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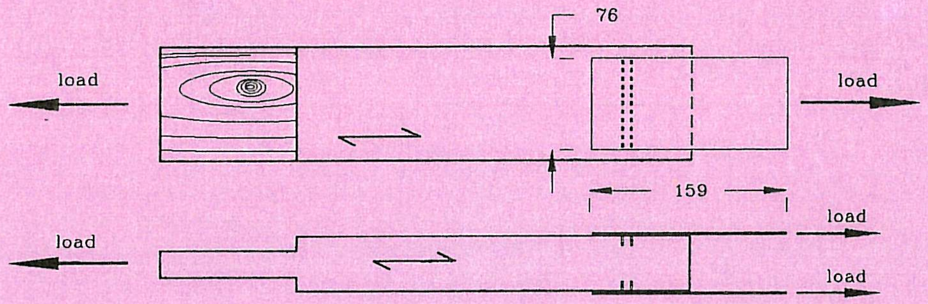

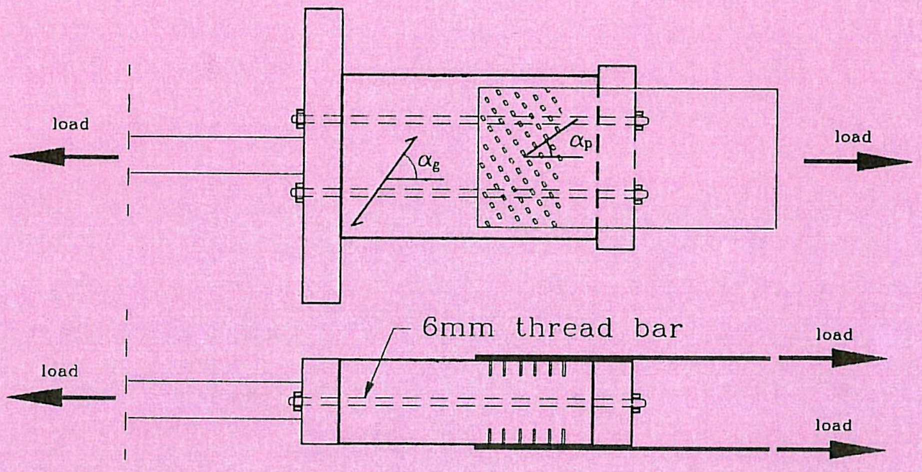

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PAPER NO. 1

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LATERALLY LOADED NAIL-PLATES

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LATERALLY LOADED NAIL-PLATES

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Abstract

Load-displacement curves from about 200 short-term and laterally loaded nail-plate joints are analysed. The nail-plates are from Gang-Nail Systems, type GNA 20 S. The test specimens and the measuring systems are described. The tests are divided into 32 different series. The influence of the number of nail row, edge distance, fixed nail-plate, bending direction, unloading, and grain direction, plate and load direction on the load-displacement curves are analysed. Mean load-displacement curves from all the tests are given.

1. Introduction

For many years nail-plates have been used in prefabricated timber frames. In Denmark nail-plates have been used in timber stuructures as: all types of trusses, beams in joist-floor. In the recent years types of trusses have been used where the stiffness and strength are highly dependent on the joints . For that reason nail-plate joints have to be analysed.

Today the design of trusses is made using rather simple models. Improvement in design of the trusses requires a model in which the joint can be semi-rigid, with non-linear load-slip characteristics. Thus more information about the behaviour of the nail-plate joint is needed.

Since the birth of the nail-plate, many researchers have investigated nail plate joints. Analytical and numerical models have been developed for short- and long-term loading.

In the spring of 1993 tensile tests have been performed on longitudinal timber joints with nail-plates. The deformation of the plate has been measured. Also tests with few nails (one or two nail rows) have been performed to determine the stiffness of single nails. A finite element program (ABAQUS) has been used to analyse the nail-plate joint as a spring model. It was found that the numerical model with the same spring characteristics as the load-displacement curves from tests with few nails are too stiff compared to tests with longitudinal timber joints. Therefore, the nail-plate joints have to be analysed further.

This paper describes a short-term test series performed at the laboratory of the Department of Building Technology and Structural Engineering . The objectives of the tests are:

- to analyse the load-displacement curves of the dependence of nails on
  - number and location of the nails,
  - unloading,
  - grain direction and plate orientation,
- to analyse a newly developed measuring systems.

The word "nail-plate" has been used for different types of plates. There are two main types of nail-plates: steel plates perforated with holes in which separate nails are used, and steel plates perforated with a stamping machine, so that the nails are made from the plate. This type is sometimes called "punched metal plate" and requires a hydraulic pressing tools to embed the nails into the wood.

A nail-plate of the latter type will be analysed in this paper. The nail-plate is from Gang-Nail Systems, type GNA 20 S. This nail-plate differs from other plates by its thickness, which is only 1mm.

The grain direction is given by the symbol: ⇀ .

2. Test Material

Timber

The timber is Swedish spruce wood (Picea abies) of strength class K-24 according to the Danish Code of Practice for Structural Use of Timber. It is placed in a conditioning room at 65% RH and 21°C until the moisture content of the wood is about 11%. The timber specimens are shaped as shown in figure 1 and figure 2. The timber dimensions 45 × 94mm in figure 1 are made by planing. The recesses in the end of the specimens are caused by the jaw distance in the tensile machine. The timber specimens for the series are randomly selected. In series 1-22 the tests have annual rings as shown in figure 1.

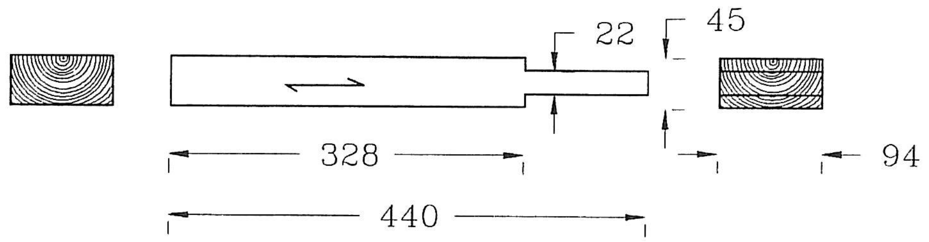

Figure 1: Measure of timber specimens used in the series 1-22. Dimensions in mm.

In series 23-34 the timber specimens are shaped as shown in figure 2. The timber dimensions 45 × 90mm are made by planing. The holes are made to fix the load equipment, see figure 5.

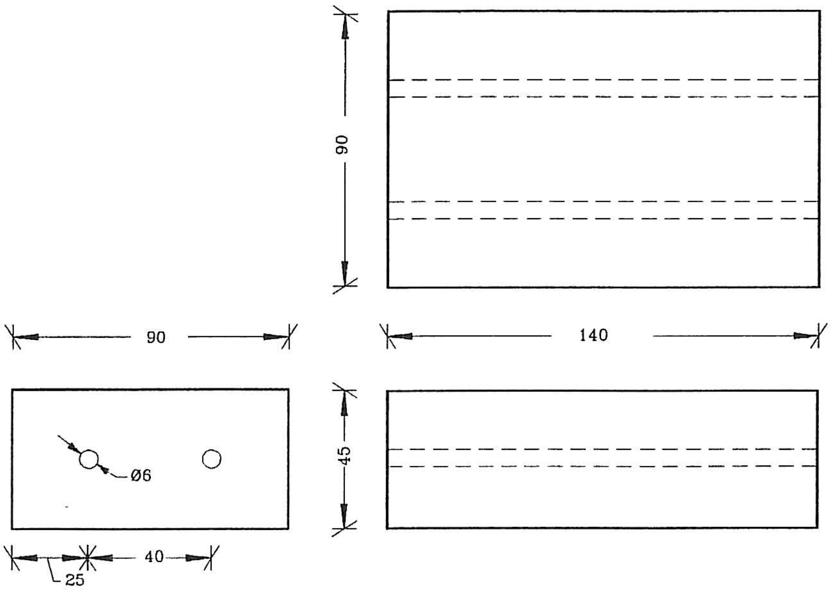

Figure 2: Measure of timber specimens used in the series 23-34. Dimensions in mm.

Nail-Plate

The galvanized nail-plate is from Gang-Nail Systems, type GNA 20 S, see figure 3. The plate thickness is 1 mm and the nail density is about 1.47nails/cm^2. The teeth are made by punching. The steel has the properties: 350MPa $< f_p <$ 470MPa, $f_u >$ 410MPa, where

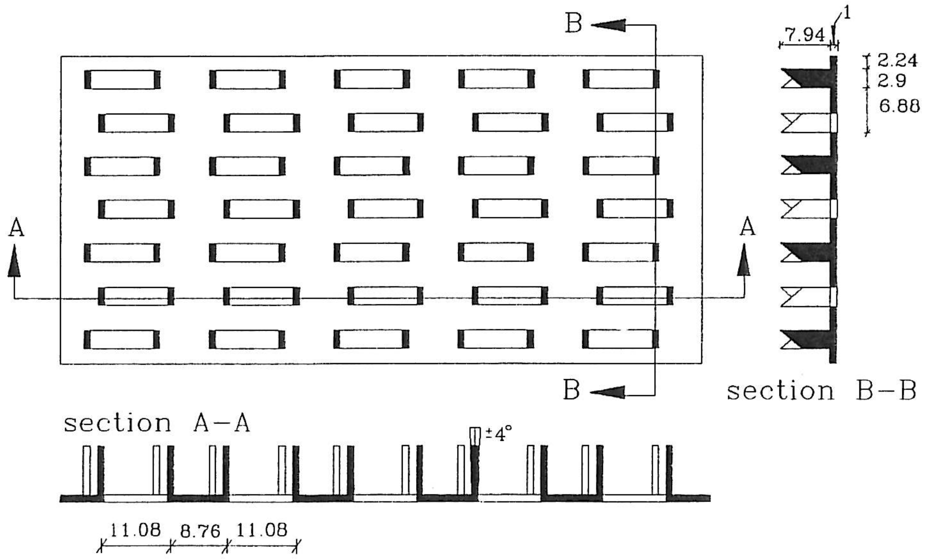

Figure 3: Nail-plate GNA 20 S. Dimensions in mm.

f_p is the limit stress of proportionality and f_u is the ultimate stress.

Test Specimens

A test specimen consists of two nail-plates embedded into a timber specimen. The test specimens in series 1-22 are shown in figure 4. The nail-plate size is 76 × 159 mm. The unwanted teeth in the nail-plates are cut off. The centre line of the plate and the timber specimens coincide and in all tests the load direction is parallel to the grain direction. Different posotions of the plates are used. The number of teeth (nails) and nail-rows are also different in the series. See also the test programme in table 2 and table 3, on page 10.

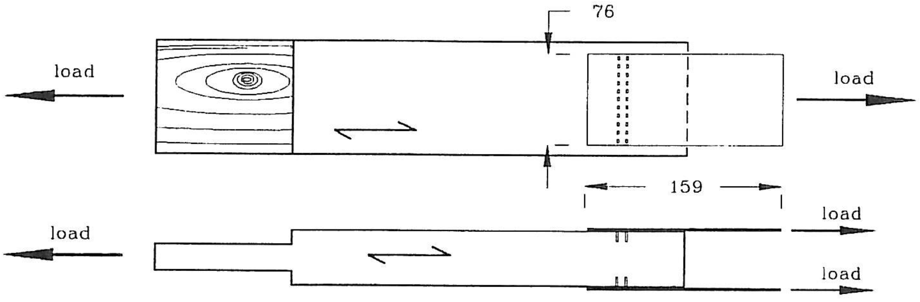

Figure 4: Test specimen in series 1-22. Dimensions in mm.

The test specimens in series 23-35 are made as shown in figure 5, because the timber specimens form an angle between their grain direction and the load direction. In series 20-35 the test specimens are made with different angles between grain, plate and load direction. α_g and α_p denote the angle between the load direction and the grain direction and the angle between the load direction and the principal axes of the plate, respectively. The choice of α_p is made so the the nails "make rows" perpendicular to the load direction.

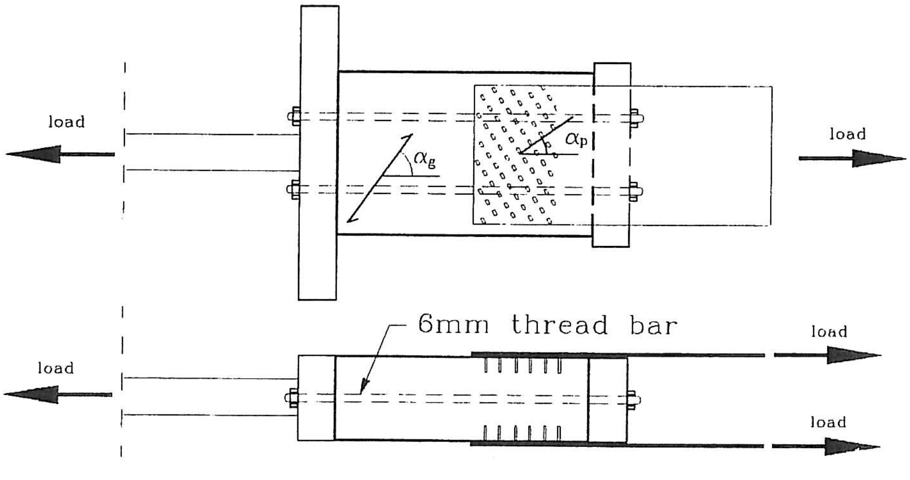

Figure 5: Test specimen in series 23-35.

The tests are then made with $\alpha_p = 0°$, $34°$, $54°$ and $90°$. Corresponding values of α_p and α_g are shown in table 4, page 11. Because of the low tensile strength perpendicular to the grain direction of the timber the load will be transmitted through two threaded bars as shown in figure 5. The timber will then be loaded in compression.

3. Test Equipment

Loading

The tension machine is a Mohr & Federhaff universal testing machine, see figure 6. The load velocity during the test is constant. The influence of the load velocity is tested in series 1, 2 and 3, see table 2. In the other series the load velocity per nail is held constant about 37N/min. At one end the timber specimens are placed beween the jaws of the tensile machine. At the other end the load is transmitted from the jaws to the nail-plate through a "T-fitting", see figure 9 on page 8. The "T-fitting" transfers the load by friction. All test specimens are centrally loaded.

In order to know the unloading properties of the load-displacement curves all the test specimens will be unloaded and reloaded once in a test.

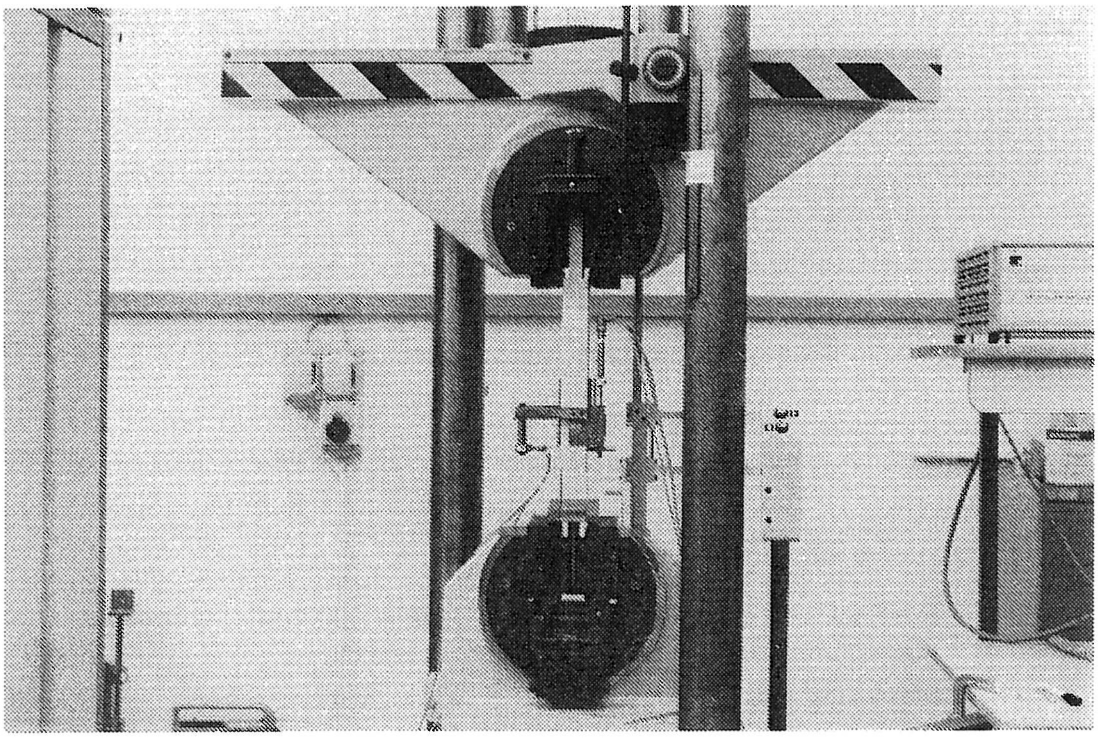

Figure 6: Mohr & Federhaff testing machine with a test specimen and two measuring systems.

