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Coupled and uncoupled nonlinear elastic finite element models for monotonically loaded sheathing-to-framing joints in timber based shear walls

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ABSTRACT

Four different elastic models for sheathing-to-framing connections are presented and evaluated on a single connection level and on a shear wall level. Since the models are elastic in their nature they are suitable mainly for cases where the sheathing-to-framing connections are subjected to monotonically increasing displacements. Of the four models one is uncoupled and the others are coupled with respect to the two perpendicular displacement directions in a two-dimensional model. Two of the coupled models are non-conservative, while the third is conservative, indicating a path independency with respect to the work done to reach a defined state of deformation. When the different models are compared it is obvious that the uncoupled model gives strength and stiffness values higher than the others; however it is not obvious which of the models to use in a shear wall analysis, each of the models having its advantages and disadvantages. For the experimental data used as input in the analyses of this study however, a coupled non-conservative model seems the most appropriate.

1. Introduction

1.1. Background

In many timber structures shear walls are used to resist lateral loads such as wind loads. The wind load acts on an exterior wall or on the roof and is then transferred to horizontal diaphragms in the flooring or in the roof. These diaphragms in turn transfer the forces to the shear walls that stabilize the house. The walls are normally designed with timber members in the top rail, the bottom rail and in the studs. A sheathing material such as gypsum board, plywood, oriented strand board (OSB) or fibre board is fastened to one of the sides, or both sides, of this timber frame. The sheet is fastened to the timber frame by means of screws or nails along the perimeter of the sheet and along the centre stud. The structural components of a timber shear wall are shown in Fig. 1. Forces are transmitted in tension, compression and in shear to the bottom rail that interacts with the foundation through contact, friction and by means of connectors.

In order to predict the capacity of such shear walls various models have been suggested and utilized. Many of these models are designed to be implemented using the finite element method. One crucial matter when formulating finite element models of timber structures in general and timber based shear walls in particular are the assumptions used for defining the behaviour of connectors, in this particular case the sheathing-to-framing joints that transfer the forces between the structural elements.

1.2. Previous work

It is a well established fact that the characteristics of the individual sheathing-to-framing joints in shear walls are crucial in the role of defining the strength and the stiffness of the wall, see for instance [1,2]. Due to their importance, also rather elaborate models have been developed, e.g. [3] including also the post-peak behaviour, [2] and hysteretic response, e.g. [4,5]. It is crucial that these models represent the behaviour of the physical connection well in order to build relevant three-dimensional structures. Attempts to build such three-dimensional models have been made by several researchers including e.g. [6,7].

Typically, connector elements are used to model the load–displacement properties of the sheathing-to-framing joint. Their properties may be nonlinear and the model may introduce (nonlinear) single spring elements or spring pair elements, see [8]. A standard 1-dimensional single spring model, i.e. with a defined force versus elongation relation, may be used to represent the load–displacement behaviour in any direction. One drawback with such a single spring model is that of zero stiffness for deformation perpendicular to the elongation of the spring. This may give

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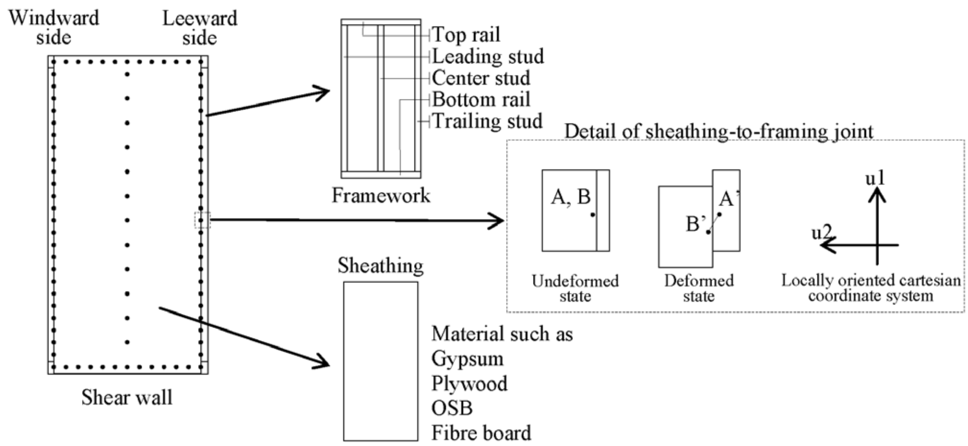

Fig. 1. Structural components of a timber shear wall. The fastener indicated (connecting point A with point B) is shown both in undeformed and deformed state.

