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Analysis of shear deflections of deep composite box-type of beams using different shear deformation models

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ABSTRACT

The deflection of deep box-type elements due to shear deformations is treated. A closed-form expression for the shear correction factor is derived by using an energy approach. The high accuracy and reliability of the developed procedure is demonstrated by comparing its results with accurate 3-D finite element results and also with the results of the conventional theories of Timoshenko with constant shear coefficient and of Reddy–Bickford applied to this kind of cross-section. A comprehensive and comparative parametric study is presented to investigate the effects of various mechanical properties and geometric dimensions for the different models. Unlike the higher-order shear deformation theories, which are accurate only for beams with rectangular cross-sections, there is a very good agreement between the results of the proposed method and the 3-D FE model. Clearly, the proposed energy method is applicable to more complicated cross-sections, including those with abrupt changes in the geometry, e.g. due to holes.

1. Introduction

In recent years timber structural systems are increasingly used in multi-storey buildings. Timber building systems have been developed for both residential and office-type of buildings. Moelven Töreboda AB, a Scandinavian glued-laminated (glulam) manufacturer, has developed a new beam-and-post system named "Trä8", especially for the market of non-residential multi-storey timber buildings. The system is based on rectangular modules, with maximum spans of 8 m (hence the name Trä8 = timber8), which offers flexibility, variety and simplicity of building design. The system is standardised and optimised, which reduces the average design time for the individual project. The primary use of the Trä8 system is for medium-rise buildings, Fig. 1 [1,2].

One special feature of the Trä8 system is the use of special continuous, prefabricated, proprietary stabilising wall elements with a composite box-type of timber cross-section, Fig. 2, along with ordinary glulam columns and beams, and prefabricated floor and roof elements. The stabilising walls are preferably placed along the facade of the building or comprise the walls of elevator shaft or staircases. The beams are connected to the continuous columns in a theoretically pinned manner and these ordinary columns are also pinned connected to the foundation. However, the special stabilising vertical elements are theoretically clamped to the substrate.

The composite stabilising wall element comprises of frame members of glulam and sheathing of laminated veneer lumber (LVL) (with the commercial name Kerto), Fig. 2. The main purpose with the intermediate vertical frame member and the horizontal noggins is to prevent buckling of the covering sheets. The single plane stabilising elements can be connected to form T-, L- or X-shaped configurations depending on their locations in the building. The combined configurations will enhance the stabilising effect of the wall element in both directions and during the erection phase. In this paper we are focusing only on the single wall element.

The framing of this wood-based panel element consists of three vertical members and short horizontal members placed at the bottom and the top of the element, at the level of each floor. The sheathing is glued and screwed to the framing members using phenol–resorcinol adhesive. The screws both connect the sheathing to the skeleton and apply the pressure during bonding. The screws also provide additional safety in case of failure of the glue. The empty spaces between the frame members are filled with insulating material, e.g. mineral wool [1].

The length of the element is dependent on the height of the designed building. The cross-sectional dimensions are intended to be standardised to minimise design time and cost. Members of the glulam framing are connected only by means of sheathing on both sides made of thick LVL Kerto-Q boards. The LVL Kerto-Q is

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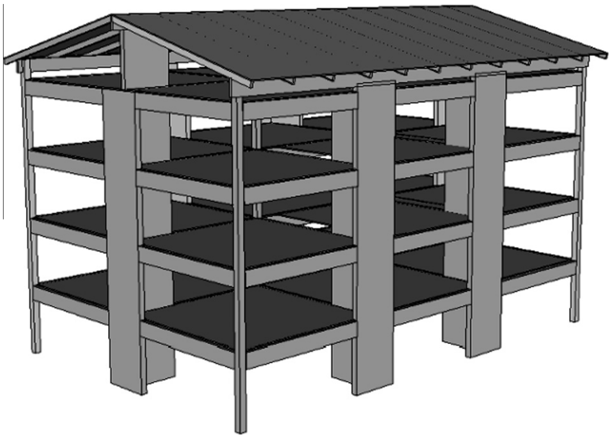

Fig. 1. Illustration of a multi-storey timber building with Trä8 post and beam structural system, including the stabilising wall elements.

