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Expert Opinion

Load-bearing capacity of RAMPA inserts with lifting pins as lifting gear

1 General

ETA-12/0481 governs RAMPA inserts A, B, BL, BV, C, CV, SK, SK330, SKL and SKL330 as connecting elements for timber structures. The company Hans Brügmann GmbH & Co. KG also wishes to use RAMPA inserts in conjunction with lifting pins as a lifting gear for components in cross-laminated and glued-laminated board made from softwood. For this, the inserts are screwed into the narrow or front ends of the components in such a way that they are arranged perpendicular to the narrow or front end, in the median plane of the components, flush with the surface. For this purpose, 25x50 mm and 36x108 mm inserts are envisaged. This expert opinion evaluates the load-bearing capacity of the inserts for three loading directions:

- Tensile loading in the axial direction of the insert;
- Shearing stress in the plane of the component;
- Shearing stress perpendicular to the plane of the component;

To create the joint, the inserts are screwed into pre-drilled holes of diameters 23 mm for the 25x50 inserts and 34 mm for the 36x108 inserts.

The basis used for evaluating the load-carrying capacity are the load-bearing capacity tests conducted by the Research Institute for Steel, Wood and Stone at the Karlsruhe Institute of Technology (test report no. 186111).

Suggestions are derived below for the determination by calculation of the load-carrying capacity of the inserts on the basis of the outcomes of these load-bearing capacity tests and of theoretical considerations.

2 Scope of application

It is intended that joints based on RAMPA inserts be used for transport and for the assembly of components in cross-laminated and glued-laminated board made from softwood. Where 25x50 mm RAMPA inserts are used, the thickness of the components must be at least 60 mm and the section width at least 300 mm; with 36x108 mm inserts, the minimum section dimensions must be 120 mm x 400 mm. The inserts must be screwed in perpendicularly to the surface of the narrow side, flush to the surface, in the median plane of the component. The angle between the insert axis and the grain direction may be between 0° and 90°.

3 Calculation models and comparison with test results

3.1 Tensile loading in the axial direction of the insert

With tensile loading in the axial direction, the insert experiences a withdrawal force (i.e. that tries to pull it out of the board). By way of deviation from the conditions in ETA-12/0481, the minimum screw-in (threaded) depth may be up to 2 D. For this reason the withdrawal capacity values are lower than those specified in ETA-12/0481. For the characteristic capacity of an insert to resist extraction, without consideration of an oscillation coefficient, it is proposed that:

$$F_{ax,\varepsilon,Rk} = k_{ax} \cdot f_{ax,k} \cdot D \cdot {}_{e}\ell \qquad (1)$$

where:

$F_{ax,\varepsilon,RK}$ Characteristic withdrawal capacity [N]

$f_{ax,k}$ Characteristic withdrawal parameter, $f_{ax,k} = 8$ N/mm²

D External thread diameter [mm]

ℓ_{ef} Thread length of insert within wooden component [mm]

k_{ax} Factor to allow for the angle between the axial and grain direction,

$k_{ax} = 1.0$ for $45° \leq \varepsilon < 90°$

$k_{ax} = 0.6 + \frac{0.4 \cdot \varepsilon}{45°}$ for $0° \leq \varepsilon < 45°$

ε Angle between the axial and grain direction

Since the load duration is only short during lifting or mounting, k_{ax} may be assumed to be higher than under ETA-12/0481. If the outer thread diameter D is greater than or equal to the layer thickness in the cross-laminated board into which the insert is screwed, or if the insert is screwed into at least 2 layers, the less favorable value ε should be used in Equation (1). If the position of the insert has not been clearly defined in advance, the value $k_{ax} = 0.6$ should be used for calculations. Table 1 shows the comparison of withdrawal capacity in the test (test report 186111) and the characteristic withdrawal capacity as derived from Equation (1).

If we calculate the ratio of the withdrawal capacity obtained from the test with the proposed characteristic withdrawal capacity, an average ratio is obtained of 1.71 and a 5% quantile value, compliant with EN 14358 and based on a lognormal distribution, of 1.01. Thus the required characteristic ratio of 1.0 is achieved.

Accordingly, equation (1) leads to an appropriate characteristic withdrawal capacity for inserts subjected to withdrawal forces in the dimensions 25x50 and 36x108 in the narrow sides of cross-laminated or glue-laminated board.

