

Large-size mechanically joined timber structure subjected to short-term and long-term load

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Abstract: *Large-size mechanically joined timber structure subjected to short-term and long-term load.* The article presents laboratory test results of a large-size timber structure joined with mechanical joints, subjected to static load considering the duration of the load application. The results obtained indicate the potential limitations in applying such solutions despite such advantages as the ease of installation, dismantling possibility, repeatability of components and relatively easy matching to various shapes.

Keywords: construction timber, long-term load, roof covering, mechanical joints

INTRODUCTION

Timber is one of the first construction materials used over generations in this part of Europe. After learning the basics of woodworking, timber was initially used in carpentry structures. It has been used in structural engineering since the invention of mechanical joints and sufficiently durable adhesives. The turning point was the introduction of laminated wood which alleviated most of the drawbacks found in solid wood (such as knots, size limitations), allowing at the same time creation of much larger structures, often with complex geometry (Fig. 1, 2). Literature devoted to such structures is very elaborate, ranging from theory and technology descriptions [1], [4], behaviour of individual components e.g. beams [3], durability problems [5], recommendations for use [2] and predicted use [6]. Despite such broad knowledge available, also in case of such structures, problems are faced, mainly due to delamination of the components (fig. 3) or even disasters in extreme cases [7] (fig. 4).



Fig. 1 Sports and entertainment arena in Chęciny

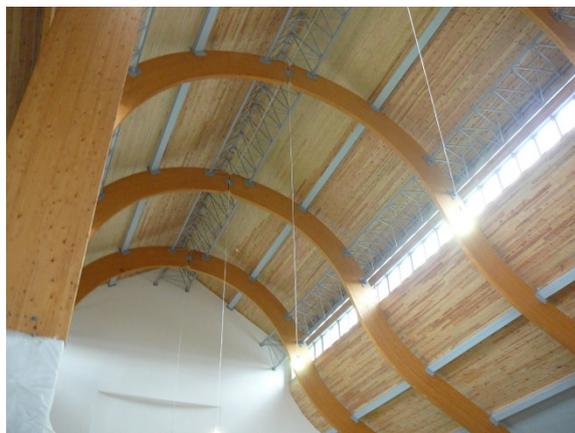


Fig. 2 Church at Bursztynowa Street in Lublin

Problems with observing the technical regime, durability of adhesive joints and logistic difficulties in transit from the workshop followed by installation and during construction of large-size laminated timber components, make the designers consider other solutions, in particular structural construction made of repeatable components of solid wood joined with mechanical joints. An example of the behaviour of such strained structure, including long-term loads, is shown below.

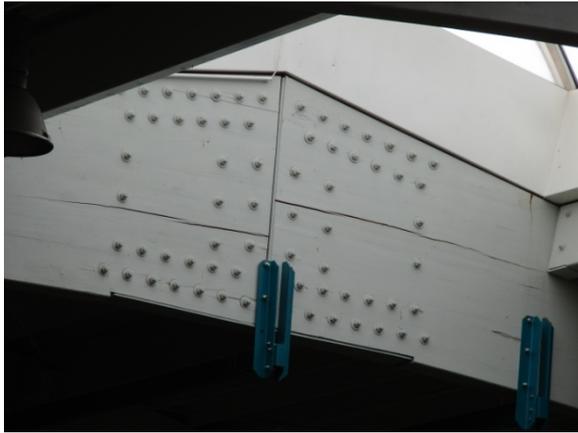


Fig. 3 Delaminated girder – sports arena in Byczyna



Fig. 4 Damaged general girder joint after collapsed roof structure in ice-arena in Bad Reichenhall [7]

CASE STUDY

The timber component tested was a section of roofing structure of a sports and entertainment arena being designed. The component comprised a load-bearing grid composed of three trusses spaced 1.25 m and length (in projection) 10.36 m, divided by seven transoms in 1.25 m centres. The trusses were arc shaped with 0.3 m rise and were made of 8 beams, 4 of which were continuous over the entire truss length, 4 beams were split (filling between transoms). The dimensions of the truss and transom boards were 60 x 200 mm. The beams were joined with $\varnothing 10 \times 120$ mm screws in 140 to 275 mm centres (shorter spacing at the trusses' ends). The trusses and transoms were mechanically joined with M26 tapped bolt. The tested component was covered with two layers of 2 x 22 mm plywood screwed to the grid. The grid was made of C27 class pine wood according to the declaration of conformity provided by the component manufacturer. The component at the test place is shown in Fig. 5.



