Load-Carrying Capacity of Timber - Wood Fibre Insulation Board - Joints with Dowel Type Fasteners

G. Gebhardt, H.J. Blaß

Lehrstuhl für Ingenieurholzbau und Baukonstruktionen

Universität Karlsruhe, Germany

1 Introduction

So far wood fibre insulation boards (WFIB) are used as thermal and acoustic insulation in timber constructions. As wood-based panels, WFIB are suited for the transfer of loads caused by wind and earthquakes in timber frame constructions. Until present this task has been undertaken by plywood, particle boards and OSB. This new field of application of WFIB has been analysed in a research project at the Universität Karlsruhe.

In this paper a proposal is given to calculate the load-carrying capacity of timber-WFIB-joints with dowel type fasteners. For this purpose the load-carrying capacity of joints in timber and WFIB may be determined according to Johansen's yield theory and an extension of this theory. Tests were carried out to estimate the embedding strength of nails in WFIB and the crown pull-through resistance of staples in WFIB. The test results verified the calculation model and the stiffness properties of timber-WFIB-joints were evaluated.

2 Characteristics of WFIB

WFIB can be fabricated in two different manufacturing processes: In both the wood chips are thermo-mechanically pulped.

In the wet process the wood fibres are mixed with water and further aggregate into a suspension. Afterwards the boards are formed and dried. For the bonding of the wood fibres only the wood´s own cohesiveness (predominantly lignin resin) is used. Due to the high use of energy for the drying process, boards with higher thicknesses are manufactured by gluing raw single-layer boards to multilayer boards. At this raw single-layer boards with different densities may be combined.

In the dry process the wood fibres are dried and sprayed with PUR resin. Afterwards the boards are formed and the resin hardens. In this process boards with thicknesses up to 240 mm may be manufactured as single-ply boards.

WFIB may be used in different parts of buildings. In roofs, rain-tight sub plates (RTSP) are fixed as sub decking. A further insulation is possible as above-rafter or interim-rafter insulation with universal insulation boards (UIB). In walls, plaster baseboards (PB) may be used in composite thermal insulation systems.

11 different WFIB of three different manufacturers were selected to analyse the characteristics needed for the use as sheathing of shear walls. The nominal density range was 110 kg/m^3 up to 270 kg/m^3. The densities and moisture contents of the tested boards were determined. The measured moisture content range was 7.3% to 10.3%. Characteristic densities are proposed for the different types of WFIB and given in table 1.

Table 1 Proposed characteristic densities of WFIB

WFIB type	Characteristic density in kg/m^3
Rain-tight sub plate (RTSB)	200
Plaster baseboard (PB)	150
Universal insulation board (UIB)	150 100

3 Embedding strength

Several dowel type fasteners may be used for the attachment of WFIB on the studs or rafters. In roofs, nails are commonly driven in through the counter battens. In walls, staples are commonly used. An alternative for staples are special screws.

For the calculation of timber-WFIB-connections according to Johansen's yield theory [1] the embedding strength of WFIB is required. Apart from the embedding strengths of the connected parts, the load-carrying capacity depends on the geometry of the connection (thicknesses of the connected parts and diameter of the fastener) and the yield moment of the fastener.

Tests with nails were carried out according to EN 383 [2] to determine the embedding strength of mechanical fasteners in WFIB. In preliminary tests an influence of the angle between force direction and production direction had not been identified. 608 embedment tests with five diameters ($d = 3.1/3.4/3.8/4.6/5.0$ mm) were performed. The embedding strength correlates with the measured density of the test specimen. In figure 1 the embedding strength is plotted vs. the density. The correlation coefficient is $r = 0.880$.