Table 1: Withdrawal capacity of inserts subjected to tensile forces compared to the characteristic withdrawal capacity obtained from equation (1).

Material	Test	D	ℓ_{ef}	ε	ρ	k_{ax}	$f_{ax,k}$	$F_{ax,Rk}$	F_{test}	$F_{test}/F_{ax,Rk}$	h	t_M
CLT	I_Z_1	25	50	90	384	1	8.0	10,000	15,100	1.51	90	30
CLT	I_Z_2	25	50	90	421	1	8.0	10,000	14,000	1.40	90	30
CLT	I_Z_3	25	50	90	443	1	8.0	10,000	15,100	1.51	90	30
CLT	II_Z_1	36	108	90	525	1	8.0	31,104	39,700	1.28	120	40
CLT	II_Z_2	36	108	90	392	1	8.0	31,104	32,300	1.04	120	40
CLT	II_Z_3	36	108	90	575	1	8.0	31,104	40,800	1.31	120	40
CLT	III_Z_1	25	50	0	461	0.6	8.0	6000	16,700	2.78	100	40
CLT	III_Z_2	25	50	0	461	0.6	8.0	6000	12,500	2.08	100	40
CLT	III_Z_3	25	50	0	466	0.6	8.0	6000	13,500	2.25	100	40
CLT	IV_Z_1	36	108	0	506	0.6	8.0	18,662	23,000	1.23	120	40
CLT	IV_Z_2	36	108	0	419	0.6	8.0	18,662	33,000	1.77	120	40
CLT	IV_Z_3	36	108	0	418	0.6	8.0	18,662	41,800	2.24	120	40
CLT	V_Z_1	25	50	0	444	0.6	8.0	6000	10,700	1.78	60	20
CLT	V_Z_2	25	50	0	367	0.6	8.0	6000	11,300	1.88	60	20
CLT	V_Z_3	25	50	0	412	0.6	8.0	6000	10,500	1.75	60	20
CLT	VI_Z_1	25	50	0	375	0.6	8.0	6000	11,100	1.85	60	20
CLT	VI_Z_2	25	50	0	396	0.6	8.0	6000	10,300	1.72	60	20
CLT	VI_Z_3	25	50	0	403	0.6	8.0	6000	10,200	1.70	60	20
BSH	VII_Z_1	25	50	0	407	0.6	8.0	6000	10,800	1.80	60	60
BSH	VII_Z_2	25	50	0	386	0.6	8.0	6000	15,300	2.55	60	60
BSH	VII_Z_3	25	50	0	484	0.6	8.0	6000	12,000	2.00	60	60
BSH	VIII_Z_1	36	108	0	460	0.6	8.0	18,662	19,500	1.04	120	120
BSH	VIII_Z_2	36	108	0	437	0.6	8.0	18,662	22,600	1.21	120	120
BSH	VIII_Z_3	36	108	0	435	0.6	8.0	18,662	26,900	1.44	120	120

h is the component thickness and t_M is the layer thickness

3.2 Shearing stress in the plane of the component

Observations during the tests indicate that the inserts fail in a manner similar to pin-shaped connecting elements in sheet steel-wood joints subjected to a single shear load where the steel plate is thin, such that no plastic hinge is observed in the insert. For a shear force acting directly on the surface of the component, the load-bearing capacity would therefore be calculated using equation 8.9 (a) of Eurocode 5. The articulation of the lifting pin used has, however, a distance ℓ_3 to the wood surface, which is for 25x50 inserts ℓ_3 = 31 mm and for 36x108 inserts ℓ_3 = 36.5 mm.

This distance corresponds to an interlayer of air and can be considered, for example, on the basis of Blass, H.J. and Laskewitz, B. (2003); Tragfähigkeit von Verbindungen mit stiftförmigen Verbindungsmitteln und Zwischenschichten [Load-bearing capacity of joints with pen-shaped connecting elements and interlayers]. Bauen mit Holz [Timber construction] 105: vol. 1 pp. 26-35 and vol. 2 pp. 30-34. If ℓ_3 is designated as t_{gap} , the load-bearing capacity of an insert for shear forces is:

$$F_{v,Rk} = f_{h,k} \cdot D \cdot t_{ef} \tag{2}$$

where

$$f_{h,k} = \frac{0{,}082 \cdot (1 - 0{,}01 \cdot D)\, \rho_k}{\max\left\{k_{90} \cdot \sin^2 \alpha + \cos^2 \alpha; 2{,}5 \cdot \cos^2 \varepsilon + \sin^2 \varepsilon\right\}} \tag{3}$$

$$t_{ef} = \sqrt{4 \cdot t_{gap}^2 + 4 \cdot t_{gap} \cdot \ell_{ef} + 2 \cdot \ell_{ef}^2} - 2 \cdot t_{gap} - \ell_{ef} \tag{4}$$

