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A NOVEL WAY TO SIMULATE THE BEHAVIOUR OF TIMBER COMPOSITE CONNECTION JOINTED THROW DOWELS

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Abstract

This paper presents a novel way to simulate, with the finite element method, the behaviour of timber composite connection jointed throw dowels. The main originality of this study is the demonstrated ability to avoid the detailed 3D finite element modelling of dowels using solid elements, which is costly ineffective. The authors developed recently a beam-to-solid approach (BTSA), where the dowels were modelled using one-dimensional beam element, while the assembled timber members were modelled using solid elements. The effectiveness of the numerical model developed was verified experimentally showing several advantages by comparison to the existing models in the literature.

1. Introduction

Composite timber connections through dowels have, and continue to be, thoroughly studied by several researchers in different laboratories due to their efficiency. To investigate the full potential of such composite systems, experimental tests need to cover as many scenarios as possible which are expected to be very expensive and time consuming. Thus, in order to understand extensively the behaviour of composite timber connections, a numerical modelling with the finite element method is used, validated against experimental result [3]. Generally, the timber and dowels was modelled using 3D solid finite elements accounting for frictional contact conditions between the timber and the dowels. However, this required to use hundreds of thousands or even small size finite elements in the model, involving unacceptable extensive computing times, in particular in general three-dimensional industrial applications. In addition, this way of modelling often leads to divergence [5], which is caused, probably, by the excessive element distortions. It is, therefore, of extreme important to develop fast and accurate numerical models to predict the behaviour of such connections.

The authors developed recently a beam-to-solid approach (BTSA), which has been successfully applied to predict the load-slip curves of timber-to-timber [1] and timber-to-concrete connections [2], in the context of single plane push-out shear tests. In that approach, the dowels were modeled using one dimensional beam elements, while the timber was modelled in detail using solid elements. Since the degrees of freedom (d.o.f.) differ from the beam element to the solid element, the authors have modified the existing 2-node beam element, involving in a 4-node beam element with only translational d.o.f. [4]. The aim of the present paper is to evaluate the appropriateness of the beam-to-solid approach, developed previously, on full-scale simply supported timber-to-timber composite multi-layer beam, where the timber layers were interconnected with welded wood dowels providing interlayer shear resistance. [3].

2. Experimental Study

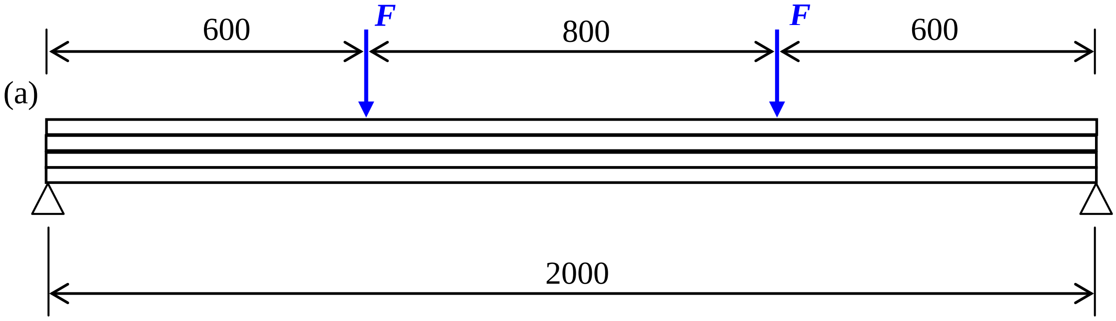
2.1. Construction process of multi-layered beams

In the first stage of this work, it was decided to replicate the earliest work done on rotational wood dowel welding of four-layer beam [3, 6]. In this study, C16 Irish Spruce was used to construct the four-layered beams. The layer dimensions were 140 x 38 x 2200 (mm). Commercially fluted beech dowels of 10 mm of diameter were used for the assemblage of layers. All four-layered beam systems had only one row of wood dowels with same diameter inserted at 60°, with respect to the plane of the substrate surface (Fig.1).

