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RESEARCH REPORTS

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BENDING PROPERTIES OF MECHANICALLY JOINTED SOLID TIMBER BEAMS

The aim of this work is the study of the load bearing capacity of two solid timber beams mechanically jointed by fully threaded timber screws. The obtained results are compared with the load bearing capacity of a glulam beam with the same dimensions. A four-point bending test according to LVS EN 408+A1:2012 points 9, 10 and 19 is performed to determine the modulus of elasticity and the bending strength. The test results are compared to analytical calculations according to Eurocode 5 requirements. The aim is achieved by comparing the characteristics of both beams. The main difference between mechanically jointed solid timber beam and a glulam beam is that joint of the beams reduces the modulus of elasticity while still providing good bending strength.

Keywords: mechanically jointed beams, solid timber, bending properties

Introduction

Timber has specific advantages over other traditional structural materials like steel and concrete. It is a renewable natural material that is safe and non-toxic. Timber has distinct environmental benefits as low embodied energy and positive carbon balance. It has a good weight to strength ratio (specific strength), it is easily worked and is considered more aesthetic. Solid timber has a disadvantage in terms of the limited size of the beams. The cross-section sizes and length of solid timber members are dependent on the tree it is made from. Glued laminated timber (glulam) offers a solution with a possible member size limited only to the dimensions of the factory. Another solution for a larger cross-section is mechanically jointed solid timber beams. Usually steel connectors are used for the jointing process. It has been shown that production of glulam is very energy

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intensive [Puettmann and Wilson 2005]. The gluing process is not environmentally friendly either. Cleaning of the work area as well as the safe disposal of the excess adhesive is costly and lowers the environmental factor [O'Loinsigh et al. 2012].

Concerns have been made about the effect of glue to human health as well. The most common glue used in production of glulam is formaldehyde. Formaldehyde emissions from products is a growing health concern, since it has adverse effects to human health. [Forest Products Laboratory 2010].

Solid timber is more environmentally friendly compared to glulam and the mechanically jointed timber beam is a way to get a larger cross-section. The Eurocode 5 [LVS EN 1995-1-1+AC+A1:2012] gives limited information on the design of mechanically jointed beams and it is addressed in an informative annex.

The advantages of fully threaded inclined screws for timber connections have been highlighted by many studies [e.g. Blaß and Bejtka 2001; Bejtka and Blaß 2002; Kevarinmäki 2002]. The inclination provides increased withdrawal capacity and stiffness [Tomasi et al. 2010].

Materials and methods

Experimental investigation

Four specimens were made with dimensions of *b* = 170 mm width, *h* = 340 mm height and *L* = 6200 mm length (span length *l* = 6000 mm).

During fabrication, a 10 mm precamber was produced in the mid-span of the jointed beam.

All beams had a strength class of C24 according to LVS EN 338:2014. Cross-section dimensions of the connected continuous beams were *b* = 170 mm width and *h* = 170 mm height.

For each specimen two solid timber beams were mechanically jointed by 42 fully threaded *Rothoblaas VGZ 9 × 400* screws inclined at 45 degrees. Spacing between screws varies between 150 mm and 250 mm as well as 10 extra screws at both ends of the beam placed in two rows (see fig. 1).

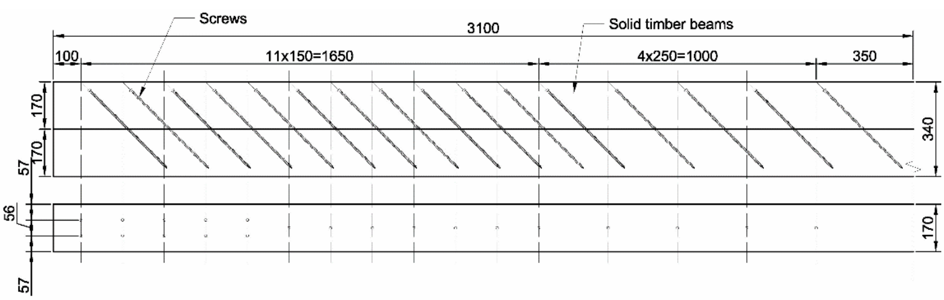

Fig. 1. Mechanically jointed beam

The specimens were tested in four-point bending set up according to LVS EN 408+A1:2012. The test set-up can be seen in figure 2. For the tests a *INSTRON 600 KN* testing machine was used with two LVDT type extensometers: LVDT1 for local deformation and LVDT2 for global deformation measurements.

