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Expert's report

Load carrying capacity of RAMPA inserts with ball bearing bolts as a lifting system

Translation of the original German document

1 General

ETA-12/0481 regulates RAMPA inserts A, B, BL, BV, C, CV, SK, SK330, SKL and SKL330 as fasteners for timber constructions. RAMPA GmbH & Co. KG also uses RAMPA inserts together with ball bearing bolts as a lifting system for members made of KVH made of softwood, sawn timber made of hardwood, cross laminated timber or glued laminated timber made of softwood or laminated veneer lumber made of softwood or hardwood. To do this, the inserts are screwed into the narrow end or side wood surfaces of the members in such a way that they are arranged flush with and at right angles to the surface of the members. In the front or narrow surfaces, the inserts are arranged centrally regarding the thickness of the member. So far, inserts 25x50 mm and 36x108 mm are foreseen for this purpose. This expert's opinion assesses the load-carrying capacity of additional inserts 33x73 for three load directions:

- tensile load in the axial direction of the insert.
- shear load in the plane of the member.
- shear load perpendicular to the plane of the member.

To create the connection, the inserts 33x73 are screwed into pre-drilled holes with a diameter of 31 mm.

As a basis for assessing the load-carrying capacity, ultimate load tests were performed by the research institute for steel, timber, and masonry at Karlsruhe Institute of Technology (test report no. 216117).

In the following, proposals for the determination of the load-carrying capacity of the inserts are derived from the test results and based on theoretical considerations.

2 Scope

Connections with RAMPA inserts are used for the transport and assembly of members made of KVH made of softwood, sawn timber made of hardwood, cross laminated timber or glued laminated timber made of softwood or laminated veneer lumber made of softwood or hardwood. When using RAMPA inserts 33x73, the thickness of the members must be at least 80 mm and the cross-section width at least 300 mm. The inserts are to be screwed in at right angles to and flush with the surface and in the front or narrow sides in the centre plane of the members. The angle between the insert axis and the grain direction may be between 0° and 90°.

3 Calculation model and comparison with test results

3.1 Tensile load in the axial direction of the insert

In the event of a tensile load in the axial direction, the insert is subject to withdrawal load. Deviating from the conditions in ETA-12/0481, the minimum screw-in depth may be up to 2 D. For this reason, the pull-out capacities are lower than according to ETA-12/0481. The following is suggested for the characteristic pull-out capacity of an insert without considering a dynamic load coefficient:

$$F_{ax,\varepsilon,Rk} = k_{ax} \cdot f_{ax,k} \cdot D \cdot \ell_{ef} \qquad (1)$$

mit:

$F_{ax,\varepsilon,RK}$ Characteristic withdrawal capacity [N]
$f_{ax,k}$ Characteristic withdrawal parameter, $f_{ax,k} = 8$ N/mm²
D Outer thread diameter [mm]
ℓ_{ef} Thread length of the insert in the wood-based member [mm]
k_{ax} Factor for considering the angle between insert axis and fibre direction,
$k_{ax} = 1{,}0$ für $45° \le \varepsilon < 90°$
$k_{ax} = 0{,}6 + \frac{0{,}4 \cdot \varepsilon}{45°}$ für $0° \le \varepsilon < 45°$
ε Angle between insert axis and fibre direction [°]

Since the duration of load effect during lifting or assembly is only short, k_{ax} may be assumed to be higher than according to ETA-12/0481. If the outer thread diameter D is greater than or equal to the layer thickness in the cross laminated timber into which the insert is screwed, or if the insert is screwed in at least 2 layers, the less favourable value ε in equation (1) should be considered. If the position of the inserts is not clearly defined in advance, $k_{ax} = 0.6$ should always be considered. Table 1 shows the comparison between the load carrying capacity in the test (test report 216117) and the characteristic Load carrying capacity according to equation (1).

