Dowel type connections in laminated bamboo with multiple slotted-in steel plates

Annex B – Testing procedure

Auteur, studentnr:	JJB Debije, 4309995
Datum:	06-02-2017
Bedrijf:	Technische Universiteit Delft
Adres:	Stevinweg 1 2628 CN Delft
Afdeling:	Faculteit Civiele Techniek en Geowetenschappen
Opleiding:	Civiele Techniek
Hoofdprofiel:	Structural Engineering
Uitstroomprofiel:	Staal en houtconstructie
Begeleiders:	prof.dr.ir. J.W.G. Van de Kuilen ir. P.A. de Vries drs. W.F. Gard drs. W.N.J. Ursem ing. A. van der Vegte

Table of Contents

1 Introduction

In light of the research to the resistance of dowel type connections in laminated bamboo using multiple slotted-in steel plates it is necessary to perform tests. to conduct tests on realistic connection designs a literature study is needed in which the design codes will be analysed and the design formulas and their theoretical backgrounds will be studied. After that, the expected resistance of a connection can be determined. To verify whether the assumption that timber design codes can also be applied on laminated bamboo is correct and the expected resistance of a connection is in line with the actual resistance lab tests have to be conducted.
To correctly determine the actual resistance of a connection test pieces have to be made that resemble an actual connection and tests have to be conducted according to the requirements prescribed in applicable testing norms. This annex gives a detailed description of the consulted norms, the resulting testing procedures that will be adopted during this research and the requirements that the test pieces have to meet.

1.1 Goal

To get adequate test results a literature study to the necessary testing procedures is required. This leads to the following question:

Which testing method is necessary to determine the strength of a dowel type connection with slotted-in steel plates in laminated bamboo?

1.2 Plan of action

The European standard for testing procedures for nails, screws, dowels and bolts (NEN-EN 1380:2009) will be consulted. This testing standard gives testing procedures for the determination of the capacity and deformation of dowel type connections in timber materials loaded in shear.
The methods specified in this norm asses connections with members of timber (solid timber or glued laminated timber), wood-based products or metal plates (but not punched metal plate fasteners) (NEN-EN 1380:2009).

For the application of this standard a number of documents are needed. These documents are listed below and, whenever necessary, will have to be studied as well. It has to be noted that for dated references, only the edition cited applies. For undated references, the latest editions of the referenced document (including the appropriate amendments) applies.

From (NEN-EN 1380:2009) is cited:

Voor de in deze norm vermelde normatieve verwijzingen bestaan in Nederland de volgende equivalenten:

Cited norm	*Dutch norm*	*Dutch title*
EN 322	*NEN-EN 322*	*Houtachtige plaatmaterialen - Bepaling van het vochtgehalte*
EN 323	*NEN-EN 323*	*Houtachtige plaatmaterialen - Bepaling van de volumieke massa*
EN 13183-2	*NEN-EN 13183-2*	*Vochtgehalte van een stuk gezaagd hout - Deel 2: Benadering met behulp van een elektrische vochtmeter*
EN 14080	*NEN-EN 14080*	*Houtconstructies - Gelijmd gelamineerd hout - Eisen*

EN 14358	*NEN-EN 14358*	*Houtconstructies - Berekening van de karakteristieke 5-percentielwaarden en aanvaardingscriteria voor de acceptatie van een steekproef*
EN 14592	*NEN-EN 14592*	*Houtconstructies - Stiftvormige verbindingsmiddelen - Eisen*
EN 26891:1991	*NEN-ISO 6891:1991*	*Houtconstructies - Verbindingen vervaardigd met mechanische verbindingsmiddelen - Algemene uitgangspunten bij de bepaling van de sterkte en vervorming*
EN 28970	*NEN-ISO 8970*	*Houtconstructies - Beproeving van Verbindingen vervaardigd met mechanische verbindingsmiddelen - Eisen aan de volumieke massa van hout*
ISO 3131	*- -*	

1.3 Reading guide

This report describes the testing procedure used for this research. After this short introduction 2 - **Requirements** will give the requirements with regard to the material to be tested, the fasteners and the fabrication of the test pieces. Next, 3 - **Test procedure** will describe the procedure that will be followed during testing. This includes the application of the load, the registration of the deformations and adaptions that may be needed during testing. After that, 4 - **Processing of the results** will give formulas for the processing of the test results.

2 Requirements

This chapter gives a description of the needed tools and requirements for determining the resistance of a connection. The required tools are the laminated bamboo, the fasteners and the testing device.

