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# FINITE ELEMENT SIMULATION OF NAILED GLULAM TIMBER JOINTS

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***Abstract***

*This paper presents a finite element modeling method for a certain type of nailed joint between glulam beams. The joint in question is a traditional arrangement of a horizontal beam and a vertical pillar but here there is also a nailed steel plate inserted on the two sides in order to strengthen the joint. Experimental results and a comparisons of simulated and experimental results are made. The model includes the elastic and plastic orthotropic behaviour of wood and the elastic and plastic behaviour of nails. The nail joint between the steel plate and the wood is modelled as an elastic-plastic surface to surface connection with elastic-plastic properties. Also the reinforcing effect of nails in the nail-affected volume of wood is taken into consideration by raising rolling shear yield limit in the affected wood volume.The comparisons show that the model works well and give results that are comparable to experimental results.*

***Key words:*** *FEM; nailed joints; timber joints; glulam;*

## INTRODUCTION

Glulam beams used for building construction are stiff and strong but there are critical areas in the design of a load carrying structure using glulam beams. Areas where the stresses can be a problem are at points where there are loading perpendicular to grain. The typical points where this happens are the points where vertical pillars meet horizontal beams such that the horizontal beams are put on top of the pillars. At such points there are large shear forces and also limited areas to uptake the forces due to the slender design of the beams and pillars. One idea to cope with high forces is to reinforce the joint between the pillar and the beams with the help of a perforated metal plate and nails, see Fig.1.

***Fig. 1a.***
***Glulam pillar (cross section 215x405 mm) below and glulam horizontal beam on top. No reinforcement.***

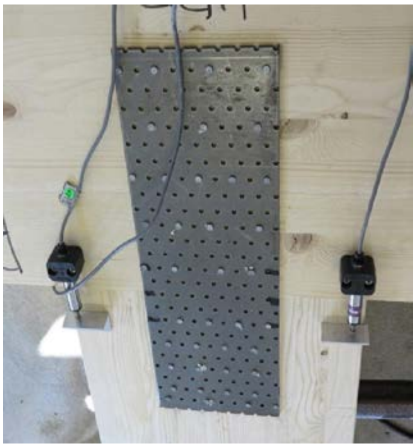

***Fig. 1b.***
***Joint reinforced with steel plate and nails.***

With this method two different joint types are working in parallel, one is the primary contact joint between fibres in the loading direction for the pillar and fibres perpendicular to the fibre direction in the horisontal beam. The other joint type is the steel plate with nails. The question is then how these two joint types work in parallel and how much load each joint type can transfer and how much the total load capacity of the combined nailed and contact joint increases compared to only having the contact type joint. The answer to this depends on how the stiffnesses and yield limits of each joint type cooperate.

Numerical modeling of the behavior of nail connections, using FEM with elastic-plastic material models, have previously been studied. For example, Hong and Barret 2010 developed a three-dimensional finite element model of a single nail to wood connection based on transversely isotropic plasticity. Model results were compared to results of lateral resistance tests with parallel and perpendicular to grain loading and good agreement was found. Hong et al. 2010 modeled a ten nail multiple connection with a mortise and tenon joint and results were compared to available connection test data. The model and test results agreed well. In both Hong and Barret 2010 and Hong et al. 2010 papers, a wood foundation method was used to model the wood surrounding the nail, this to address the crushing behavior induced by nail slip. Zhou and Guan 2011 used an orthotropic elastic-perfectly plastic material model together with an inverse modeling technique to simulate flat nails embedding strengths. Experiments and simulation results correlated well. However conclusions were that simulating 20-30 nails in 3D is time consuming and ineffective. To be able to apply the models in a more efficient way more novel ways will have to be used. Meghlat et al. 2012 presented a way to simulate timber nail joints using finite elements. To avoid 3D modeling of nails using solid elements, beam elements were used. A push out shear test of a single shear timber to timber connection was simulated successfully.

## OBJECTIVE

The purpose of this paper is to describe a method to model the reinforcing effect of nails in a glulam timber joint with a finite element model. Also to show results from simulations with the model and experimental results and to compare them.

## MATERIAL, METHOD, EQUIPMENT

Experimental tests with various amounts of nails were made similar to the simulations with the geometry shown in Fig. 2. The steel plate geometry is shown in Fig. 3. The test and model cases was denoted 2A, 2B, 2C, 2D and 2E. The number of nails in these were 0+0, 20+20, 40+40, 60+60/1, 60+60/2. Here 20+20 means 20 nails on each side since there were one plate on each side of the joint. The difference between the two last variants are that the nail patterns were changed. For all variants except the last, the nails were evenly distributed over the plates but for the last variant (2E) a grouping of nails was made in two groups on each side of the joint.