The ratio from the load-carrying capacity in the test to the proposed characteristic load-carrying capacity, results in a mean value of 1.75, a minimum value of 1.21 and a 5-percentile determined according to EN 14358 based on a lognormal distribution of 0.98. The required characteristic ratio of 1.0 is only slightly undershot, especially since the smallest ratio of 1.21 is well above 1. If one evaluates the test results together with the results from the test report no. 186111, in which tests with inserts 25x50 and 36x108 are documented, the result is an average ratio of load carrying capacity in the test to the proposed characteristic load carrying capacity from a total of 42 tests of 1.75 and a 5-percentile of 1.02 determined according to EN 14358 based on a lognormal distribution. Equation (1) therefore leads to an appropriate characteristic load-carrying capacity of the 33x73 inserts in the end-grain, narrow or side surfaces of cross laminated timber or glulam that are subjected to withdrawal loads.

Table 1: Load-carrying capacity of axially loaded inserts in comparison to the characteristic load-carrying capacity according to the 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	33	73	90	521	1	8,0	19272	28800	1,49	80	40
CLT	I_Z_2	33	73	90	523	1	8,0	19272	28200	1,46	80	40
CLT	I_Z_3	33	73	90	463	1	8,0	19272	27200	1,41	80	40
CLT	II_Z_1	33	73	90	407	1	8,0	19272	32100	1,67	100	40
CLT	II_Z_2	33	73	90	406	1	8,0	19272	24900	1,29	100	40
CLT	II_Z_3	33	73	90	382	1	8,0	19272	26900	1,40	100	40
CLT	III_Z_1	33	73	90	486	1	8,0	19272	23800	1,23	80	40
CLT	III_Z_2	33	73	90	431	1	8,0	19272	28400	1,47	80	40
CLT	III_Z_3	33	73	90	453	1	8,0	19272	23400	1,21	80	40
CLT	IV_Z_1	33	73	90	579	1	8,0	19272	31400	1,63	100	40
CLT	IV_Z_2	33	73	90	457	1	8,0	19272	34600	1,80	100	40
CLT	IV_Z_3	33	73	90	381	1	8,0	19272	24900	1,29	100	40
CLT	V_Z_1	33	73	0	453	0,6	8,0	11563	30100	2,60	80	40
CLT	V_Z_2	33	73	0	401	0,6	8,0	11563	24400	2,11	80	40
CLT	V_Z_3	33	73	0	463	0,6	8,0	11563	32400	2,80	80	40
CLT	VI_Z_1	33	73	0	435	0,6	8,0	11563	27100	2,34	100	40
CLT	VI_Z_2	33	73	0	435	0,6	8,0	11563	31200	2,70	100	40
CLT	VI_Z_3	33	73	0	493	0,6	8,0	11563	29200	2,53	100	40
h is the member thickness and t_M the layer thickness												

3.2 Lateral load parallel to member plane

Observations during the tests show that the insert fails similarly to a single-shear dowel-type fastener in steel-to-timber connections with thin steel plates, whereby no plastic hinge was observed in the insert. For a lateral load that acts directly on the surface of the member, the load-carrying capacity can therefore be calculated according to Equation 8.9 (a) of Eurocode 5. However, the joint of the ball bearing bolt used has a distance ℓ_3 to the wood surface, which is ℓ_3 = 36.5 mm for inserts 33x73.

This distance corresponds to an intermediate layer of air and can be calculated according to Blass, H.J. and Laskewitz, B. (2003); Tragfähigkeit von Verbindungen mit stiftförmigen Verbindungsmitteln und Zwischenschichten. Bauen mit Holz 105: Heft 1 S. 26-35 und Heft 2 S. 30-34. When ℓ_3 is referred to as t_{gap}, the lateral capacity of an insert is:

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

with

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

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

Where:

$F_{v,Rk}$	Characteristic lateral load-carrying capacity of an insert in N
$f_{h,k}$	Characteristic embedding strength in N/mm²
D	Outer thread diameter [mm]
ρ_k	Characteristic density of the layers of the wood-based member in kg/m³
α	Angle between force and grain direction [°]
ε	Angle between insert axis and grain direction [°]
k_{90}	Coefficient to consider the angle α, k_{90} = 1.845 for inserts 33x73
t_{ef}	Effective connection depth in mm, t_{ef} = 17,2 mm for inserts 33x73
ℓ_{ef}	Thread length of the insert in the wooden member [mm]
t_{gap}	Dimension ℓ_3 of the ball bearing bolt, $\ell_3 = t_{gap}$ = 36,5 mm for inserts 33x73

Table 2 shows the comparison between the load-carrying capacity in the test according to test report 216117 and the characteristic load-carrying capacity according to the equation (2).

Table 2: Load-carrying capacity of laterally loaded inserts in comparison to the characteristic load-carrying capacity according to the equation (2).

Material/ specimen		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	33	73	36,5	0	90	350	1,845	19,2	10935	15800	1,44	80
CLT	I_X_2	33	73	36,5	0	90	350	1,845	19,2	10935	16400	1,50	80
CLT	I_X_3	33	73	36,5	0	90	350	1,845	19,2	10935	14800	1,35	80
CLT	I_Y_1	33	73	36,5	90	90	350	1,845	10,4	5927	12000	2,02	80
CLT	I_Y_2	33	73	36,5	90	90	350	1,845	10,4	5927	11900	2,01	80
CLT	I_Y_3	33	73	36,5	90	90	350	1,845	10,4	5927	11400	1,92	80
CLT	II_X_1	33	73	36,5	0	90	350	1,845	19,2	10935	15600	1,43	100
CLT	II_X_2	33	73	36,5	0	90	350	1,845	19,2	10935	15400	1,41	100
CLT	II_X_3	33	73	36,5	0	90	350	1,845	19,2	10935	14800	1,35	100
CLT	II_Y_1	33	73	36,5	90	90	350	1,845	10,4	5927	8510	1,44	100
CLT	II_Y_2	33	73	36,5	90	90	350	1,845	10,4	5927	9300	1,57	100
CLT	II_Y_3	33	73	36,5	90	90	350	1,845	10,4	5927	10800	1,82	100
CLT	III_X_1	33	73	36,5	0	90	350	1,845	19,2	10935	18600	1,70	80
CLT	III_X_2	33	73	36,5	0	90	350	1,845	19,2	10935	20900	1,91	80
CLT	III_X_3	33	73	36,5	0	90	350	1,845	19,2	10935	17800	1,63	80
CLT	IV_X_1	33	73	36,5	0	90	350	1,845	19,2	10935	17200	1,57	100
CLT	IV_X_2	33	73	36,5	0	90	350	1,845	19,2	10935	14100	1,29	100
CLT	IV_X_3	33	73	36,5	0	90	350	1,845	19,2	10935	18600	1,70	100
CLT	V_X_1	33	73	36,5	90	0	350	1	7,7	4374	7170	1,64	80
CLT	V_X_2	33	73	36,5	90	0	350	1	7,7	4374	8540	1,95	80
CLT	V_X_3	33	73	36,5	90	0	350	1	7,7	4374	6660	1,52	80
CLT	VI_X_1	33	73	36,5	90	0	350	1	7,7	4374	6900	1,58	100
CLT	VI_X_2	33	73	36,5	90	0	350	1	7,7	4374	8800	2,01	100
CLT	VI_X_3	33	73	36,5	90	0	350	1	7,7	4374	8750	2,00	100

3.3 Lateral load perpendicular to member plane

Observations during the tests show that the insert fails like a laterally loaded insert in the member plane. In the test series V_Y and VI_Y, the cross laminated timber member partially split due to transverse tensile stress. Therefore, in the case of stress perpendicular to the plane of the member made of cross laminated timber, the transverse tensile failure must be considered in the verification in addition to Equation (2). Since transverse tensile failure was only occasionally observed, this verification only must be carried out under unfavourable boundary conditions:

- Cross laminated timber members with insert diameter/member thickness D/h > 0.4
- Grain direction of the cover layers perpendicular to the axis of the insert

The governing equations for connections with load members perpendicular to the member axis are:

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

Where:

$F_{90,Rk}$	Characteristic load-carrying capacity of an insert in N
h_e	Distance of the insert axis from the member surface in mm
h	Member thickness in mm
h_e/h	= 0,5 with a central insert arrangement
t_{ef}	effective connection depth in mm according to the equation (4), t_{ef} = 17,2 mm for inserts 33x73
$f_{t,90,k}$	Characteristic value of the transverse tensile strength

With h_e/h = 0,5 and $f_{t,90,k}$ = 0,5 N/mm² $F_{90,Rk}$ results as:

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

Table 3 shows the comparison between the load-carrying capacity in the test according to test report 216117 and the characteristic load-carrying capacity according to equation (2). Because of the boundary condition "cross laminated timber members with insert diameter/panel thickness D/h > 0.4 and grain direction of the cover layers perpendicular to the insert axis", Equation (5) was only decisive for test series V_Y. Nevertheless, the characteristic load-carrying capacities of the test series were determined exclusively according to Equation (2), Equation (5) would lead to even lower load-carrying capacities.

Tables 2 and 3 show that the proposed calculation model accurately reflects the different test configurations. If the ratios $F_{test}/F_{v,Rk}$ are evaluated together according to EN 14358, the result is a characteristic ratio value of 1.11 determined based on a lognormal distribution, which is above the target value of 1.0. The calculated ratios are between 1.04 and 2.02 with a mean of 1.56.

Evaluating the test results together with the results from the test report no. 186111, in which tests with inserts 25x50 and 36x108 are documented, the result is a mean ratio of the load-carrying capacity in the test to the proposed characteristic load-carrying capacity from a total of 78 tests of 1.55 and a 5-percentile of 1.06 determined according to EN 14358 based on a lognormal distribution. Therefore, Equation (2) with Equation (5) leads to an appropriate characteristic load-carrying capacity of the 33x73 inserts subjected to shear loads in the end-grain, narrow or side surfaces of cross laminated timber or glulam.

Table 3: Load-carrying capacity of laterally loaded inserts in comparison to the characteristic load-carrying capacity according to equation (2)

Material/ specimen		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	III_Y_1	33	73	36,5	90	90	350	1,845	10,4	5927	6470	1,09	80
CLT	III_Y_2	33	73	36,5	90	90	350	1,845	10,4	5927	6140	1,04	80
CLT	III_Y_3	33	73	36,5	90	90	350	1,845	10,4	5927	8700	1,47	80
CLT	IV_Y_1	33	73	36,5	90	90	350	1,845	10,4	5927	8190	1,38	100
CLT	IV_Y_2	33	73	36,5	90	90	350	1,845	10,4	5927	6790	1,15	100
CLT	IV_Y_3	33	73	36,5	90	90	350	1,845	10,4	5927	8470	1,43	100
CLT	V_Y_1	33	73	36,5	90	0	350	1	7,7	4374	5740	1,31	80
CLT	V_Y_2	33	73	36,5	90	0	350	1	7,7	4374	5600	1,28	80
CLT	V_Y_3	33	73	36,5	90	0	350	1	7,7	4374	5540	1,27	80
CLT	VI_Y_1	33	73	36,5	90	0	350	1	7,7	4374	6390	1,46	100
CLT	VI_Y_2	33	73	36,5	90	0	350	1	7,7	4374	7050	1,61	100
CLT	VI_Y_3	33	73	36,5	90	0	350	1	7,7	4374	7710	1,76	100

