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Influence of Distribution of Finger Joints and Timber Flaws on the Damage Evolution of Laminated Glued Timber Beams

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Abstract. A group of six glued laminated timber beams was tested in four-point bending until failure. Both standard measuring devices mounted to the beams and digital cameras were employed to provide for a continuous measuring of displacements and strains as well as visualization of damage evolution and subsequently for quantification of damage mechanisms leading to failure of individual beams. This was accompanied by identification of positions of all visible knots and finger joints. It is shown that their distribution plays an important role in the onset of damage evolution and final failure pattern.

Introduction

All six tested beams were commercially manufactured adopting standard manufacturing process. They were made of spruce having the same geometry and number of layers. However, the number of segnents, their length and arrangement and thus the location of finger joints varied from beam to beam. No particular attention has been paid to the selection of individual laminations. This resulted in a considerable spread of the ultimate strength in between beams. In particular, the ultimate loading ranged from 68kN do 148kN. The objective of this paper is to reconcile such differences by drawing parallel with the location and density of individual finger joints, knots and other visible timber flaws in the region of the maximum stress, and corresponding strength of local segments of timber. This might help in formulation of various structural recommendations leading to an increase of bearing capacity of laminated timber beams loaded primarily in bending. Based on the available graphical documentation of failure, it is possible to tie the onset of damage evolution to a particular flaw, i.e. the finger joint or a secondary flaw such as knot.

Monitoring Crack Evolution

The loading was introduced with the help of hydraulic cylinders. The location of points of load application, beam supports and the specimen geometry is evident from Fig. 1, see also [1]. A step-wise increase of loading forces with a constant increment of 4kN and constant hold period prior to a new load increment as plotted in Fig. 1 was maintained. A gradual monitoring of the failure process was accomplished by employing a high-speed digital camera. However, it was impossible to track every detail of the failure process owing to the load control regime and a relatively short time between the first crack appearance and final failure. In some cases, this took less than 1s. Nevertheless, it was still possible to get a clear insight into various failure mechanisms. The final collapse was always initiated by the crack

developed at the most stressed central part of the beam due to the presence of a finger joint or a large knot.
To this end, two groups of beams were examined in this study. Four beams in particular were manufactured from one set of wood while other two beams from a different one. Both beams in the second set were also subjected to DIC (Digital Image Correlation) measurements to assess the evolution of displacements and potentially also strains and damage. However, recall the load control regime which precluded a direct exploitation of these measurements in this study. Nevertheless, they provided useful information utilized in statistical analysis of effective elastic properties within the framework of Bayesian inference [4]. In this study we only present averages of longitudinal Young's moduli in GPa pertinent to individual laminations. These were determined from a large set of measurements using the Pilodyn 6J measuring device [2,3].