There is a smaller correlation between the embedding strength and the thickness of the boards. A negative correlation exists between the embedding strength and the diameter of the fastener. Due to a correlation between the density and the thickness and the higher correlation between embedding strength and thickness, the parameters diameter and density are considered in the calculation model for the embedding strength. By means of a multiple regression analysis, equation (1) could be derived to estimate the embedding strength f_h of WFIB.

$$f_{\mathrm{h}} = 18.5 \cdot 10^{-5} \cdot \rho^{2.04} \cdot d^{-0.74} \quad \text{in N/mm}^2 \qquad (1)$$

where ρ is the density of the WFIB in kg/m^3 and d the diameter of the fastener in mm

In figure 2 the tested embedding strength values are plotted vs. the calculated embedding strength values. The correlation coefficient is $r = 0.916$. The slope of the regression straight is $m = 1.02$ and the y-intercept is $b = -0.090$.

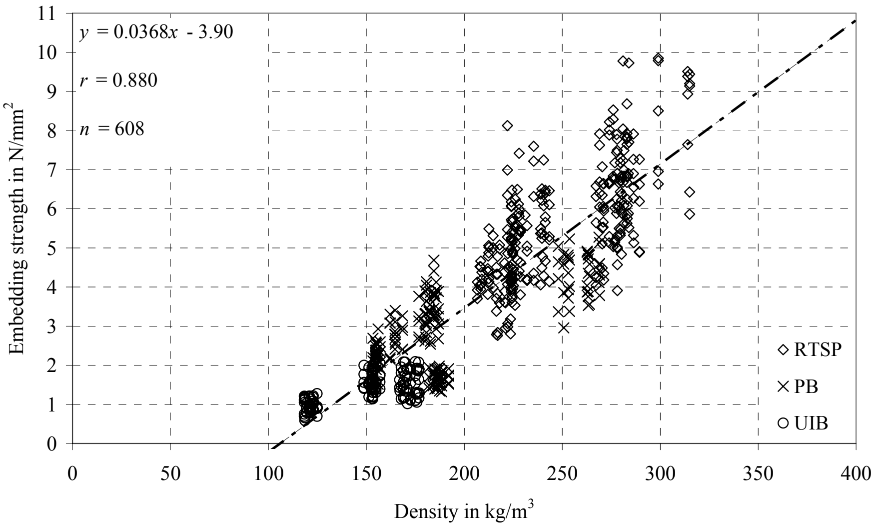

Figure 1 Embedding strength vs. density

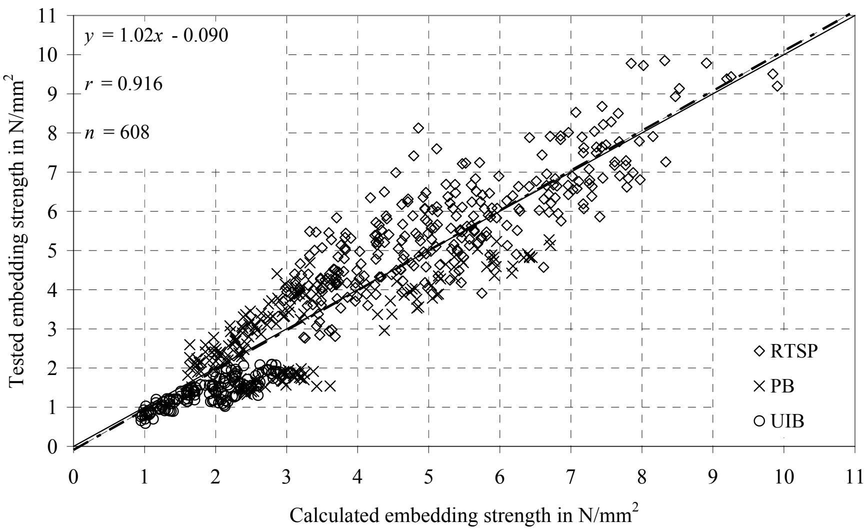

Figure 2 Tested embedding strength vs. calculated embedding strength

Characteristic values of the embedding strength may be calculated considering the proposed characteristic densities for the different types of WFIB (equation (2)).