2.1 Laminated bamboo

In paragraph 5.2 of (NEN-EN 1380:2009) requirements are stated with respect to wood-based products. The requirements state that the products used for the individual members of the test pieces shall be representative of the class/range of product to which they belong. One unique grade shall be used and for each test piece, the individual members shall be selected from separate pieces of material (NEN-EN 1380:2009).
For glued laminated timber (under the assumption that laminated bamboo will have similar behaviour) paragraph 5.1 (NEN-EN 1380:2009) states the timber used for tests shall satisfy the requirements set by (NEN-EN 14080, 2005) and (NEN-EN 14081-1, 2012).

(NEN-EN 14080, 2005)	Gives requirements for glued laminated timber
(NEN-EN 14081-1, 2012)	Gives requirements for timber with rectangular cross sections

The testing material will be selected according to (NEN-ISO 8970, 2010). The primary requirements stated by this norm concern defects in the timber and the wood density. In order to minimise the effect of defects of the timber during testing this norm states that every equivalent test piece should consist of individual parts (note that this concurs with paragraph 5.2 of (NEN-EN 1380:2009)). All individual parts are required to have no large deviations in size as this could lead to unwanted failure modes. An example of this would be a test piece that fails at a location outside of the connection to be tested.
Also of importance is the density of the selected parts. The density of the test pieces has to be similar to the density of the material in which the connection will be made in practice (otherwise the capacity of the tested connection will have a large deviation to the capacity of a connection in a structural application). The following restriction is given with respect to the density of the chosen test pieces:

$$0{,}95\rho_m \leq \rho_{m,sel} \leq 1{,}05\rho_m$$

In which:

ρ_m	The average density of the material on which the test results need to apply
$\rho_{m,sel}$	The average density of the selected test pieces

2.2 Fasteners

In this research only dowel type fasteners will be used. The requirements with respect to dowel type fasteners are given in (NEN-EN 14592+A1, 2012).
The nominal diameter of the used dowels shall be within 2.5% of the declared value and the characteristic yield moment $M_{y,k}$ can be calculated from relevant equations given in (NEN-EN 1995-1-1+C1+A1:2011). For this research however, the theoretical yield moment of the dowels will be determined according to formulas determined by Meyer and given in (Jorissen, A., Leijten, A., 2005).

2.3 Conditioning

The test pieces shall be manufactured with the timber (or wood-based products) at an equilibrium moisture content that corresponds to (20 ± 2) °C and (85 ± 5) % relative humidity (NEN-EN 1380:2009). Bringing the timber up to a certain moisture content and temperature is called conditioning. Conditioning of timber is done in a climate chamber. Here the moisture content of the wood is artificially altered by adapting the relative humidity and temperature of the chamber (潘景龙, 陈志勇, 陈松来, 樊承谋 &, 2009年8月). The material is conditioned when it attains constant mass. Constant mass is considered to be attained when the

results of two successive weightings, carried out at intervals of 6h, do not differ by more than 0.1% of the mass of the material (NEN-EN 1380:2009). For comparable test result the test pieces should be, at the start of each test, of similar moisture content. After manufacturing, but prior to testing, the test pieces shall be stored for at least one week at (20 ± 2) °C and (65 ± 5) % relative humidity.

2.4 Fabrication of test pieces

In this research no special requirements will be made with regard to the test pieces. In this case (NEN-EN 1380:2009) states that the test pieces shall be fabricated with the fasteners perpendicular to the member surface and the insertion of the fasteners shall follow normal preparation (e.g. pre-boring). In principle the connection will be symmetrical with respect to the direction of the load.

3 Test procedure

The testing procedure shall be carried out in accordance with (NEN-ISO 6891, 1991). The loading procedure is given in chapter 8 of that norm.

3.1 Estimation of load

The estimated maximum load, F_{est}, for the joint to be tested shall, prior to testing, be determined, and should, in between tests, be adjusted if necessary.