Displacement Measuring

Two displacement measuring systems are developed, see figure 9. One of the displacement systems uses HBM displacement transducers of type W2TK, see figure 7 and figure 9 A,

B. A small pointed bar is placed in a hole in the nail-plate. The pointed bar is connected perpendicular to another bar which can slide undisturbed. This bar is prestressed with a spring and is is parallel connected to the transducer through an extension pin. Sudden movements of the nail-plate will cause a decoupling of the transducer as the extension pin will fall off.

The other system uses strain gauges on small cantilever beams (pins), see figure 8.

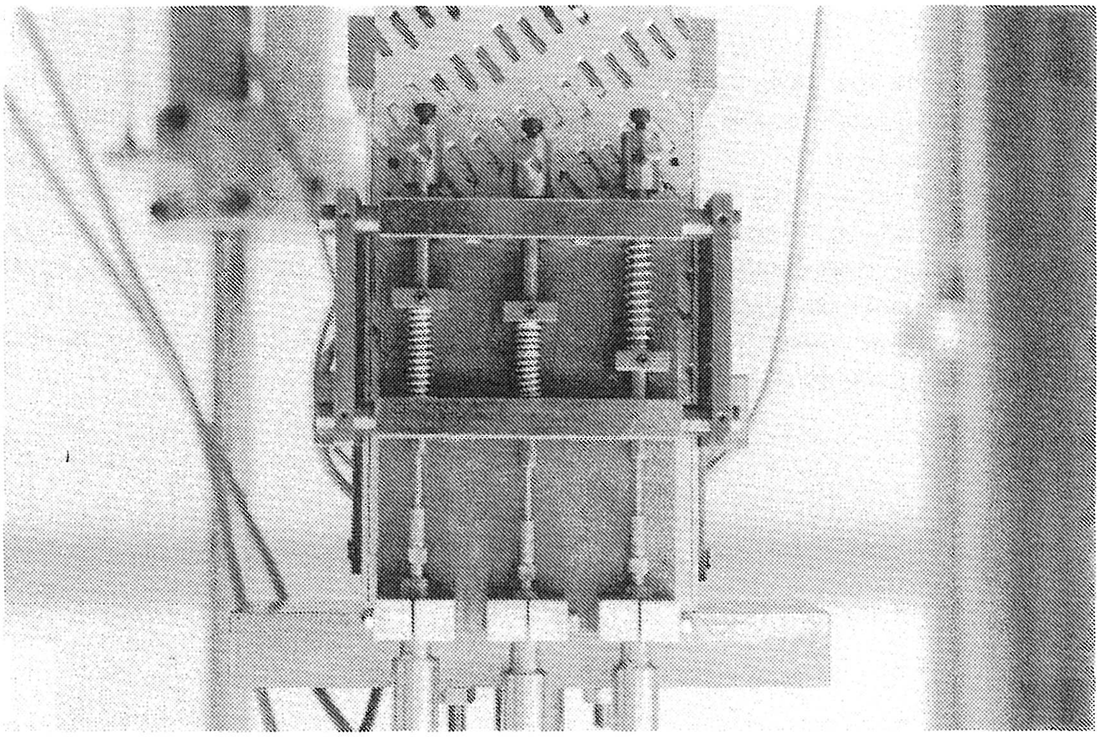

Figure 7: The transducer displacement measuring system with 3 transduceres.

Data of the two systems are shown in table 1.

The differences between the two systems are obvious. The accuracy of the "transducer system" is high but the system is not very flexible. The flexibility of the "pins system" is very high and the accuracy (linearity error) is satisfactory. The pin system cannot be used for tests to failure, because the pins will then develop some plastic deformations. The "pin

Measuring system	"transducer system"	"pin system"
No. disp. measurings	1,2,3	1,2,3......
Nominal measuring range	4mm (±2mm)	4mm (±2mm)
Linearity error	±0.008mm	±0.01mm
Measuring until failure	yes	no
Measuring direction	one direction	$0 - 360°$
Flex. location of the measurings	no	yes

Table 1: Data of the two measuring systems.

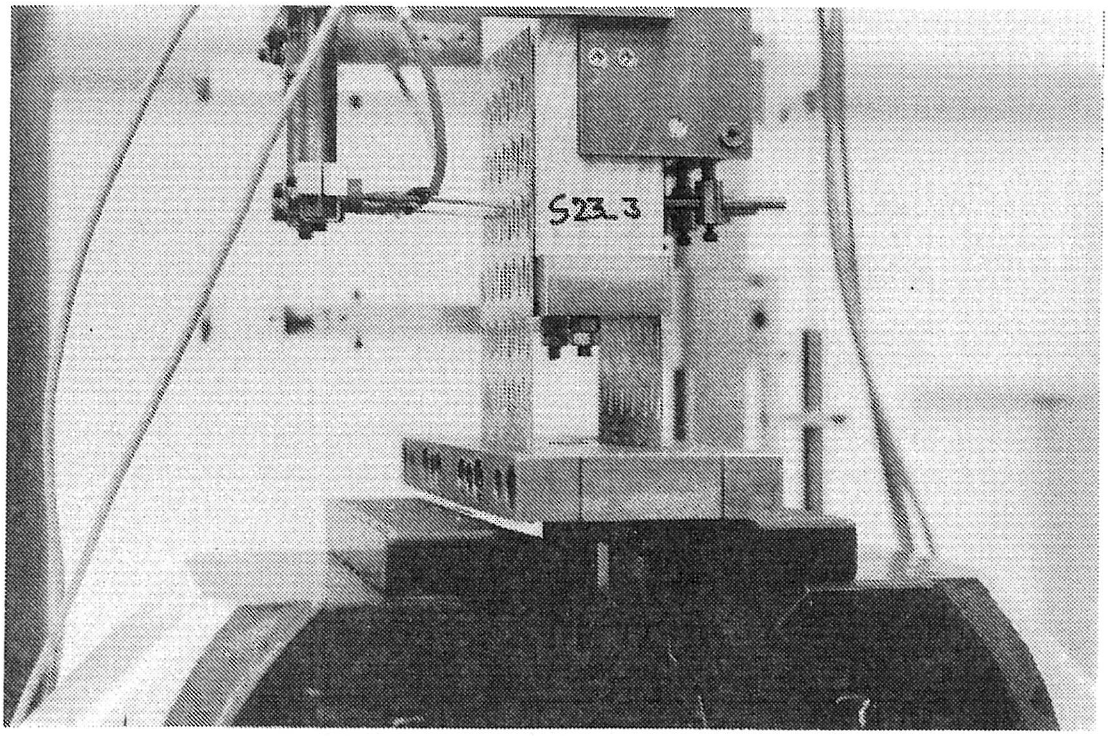

Figure 8: The "pin" displacement measuring system with two pins.

system" is working on the assumption that the pin is in a linear-elastic state.
The displacements are measured relative to the timber as both systems are fastened to the timber by the star-screws, see figure 9 B on page 8.
As some test series use nail-plates which are fixed to the timber, a special lock-fitting is made. The reasons for this are given on page 9.

In all tests 5 displacement measurings (3 transduceres and 2 pins) are performed.

Storage Equipment
A storage program from HBM, (UG6IEBE, 15/9-89), was used to store the data form the force and the five displacement measurings through an HBM data acquisition system (HMB UGR 60). The recording frequency is 0,1Hz. The data are saved on disk.

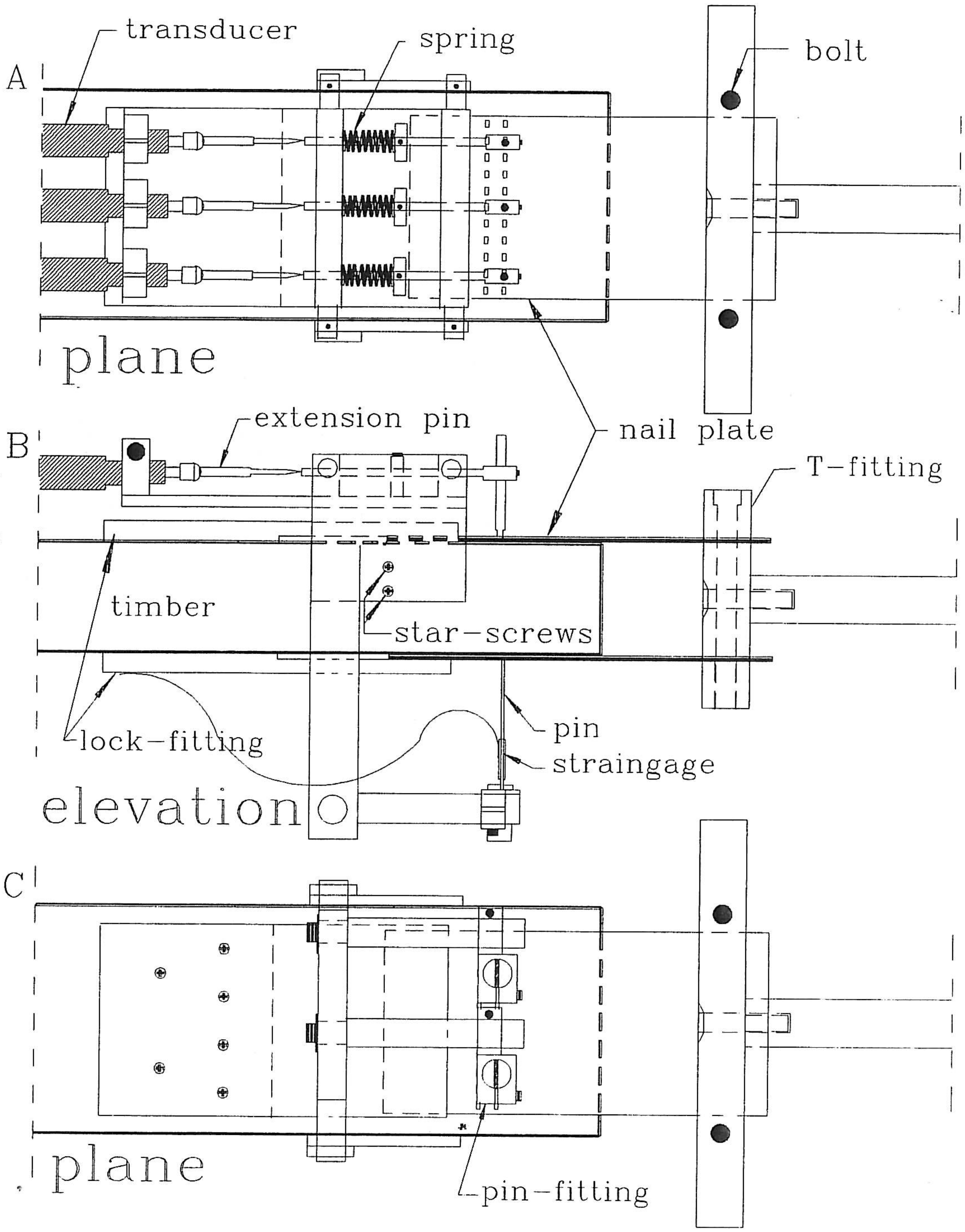

Figure 9: Displacement measuring systems. A: "the transducer system", B: both systems, C: "the pin system".

4. Test Programme

The test programme is divided into 3 main programmes. In the main programmes the following items will be analysed: (Numbers in brackets refer to the series number.)

- **Main programme 1 :** (Series no. 1 - 9)
  Dependence of the load-displacement curves on:
  - load velocity (1,2,3),
  - the bending direction (1,4)(5,9), The bending resistance perpendicular to the major axes of the plate is dependent on the nail bending direction, see figure 10 on page 9. The nails are divided into two types:
    - * Type W:
      The nail is bending **with** the original stamping direction.
    - * Type A:
      The nail is bending **against** the original stamping direction.

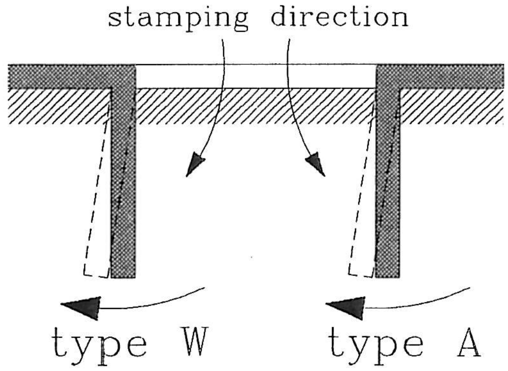

Figure 10: Bending direction/types of nail.

  - the plate being locked or unlocked to the timber (1,5)(4,9)(11,14). The back of the nail-plate will be fixed to the timber with a lock-fitting, see figure 9 on page 8. During loading the back of an unlocked nail-plate will rise, see figure 48 on page 34. This will cause a different nail stiffness dependent on the location of the nails in plates with several nail-rows. The nail-plate under the lock-fitting can slide undisturbed parallel the load. The lock-fitting is fastened to the timber by star-screws, see figure 9 C on page 8.
  - the number of nails in a row (1,7,8). A row is here defined as a number of nails in a line perpendicular to the load direction.
  - the number of rows (1 or 2 rows), (1,4,6)

- **Main programme 2 :** (Series no. 10-18)
  - group effect of the nails (1, 6, 8, 5 and 4 rows in the series 1, 10, 11, 12 and13).
  - edge distance (1,15,16) (13,17) (11,18).

- **Main programme 3 :** (Series no. 20-34)
  - angles between plate/load and grain/load. All the tests have an edge distance of 20mm and the nail-plates are not locked. The nails make minimum 5 rows on each plate.

The unloading properties in all the tests will also be analysed.
There are generally 6 identical tests in a series. However, in main programme 3 only 4 identical tests are made in a series.
The test programme is shown in tables 2, 3 and 4.

MAIN PROGRAMME 1								
Test	**TIMBER**		**NAILS/PLATE**					**LOAD**
	edge dist. mm	α_g	α_p	No. row	No. teeth	Bending direc.	Lock	Load velocity $\frac{kN}{min}$ ($\frac{kN}{min \cdot nail}$)
S1	40	0	0	1	2 x 11	W	Yes	0.8 (0.037)
S2	40	0	0	1	2 x 11	W	Yes	0.4 (0.018)
S3	40	0	0	1	2 x 11	W	Yes	1.2 (0.055)
S4	35	0	0	1	2 x 11	A	Yes	0.8 (0.037)
S5	40	0	0	1	2 x 11	W	No	0.8 (0.037)
S6	40	0	0	2	4 x 11	W/A	Yes	1.6 (0.037)
S7	40	0	0	1	2 x 7	W	Yes	0.5 (0.037)
S8	40	0	0	1	2 x 5	W	Yes	0.4 (0.037)
S9	35	0	0	1	2 x 11	A	No	0.8 (0.037)

Table 2: Tests in main programme 1.

MAIN PROGRAMME 2								
Test	**TIMBER**		**NAILS/PLATE**					**LOAD**
	edge dist. mm	α_g	α_p	No. row	No. teeth	Bending direc.	Lock	Load velocity $\frac{kN}{min}$ ($\frac{kN}{min \cdot nail}$)
S10	20	0	0	6	12 x 11	W/A	Yes	4.9 (0.037)
S11	20	0	0	8	16 x 11	W/A	Yes	6.5 (0.037)
S12	20	0	0	5	10 x 11	W/A	Yes	4.1 (0.037)
S13	20	0	0	4	8 x 11	W/A	Yes	3.3 (0.037)
S14	5	0	0	6	12 x 11	W/A	No	4.9 (0.037)
S15	5	0	0	1	2 x 11	W	Yes	0.8 (0.037)
S16	10	0	0	1	2 x 11	W	Yes	0.8 (0.037)
S17	5	0	0	4	8 x 11	W/A	Yes	3.3 (0.037)
S18	5	0	0	8	16 x 11	W/A	No	6.5 (0.037)

Table 3: Tests in main programme 2.

