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NUMERICAL AND EXPERIMENTAL STUDY OF PUNCHED METAL PLATE CONNECTION USED FOR LONG-SPAN PITCHED TIMBER ROOF TRUSS STRUCTURE

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ABSTRACT: According to the harmonized European design code for timber structures, Eurocode 5, all pitched timber trusses are designed as an in-plane structure meaning that the bracing systems used must be designed to prevent the out-of-plane failure of the truss. Results from numerical 3D stability analysis of the whole roof structure with respect to the out-of-plane buckling failure indicate, that this assumption needs to be further studied for long-span timber structures. The presented paper is focused on how the stiffness properties of the mechanical connections in the roof structure have influence on the results of the stability analysis. The connections are simplified to springs connecting beam elements in the roof model subjected to the stability analysis. The spring stiffness of connections made by punched metal plate fasteners is derived from full-scale tests which were made for all in- and out-of-plane degrees of freedom. To evaluate the experimental testing, a digital image correlation method was used. The digital images were compared with numerical simulations of the experimentally tested connections to check the potential of using the numerical simulations instead of the experimental testing to get the stiffness properties of various connections used in the whole roof stability analysis. Based on such analysis conclusions are drawn on the behaviour of the truss.

KEYWORDS: Timber truss structures, punched metal plate connections, numerical analysis, top chord buckling length

1 INTRODUCTION

For roof structures with semi-rigid bracing systems of wood (bracing truss, wind brace and roof battens in Figure 1), the out-of-plane buckling length is one of the critical parameter for the top chord design [1].

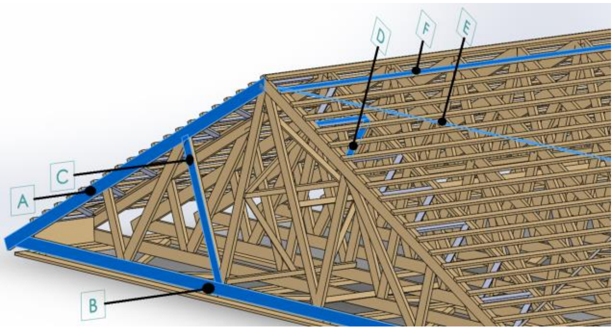

Figure 1: *Pitched timber roof structure with semi-rigid bracing system of wood: A-top chord, B-bottom chord, C-diagonal, D-bracing truss, E-wind brace, F-roof battens.*

The out-of-plane buckling length of the top chord is mainly determined by the centre-to-centre distances between the roof battens, stiffness of connections between top chords and roof battens, stiffness of the roof bracing system (bracing truss in Figure 1) [2], the cross-sectional dimensions and modulus of elasticity in the material in use [3]. Additionally, this buckling length may also be influenced by the stiffness contribution from the other connected members, such as bottom chord through the heel joint and diagonals jointed in several points along the top chord [4].

The aim of this study is to compare the influence of the previously listed factors determining the out-of-plane buckling length of the top chord. The main emphasis will be on the influence of the various connections between members in the truss respectively. The comparison is made by 3D stability analysis which requires the knowledge of all in- and out-of-plane slip moduli (spring stiffness) in the connections between the truss members (top chords, bottom chord and diagonals in Figure 1).

2 EXPERIMENTAL AND NUMERICAL ANALAYSIS OF CONNECTION

The presented study focuses on slip moduli of punched metal plate fasteners commonly used in connections between the truss members. The slip moduli is obtained by experimental testing when connections are subjected to the short-term external loading. It is also checked if previously developed 3D model of mechanical connection with punched metal plate fasteners [5] can be used to simulate the experimental results for the out-of-plane action.

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To obtain the spring stiffness representing six uncoupled degrees of freedom in the joint (axial shear, in-plane shear, in-plane bending, twist, out-of-plane shear, out-of-plane bending), connections of timber boards (strength grade C24) made by punched metal plate fasteners (type GNT 100S) commonly used for timber trusses were subjected to full-scale experimental testing. An example of the specimen tested in twist is shown in Figure 2.

