Construction and Building Materials 25 (2011) 3291–3300

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Efficient finite element modelling of timber beams strengthened with bonded fibre reinforced polymers

Hamid R. Valipour *, Keith Crews

School of Civil and Environmental Engineering, University of Technology, Sydney, Australia

A R T I C L E   I N F O

Article history:
Received 17 December 2010
Received in revised form 1 February 2011
Accepted 1 March 2011
Available online 26 March 2011

Keywords:
Fibre reinforced polymer
Flexibility formulation
Shear-slip
Timber beam

A B S T R A C T

This paper presents development and application of a simple and efficient frame finite element (FE) able to estimate the load-carrying capacity of timber beams flexurally strengthened with externally bonded fibre reinforced polymer (FRP) strips and near-surface mounted FRP bars. The developed element is able to model collapse due to timber crushing under compression, timber fracture under tension and FRP rupture and it is developed in the framework of a flexibility-based fibre element formulation. Furthermore, a novel method based on central difference method in conjunction with composite Simpson's integration scheme along the element axis is developed to take account of shear-slip. The developed model is employed to predict the loading capacity and the applied load-mid span deflection response of timber beams strengthened with FRP and the numerically simulated responses agree well with the corresponding experimental results. The major features of this frame FE are its simplicity and efficiency compared with more complex and computationally expensive FEs which makes it a suitable tool for practical use in design-oriented parametric studies.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Ageing, biological attacks and increase of service loads deteriorate existing timber beams which can lead to significant reductions in the capacity and subsequently safety of timber structures. In such cases repair or strengthening of the elements may be recommended rather than costly replacement of deteriorated and damaged timber elements [1–5].

In deteriorated timber structures application of steel or aluminium plates mechanically (e.g., bolts and nails) connected to the beams may not be an effective method of strengthening. However, application of bonded fibre reinforced polymer (FRP) sheets (bars) is a promising solution to repair (strengthen) timber beams, due to their high strength and stiffness-to-weight ratios and simplicity of installation [6]. The two FRP types most commonly used for strengthening timber beams are glass fibres (GFRP) and carbon fibres (CFRP) [2,7–11].

FRP composites are usually bonded on the tensile soffit of timber beams to increase the flexural loading capacity and stiffness. Such strengthening work is conducted with externally bonded FRP strips/sheets or near-surface mounted (NSM) FRP bars [1,8,12]. Alternatively, FRP sheets may be wrapped around the timber beams which can significantly increase the flexural capacity as well as the strength of the beam against splitting due to shear [13]. It is noteworthy that application of bonded FRP for strengthening timber beams not only increases the loading capacity but also can alter the mode of failure from a brittle mode to a more ductile mode, which is desirable from a structural design point of view [1,14].

Over the last two decades, extensive research has been devoted to experimental study and improvement of detailed numerical models based on continuum-based FE models as well as development of simplified methods and design provisions for timber beams strengthened with FRP [10,13,15–18]. The experimental studies undertaken by different research groups cover various local and global aspects of timber beams strengthened with FRP, such as effect of different preservative and treatment methods on mechanical properties of materials [19,20], bond strength and stress analysis of FRP-wood interface [21,22], durability, long-term behaviour and serviceability [23–25] and development of new construction techniques and design provisions [4,16,26,27]. With regard to the numerical studies undertaken to date, most of the researches focus on application of nonlinear continuum-based FE models in which the timber beam and FRP sheets/strips are divided to small brick or membrane elements and the bond between FRP and wood is assumed to be either perfect or alternatively modelled by contact elements [9,11,21,28]. These nonlinear continuum-based models offer good versatility and accuracy which are required for the detailed study of local effects, but they are very complicated and time-demanding and such complexity and demands on computational resources make the continuum-based

* Corresponding author. Address: School of Civil and Environmental Engineering, The University of Technology, Sydney UTS, Sydney 2007, Australia. Tel.: +61 2 9514 2652.

E-mail address: Hamid.valipour@uts.edu.au (H.R. Valipour).

0950-0618/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2011.03.017

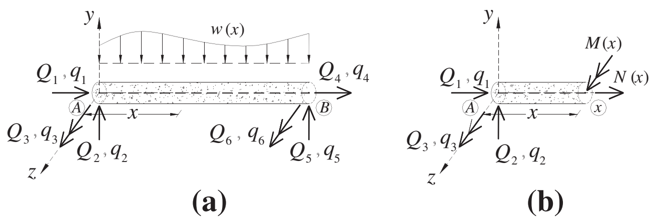

Fig. 1. (a) 2-Node frame element *AB* in *x*–*y* plane, (b) free body diagram for *Ax*.

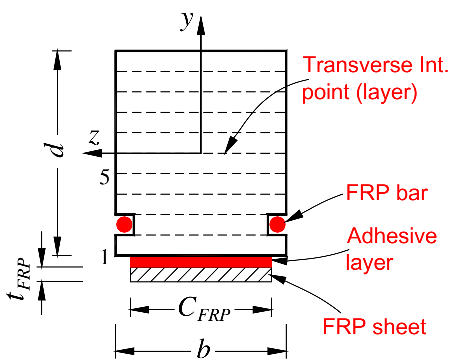

Fig. 2. Outline of the timber section strengthened with FRP sheet or near-surface mounted bar within the present formulation.

