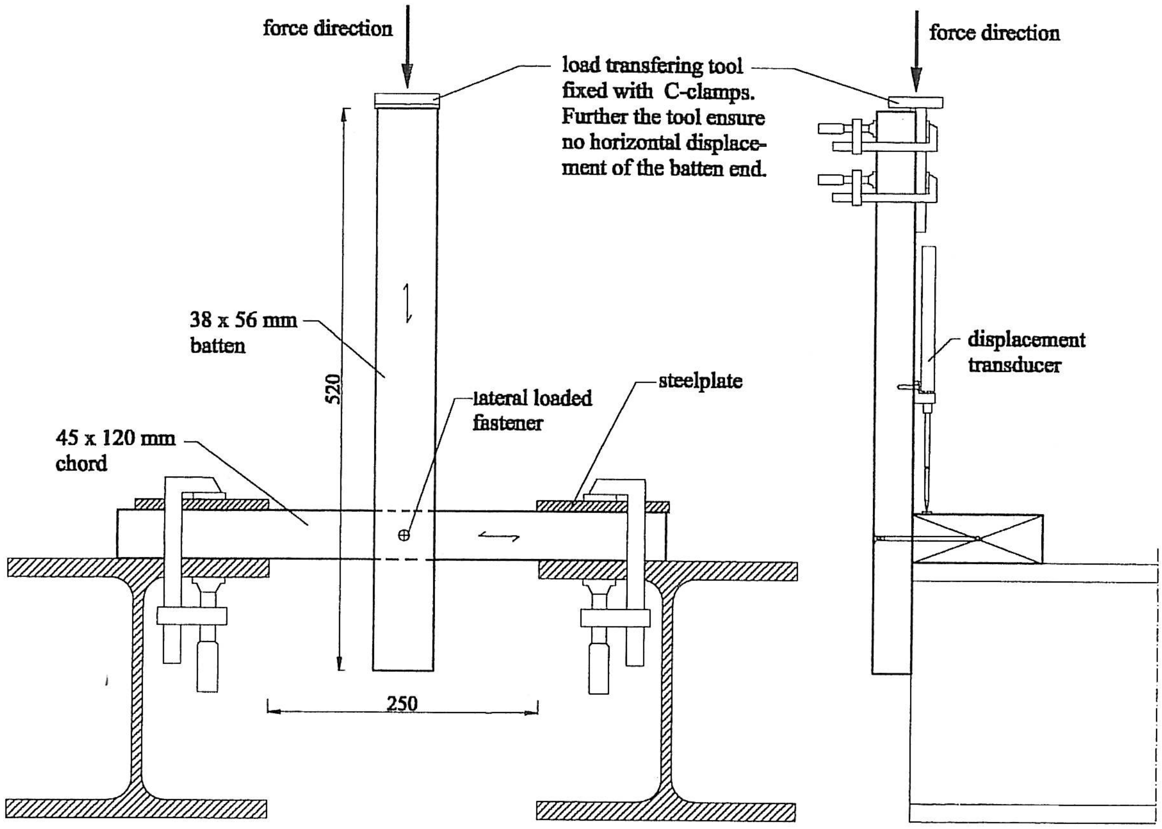


Figure 4: Test arrangement. Dimensions in mm.

RESULTS AND DISCUSSION

The mean value m, the standard deviation s, and the coefficient of variation δ are calculated according to EN 1058. ρ is the density of the timber.

Failure load

In table 2 the results for the failure load are given. The failure load is defined as the maximum load obtained before 15 mm deformation.

In table 2 "cor" denotes the correlation between the timber density ρ and the failure load. $U_{F_{max}}$ is the average displacement at failure load.

In general, no wood splitting was found in any of the test specimens and most of the joints did not fail. In these cases the tests were stopped when the deformation was larger than 15 mm. In a few tests in series S5 and all tests in series S7 tension failure occurred in the screw.
During loading the fastener bend and embedding slots into both chord and batten are observed. In series with square nails 1-2 mm withdrawal is observed as a gap between the batten and the chord (squeeze strip). In series with ringed nails and screws some minor (2-4 mm) penetration of the fastener head into the batten is observed. No withdrawal was observed in these tests.
In a few tests in series S6 and S7 a small crack from the fastener to the batten end was observed. The size of the crack was found to be unchanged during the test.
By comparing S2 and S3 it is seen that the failure load is unaffected of a joints with a squeeze strip.
In general, the correlation between the timber densities of the chord and batten and the failure load is to be very weak. However, in series S1, S2 and S3 the failure load seems to be correlated with the density of the chord.

