CIB-W18/44-7-1

**INTERNATIONAL COUNCIL FOR RESEARCH AND INNOVATION
IN BUILDING AND CONSTRUCTION**

WORKING COMMISSION W18 - TIMBER STRUCTURES

PULL-THROUGH CAPACITY IN PLYWOOD AND OSB

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MEETING FORTY FOUR
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ITALY
AUGUST 2011

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Introduction

The characteristic pull-through capacity of heads of nails and screws is needed to determine the rope effect for laterally loaded fasteners used to fix sheathing to timber-frames. There is no values given in EN 1995 (Eurocode 5) but data for the pull through capacity of nail and screw heads has been found in four different references. All fasteners and panels are North American. A fairly general and accurate model is found and the characteristic values according to EN 1990 are determined.

Data

The data used originates from the following four references:

1 Herzog & Yeh (2006)
8d box nails in plywood and OSB of different thickness. About 40 repetitions for each type of panel, conditioned at 20 °C and 65 % RH. The diameter of the head d_{head} and panel thickness t in inches is also given in APA (2007). These values are used here as they seem to be more accurate than the values in mm stated in the paper.

2 Chow et al. (1998)
6d common nails in one type of plywood and two grades of OSB. 50 repetitions for each type of panel, conditioned at 20 °C and 65 % RH. d_{head} is not stated but according to the standard specification for 6 d common nails it is 17/64 inch or 6,75 mm.

3 Chui & Craft (2002)
Different types of round-headed screws (gauge 8 and 14), common nails (2" and 3") and power nails with full but eccentric head and with clipped (D-shaped) head. 30 repetitions for each type of panel, conditioned at 20 °C and 80 % RH. Measured values of d_{head} is reported and given in Table 1. For the power driven nails the heads are not circular but both max and min diameter are given. d_{head} in Table 1 is taken as the square root of the product of max and min diameter. This is likely to underestimate the area of the head for the clipped head nails slightly.

4 Forintek (n.a.)
Wood screw gauge 10 in thin plywood and OSB with thickness up to 18 mm. 10 repetitions for each type of panel. Conditioning, densities and d_{head} are not reported. According to American Standard B18.6.1 - 1961 the diameter for flat headed wood screws should be in the range 0,34 - 0,385 inch or 8,6 - 9,8 mm. According to a manufacturers brochures round-headed wood screws should be expected to be 5-10 % smaller. It is chosen to use d_{head} = 9,3 mm (the upper limit is the safe choice).

In all cases the mean value ($F_{head,obs}$) and the coefficient of variation (V_{obs}) (or standard deviation) are reported. All the data are assembled in Table 1. They represent plywood and OSB panels from many different manufactures and different thicknesses, even though most panels are about ½ inch thick. All thicknesses are nominal. The fastener types comprise round-headed wood screws, flat headed nails and power driven nails with eccentric head. Unfortunately no data for flat headed screws are found.

Model

In Herzog & Yeh (2006) and Forintek (n.a.) it is demonstrated for a specific type of fastener that the relationship between the pull-through capacity and the thickness of the panel is:

– linear,
– the same for plywood and OSB, and
– independent of density.

It appears that a quite good model for the mean value is

$$F_{head,model} = b\, t\, d_{head}$$

where b is a constant with dimension force/length^2, t is the nominal thickness of the panel and d_{head} is the diameter of the head, in principle the real diameter but otherwise the most informed guess. This is a physically reasonable model as the area of the rupture surface is proportional to $t\, d_{head}$ if a cone shaped rupture surface is anticipated.

EN 1990 offers in section D8 a method to estimate the characteristic load-carrying capacity when such a model is applied. The following is based on that method, modified to be used for data where only the mean value and the coefficient of variation are known for repetitions of the same test. The modifications are given in Annex A together with some quite accurate approximations that apply for practical use in general. These approximations are also given in Munch-Andersen et al. (2010).