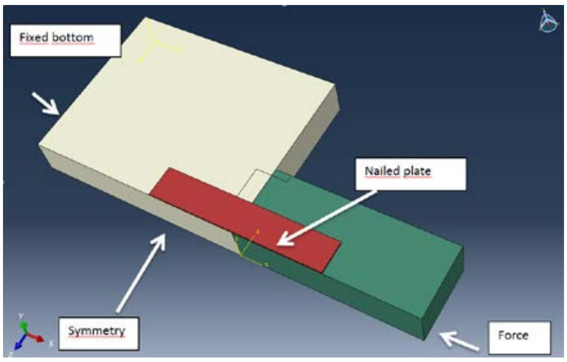


***Fig. 2.***
***¼-model of joint***

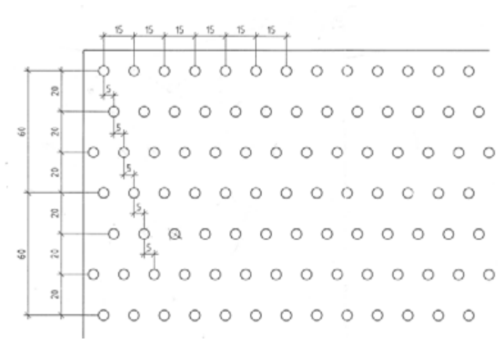

***Fig. 3.***
***Perforated steel plate***

Tests were conducted using slowly applied hydraulic loading with recording of load and deformation over a certain distance, see Fig.1 for an example of displacement gauge placement. At least three test samples were used to evaluate a mean test value curve which consist of two straight lines. From the test curves, see Fig. 4 for an example for case 2A and 2B, the two straight lines were adjusted, one for the elastic behaviour with high slope and one for the behaviour after yield with much less slope. These straight lines were then used as test results to be compared with model results.

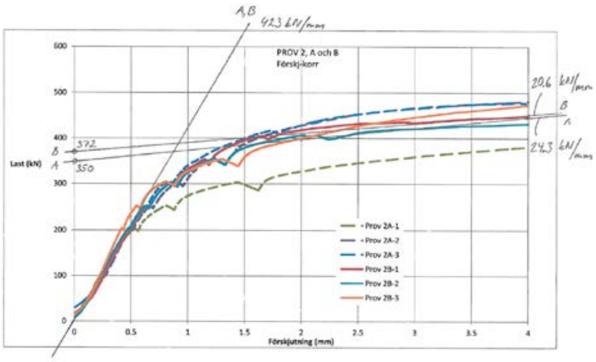

**Fig. 4.**
***Test results for combined joint with 0 nails (2A) and with 20+20 nails (2B)***

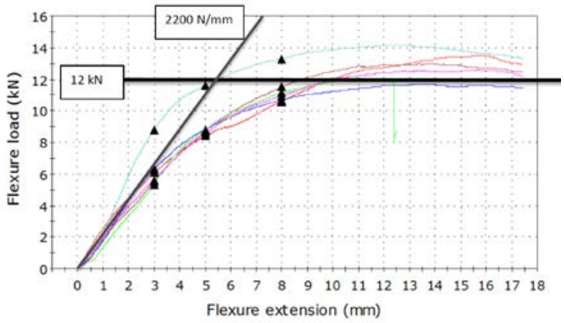

**Fig. 5.**
***Test results (thin lines) for 4 nails from 6 tests and idealized model (solid thick lines) for results***

Simulations were conducted with the commercial finite element code ABAQUS (Abaqus, 2012) and with a user-supplied routine for orthotropic plasticity (Ekevad 2006, Ekevad 2010). The glue model used was the surface based cohesive behaviour that is a part of the ordinary ABAQUS programme. Elements are parabolic 20-nodes brick with reduced integration.

The wooden material used was glulam beams made of spruce with grade according to Eurocode 5 glulam L40c. The cross sections were 215x405mm and 215x630mm for the pillar and horisontal beam, respectively. The length of the horisontal beam was 1000mm. The horisontal beam was supported on the opposite side of the side that was loaded and the load was put on the pillar, see Fig. 2. The green pillar part shown in Fig. 2 was loaded in the fibre direction while the horisontal beam (white i Fig. 2) was loaded in cross-fibre direction. Nails were 50mm long with diameter 4mm.