MAIN PROGRAMME 3				
Test	TIMBER	NAILS/PLATE		LOAD
		α_p	No. teeth	Load velocity $\frac{\text{kN}}{\text{min}}$ $(\frac{\text{kN}}{\text{min}\cdot\text{nail}})$
S20	$\alpha_g = 0°$	34°	2 x 56	4.1 (0.037)
S21		54°	2 x 54	4.0 (0.037)
S22		90°	2 x 48	3.6 (0.037)
S23	$\alpha_g = 34°$	0°	2 x 66	4.9 (0.037)
S24		34°	2 x 53	3.9 (0.037)
S25		54°	2 x 54	4.0 (0.037)
S26		90°	2 x 48	3.6 (0.037)
S27	$\alpha_g = 54°$	0°	2 x 66	4.9 (0.037)
S28		34°	2 x 56	4.1 (0.037)
S29		54°	2 x 54	4.0 (0.037)
S30		90°	2 x 48	3.6 (0.037)
S31	$\alpha_g = 90°$	0°	2 x 66	4.9 (0.037)
S32		34°	2 x 56	4.1 (0.037)
S33		54°	2 x 54	4.0 (0.037)
S34		90°	2 x 48	3.6 (0.037)

Table 4: Tests in main-programme 3.

5. Test Procedure

The test procedure is as follows:

- The T-fitting is placed on the nail-plates of the test specimen.
- The lock-fitting is placed if desired.
- The measuring systems are placed.
- The test specimen is placed and centered in the tensile machine.
- A small tension force (1 kN) is applied to the test specimen, thus the obliquity between the nail-plates is reduced.
- The bolts in the T-fitting are then tightened to 35 Nm.
- The pins and transducers are placed. The pins are given a small prestress.
- The test specimen is unloaded and the computer is reset.
- The loading is then started.
- At a given load state the test specimen is unloaded.
- At a given load state the test specimen is reloaded until failure.
- Near failure the pin system is decoupled while the test is running.
- After failure the measuring systems are dismounted, the timber specimen is weighed and the moisture content is determined.

6. Test Results

General Comments

The types of failure which occurred in the series of main programmes 1 and 2 were:

series	Decription of the deformation and failure.
5	Small nail bending and plate bending as shown in figure 48 on page 34. Small penetration of the nail into the wood followed by withdrawal of the nails.
10	Nail bending and penetration into the wood followed by withdrawal of the nails. In some tests plate failure occurred in one plate only.
11	Small nail bending and penetration into the wood followed by plate failure.
14	Nail bending, penetration into the wood, small plate bending followed by withdrawal of the nail and wood failure in front of the nail closest to the timber edge. In some series plate failure occurred in one plate alone.
15	Small nail bending and penetration into the wood followed by wood failure in front of the nail closest to the timber edge.
17	Nail bending, penetration into the wood followed by withdrawal of the nails and wood failure in front of the nail closest to the timber edge.
18	Small nail bending and penetration into the wood followed by plate failure and incipient wood failure in front of the nails nearest to the timber edge.
other	Nail bending and penetration into the wood followed by withdrawal of the nails.

The load-displacement curves from series with plate failure (series 10, 11, 14 and 18) are used to analyse the stiffness properties. The failure value in these series is not used, because it is not a "nail-to-wood" behaviour. The failure types for main programme 3 are given in table 5.

Failure type	Series	α_g
Plate failure	20,21	0°
	25	34°
Withdrawel of the nails	22	0°
	23,24,26	34°
Failure in timber	27 - 30	54°
	31 - 34	90°

Table 5: Failure types in mainprogramme 3.

The failure values from tests with plate failure or failure in timber are not used, because it is not a "nail-to-wood" behaviour. The displacement measurings from tests with the load direction perpendicular to the grain are not reliable because of large compression of the timber. Especially the results from series 31 were bad, see figure 41 on page 30. In some tests the timber bend because of the stiffness difference on each side of the timber. The core is then not placed in the centre of the timber. When the core appears in the centre there are still large compressions, but the timber is deformed equally on each side. The failure load per nail and the standard deviation are given in table 6.

Series	Max. load	Std. dev.	Series	Max. load	Std. dev. [N]
	N	N		N	N
1	316	17	20	227	3
2	311	11	21	236	5
3	325	11	22	222	8
4	300	22			
5	270	12	23	219	5
6	282	14	24	206	18
7	308	15	25	239	5
8	-	-	26	306	6
9	251	26			
10	266	11	27	173	11
11	218	12	28	221	13
12	267	15	29	195	16
13	275	14	30	225	2
14	234	11			
15	239	5	31	-	-
16	309	8	32	163	19
17	154	8	33	143	24
18	205	9	34	134	21

Table 6: Mean failure load per nail and standard deviation of each series.

The max. load is given by the testing machine. The displacement corresponding to the failure load is not given, because this will require a very high recording frequency.
Series 8 is not carried out.
The numbering of the tests are as follows: Test number 6 in series 2 with (2 × 11) 22 nails is numbered S2_22_6.
In a few tests the loading was not equally distributed over the nail-plates, see figure 11. In test S1_22_7 the load-displacement curves of transducer no. 1 and pin no. 1 have less stiffness than the other curves. This can be caused by a small rotation of both plates about a horisontal axis, see figure 12. It can of course also be caused by inhomogeneous wood material.

In test S12_110_5 the load is not equally distributed over each plate, ie. $q_1 \neq q_2$. The displacement of plate 1 is larger than the displacement of plate 2 see figure 12.

The solid lines in figure 11 are the mean load-displacement curves of the test. As seen in test S12_110_5 a discontinuity is arises in the mean load-displacement curve. This is caused by uncoupling of pins. In most cases the load-displacement curves of the tests coincide.

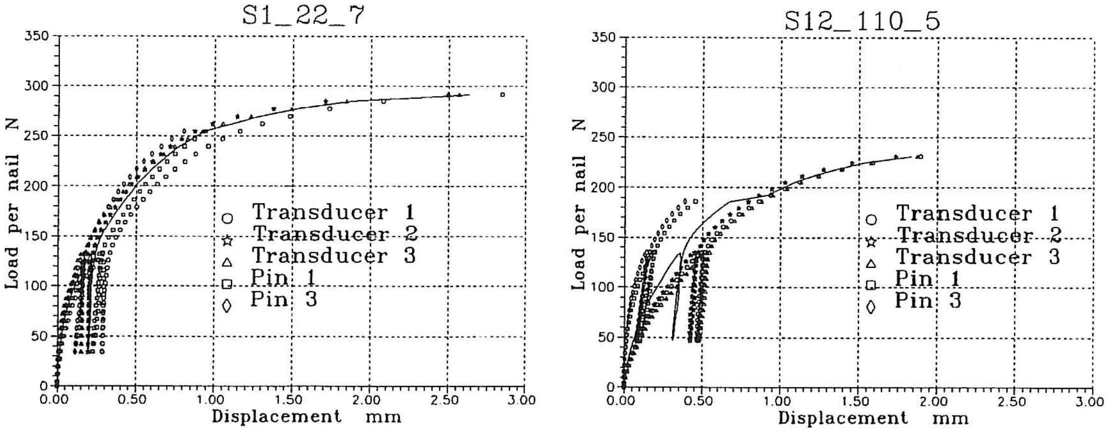

Figure 11: Load-displacement curves of test S1_22_7 and S12_110_5.

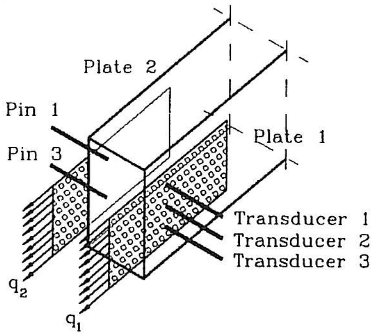

Figure 12: Placing of the pins and transduceres.

In the following only the mean load-displacement curves of the tests are shown. If not mentioned otherwise the following conditions are governing:

- load velocity per nail is $0,037 N/min$,
- plate, grain and load direction coincide,
- 11 nails in each row (only series 1-18),
- "W-type" nail (only 1 row tests)

Tests from Main Programme 1

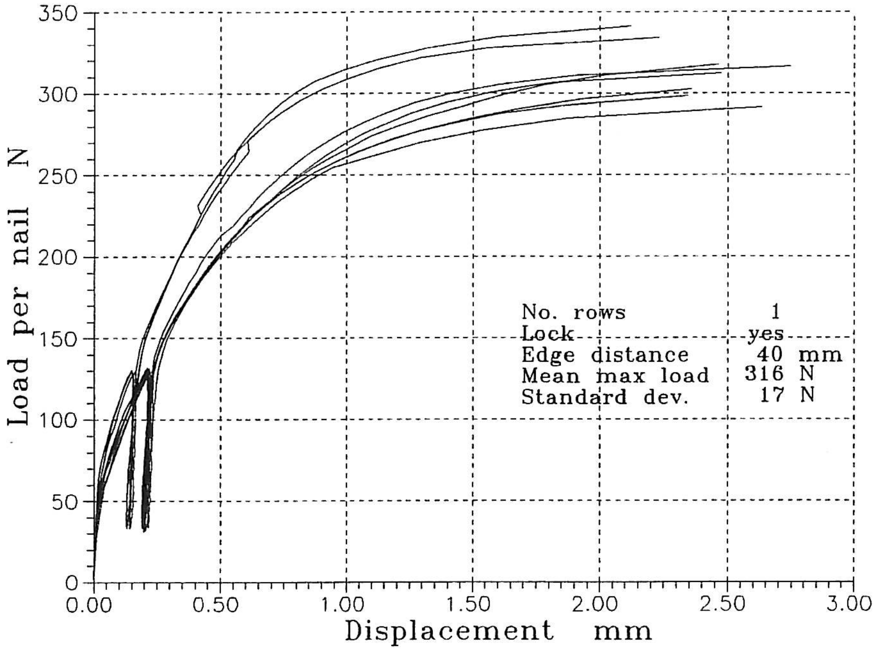

Figure 13: Load-displacement curves of series 1.

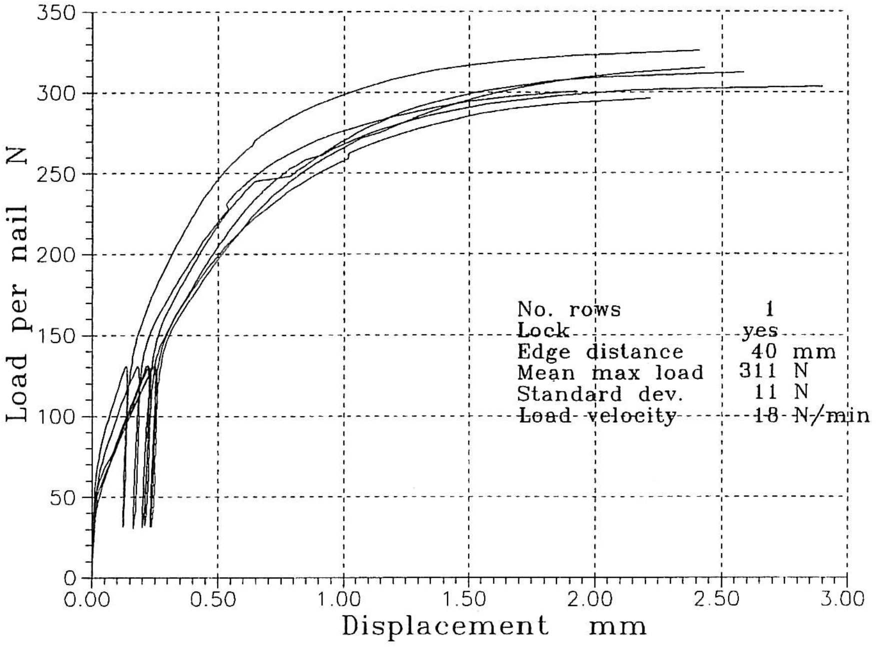

Figure 14: Load-displacement curves of series 2.

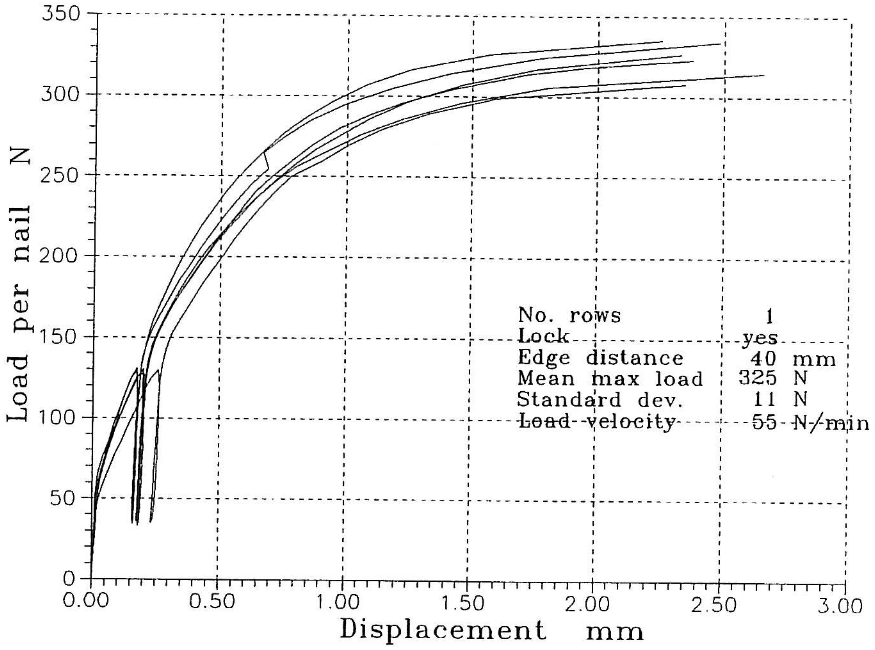

Figure 15: Load-displacement curves of series 3.

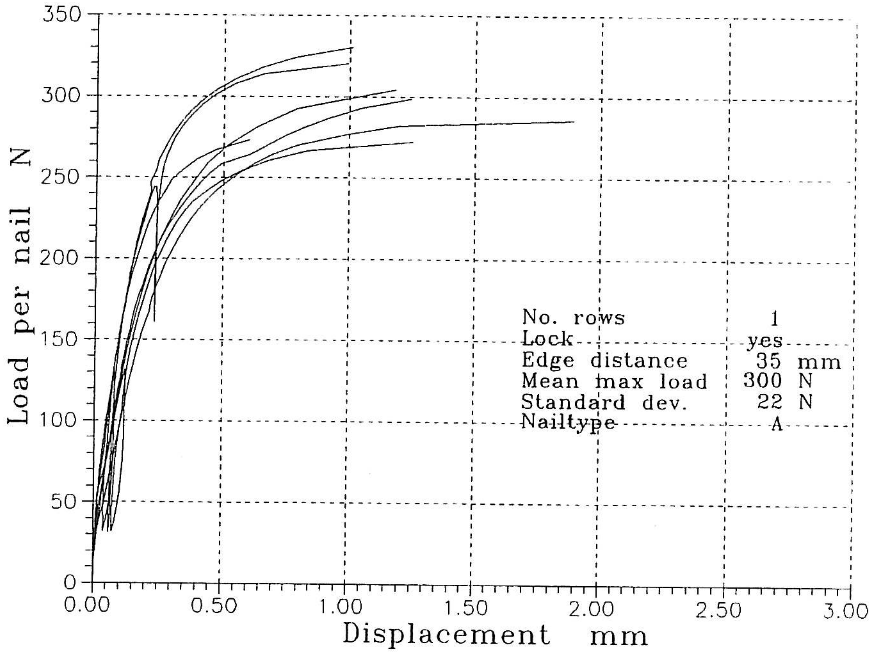

Figure 16: Load-displacement curves of series 4.

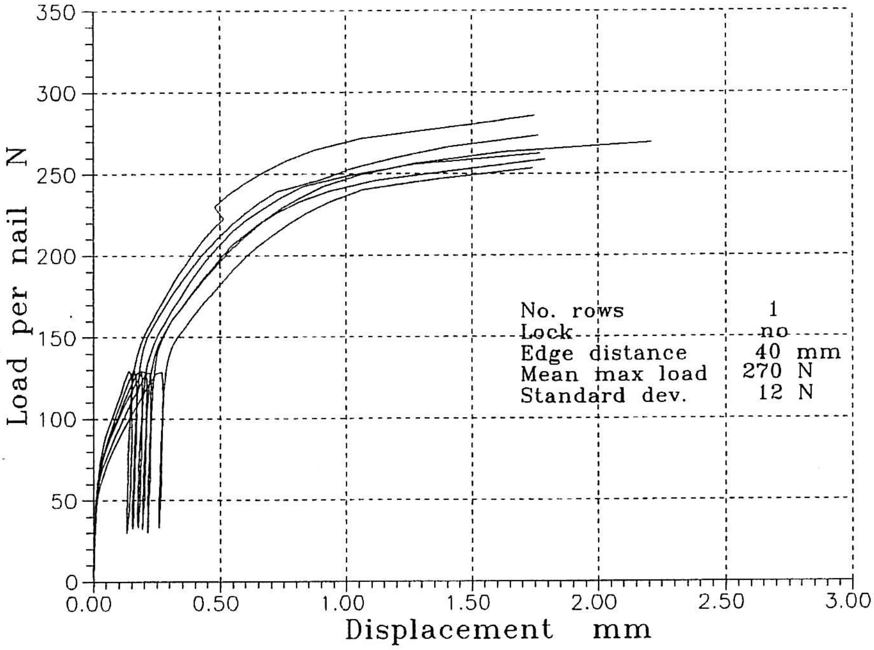

Figure 17: Load-displacement curves of series 5.