Fig. 5 Component at the test rig

In order to correctly represent the model performance in relation to the structure under design, one side of it was lifted to the height 1.0 m (Fig. 6). The support was provided by articulated joints at the lower edge of the trusses. In addition to that, at the lowered side sliding bearings of teflon plates were installed (Fig. 7).



Fig. 6 Lifted side of the tested model



Fig. 7 Lowered side of the model

The tests were performed in the following ambient conditions: temperature 23°C - 24 °C, relative air humidity 64%-65%.

wood. Basic data of the model:

- model weight $G= 3200$ kg
- truss span in projection $L1=10.36$ m;
- truss girth $L2_w= 10.44$ m;
- sheathing girth $L2_p= 10.00$ m;
- arc rise before tests $f_1=0.29$ m;
- arc rise after tests $f_2=0.13$ m;
- sheathing width $d =2.5$ m;
- lifting height $s = 1.0$ m.

Tab. 1 Moisture content of the model

Wood moisture content [%]	
Truss (p1)	Slab (p2)
14.3	18.5
15.5	19.1
15.4	21.9
16.8	19.9
14.8	21.5
16.3	21.2



Fig. 8 Photographic documentation of individual loading steps/stages

The tests were carried out to determine strength parameters of the model of timber structure joined with mechanical joints, with plywood sheathing. The component was tested until the load 5.0 kN/m was achieved in relation to the middle truss (w1) and 2.5 kN/m in relation to extreme trusses (w2). The load was applied by gravity with reinforced concrete slabs with dimensions 1.0 x 0.75 x 0.12 m and weight from 134 kg to 143 kg and steel and concrete beams with dimensions 1.5 x 0.35 x 0.15 m and weight from 251 kg to 335 kg. The tested mode was loaded in nine stages, applying the load in a uniform manner. Photographic documentation of individual layers is shown in Fig. 8.

Induction sensors were installed to measure the displacement. 50/120 LY41-4L-10M type tensometers were used to measure the deformation. Figure 9 shows the layout of sensors and tensometers and basic dimensions for determining the rotation angle. The tensometers were bonded on the girder sides and located at the extreme continuous belts, i.e. on the bottom truss belt and on the second one from the top.