Fig. 1: Four-layer beam held in clamps during construction

2.2. Bending tests and measurements

This part of study presents some results of an experimental program which includes bending tests of multi- layered beams, assembled with different number of wood dowels, performed according to the EN 26891 Standard European Norm [7].
The experimental program consists of bending tests of four-layered beams, assembled with 20 wood dowels. The series of four-layer doweled beams systems have been tested. Post-elastic behaviour was not the focus of this early study, thus we didn’t want to fail the beams initially as we wanted to be able to repeat tests if necessary. The four-layer beams was loaded up to 7.22 KN, with test arrangement as shown in Figure 2. The load was applied using an Instron 8500 series load cell. A steel jig consisting of two 80 mm and 90 mm box sections and two half cylindrical load pads were used to convert the one point load of the Instron load cell to two point loads acting on the beam. In each case, an un-joined layered beam was loaded and the load-deflection curves were recorded for control.



(b)

Fig. 2: Four-point bending tests: (a) test arrangement (in mm) (b) four- layer beam during test.

3. Finite Element Modelling

In the last decade, constitutive modelling of timber material, using the finite element method, has increasingly been used as a development and analysis tool in a large number of research laboratories. The analysis of non-linear behaviour of timber has been studied by many authors using 2D or 3D approaches. This section presents, firstly a 3-D FE-model as an attempt to simulate the structural response of the doweled four-layered beams. Once the FE-model is verified against experiments, parametric study can be undertaken towards the improvement of the design of multi- layered beam systems, with limited number of measurements and structural tests.

The ABAQUS finite element code was used to investigate the behavior of the jointed connected members through dowels. Since the connection geometries admit two plans of symmetry, only one quarter was modelled. 3D finite element model was assumed and eight-node solid elements have been used for the discretization of the timber. The dowels have been modelled using 4-node one-dimensional beam element.

3.1. The 3D Solid Finite Element Modelling

By considering the two plans of symmetry, only one quarter of the two-layer beam was modelled, involving two types of external boundary conditions: those due to symmetry (for both the layers and dowels) and supports, and those due to loading. The load was introduced by imposing controlled displacement according to the arrangement shown in Figure 2a. The layers and dowels were meshed using 8-node hexahedral elements. Figure 3 shows typical mesh generation for a four-layer beam including loading and boundary conditions. Since there was expected to be high deformation in the area of the dowel where the four layers move in opposite directions, relatively fine meshes were used in these zones.

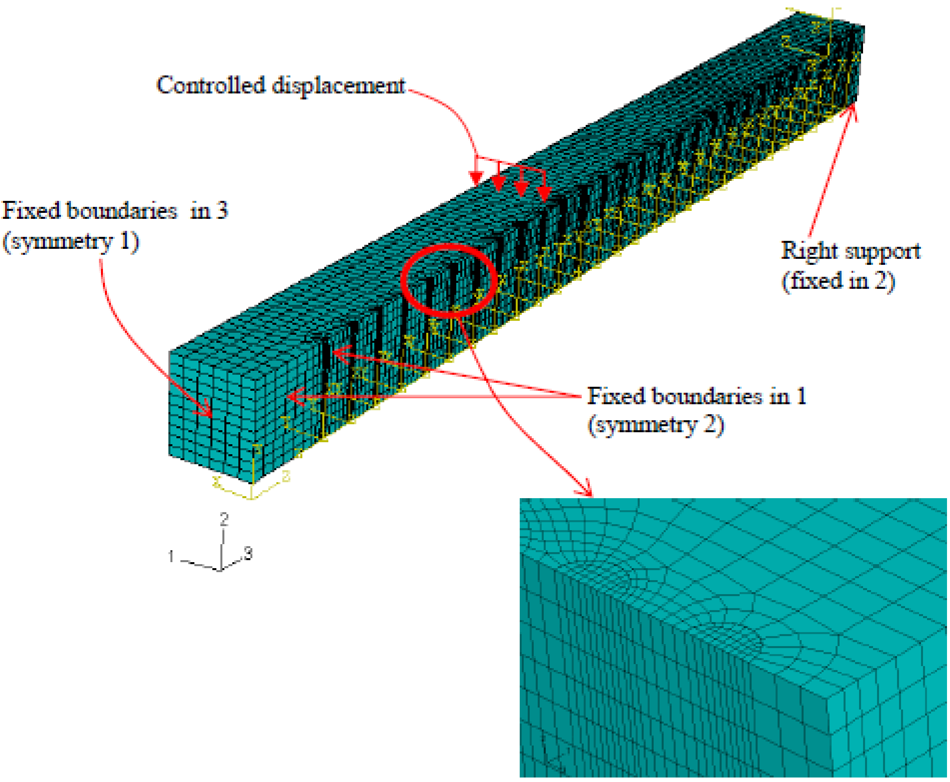


Fig. 3: Mesh generation for one quarter of the four-layer beam with boundary conditions.

