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A weak shear web model for deflection analysis of deep composite box-type beams

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ABSTRACT

Deep box-type beams, consisting of framing members and sheathings, are sensitive to shear deformations and hence appropriate refined theories or complicated magnification factors are needed to be used to obtain accurate results. For sheathings or webs between the framing members that are weak in shear, additional shear deformations occur corresponding to the relative axial displacement between the framing members. These sandwich-type or partial interaction-type of in-plane shear behaviour between the framing members, needs to be taken into account, especially when the web shear stiffness is very low. The composite box-type beam treated here is composed of three framing members with sheathings on both sides. To incorporate effects of the sheathings shear deformations between the framing members on the deflection, the sheathings, here called web interlayers, are modelled as shear media with equivalent slip moduli corresponding to a partially interacting composite beam model. Governing equilibrium equations of the model are obtained using the minimum total potential energy principle and solved explicitly. The obtained results are compared with those based on different conventional beam theories and 3-D finite element (FE) simulations. It is shown that the model is capable of predicting accurately the deflection for a wide range of geometry and property parameters. It is demonstrated that the deflection of such deep box-type beams can be expressed as the summation of three different effects, namely bending deformations, conventional shear deformations in the framing members and sheathings, and additional in-plane shear deformations or shear slips of the weak web causing relative axial displacements between the framing members.

1. Introduction

Timber structures are of increasing interest for the construction of multi-storey buildings. A Scandinavian glulam manufacturer, Moelven Töreboda AB, has developed a prefabricated beam-and-post system named "*Trä8*" for the market of non-residential multi-storey timber buildings. The system is based on the rectangular modules, with maximum spans of 8 m (hence the name *Trä8* = *timber8*), for details, see [1–3]. The Trä8 system is composed of several elements and components which are mostly produced off-site. They are assembled after delivery to the building site. The main elements of the system are continuous columns, beams, prefabricated stabilising wall elements, prefabricated floor cassettes and roof elements (Fig. 1) [1–3].

The stabilising wall element of the Trä8-system is a continuous, prefabricated, proprietary vertical element with a composite box-type of timber cross-section which is installed together with ordinary glulam columns and beams (post-and-beam system), and prefabricated floor and roof elements. The stabilising walls are preferably placed along the facade of the building (see Fig. 1).

The beams of Trä8 are connected to the continuous columns in a theoretically pinned manner and these ordinary columns are also pinned connected to the foundation. However, the stabilising wall element is theoretically clamped to the substrate. This clamping of the stabilising element to the foundation can be designed as shown in Fig. 2 [2,3].

The composite stabilising wall element is considered as a vertical cantilever beam clamped to the substrate and subjected to a horizontal point load from the wind (Fig. 3a). This stabilising element is a deep box-type beam comprised of glued-laminated timber for the three framing members and laminated veneer lumber (LVL) for the sheathing on both sides (Fig. 3b). The sheathing is glued and screwed to the framing members using phenol–resorcinol adhesive to make perfect bounding between them. The screws both connect the sheathing to the skeleton and apply the pressure during bonding. The screws also

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Fig. 1. Trä8 main components, including stabilising wall elements, in a multi-storey timber building [1–3].