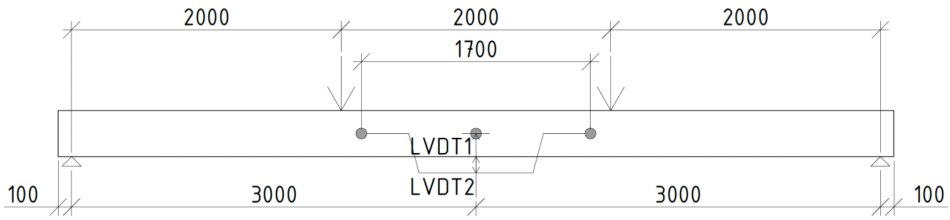

Fig. 2. Test set-up

The modulus of elasticity and strength of the specimens were calculated using a simplified method with equations from LVS EN 408+A1:2012. Local modulus of elasticity is calculated using the equation:

$$E_{m,l}=\frac{a l_1^2 (F_2-F_1)}{16 I (w_2-w_1)} \tag{1}$$

while global modulus of elasticity:

$$E_{m,g}=\frac{3al^2-4a^3}{4bh^3\frac{w_2-w_1}{F_2-F_1}} \tag{2}$$

Bending strength parallel to grain is determined by:

$$f_m=\frac{3Fa}{bh^2} \tag{3}$$

where: a – distance between a loading position and the nearest support, mm;

l_1 – gauge length, mm;

$F_2 - F_1$ – an increment of load on the regression line with a correlation coefficient of 0,99 or better, N;

$w_2 - w_1$ – the increment of deformation corresponding to $F_2 - F_1$, mm.

Analytical solution according to EC5

Analytical calculations according to LVS EN 1995-1-1+AC+A1:2012 for mechanically jointed beams have been done. Load bearing capacity of the studied beam was calculated using Annex B “Mechanically jointed beams”. A different equation was used for the calculation of slip modulus since it is recognized that the value of slip modulus K_{ser} (4) according to Eurocode 5 is very low in comparison to test values [Branco et al. 2014]:

$$K_{ser} = \rho_m^{1.5} \cdot d / 23 \tag{4}$$

where: ρ_m – mean density, kg·m^{-3},
d – outer thread diameter, mm.

Instead an equation (5) from the European Technical Approval ETA-11/0030 [ETA-Danmark A/S 2011] was used:

$$K_{ser} = 780 \cdot d^{0.2} \cdot l_{ef}^{0.4} \tag{5}$$

where: d – outer thread diameter, mm,
l_{ef} – penetration length in the structural member, mm.

Furthermore, the load-bearing capacity of a glulam beam with the same dimensions was calculated for comparison. Assumed glulam strength class GL24h according to LVS EN 14080:2013.

For ultimate limit state (ULS) criteria, normal stresses are used since in bending shear stresses are not dominant. For serviceability limit state (SLS) criteria, deflection limit *l*/200 (where *l* is span) is used (according to Latvia's EC5 National Annex for timber pedestrian bridges).

Results and discussion

Results of experimental investigation

The results of the experimental investigation were processed according to LVS EN 14358:2007 to calculate the characteristic 5-percentile values.

From the results, it can be seen that there is a considerable difference between the local and global modulus of elasticity. Local modulus of elasticity measures the value of deflection at the central pure bending region of the specimen, while the global modulus of elasticity accounts for the shear effects as well. However, research done by Ridley-Ellis et al. [2009] shows that "The main reason for the difference between global and local MoE [modulus of elasticity] is not shear, but the variation of MoE within a specimen" [Ridley-Ellis et al. 2009].

Since the local modulus of elasticity is more sensitive to local defects of timber and the range of the values of deflection is smaller, global modulus of elasticity is used for further calculations and graphs.

Table 1 show that the characteristic bending strength is almost the same as is given for the timber with strength class C24. Therefore, it can be said that the connection has not reduced the bending strength, only the modulus of elasticity.

The load-deformation graph for specimens given in figure 5 show that the character of the beam for all specimens is similar.

