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Faculty of Architecture, Building and Management
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Report TUE-BCO-01-03:
Determination of the Embedding Strength of Plybamboo

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1. INTRODUCTION

This research deals with the determination of the embedding strength of two kinds of plybamboo: bamboo mat board (MB) from India and bamboo strip board (SB) from China.

The results presented in this report would be of important use for the calculation of the capacity of lateral-loaded nailed connections between plybamboo sheets.

Hence, the goal of this research is to obtain the embedding strength for bamboo mat board and bamboo strip board and compare these values with actual theoretical equations.

The part of the report hereafter is divided in four chapters: 2, 3, 4 and 5.

Chapter 2 describes the state of the art regarding lateral connections in wooden materials and the importance of the embedding strength property for wooden-based materials. It also gives theoretical derived equations for calculating the embedding strength for solid wood and plywood and equations for obtaining ultimate capacities for lateral-loaded nailed joints (annex 1).

Chapter 3 presents the experimental tests details such as test setup, specimen sizes, description of test apparatus, load and deformation measurements and so on.

The next chapter is about the obtained results and its respective analyses.

The last chapter gives final conclusions and recommendations.

2. STATE OF THE ART WITH REGARD TO EMBEDDING STRENGTH

2.1 American Approach [1]

Maximum lateral resistance and safe design load values of nails were based on an empirical method prior to 1991. Research conducted during the 80's resulted in lateral resistance values that are based on a yield model theory.

Before 1991, the following formula was used:

$$p = KD^{3/2} \tag{1}$$

Where,

p : lateral load per nail, K : coefficient (depending on density and type of fastener),
D : diameter of nail.

The equation applies when the connected materials are approximately of the same density. The test loads were measured at joint slips of 0.38 mm. For ultimate loads, equation 1 can be increased 3.5 times for softwoods and 7 times for hard woods. The length of the nail in the wood receiving the point should be at least 10 times the diameter of nail for dense woods (more than 610 kg/m^3 in density) and 14 times the diameter for woods with a density less than 420 kg/m^3.

After 1991, a yield model theory based on the European approach is adopted. This model selects the worst case of yield modes based on different possibilities of wood bearing and nail bending. Figure 1 shows various combinations of wood-bearing and fastener-bending yields. Equations were developed for each of the failure modes and are shown in table 1. They depend on the dowel bearing strength (or embedding strength), dimensions of the wood members and the bending yield strength and diameter of the fastener. The dowel bearing strength of the wood is experimentally determined by compressing a dowel into a wood member. An empirical relation has been determined between bearing strength (F_e) and specific gravity of the wood (G) as:

$$F_e = 114.5G^{1.84} \tag{2}$$

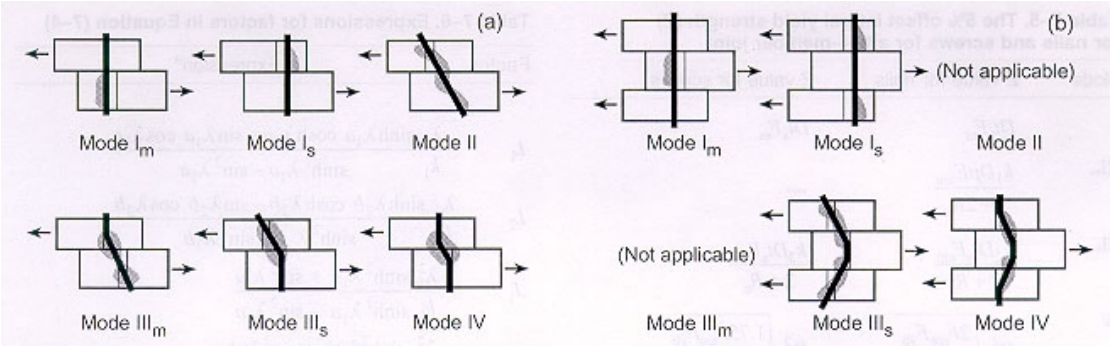

Figure 1. Failure modes for fastened connections under lateral load. Taken from reference [1].

Table 1. Equations to obtain the capacity of a lateral joint. Taken from reference [1].

Mode	Z value for nails	Z value for screws
I_s	Dt_sF_{es}	Dt_sF_{es}
III_m	$\frac{k_1DpF_{em}}{1+2R_e}$	—
III_s	$\frac{k_2Dt_sF_{em}}{2+R_e}$	$\frac{k_3Dt_sF_{em}}{2+R_e}$
IV	$D^2\sqrt{\frac{2F_{em}F_{yb}}{3(1+R_e)}}$	$D^2\sqrt{\frac{1.75F_{em}F_{yb}}{3(1+R_e)}}$

Definitions

- D nail, spike, or screw diameter, mm (in.) (for annularly threaded nails, D is thread-root diameter; for screws, D is either the shank diameter or the root diameter if the threaded portion of the screw is in the shear plane)
- F_{em} dowel bearing stress of main member (member holding point), kPa (lb/in^2)
- F_{es} dowel bearing stress of side member, kPa (lb/in^2)
- F_{yb} bending yield stress of nail, spike, or screw, kPa (lb/in^2)
- p penetration of nail or spike in main member, mm (in.)
- t_s thickness of side member, mm (in.)
- Z offset lateral yield strength
- $R_e = F_{em}/F_{es}$

$$k_1 = -1 + \sqrt{2(1+R_e) + \frac{2F_{yb}(1+2R_e)D^2}{3F_{em}p^2}}$$

$$k_2 = -1 + \sqrt{\frac{2(1+R_e)}{R_e} + \frac{2F_{yb}(2+R_e)D^2}{3F_{em}t_s^2}}$$

$$k_3 = -1 + \sqrt{\frac{2(1+R_e)}{R_e} + \frac{F_{yb}(2+R_e)D^2}{2F_{em}t_s^2}}$$

2.2 European Approach

As said before, the American approach after 1991 was based on the European approach which is a model of bearing failure of the joint members or the simultaneous development of a bearing failure of the joint members and plastic hinge formation in the fastener. This theory is presented in annex 1 and is known as Johansen's equations [2]. With this theory, ultimate capacities of lateral joints between wooden members can be calculated. The parameters needed to obtain these resistance values are (see figure 2):

1. The timber thickness and fastener penetrations (t_1 and t_2),
2. Embedding strength corresponding to t_1 ($f_{h,1}$),
3. Embedding strength corresponding to t_2 ($f_{h,2}$),
4. Diameter of the fastener (d) and,
5. Yield moment for fastener (M_y).

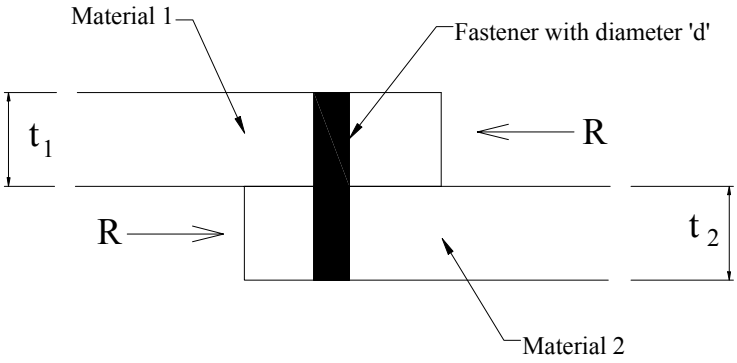

Figure 2. Parameters needed for the embedding strength calculation.

Looking at the equations of the different failure modes in annex 1, it can be noticed that the embedding strength (f_h) is a very important property of the connection system.

Theoretical formulas for embedding strength according to Eurocode [3]:

$$f_{h,k} = 0.082\rho_k d^{-0.3} \quad (3)$$

$$f_{h,k} = 0.082(1-0.01d)\rho_k \quad (4)$$

$$f_{h,k} = 0.11\rho_k d^{-0.3} \quad (5)$$

$$f_{h,k} = 0.11(1-0.01d)\rho_k \quad (6)$$

Where,

$f_{h,k}$: Characteristic embedding strength in N/mm^2.
d : diameter of nail in mm.
ρ_k : characteristic density in kg/m^3.

Equation 3 is for nailed connections of solid wood without the use of predrilled holes.
Equation 4 is for nailed connections of solid wood using predrilled holes.
Equation 5 is for plywood connections without the use of predrilled holes.
Equation 6 is for plywood bolted connections which would be similar to nailed connections with predrilled holes.

3. EXPERIMENTAL TESTS

3.1 Test setup

The way of determining the embedding strength for nailed connections in plybamboo was based on the European Standard EN 383 [4] which is attached as Annex 2. However, the loading procedure was different. As can be seen in page 24, when 40% of the maximum load is reached, 30 seconds after it should be reduced to 10% of the maximum load and then increased again. The purpose of this procedure is to obtain the foundation modulus values (see equations 2 to 7 in page 25). This part was skipped because it was not of interest for the purpose of this research and as can bee seen in the curves in annex 4, if this change had been done it would not have had an influence on the maximum load.

3.2 Test specimens

The test specimens used were bamboo mat boards (MB) from India (12 mm thick and woven at 45 º, see figure 3) and bamboo strip boards (SB) from China (18 mm thick, three layers with the internal one perpendicular to the external ones, see figure 3). Some physical and mechanical properties of these materials can be seen in annex 3.
30 specimens of MB of 12x50x120 mm were tested as well as 30 specimens of SB of 18x50x120 mm. 5 mm nails were used for each of the 60 tests.

Figure 3. Bamboo mat boards (left) and bamboo strip boards (right).

3.3 Equipment and test apparatus

The equipment used was quite simple. Since the size of the apparatus and specimens were rather small, the tests were able to be done in a compression machine with a load capacity of about 100 kN.
Figure 4 shows (a description of) the equipment and test apparatus used.

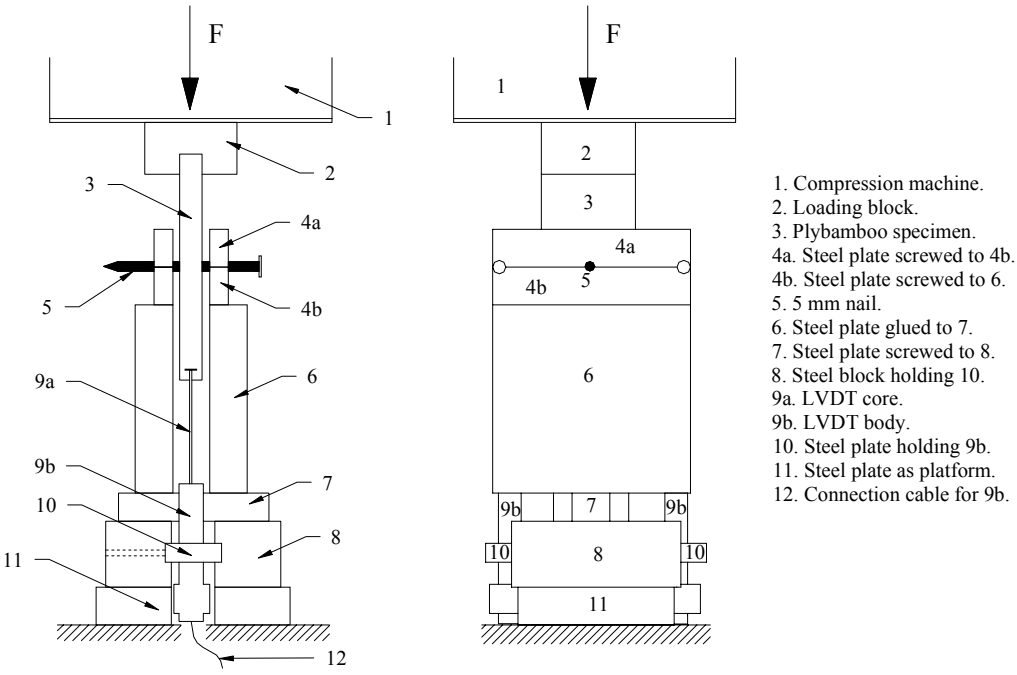

Figure 4. Equipment and test apparatus used.

Apparatus:

The test apparatus consists of different pieces of steel joined together in order to allow the positioning of the specimen and the LVDT's (Linear variable differential transformers). These pieces of steel are numbered in figure 4 as:
11: Two parts acting as a platform of the whole apparatus.
8: Two steel blocks glued to 11 with a channel section on their sides in which 10 is going to fit. One of the blocks has a hole with a bolt that can tight 10 (figure 4).
7: One part acting as a connector between 8 and 6. It is screwed to 8 and glued to 6.
6: Two steel plates that give the appropriate space for the test specimen to move.
4b: Two steel plates screwed to 6 with half a circular hole in the center on which the nail is going to rest.

Test procedure:

1. The specimen is cut into size (120x50 mm). The thickness is the one of the sheet (12 mm for MB and 18 mm for SB). This size was determined according to the range of sizes given in annex 2 (see page 22) depending on the thickness of the sheet and nail diameter (See figure 5).

Figure 5. Test specimens.

2. The specimen is predrilled with either a 4 mm, 4.5 mm or 5 mm hole. The location of the hole is the center of the specimen (figure 6).

