Use of an optimization procedure for the ULS design of bolted glulam timber joints

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Bolted connections are widely used in glued-laminated portal frame connections. Usually, an elastic method is used to compute the strength of these connections. The applied forces and moments are considered uniformly distributed between the bolts. It is generally assumed that the first bolt that reaches its embedment strength under the considered loading conditions the overall joint strength. Typically, the load carrying capacity of a given bolt is calculated from the Johansen equations [1] which take the embedment strength into account. However, this computation method is conservative: clearly, once the most loaded bolt in the joint reaches its load carrying capacity, the joint does not collapse because the other bolts don't reach their respective load carrying capacities yet.

Therefore, an ultimate limit state (ULS) design can be considered in order to go further in terms of strength, taking into account the capacity of *all* the bolts in the joint. Indeed, if the load exceeds the load carrying capacity of a set of bolts, the excess forces will redistribute, until all the bolts reach their capacity. This approach obviously leads to higher strength values, and consequently, to potential material savings.

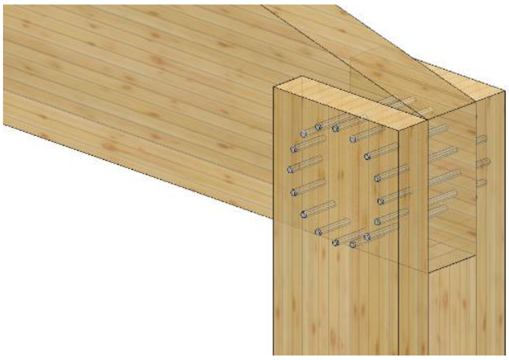

Figure 1 : Bolted joint

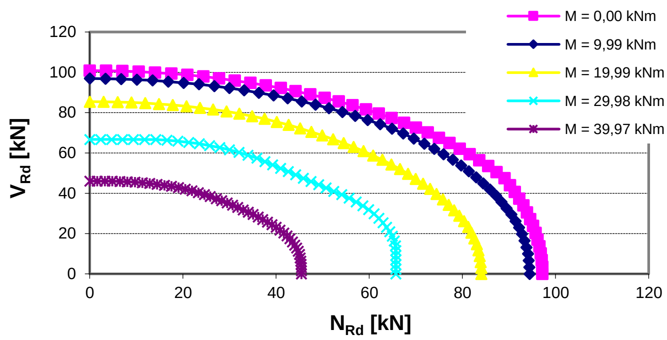

Figure 2 : Example of yield surface

The studied method uses the static theorem of limit analysis [2], also known as the lower bound theorem: if statically and plastically admissible generalized stresses can be found, the associated load is a lower bound of the limit load. Therefore, maximizing a load related to a statically and plastically admissible generalized stress state allows to approach the actual limit load of a system. In the present study, the generalized stresses are in fact the forces acting on each bolt of the joint. The related load is the set of internal forces and moments (axial force, shear force and bending moment) the joint is subjected to.

The problem is solved as an optimization problem. The objective function is the load to maximize, and the main constraints are provided by the equations of Johansen and the equations of equilibrium of the joint. Since the load must depend on only one parameter, the three above-mentioned forces and moments are considered dependent on each other, by means of two parameters.

By fixing a value for these parameters, it is possible to obtain a point of the so called yield surface of the joint. Running the algorithm for a large set of parameters values allows to build, in a "point by point" approach, the complete yield surface, in the sense of limit analysis. For portals with long spans, the results show that the proposed ULS design method allows to increase the joint strength up to 15% compared with the traditional method. Moreover, this procedure allows to highlight the impact of the main parameters (such as the thickness of timber and the diameter of bolts) on the yield surface and on the improved performances. It is then possible to adjust the characteristics of the joints in order to improve its behavior.

References

[1] NBN EN 1995-1-1: 2004, Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings, January 2005.
[2] W. PRAGER, Limit analysis and design, November 1952.