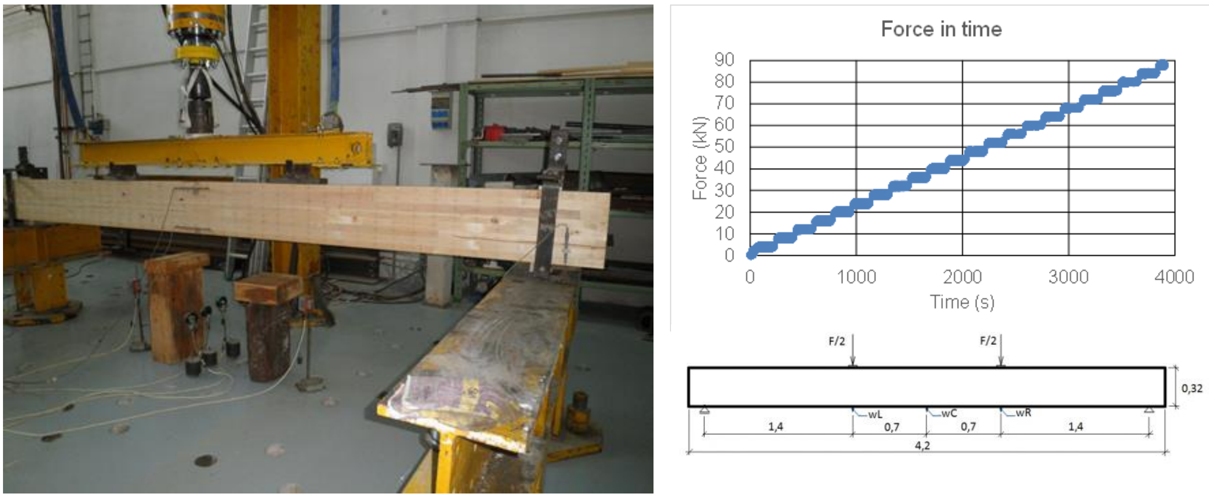

Figure 1: Example of tested beam including the test setup and time variation of the applied load

Beam1. The beam No. 1 experienced loading out of the original loading plane just prior to the final collapse. This might explain its relatively low bearing capacity equal to 68kN only. The onset of failure can be attributed to a pair of large knots in the middle part of the beam having the distance of 35mm only and spreading the entire thickness of the second and third bottom plies, respectively, see Fig. 2.

These partial results suggest the following rather intuitive recommendations. First, large knots spreading the whole lamination thickness should be removed. If that is not possible, we should avoid grouping of knots. One should also pay attention to the location of finger joints and if possible to avoid their grouping at least in the most stressed section of the beam as well.

Beam 2. The beam No. 2 experienced the first failure in the finger joint which happened to be located exactly in the center of the bottom ply. The failure then propagated to the right up to the second bottom ply. Next crack opened in the third bottom ply, which was found to have the smallest average stiffness over the entire length, see Fig. 2. The next failure appeared in a poor-quality joint in the fifth ply from the bottom located 25cm to the right from the first failed joint. This was followed by the total collapse connecting all preceding cracks. This beam reached the collapse load equal to 88kN. As seen from Fig.2 it contained five finger joints located in the central part of the beam with one not suitably placed in the beam center. The partial design recommendation thus suggest to avoid application of poor-quality joints, to divide the most loaded bottom ply into the least number of laminations and to distribute all joints evenly throughout the beam.

