Numerical Modelling and Experimental Analysis of Step Joints in Hardwood

▶ Abstract

Because of the widespread usage of Computer Numerical Control machinery, wood-to-wood connections recently have become more common in timber constructions than before. Among wood-to-wood connections, step joints have performed well on mechanical properties especially regarding compressive load capacity. In recent research, the geometries are developed as a multi-step joint with same step depth, which have high load capacity and reduce the chord height for notches. To improve load capacity, the geometries in this thesis are optimized with increasing step depths to avoid shear failure between notches. This thesis investigated the development of geometry and compressive load capacity through numerical modelling and experimental analysis. The numerical models simulated by a Finite Element Method solver allowed to determine the load capacity and stress distribution with variable step numbers and depths. The experiments focused on load capacity and failure modes of six joints with different geometries based on European standards, recent research and optimized geometries. The numerical and experimental results both indicate that the step joint with a large total depth and a deep rear notch has a high load capacity. Experimental results demonstrate that the load capacity of optimized multi-step joint is twice as strong as single step joint. From experimental observations, optimized multi-step joint can resist shear stress more than other multi-step joint with constant depths. In conclusion, multi-step joints have benefits on the reduction on chord height and an increase of the load capacity. Experimental results indicate that optimized multi-step joints lead to a higher load capacity than ones with constant depths.

▶ Numerical Modelling

Ten geometries with variable step numbers and depths were chosen for simulations regarding compressive load capacity and stress distribution. The results indicate that the triple step joint with a constant depth of 30 mm has the highest load capacity and stiffness. Besides, the results from numerical modelling indicate that the stiffness highly relates to the total step depth. Regarding stress distribution close to the contact surface, the compressive stress in the strut mainly occurs at the front and rear notch while the shear stress distributes on the vicinity of the front notch and the area between notches.

The wood species considered to produce specimens is European beech (Fagus sylvatica L.). The boards were glued to achieve strength class GL40h.

The results indicate that the optimized joint '5-T10-D5' has the highest load capacity of 481 kN and stiffness. The load capacity of the joint '5-T10-D5' is 10% and 100% higher compared to the multi-step joint '10-T10-D0' and single step joint '1-T30-D0' respectively. Moreover, optimized multi-step joints '5-T10-D5' and '6-T10-D2' lead to a higher load capacity and stiffness than the joint '10-T10-D0' with constant depths. The failure mode of single and double step joints was only compressive crushing whereas the failure modes of multi-step joints were combined shear crack and compressive crushing. The ultimate failure mode of multi-step joints was shear failure from the chord edge along the grain.

The estimated load capacity of multi-step joints is generally lower than the experimental value because of unexpected shear failure. It is suggested to consider the shear efficient length to be the complete length from chord edge to the notch instead of the length between notches.

Comparing experimental results from this investigation with published results, hardwood step joints seem to have a double load capacity compared to softwood joints using GL28h and the same geometries. The load capacity of the joint '10-T10-D0' in hardwood is 140% higher compared to softwood joints.

▶ Experimental Analysis

Based on numerical modelling, six geometries were chosen for experiments. Series of single and double step joints comprising 5 specimens and series of multiple step joints comprising 6 specimens were tested.

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▶ Discussions

Numerical and experimental results both indicate that the optimized five-step joint '5-T10-D5' with a large total depth and a deep rear notch has the highest load capacity and stiffness among six joint series. 50% of specimens of the joint series '5-T10-D5' failed by crushing indicate that the optimized geometry with increasing depths can avoid shear crack along the grain between notches.

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Comparing experimental results from this investigation with published results, hardwood step joints seem to have a double load capacity compared to softwood joints using GL28h and the same geometries. The load capacity of the joint '10-T10-D0' in hardwood is 140% higher compared to softwood joints.

▶ Conclusion

Optimized multi-step joints lead to the higher load capacity than joints with constant depths. Hardwood joints in GL40h seem to have a double load capacity compared to softwood joints in GL28h.