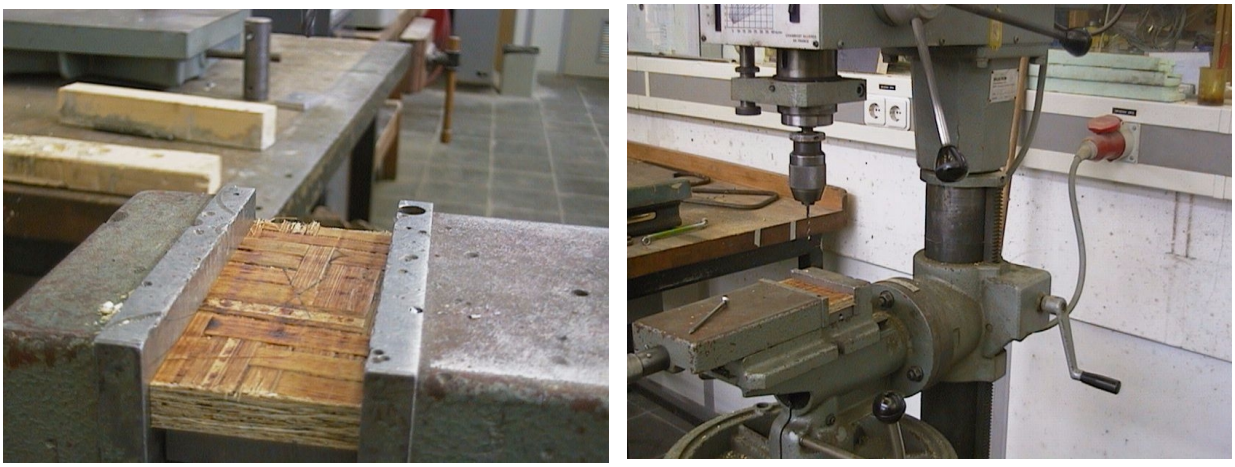

Figure 6. Drilling the hole in the specimen.

3. The nail is placed into the specimen as straight as possible (the angle between the nail and the specimen should be approximately 90º). In order to achieve this, the nail was pushed by the drilling machine as shown in figure 7. This is possible because the part of the drilling machine that holds the drill could be closed producing a flat surface on which the nail was held. Then, the machine goes downwards pushing the nail into the specimen.

Figure 7. Placing the nail into the specimen.

4. The LVDT cores (figure 8a) were placed on the specimen at 5 mm from the bottom edge as shown in figure 8b.

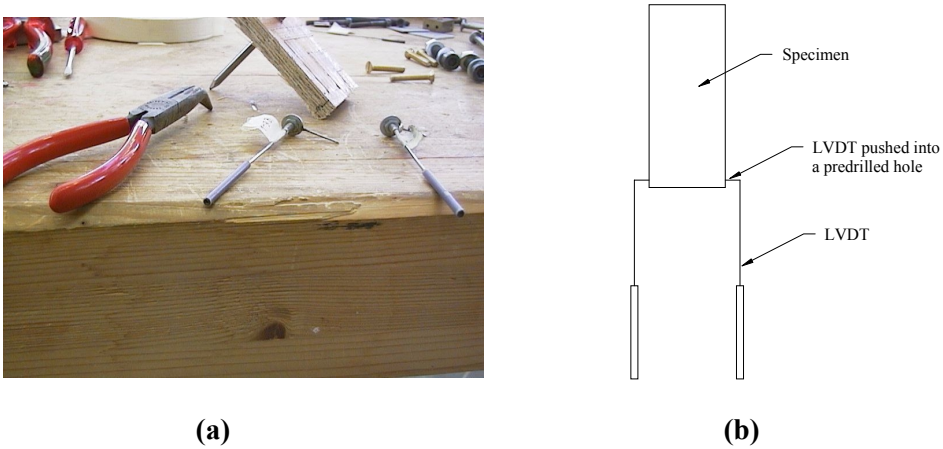

Figure 8. (a) LVDT's. (b) Placing LVDT's on the specimen.

5. The LVDT bodies (9b in figure 4) are placed on the test apparatus with the help of a metal plate (number 10 in figure 4). 9b can move upwards and downwards through a hole in 10 and can be tight by a bolt (see green circle in figure 9).

6. The specimen is placed on the test apparatus (See figure 9).

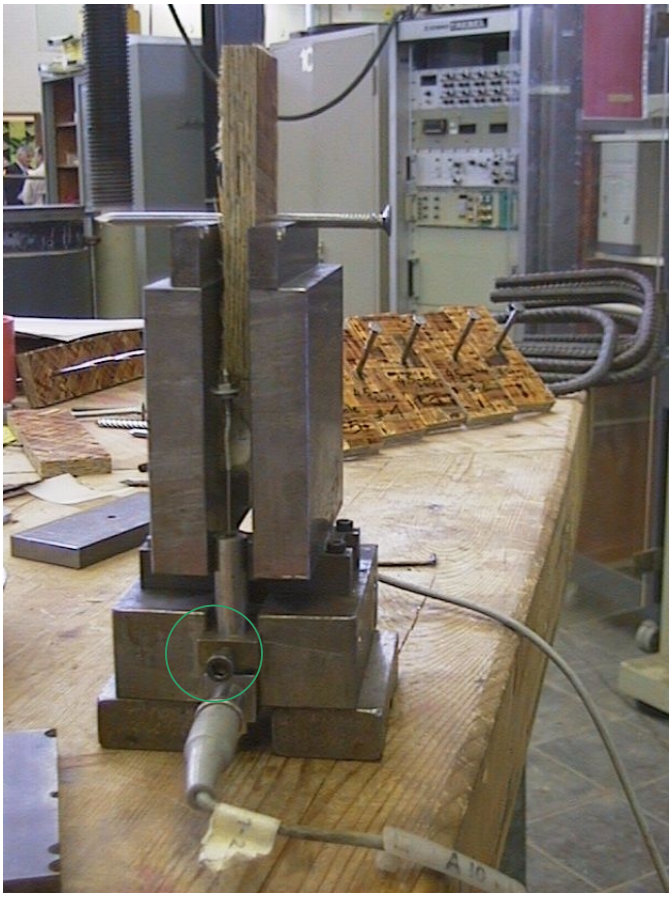

Figure 9. Placing the specimen on the apparatus.

7. The steel plates named 4a in figure 4 are screwed to the plates 4b and the loading block is put above the specimen. Afterwards, the specimen and apparatus are placed on the compression machine in order to begin the test (figure 10).

Figure 10. Test ready to start.

3.4. Measurement of load and deflection

The load and deflection were measured every 5 seconds at a speed rate of 1 mm/min. The tests were stopped at a deflection of about 8-10 mm. Nevertheless, 5 mm was enough to obtain the maximum load (see Annex 2). The maximum load was defined as the load at a deflection of 5 mm.

4. Experimental results and analysis

Table 2 shows a summary of the experiments design. Three variables were combined: material, direction and predrilled hole. For each possible combination, 5 tests were done which gives 60 experimental tests in total.

Table 2. Experiments design scheme.

Combination	Material*	Direction**	Predrilled hole (mm)	Number of tests
1	1	1	4	5
2	1	1	4.5	5
3	1	1	5	5
4	1	2	4	5
5	1	2	4.5	5
6	1	2	5	5
7	2	3	4	5
8	2	3	4.5	5
9	2	3	5	5
10	2	4	4	5
11	2	4	4.5	5
12	2	4	5	5
			Total number of tests	**60**

* 1: Bamboo Mat Board, 2: Bamboo Strip Board.

** 1: MB cut in the direction of the fibers, 2: MB cut as they are (woven into 45º), 3: SB with center ply perpendicular to the force, 4: SB with center ply parallel to the force.

The Load-Deflection diagrams for each combination are shown in annex 4.
The results of all the tests are presented in table A5.1 (See Annex 5).
In order to determine if there was a statistical significance for each of the factors on the embedding strength, a multifactor analysis of variance (ANOVA) for the embedding strength was done.
Firstly, the analysis was done with all the tests (60) comparing the factors hole and material (See Annex 5, statistical analysis #1). This analysis was made in order to corroborate if the material had an influence on the final result. Direction was not evaluated in this analysis because it is a material-dependant property. In table A5.2 can be seen that the P-value for material is less than 0.05 which means that there is a statistically significant effect on the embedding strength. The P-value for hole being larger than 0.05 (0.46) indicates that there is no statistically significant effect on the embedding strength. In other words, each material has a different embedding strength value independently from the size of the predrilled hole in the range of 4 and 5 mm.
The second analysis was done for material 1 (30 tests) comparing the factors direction and hole (annex 5, statistical analysis #2). The ANOVA analysis (table A5.4) showed that hole and direction do not have a statistically significant effect on the embedding strength since both P-values were larger than 0.05 (0.63 for direction and 0.32 for hole).
The last analysis (annex 5, statistical analysis #3) showed the same result as the previous one for material 2. In this case the P-values were 0.67 for direction and 0.29 for hole.
All the statistical analyses were done using the program STATIGRAPHICS Plus 4.0 [6]. All the tables and figures in Annex 5 are from the program except table A5.1.

Since hole and direction do not have a significant effect on the embedding strength of plybamboo, the embedding strength average for each material can be obtained. From table A5.3 in annex 5, 92.5 and 86.2 N/mm^2 were the mean embedding strength values for mat board and strip board respectively. The standard deviations for these values are 8.1 and 7.8 respectively. The 95% confidence intervals are 89.6-95.4 for MB and 83.4-89.2 for SB. Table 3 compares different values of embedding strength using equations 2, 4 and 6 and the experimental values obtained from the tests. The densities used for MB and SB were 790 and 720 kg/m^3 respectively (see annex 3). The diameter of the nail used for equations 4 and 6 was 5 mm. From the table it can be seen that the most accurate equation is equation 6 which is the one for bolted connections in plywood. Is clear that equation 4 gives the smaller values because is only for solid wood connections. Equation 2 does not consider the diameter of the nail but is also only for wood. However, it gives higher values than equation 4. The difference between equation 6 and the obtained results is approximately 10%.

Table 3. Embedding strength values in N/mm^2.

Equation / Material*	MB	SB
(2)	74.2	62.6
(4)	61.5	56.1
(6)	82.6	75.2
E.V.**	92.5 ($\pm$ 2.9)	86.2 ($\pm$ 2.9)

* MB: Mat Board, SB: Strip Board.
**E.V. : Mean Experimental Value with 95% confidence intervals.

5. CONCLUSIONS AND RECOMMENDATIONS

- Based on the European Standard 383 test method (annex 2), the embedding strength of bamboo mat board, 12 mm thick, 790 kg/m^3 of density, using predrilled holes between 4 and 5 mm diameter smooth round nails is around 89 and 96 N/mm^2 (92.5 in average) regardless of the direction of the grain.

- Based on the European Standard 383 test method (annex 2), the embedding strength of bamboo strip board, 18 mm thick, 720 kg/m^3 of density, using predrilled holes between 4 and 5 mm diameter smooth round nails is around 83 and 89 N/mm^2 (86.2 in average) regardless of the direction of the grain.

- Equation (6) from Eurocode 5 could be conservatively used for calculating embedding strength values for plybamboo with different nail diameters.

- With the experimental results and statistical analysis was proved that the direction of the grain and size of the predrilled hole do not have an effect on the embedding strength for plybamboo and hence, its behavior is similar to that one of plywood and that density is the most important property affecting the embedding strength.

- More experimental tests should be carried out varying the nail diameter and thickness of the plywood in order to develop a corresponding equation for the embedding strength of plybamboo.

- Lateral joints tests could be carried out and the experimental results could be compared to those ones theoretically calculated using equation (6).

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4. EN 383, 1993. Timber structures-Test Methods. Determination of embedding strength and foundation values for dowel type fasteners. European Committee for Standardization (CEN), 8p.

5. IPIRTI-Project Bamboo Mat Board, 1999. Manufacture of Bamboo Mat Board, a manual. India, 27p.

SOFTWARE

6. STATIGRAPHICS Plus 4.0.

ANNEX 1

Johansen's equations. Fasteners in single shear

In deriving Johansens's ultimate load equations it is assumed that both the fastener and the timber are ideal rigid-plastic materials, e.g. the load-embedment characteristic for the timber is as shown in Figure 4. This approximation simplifies the analysis and makes little difference to the final result.

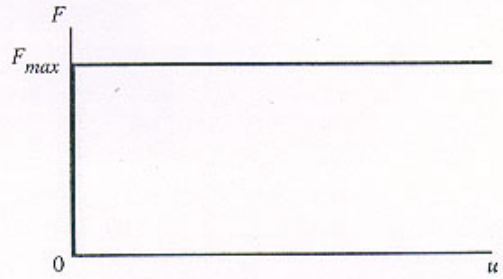

Figure 4 Simplified load-embedment characteristic.

The following notation is used:

t_1 and t_2 are the timber thicknesses or fastener penetrations,
$f_{h,1,k}$ is the characteristic embedding strength corresponding to t_1.
$f_{h,2,k}$ is the characteristic embedding strength corresponding to t_2,

$\beta = \frac{f_{h,2,d}}{f_{h,1,d}}$ where $f_{h,d} = \frac{k_{mod} f_{h,k}}{\gamma_M}$ is the design value of embedding strength,

d is the diameter of fastener,
$M_{y,k}$ is the characteristic yield moment for fastener,

$M_{y,d} = \frac{M_{y,k}}{\gamma_M}$ is the design value of fastener yield moment and

R_d is the design resistance per shear plane.