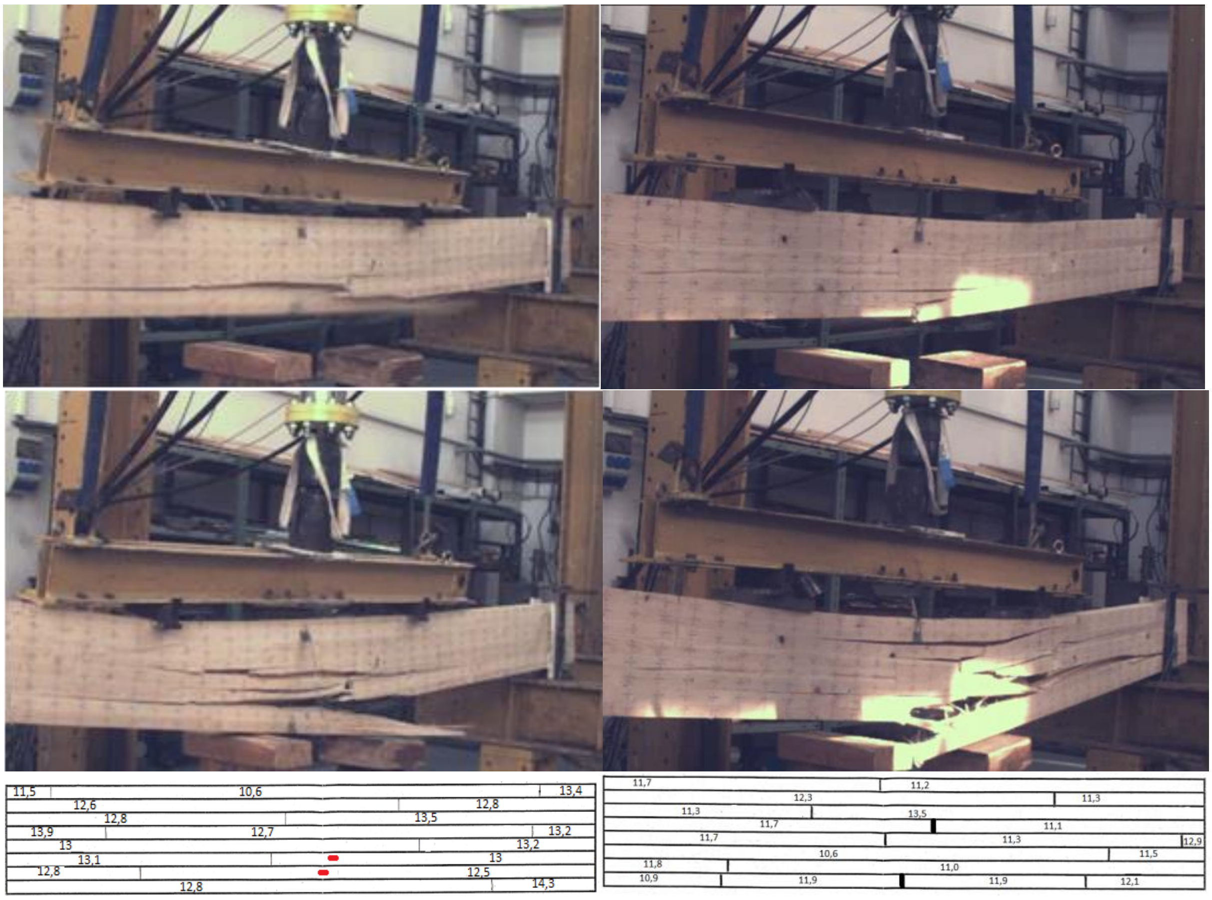

Figure 2: Final collapse of the first beam at the load of 68kN and final collapse of the 2nd beam at the load of 88kN

Beam 3. This beam achieved the same bearing capacity as the previous one. Even here the distribution of finger joints is completely unsuitable. Each ply contains one finger joints found within a 60cm wide band around the beam central part. Five of them, all located in first five bottom plies, were damaged upon the final failure of the beam. The failure mechanism is therefore rather predictable.

As shown in Fig. 3, the beam broke from bottom up due to crack propagation from one joint to the other. In this case, the distribution of large knots and an average stiffness of individual laminations had no effect on the beam failure, even though the two laminations with the smallest stiffness were placed in the bottom ply.

Beam 4. This beam reached a bit higher load bearing capacity equal to 96kN. The failure mechanism was, however, similar to the previous one. Herein, the first crack initiated from the damaged finger joint in the bottom ply and propagated towards the finger joint in the third bottom ply. Most probably, this region contained a hidden defect leading to fracture of the fourth ply in the same location. This indicates the need for identification and removal of such defects prior to gluing. The crack then propagated within this ply in the longitudinal direction. Yet before the final collapse another crack initiated in the fifth ply in the section having a significantly smaller stiffness of about 11.4GPa in comparison to the surrounding, see Fig. 3. Similarly to the previous cases, a finger joint located in the center of the beam caused the final failure. This further supports the need for not having joints in the most stressed regions. Apart from knots and finger joints, we might also want to concentrate on at least approximate knowledge of elastic moduli in individual laminations. These should be examined prior to manufacturing to avoid placing laminations of a large stiffness difference next to each other. This is certainly achievable for machine-wise classification of wood.