An elastic-ideally plastic orthotropic material model was used for wood parts with elastic modulii according to rules in Eurocode 5 set as 410, 410, 13000, 114,760,760MPa in the 1, 2, 3, 12, 13, 23-directions. 1, 2 and 3 stands for radial, tangential and fibre directions, respectively. Poissons ratios were set to zero. The yield stress limits were set to 1.5 times characteristic strength according to Eurocode 5 for glulam L40c which gives yield stresses 4.05, 4.05, 38.1, 0.61, 4.05, 4.05MPa in directions 1, 2, 3, 12, 13 and 23. However the value 0.61 MPa for rolling shear yield stress was raised from 0.61 to 6.1MPa in order to effectively reduce rolling shear plastic deformation in the wood material in order to model the reinforcing effect of the nails on the volume of wood that is penetrated with nails. Rolling shear yield was only important for the wood material just below the steel plate on the horisontal beam. Elastic modulus 210000MPa and Poissons ratio 0.3 were used for the steel plate.

First 6 tests were conducted with no pillar but instead with load applied directly on the steel plates and with only 4 nails, 2 on each side, in order to achieve load deformation curves and usable stiffness and yield data for single nails, see Figs. 5, 6 and 7. Because no pillar was included stiffness and yield was only influenced by the nails. Four tests with load parallel to fibre direction and 2 tests with load perpendicular to fibre direction were conducted. The solid lines in Fig. 5 show the idealized model that was achiveved from these 6 tests and results were an elastic stiffness of 550 N/mm per nail and an ultimate or yield load of 3kN per nail. However, for simulations of combined joint, it was found from comparisons between test data and simulation results that the single nail stiffness should be increased to twice its value from the single nail tests, to 1100N/mm per nail. The reason for this is not known but may have to do with the influence of contact area and friction between the steel plate and the wood since part of the stiffness of the nail joint comes from friction between steel and wood. Another cause may be influence from number of nails on a certain area. The yield limit 3 kN/nail was used for all modelling.The nail connection between the steel plate and the wood material was modelled as a glued joint between the steel plate and the wood surface. The glue inbetween the steel surface and the wood surface was given an elastic stiffness of 1100N/mm per nail and also an yield limit of 3kN per nail.

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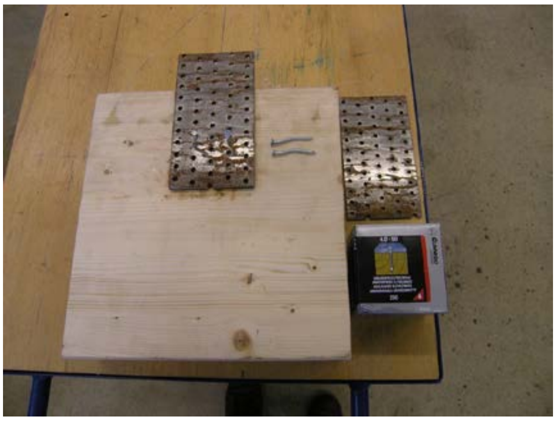

*Fig. 6.*
***Glulam beam, steel sheet and nails after test with load perpendicular to grain***


*Fig. 7.*
***Glulam beam, steel sheet and nails after test with load along grain***

**RESULTS AND DISCUSSION**

Results for combined joint models are shown in Fig. 8 which show that there was an increase of load bearing capacity of the combined joint when the number of nails increased. Model for 0 nails fits very well to experiments but model for 20+20 nails fits less well. Model for other number of nails fits reasonably well. The load bearing decrease between model 2D and 2E because of change of nail pattern is realistic in the model. Deformation examples are shown in Figs. 9 and 10.