The numbering of the failure modes used in the following derivations follows that used by Johansen.

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Failure mode 1b

From Figure 5 $R_d = f_{h,1,d}\, t_1\, d$ (2)

From Figure 6 $R_d = f_{h,2,d}\, t_2\, d$

$R_d = \beta\, f_{h,1,d}\, t_2\, d$ (3)

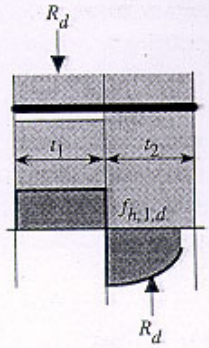

Figure 5 *Mode 1b failure in t_1.*

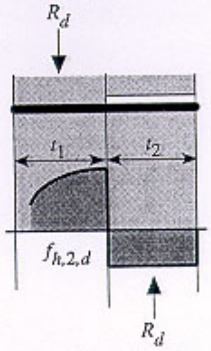

Figure 6 *Mode 1b failure in t_2.*

Failure mode 1a

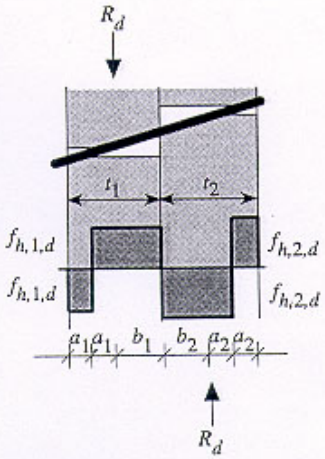

Figure 7 *Mode 1a failure.*

$R_d = f_{h,1,d}\, d\, b_1 = f_{h,2,d}\, d\, b_2 = \beta\, f_{h,1,d}\, d\, b_2$

$b_1 = \beta\, b_2$

Moment at interface $= f_{h,1,d}\, d \left(\frac{b_1^2}{2} - a_1^2 \right)$

$= f_{h,2,d}\, d \left(a_2^2 - \frac{b_2^2}{2} \right)$

$= \beta\, f_{h,1,d}\, d \left(a_2^2 - \frac{b_2^2}{2} \right)$

Equating and putting $b_2 = \frac{b_1}{\beta}$ gives:

$$\frac{b_1^2}{2}\,\frac{\beta + 1}{\beta} = \beta a_2^2 + a_1^2$$

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$$a_1 = \frac{t_1 - b_1}{2} \text{ and } a_2 = \frac{t_2 - b_2}{2} = \frac{\beta\, t_2 - b_1}{2\beta}$$

Substitution gives:

$$b_1^2\left(\frac{1+\beta}{\beta}\right) + 2\,b_1\,(t_1 + t_2) - (t_1^2 + \beta\, t_2^2) = 0$$

Solving for b_1 gives:

$$b_1 = \frac{t_1}{1+\beta}\left[\sqrt{\beta + 2\,\beta^2\left[1 + \frac{t_2}{t_1} + \left(\frac{t_2}{t_1}\right)^2\right] + \beta^3\left(\frac{t_2}{t_1}\right)^2} - \beta\left(1 + \frac{t_2}{t_1}\right)\right]$$

$$R_d = f_{h,1,d}\, d\, b_1$$

$$R_d = \frac{f_{h,1,d}\, d\, t_1}{1+\beta}\left[\sqrt{\beta + 2\,\beta^2\left[1 + \frac{t_2}{t_1} + \left(\frac{t_2}{t_1}\right)^2\right] + \beta^3\left(\frac{t_2}{t_1}\right)^2} - \beta\left(1 + \frac{t_2}{t_1}\right)\right] \quad (4)$$

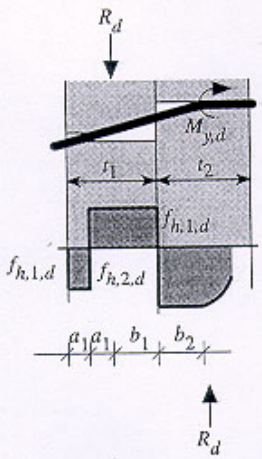

Figure 8 *Mode 2a failure.*

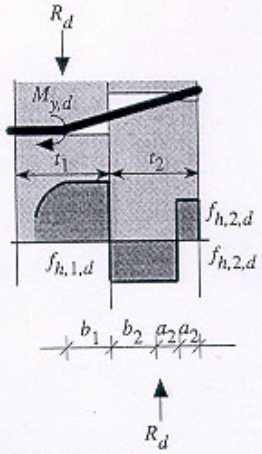

Figure 9 *Mode 2b failure.*

Failure mode 2a (from Figure 8)

At M_{max} shear $= 0$

$$f_{h,1,d}\; d\; b_1 = f_{h,2,d}\; d\; b_2 = \beta\, f_{h,1,d}\; d\; b_2$$

$$b_1 = \beta\, b_2$$

$$M_{y,d} = -f_{h,2,d}\, d\, \frac{b_2^2}{2} + f_{h,1,d}\, d\,(b_1 + a_1)\left(b_2 + \frac{b_1 + a_1}{2}\right) - f_{h,1,d}\, d\, a_1\left(b_1 + b_2 + \frac{3\,a_1}{2}\right)$$

Substituting $f_{h,2,d} = \beta\, f_{h,1,d}$ and $a_1 = \frac{t_1 - b_1}{2}$ gives:

$$b_1^2 + t_1\,\frac{2\,\beta}{2+\beta}\,b_1 - \frac{\beta\, t_1^2}{2+\beta} - \frac{M_{y,d}}{f_{h,1,d}\, d}\,\frac{4\,\beta}{2+\beta} = 0$$

then $b_1 = \frac{t_1}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\frac{4\beta(2+\beta)M_{y,d}}{f_{h,1,d}\,d\,t_1^2}}-\beta\right]$

and $R_d = f_{h,1,d}\,d\,b_1$

$$R_d = \frac{f_{h,1,d}\,d\,t_1}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\frac{4\beta(2+\beta)M_{y,d}}{f_{h,1,d}\,d\,t_1^2}}-\beta\right] \quad (5)$$

Failure mode 2b (from Figure 9)

As before $b_1 = \beta\, b_2$

$$M_{y,d} = f_{h,1,d}\,d\left[\frac{-b_1^2}{2}+\beta\,b_2\left(b_1+\frac{b_2}{2}\right)+\beta\,a_2\left(b_1+t_2-\frac{3a_2}{2}\right)-\beta\,a_2\left(b_1+t_2-\frac{a_2}{2}\right)\right]$$

Substituting $b_1=\beta\,b_2$ and $a_2=\frac{t_2-b_2}{2}$ gives:

$$b_2^2+\frac{\beta}{2}\,\frac{4\,t_2\,b_2}{\beta(2\beta+1)}-\left(\frac{\beta\,t_2^2}{4}+\frac{M_{y,d}}{f_{h,1,d}\,d}\right)\frac{4}{\beta(2\beta+1)}=0$$

$$b_2=\frac{-t_2}{2\beta+1}+\sqrt{\frac{t_2^2}{(2\beta+1)^2}+\frac{t_2^2}{2\beta+1}+\frac{4M_{y,d}}{f_{h,1,d}d\beta(2\beta+1)}}$$

$$R_d=\beta f_{h,1,d}\,d\,b_2$$

$$R_d=\frac{f_{h,1,d}\;d\;t_2}{1+2\beta}\left[\sqrt{2\beta^2(1+\beta)+\frac{4\beta(1+2\beta)M_{y,d}}{f_{h,1,d}\;d\;t_2^2}}-\beta\right] \quad (6)$$

Failure Mode 3 (from Figure 10)

$$M_{y,d}+M_{y,d}=f_{h,1,d}\;d\;b_1\left(b_2+\frac{b_1}{2}\right)-\beta\;f_{h,1,d}\;d\;\frac{b_2^2}{2}$$

$$b_2=\frac{b_1}{\beta}$$

$$b_1=\sqrt{\frac{2M_{y,d}}{f_{h,1,d}\;d}}\sqrt{\frac{2\beta}{1+\beta}}$$

$$R_d = f_{h,1,d}\, d\, b_1 = \sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,d}\, f_{h,1,d}\, d} \qquad (7)$$

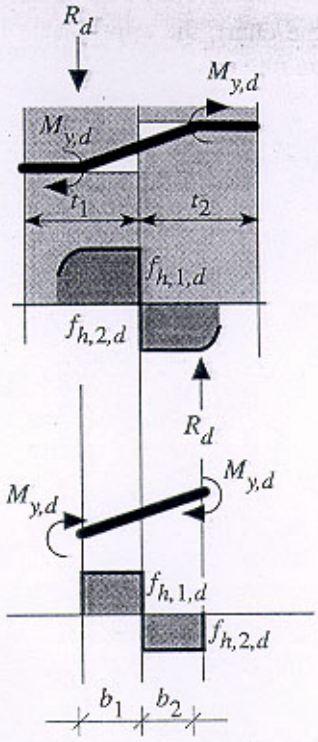

Figure 10 Mode 3 failure.

Johansen's equations may also be derived using the Virtual Work approach (Aune and Patton-Mallory, 1986).

Additional resistance

As the fastener deforms under load axial forces can develop for failure modes 2 and 3. These are caused by friction between the fastener and the timber and also by the constraints produced by the heads of nails and the washer assemblies in bolts.

The force in the inclined part of the fastener will have a component parallel to the applied load and will, therefore, enhance the resistance. EC5 takes this effect into account by enhancing the resistance for modes 2 and 3 failures by 10 per cent.

In an actual joint the load carrying capacity will correspond to the lowest value obtained for R_d by substituting into the full set of equations. The equation giving the lowest capacity will also identify the failure mode.

ANNEX 2

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 383

July 1993

UDC 694.142.2 : 624.011.1 : 620.176.3

Descriptors: Timber construction, sawn timber, laminated board, mechanical strength, determination, rigidity, fasteners

English version

Timber structures — Test methods — Determination of embedding strength and foundation values for dowel type fasteners

Structures en bois — Méthodes d'essais — Détermination de caractéristiques de fondation et de la portance locale d'élements d'assemblages de type broche

Holzbauwerke — Prüfverfahren — Bestimmung der Lochleibungsfestigkeit und Bettungswerte für stiftförmige Verbindungsmittel

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Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

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CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

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Ref. No. EN 383 : 1993 E

Foreword

This European Standard was prepared by CEN/TC 124 'Timber structures'. It was approved for the CEN final voting by the TC on 9th December 1991.

This standard is one of a series of standards for test methods for building materials and components. It was prepared by a working group under the convenorship of NSAI.

NOTE. It is considered desirable to maintain the same clause numbers consistently throughout this series of standards. Consequently, some clauses are void in this edition of this standard, but it is envisaged that future editions may need to include a text in these clauses.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 1994, and conflicting national standards shall be withdrawn at the latest by January 1994.

The standard was approved and in accordance with the CEN/CENELEC Internal Regulations, the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom.

No existing European Standard is superseded.

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1 Scope

This standard specifies laboratory methods of determining the embedding strength and foundation values of solid timber, glued laminated timber, and wood based sheet products with dowel type fasteners.

2 Normative references

None.

3 Definitions

For the purposes of this standard, the following definitions apply.

3.1 dowel type fastener

Bolt, nail, dowel or the like with plain or patterned surfaces.

3.2 embedding strength

Average compressive stress at maximum load in a piece of timber or wood based sheet product under the action of a stiff linear fastener. The fastener's axis is perpendicular to the surface of the timber. The fastener is loaded perpendicular to its axis.

3.3 maximum load

Maximum load measured before the deformation of the specimen has reached the deformation limit.

3.4 fastener section dimension

1) Actual diameter of a plain round fastener; or

2) Shank diameter of a profiled fastener; or

3) Length of one side of the section of a square fastener; or

4) Minimum dimension of the section of an oval or rectangular fastener.

4 Symbols

d	fastener section dimension, in millimetres
F	load, in newtons
F_{max}	maximum load, in newtons
$F_{max,est}$	estimated maximum load, in newtons
f_h	embedding strength, in newtons per square millimetre
$f_{h,est}$	estimated embedding strength, in newtons per square millimetre
K_e	elastic foundation modulus, in newtons per cubic millimetre
K_i	initial foundation modulus, in newtons per cubic millimetre
K_s	foundation modulus, in newtons per cubic millimetre
t	thickness, in millimetres
w	indentation or deformation, in millimetres
w_e	elastic deformation, in millimetres
w_i	initial deformation, in millimetres
$w_{i,mod}$	modified initial deformation, in millimetres
w_0	deformation of the test apparatus at any given load, in millimetres

5 Requirements

The fasteners and the timber, glued laminated timber or wood based sheet product shall be, as far as possible, of the minimum quality allowed by the relevant specification.

6 Test method

6.1 Principle

The test shall be carried out on the test piece and using the apparatus shown in figure 1. It is a principle of this test to avoid bending of the fastener under test.