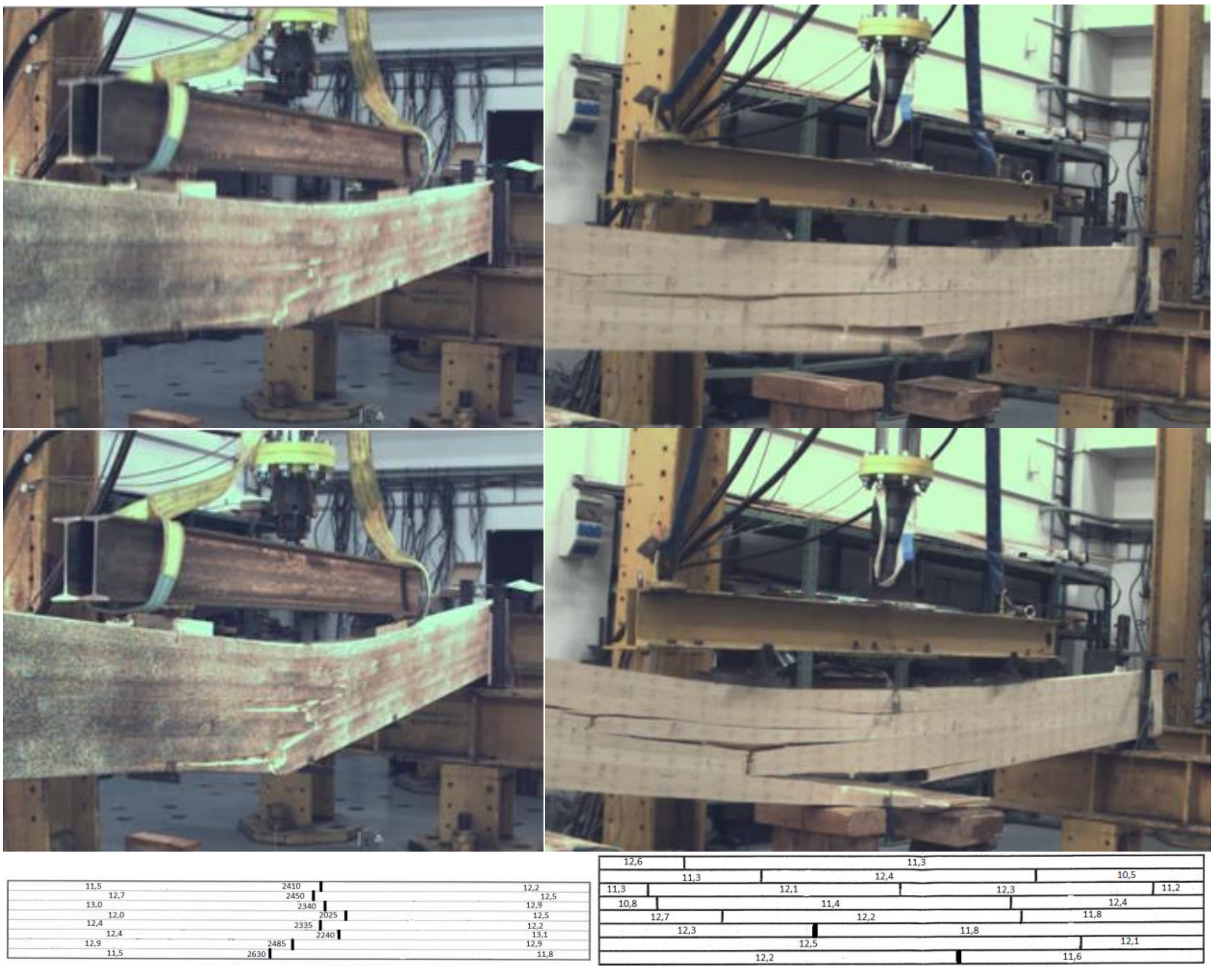

Figure 3: Gradual evolution of cracks. Location of finger joints measured in mm from the right and final collapse of the first beam at the load of 96kN.

Beam 5. A totally different failure mechanism has been observed for the last two tested beams having a considerably higher load bearing capacity. This beam, the last before one in terms of bearing capacity, collapsed at the load of 128kN, which is more than 30% higher load than encountered for the previously discussed beams. On the other hand, the actual progress of damage resembled almost a brittle failure. The first two photographs in Fig. 4 were taken 1s apart. Only one finger joint, highlighted also in Fig.4, failed in this case. Again it was damaged not until propagation of longitudinal cracks. The sequence of photographs in Fig. 4 further indicates that no finger joint contributed to the beam failure as three longitudinal cracks developed in the middle most loaded section of the beam. The first crack initiated in the third bottom ply having the lowest stiffness equal to 10.8GPa. This was also the lowest value of the Young modulus among all tested laminations. The next crack appeared one ply above with the average value of the Young modulus equal to 11.6GPa. Occasionally, the crack propagation was terminated at the finger joint. These joints, however, were always found out of the most loaded central part of the beam. Fracture of the bottom ply approximately in the middle of the beam took place at the final stage of the total collapse. Reading the damage pattern was simplified through a regular grid of points, where indentation measurements of Young's modulus took place.