$$
\begin{array}{lll}
\text{RTSP} & \rho_k = 200\ \text{kg/m}^3 & f_{h,k} = 8.88 \cdot d^{-0.75} \\
\text{PB} & \rho_k = 150\ \text{kg/m}^3 & f_{h,k} = 4.25 \cdot d^{-0.75} \\
\text{UIB} & \rho_k = 150\ \text{kg/m}^3 & f_{h,k} = 3.53 \cdot d^{-0.75} \\
\text{UIB} & \rho_k = 100\ \text{kg/m}^3 & f_{h,k} = 1.57 \cdot d^{-0.75}
\end{array}
\quad \text{in N/mm}^2 \qquad (2)
$$

4 Crown pull-through resistance

The load-carrying capacity may be calculated according to Johansen's yield theory considering the geometry of the connection (thicknesses of the connected parts and diameter of the fastener), the embedding strengths of the members (for WFIB presented in chapter 3) and the yield moment of the fastener. The load-carrying capacity may be increased if the fastener can be loaded axially apart from loading laterally. The increasing value depends on the withdrawal strength of the fastener in the first part and the head/crown pull-through resistance in the second part. In order to calculate the rope effect the crown pull-through resistance of staples in WFIB was examined.

According to EN 1383 [4] about 100 tests with RTSP and PB were carried out. For each of the 15 different WFIB at least four tests were performed. The displacement at maximum load correlates with the thickness of the WFIB. In figure 3 the displacement at maximum load is plotted vs. the thickness of the WFIB. The correlation coefficient is $r = 0.893$. The slope of the regression straight is $m = 0.500$ and the y-intercept is $b = 0.115$.

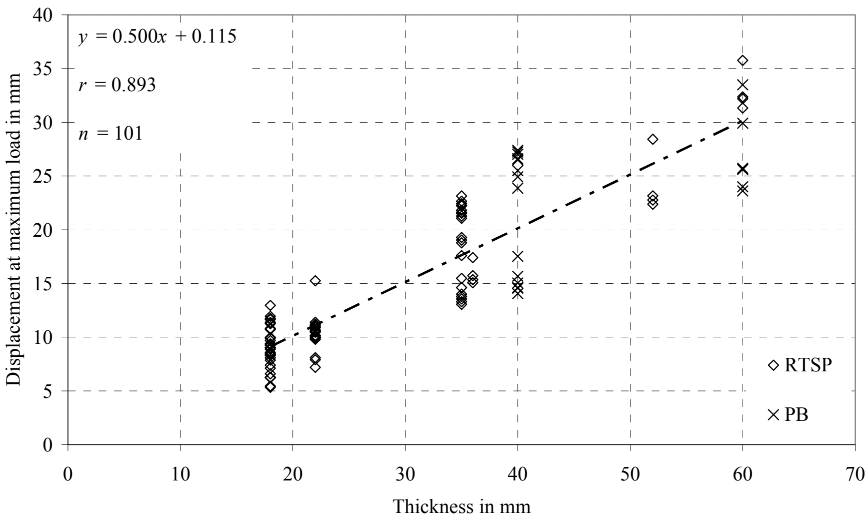

Figure 3 Displacement at maximum load vs. thickness

By means of a multiple regression analysis, equation (3) could be derived to estimate the crown pull-through resistance $R_{ax,2}$ of staples in WFIB.

$$R_{ax,2} = 0.040 \cdot \rho^{1.17} \cdot t^{0.95} \quad \text{in N} \qquad (3)$$

where ρ is the density of the WFIB in kg/m^3 and t the thickness of the WFIB in mm

In figure 4 the tested crown pull-through resistance values are plotted vs. the calculated crown pull-through resistance values. The correlation coefficient is $r = 0.814$. The slope of the regression straight is $m = 1.01$ and the y-intercept is $b = -0.01$. Test results of one RTSP with relative high thickness and density could not be explained by the regression model but test values are greater than calculated values. To explain thicker WFIB with higher densities further tests are needed.