The slope should be estimated from Eq. (D.7) in EN 1990 as

$$b = \frac{\Sigma F_{head,obs}\, t\, d_{head}}{\Sigma (t\, d_{head})^2}$$

where each value of $F_{head,obs}$ is repeated n_i times according to the number of repetitions it represents. In Table 2 the estimated values are given. It is seen that b is almost identical for plywood and OSB. Figure 1 shows the observed mean values of the capacities plotted against the value estimated by the model. The estimation method for b ensures that the deviation from the ideal line with slope 1 is minimized. It should be noted theat the above model for b is a generalisation of the model in Eq. (D.7) in EN 1990 which ensures that the bias becomes one).

Table 1. Data for pull-through capacity for nails and screws in plywood and OSB.

Fastener type	d_{head} mm	t mm	ρ kg/m3	n_i	$F_{head,obs}$ N	V_{obs}	$F_{head,model}$ N	$\overline{\Delta}_i$	Ref.
Plywood									
Clipped 2 3/8 pw.n.	6,9	11,1	400	30	1095	0,12	1437	-0,27	3
Clipped 3" pw. nail	6,2	11,1	400	30	1121	0,13	1291	-0,14	3
Wood screw #14	11,7	11,1	400	30	2215	0,13	2420	-0,09	3
Wood screw #8	7,2	11,1	400	30	1406	0,16	1492	-0,06	3
6d common nail	6,8	12,7	525	50	1526	0,15	1603	-0,05	2
2" common nail	6,2	11,1	400	30	1242	0,18	1288	-0,04	3
Wood screw #10	9,3	7,9	-	10	1342	0,09	1380	-0,03	4
8d box nail	7,5	9,5	519	40	1353	0,20	1343	0,01	1
Full 2 3/8 pw.nail	7,1	11,1	400	30	1503	0,10	1470	0,02	3
8d box nail	7,5	12,7	559	40	1909	0,12	1790	0,06	1
Full 3" power nail	6,0	11,1	400	30	1349	0,15	1249	0,08	3
3" common nail	8,1	11,1	400	30	1939	0,13	1683	0,14	3
OSB									
Clipped 2 3/8 pw.n.	6,9	11,1	590	30	1131	0,39	1440	-0,24	3
Wood screw #10	9,3	11,1	-	10	1648	0,27	1936	-0,16	4
6d common nail	6,8	12,7	685	50	1477	0,15	1606	-0,08	2
Wood screw #14	11,7	11,1	590	30	2241	0,20	2426	-0,08	3
Wood screw #10	9,3	18,3	-	10	2968	0,21	3181	-0,07	4
Full 2 3/8 pw. nail	7,1	11,1	590	30	1387	0,38	1473	-0,06	3
Clipped 3" pw. nail	6,2	11,1	590	30	1219	0,46	1294	-0,06	3
6d common nail	6,8	12,7	699	50	1526	0,18	1606	-0,05	2
6d common nail	6,8	11,1	659	50	1348	0,19	1405	-0,04	2
8d box nail	7,5	11,1	588	40	1566	0,19	1570	0,00	1
8d box nail	7,5	9,5	627	40	1353	0,27	1346	0,01	1
6d common nail	6,8	11,1	707	50	1428	0,20	1405	0,02	2
8d box nail	7,5	11,9	598	40	1749	0,17	1682	0,04	1
2" common nail	6,2	11,1	590	30	1399	0,20	1291	0,08	3
Wood screw #8	7,2	11,1	590	30	1628	0,20	1495	0,09	3
3" common nail	8,1	11,1	590	30	1862	0,26	1686	0,10	3
Full 3" power nail	6,0	11,1	590	30	1510	0,32	1252	0,19	3
Wood screw #10	9,3	15,1	-	10	3214	0,13	2628	0,20	4

The observations with power nails with clipped head (D-shaped) are not included in the analysis because the measurements reveal a significantly smaller capacity than predicted by the model for the other types of fasteners. Besides the size of the head is underestimated when the equivalent head diameter is calculated as it is done here. Further the coefficient of variation for OSB is extremely large (30 % – 50 %), see Table 1.