After preliminary 3D simulations of some doweled two- layer beam systems, it was found that the effort and computational times required for such problem could be prohibitive and unacceptable. Simulation of such a problem is thus subjected to practical difficulties when the angle of insertion of the dowels is not equal to 90°, particularly in the case of full-scale geometry. In fact, it would be necessary to use hundreds of thousands or even smaller tetrahedral elements in the FE-model, involving unacceptable extensive computing times. As a first assumption for this study, the real dowel inserted at 60° was replaced by a fictitious dowel inserted at 90°, and considering its local material orientation turned (swivelled) by 60°, to take into account the oblique properties of real dowels (Figure 4).

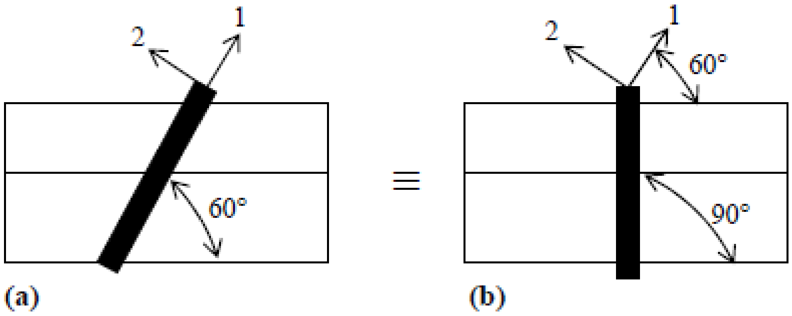


Fig. 4: Assumption adopted for the FE model: (a) real dowel, (b) fictitious dowel

The contact between the layer interfaces is based on the master–slave contact approach. The Coulomb traction model was adopted with friction ratio m = 0.18 and the interaction between layers is formulated using the finite sliding approach, which allows the separation of the two surfaces during sliding. The weld at the dowel/hole interfaces was not modelled in details but each interface between the holes and the dowels is clearly identified in the 3D FE-model. Detailed F.E modelling and analysis are difficult and beyond the scope of the present study which aims more to have a global understanding of the problems involved in the analysis and design of doweled multi-layered beams.

3.2. The Beam-To-Solid Approach (BTSA)

The main motivation of the BTSA is to develop a FE model that reduces the simulation efforts and able to work for large size industrial applications. In fact, as documented in the Introduction the 3D detailed modelling of dowels, using solid elements, requires the use of hundreds of thousands small finite elements or even more to model dowels, leading to unacceptable computational effort [1, 2]. This is particularly true in the case of large size industrial applications with a large number of dowels. Although detailed modelling of dowels using 3D solid elements can accurately predict stress and strain distributions within the timber members it would be very expensive in terms of computational time point of view.

In a typical doweled joint connection, the load transfer is achieved by relative slip of the connected members. The internal forces acting on the dowel are: tension (or compression), shearing and bending (Fig. 5).

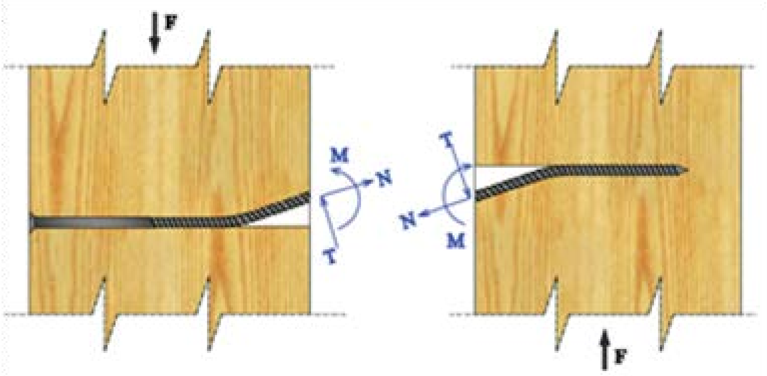


Fig.5: Typical connection loaded laterally and forces acting on the dowel.