3.2 Application of load

During testing the load shall be applied up to 0.4 F_{est} where it will be maintained for 30 seconds. The load shall then be reduced to 0.1 F_{est} and maintained for 30 seconds. Thereafter the load shall be increased until the ultimate load or slip of 15mm is reached. Note that the requirement of a 30 second constant load at 0.1 and 0.4 F_{est} is to permit adequate time for the loading to be reversed, it is not intended to provide information on the creep behaviour of the material.
Below a loading of 0.7 F_{est} a constant rate of load shall be used corresponding to a value of 0.2 F_{est} ± 25% per minute. Up until this force value, the test will thus be load controlled. Above a loading of 0.7 F_{est} a constant rate of slip shall be used such that the ultimate load or slip of 15mm is reached in 3 to 5 minutes. This stage of testing will thus be deformation controlled. The total testing time will be about 10 to 15 minutes.
The load reached before or at a slip of 15mm shall be recorded as the maximum load, F_{max}, for each specimen. The loading procedure is visualized in Figure 1 – Loading procedure.

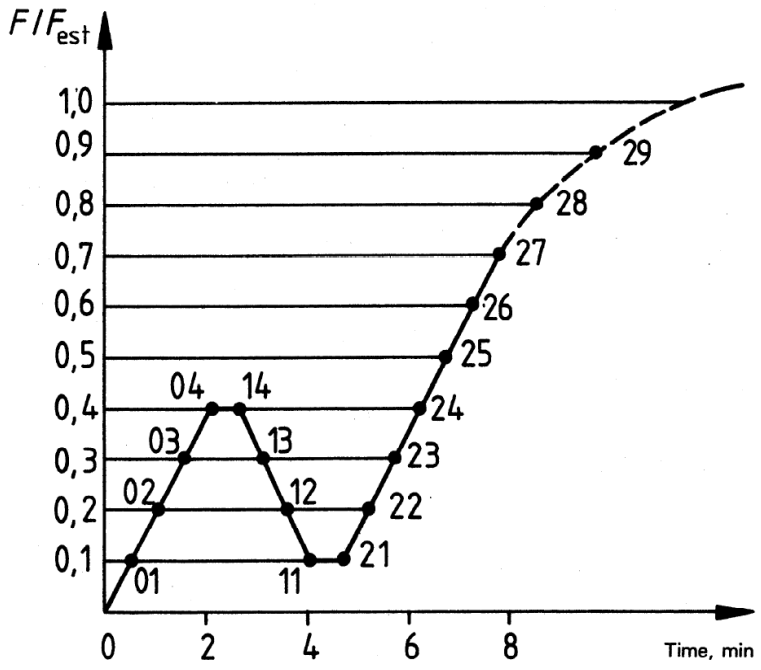

Figure 1 – Loading procedure

3.3 Determination of displacements

The relative displacement of the test pieces shall be measured according to (NEN-ISO 6891, 1991). This norm states that the displacement shall be measured with an accuracy of 1%. The deformation at intervals shown in Figure 2 – Idealized load-deformation curve shall be stated. When no exact load-deformation curve can be made (e.g. due to technical limitations) the deformation shall be measured at intervals of 0.1 F_{est}.

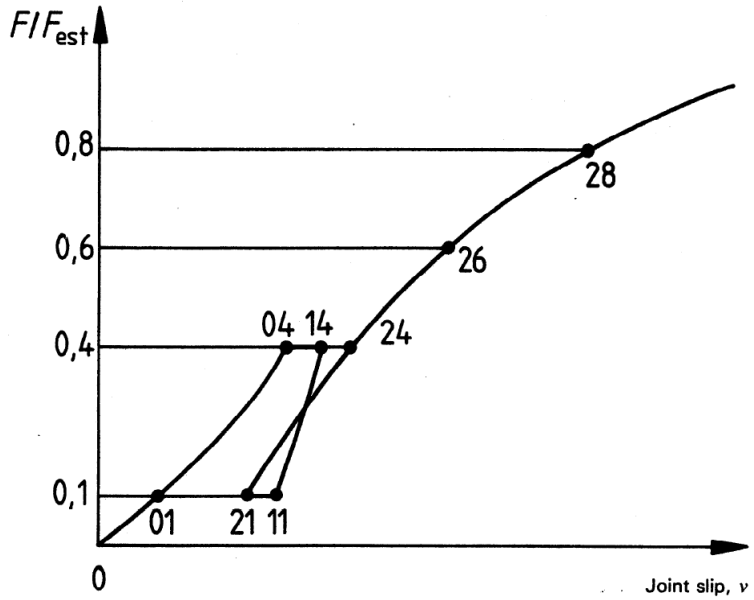

Figure 2 – Idealized load-deformation curve

By means of these measuring points the stiffness of the connection k_{ser} can be determined. According to EN 26891, the slips at points 01 and 04 must be taken to determine the actual stiffness of the joint (Sandhaas, 2012). The purpose of the initial loop (points 01 to 11) is to settle the test specimen before loading it up to failure.