Table 2. Estimated parameters.

	b, N/mm^2	V_δ	"b_k", N/mm^2
Plywood and OSB	18,72	0,21	13,0
Only plywood	18,70	0,16	14,2
Only OSB	18,74	0,23	12,4

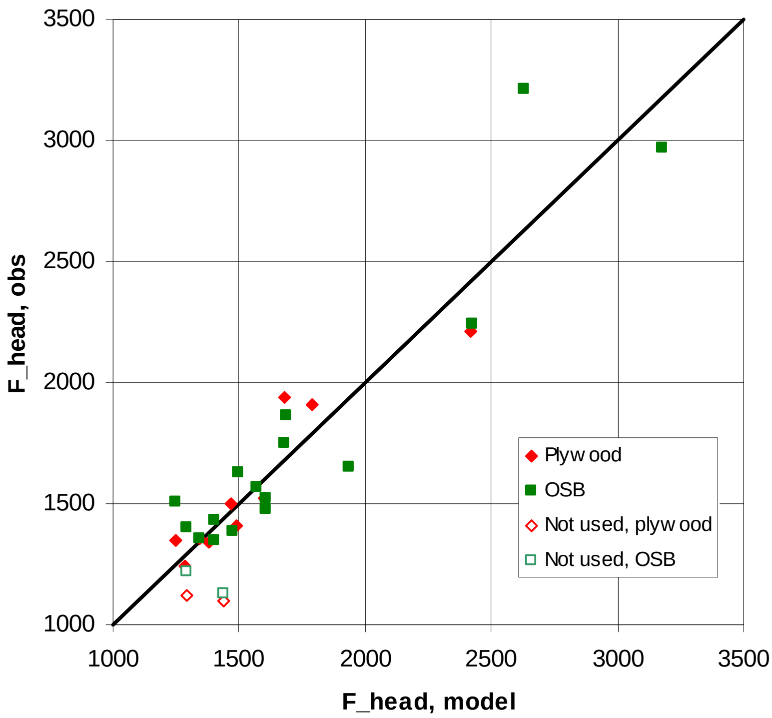

Figure 1. The observed mean pull-through capacities versus the capacities estimated from the model.

The coeffient of variation V_δ of the model is estimated from Eq (7) in Annex A with $s_{\Delta_i} = V_{obs}$ and $\overline{\Delta}_i = \ln(F_{head,obs,i} / F_{head,model,i})$. In Table 2 it is seen that the coefficient of variation is significantly smaller for plywood than for OSB implying that the characteristic value for plywood will be higher than for OSB, even though the model for the mean value is identical.

A large V_δ indicates a bad model. Attempts to include the density in the model or to use a power on t and d_{head} give no real improvement. For plywood it is somewhat surprising that the density does not matter.

When calculating the characteristic capacity using the procedure in EN 1990, Annex D the uncertainty of the basic variables should be added to the model uncertainty V_δ. But since there is no dependency on the density and because the tests represent a broad range of panels and fasteners there are no other uncertainties of the basic variables than those reflected by the tests. The term V_x in EN 1990 can therefore be assumed to be nil. The ratio between the characteristic and the mean value can then be estimated from

$$\eta = \exp(-k_s V_\delta - 0,5 V_\delta{}^2)$$

where k_s is a number depending on the number of tests and the last term is a correction due to LogNormal-distribution of the capacity. Since there are many tests, k_s = 1,64 can be used. In Table 2 is given values for $"b_k" = \eta b$.

Discussion and conclusions

Based on results from about 1000 pull-through tests with various types of fasteners in plywood and OSB is it found that the pull-through capacity is proportional to the nominal thickness t of the panel and the diameter d_{head} of the head of the fastener. The characteristic capacities can be estimated from

$$\text{Plywood:}\ F_{head,k} = 14\ \text{N/mm}^2\ t\ d_{head}$$

$$\text{OSB:}\qquad F_{head,k} = 12\ \text{N/mm}^2\ t\ d_{head}$$

with the following limitations:

- 9 mm $\leq t \leq$ 18 mm
- $d_{head} < t$
- For plywood the capacity should be reduced by 30% when applied to power nails with clipped head and screws with flat head.
- For OSB the estimate is not applicable to power nails with clipped head and screws with flat head.

The limits on t and d_{head} reflect the range of parameters represented in the tests. For t > 18 mm the value for t = 18 mm can be used.

Flat headed screws are not included in the test and power nails with clipped head gives quite low values.