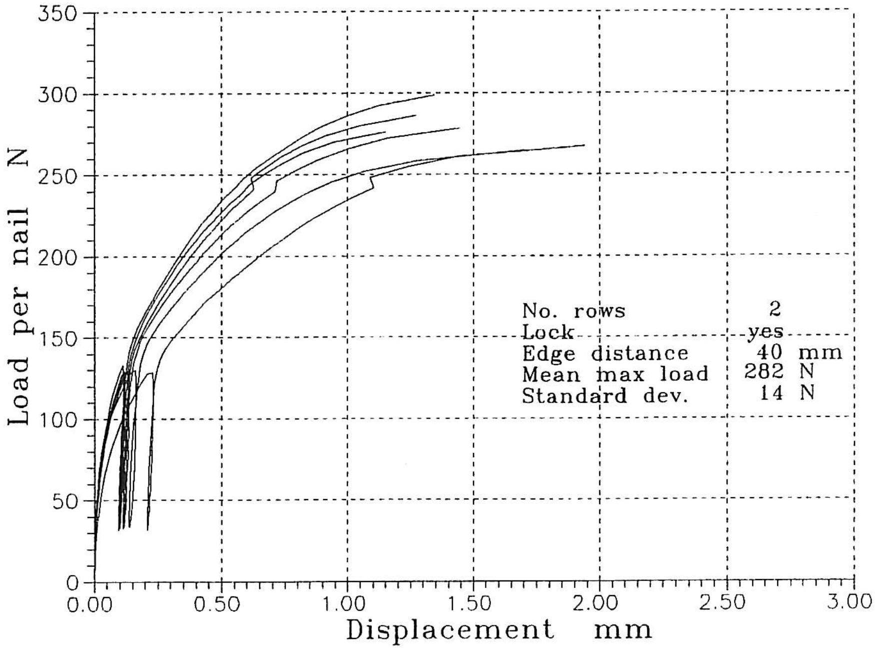

Figure 18: Load-displacement curves of series 6.

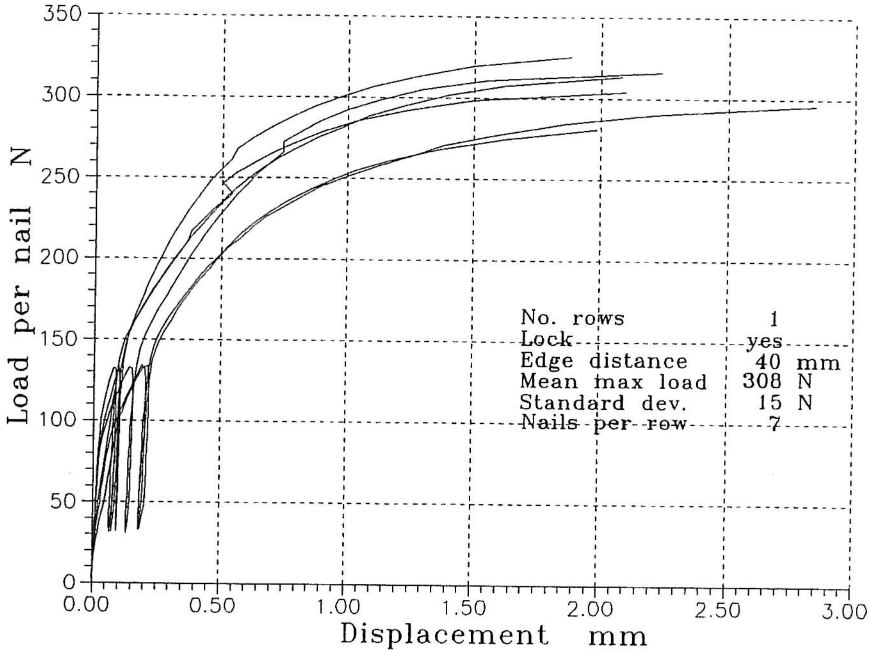

Figure 19: Load-displacement curves of series 7.

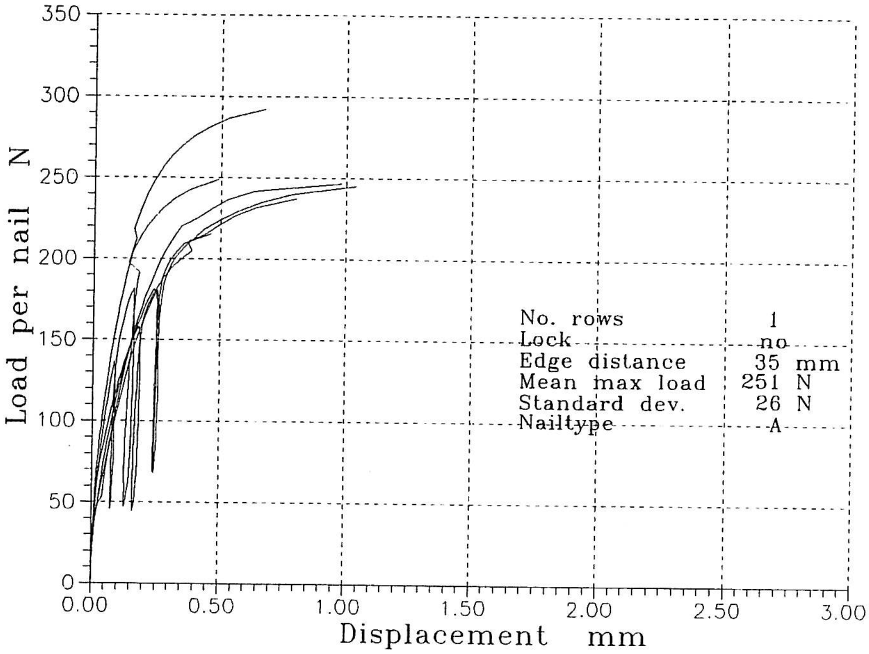

Figure 20: Load-displacement curves of series 9.

Tests from Main Programme 2

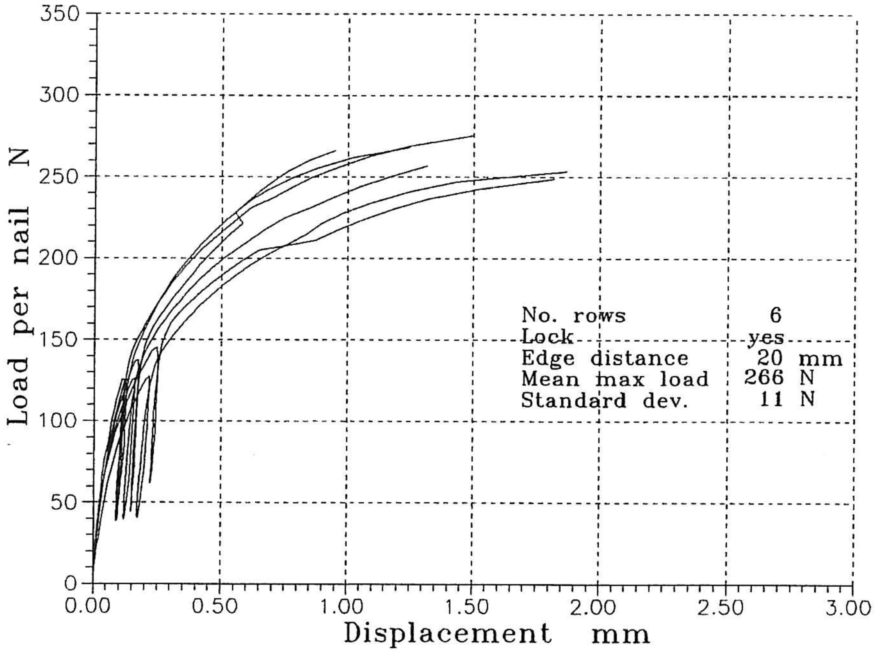

Figure 21: Load-displacement curves of series 10.

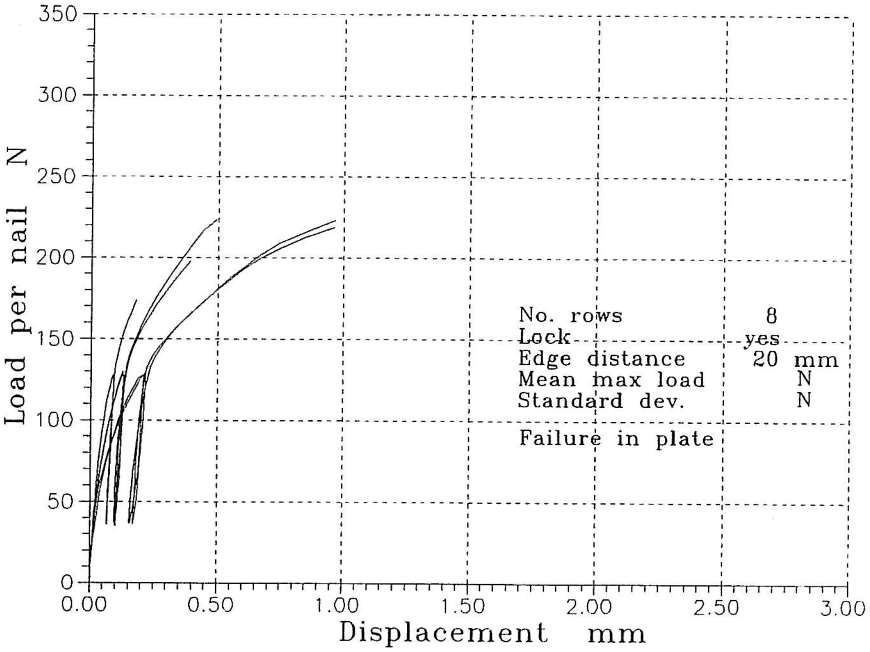

Figure 22: Load-displacement curves of series 11.

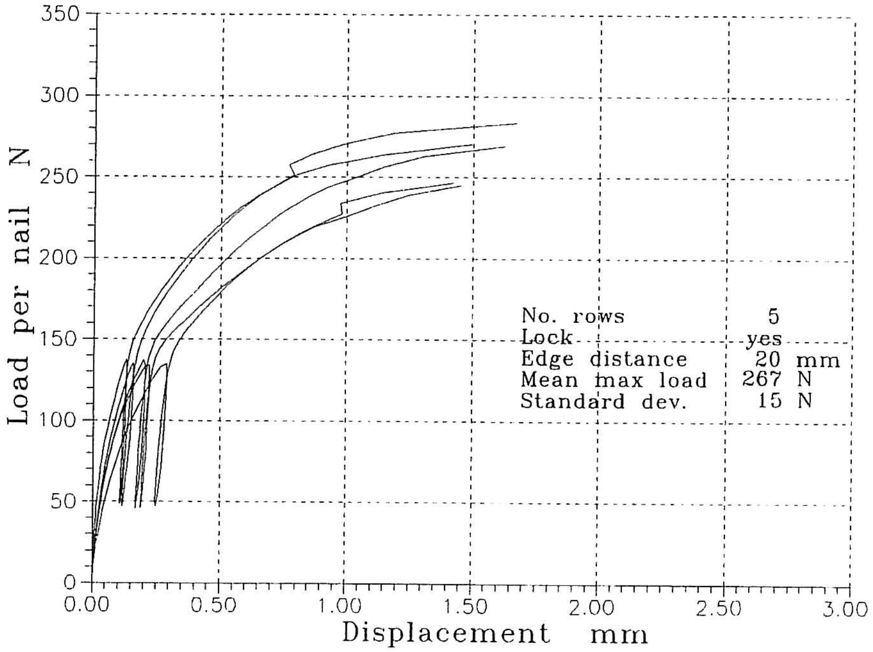

Figure 23: Load-displacement curves of series 12.

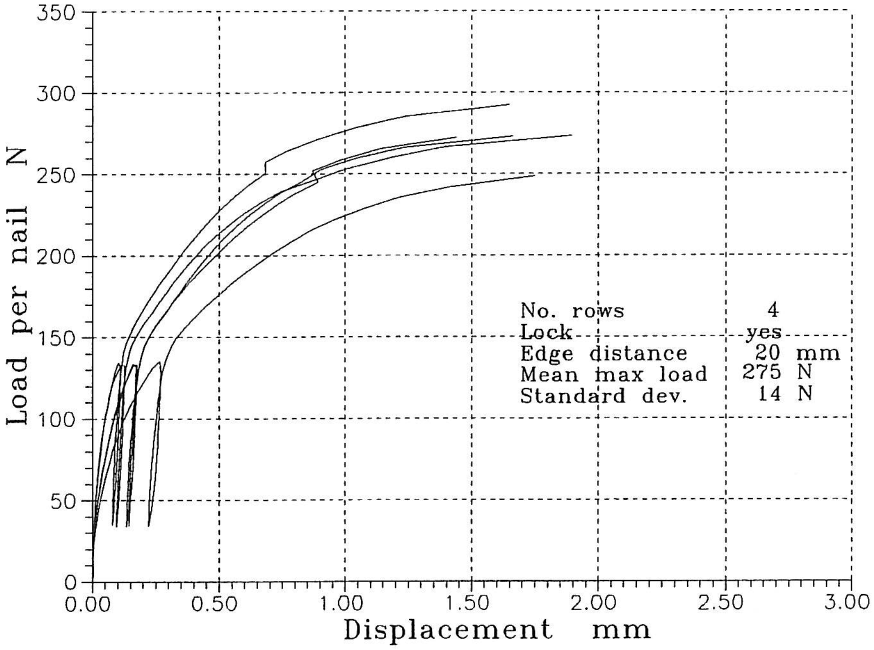

Figure 24: Load-displacement curves of series 13.

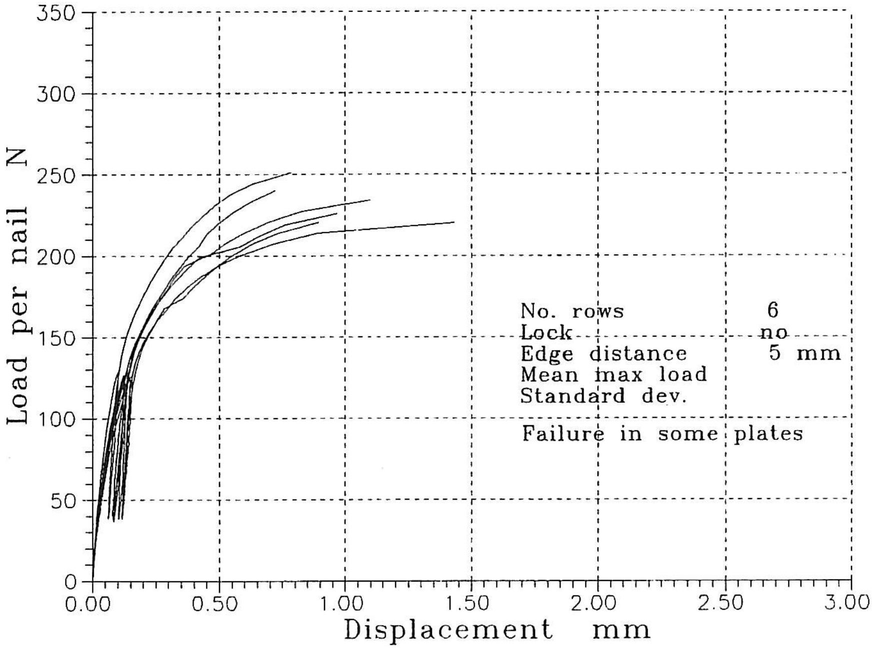

Figure 25: Load-displacement curves of series 14.