The fastener is loaded perpendicular to its axis through a steel loading apparatus and the load and the corresponding indentation or deformation is measured, see figure 1.

The loading may be either in compression, see figure 2a, or in tension, see figure 2b. For solid timber and layered wood products with only one grain direction the loading may be either parallel to the grain, see figures 2a and 2b or compression perpendicular to the grain, see figure 2c.

NOTE. The principles of this standard may be used for other angles between the load and the grain.

6.2 Test pieces

The test piece is a rectangular prism of wood or wood based sheet product with a fastener placed with its axis perpendicular to the surface of the prismatic test piece. The sizes of the test pieces are given in table 1.

NOTE. The thickness t should be in the range $1,5d$ to $4d$ in order to comply with the principle of the test.

For wood based sheet products, the thickness of the test piece shall be the thickness of the panel as produced.

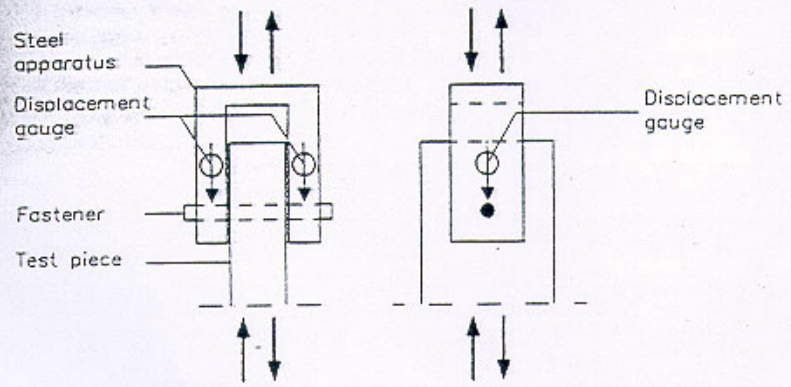


Figure 1. Test principle

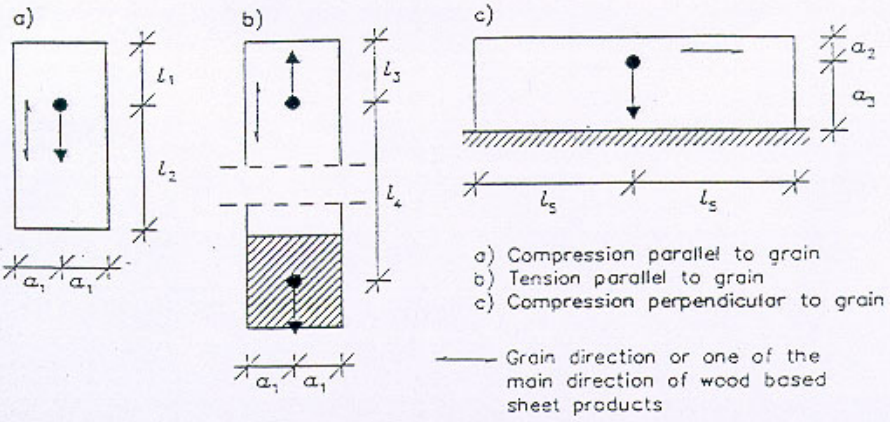


Figure 2. Sizes of test pieces as specified in table 1.

Table 1. Sizes of test pieces

Measurement	Nails - not prebored	Nails - prebored	Bolts or dowels	Test piece material
a_1	$5d$	$5d$	$3d$	Timber or wood based sheet products
l_1	$20d$	$12d$	$7d$	
l_2	$20d$	$12d$	$7d$	
l_3	$20d$	$12d$	$7d$	
l_4	$40d$	$40d$	$30d$	
a_2	$5d$	$5d$	$2d$	Timber or layered wood products with one grain direction
a_3	$5d$	$5d$	$4d$	
l_5	$20d$	$12d$	$7d$	

Measurements given in figure 2 are dependent on d, where d is defined, see clause 3.4.

6.3 Apparatus

The test apparatus shall be such that no friction between steel plates and test pieces may influence the measurements. In addition to equipment for measuring the geometry, moisture content, etc. of the test pieces, the following shall be available:

a) loading equipment capable of applying and continuously recording the load to an accuracy of ± 1 % of the load applied to the test piece or, for loads less than 10 % of the maximum load applied to the piece, with an accuracy of ± 0,1 % of the maximum load;

b) equipment to continuously record the displacement of the fasteners in the wood with an accuracy of ± 1 % of the displacement, or for displacement less than 2 mm with an accuracy of ± 0,02 mm.

NOTE. The equipment should ensure that eccentricities, twist, etc. have no influence on the measurements.

6.4 Preparation of test pieces

Before placing the fastener, the wood material shall be conditioned to constant mass in an environment having a relative humidity of (65 ± 5) % and a temperature of (20 ± 2) °C. After fabrication the test piece shall be conditioned again in the same environment. Constant mass is considered to be attained when the results of two successive weighings, carried out at an interval of 6 h, do not differ by more than 0,1 % of the mass of the test piece.

NOTE. For particular investigations, it may be appropriate to condition the test piece to other moisture conditions both before and after placing the fastener; if other climatic conditions are used, they are to be reported.

6.5 Procedure

6.5.1 *Apparatus calibration*

Initially the stiffness characteristic of the loading apparatus shall be determined. A steel specimen with a tight-fitting pin of the same diameter as the fastener shall be placed in the apparatus and the load deformation curve shall be determined as described in **6.5.6**.

6.5.2 *Placing of fastener*

The diameter of the fastener and the thickness of the test piece shall be measured in millimetres to an accuracy of 1 %.

The fasteners shall be placed in the same way as would be used in practice (e.g. preboring or no-preboring for nails, tight-fitting holes for dowels, oversized holes for bolts).

NOTE. To ensure that the axis of the fastener is perpendicular to the surface of the test piece a guide should be used.

6.5.3 *Placing of test piece in apparatus*

The test piece shall be placed symmetrically in the test apparatus. The load shall be applied in the axis of the test piece.

6.5.4 *Estimation of maximum load*

The estimated maximum load $F_{max,est}$ shall be determined on the basis of experience, calculation or preliminary tests.

NOTE. The estimations should be adjusted as described in 6.6.2.

6.5.5 *Application of load*

The loading procedure as shown in figure 3 shall be followed except that, for particular tests, the preload cycle up to 0,4 $F_{max,est}$ may be omitted with a corresponding adjustment to the total testing time. The load shall be increased to $0{,}4F_{max,est}$ and maintained for 30 s.

The load shall then be reduced to 0,1 $F_{max,est}$ and maintained for 30 s. Thereafter the load shall be increased.

The test shall then be stopped either when the maximum load is reached or when the deformation is w_0 + 5 mm.

The load shall be increased or decreased at a constant rate of loading-head movement. The load shall be so adjusted that the maximum load is reached within (300 ± 120) s.

6.5.6 *Recording of deformation*

The deformations w_{01}, w_{04}, w_{14}, w_{11}, w_{21}, w_{24}, w_{26} and w_{28} corresponding to the points 01, 04, 14, 11, 21, 24, 26 and 28 as shown in figure 4 shall be recorded for each test piece to give the load deformation curve. The deformation at maximum load F_{max} shall also be recorded.

When a load deformation curve is not available, measurements of deformation should be taken at each 0,1 $F_{max,est}$ increment of load, see figure 3.

6.5.7 *Determination of density and moisture content*

Determine the density and moisture content of the timber or wood based sheet products.

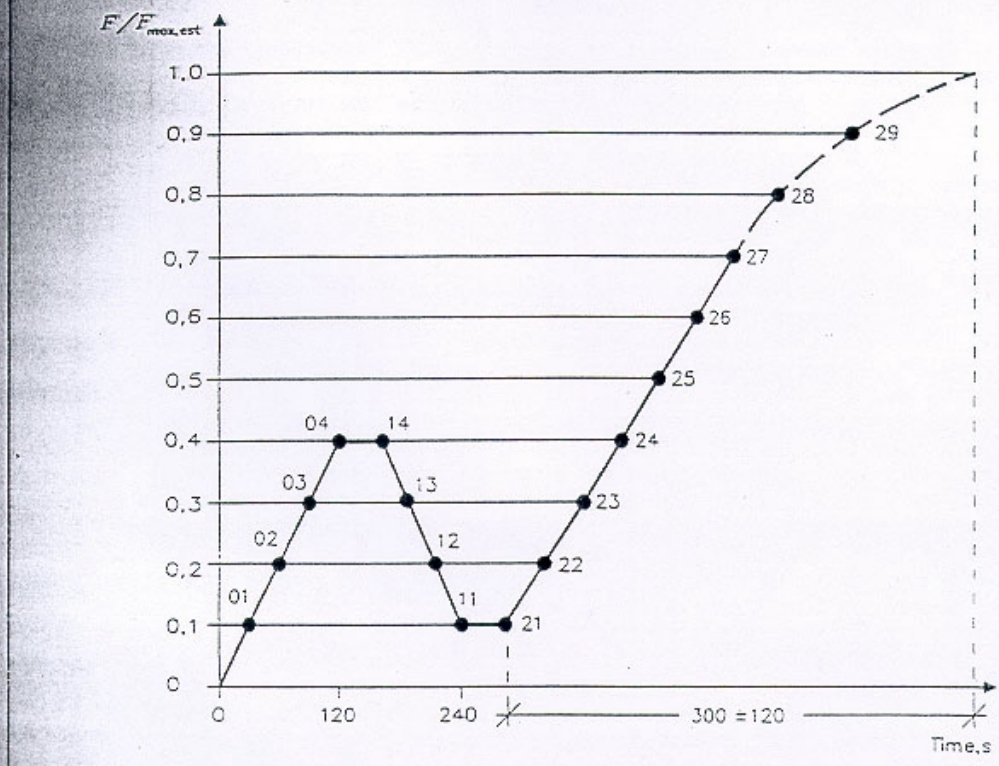


Figure 3. Loading procedure

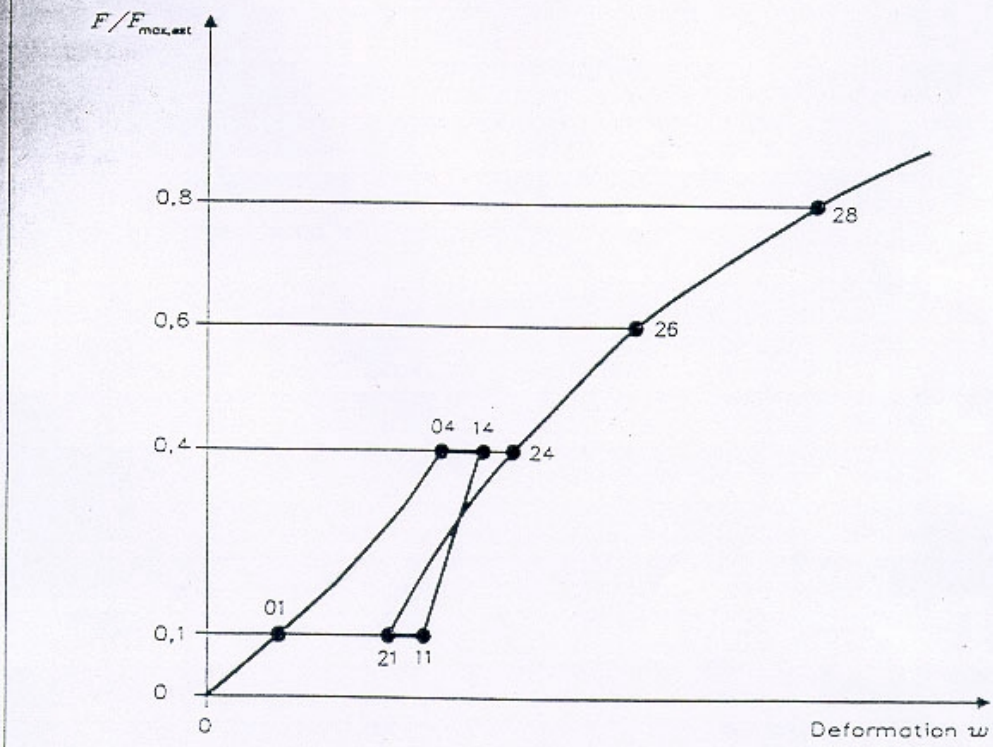


Figure 4. Idealized load-deformation curve and measurements

6.6 Results

6.6.1 ***Calculations***

The embedding strength f_h and the estimated embedding strength $f_{h,est}$ shall be calculated to an accuracy of 1 % using the following formulae:

$$f_h = \frac{F_{max}}{dt} \quad (1a)$$

$$f_{h,est} = \frac{F_{max,est}}{dt} \quad (1b)$$

From the recorded measurements the following values, if relevant, shall be calculated:

initial deformation:

$$w_i = w_{04} \quad (2)$$

modified initial deformation:

$$w_{i,mod} = \frac{4}{3}(w_{04} - w_{01}) \quad (3)$$

elastic deformation:

$$w_e = \frac{2}{3}(w_{14} + w_{24} - w_{11} - w_{21}) \quad (4)$$

initial foundation modulus:

$$K_i = \frac{0,4\, f_{h,est}}{w_i} \quad (5)$$

foundation modulus:

$$K_s = \frac{0,4\, f_{h,est}}{w_{i,mod}} \quad (6)$$

elastic foundation modulus:

$$K_e = \frac{0,4\, f_{h,est}}{w_e} \quad (7)$$

deformation at 0,6 F_{max}:

$w_{0,6}$

deformation at 0,8 F_{max}:

$w_{0,8}$

The measured load deformation curve shall, if relevant, be corrected as shown in figure 5.