For clipped heads in plywood the 30% reduction should be safe as the observations are 27% and 14% below the model and the coefficient of variation V_{obs} is similar to other types of fasteners. For OSB the very large coefficient of variation makes it impossible to estimate a value based on the few tests.

The large variation in general for OSB might be due to larger inhomogeneities in the material. The average density is higher than for plywood which might explain why the mean capacity becomes the same as for plywood. The particular large coefficient of variation and small mean value for clipped heads might be because those nails damage the surface more than the other types.

For flat headed screws the capacity might be smaller. For the more homogeneous plywood it is unlikely to be a great reduction, so 30 % will be a conservative guess. For OSB the surface will be damaged in an unpredictable way.

The density has no significant influence on the capacity.

References

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Annex A
Estimation of CoV of model error from data from literature

When a model of the type

$$x = bt \qquad (1)$$

is used to describe the relation between the independent (input) variable t and the dependent (output) variable x the factor b should be estimated from test results.

When n levels of t are used the independent variables can be named t_i , $i = 1 \,.\,.\, n$. If the test is repeated n_i times for level i the dependent variables can be named x_{ij} , $j = 1 \,.\,.\, n_i$. The total number of tests is

$$N = \sum_{i=1}^{n} n_i$$

According to section D8 in EN 1990 the variation of the model error is determined from the standard deviation of

$$\Delta_{ij} = \ln \frac{x_{ij}}{bt_i} \qquad (2)$$

The coefficient of variation of the error becomes approximately

$$V_\delta^2 \approx s_\Delta^2 = \frac{1}{N-1} \sum_{i=1}^{n} \sum_{j=1}^{n_i} \left(\Delta_{ij} - \overline{\Delta} \right)^2 \qquad (3)$$

where

$$\overline{\Delta} = \frac{1}{N} \sum_{i=1}^{N} \Delta_{ij} \qquad (4)$$

When data are found in the literature usually only t_i, the mean values $\overline{x}_i$ and the coefficient of variations V_{x_i} is reported. In the following it is shown how V_δ can be estimated based on these information. With the definitions

$$\overline{\Delta}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \Delta_{ij} \qquad \text{and} \qquad (5)$$

$$s_{\Delta_i}^2 = \frac{1}{n_i - 1} \sum_{j=1}^{n_i} \left(\Delta_{ij} - \overline{\Delta}_i \right)^2 \qquad (6)$$

Eq (3) can be rewritten

$$V_\delta^2 \approx s_\Delta^2 = \frac{1}{N-1} \sum_{i=1}^{n} \left[\left(n_i - 1 \right) s_{\Delta_i}^2 + n_i \left(\overline{\Delta}_i - \overline{\Delta} \right)^2 \right] \qquad (7)$$

In Eq. (4) $\overline{\Delta} = 0$ will be a very accurate estimate, even for not very good models.

Eq (5) can for normal cases with good accuracy be substituted by

$$\overline{\Delta}_i \approx \ln \frac{\overline{x}_i}{bt_i} \qquad (8)$$

where the mean of the logarithms is replaced by the logarithm of the mean.

In Eq. (6) the last term can be then rewritten

$$\Delta_{ij} - \overline{\Delta}_i = \ln\frac{x_{ij}}{bt_i} - \ln\frac{\overline{x}_i}{bt_i} = \ln x_{ij} - \ln \overline{x}_i$$

so

$$s_{\Delta_i}^2 = \frac{1}{n_i - 1}\sum_{j=1}^{n_i}\left(\ln x_{ij} - \ln \overline{x}_i\right)^2$$

which is seen to be equal to the standard deviation of $\ln(x_i)$. This can with good accuracy can be substituted by V_{x_i} . Therefore

$$s_{\Delta_i}^2 \approx V_{x_i}^2 \qquad (9)$$

Hereby good estimates for all terms in Eq. (7) are available.

Note: When the factor b is estimated from the mean values $\overline{x}_i$ these should be weighted by n_i if the number is not the same for all levels of t_i. The easiest way is to repeat each $\overline{x}_i$ n_i times in the estimation.

Example

In Table A1 is given an example with constructed data chosen such that b = 10 and the coefficient of variation for each level of t is approximately constant. Figure 1 shows a plot of x_{ij} versus bt_i.

