Design of three dimensional nailing plates

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Summary

There is a significant possibility to improve calculated load bearing capacities of spatial connections with thin walled metal nailing plates making them more consistent with the results from tests. The reason is that the design of these connecting elements has inadequate support in the existing Standards. Therefore, it is the intention of the research to improve on this state of knowledge. This paper describes the whole process of the research which consists of the full scale experiments, 3D FEM models in Abaqus CAE and the developing of an existing analytic solution.

1. Introduction

Timber connection using thin-walled metal elements gradually supplant traditional carpentry joints. Their main advantage is that they do not weaken connected timber elements. Other advantages include the possibility of in-situ implementing or possibility of direct connection of timber elements to steel and concrete structures.

The most common thin-walled metal connector is steel angle with annular ring nails (see Fig. 1).

2. Behavior of spatial connections by thin-walled metal elements

Connections by thin walled metal elements are very ductile. This is very favorable, because the over-loaded structure can be easily identified by eye.

Load bearing capacity of these connections can be generally determined by three possible forms of collapse: failure of steel element, splitting of timber element caused by

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tension and failure of nails.

Nevertheless it has been proved by experiment that the failure of nails is predominant. The splitting of timber element is eliminated by the check according to EC5 [1], which must be part of every static design. Also steel plates are punched to avoid inappropriate stresses.

3. Current support in Standards and the specialized literature

Eurocode 3 [2] contains the calculation procedure for steel membrane that can be used to determine the stresses in steel plate. There is also a table of minimum spacing and edge and end distances for nails.

The Structural Timber Education Programme (STEP) [3] contains general knowledge about static schema of spatial joints by thin-walled metal elements and the example of calculation of end of the beam connection to main beam by U-lug.

The Technical Report 17 (TR17) [4] published by the European Organisation for Technical Approvals (EOTA) contains the example of calculation of a spatial joint of timber elements by steel angle loaded in a direction that is opening to the angle. The load bearing capacity is determined according to the model, where the resisting features are two plastic hinges and a group of nails in tension which is expressed by equation:

\[
F_{\text{max}} = \left[ M_{\text{purlin},k} + M_{\text{beam},k} + k_{\text{ax}} F_{\text{ax},k} n \cdot x_{y} - \Sigma x \right] / x_{y}
\]

\(F_{\text{max}}\) is maximum force per angle bracket

\(M_{\text{purlin},k}\) is moment capacity of the plastic hinge in the corner of the angle bracket

\(M_{\text{purlin},k}\) is moment capacity of the plastic hinge in the shoulder of the angle bracket

\(k_{\text{ax}}\) is efficiency factor for axially loaded nails

\(F_{\text{ax},k}\) is withdrawal capacity of the used annular ring nail

\(n\) is number of efficient nails

\(x_{y}\) is position of plastic hinge in the shoulder of the angle bracket

\(\Sigma x\) is sum of coordinates of nails

Fig. 2 Static schema from EOTA TR TR17
This approach is not only very simplified but also difficult to use. The first simplification is that the hinges are not linear. It is proved by experiment that their real shape is determined according to the rules of the path of least resistance. The second simplification is that the secondary reinforcement of the nails due to prying of the nails is neglected. And the third and the most important simplification is that there is neglected the dangerous influence of the pushing end of the angle bracket. This simplification is dangerous because the pushing end acts at the dangerous side of the calculation.

The main reason why this calculation is difficult to use is incalculable input data. The moment capacities and places of plastic hinges are determined experimentally. Withdrawal capacity of the used nail is not according to the Eurocode 5 [1] but according to the Danish timber code. And the number of efficient nails is determined without any explanation.

Given these reasons one part of the author’s research was to develop this calculation. This part is used as a model example to describe the whole research project.

4. Research at The Czech Technical University in Prague

The research is in cooperation with two companies: BOVA Březnice (Czech producer of thin-walled three-dimensional metal plates) and FINE (Czech software company, SW for civil engineers). The fundamental steps of the research are described as follows.

**Optimization on 3D FEM models**

To determine positions of the nails and shapes of the thin-walled steel elements, FEM models were made in Abaqus CAE. The model of the material of the steel element was elasto-plastic. Timber was simplified to elastic boundary conditions. And nails were fixed by springs in tension. This reduced model was accurate enough for the design.

**Experiments**

Full scale experiments according to EOTA TR 16 [5] were made to determine experimental load bearing capacities of chosen angle brackets. Partial load bearing capacities were determined by two limits – collapse and maximal displacement of 15 mm. Each set of the experiments had 10 samples. Final characteristic load bearing capacities were firstly calculated according to EC0 [6] and then reduced according to EOTA TR 16 [5].
5. Methods and Prospects

Analysis of the experiments shows that the approach from EOTA TR17 [4] can be easily simplified. Plastic hinges can be placed to the corner of the rib and to the end of the rib. And load distribution to the nails between the hinges can be conservatively set as being linear. Nevertheless it is important to do more experiments so as for example to verify the check on the possibility of the rib to resist to the bending moment between the plastic hinges.

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References