Here:

$F_{v,Rk}$	Characteristic load-bearing capacity of an insert to shear force in N
$f_{h,k}$	Characteristic bearing stress resistance in N/mm²
D	External thread diameter [mm]
ρ_k	Characteristic gross density of the cross-laminated or glued-laminated timber in kg/m³
α	Angle between the force and grain direction
ε	Angle between the insert axis and grain direction
k_{90}	Coefficient to allow for the angle α, $k_{90} = 1.725$ for 25x50 inserts, $k_{90} = 1.89$ for 36x108 inserts
t_{ef}	Effective connection depth in mm, $k_{ef} = 10.7$ mm for 25x50 inserts, $k_{ef} = 29.8$ mm for 36x108 inserts
ℓ_{ef}	Thread length of insert within wooden component [mm]
t_{gap}	Dimension ℓ_3 of lifting pin; $\ell_3 = t_{gap} = 31$ mm 25x50 inserts, $\ell_3 = t_{gap} = 36.5$ mm for 36x108 inserts

Table 2 shows the comparison of load-bearing capacity in the test (test report 186111) and the characteristic load-bearing capacity as derived from equation (2).

Table 2: Load-bearing capacity of inserts subjected to shear forces compared to the characteristic withdrawal capacity obtained from equation (2).

Material/test body		D	t	t_{gap}	α	ε	ρ_k	k_{90}	$f_{h,k}$	$F_{v,Rk}$	F_{test}	$F_{test}/F_{v,Rk}$	h
CLT	I_X_1	25	50	31	0	90	350	1.725	21.5	5733	6230	1.09	90
CLT	I_X_2	25	50	31	0	90	350	1.725	21.5	5733	10,700	1.87	90
CLT	I_X_3	25	50	31	0	90	350	1.725	21.5	5733	8940	1.56	90
CLT	II_X_1	36	108	36,5	0	90	350	1.89	18.4	19,687	28,800	1.46	120
CLT	II_X_2	36	108	36,5	0	90	350	1.89	18.4	19,687	28,400	1.44	120
CLT	II_X_3	36	108	36.5	0	90	350	1.89	18.4	19,687	29,000	1.47	120
CLT	III_X_1	25	50	31	90	0	350	1	8.6	2293	5080	2.22	100
CLT	III_X_2	25	50	31	90	0	350	1	8.6	2293	5170	2.25	100
CLT	III_X_3	25	50	31	90	0	350	1	8.6	2293	4840	2.11	100
CLT	IV_X_1	36	108	36.5	90	0	350	1	7.3	7875	14,900	1.89	120
CLT	IV_X_2	36	108	36.5	90	0	350	1	7.3	7875	13,200	1.68	120
CLT	IV_X_3	36	108	36.5	90	0	350	1	7.3	7875	13,100	1.66	120
CLT	V_X_1	25	50	31	0	90	350	1.725	21.5	5733	7040	1.23	60
CLT	V_X_2	25	50	31	0	90	350	1.725	21.5	5733	6390	1.11	60
CLT	V_X_3	25	50	31	0	90	350	1.725	21.5	5733	6500	1.13	60
CLT	VI_X_1	25	50	31	90	0	350	1	8.6	2293	3870	1.69	60
CLT	VI_X_2	25	50	31	90	0	350	1	8.6	2293	5270	2.30	60
CLT	VI_X_3	25	50	31	90	0	350	1	8.6	2293	3700	1.61	60

3.3 Shearing stress perpendicular to the plane of the component

Observations during the tests indicate that the inserts fail in a manner similar to that with a shearing stress in the plane of the component. In the VI_Y series of tests the cross-laminated board component broke up as a result of tensile stress perpendicular to the grain. Accordingly, where there is loading perpendicular to the plane of the component, consideration must be given in the verification to the transverse stress failure in addition to equation (2). Since transverse stress failure was only observed in one series of tests, this proof must only be performed where the boundary conditions are unfavorable:

- Cross-laminated component with insert diameter/board thickness D/h > 0.4
- Grain direction of surface layers perpendicular to axis of insert

The significant equations for transverse connections are:

$$F_{90,Rk} = \left(6{,}5 + \frac{18 \cdot h_e^2}{h^2}\right) \cdot \left(t_{ef} \cdot h\right)^{0,8} \cdot \qquad (5)$$

Here:

$F_{90,Rk}$	Characteristic load-bearing capacity of an insert to shear force in N
h_e	Distance of insert axis from component surface in mm
h	Component thickness in mm
h_e/h	= 0.5 where insert is positioned centrally
t_{ef}	Effective connection depth in mm from equation (4), k_{ef} = 10.7 mm for 25x50 inserts, k_{ef} = 29.8 mm for 36x108 inserts
$f_{t,90,k}$	Characteristic value of transverse tensile strength, $f_{t,90,k}$ = 0.5 N/mm²

With h_e/h = 0.5 and $f_{t,90,k}$ = 0.5 N/mm² we thus obtain

$$F_{90,Rk} = 11 \cdot \left(t_{ef} \cdot h\right)^{0,8} \cdot f_{t,90,k} \qquad (6)$$

Table 3 shows the comparison of load-bearing capacity in the test (test report 186111) and the smaller characteristic load-bearing capacity as derived from equations (2) and (5). Because of the boundary conditions 'Cross-laminated component with insert diameter/board thickness D/h > 0.4' and 'Grain direction of surface layers perpendicular to axis of insert', equation (5) should only be used for the test series CLT VI_Y. The characteristic load-bearing capacities of the other Y test series have been determined using solely equation (2).

Tables 2 and 3 show that the calculation model proposed adequately describes the different test configurations. If we evaluate the ratios $F_{test}/F_{v},R_{k}$ together on the basis of EN 14358, a characteristic ratio determined on the basis of a lognormal distribution is obtained of 1.01, which matches very closely with the target value of 1.0. The calculated ratios range between 0.95 and 2.30 with an average of 1.54.

Table 3: Load-bearing capacity of inserts subjected to shear forces compared to the characteristic withdrawal capacity obtained from equation (2).

Material/test body		D	t	t_{gap}	α	ε	ρ_k	k_{90}	$f_{h,k}$	$F_{v,Rk}$	F_{test}	$F_{test}/F_{v,Rk}$	h
CLT	I_Y_1	25	50	31	90	90	350	1.725	12.5	3324	5190	1.56	90
CLT	I_Y_2	25	50	31	90	90	350	1.725	12.5	3324	6640	2.00	90
CLT	I_Y_3	25	50	31	90	90	350	1.725	12.5	3324	5340	1.61	90
CLT	II_Y_1	36	108	36.5	90	90	350	1.89	9.7	10,416	12,600	1.21	120
CLT	II_Y_2	36	108	36.5	90	90	350	1.89	9.7	10,416	12,500	1.20	120
CLT	II_Y_3	36	108	36.5	90	90	350	1.89	9.7	10,416	9890	0.95	120
CLT	III_Y_1	25	50	31	90	0	350	1	8.6	2293	4180	1.82	100
CLT	III_Y_2	25	50	31	90	0	350	1	8.6	2293	4840	2.11	100
CLT	III_Y_3	25	50	31	90	0	350	1	8.6	2293	3470	1.51	100
CLT	IV_Y_1	36	108	36.5	90	0	350	1	7.3	7875	11,700	1.49	120
CLT	IV_Y_2	36	108	36.5	90	0	350	1	7.3	7875	10,800	1.37	120
CLT	IV_Y_3	36	108	36.5	90	0	350	1	7.3	7875	8050	1.02	120
CLT	V_Y_1	25	50	31	90	0	350	1	8.6	2293	3110	1.36	60
CLT	V_Y_2	25	50	31	90	0	350	1	8.6	2293	2870	1.25	60
CLT	V_Y_3	25	50	31	90	0	350	1	8.6	2293	3330	1.45	60
CLT	VI_Y_1	25	50	31	90	0	350	1	8.6	966	1480	1.53	60
CLT	VI_Y_2	25	50	31	90	0	350	1	8.6	966	1750	1.81	60
CLT	VI_Y_3	25	50	31	90	0	350	1	8.6	966	1620	1.68	60
BSH	VII_Y_1	25	50	31	90	0	385	1	9.5	2523	3350	1.33	60
BSH	VII_Y_2	25	50	31	90	0	385	1	9.5	2523	3820	1.51	60
BSH	VII_Y_3	25	50	31	90	0	385	1	9.5	2523	3300	1.31	60
BSH	VIII_Y_1	36	108	36.5	90	0	385	1	8.1	8662	11,400	1.32	120
BSH	VIII_Y_2	36	108	36.5	90	0	385	1	8.1	8662	12,500	1.44	120
BSH	VIII_Y_3	36	108	36.5	90	0	385	1	8.1	8662	9920	1.15	120