Characteristic values of the crown pull-through resistance may be calculated considering the proposed characteristic densities for the different types of WFIB (equation (4)).

$$R_{\text{ax,2,k}} = 0.032 \cdot \rho_{\text{k}}^{1.17} \cdot t^{0.95} \qquad \text{in N} \qquad (4)$$

where ρ_{k} is the characteristic density of WFIB in kg/m³

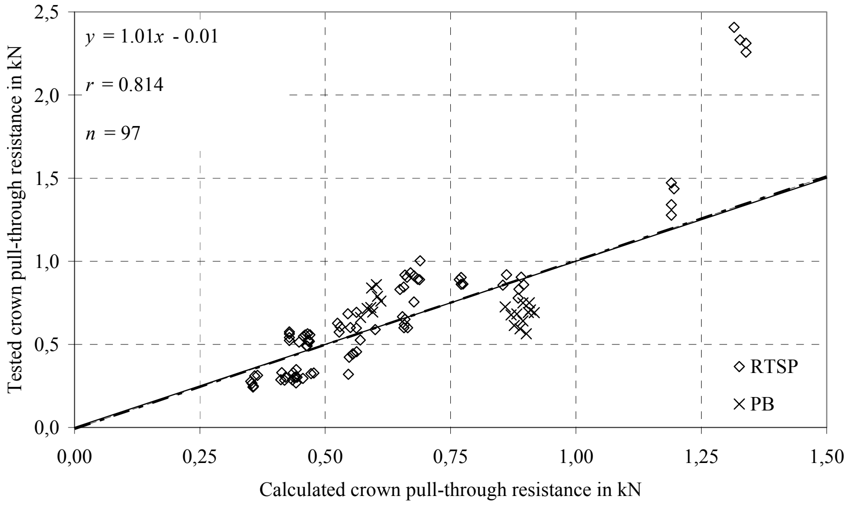

Figure 4 Tested crown pull-through resistance vs. calculated crown pull-through resistance

5 Calculation model for Timber - Wood Fibre Insulation Board – Joints

The load-carrying capacity may be calculated according to Johansen's yield theory considering the different failure mechanisms. If the fastener is driven in through a counter batten, in failure modes 1a and 2b an extension of the existing equations is necessary. In failure modes 1a and 2b the embedding strength in the counter batten is reached and this effect increases the load-carrying capacity. The load path is from the stud into the sheathing board. There is no resulting load in the counter batten. Force and moment equilibrium, considering the existing embedding strength distribution and the yield moment, deliver equation (5) for extended failure mode 1a and equation (6) for extended failure mode 2b. The failure modes activating the influence of the counter batten are shown in figure 5.

$$R = \frac{f_{\text{h},1} \cdot t_1 \cdot d}{1+\beta_2}\left[\sqrt{\beta_2 + 2\beta_2^2\left[1+\left(\frac{t_2}{t_1}\right)+\left(\frac{t_2}{t_1}\right)^2\right]+\beta_2^3\left(\frac{t_2}{t_1}\right)^2+\beta_2\cdot\beta_3\left(1+\beta_2\right)\left(\frac{t_3}{t_1}\right)^2}-\beta_2\left(1+\frac{t_2}{t_1}\right)\right] \qquad (5)$$

$$R = \frac{f_{\mathrm{h},1} \cdot t_2 \cdot d}{1+2\beta_2}\left[\sqrt{2\beta_2^2\left(1+\beta_2\right)+\frac{4\beta_2\left(1+2\beta_2\right)M_y}{f_{h1} \cdot d \cdot t_2^2}+\beta_2 \cdot \beta_3\left(1+2\beta_2\right)\left(\frac{t_3}{t_2}\right)^2}-\beta_2\right] \tag{6}$$

where t_3 is the thickness of the counter batten and $f_{\mathrm{h},3}$ is the embedding strength of the counter batten

and $\beta_2 = \frac{f_{\mathrm{h},2}}{f_{\mathrm{h},1}}$, $\beta_3 = \frac{f_{\mathrm{h},3}}{f_{\mathrm{h},1}}$