It is seen that $n = 4$ and all $n_i = 5$ so $N = 20$. From Eqs. (3) and (4) are found

$s_\Delta = 0{,}0775$ and $\overline{\Delta} = 0{,}0006 \approx 0$.

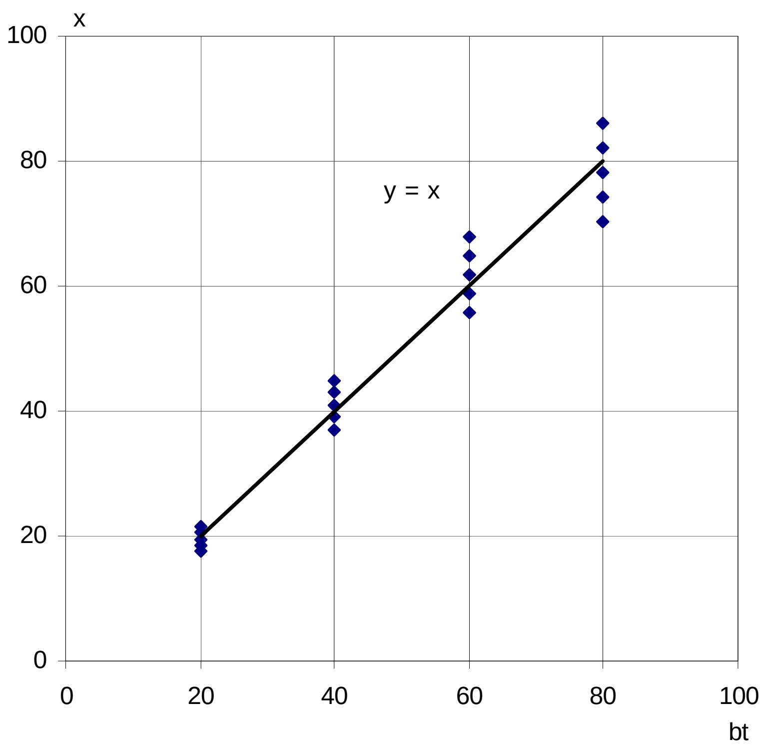

Figure A1. The observed values versus the estimated for b = 10. b should be chosen such that the slope of the best linear regression line becomes 1.

Table A1. Data and calculations when all data are available.

i	j	t_i	x_{ij}	bt_i (1)	Δ_{ij} (2)	$\overline{\Delta}_i$ (5)	s_{Δ_i} (6)
1	1	2	17,5	20	-0,134		
1	2	2	18,5	20	-0,078		
1	3	2	19,5	20	-0,025		
1	4	2	20,5	20	0,025		
1	5	2	21,5	20	0,072	-0,0280	0,0814
2	1	4	37,0	40	-0,078		
2	2	4	39,0	40	-0,025		
2	3	4	41,0	40	0,025		
2	4	4	43,0	40	0,072		
2	5	4	45,0	40	0,118	0,0223	0,0774
3	1	6	55,9	60	-0,071		
3	2	6	58,9	60	-0,019		
3	3	6	61,9	60	0,031		
3	4	6	64,9	60	0,079		
3	5	6	67,9	60	0,124	0,0288	0,0769
4	1	8	70,2	80	-0,131		
4	2	8	74,2	80	-0,075		
4	3	8	78,2	80	-0,023		
4	4	8	82,2	80	0,027		
4	5	8	86,2	80	0,075	-0,0254	0,0812

If only $\overline{x_i}$ and V_{x_i} are known the data will be as in Table A2. From Eq. (7) is found $s_\Delta = 0{,}0773$. It is seen to be very accurate for this example.

Table A2. Data and calculations when only mean values and coefficient of variation is known.

i	n_i	t_i	$\overline{x_i}$	bt_i (1)	V_{x_i}	$\overline{\Delta}_i$ (8)	s_{Δ_i} (9)
1	5	2	19,5	20	0,0811	-0,025	0,0811
2	5	4	41	40	0,0771	0,025	0,0771
3	5	6	61,9	60	0,0766	0,031	0,0766
4	5	8	78,2	80	0,0809	-0,023	0,0809