4 Combined loading

Where tensile forces in the direction of the insert axis and shearing stresses both in the direction of and perpendicular to the component plane are simultaneously present, the following quadratic interaction condition should be maintained:

$$\left(\frac{F_{x,Ed}}{F_{x,Rd}}\right)^2 + \left(\frac{F_{y,Ed}}{F_{y,Rd}}\right)^2 + \left(\frac{F_{z,Ed}}{F_{z,Rd}}\right)^2 \leq 1 \tag{7}$$

Here:

$F_{x,Ed}$ Design value of shearing stress in component plane in N including oscillation coefficient

$F_{y,Ed}$ Design value of shearing stress perpendicular to component plane in N including oscillation coefficient

$F_{z,Ed}$ Design value of tensile loading in axial direction of the insert in N including oscillation coefficient

$F_{x,Rd}$	Design value of shear load capacity in component plane from equation (2) in N
$F_{y,Rd}$	Design value of shear load capacity perpendicular to component plane from equation (2) in N, taking equation (5) into consideration where necessary
$F_{z,Rd}$	Design value of load-bearing capacity in axial direction of the insert in N

The design values of the loading should be obtained by multiplying the tare weight of the components by the partial safety factor γ_G as per EN 1990 and with an oscillation coefficient of at least 2.0.

The design values of the load-bearing capacity should be obtained from equations (1), (2) and (5) using a partial safety factor γ_M as per EN 1995-1-1. The coefficient k_{mod} may be assumed to be 1.0.

5 Summary

The company Hans Brügmann GmbH & Co. KG wishes to use RAMPA inserts in conjunction with lifting pins as a lifting gear for components in cross-laminated and glued-laminated board made from softwood. For this, the inserts are screwed centrally into the narrow or front ends of the components in such a way that they are arranged perpendicular to the narrow or front end, flush with the surface.

For the purposes of this expert opinion, suggestions for the dimensioning of the lifting gear comprising RAMPA inserts and associated lifting pins were drawn from the results of the load-bearing capacity tests conducted by the Research Institute for Steel, Wood and Stone at the Karlsruhe Institute of Technology (test report no. 186111).

The design values of load-bearing capacity apply within the following boundary conditions:

- Thickness of components in cross-laminated or glue-laminated board at least 60 mm for 25x50 inserts and at least 120 mm for 36x108,
- Width of components in cross-laminated or glue-laminated board at least 300 mm for 25x50 inserts and at least 400 mm for 36x108,
- Distance of RAMPA inserts to edge at least 150 mm for 25x50 inserts and at least 200 mm for 36x108,
- Ratio of external thread diameter to component thickness not greater than 0.45,
- The inserts should be screwed centrally into the narrow side of the components to their full length,
- Characteristic tensile load capacity in axial direction of insert is obtained from equation (1),
- Characteristic shear load capacity perpendicular to axial direction of insert is obtained from equation (2),

- Characteristic shear load capacity perpendicular to axial direction of insert and perpendicular to the component plane is obtained from equation (5) only for cross-laminated board components with insert diameter/plate thickness $D/h > 0.4$ and grain direction of outer layers perpendicular to insert axis,
- An oscillation coefficient is applied of at least 2.0,
- Partial safety factors γ_G to Eurocode 0 and γ_M to Eurocode 5 are applied,
- A modification factor $k_{mod} = 1.0$ is applied.

If the above-stated conditions are met, it is my view that the use of the lifting gear comprising RAMPA inserts and associated lifting pins should meet no objection.

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