Table 1. Results of experimental investigation

Specimen	1	2	3	4
Failure load, kN	113.9	97.6	125.7	114.3
Local modulus of elasticity, GPa	9.44	10.1	10.8	11.4
Mean local modulus of elasticity, GPa	10.4			
Characteristic local modulus of elasticity, GPa	8.39			
Global modulus of elasticity, GPa	8.20	7.88	9.00	8.92
Mean global modulus of elasticity, GPa	8.50			
Characteristic global modulus of elasticity, GPa	7.14			
Bending strength, MPa	33.8	28.9	38.6	34.5
Mean bending strength, MPa	33.9			
Characteristic bending strength, MPa	24.6			

Fig. 3. Failure of experimental investigation specimen No.2

All specimens failed in a similar way, by failing in the tension zone at the bottom of the beam. As can be seen in figure 3 the bottom beam has cracked. A gap between the beams did not form and no visible slip was observed between the beams for any of the specimens.

To sum up the results of the experimental investigation, the jointed beam showed good strength properties. Bending strength of the jointed beam was the same as that of timber used for the making of the beam. Due to the connections, the modulus of elasticity was lower than for solid timber beams. Comparing the results with the solid timber strength classes given in LVS EN 338:2014 it can be said that the bending properties of mechanically jointed beams meets the values of solid timber with strength class C22.

Results of analytical solution and discussion

Analytical calculations were done to compare the experimental load bearing capacity of the jointed beam with the analytical according to Eurocode 5. If slip modulus is calculated using the equation given in Eurocode 5, the load bearing capacity is 9% lower for ULS and 30% lower for SLS than the load bearing capacity calculated using equation (5).

Figure 4 shows the beam's load bearing capacity of analytical solution according to Eurocode 5 (analytical), calculations done with results from experimental investigation (experimental) and load bearing capacity of a glulam beam with the same dimensions (GL24h).

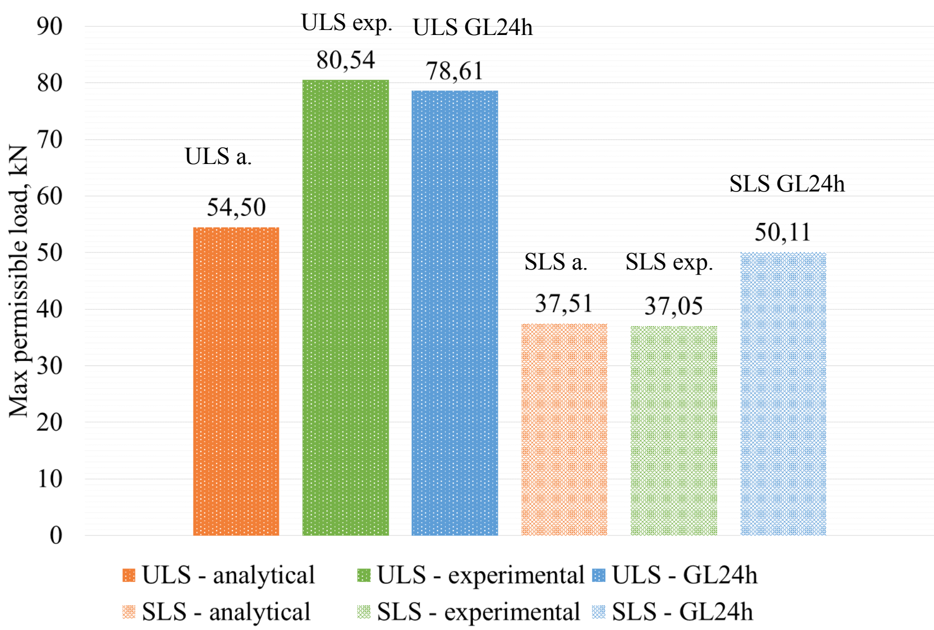

Fig. 4. Load bearing capacity of mechanically jointed beam and glulam beam

The diagram shows that for ULS the highest permissible load is achieved from experimental investigation test results. The load bearing capacity of a glulam beam is just a little lower. Therefore, the bending strength of the mechanically jointed beam has great values and can compete with glulam beams. The analytical solution gave considerably lower load bearing capacity than was achieved during experimental investigation.