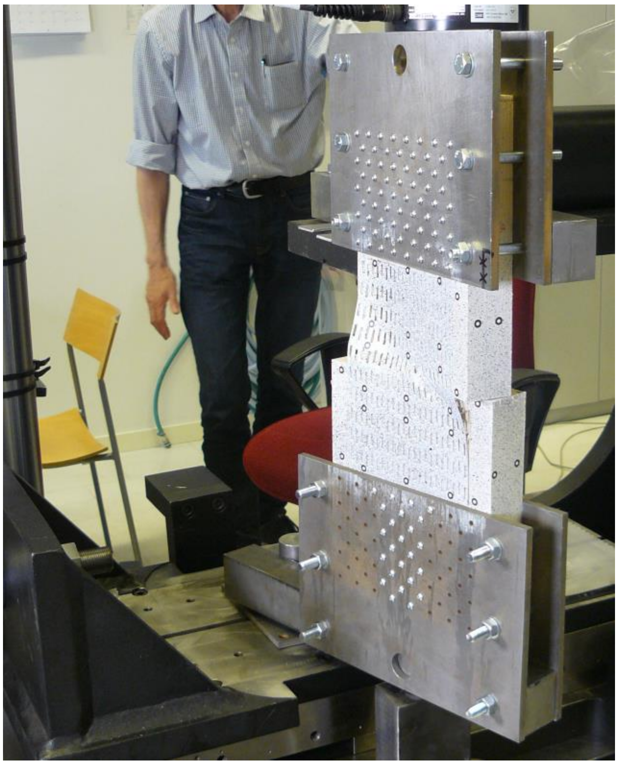
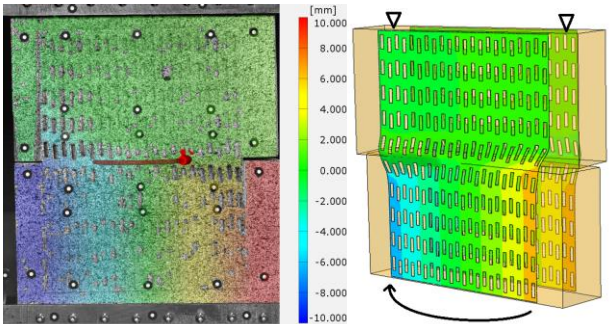


Figure 2: *Two timber boards connected by punched metal plate fasteners from both sides. Ends of the boards are fixed to the MTS biaxial machine with a twist test setup.*

The tested specimens were analysed by using a digital image correlation analysis (Aramis), to study the displacements and the strain development in the punched metal plates and the timber in close vicinity of the plates. For each degree of freedom, the connection spring stiffness was derived from the load-to-slip curves measured at the edge of the gap between the connected members. The same test setup was used to load timber boards without connections to be able to analyse the difference between the responses to the identically applied external loading.

Numerical models in Abaqus were made to simulate the experimental testing for all six test setups. The volume elements were used for timber boards. Shell elements were used for punched metal plate fasteners. Between the surfaces of timber volumes and shells representing the punched metal plates, contact using frictionless interaction was used according to [5]. Individual nails were modelled by using point based fasteners with defined elastic properties in 1 axial and 2 lateral directions according to [5].

Aramis-measured and simulated displacement (colour) fields for the twisted connection are shown in Figure 3. The figures illustrate clearly the twisted geometry and the local gap between the connected timber boards.



(a) (b)

Figure 3: *Punched metal plate connection loaded in twist by 1.73 kNm with colour plot for the out-of-plane displacements.*
(a) Illustration of Aramis-measured displacements.
(b) Simulated twist deformations of tested connection specimen.

3 CONCLUSIONS

Aramis-measured displacements used to calculate the strain development in the punched metal plates showed it to be an efficient way to compare the results from full-scale 3D connection tests with results from the numerical simulations. The presented numerical simulation approach seems to be an efficient alternative to the experimental testing used to get the slip moduli of connections. The benefit of numerical simulations is the possibility to create stiffness for various types of connections like heel joints with various punched metal plate fasteners regarding sizes, positions and orientation to the timber grain which may be difficult to test experimentally. The obtained slip moduli of connections may be used for 3D stability analysis of the whole long-span pitched timber roof structure with respect to the out-of-plane buckling failure.

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