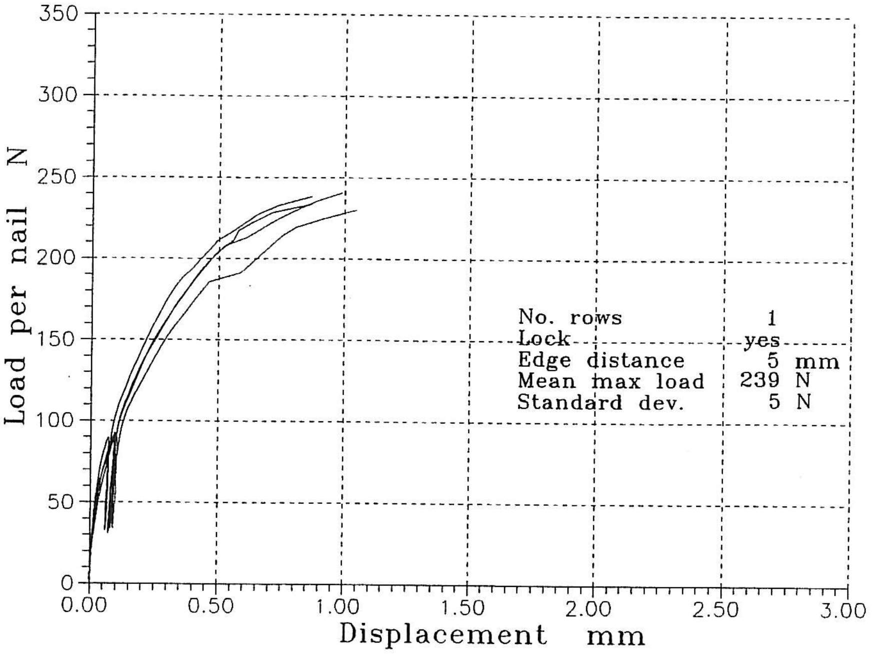

Figure 26: Load-displacement curves of series 15.

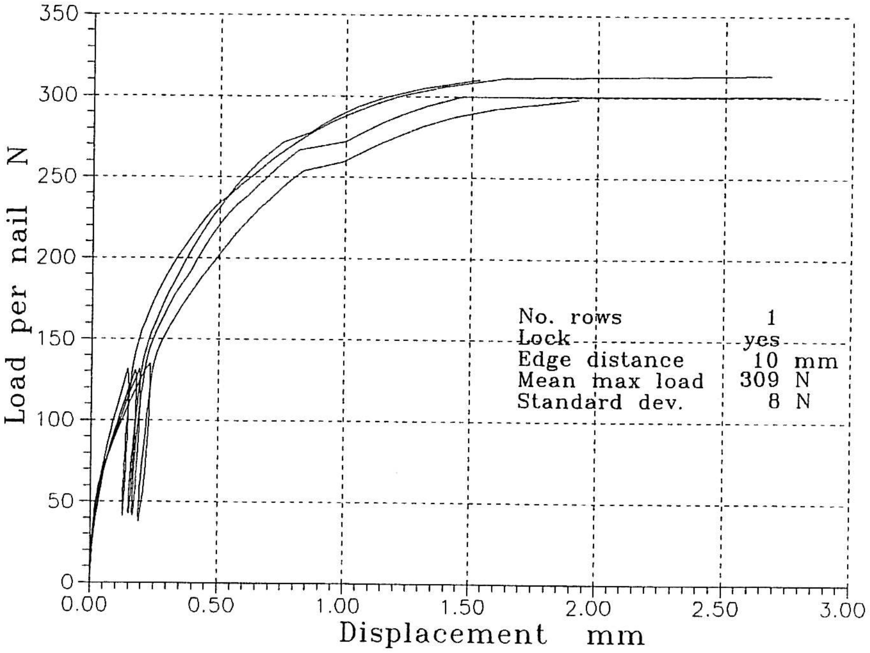

Figure 27: Load-displacement curves of series 16.

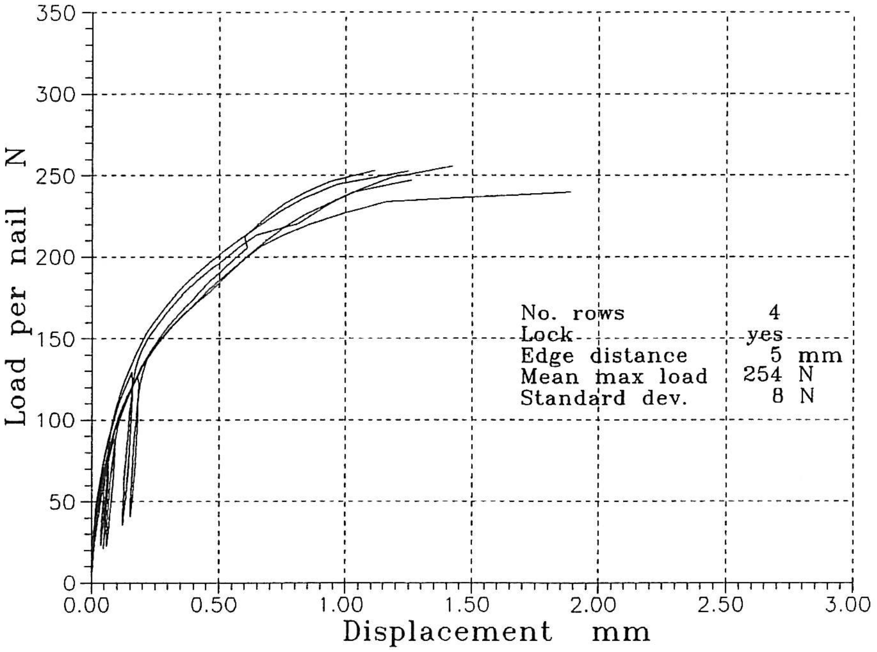

Figure 28: Load-displacement curves of series 17.

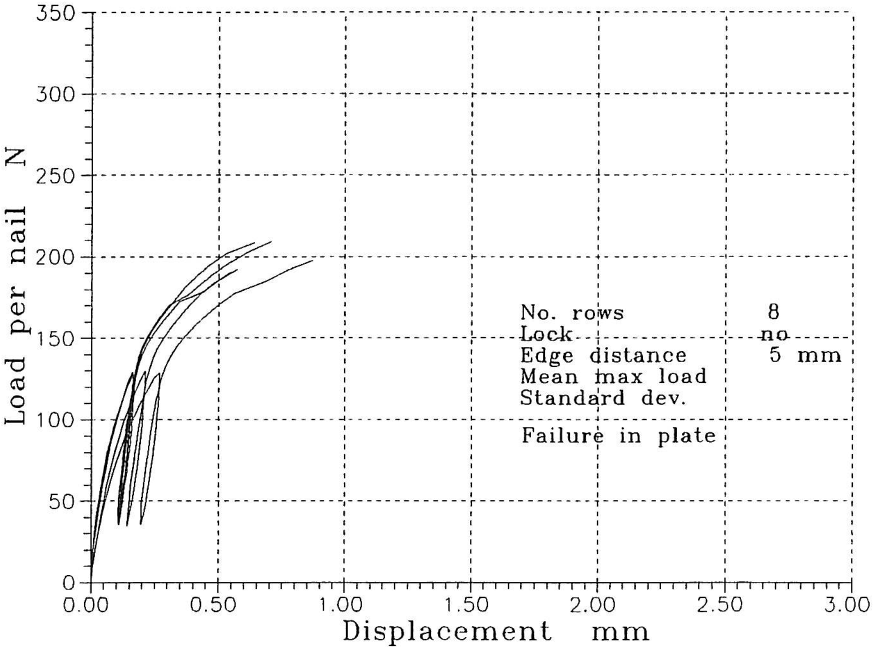

Figure 29: Load-displacement curves of series 18.

Tests from Main Programme 3

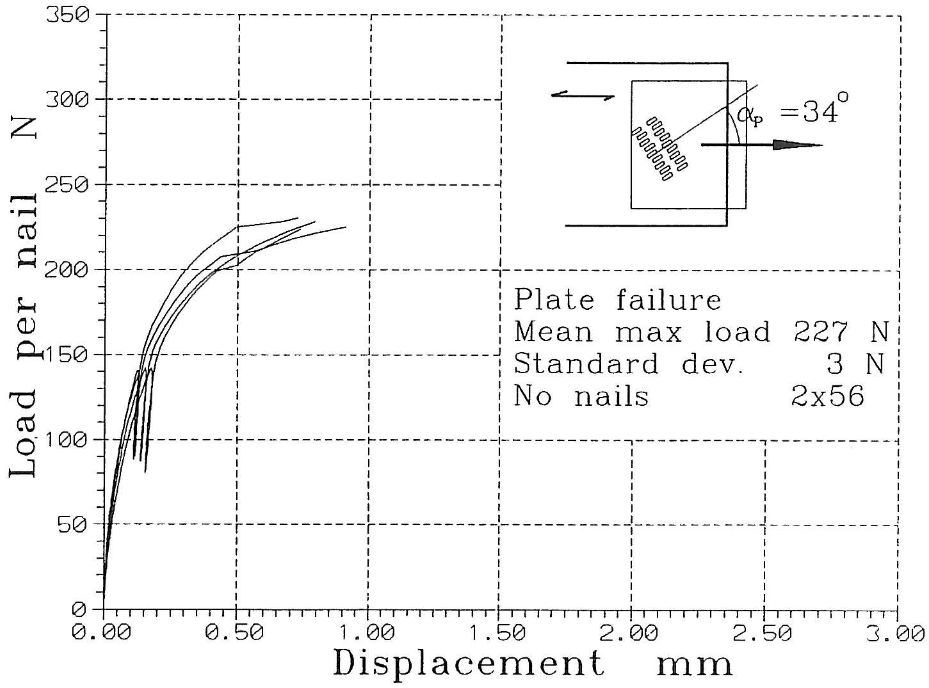

Figure 30: Load-displacement curves of series 20.

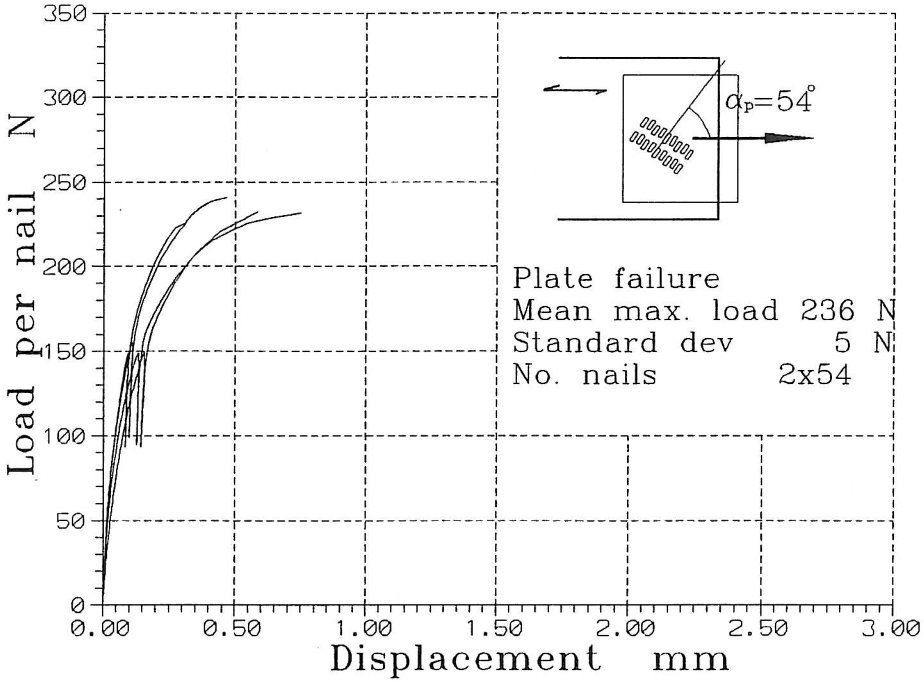

Figure 31: Load-displacement curves of series 21.

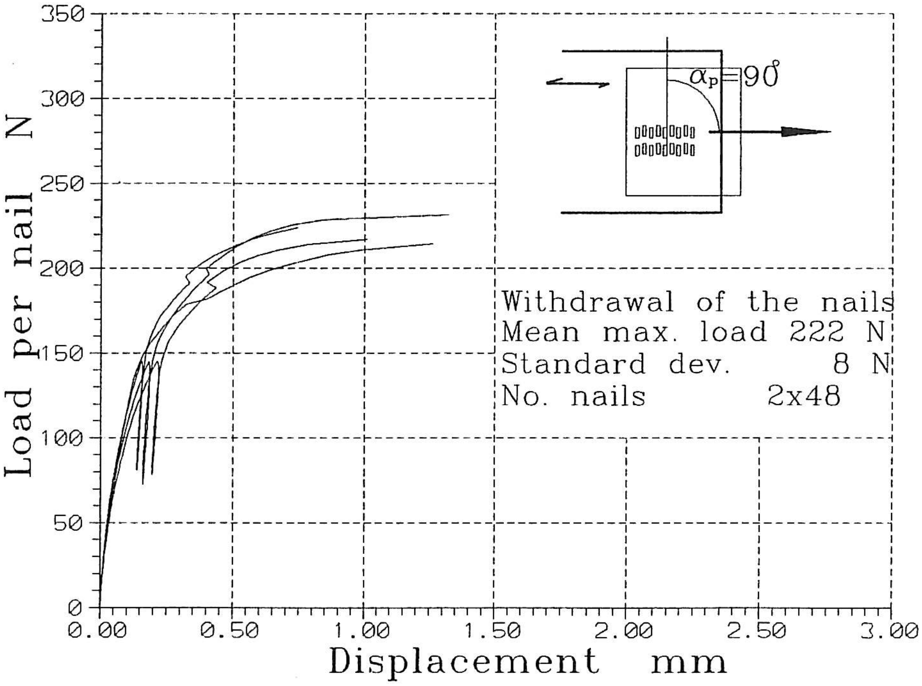

Figure 32: Load-displacement curves of series 22.

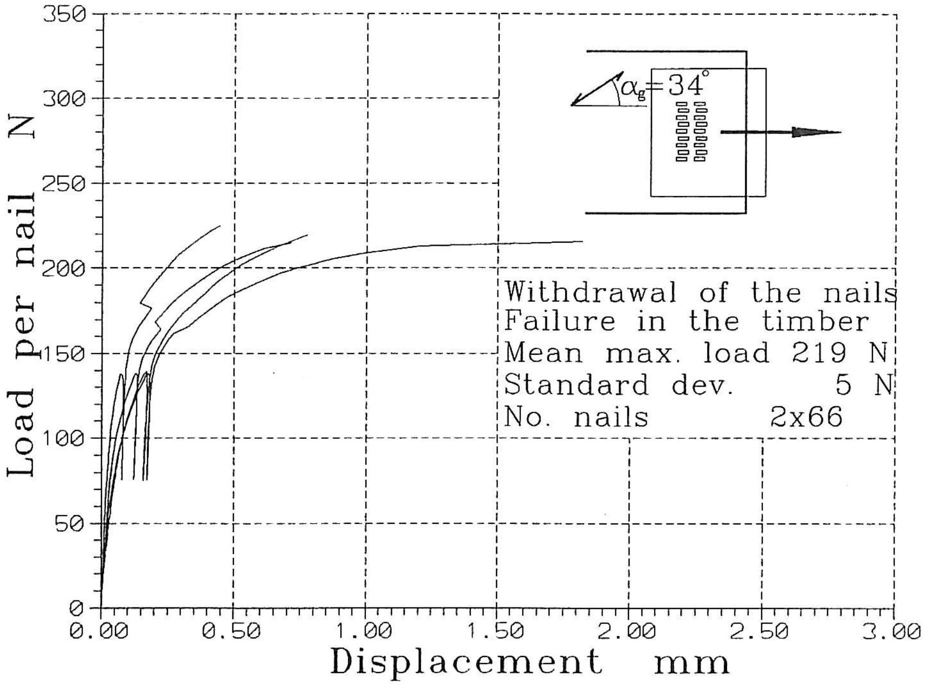

Figure 33: Load-displacement curves of series 23.