The shear force and bending are caused by bearing the dowels against the timber surface, while the tensioning (or compression) is due to the axial withdrawal force. The numerical approach presented here introduces the concept of assuming two different behaviors for the dowel and the connected members. By neglecting the initial stresses caused by driving the dowel into the timber, the basic idea is to use one-dimensional beam element to predict the behavior of the timber dowels and detailed 3D solid elements to predict the behavior of the timber members (Fig. 5). This is referred to as beam-to-solid coupling. In a general beam-to-solid coupling, it is necessary to deal with the stiffness contribution of the solid element to the rotation of the section of the beam element [8], since the d.o.f. differ from the beam element to the solid element. However, this leads to a clamping condition which is obviously not fulfilled for dowels in timber. Therefore, the basic idea is to use one-dimensional beam element (Figs. 6a and 6b) to model the dowels and detailed 3D elements to model the timber.

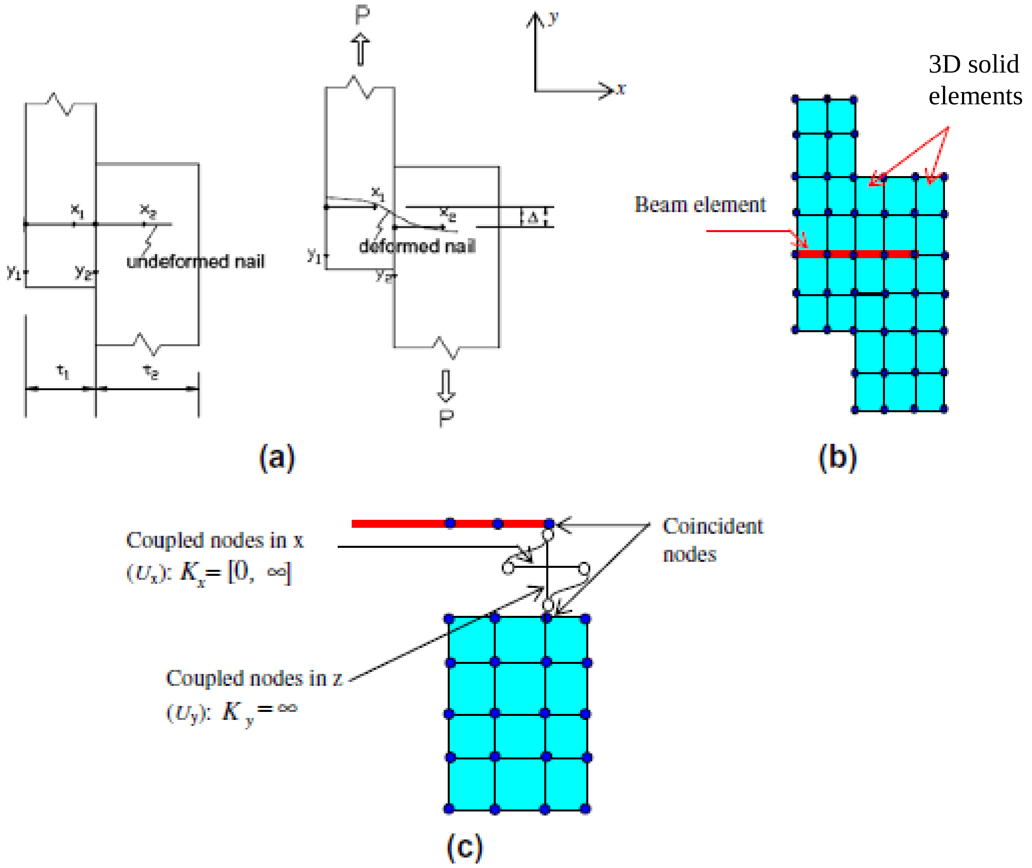


Fig.6: The global flowchart of the beam-to-solid approach [1].

In this study, the authors use a special 4-node beam element with only translational d.o.f., which has been obtained by the modification of the existing 2- node beam element, with translational and rotational d.o.f. [1, 2, 4]. That beam element has been developed, especially to deal with beam-to-solid coupling related to modeling problem that arise when screws in timber are considered.