In table 3 the mean and the minimum failure load are compared with the characteristic values, F_k, according to

Table 2: Failure load, timber density and displacement at failure load of each series.

Series	No.	Failure load			Chord			Batten			$U_{F_{max}}$
	tests	m	s	δ	ρ	s	cor	ρ	s	cor	
		kN	kN	%	kg/m^3	kg/m^3		kg/m^3	kg/m^3		mm
S1	10	1.71	0.24	15	466	51	0.91	491	25	-0.13	10
S2	11	2.03	0.34	17	458	44	0.60	480	32	0.42	10
S3	10	1.97	0.24	12	480	40	⋆0.80	487	35	0.31	11
S4	10	2.08	0.09	4	462	19	0.24	459	26	-0.67	14
S5	10	2.57	0.61	24	483	25	-0.22	474	35	0.13	13
S6	10	0.92	0.11	12	470	52	-0.02	479	37	-0.34	11
S7	10	1.11	0.11	10	508	88	0.58	493	41	-0.13	7

⋆ The average density for the squeeze strip is 542 kg/m^3.

DS 413 (Eurocode 5).

Table 3: Comparison between failure loads from tests and DS 413.

Fastener	Series	Diameter	Failure load		DS 413
	no.	d	m	min	F_k
		mm	kN	kN	kN
34/90	S1	3.4	1.71	1.36	1.36
38/100	S2	3.8	2.03	1.46	1.64
	S3	3.8	1.97	1.65	
31/90	S4	3.1	2.08	1.91	0.92
45/80	S5	3.2	2.57	1.97	⋆0.86
31/90	S6	3.1	1.05	0.77	-
45/80	S7	3.2	1.11	0.89	-

⋆ f_y of the screw is assumed to exceed 360MPa.

The characteristic lateral bearing capacity, F_k, found by DS 413, demands a minimum edge distance of 10 d and a minimum of 2 nails. With a chord thickness of 45 mm only an edge distance of 6-7 d can be obtained.

From table 3 it is seen that DS 413 estimates the failure loads for the square nails quite well. However, a small overestimation is observed compared to the minimum failure load of series S2. DS 413 underestimates the failure load of the tested ringed nails and screws with a factor 2.
Expressions to estimate the load-bearing capacity of nails in battens spliced at the chord as in series S6 and S7 are not given in DS 413. In table 3 it is seen that the load-bearing capacity in these cases are only half of that of an unspliced joint. This result is only valid when the load is directed towards the batten end (compression). With tension forces in the batten the failure load of the spliced single fastener joint will be caused by splitting at the end of the batten and/or maybe by withdrawal of the fastener also. In this case the failure load is assumed to be lower than failure loads found in series S6 and S7.

In total it is concluded that the characteristic lateral bearing capacity of the tested unspliced joint can be estimated according to DS 413.

Stiffness
Load-displacements curves of all the tests are shown in figures 5 and 6. In general the stiffness properties of the joints are found to be ductile since no failure is observed even with deformation larger than 15 mm. In one test in series S5 and all tests in series S7 total failure occurred (can be observed as a steep downward linear jump in the load and a positive displacement, in figure 6 (a) and (c). As seen in table 2 and in figure 5 the maximum load for the square nails is reached at 10 mm displacement.

The load-displacement curves for the joints with ringed nails and screws are still increasing during loading and therefore the maximum load is found close to the 15 mm deformation limit. One test in series S6 was stopped before 15 mm deformation caused by a lack in the hydraulic load system. No explanation is found for the very