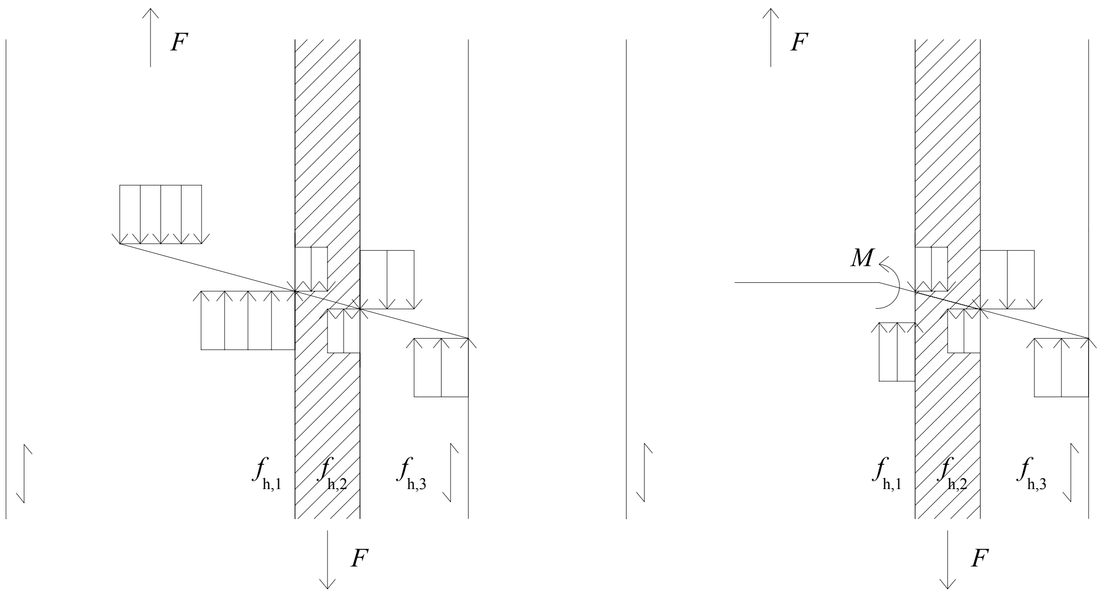

Figure 5 Extended failure modes 1a and 2b according to Johansen's yield theory

6 Tests with Timber-WFIB-Joints

In order to verify the results obtained in the tests presented in chapter 3 and 4 and to examine the stiffness of joints, further tests were performed. Nails and staples were used as fasteners. Staples may be driven directly into the WFIB or through the counter batten like nails. In figure 6 the test specimens for the tests with nails and staples are shown. The relative deformations between WFIB and stud were measured at each of the four fasteners. The tests were carried out according to EN 26891 [5], firstly force-controlled and afterwards displacement-controlled. The maximum load was reached at a displacement of 15 mm. The analysis of the joint stiffness requires linear load-displacement behaviour up to 40% of the maximum load. In the tests non-linear load-displacement behaviour was observed. Due to this the analysis of the stiffness was calculated for a constant displacement of 0.3 mm.