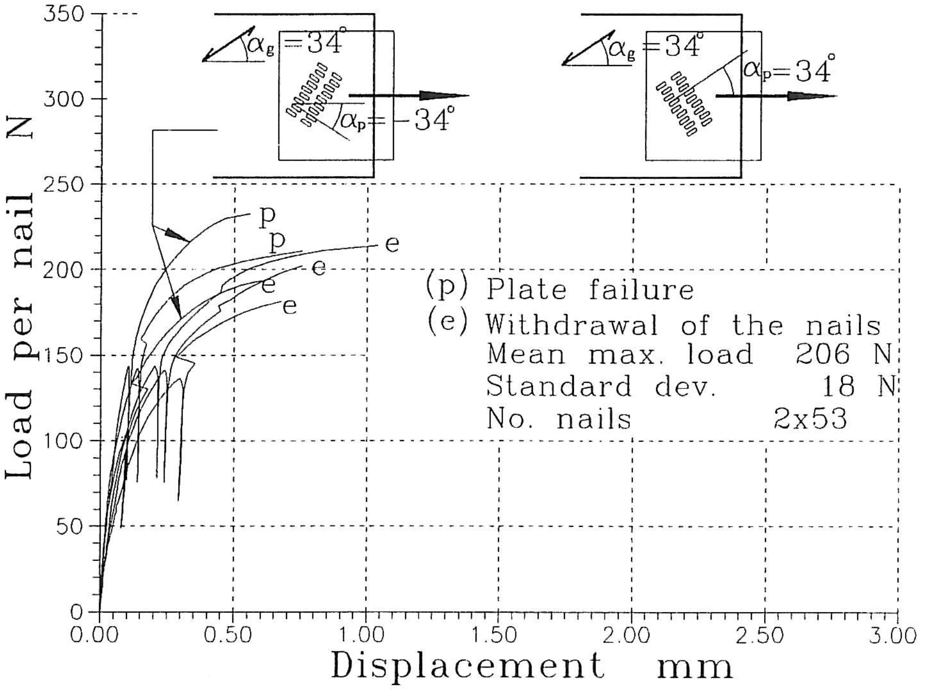

Figure 34: Load-displacement curves of series 24.

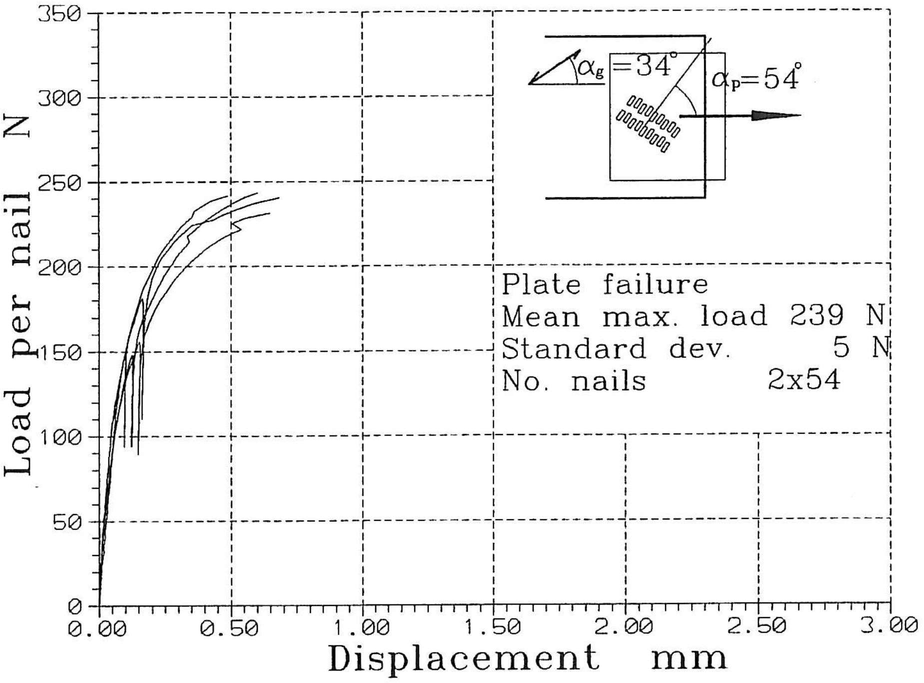

Figure 35: Load-displacement curves of series 25.

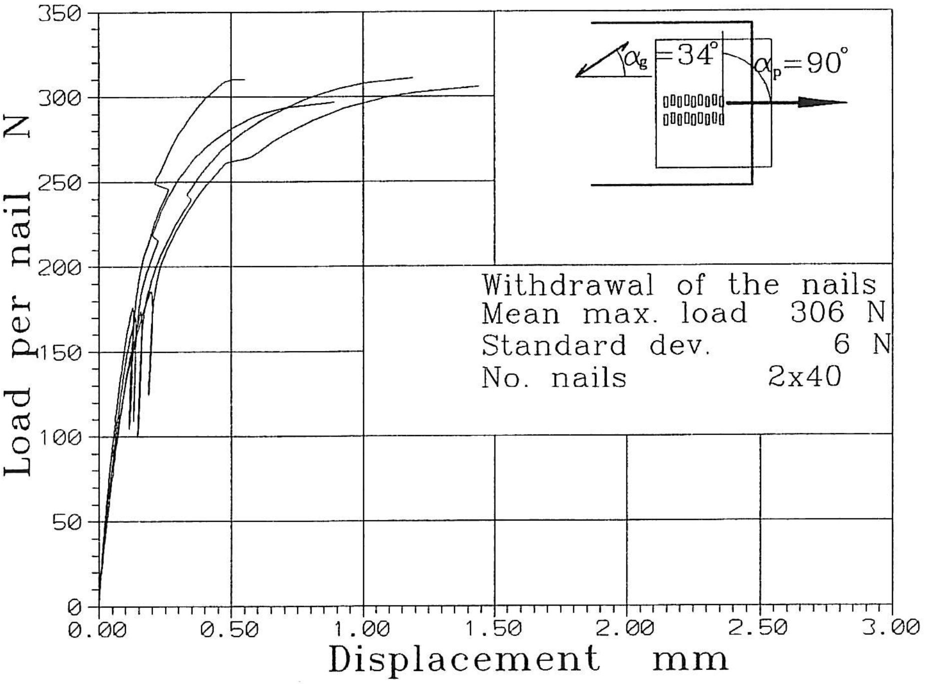

Figure 36: Load-displacement curves of series 26.

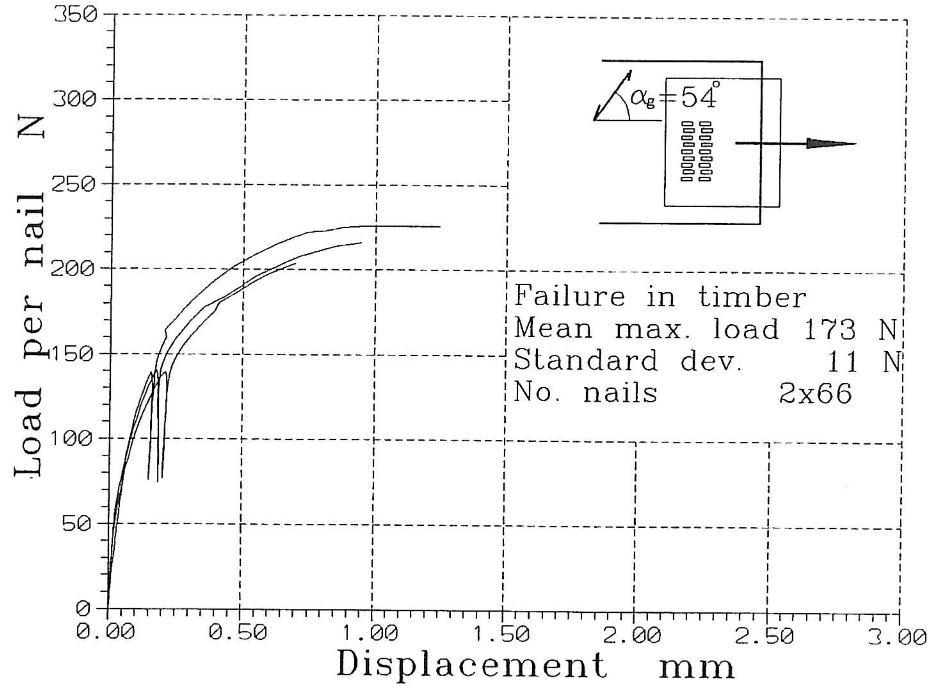

Figure 37: Load-displacement curves of series 27.

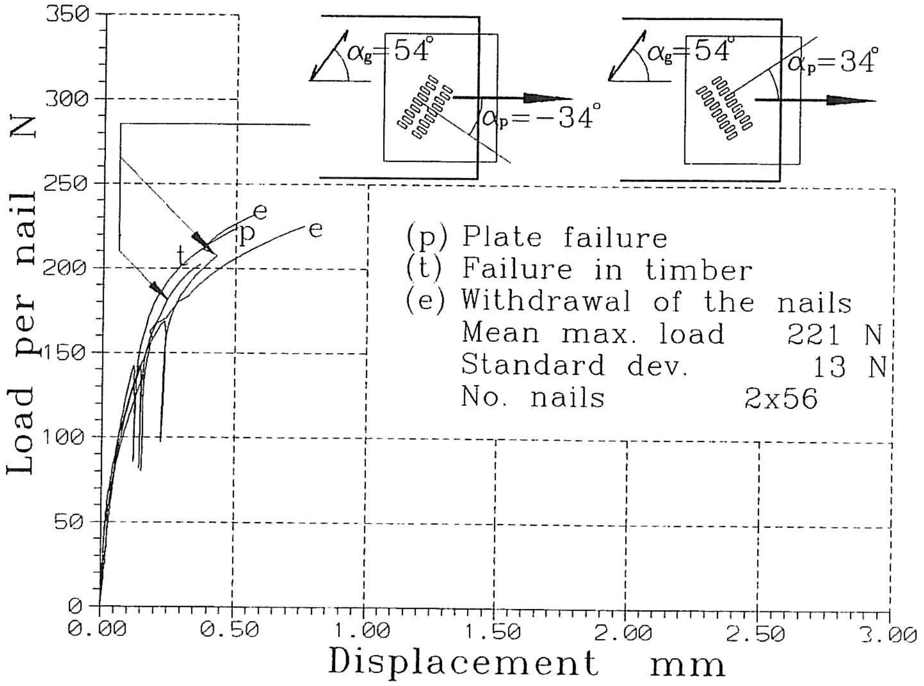

Figure 38: Load-displacement curves of series 28.

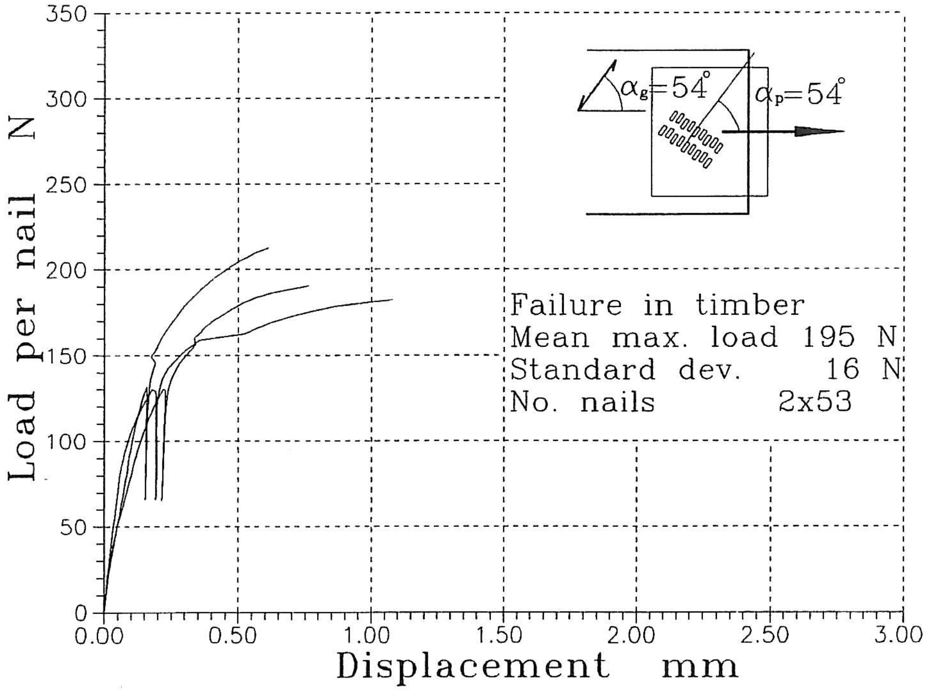

Figure 39: Load-displacement curves of series 29.

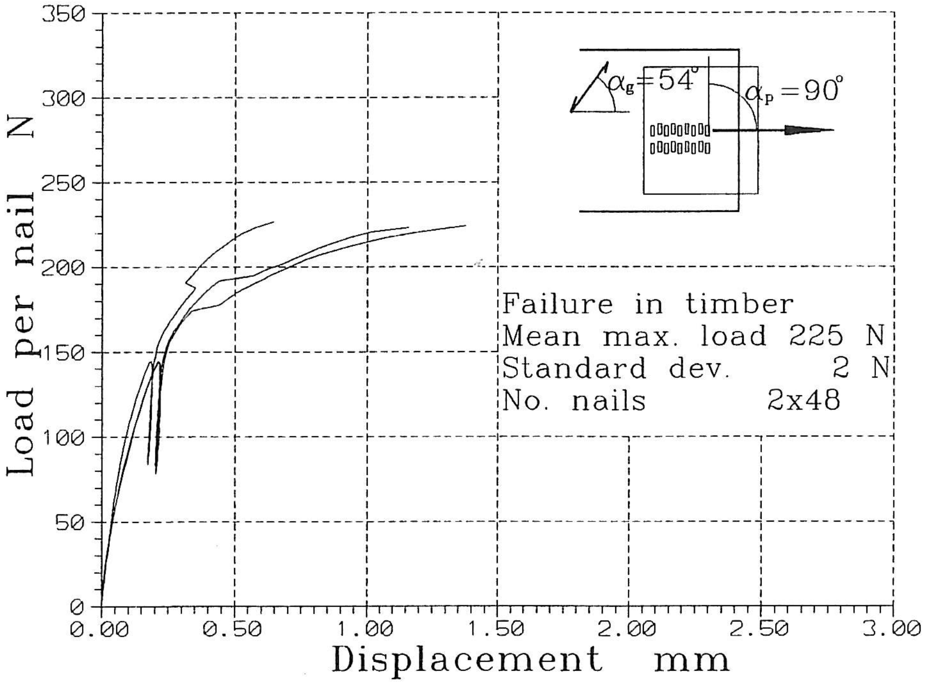

Figure 40: Load-displacement curves of series 30.

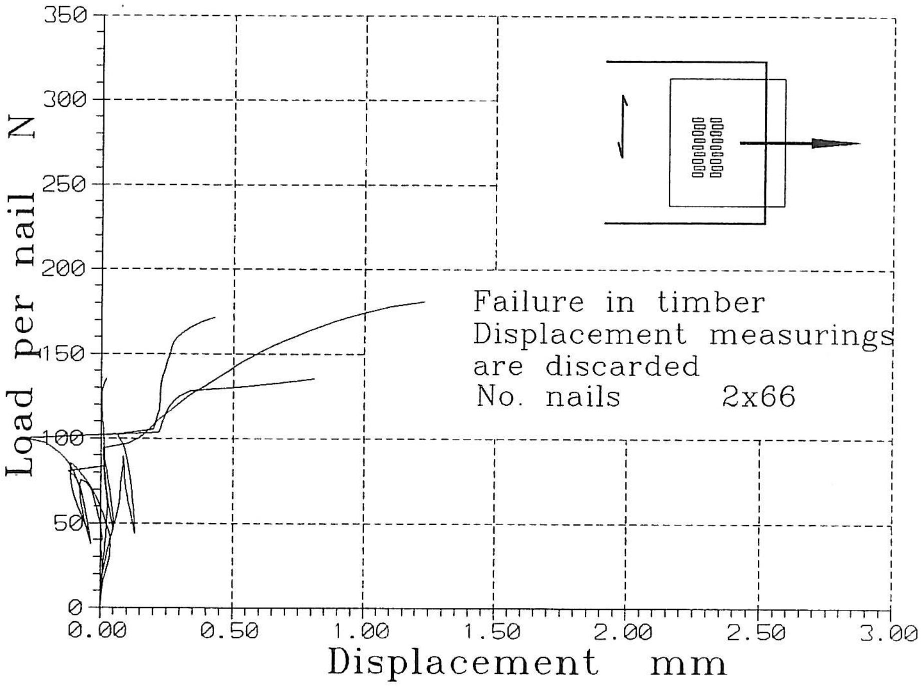

Figure 41: Load-displacement curves of series 31.