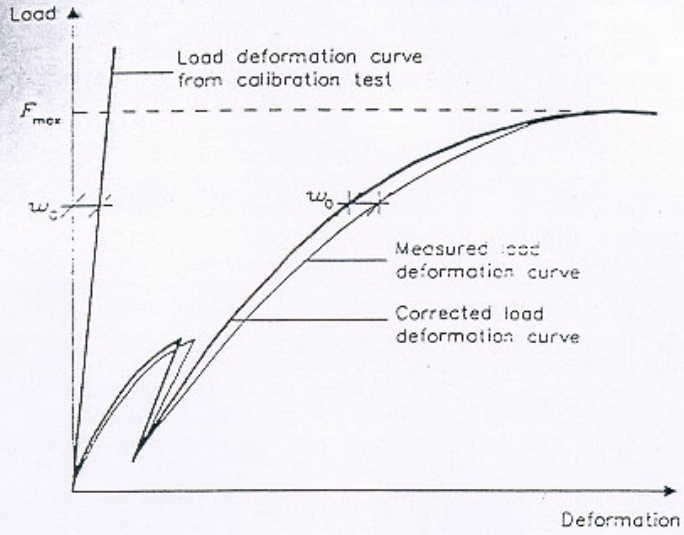


Figure 5. Correction of the measured load deformation taking into account the stiffness characteristics of the loading apparatus. The measured deformation at the load F is reduced by the deformation w_0 at the same load found by the apparatus calibration

6.6.2 ***Adjustments***

If, during the execution of the tests, the mean value of the maximum load of the tests already carried out deviates by more thatn 20 % from the estimated value, this value shall be adjusted correspondingly for subsequent tests. The values of maximum load already determined may be accepted without adjustment as part of the final results. In this case, the values of deformation and foundation moduli determined in equations (2) to (7) shall be adjusted to correspond to the adjusted values of the estimated value.

6.7 Test report

The test report shall include the following:

a) sampling procedure;

b) specification and quality of material: species, density, grain direction or main orientation, strength properties;

c) type, diameter, strength characteristics and surface treatment of the fastener (including anticorrosion protection);

d) size of the test pieces, diameter of the hole and manner of placing the fastener in the specimen;

e) conditioning of test pieces before and after preparation, moisture content at test;

f) test results and information regarding adjustments, mean values and standard deviations, and descriptions of the modes of failure.

ANNEX 3

Table A1. Several properties of plybamboo.

Property / Type of plybamboo	MB	SB
Density (Kg/m^3)	790	720
Moisture (%)	-	8-10%
Tensile strength (N/mm^2)	-	105 (1)
Compressive strength (N/mm^2)	35.3	52.0, 17.7 (2)
Bending strength (N/mm^2)	59.4	93.8 (3)
Modulus of Elasticity (N/mm^2)	3114	6505 (3)
Shear panel strength (N/mm^2)	-	9.4 (4)

(1) According to ASTM D3500-90.
(2) According to ASTM D3501-86, the first value corresponds to the compressive strength parallel to the grain and the second perpendicular to the grain.
(3) According to ASTM D3043-87.
(4) According to British Standard #373.

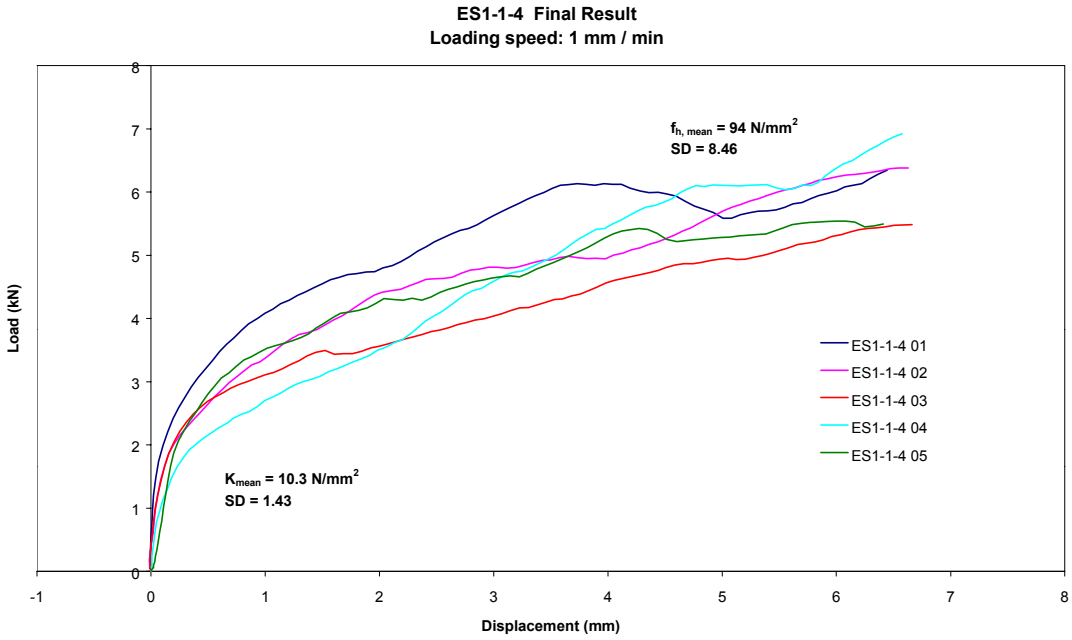
The values for MB were obtained from reference [5] and they were based on the ASTM standard procedures according to Dr. H.N. Jagadesh from IPIRTI [5]. The values for SB were provided by Mr. Samuel Yao from Qingfeng Bamboo Flooring (Internet address: http://www.china-qingfeng.com).
All the data represent mean values from certain number of tests.

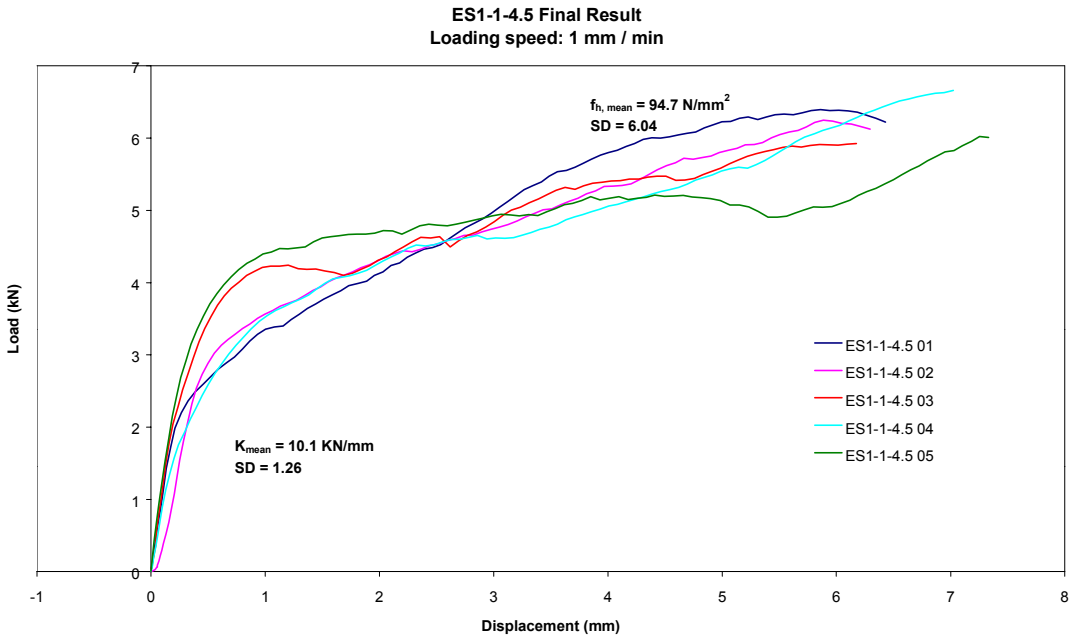
ANNEX 4

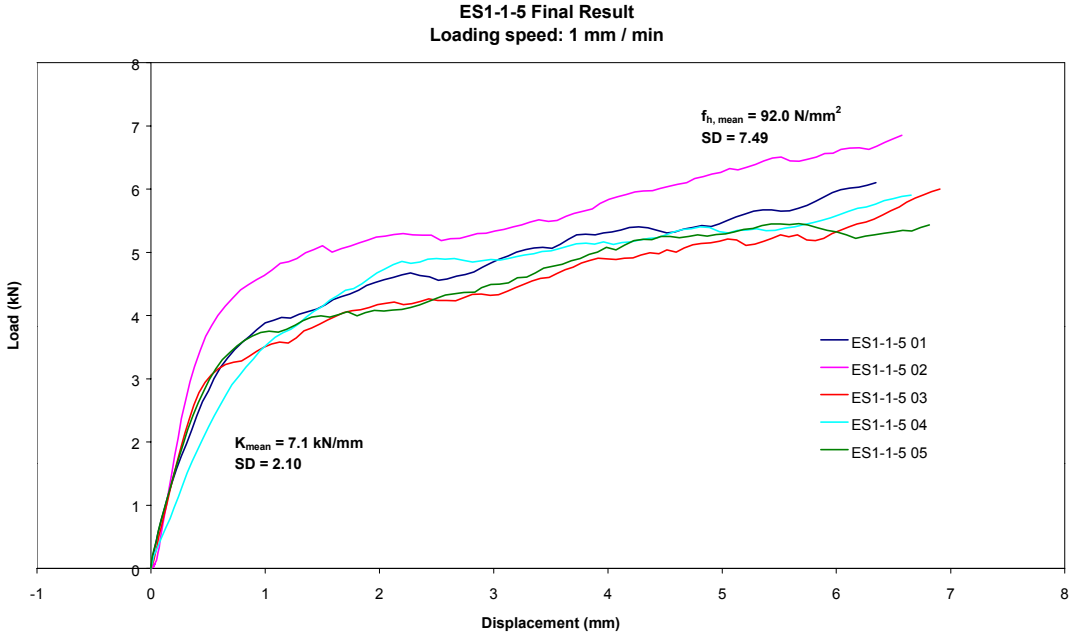
Notation:

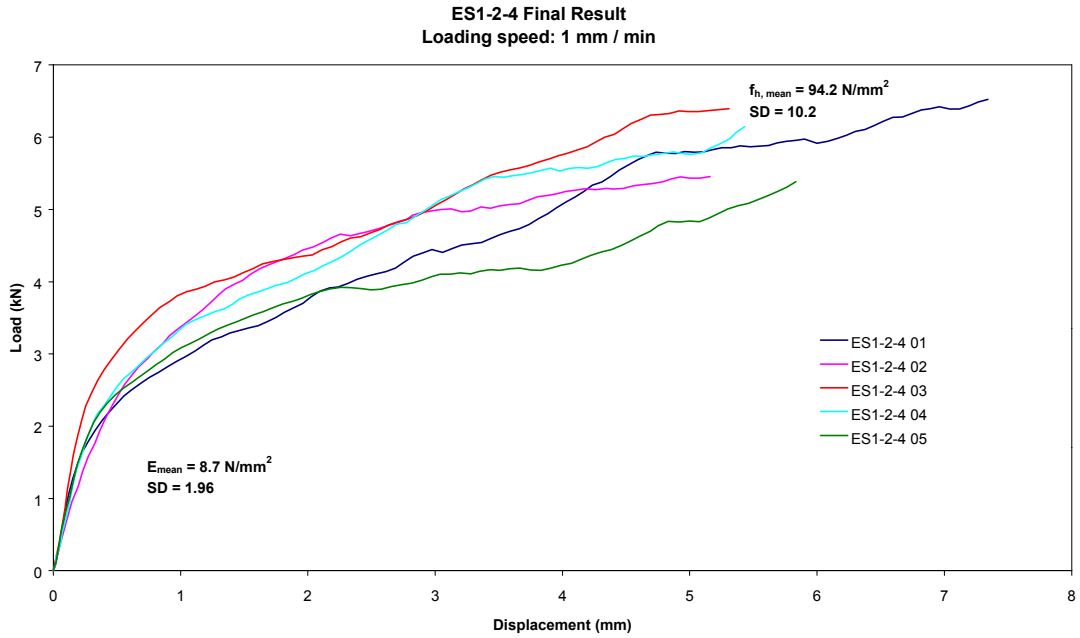
ES: Embedding strength test, the first number indicates the material. Number 1 is for bamboo mat board and number 2 for bamboo strip board. The second number indicates the direction of the fiber as explained in page 10. The third and last number indicates the size of the hole in mm.