4 Combined loading

If tensile loads in the direction of the insert axis and lateral loads in and at right angles to the member plane occur simultaneously, the following quadratic interaction condition should be observed:

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

Where:

$F_{x,Ed}$ Design value of the lateral load in the member plane in N including the dynamic coefficient

$F_{y,Ed}$ Design value of the lateral load perpendicular to the member plane in N including the dynamic coefficient

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

$F_{x,Rd}$ Design value of the lateral load carrying capacity in member plane according to equation (2) in N

$F_{y,Rd}$ Design value of the lateral load carrying capacity perpendicular to the member plane according to Equation (2) in N, if necessary, taking into account Equation (5)

$F_{z,Rd}$ Design value of the load-carrying capacity in the axial direction of the insert in N

The design values of the action should be determined from the dead weight of the members multiplied by the partial safety factor γ_G according to EN 1990 and a dynamic factor of at least 2.0.

The design values of the load-carrying capacity should be determined according to equations (1), (2) and (5) with the partial safety factor γ_G according to EN 1995-1-1. The coefficient k_{mod} may be assumed to be 1.0.

5 Summary

The company RAMPA GmbH & Co. KG plans to use RAMPA inserts together with ball bearing bolts as a lifting system for members made of KVH made of softwood, sawn timber made of hardwood, cross laminated timber or glued laminated timber made of softwood or laminated veneer lumber made of softwood or hardwood. To do this, the inserts are screwed into the side surfaces and in the middle of the narrow or front sides of the members in such a way that they are arranged flush with and at right angles to the narrow or front side of the members.

In this expert's opinion, suggestions for the design of the lifting system consisting of RAMPA inserts and associated ball bearing bolts were derived from the results of ultimate load tests carried out by the research institute for steel, timber, and masonry at Karlsruhe Institute of Technology (test report no. 216117).

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

- Members made of KVH made of softwood, sawn timber made of hardwood, cross laminated timber or glued laminated timber made of softwood or laminated veneer lumber made of softwood or hardwood,
- The design values of the load-carrying capacity for members made of hardwood are determined in the same way as for members made of softwood. The higher embedding strength, withdrawal, or transverse tensile strength of the hardwood is not considered.
- The design values of the load-carrying capacity for members made of laminated veneer lumber are determined in the same way as for members made of glulam made of softwood. The higher embedding strength, withdrawal or transverse tensile strength of the laminated veneer lumber is not considered.
- Thickness of the members at least 60 mm for inserts 25x50, at least 80 mm for inserts 33x73 and at least 120 mm for inserts 36x108,
- Width of the members made of cross laminated timber or glulam at least 300 mm for inserts 25x50 and at least 400 mm for inserts 33x73 or 36x108,
- Edge distance of the RAMPA inserts in cross-laminated timber and end distance for KVH made of softwood, sawn timber made of hardwood, glued laminated timber made of softwood or laminated veneer lumber made of softwood at least 150 mm for inserts 25x50 and at least 200 mm for inserts 33x73 or 36x108,
- Ratio of outer thread diameter to member thickness no more than 0.45,

- The inserts are to be screwed into the side surfaces and in the centre of the end-grain or narrow sides of the members over their full length,
- Determination of the characteristic tensile capacity in the axial direction of the insert according to equation (1),
- Determination of the characteristic lateral capacity perpendicular to the axis of the insert according to equation (2),
- Determination of the lateral capacity perpendicular to the axis of the insert and perpendicular to the member plane according to equation (6) only for cross laminated timber members with insert diameter/plate thickness $D/h > 0.4$ and grain direction of the cover layers perpendicular to the insert axis,
- Application of a dynamic coefficient of at least 2.0,
- Application of the partial safety factors γ_F and γ_M according to Eurocode 5,
- Application of a modification factor $k_{mod} = 1.0$.

If the above conditions are observed, I am convinced that there are no objections to using the lifting system made of RAMPA inserts 33x73 and the associated ball bearing bolts.

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