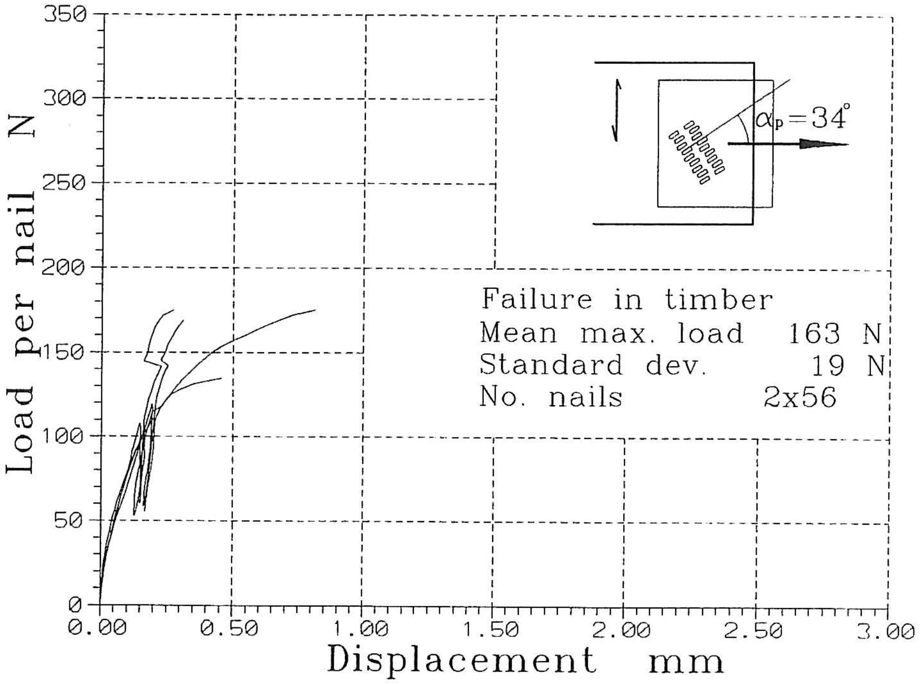

Figure 42: Load-displacement curves of series 32.

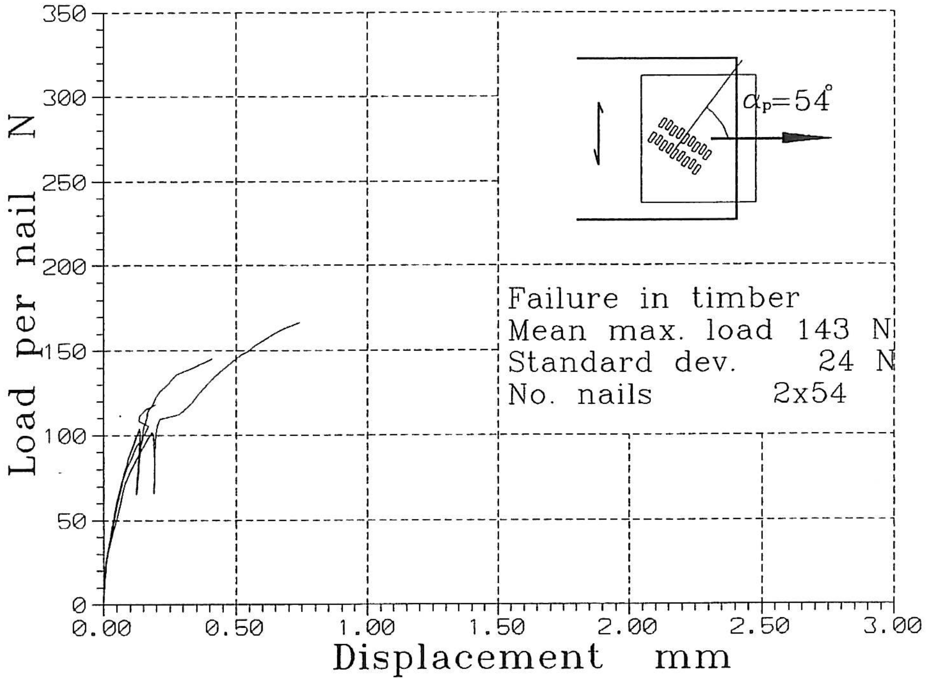

Figure 43: Load-displacement curves of series 33.

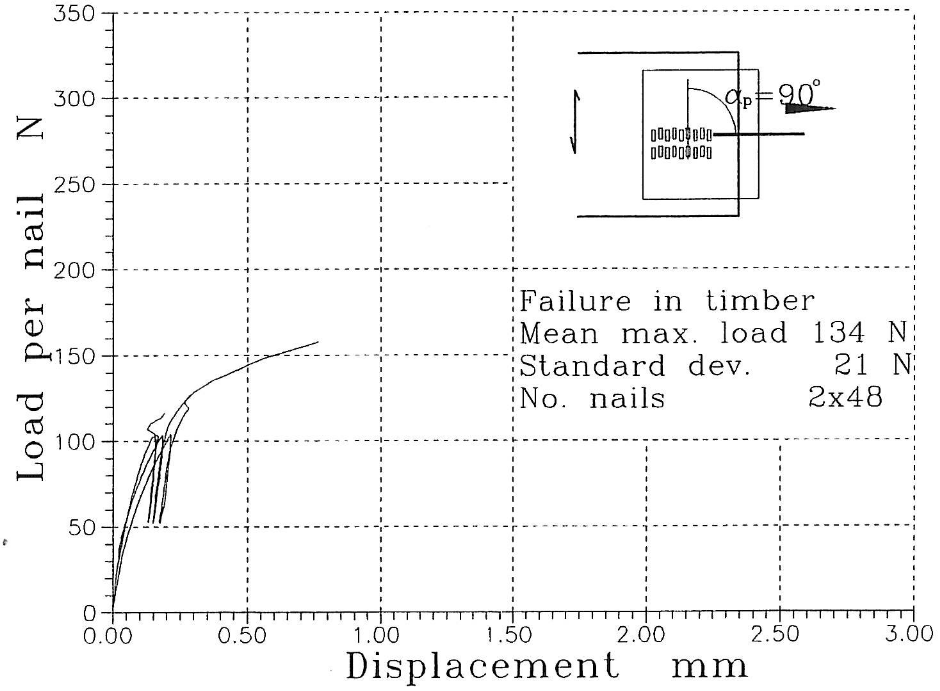

Figure 44: Load-displacement curves of series 34.

7. Analysing Main Programmes 1 and 2

Comparisons between the series are made to find the influence of physical parameters on the load-displacement curve. This is done by comparing the individual ranges of variation of the load-displacement curves in each series. In figure 45 the two thin solid lines are the maximum and the minimum load-displacement curves of series 1, ($S1$). Other load-displacement curves of series 1 are then located between the maximum and the minimum line. They are not shown. The thick solid lines are then the max. and min. load-displacement curves of series 3 and the thick dashed lines are the max. and min. load-displacement curves of series 2.

A few load-displacement curves in some tests are discarded caused by knotty timber or extremely high density.

Load Velocity

Comparisons of the series 1, 2 and 3 show the influence of the load velocity. In figure 45 it is seen that the tested load velocity has no significant effect on the load-displacement curves. A comparison of the mean value of the maximum loads with the load velocities, see table 7, shows, however, a tendency that the max. load is increased with increased load velocity. This tendency is well known.

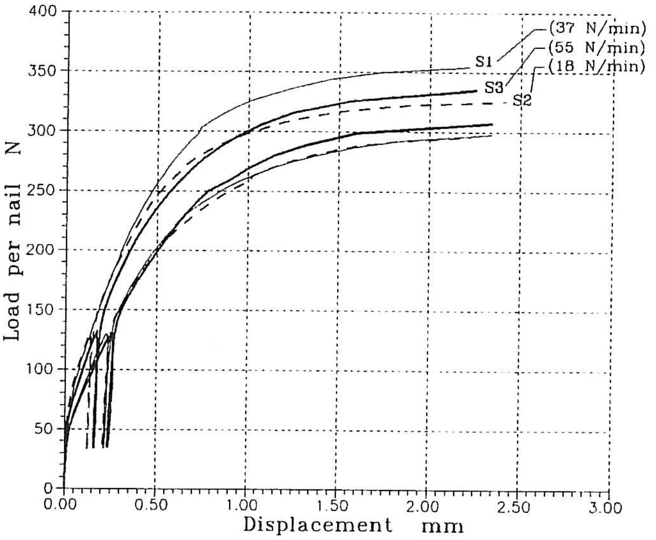

Figure 45: Variation of load-displacement curves of series 1, 2 and 3.

Number of Nails in a Row

Comparisons between series 1 and 7 show the influence of the number of nails in a row. In figure 46 it is seen that the load-displacement curves are independent of the number of nails in the row.

Bending Direction

Comparisons between the series 1, 4 and 5, 9 shows the influence of the bending direction. In figure 47 it is seen that the stiffness of the "A-type" nail is larger than the stiffness of

Series	load velocity $\frac{N}{mm}$	Mean max. load per nail N (see table 6 page 13)
2	18	311
1	37	316
3	55	325

Table 7: Comparisons bwtween the load velocity and the max. load.

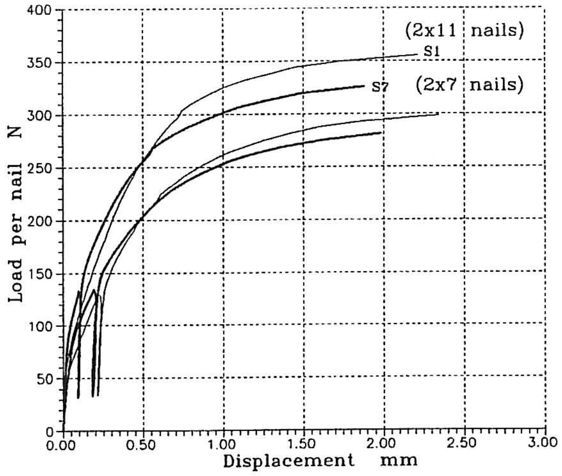

Figure 46: Max. and min. load-displacement curves of series 1 and 7.

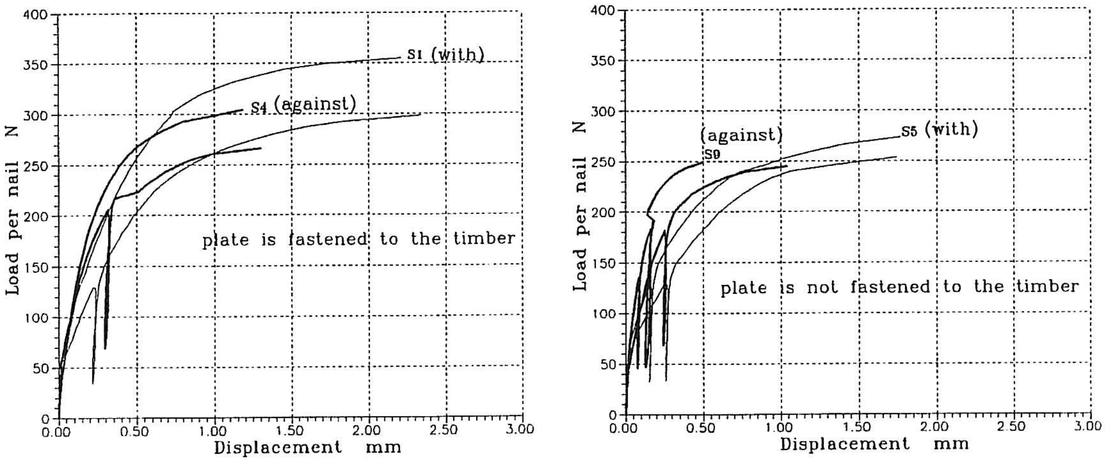

Figure 47: Max. and min. load-displacement curves of series 1, 4, 5 and 9.

the "W-type" nail. This is caused by the different stiffness of the plate in the area in front of the nail row. The stiffness of the plate with "W-type" nails is smaller owing to the holes. The deformation of the plate with "W-type" nails is shown in figure 48. The failure load and displacement are smaller than for the "A-type" nails. This is caused by the increased withdrawal of the nails owing to the larger stiffness of the plate in front of the nail row.

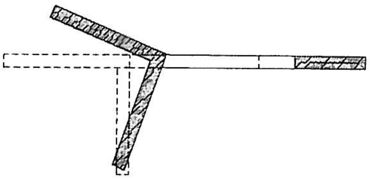

Figure 48: Deformation of a unlocked plate with "W-type" nail.

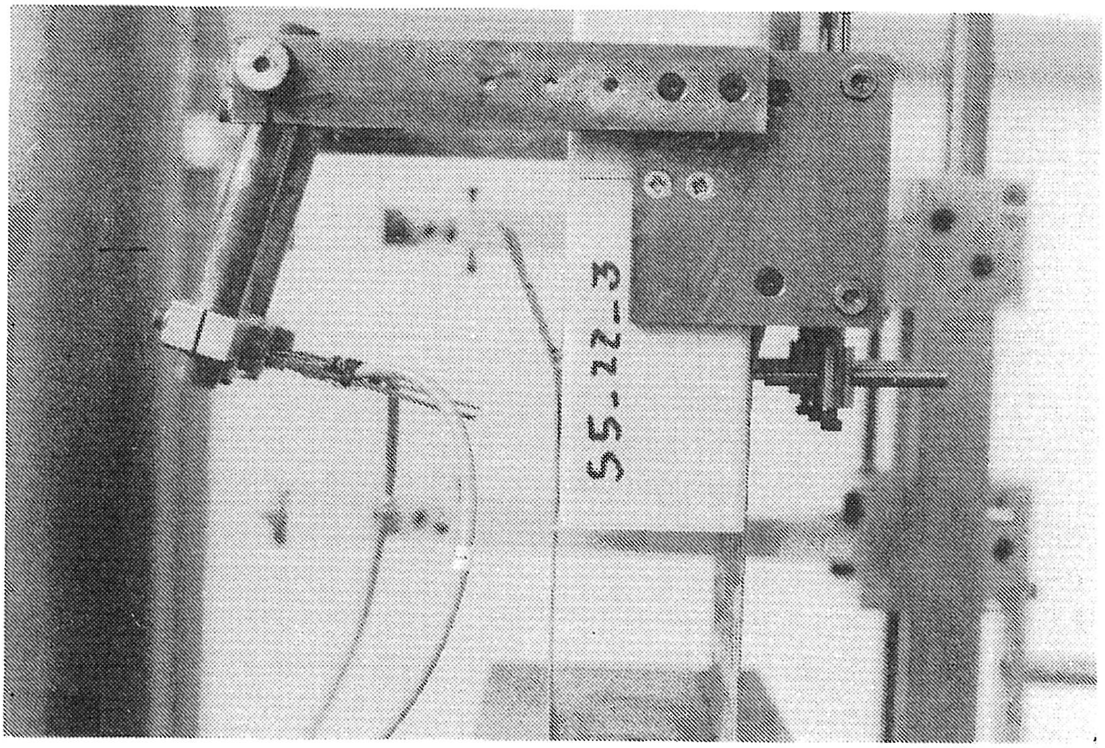

Figure 49: Deformation of a unlocked plate with "W-type" nail.

Plate being Locked or Unlocked

In series 1, 5 and 4, 9 the influence of a locked plate is tested. In figure 50 it is seen that the load-displacement curve of the "W-type" nail is stiffer when the plate is fastened to into the timber. The failure value is also increased by about 17%. There is no significant stiffness difference between the load-displacement curves of the "A-type" nail, the failure load of the fastened plate is, however, 20% higher than the unfastened plate.

Number of Rows (1 or 2)

In series 1, 4 and 6 the difference between one ("W-type","A-type") nail row and two nail rows is investigated. From figure 51 it is seen that some of the load-displacement curves from tests with 2 rows have less stiffness than load-displacement curves from tests with 1 row.

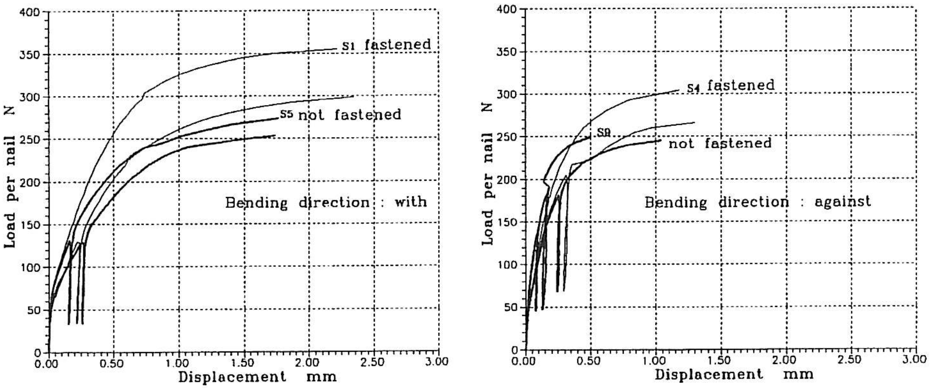

Figure 50: Max. and min. load-displacement curves of series 1, 5, 4 and 9.