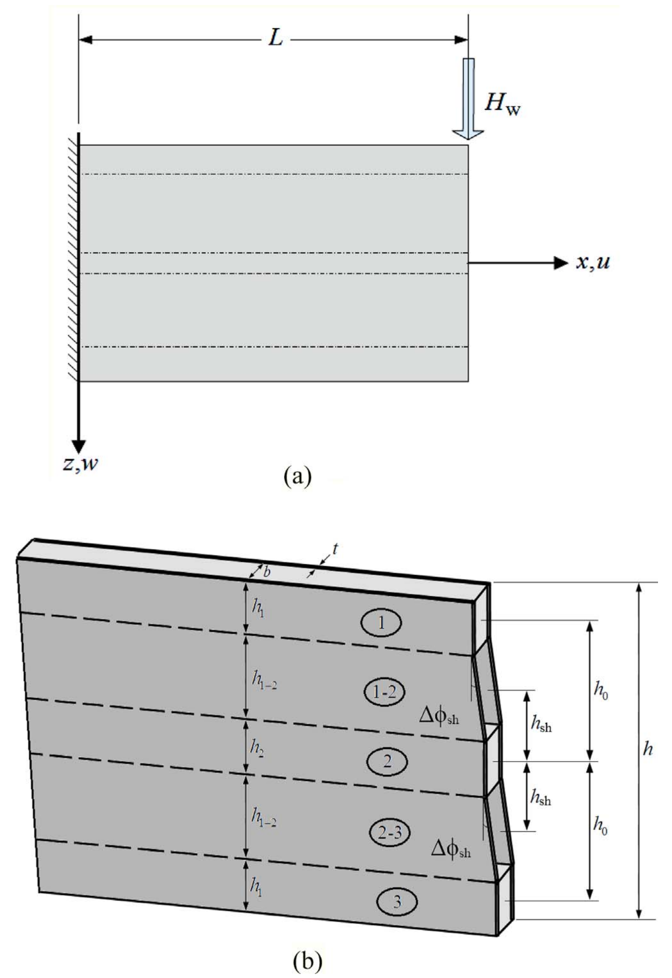

Fig. 3. (a) Trä8 stabilising wall element, where the coordinate system is defined (for convenience, the element is rotated); (b) Perspective of the cross-section in a deformed state due to “shear slip” between the framing members. The digits 1 and 2 refer to the upper/lower and intermediate framing members, respectively including the sheathing on each side. $h_0 = (h - h_1)/2, h_{sh} = (h_{1-2} + h_2)/2$.

provide additional safety in case of failure of the glue. Accurate prediction of the transverse deflection including shear effects in the plane of this structural element is of importance to ensure limited deformations in the serviceability limit state and for its optimal design.

The deflection is due to bending and shear. Accurate prediction of the shear deformations of the stabilising wall element, as a deep composite box-type beam, was investigated by Girhammar and Atashipour in a previous study [1]. In that study, a formula for the shear correction factor was derived for this kind of box-type cross-section with abrupt geometrical and property variations. The web was modelled in the same way as the framing members. This model works well for ordinary practical ranges of geometrical and property parameters, but not for situations when the web is very weak in shear. As pointed out by Girhammar and Atashipour [1], a relative displacement along the *x*-axis between the framing members due to the weak shear webs could be observed on the contour plot from a 3-D finite element analysis. A corresponding plot is re-illustrated from [1] and shown in Fig. 4, for the Trä8 stabilising wall element as a cantilever deep beam subjected to a point load from wind. The point load is uniformly distributed over the whole cross-section at one end and, at the other end, the beam is clamped by setting the 3-D displacement components to zero. The deflection in the transverse direction (i.e. along z-axis according to Fig. 3a) at the upper and lower surfaces and at the centre of the cross-section is shown in the figure. It is observed that there is a relative horizontal displacement between the upper and lower flanges due to the weak shear web which results in an increase in the deflection.

This behaviour is similar to the behaviour of a sandwich-type of beam. There is equivalence with respect to the fundamental behaviour and governing differential equations between shear connections (lap joints mechanically or adhesively jointed), see e.g. the fundamental works [4–9], sandwich constructions (sandwich beams and columns with cores of low shear rigidity), see e.g. the fundamental works [10–12], and composite structures with interlayer slip, see e.g. the works [13–16]. The equivalent slip modulus for the sheathing depends on its shear modulus, thickness and height.

In the present study, the shear effect of the web between the framing members is modelled as an interlayer with a shear stiffness corresponding to a slip modulus in a partially interacting composite beam and the relative displacement between the framing members

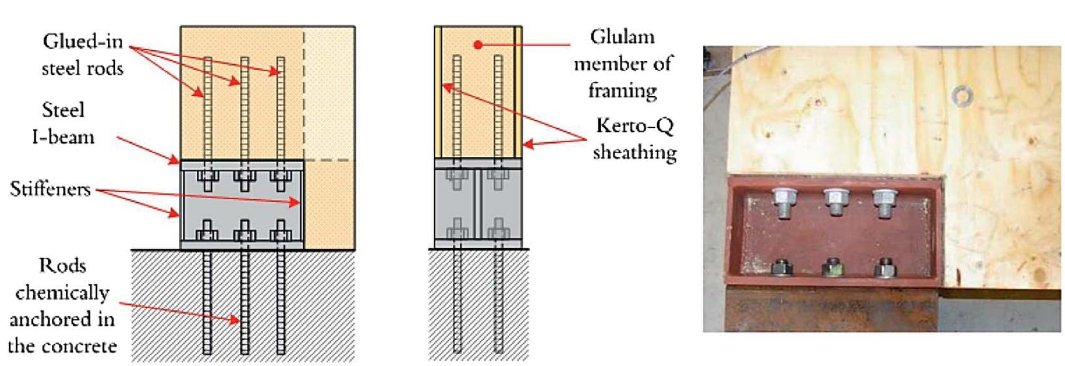

Fig. 2. Anchorage device with glued-in rods for fixing the stabilising element to the foundation [2,3].