The ABAQUS finite element code was used to investigate the behavior of the jointed connected members with dowels. Since the connection geometries admit two plans of symmetry, only one quarter was modeled for each application example (Fig. 7). 3D finite element model was assumed and eight-node solid elements have been used for the discretization of the timber members (Fig. 7). Orthotropic anisotropic elasto-plastic material model [3, 9] has been assumed for the timber behavior, while the dowels have been assumed as orthotropic anisotropic material and modeled using 4-node one-dimensional beam element. Coupling constraints have been applied to the common nodes between the dowels and timber members. The contact formulation, between timber/concrete interfaces, is based on the master-slave contact approach supported in ABAQUS finite element code. The Coulomb friction model has been used with a frictional ratio m = 0.2 and the interaction between the contact interfaces has been formulated using the finite sliding approach, which allows separation of the interfaces during sliding.

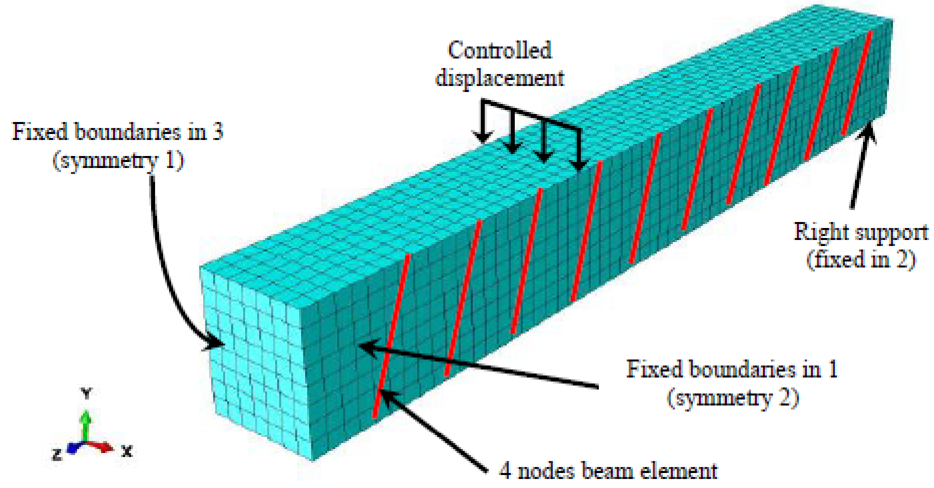


Fig.7: Finite element mesh of the four-layer beam with the new beam element (one quarter).

4. Result and discussion

Figure 1 shows the predicted load–deflection curves for the studied timber composite beam. A fairly good agreement is found between numerically predicted results and those published in [3].

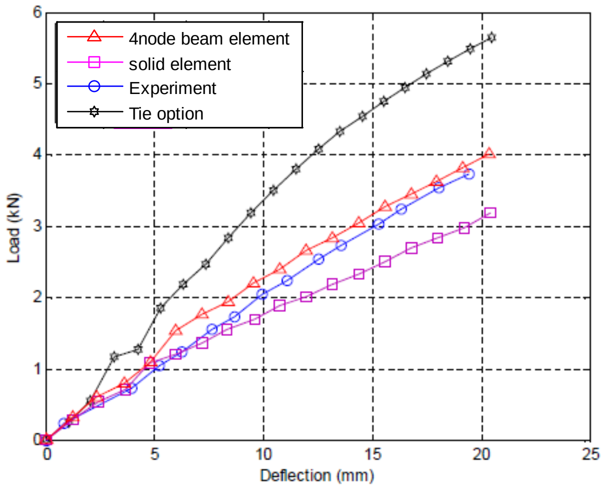


Fig. 1: Numerically predicted load–deflection curves: comparison with experiment

5. Conclusion

In this paper, a simplified way, called beam-to-solid approach (BTSA), to predict the load-slip behavior of screwed joints is proposed and validated against experimental results. In the BTSA, the screws are modelled using a special one-dimensional beam element, with only translational degrees of freedom, while the assembled members are modelled in detail using solid elements. Thus, the interaction between dowels and timber is represented using multi-point coupling constraints. The obtained results demonstrate clearly that the proposed approach can adequately predict the load-slip curve of joints, since it shows close results to reality. Also, this numerical approach seems to be fast and helpful for engineers from the design purpose point of view, since it predicts accurately the load–slip characteristics.

The main advantages of the proposed approach are:

- It does not require fitting parameters that should be determined by experimental tests but based only on known mechanical properties of materials;
- It is arguable that it reduces simulation efforts when compared to 3D FE models which use detailed modelling of the dowels using solid elements;
- It is arguable that it may work better for large size examples with a large number of dowels than the existing models, regarding the global behaviour;

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