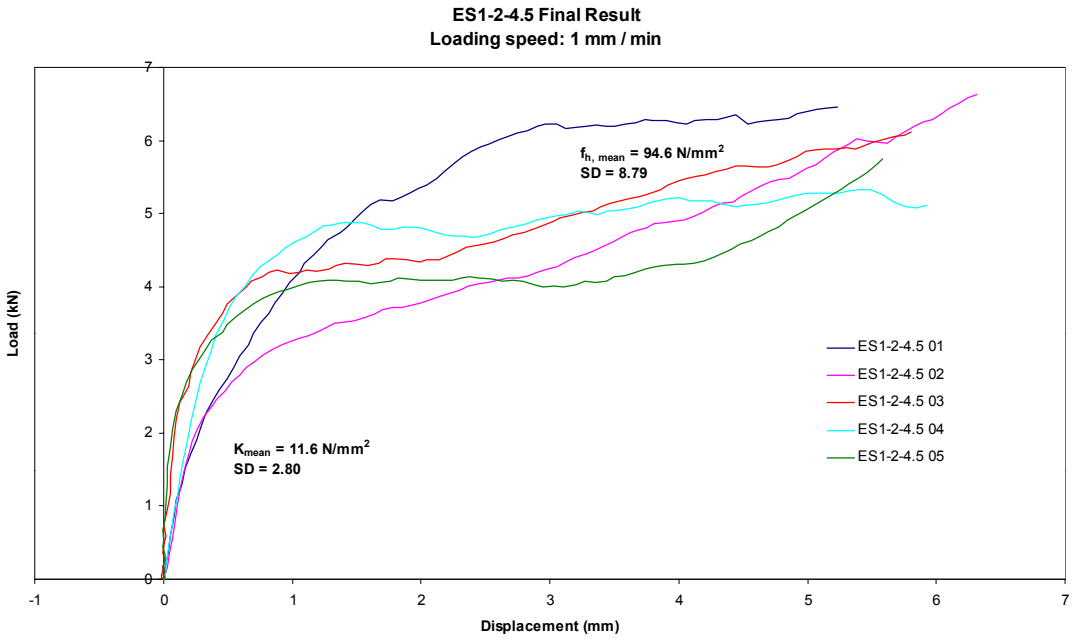
$f_{h,mean}$: Embedding strength mean.
K_{mean}: Rigidity of the test.
SD: Standard deviation.

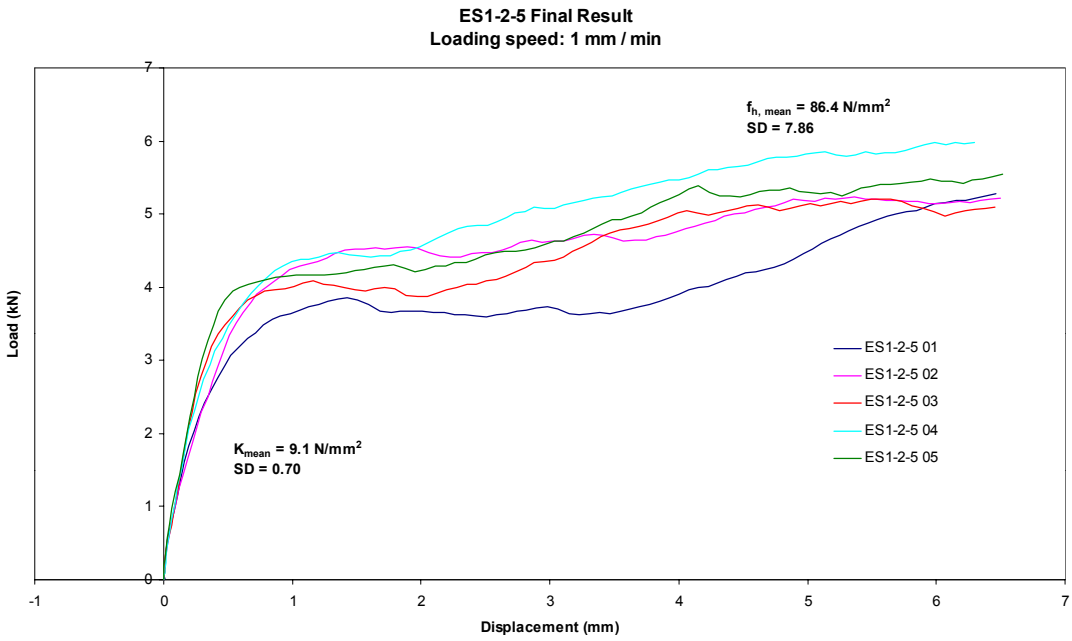


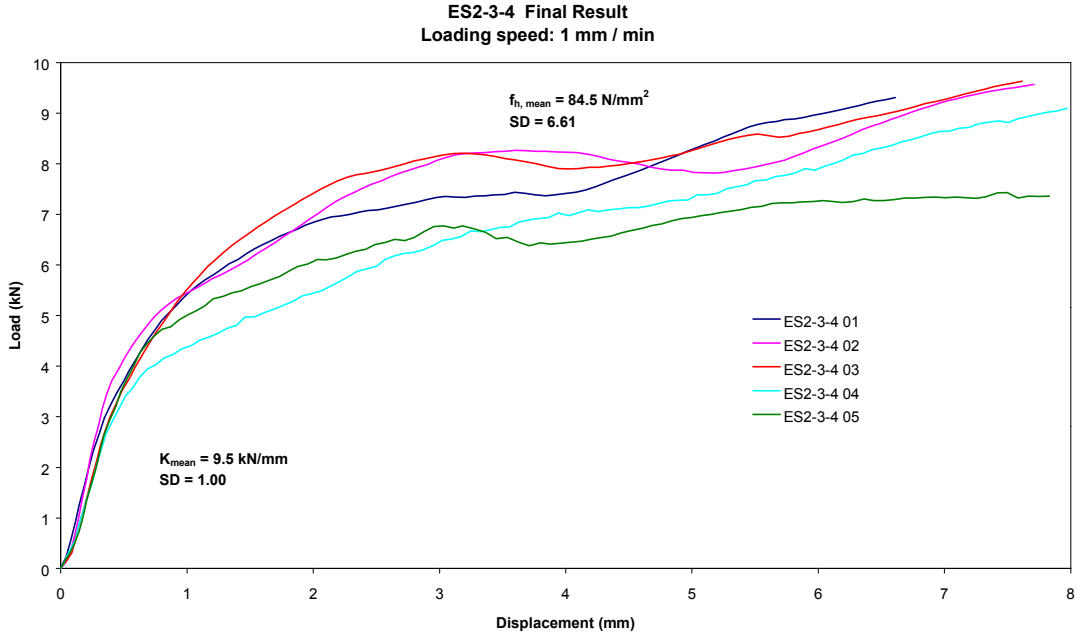


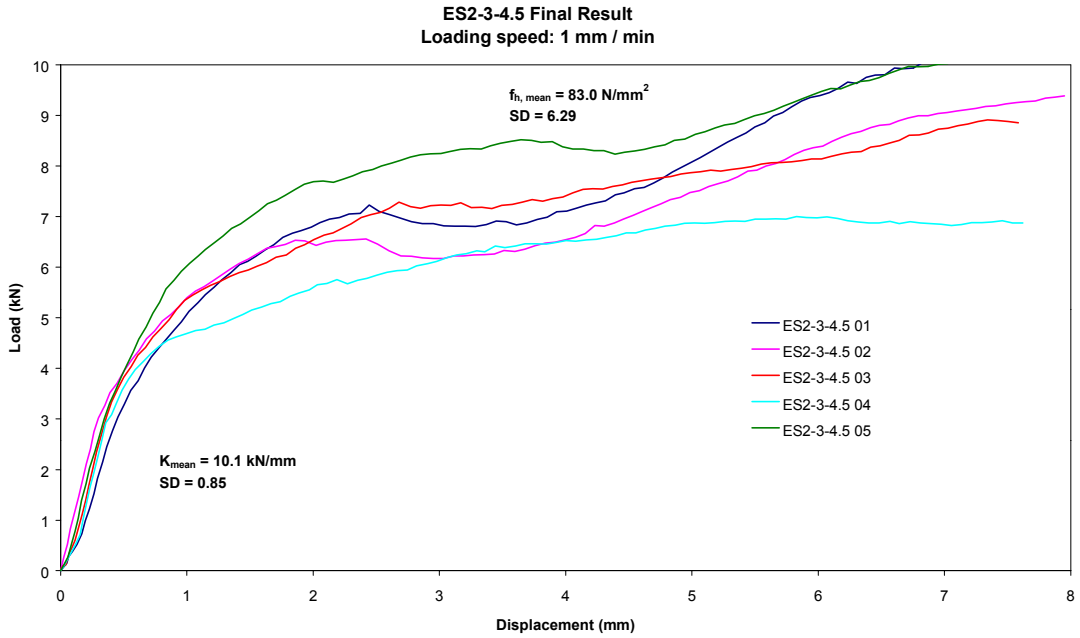

ES1-1-5 Final Result
Loading speed: 1 mm / min
$f_{h,mean}$ = 92.0 N/mm^2
SD = 7.49
K_{mean} = 7.1 kN/mm
SD = 2.10
ES1-1-5 01
ES1-1-5 02
ES1-1-5 03
ES1-1-5 04
ES1-1-5 05
Load (kN)
Displacement (mm)

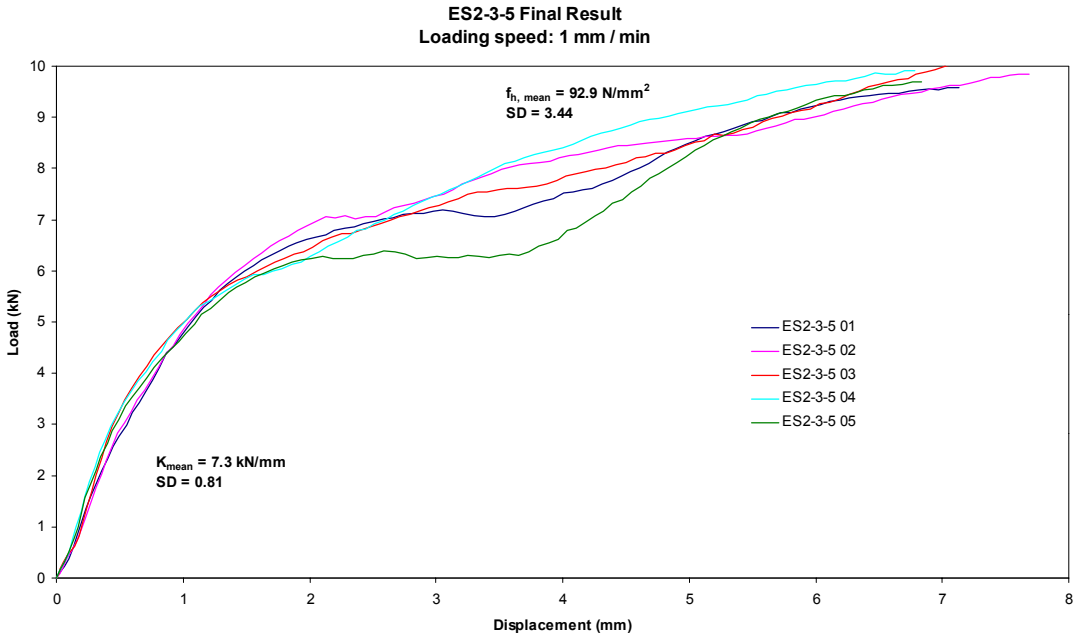

ES1-2-4 Final Result
Loading speed: 1 mm / min
$f_{h,mean}$ = 94.2 N/mm^2
SD = 10.2
E_{mean} = 8.7 N/mm^2
SD = 1.96
ES1-2-4 01
ES1-2-4 02
ES1-2-4 03
ES1-2-4 04
ES1-2-4 05
Load (kN)
Displacement (mm)

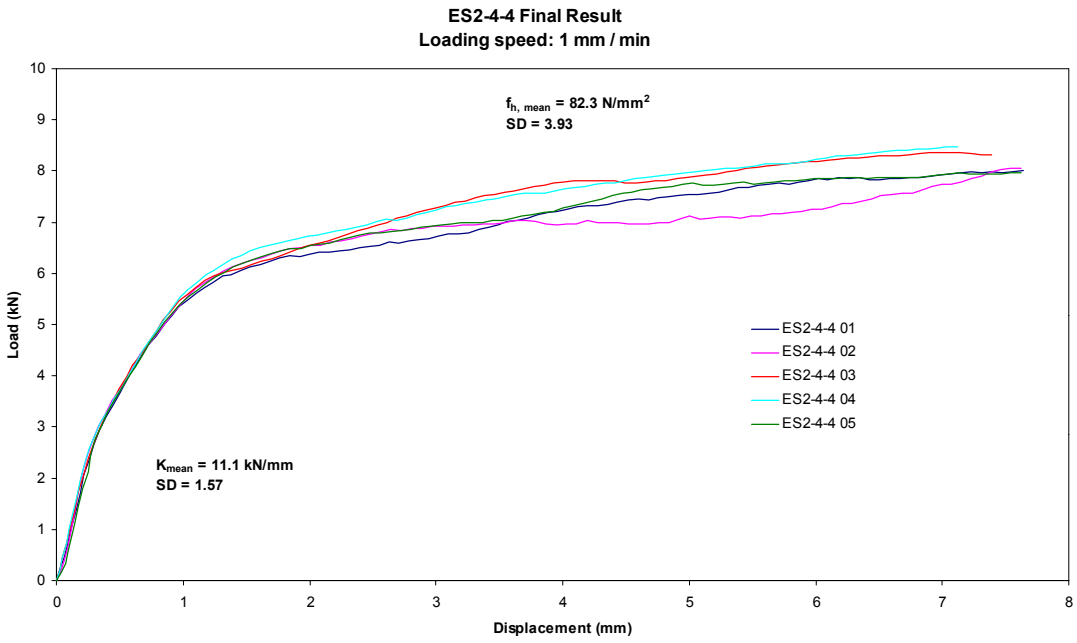

ES1-2-4.5 Final Result
Loading speed: 1 mm / min
Load (kN)
Displacement (mm)
$f_{h,\,mean}$ = 94.6 N/mm²
SD = 8.79
K_{mean} = 11.6 N/mm²
SD = 2.80
ES1-2-4.5 01
ES1-2-4.5 02
ES1-2-4.5 03
ES1-2-4.5 04
ES1-2-4.5 05