Beam 6. The last beam with the highest load bearing capacity failed at the load level of 148kN. The failure mechanism was similar to the beam No. 5 so that the beam failed again due to the massive evolution of longitudinal cracks as seen in Fig. 4. In this case the first crack initiated in the bottom ply below the left force and propagated through the corresponding lamination to the right up to the point of force application. The first failure was followed by the evolution and propagation of cracks in the second and third bottom plies starting in the vicinity of two large knots below the right force. The whole fracturing process is documented via a series of photographs in Fig. 4. Checking the average values of Young's modulus we notice a smaller value of longitudinal modulus in the first two bottom plies in comparison to the third ply. The lower value of the elastic modulus suggests also a lower wood density and consequently a lower strength. Nevertheless, these moduli are still of about 1 to 2 GPa higher when compared to the beam No. 5. This explains, together with a better redistribution of finger joints in the most stressed section, its larger load bearing capacity. The two finger joints in the bottom ply played no role as they were located out of the most stresses section. By coincidence the second bottom ply was compact made of one lamination and the third bottom ply had a finger joint close to the support. On the contrary, there was a finger joint in the center of the top ply. It thus can be expected that flipping the beam upside down would result in a much lower load bearing capacity. So apart from grouped large knots in the most stressed section the position of the beam should be correctly selected.