Comparing the load bearing capacity for SLS it shows that the analytical solution and results from the experimental investigation gave very similar values. Since glulam has a higher modulus of elasticity than solid timber and by mechanically joining the beams it makes the beam even more elastic, glulam has a noticeably higher permissible load for SLS.

It can be concluded that the load bearing capacity calculations of the mechanically jointed beam according to Eurocode 5 regarding ultimate limit state are somewhat conservative. The tests of the experimental investigation proved that the beam has higher actual load bearing capacity. At the same time, the calculations of deflection for the serviceability limit state are very close to the actual value.

In figure 5, all the beams are compared in a load-deformation graph. In the graph are shown specimens No. 1 to No. 4 from the experimental investigation (Specimens), the analytical solution with substituted slip modulus equation (Analytical) and with the slip modulus equation form Eurocode 5 (Analytical (Eurocode 5)), calculations done with characteristic values of experimental investigation (Experimental) and solution with glulam beam (GL24h).

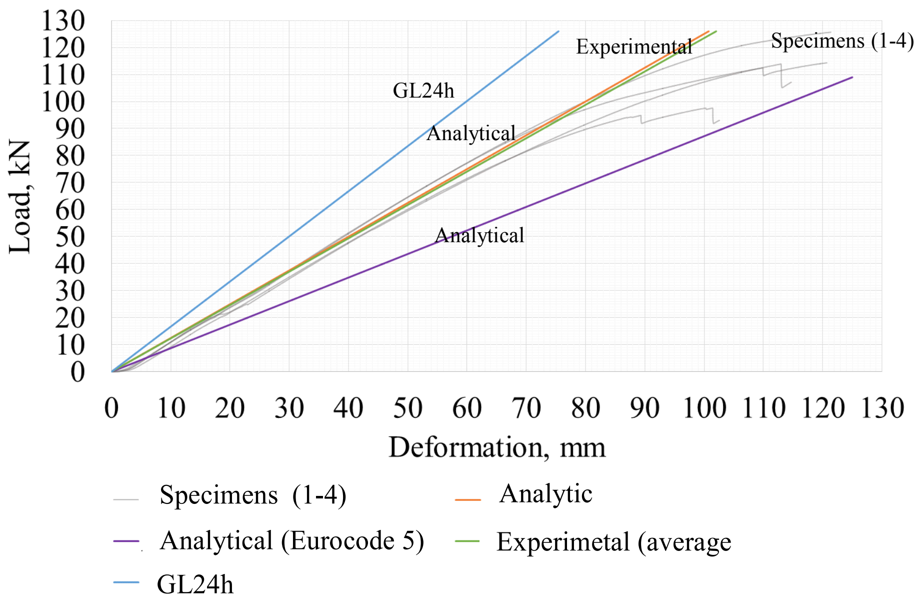

Fig. 5. Load-deformation graph of experimental investigation, analytical solution and glulam beam

Specimen curves of figure 5 show that near the maximum load the screws start to yield. However, to a degree, the overall behavior of the beam is brittle.

The analytical solution corresponds well with the specimens and calculations done with characteristic values of experimental investigation. Whereas the analytical solution, according to Eurocode 5 estimated considerably lower stiffness of the jointed beam. The equivalent glulam beam has considerably higher stiffness than the investigated mechanically jointed beam.

Conclusions

1. By mechanically jointing solid timber beams, the stiffness of the jointed beam is reduced compared to the solid timber and it is considerably lower than the stiffness of an equivalent glulam beam.
2. The bending strength is not reduced by mechanically jointing solid timber beams, compared to the bending strength of solid timber that the beams are made of. In terms of bending strength, the jointed beam can compete with the equivalent glulam beam.
3. The analytical solution according to Eurocode 5 gives elastic properties of the mechanically jointed beam that are very close to actual values of experimental investigation.
4. The analytical solution according to Eurocode 5 is conservative regarding the ultimate limit state. Experimental investigation showed considerably higher load bearing capacity.
5. The length of the mechanically jointed solid timber beam is limited by the availability of solid timber beams.
6. A mechanically jointed solid timber beam is a good, more environmentally friendly and cheaper alternative to glulam beams. It can be used where deflection is not of great concern while good load bearing capacity in bending needs to be provided.

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