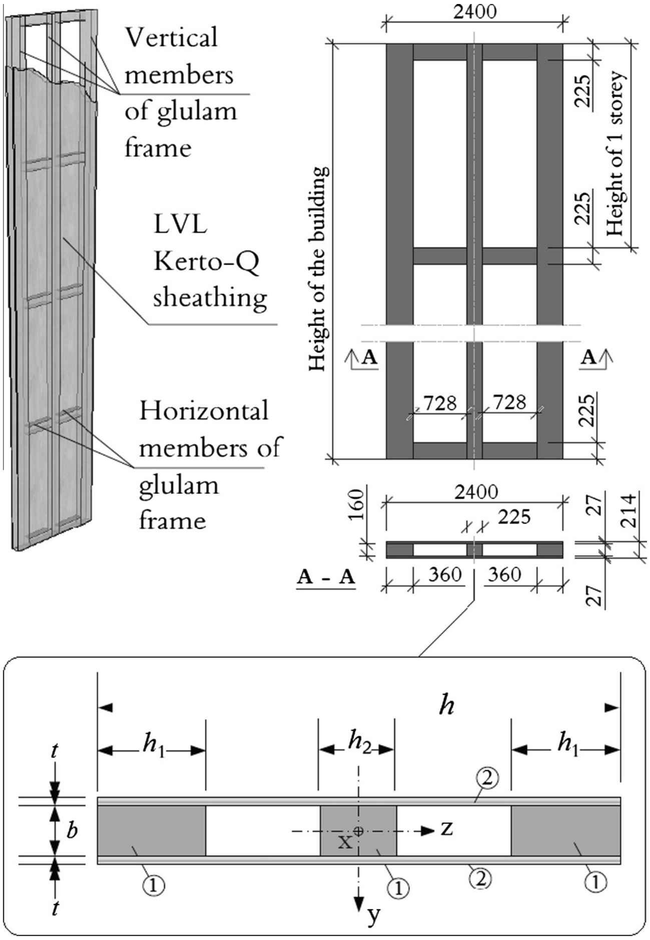

Fig. 2. Configuration and cross-section of the Trä8 composite stabilising wall element.

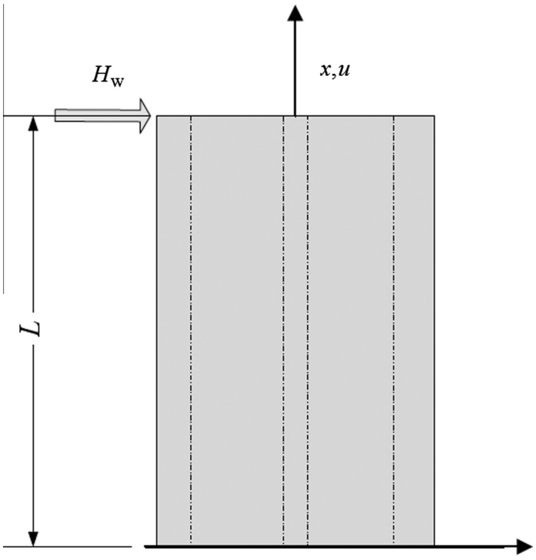

Fig. 3. Composite stabilising wall element acting as a cantilever and subjected to a horizontal transverse point load from wind (H_w). The height of the element (L) represents the theoretical height between two stories.

a product that has high in-plane shear strength due to about 20% of the veneers being laminated in the transverse direction [1].

The composite stabilising wall element is in principle acting as a composite box cantilever with a very deep cross-section subjected to a horizontal transverse point load from wind according to Fig. 3. The deflection of these elements due to shear deformations is at focus of this paper. The study is general in nature for this type of cross-section, but the stabilising wall element in the Trä8-system is used as an application and a reference case in the parametric evaluation.

There are some studies in the literature for the static analysis of composite box beams. Jeon et al. [3] studied static and dynamic behaviour of composite box beams using a large deflection beam theory and the finite element method. Kim et al. [4] investigated a shear correction factor for thin-walled composite box beams. McCarthy and Chattopadhyay [5] developed a refined higher-order beam theory for composite box beams of rectangular shape with arbitrary wall thicknesses. They presented a finite element solution for the obtained governing equations. Suresh and Malhotra [6] presented a finite element method based on Mindlin theory for the determination of transverse displacement of composite thin-walled box beams. Hutchinson [7] derived a new formula for the shear coefficient of Timoshenko beam theory. His formula gives accurate results for hollow circular cross sections. Gruttmann and Wagner [8] calculated a shear correction factor for arbitrary shaped beam cross-sections based on linear elasticity theory and finite element method. Milner and Tan [9] modelled deformations of thin webbed timber box beams with rectangular cross-section. A new composite thin wall beam element of arbitrary cross-section based on a first-order shear deformation theory was developed by Mitra et al. [10]. Yaping et al. [11] derived formulas for calculating bending stresses and deflection of symmetric single-cell thin-walled composite laminated box beams with rectangular cross-section. Vo and Lee [12] presented an analytical model for flexural–torsional behaviour of thin-walled composite box beams with rectangular cross-section based on classical laminated theory. They used a finite element method to solve the problem equations. Later, they carried out a similar study based on a shear deformable theory [13]. Recently, Vo and Lee [14,15] presented geometrically nonlinear analyses for thin-walled composite box beams based on the classical laminated and shear deformable beam theories and the finite element solution.

In this paper we study the shear deflections of the stabilising wall panel using different types of shear deformation models. Linear elastic conditions will be assumed as well as full interaction between the framing and sheathing components in the composite section. Two types of shear deformation theories are employed as well as an efficient energy method to present an explicit formula for predicting the shear deflections in deep composite beams