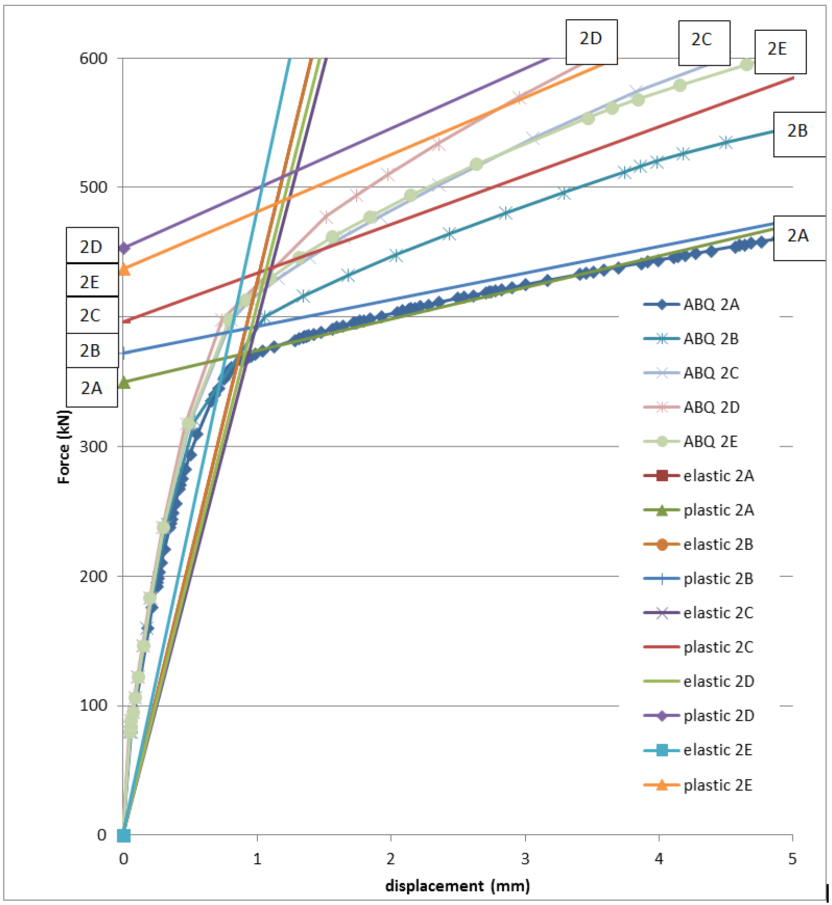


*Fig. 8.*
***Test results (solid straight lines) and model results (dotted curved lines) for joints with number of nails 0+0 (2A), 20+20 (2B), 40+40(2C), 60+60/1 (2D) and 60+60/2 (2E)***