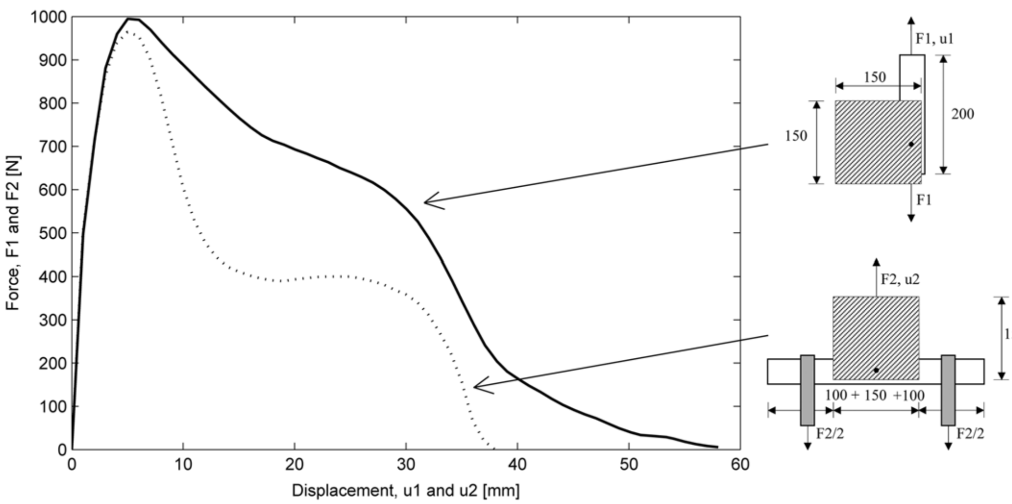

Fig. 2. Load–displacement relations for loading in parallel and in perpendicular directions respectively to the timber member.

numerical difficulties if the trajectory is dramatically changed. Another drawback is that the load–displacement characteristics only allow for one of the two local orthogonal directions ($u1$ and $u2$) to be considered, see Fig. 1. A common approach to overcome these disadvantages is to use an uncoupled nonlinear model consisting of two orthogonally oriented springs, see [9,10]. In such a model each of the two springs may be given any load–displacement property. However this spring pair model typically overestimates the strength and stiffness of nonlinear sheathing-to-framing joints for any loading pattern involving a mixed mode loading path, i.e. a combination of displacement in the $u1$ and $u2$ directions. This may be compensated for by scaling the spacing between the joints in a shear wall to obtain balance with respect to the energy absorbed [9]. It may also be compensated for by modifying the load–displacement properties of the individual joint until they fit an experimentally obtained load–displacement relation for a larger structure, such as for instance a shear wall, [11]. Both these approaches may give a reasonable response to a specific load case on a shear wall, but in the first case the geometry has to be changed during the analysis, which is both non-physical and time-consuming, and in the latter case the joint properties cannot be verified by experiments.

Another modification of the spring pair model has been suggested by Judd and Fonseca [8]. They used an uncoupled spring pair model and oriented the model with respect to the initial displacement trajectory. By using such an approximation the uncoupled spring pair model will not overestimate the strength, as long as the displacement continuously takes place along that initially specified trajectory (i.e. a radial displacement trajectory in the $u1$–$u2$ space). This approximation is efficient as long as the joint does not diverge from that initially determined trajectory. Once this happens, the model may still give high strength values. It may also be difficult to handle different load–displacement characteristic in the two orthogonal directions effectively, i.e. longitudinal and perpendicular to the grain, in such a model. Xu and Dolan [5] used the approximation suggested by Judd and Fonseca [8] to model shear walls subjected for cyclic loading. They used the same hysteretic model in the spring parallel to the initial trajectory as well as the spring perpendicular to the initial trajectory. This might be a choice that is acceptable for cyclic loading, but in the case of successively increasing loading the orthotropic characteristics of the joint, indicated for instance by the experimental results shown in Fig. 2, should be included in the analyses.

1.3. Objectives of the present study

In order to model shear walls with higher accuracy and to really capture the actual response, one of the crucial points is to develop more accurate sheathing-to-framing joint models and these should not be too demanding in terms of computational cost. The main objective of this paper is to investigate the general behaviour of nonlinear *elastic* spring pair models and thus gaining knowledge about the possibilities and limitations related to the