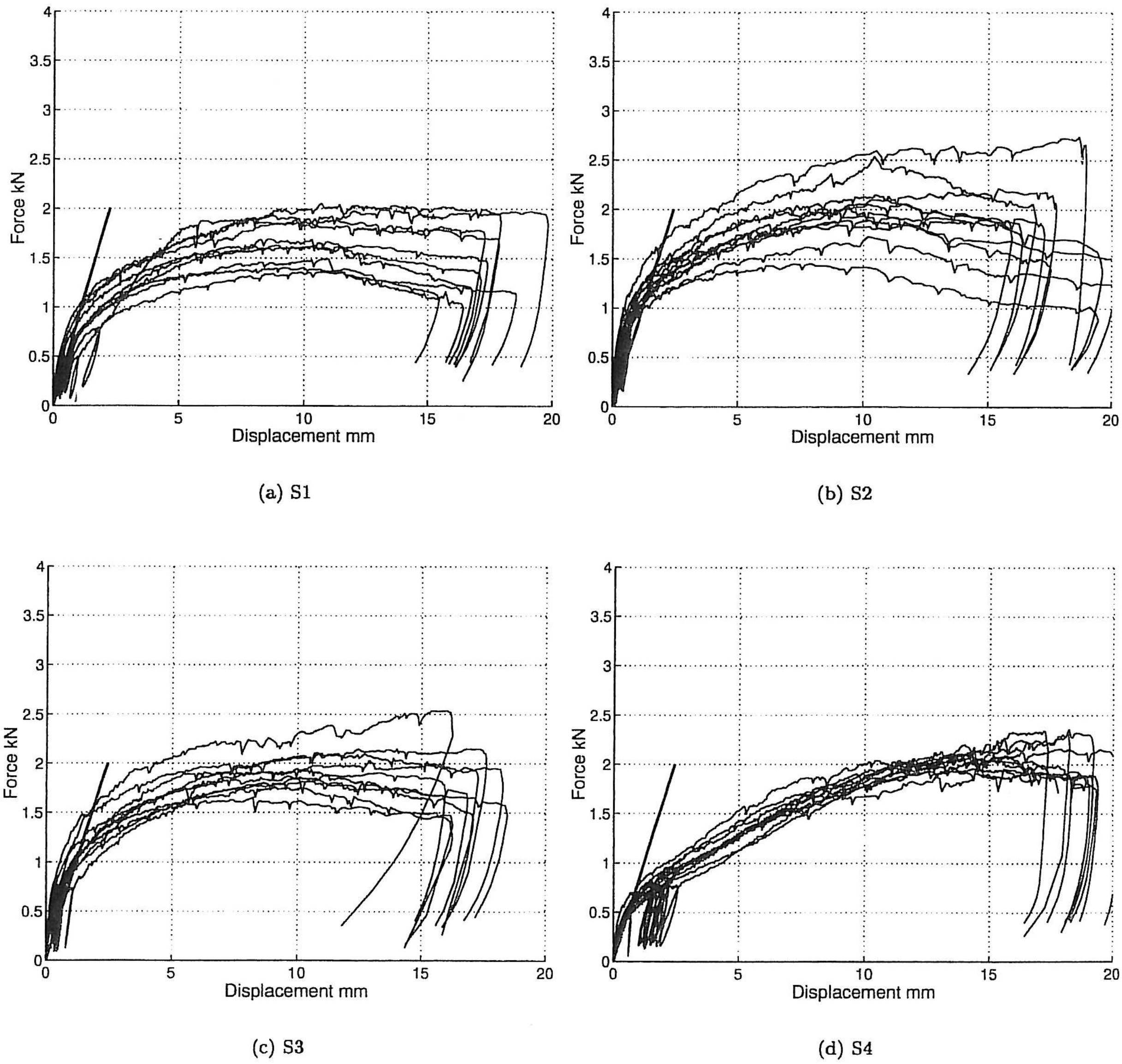
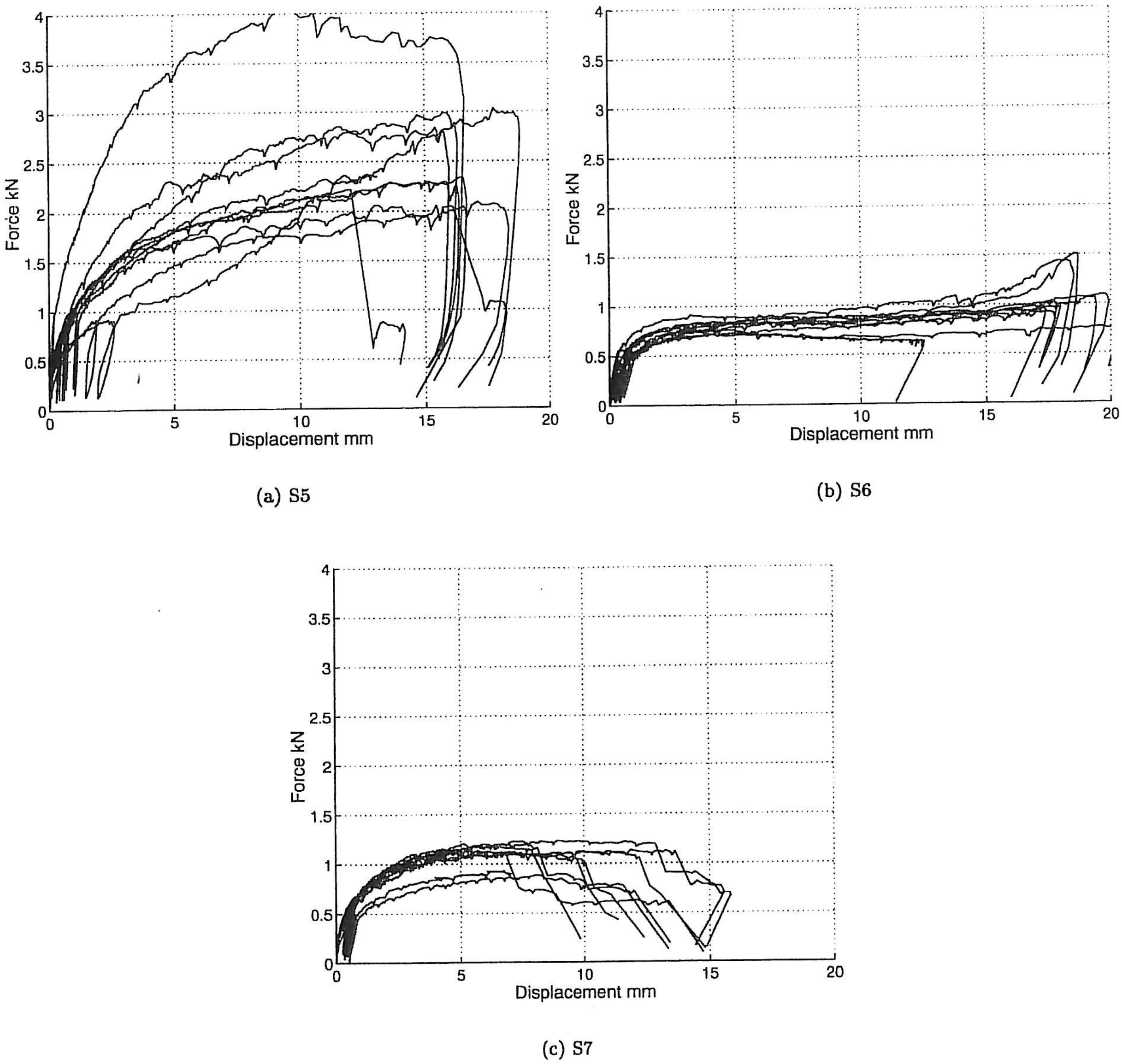