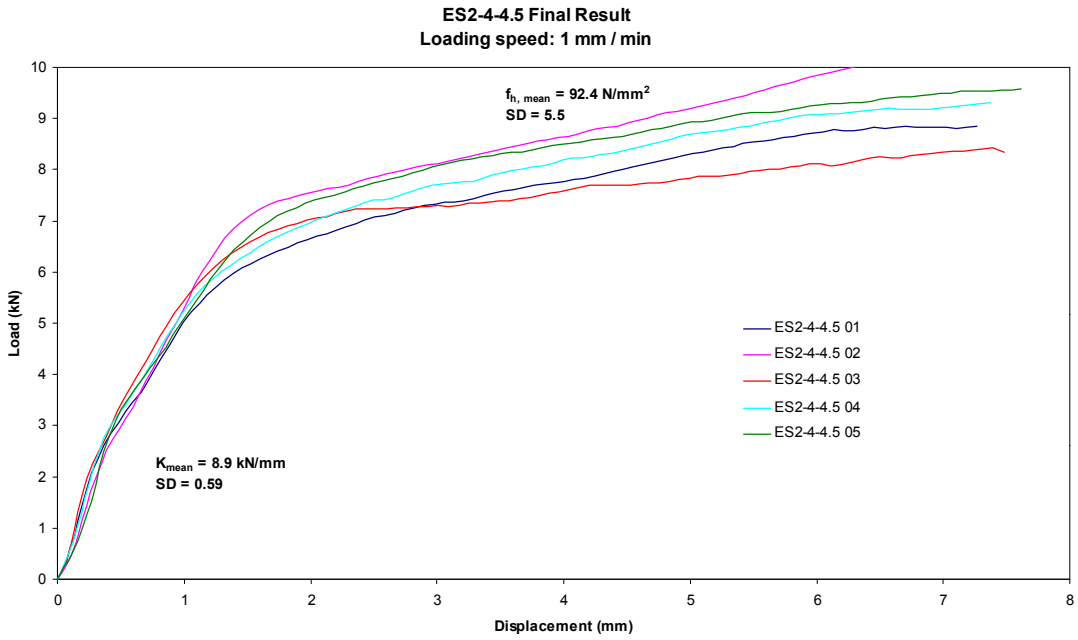

ES1-2-5 Final Result
Loading speed: 1 mm / min
Load (kN)
Displacement (mm)
$f_{h,\,mean}$ = 86.4 N/mm²
SD = 7.86
K_{mean} = 9.1 N/mm²
SD = 0.70
ES1-2-5 01
ES1-2-5 02
ES1-2-5 03
ES1-2-5 04
ES1-2-5 05

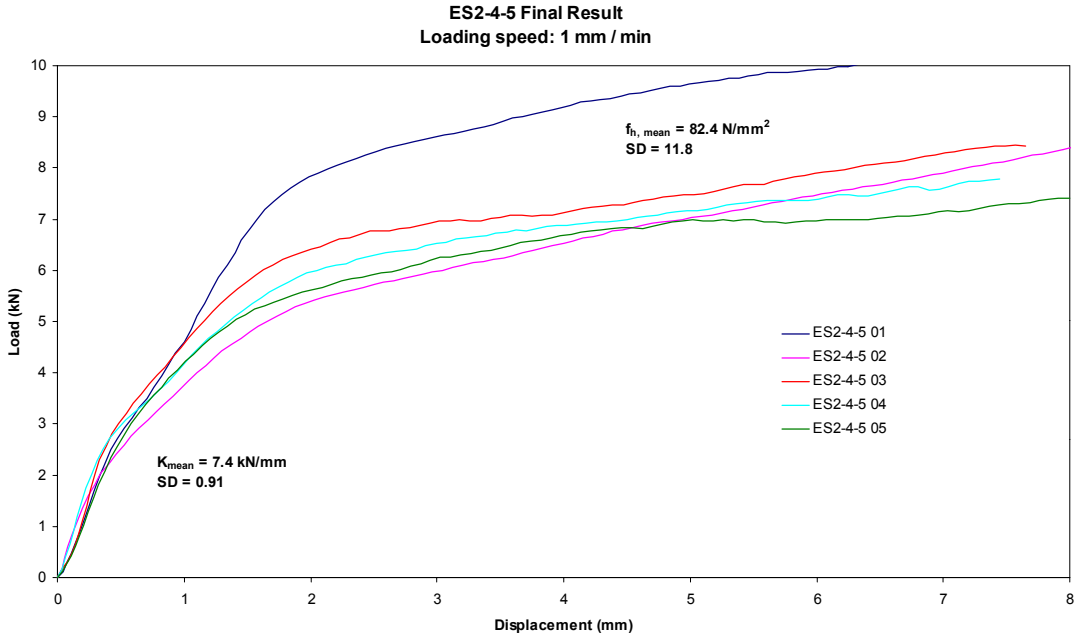

ES2-3-4 Final Result
Loading speed: 1 mm / min
$f_{h,mean}$ = 84.5 N/mm^2
SD = 6.61
K_{mean} = 9.5 kN/mm
SD = 1.00
ES2-3-4 01
ES2-3-4 02
ES2-3-4 03
ES2-3-4 04
ES2-3-4 05
Load (kN)
Displacement (mm)


ES2-3-4.5 Final Result
Loading speed: 1 mm / min
$f_{h,mean}$ = 83.0 N/mm^2
SD = 6.29
K_{mean} = 10.1 kN/mm
SD = 0.85
ES2-3-4.5 01
ES2-3-4.5 02
ES2-3-4.5 03
ES2-3-4.5 04
ES2-3-4.5 05
Load (kN)
Displacement (mm)


ES2-3-5 Final Result
Loading speed: 1 mm / min
$f_{h,\,mean}$ = 92.9 N/mm^2
SD = 3.44
K_{mean} = 7.3 kN/mm
SD = 0.81
ES2-3-5 01
ES2-3-5 02
ES2-3-5 03
ES2-3-5 04
ES2-3-5 05
Load (kN)
Displacement (mm)


ES2-4-4 Final Result
Loading speed: 1 mm / min
$f_{h,\,mean}$ = 82.3 N/mm^2
SD = 3.93
K_{mean} = 11.1 kN/mm
SD = 1.57
ES2-4-4 01
ES2-4-4 02
ES2-4-4 03
ES2-4-4 04
ES2-4-4 05
Load (kN)
Displacement (mm)


ES2-4-4.5 Final Result
Loading speed: 1 mm / min
$f_{h,\,mean}$ = 92.4 N/mm^2
SD = 5.5
K_{mean} = 8.9 kN/mm
SD = 0.59
ES2-4-4.5 01
ES2-4-4.5 02
ES2-4-4.5 03
ES2-4-4.5 04
ES2-4-4.5 05
Load (kN)
Displacement (mm)


ES2-4-5 Final Result
Loading speed: 1 mm / min
$f_{h,\,mean}$ = 82.4 N/mm^2
SD = 11.8
K_{mean} = 7.4 kN/mm
SD = 0.91
ES2-4-5 01
ES2-4-5 02
ES2-4-5 03
ES2-4-5 04
ES2-4-5 05
Load (kN)
Displacement (mm)

ANNEX 5

Table A5.1 Experimental Results.

Test number	Embedding Strength (N/mm^2)	Direction	Hole	Material
1	102	1	4	1
2	95	1	4	1
3	80	1	4	1
4	100	1	4	1
5	88	1	4	1
6	103.3	1	4.5	1
7	96.7	1	4.5	1
8	93.3	1	4.5	1
9	93.3	1	4.5	1
10	86.7	1	4.5	1
11	91.7	1	5	1
12	105	1	5	1
13	86.7	1	5	1
14	88.3	1	5	1
15	88.3	1	5	1
16	96.7	2	4	1
17	90	2	4	1
18	107.7	2	4	1
19	96.7	2	4	1
20	80	2	4	1
21	107.7	2	4.5	1
22	95	2	4.5	1
23	97	2	4.5	1
24	88.3	2	4.5	1
25	85	2	4.5	1
26	75	2	5	1
27	87	2	5	1
28	85	2	5	1
29	97	2	5	1
30	88	2	5	1
31	89.2	3	4	2
32	89.2	3	4	2
33	89.2	3	4	2
34	79.6	3	4	2
35	75.3	3	4	2
36	83.9	3	4.5	2
37	80.6	3	4.5	2
38	84.9	3	4.5	2
39	74.2	3	4.5	2
40	91.4	3	4.5	2
41	91.4	3	5	2
42	92.5	3	5	2
43	91.4	3	5	2
44	98.9	3	5	2
45	90.3	3	5	2

Table A5.1 Continuation.

Test number	Embedding Strength (N/mm^2)	Direction	Hole	Material
46	80.6	4	4	2
47	76.3	4	4	2
48	84.9	4	4	2
49	86	4	4	2
50	83.9	4	4	2
51	89.2	4	4.5	2
52	98.9	4	4.5	2
53	84.9	4	4.5	2
54	93.5	4	4.5	2
55	95.7	4	4.5	2
56	103.2	4	5	2
57	75.3	4	5	2
58	80.6	4	5	2
59	77.4	4	5	2
60	75.3	4	5	2

Statistical analysis #1

Notation:

ES: Embedding strength

```
Analysis Summary

Dependent variable: ES
Factors:
        Hole
        Material

Number of complete cases: 60


The StatAdvisor
---------------
   This procedure performs a multifactor analysis of variance for ES.
It constructs various tests and graphs to determine which factors have
a statistically significant effect on ES.  It also tests for
significant interactions amongst the factors, given sufficient data.
The F-tests in the ANOVA table will allow you to identify the
significant factors.  For each significant factor, the Multiple Range
Tests will tell you which means are significantly different from which
others.  The Means Plot and Interaction Plot will help you interpret
the significant effects.  The Residual Plots will help you judge
whether the assumptions underlying the analysis of variance are
violated by the data.
```

Table A5.2 ANOVA table for ES with hole and material as factors.

Analysis of Variance for ES - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Hole	98.0213	2	49.0107	0.78	0.4630
B:Material	580.948	1	580.948	9.26	0.0036
INTERACTIONS					
AB	189.297	2	94.6487	1.51	0.2304
RESIDUAL	3388.28	54	62.746		
TOTAL (CORRECTED)	4256.55	59			

All F-ratios are based on the residual mean square error.

The StatAdvisor

The ANOVA table decomposes the variability of ES into contributions due to various factors. Since Type III sums of squares (the default) have been chosen, the contribution of each factor is measured having removed the effects of all other factors. The P-values test the statistical significance of each of the factors. Since one P-value is less than 0.05, this factor has a statistically significant effect on ES at the 95.0% confidence level.

Table A5.3 Means and confidence intervals for hole and material as factors.

Table of Least Squares Means for ES
with 95.0 Percent Confidence Intervals

Level		Count	Mean	Stnd. Error	Lower Limit	Upper Limit
GRAND MEAN		60	89.3683			
Hole						
4		20	88.515	1.77124	84.9639	92.0661
4.5		20	91.175	1.77124	87.6239	94.7261
5		20	88.415	1.77124	84.8639	91.9661
Material						
1		30	92.48	1.44621	89.5805	95.3795
2		30	86.2567	1.44621	83.3572	89.1562
Hole by Material						
4	1	10	93.61	2.50491	88.5879	98.6321
4	2	10	83.42	2.50491	78.3979	88.4421
4.5	1	10	94.63	2.50491	89.6079	99.6521
4.5	2	10	87.72	2.50491	82.6979	92.7421
5	1	10	89.2	2.50491	84.1779	94.2221
5	2	10	87.63	2.50491	82.6079	92.6521

The StatAdvisor

This table shows the mean ES for each level of the factors. It also shows the standard error of each mean, which is a measure of its sampling variability. The rightmost two columns show 95.0% confidence intervals for each of the means. You can display these means and intervals by selecting Means Plot from the list of Graphical Options.