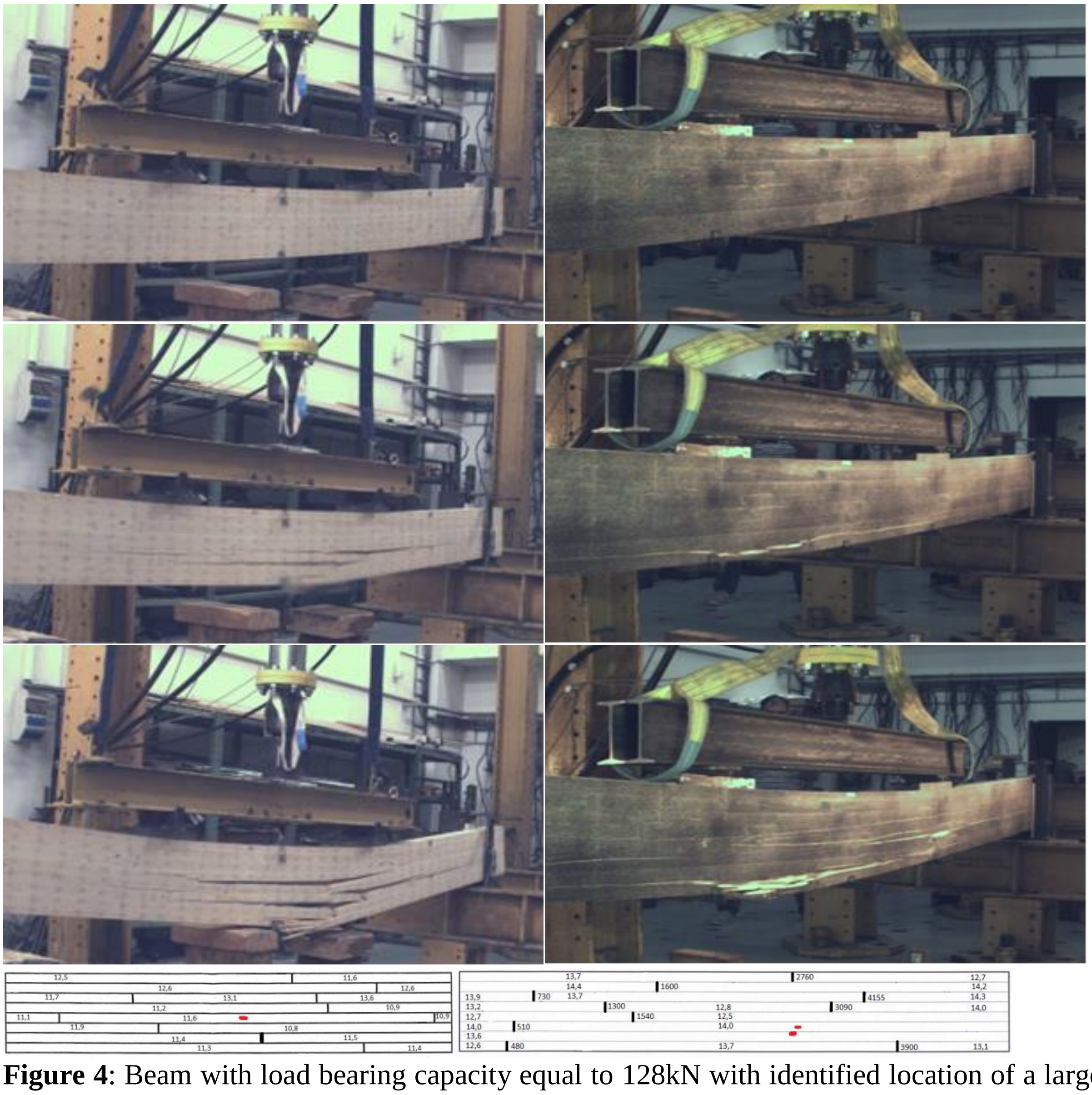

Figure 4: Beam with load bearing capacity equal to 128kN with identified location of a large knot and damaged finger joint and beam with load bearing capacity equal to148kN and the location of pair of knots.

Discussion

The presented study suggests several import design recommendations for glued laminated timber beams. Even though the finger joints are processed according to the current standards, they still present the weakest point in the beam when loaded in four-point bending. All three beams with such an arrangement, recall beams No. 2-4, experienced the first failure in the finger joint. On the contrary, the longitudinal interfacial joints played no role. Cracks have always propagated through individual laminations and their transition from one ply to the other was smooth regardless of the horizontal glued surfaces. Thus suitably arranging the finger joints may considerably increase the beam load bearing capacity, which amounted to more than 30% in our particular case.

From the presented results we may identify two particular failure mechanisms. In all beams with an unsuitably located finger joint in the most stressed section the final fracture took place across this joint leading to a relatively low ultimate load bearing capacity. In the last two beams with a higher capacity the final failure was manifested by a longitudinal fracture of one of the bottom lamination having the lowest stiffness compare to its surrounding or containing large knots.

Conclusions

To increase the load bearing capacity of glued laminated timber beams it is crucial to ensure a suitable redistribution of finger joints. Avoiding their placement in the most stressed section increased the bearing capacity in our study from about 30 up to 50%.

Similar to finger joints the large knots should also be excluded from the most stressed sections. Regions containing a group of such knots are also source of bearing capacity reduction.

Next step should ensure a correct position of individual laminations within individual plies of the beam from their stiffness point of view. It has been suggested that neighboring laminations should not have a significant difference in their stiffness.

When fulfilling all these recommendations we most probably encounter a collapse mechanism initiated by the evolution of longitudinal crack in one the bottom most stressed laminations.

Acknowledgement

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References

[1] L. Melzerová, M. Šejnoha, P. Klapálek, Bending test and simulations of GLT beams. Applied Mechanics and Materials. 611 (2014) 54-59.

[2] L. Melzerová, M. Šejnoha, Results of penetration tests performed on timber GLT beams. WCTE 2014 World Conference on Timber Engineering, Proceedings. (2014) 49-50.

[3] L. Melzerová, M. Šejnoha, M, Influence of distribution of finger joints and timber flaws on the damage evolution of laminated glued timber beams during four point bending. WCTE 2016 CD-ROM Proceedings. (2016).

[4] M. Šejnoha, T. Janda, L. Melzerová, V. Nežerka, J. Šejnoha, Modeling glulams in linear range with parameters updated using Bayesian interface, Engineering Structures. 138 (2017) 293-307.