In Eurocode 5 an empirical equation is given to determine a value for k_{ser} per shear plane per fastener. This formula uses the mean density of the timber and the dowel diameter as variables.

$$k_{ser} = \rho_{mean}^{1.5} * \frac{d}{23} \quad (1)$$

It is defined that the obtained value for k_{ser} should be multiplied by two for steel-to-timber joints (Sandhaas, 2012).

3.4 Adjustment

If, during the execution of the tests, the mean value of the maximum load, F_{max}, of the tests already carried out deviates by more than 20% from the estimated load, F_{est}, (NEN-ISO 6891, 1991) states that F_{est} should be adjusted correspondingly for subsequent tests. The values of F_{max} that were already determined may be accepted without adjustment as part of the final results.

4 Processing of the results

For processing of the results (NEN-EN 1380:2009) refers to (NEN-EN 14358:2007). This document describes the method in which the mean value, the standard deviation and the 5-percentile value of a series of tests can be deduced from the test results.

4.1 Calculation of values from test results

The characteristic value of a material parameter will be determined at a confidence level of α = 75%. In this, the confidence level is defined as the probability of which the characteristic value is greater than the estimator on the characteristic value (NEN-EN 14358:2007). A confidence level of 75% corresponds to the value recommended in (NEN-EN 1990+A1+A1/C2, 2011).

The characteristic value m_k of a parameter, modelled as a stochastic variable, is defined as the p-percentile in the distribution function of m, corresponding to an infinitely large number of specimens.
The characteristic value m_k will be taken as the 5-percentile value. So p = 5%.

For the determination of the values it is assumed that n tests values are available and that these values originate from a homogeneous population. The values are assumed to be logarithmically normally distributed and independent. They are denoted m_1, m_2, m_3…m_n.
The mean value $\bar{y}$ and the standard deviation s_y for a stochastic variable $y = \ln(m)$ are determined as:

$$\bar{\bar{y}} = \frac{1}{n}\sum_{i=1}^{n} \ln(m_i) \tag{2}$$

$$s_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (\ln(m_i) - \bar{y})^2} \tag{3}$$

With these values the characteristic value m_k can be determined with the following.

$$m_k = exp\left(\bar{y} - k_s s_y\right) = e^{(\bar{y} - k_s s_y)} \tag{4}$$

The value for k_s can be determined with the formulas given in paragraph 4.6 of (NEN-EN 14358:2007) or taken from table 1 in the same chapter. The table with values for k_s is also given in Table 1 - Factor k_s values. In the formula for m_k the standard deviation has to be taken as no less than 5%.

Number of test specimens	Factor
n	k_s
3	3,15
5	2,46
10	2,10
15	1,99
20	1,93
30	1,87
50	1,81
100	1,76
500	1,71
∞	1,65

Table 1 - Factor k_s values **(NEN-EN 14358:2007)**

4.2 Acceptance criteria for a sample

If a variable control method is applied to control the determined material parameters, this control method shall be composed with a significance of α = 75%. Here the significance level α is defined as the probability of not accepting a delivery not having the required characteristic value (NEN-EN 14358:2007).
Assumed is again that n test values are available and that they are derived from a homogeneous population. The test values are assumed to be independent and logarithmically normally distributed. They are denoted as m_1, m_2, m_3…m_n.
Again the mean value $\bar{y}$ and the standard deviation s_y for a stochastic variable $y = \ln(m)$ are determined as:

$$\bar{\bar{y}} = \frac{1}{n}\sum_{i=1}^{n} \ln(m_i) \tag{5}$$

$$s_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (\ln(m_i) - \bar{y})^2} \tag{6}$$

The control shall be performed by showing that, for the random sample with n test specimens:

$$exp(\bar{y} - k(n)s_y) > m_k \tag{7}$$

The factor $k(n)$ can be determined from formulas in paragraph 5.6 of (NEN-EN 14358:2007) or can be taken from table 2 in the same paragraph. This table is also shown in Table 2 – Factor k(n) values below.

Number of test specimens	Factor
n	*k(n)*
3	2.03
5	1.95
10	1.86
15	1.82
20	1.8
30	1.77
50	1.74
100	1.69
500	1.67
∞	1.65

Table 2 – Factor k(n) values **(NEN-EN 14358:2007)**

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