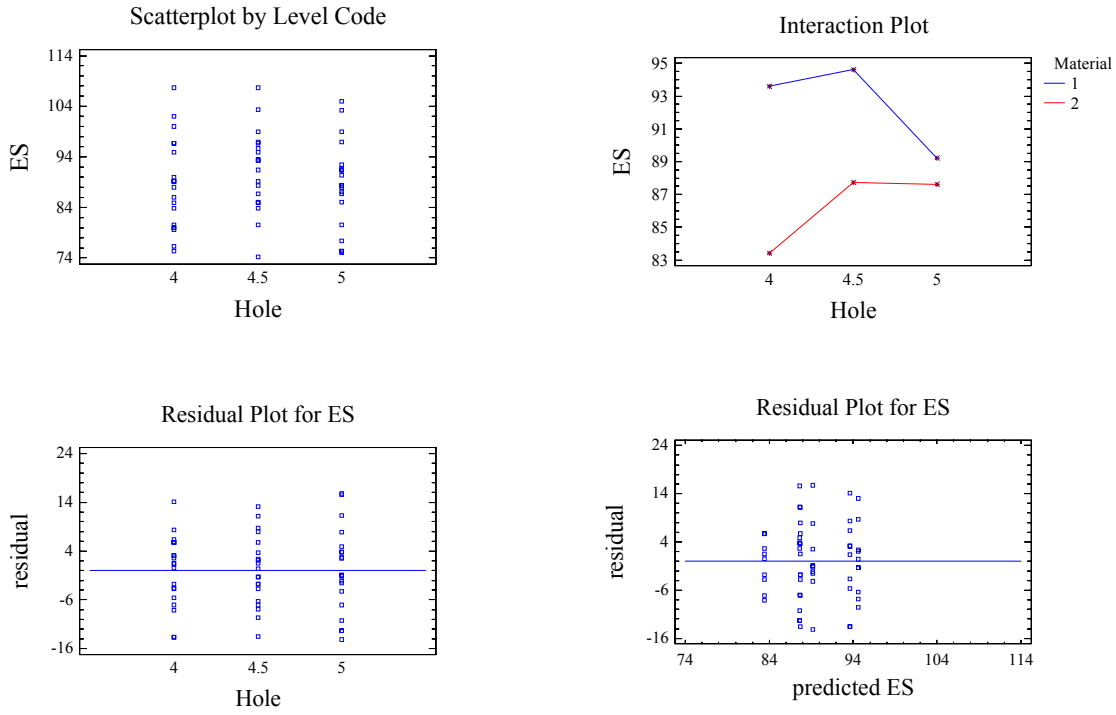


Figure A5.1 Several statistical plots for material and hole as factors.

Statistical analysis #2

```
Analysis Summary

Dependent variable: ES
Factors:
        Direction
        Hole
Selection variable: Material=1

Number of complete cases: 30


The StatAdvisor
---------------
   This procedure performs a multifactor analysis of variance for ES.
It constructs various tests and graphs to determine which factors have
a statistically significant effect on ES.  It also tests for
significant interactions amongst the factors, given sufficient data.
The F-tests in the ANOVA table will allow you to identify the
significant factors.  For each significant factor, the Multiple Range
Tests will tell you which means are significantly different from which
others.  The Means Plot and Interaction Plot will help you interpret
the significant effects.  The Residual Plots will help you judge
whether the assumptions underlying the analysis of variance are
violated by the data.
```

Table A5.4 ANOVA table for ES with direction and hole as factors for material 1.

Analysis of Variance for ES - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Direction	16.428	1	16.428	0.24	0.6314
B:Hole	166.578	2	83.289	1.20	0.3193
INTERACTIONS					
AB	65.702	2	32.851	0.47	0.6292
RESIDUAL	1669.04	24	69.5433		
TOTAL (CORRECTED)	1917.75	29			

All F-ratios are based on the residual mean square error.

The StatAdvisor

The ANOVA table decomposes the variability of ES into contributions due to various factors. Since Type III sums of squares (the default) have been chosen, the contribution of each factor is measured having removed the effects of all other factors. The P-values test the statistical significance of each of the factors. Since no P-values are less than 0.05, none of the factors or interactions have a statistically significant effect on ES at the 95.0% confidence level.

Table A5.5 Means and confidence intervals for material 1.

Table of Least Squares Means for ES
with 95.0 Percent Confidence Intervals

Level		Count	Mean	Stnd. Error	Lower Limit	Upper Limit
GRAND MEAN		30	92.48			
Direction						
1		15	93.22	2.15319	88.776	97.664
2		15	91.74	2.15319	87.296	96.184
Hole						
4		10	93.61	2.63711	88.1673	99.0527
4.5		10	94.63	2.63711	89.1873	100.073
5		10	89.2	2.63711	83.7573	94.6427
Direction by Hole						
1	4	5	93.0	3.72943	85.3028	100.697
1	4.5	5	94.66	3.72943	86.9628	102.357
1	5	5	92.0	3.72943	84.3028	99.6972
2	4	5	94.22	3.72943	86.5228	101.917
2	4.5	5	94.6	3.72943	86.9028	102.297
2	5	5	86.4	3.72943	78.7028	94.0972

The StatAdvisor

This table shows the mean ES for each level of the factors. It also shows the standard error of each mean, which is a measure of its sampling variability. The rightmost two columns show 95.0% confidence intervals for each of the means. You can display these means and intervals by selecting Means Plot from the list of Graphical Options.

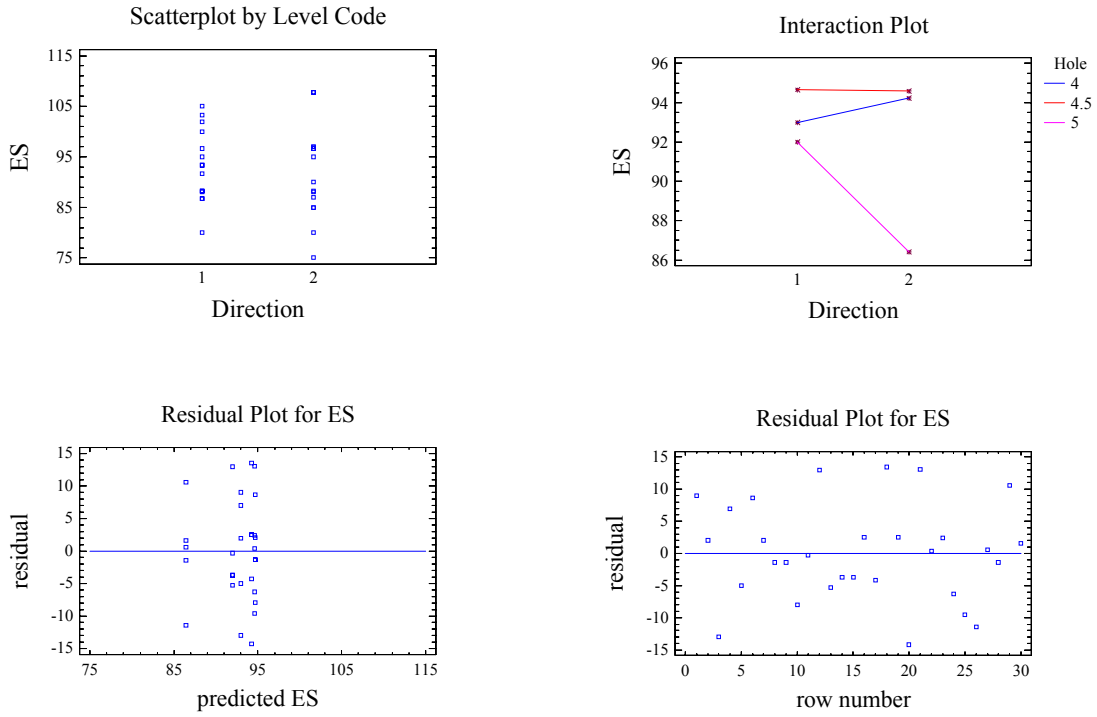


Figure A5.2 Several statistical plots for hole and direction as factors for material 1.

Statistical analysis #3

```
Analysis Summary

Dependent variable: ES
Factors:
        Direction
        Hole
Selection variable: material=2

Number of complete cases: 30


The StatAdvisor
---------------
   This procedure performs a multifactor analysis of variance for ES.
It constructs various tests and graphs to determine which factors have
a statistically significant effect on ES.  It also tests for
significant interactions amongst the factors, given sufficient data.
The F-tests in the ANOVA table will allow you to identify the
significant factors.  For each significant factor, the Multiple Range
Tests will tell you which means are significantly different from which
others.  The Means Plot and Interaction Plot will help you interpret
the significant effects.  The Residual Plots will help you judge
whether the assumptions underlying the analysis of variance are
violated by the data.
```

Table A5.6 ANOVA table for ES with direction and hole as factors for material 2.

Analysis of Variance for ES - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Direction	8.85633	1	8.85633	0.19	0.6677
B:Hole	120.741	2	60.3703	1.29	0.2942
INTERACTIONS					
AB	503.321	2	251.66	5.37	0.0118
RESIDUAL	1124.94	24	46.8723		
TOTAL (CORRECTED)	1757.85	29			

All F-ratios are based on the residual mean square error.

The StatAdvisor

The ANOVA table decomposes the variability of ES into contributions due to various factors. Since Type III sums of squares (the default) have been chosen, the contribution of each factor is measured having removed the effects of all other factors. The P-values test the statistical significance of each of the factors. Since one P-value is less than 0.05, this factor has a statistically significant effect on ES at the 95.0% confidence level.

Table A5.7 Means and confidence intervals for material 2.

Table of Least Squares Means for ES
with 95.0 Percent Confidence Intervals

Level		Count	Mean	Stnd. Error	Lower Limit	Upper Limit
GRAND MEAN		30	86.2567			
Direction						
3		15	86.8	1.76772	83.1516	90.4484
4		15	85.7133	1.76772	82.0649	89.3617
Hole						
4		10	83.42	2.165	78.9516	87.8884
4.5		10	87.72	2.165	83.2516	92.1884
5		10	87.63	2.165	83.1616	92.0984
Direction by Hole						
3	4	5	84.5	3.06178	78.1808	90.8192
3	4.5	5	83.0	3.06178	76.6808	89.3192
3	5	5	92.9	3.06178	86.5808	99.2192
4	4	5	82.34	3.06178	76.0208	88.6592
4	4.5	5	92.44	3.06178	86.1208	98.7592
4	5	5	82.36	3.06178	76.0408	88.6792

The StatAdvisor

This table shows the mean ES for each level of the factors. It also shows the standard error of each mean, which is a measure of its sampling variability. The rightmost two columns show 95.0% confidence intervals for each of the means. You can display these means and intervals by selecting Means Plot from the list of Graphical Options.

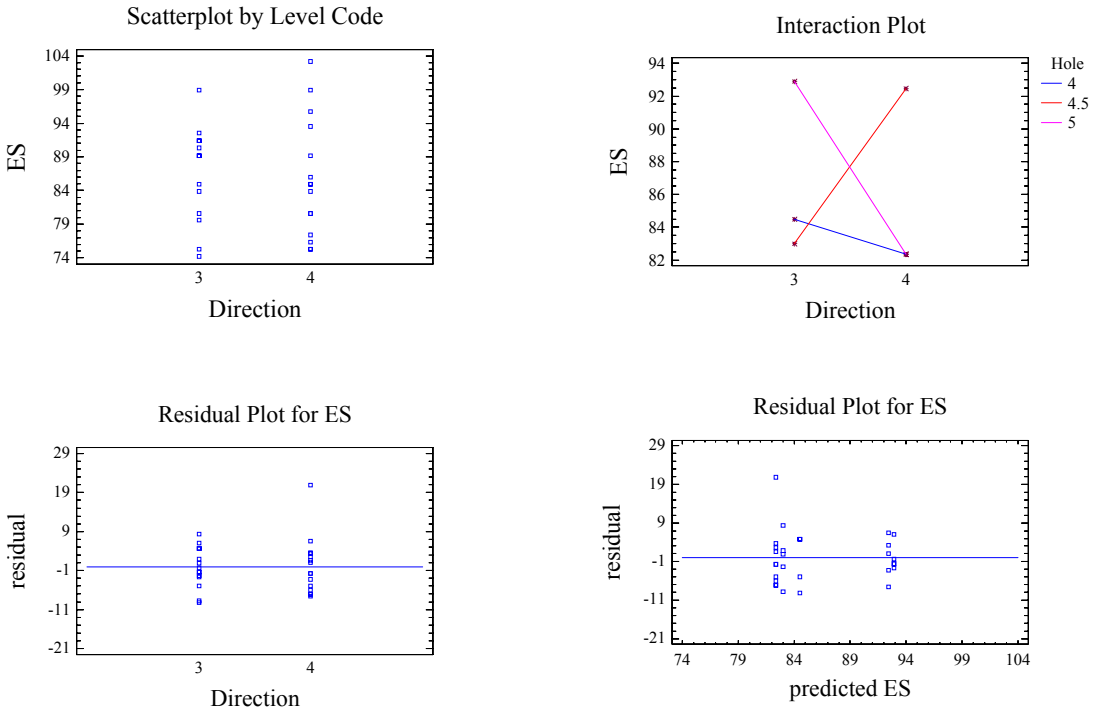


Figure A5.3 Several statistical plots for hole and direction as factors for material 2.