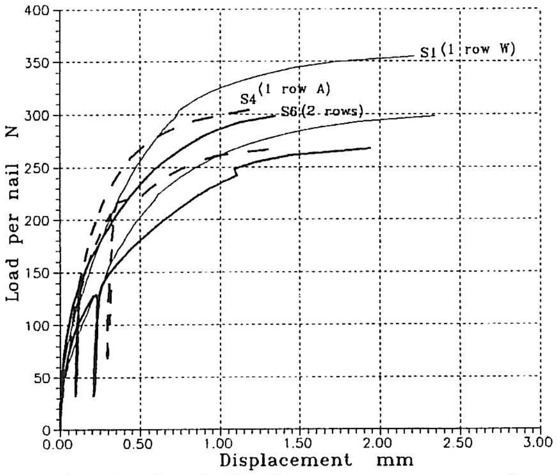

Figure 51: Max. and min. load-displacement curves of series 1,4 and 6.

Number of Rows (1 4, 5, 6, or 8)

In series 1, 10, 11, 12, and 13 the influence of the number of rows is tested when the plate is fastened. The tests are not affected by the edge distance. In figure 52 it is seen that the load-displacement curves from tests with 4, 5, 6 and 8 rows coincide. The initial stiffness is the same for all tests, but at a load between 150 – 200N/nail the tests with several rows lose stiffness compared to the load-displacement curves with 1 row. The difference can be caused by

- the load distribution over the nails, as it can be shown that the more uneven load distribution over the nails the smaller the stiffness and failure value of the joint,
- a sort of group effect. The wood in front of and between the nails is affected by several nails.

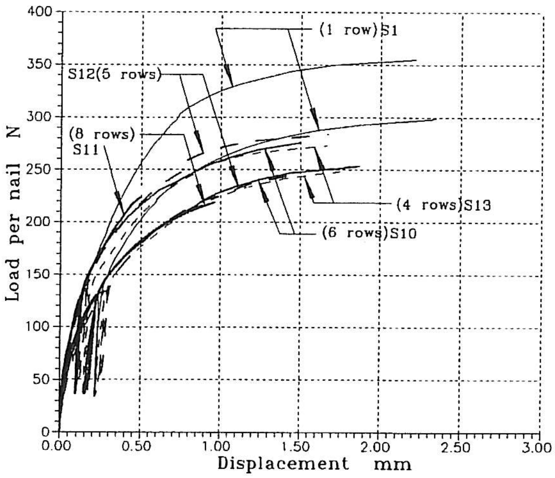

Figure 52: Max. and min. load-displacement curves of series 1, 10, 11, 12 and 13. All plates in the tests are fastened.

The failure value per nail of the tests with several rows is the same, see series S10, S11, S12 and S13 table 6 on page 13. The failure load in tests with 8 (S11) rows is, however, smaller. This is caused by failure in the plate and is not a phenomenon of the "nail-to-wood" behaviour.

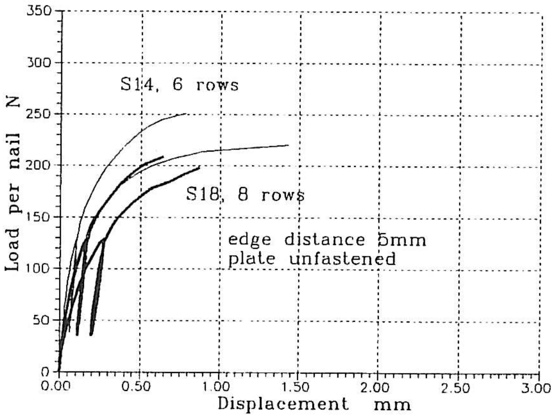

Figure 53: Max. and min. load-displacement curves of series 14 and 18.

In figure 53 the series 14 and 18 are compared. It is seen that the stiffness of the load-displacement curves from tests with 6 rows are higher than the stiffness of the load-displacement curves from tests with 8 rows. In tests with 8 rows failure occurs in the plate.

Distance to Timber Edge.

In figure 54 the load-displacement curves of series 1, 15 and 16 are shown.

The influence of the distance from the nail row to the timber edge measured in load direction is analysed. In figure 54 it is seen that a test with a 10mm edge distance has

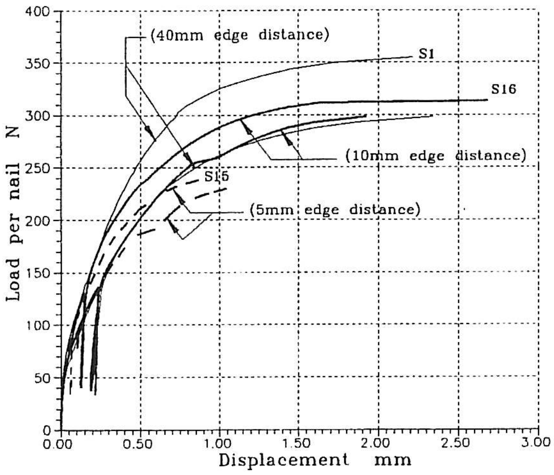

Figure 54: Max. and min. load-displacement curves of series 1, 15 and 16.

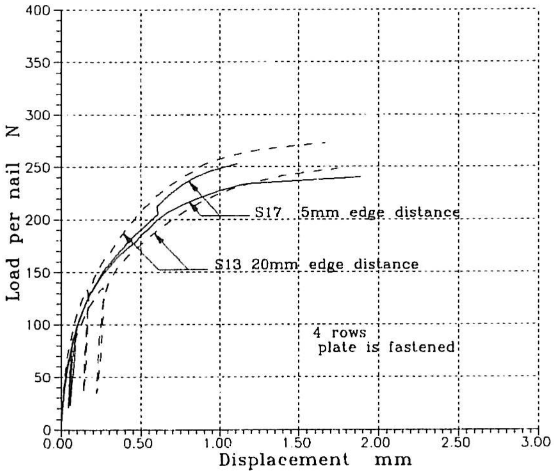

Figure 55: Max. and min. load-displacement curves of series 13 and 17.

obtained the full stiffness and load-carrying capacity compared to atest with 40mm edge distance (series 1). When the edge distance is 5mm the initial stiffness is unaffected but at the load 200N/nail the joint lose stiffness and fails at a much lower load. This is caused by failure in the wood in front of the nails closest to the timber edge. The wood in front of the nails is simply pressed away in small blocks.

In figure 55 the edge distance effect is analysed in tests with 4 rows. It is seen that the stiffness is in general unaffected. The tests with 5mm edge distance have a lower failure value, see table 6 on page 13. The failure of the tests in series 17 is caused by wood failure in front of the nail row closest to the timber edge. In figure 56 comparisons are made between series 10 and 14 to test the edge distance effect for 6 nail rows. The difference between the series is small, the failure load of tests with 5mm edge distance is, however, smaller (234N < 266N), see table 6.

In figure 57 comparisons are made of the series 11 and 18. In both series the plates are

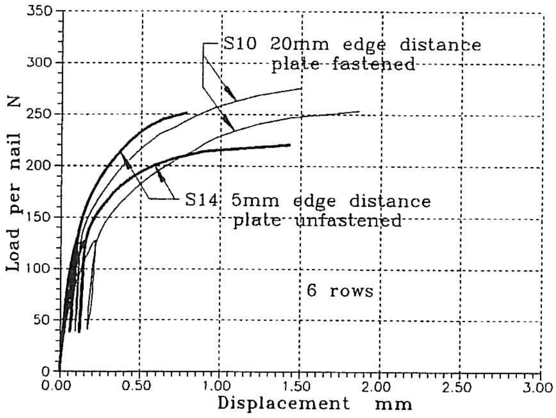

Figure 56: Max. and min. load-displacement curves of series 10 and 14.

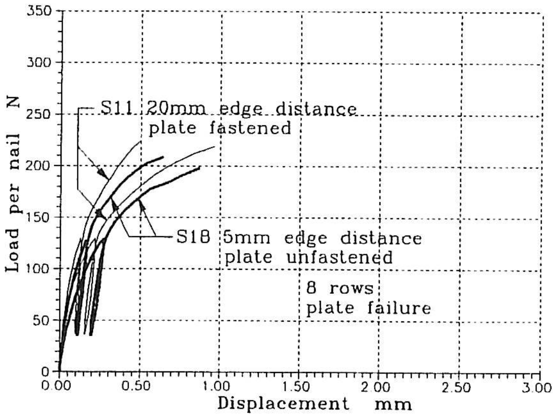

Figure 57: Max. and min. load-displacement curves of series 11 and 18.

failing. The load-displacement curves are slightly affected by the lock-fitting because the load level per nail is too low during the test. The difference between the load-displacement curves of series 11 and 18 is caused by the edge distance. The difference is, however, small.

8. Analysing Mainprogramme 3

In main programme 3 the influence of the orientation of grain, plate and load direction on the load-displacement curves is analysed. In figures 59 and 60 the mean load-displacement curves from each series are shown. The arrows indicate the load direction, and $\alpha_p - \alpha_g$ is the angular difference between the principal axes of the plate and the grain direction. All the tests are centrally loaded even though only a few nails are shown.

When the load is perpendicular to the grain direction the load-displacement curves are not reliable see eg. figure 41 on page 30. In tests with $\alpha_p - \alpha_g = 0°$ the initial stiffness is unaffected by the load direction, however, the initial stiffness is lower when the load

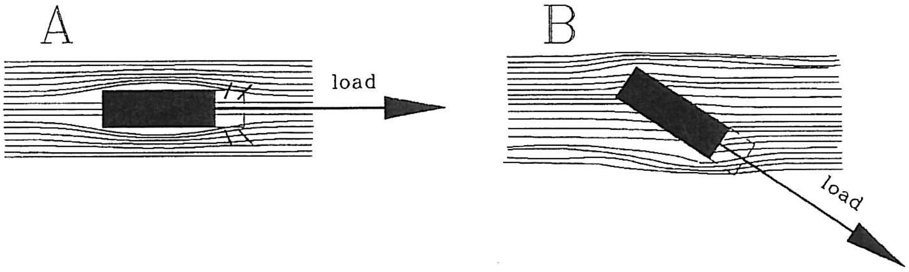

Figure 58: Deformation of the timber in front of a nail. The thin lines show the grain and the black rectangle denotes a nail.

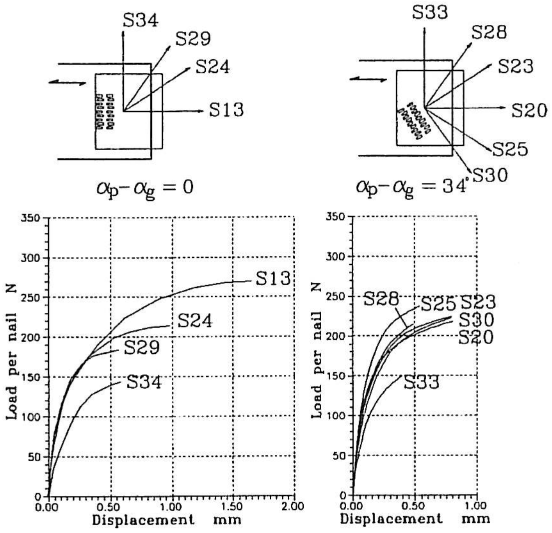

Figure 59: Load-displacement curves from tests with an angular difference between plate and grain direction of 0° and 34°.

direction is perpendicular to the grain. The failure load is getting smaller as the angle between load- and grain direction is increased. The failures in series 29 and 34 were caused by failure in the timber.

In tests with $\alpha_p - \alpha_g = 34°$ the stiffness is only slightly affected by the load direction, however, the stiffness in series 25 is increased a bit. In series 25 the load direction is nearly perpendicular to the principal axes of the plate, i.e. the bending stiffness of the nails is at a maximum. When the nail is loaded parallel to the grain the nail will displace the wood in front of the nail - the wood is splitting, see figure 58 A. The wood will easily split because of the low tensile strength perpendicular to grain. When the nail has a load direction which forms a small angle with the grain the splitting tendency will not occur easily, and the "nail to wood" behaviour will increase in stiffness, see figure 58 B. This effect is obvious in series 26, see figure 60.

In figures 59 and 60 it is seen that the stiffness in several tests is only slightly affected by the orientation of the plate, grain and load. The failure load is, however, different.

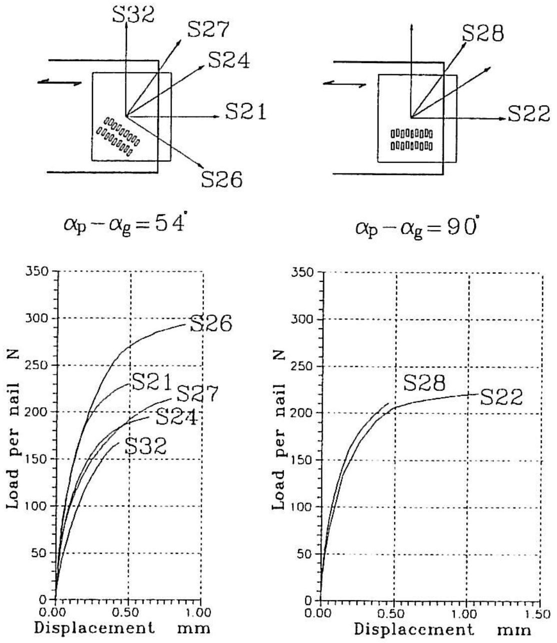

Figure 60: Load-displacement curves from tests with an angular difference between plate and grain direction of 54° and 90°.

9. Unloading

All the tests have been unloaded. Some tests have been unloaded once or twice to analyse the influence on the unloading curve. In figure 61 the unloading part of the load-displacement curves from various tests is shown.

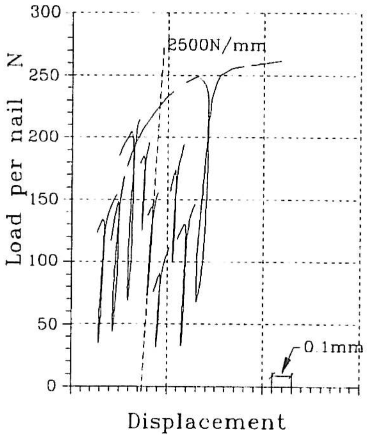

Figure 61: Unloading curves from different tests.

There are unloading curves from tests in series 2,4,13,15,22,26. To make the difference between unloading curves more distinct the curves have been moved horizontally. From figure 61 is it seen that:

- the stiffness of the unloading curves is independent of the load level,
- the stiffness of the unloading curves is $\sim$ 2500N/mm.

From figure 61 and others it is seen that:

- the stiffness of the unloading curves is equal to the inital stiffness of the load displacement curves,
- the stiffness of the unloading curves is independent of the angles between grain, plate and load direction,

10. Conclusion

Laterally loaded nailplates have been analysed from measurings of about 200 tests distributed on 34 series. Two displacement measuring systems have been developed and used in all tests. The systems are working perfectly.

The main results of the 3 main programmes are as follows:

- The tested load velocity (18, 37, 57 N/min) has no significant effect on the load-displacement curves.
- The load-displacement curves of a nail are dependent on the load direction in relation to the original stamping direction of the nail.
- A group effect arises in tests with several nail rows. The stiffness and failure load per nail is smaller in tests with several nail rows than in tests with only one nail row.
- The full load and stiffness capacity is obtained with nails placed at a distance greater than or equal to 10mm from the timber edge.
- The stiffness is only slightly affected by the orientation of the plate, grain and load. The failure load is, however, different as the ultimate load gets smaller when the angular difference between the grain and load direction is increased.
- The unloading stiffness is independent of the load level and it is equal to initial stiffness $\sim$ 2500N/mm. It is slightly affected of the orientation of the grain, plate and load direction.

For tests with the load perpendicular to the grain direction the load-displacement curves are not reliable, due to the small stiffness of timber. The deformations of the timber are large and they will disturb the displacement measurings.

11. Acknowledgement

The test material is favourably delivered by MULTISPÆR A/S, Vester Hassing. The tests and the equipment was prepared by Morten Olsen and Jørn Hasselgren. They are all greatly acknowledged.

Special thanks to Henning Andersen, who has been an invaluable help during the development of the measuring system and performance of the tests.

STRUCTURAL DESIGN PAPERS

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