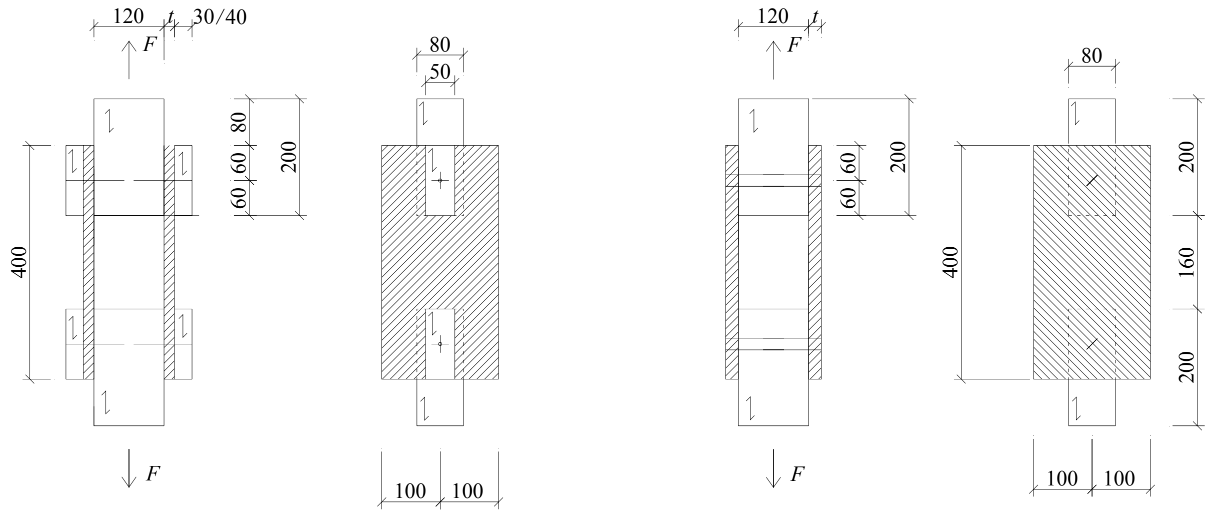

Figure 6 Test specimens for tests with nails and staples

6.1 Tests with nails

27 tests with nails and RTSP were performed. RTSP of three manufacturers in three thicknesses respectively and two nail diameters were used. The load-carrying capacity may be obtained according to Johansen's yield theory considering the results in the presented tests and the extended calculation model. The yield moments of the nails were evaluated according to EN 409 [6]. The embedding strength of WFIB was determined in previous tests (see chapter 3) and the embedding strength of the timber was calculated according to DIN 1052 [7] considering the evaluated densities. Although failure mode 1b was authoritative, failure mode 3 was observed in the tests. This may be explained by friction between the joint members. The withdrawal resistance and the pull-through resistance were calculated according to DIN 1052. In figure 7 the tested load-carrying capacity is plotted vs. the calculated load-carrying capacity.

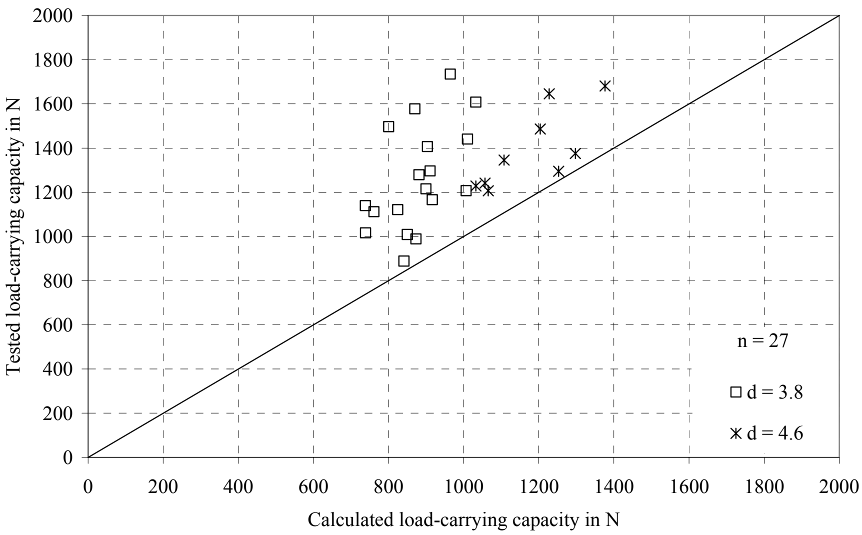

Figure 7 Tested load-carrying capacity vs. calculated load-carrying capacity for nails

6.2 Tests with staples driven in through counter battens

27 tests with staples and RTSP were performed. RTSP of three manufacturers in three thicknesses respectively were used. The load-carrying capacity may be obtained according to Johansen's yield theory considering the results in the presented tests and the extended calculation model. The yield moments of the staples were evaluated according to EN 409 [6]. The embedding strength of staples in WFIB was calculated according to equation (1) assuming the validity for diameters smaller than the tested ones and the embedding strength of the timber according to DIN 1052 [7] considering the evaluated densities. The withdrawal resistance was calculated according to DIN 1052. In figure 8 the tested load-carrying capacity is plotted vs. the calculated load-carrying capacity.