Figure 5: Load-displacement curves for series S1, S2, S3 and S4.



(a) S5

(b) S6

(c) S7

Figure 6: Load-displacement curves for series S5, S6 and S7.

stiff and strong test in series S5. The density of the chord and batten in this test is found as 458kg/m^3 and 456 kg/m^3.

According to DS 413 6.3.2(6) the short-term stiffness, K_{ser}, for nails loaded in the serviceability state is given by (1),

$$K_{ser} = \frac{\rho_k^{1.5}}{25} d^{0.8} \quad \text{N/mm} \tag{1}$$

where ρ_k is the characteristic density of the timber, and d is the diameter in mm. In figure 5, K_{ser} is compared to the load-displacement curves. All the stiffness values in the figures are based on the *average density* of all the chord and batten specimens used ~480kg/m^3. It is seen that the deformation is slightly overestimated by DS 413.

CONCLUSION

Based on the tests the following conclusions can be made:

- The lateral failure load for joints with 34/90 or 38/100 square nails can be estimated by the standard DS 413, even if only one fastener is used and the edge distance is only 6-7 d.
- The unspliced joints are found to be very ductile.
- The lateral failure load for the analysed ringed nails and screws are underestimated by a factor 2 in the standard.
- The stiffness estimated for nails by DS 413 is underestimated compared to the tested joints.

In further analyses it is recommended to test series with a larger number of test specimens(e.g. 40) to get a better estimate on the characteristic failure load.

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