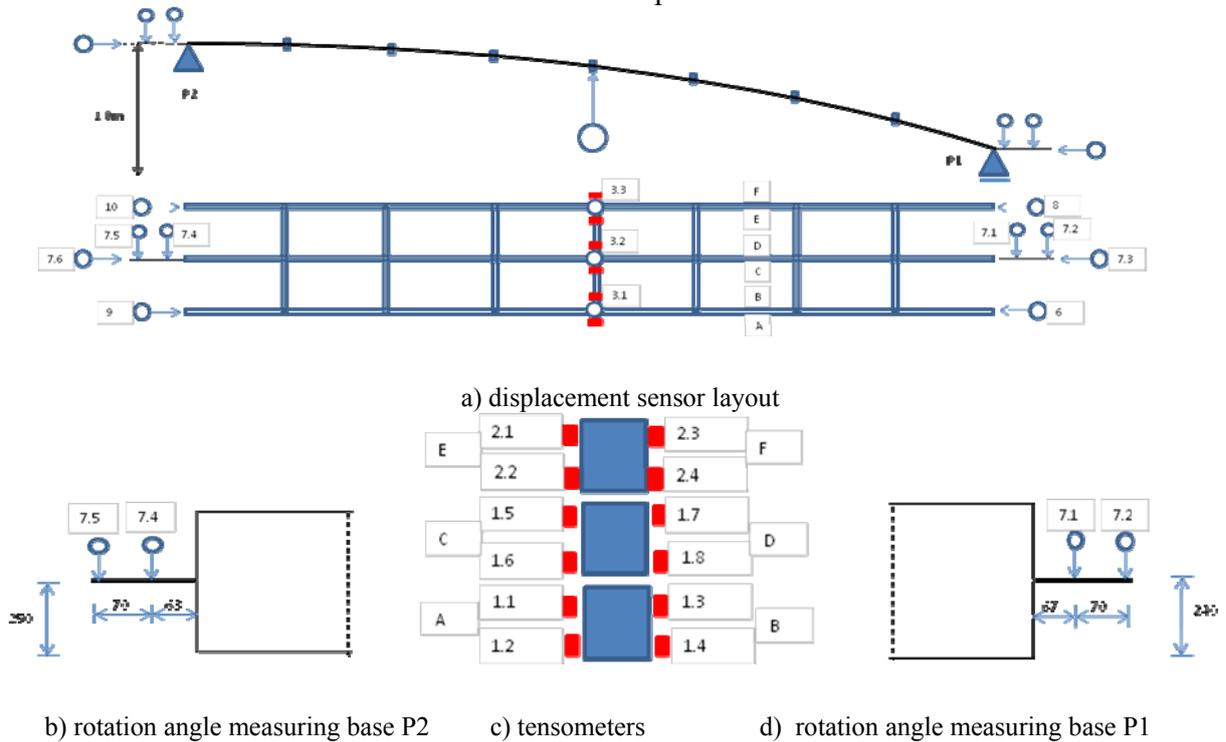


Fig. 9 Location of the displacement sensors and tensometers

RESULTS

The result of the measurements was the flexure (Fig. 10), horizontal support displacement (Fig. 11) and rotation angles vs. the surface load.

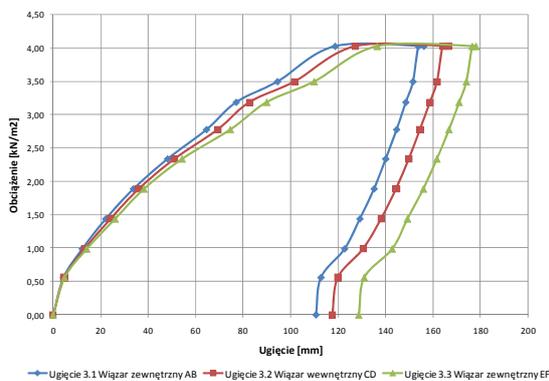


Fig. 10 Deflection vs. surface load

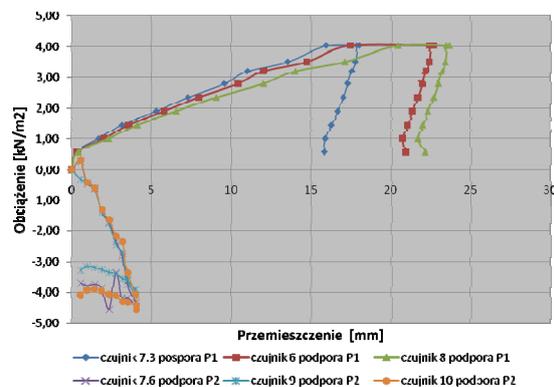


Fig. 11 Longitudinal displacement of supports vs. surface load

The curves (Fig. 12, 13) show the stress in MPa depending on the load level. The load levels are denoted with continuous numbering in the curves. Numbers 1 to 10 corresponds to loading a component, numbers from 11 to 19 to relieving load from the component after 10 hours.

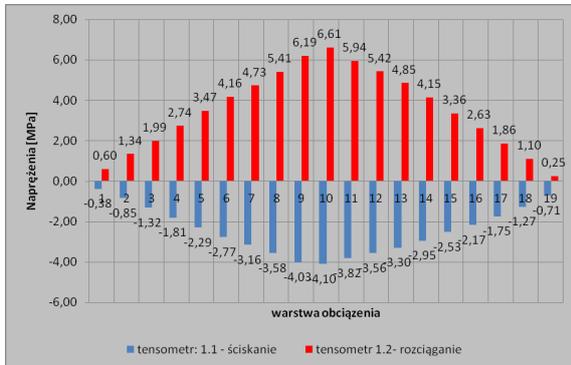


Fig. 12 Stress – outer truss side A

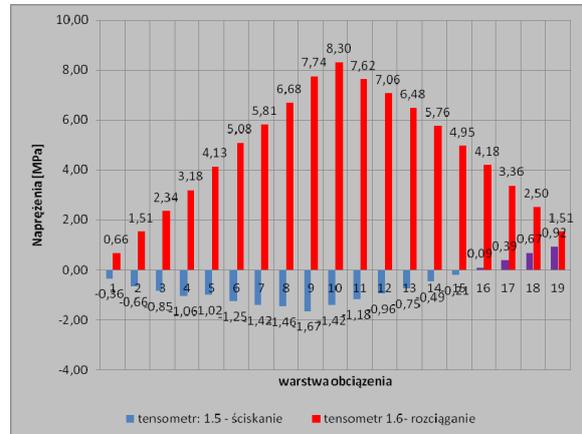


Fig. 13 Stress – inner truss side C

No sheathing damage was found after the tests. After removing the sheathing while removing the truss, longitudinal cracks were found in the beams (Fig. 14, 15). Beam cracks are present in the support area. The cracking occurred in the following areas:

- outer truss (AB): beam 2, 3 and 5 from top (the sheathing side);
- inner truss (CD): beam 3 from the top;
- outer truss (EF): beam 3 and 5 from the top.

Permanent flexure after the entire test cycle was:

- truss (AB): 110.8mm, (CD): 117.7mm, (EF): 128.8mm.

The arc flexure reduced to: $0.29 - 0.13 = 0.16m$.

Permanent displacement of the supports:

- support P1 truss (AB): 20.9mm, (CD): 15.8mm, (EF): 22.9mm,
- support P2 (lifted) truss (AB): 3.3mm, (CD): 3.7mm, (EF): 4.1mm



Fig. 14 Longitudinal beam cracks – top view



Fig. 15 Longitudinal beam cracks from the beam front

Outside the linear flexure-load relationship (above 2.34 kN/m^2), the flexure vs. load characteristics becomes non-linear with clear disturbance at the load level 2.78 kN/m^2 to the maximum of 4.03 kN/m^2 . After 10 hours of maintaining the maximum load and gradual relieving of load from the model, the offset of the load-flexure relationship is clear as compared to the increasing load. At the end phase of loading, at the level 1.44 kN/m^2 to 0, anomaly was found in the stress direction, i.e. only compressive stress occurred vertically.

CONCLUSIONS

1. Within the load range up to level 5, i.e. 2.34 kN/m^2 , the load and stress is close to linear in nature. Structure flexure, depending of the load (except for the pre-load) is of linear character, with the average matching factor $R = 0.9905$. Above the level 5, non-linear relationships occur.
2. The stress distribution in relation to the increased load, in all instances, was close to linear in nature. The location of the neutral centreline, in case of each girder, is shifted above the geometric centre of the truss, towards the sheathing. This proves that the sheathing is also activated.
3. The timber roofing structure tested, joined only with mechanical joints, showed less rigidity that comparable structures made of laminated wood. This is mainly due to a lower integrity of individual components of the structures, more freedom in movement as this is the case of laminated parts, which – before the adhesive bonding is broken – the component acts as a solid piece. Attention is also drawn to larger permanent structure deformation than expected by the designers, which sets significant limitations on the solutions supposed to ensure water tightness of the roofing.

REFERENCES

1. Chugg W. A., Glulam. The theory and practice of the manufacture of glued laminated timber structures, 1964.
2. Dietsch, P; Wolfrum, A.; Winter, S.: Evaluation of wide-span timber structures – results and recommendations. WCTE 2008 conference, Miyazaki, Japan.
3. Falk R., Colling F., Laminating effects in glued-laminated timber beams, Journal of structural engineering, 1995.
4. Noren B., Glued timber structures, 1965.
5. Raknes, E., Durability of structural wood adhesives after 30 years ageing. Holz als Roh- und Werkstoff 55 (1997) 83-90. Springer Verlag, 1997.
6. Stabholz A., Glued Laminated Timber Structures in Europe, Current Trend and Development, International Timber Engineering Conference, 1991.
7. Winter S., Kreuzinger H., The Bad Reichenhall ice-arena collapse and the necessary consequences for wide span timber structures, WCTE 2008 conference, Miyazaki, Japan.

Streszczenie: *Wielkogabarytowa konstrukcja drewniana łączona mechanicznie pod działaniem obciążeń doraźnych i długotrwałych. W pracy przedstawiono wyniki badań laboratoryjnych wielkogabarytowej konstrukcji drewnianej łączonej łącznikami mechanicznymi, poddanej obciążeniom statycznym z uwzględnieniem długotrwałości działania obciążenia. Uzyskane wyniki badań wskazują na potencjalne ograniczenia w stosowaniu tego typu rozwiązań, pomimo zalet związanych zarówno z łatwością montażu, z możliwością rozbiórki, powtarzalnością elementów oraz stosunkowo łatwym dopasowywaniem do różnych kształtów.*

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