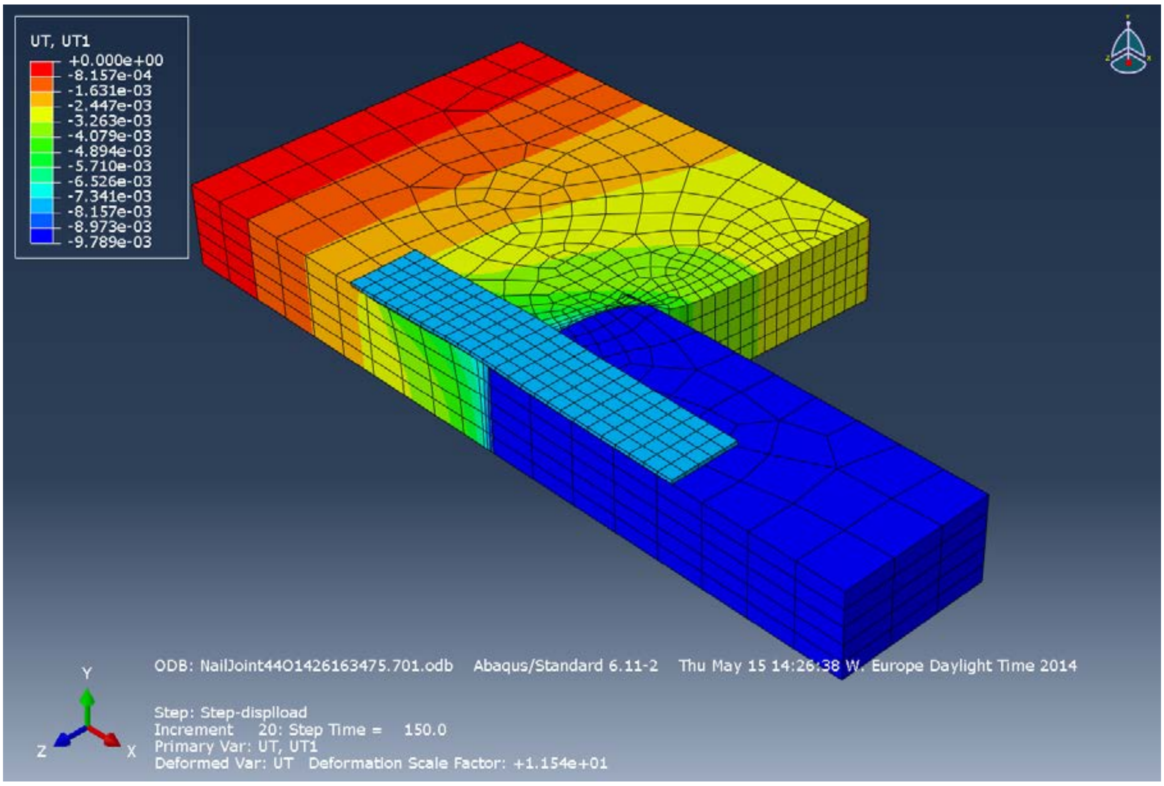


***Fig. 9.***
***Deformation in x direction for model with 40+40 nails (2C). Load 600 kN***

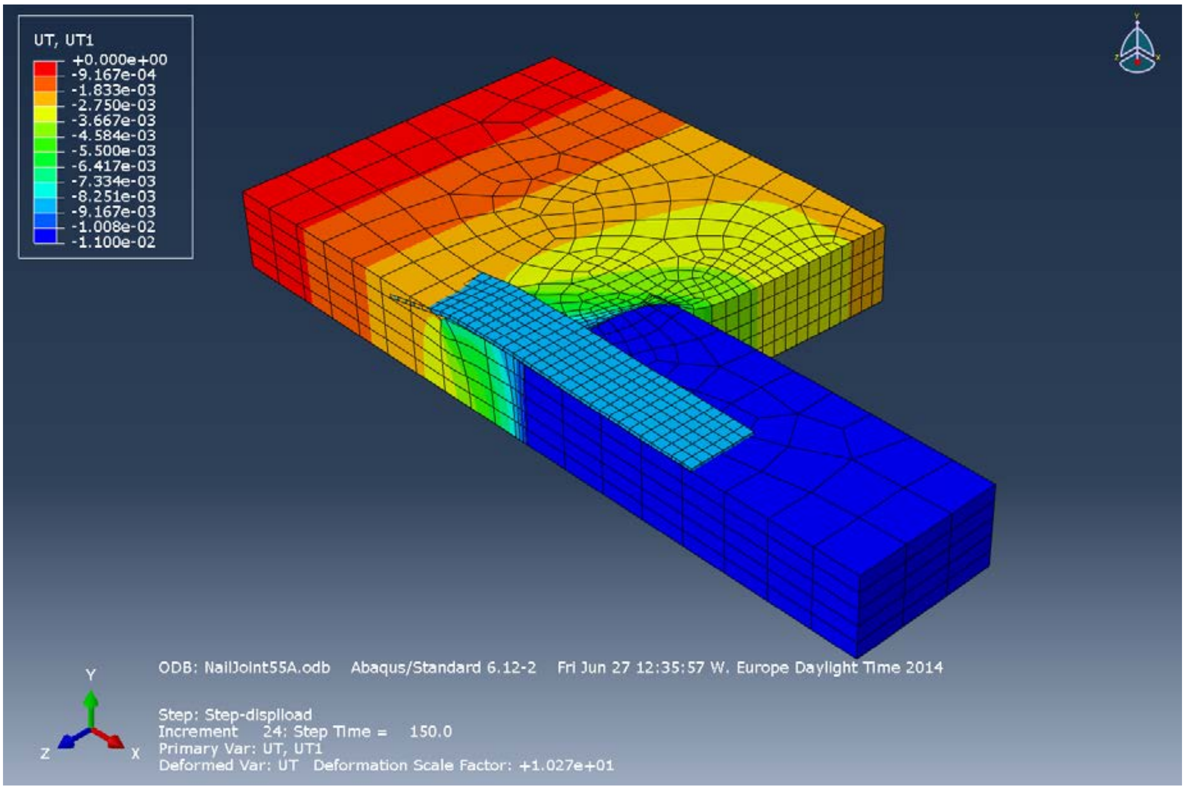


***Fig. 10.***
***Deformation in x direction for model with 60+60/2 nails (2E). Load 600 kN***

## CONCLUSIONS

The results show that the model works suffiently well compared to test results with the elastic and plastic material parameters that were described above. However, test results show much spread and there is a need for more tests in order to verify and possibly improve the model. One such issue to investigate is the influence of various nail patterns and concentrations of nails and if such varying nail distributions influence the results. Also interesting is to further investigate the reinforcing effect of nails on the affected wood volume and wheter this effect that is here described as an increased rolling shear yield limit also affects the wood properties in some other way. The depth of influence of the nails is also an unknown parameter. Further studies may shed light on those issues.

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