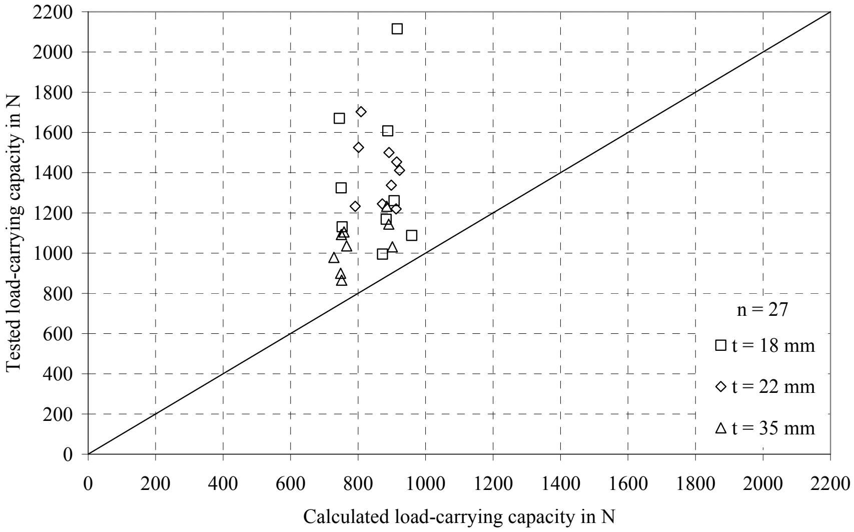

Figure 8 Tested load-carrying capacity vs. calculated load-carrying capacity for staples driven in through counter battens

6.3 Tests with staples driven in directly

36 tests with staples and RTSP/PB were performed. RTSP and PB of three manufacturers were used. The load-carrying capacity may be obtained according to Johansen's yield theory considering the results in the presented tests. The yield moments of the staples were evaluated according to EN 409 [6]. The embedding strength of staples in WFIB was calculated according to equation (1) assuming the validity for diameters smaller than the tested ones and the embedding strength of timber according to DIN 1052 [7] considering the evaluated densities. The pull-through resistance was determined in previous tests (see chapter 4). In figure 9 the tested load-carrying capacity is plotted vs. the calculated load-carrying capacity.

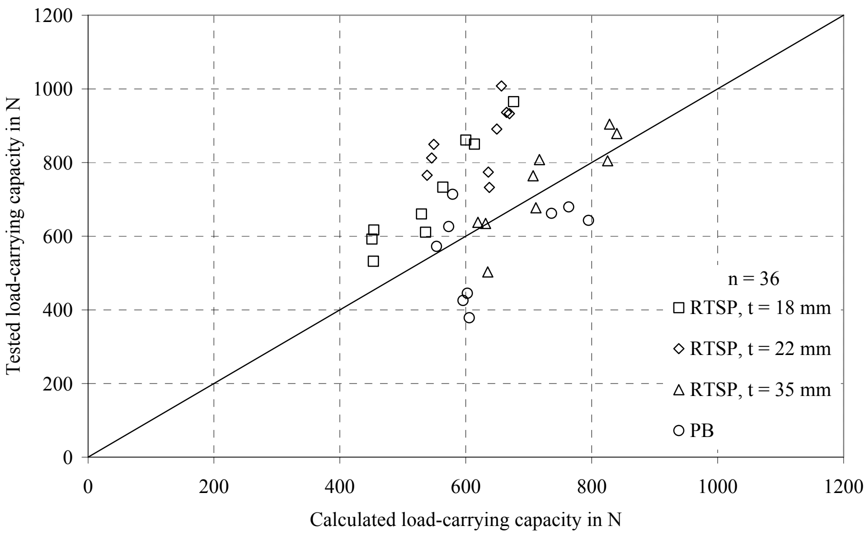

Figure 9 Tested load-carrying capacity vs. calculated load-carrying capacity for staples driven in directly

6.4 Stiffness of timber-WFIB-joints

By means of a multiple regression analysis, equation (7) could be derived to calculate the stiffness of a timber-WFIB-joint. In figure 10 the tested stiffness is plotted vs. the calculated stiffness. The correlation coefficient is r = 0.898. The slope of the regression straight is m = 1.00 and the y-intercept is b = -0.404.