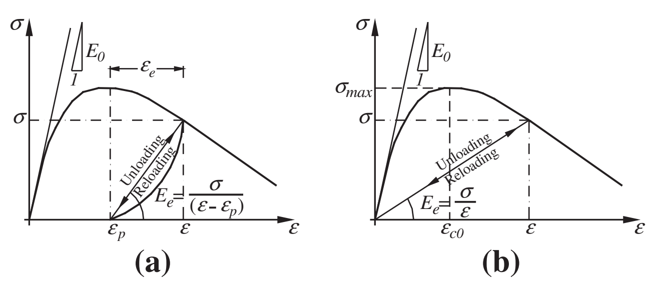

Fig. 3. Schematic outline of the uni-axial constitutive law for (a) plastic-damage model, (b) total damage model.

FE models inapplicable for design-oriented parametric studies in which only the global response is required. Discrete frame models, however, are a good compromise between accuracy and efficiency for predicting the global response and design-oriented parametric studies of beams strengthened with FRP.

Accordingly, in this study the force interpolation concept is used to formulate an efficient nonlinear 1D frame element which is applicable for design-oriented parametric studies. Material nonlinearities are taken into account by adopting appropriate uni-axial constitutive laws for timber and FRP sheets (bars) and a shear cap at section level is employed to predict the possible shear failure. The section flexibility (stiffness) is calculated by a numerical integration scheme rather than discretising the section to fibres and integrations along the element axis are estimated by utilising a composite Simpson's method [29]. Moreover, a novel approach based on central difference method in conjunction with composite Simpson's integration method along the element axis is developed within the formulation to implicitly take account of bond shear-slip.

2. Element formulation

2.1. Equilibrium and compatibility equations

Fig. 1a shows a 2-node plane frame element *AB* with three degrees of freedom at each node. The generalised displacement and force vector are denoted by **q** and **Q**, respectively. The equilibrium of the configuration *Ax* (Fig. 1b), yields [30,31]

$$\mathbf{D}(x) = \mathbf{b}(x)\mathbf{Q}_A + \mathbf{D}^*(x), \tag{1}$$

$$\mathbf{b}(x) = \begin{bmatrix} -1 & 0 & 0 \\ 0 & x & -1 \end{bmatrix}, \tag{2}$$

where $\mathbf{D}(x) = [N(x)M(x)]^{\mathrm{T}}$ is the vector of section generalised force, $\mathbf{b}(x)$ is the force interpolation matrix, $\mathbf{Q}_A = [Q_1\ Q_2\ Q_3]^{\mathrm{T}}$, is the vector of nodal generalised force at end *A* and $\mathbf{D}^*(x) = [N^*(x)M^*(x)]^{\mathrm{T}}$ is a vector of total section forces solely due to element loads.

Equilibrium across the section requires that

$$\mathbf{D}(x) = \left[\int_{\Omega} \sigma_x dA - \int_{\Omega} y\sigma_x dA\right]^T, \tag{3}$$

where y is the distance of the integration point from the element mid-plane (see Fig. 2) and σ_x is the total x–x stress component at the monitoring points.

Adopting the Navier–Bernoulli theory, the compatibility requirement over section depth yields

$$\varepsilon_x = \varepsilon_r - y\kappa, \tag{4}$$

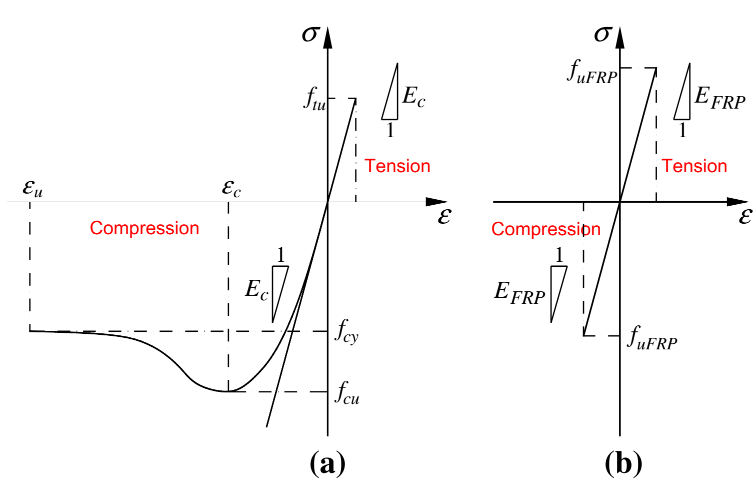

Fig. 4. Schematic outline of the adopted stress–strain relationship in this study for (a) timber, (b) FRP sheet (bar).

Download English Version:

https://daneshyari.com/en/article/259808

Download Persian Version:

https://daneshyari.com/article/259808

Daneshyari.com