$$K_{\text{ser}} = 1.25 \cdot \rho_{\text{WFIB}}^{0.80} \cdot \rho^{0.30} \cdot t^{-0.32} \cdot d^{1.29} \quad \text{in N/mm} \qquad (7)$$

where ρ_{WFIB} is the density of the WFIB in kg/m^3, ρ is the density of the timber in kg/m^3, t is the thickness of the WFIB in mm and d is the diameter of the fastener in mm

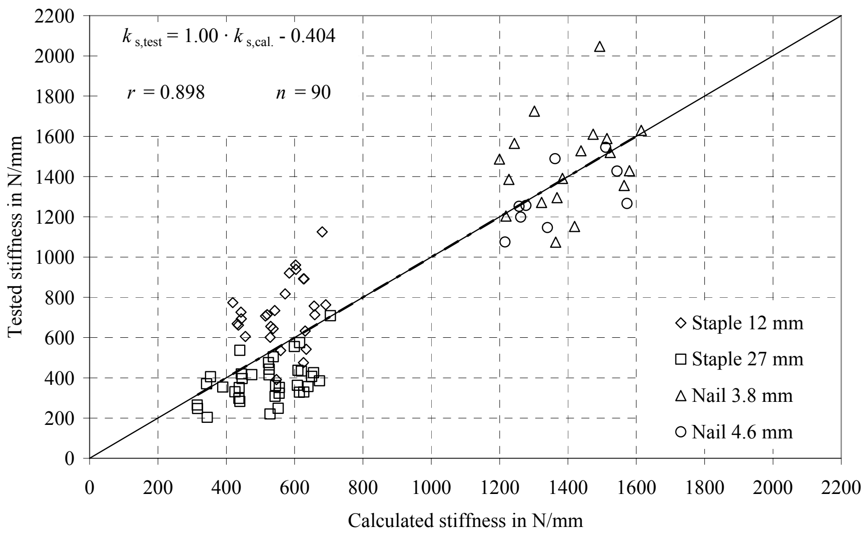

Figure 10 Tested stiffness vs. calculated stiffness

7 Conclusions

The embedding strength of nails in WFIB was tested. As result of a multiple regression analysis, the embedding strength may be calculated considering the density of the WFIB and the diameter of the fastener. In further tests, the pull-through resistance of staples in WFIB was examined. The pull-through resistance depends on the thickness and the density of the WFIB. To consider the influence of a counter batten in the failure modes according to Johansen's yield theory, the equations for two failure modes were extended. The results of the previous tests were used to calculate predictive values of the load-carrying capacity of timber-WFIB-joints tested in further tests. The stiffness of timber-WFIB-joints may be calculated depending on the densities of the joint members, the thickness of the WFIB and the diameter of the fastener. With these results the load-carrying and displacement characteristics of timber-WFIB-joints may be evaluated and further be used for the calculation of shear walls with WFIB sheathing.

8 References

[1] Johansen, K. W.: Theory of timber connections. International Association of bridge and structural Engineering, Bern. P. 249-262

[2] EN 383:1993: Timber structures; Test methods; Determination of embedding strength and foundation values for dowel type fasteners

[3] Blaß, H. J.; Gebhardt, G.: Holzfaserdämmplatten – Trag- und Verformungsverhalten in aussteifenden Holztafeln. Karlsruher Berichte zum Ingenieurholzbau, Band 14, Lehrstuhl für Ingenieurholzbau und Baukonstruktionen (Ed.), Universität Karlsruhe (TH), 2009

[4] EN 1383:1999: Timber structures; Test methods; Pull through resistance of timber fasteners

[5] EN 26891:1999: Timber structures; Joints made with mechanical fasteners; General principles for the determination of strength and deformation characteristics

[6] EN 409:1993: Timber structures – Test methods – Determination of the yield moment of dowel type fasteners

[7] DIN 1052:2004: Design of timber structures – General rules and rules for buildings