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FINITE ELEMENT MODELING OF CARBON FIBRE REINFORCED POLYMER (CFRP) STRENGTHENED STEEL TUBES UNDER AXIAL IMPACT

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ABSTRACT

Steel hollow sections used in structures such as bridges, buildings and space structures involve different strengthening techniques according to their structural purpose and shape of the structural member. One such technique is external bonding of CFRP sheets to steel tubes. The performance of CFRP strengthening for steel structures has been proven under static loading while limited studies have been conducted on their behaviour under impact loading. In this study, a comprehensive numerical investigation is carried out to evaluate the response of CFRP strengthened steel tubes under dynamic axial impact loading. Impact force, axial deformation impact velocities are studied. The results of the numerical investigations are validated by experimental results. Based on the developed finite element (FE) model several output parameters are discussed. The results show that CFRP wrapping is an effective strengthening technique to increase the axial dynamic load bearing capacity by increasing the stiffness of the steel tube.

KEYWORDS

CFRP, strengthening, axial impact, steel tubes.

INTRODUCTION

Strengthening of concrete structures using CFRP sheets is a proven efficient strengthening system in civil engineering applications for both existing and new structures. There are many studies conducted related to the behaviour of CFRP strengthening systems under static loading conditions (Bambach et al. 2009, Fawzia et al. 2006 and Fawzia 2013). However, this application has limited knowledge in strengthening steel structural members especially, to resist impact loading conditions. There are some research works on the axial crushing of CFRP strengthened metal tubes and most of them are directly related to the automated industry (Costas et al. 2013; Fyllingen et al. 2010; Mirzaei et al. 2012). The experiments conducted show that CFRP strengthened hollow sections can sustain higher load even under impact loading by absorbing more energy (Abramowicz 2003; Obradovicet al. 2012; Bambach 2013). This principle can be applied to several Civil engineering applications where the structure can be subjected to impact loading conditions. Bambach et al. 2009 conducted an experimental programme on CFRP strengthened square hollow sections under axial impact loading. He studied the effect of number of CFRP layers and structural effectiveness of CFRP strengthening systems on square hollow sections. Current paper discusses the validation of finite element modelling of CFRP strengthened steel tube under axial impact loading and also investigate its structural behaviour based on Bambach's (Bambach et al. 2009) experimental programme.

FINITE ELEMENT MODELLING AND NUMERICAL ANALYSIS

Material Models

Finite element model was created for axially impacted square steel hollow sections strengthened with CFRP using LS-DYNA. 2 mm thick steel tube with 50mm×50mm cross section and 300mm in height was modelled with shell elements with Belytschko-Tsay formulation. Two CFRP layers were modelled with Belytschko-Tsay formulation, one in axial direction and the other one in transverse direction with the layer thickness of 0.176mm. Geometry of the finite element model is shown in Figure 1.

The yield strength of the steel used in the experiment was 360MPa and CFRP material had 3790MPa ultimate strength and 230GPa elastic modulus of fibre. The impact mass was 574kg with 6ms^{-1} velocity.

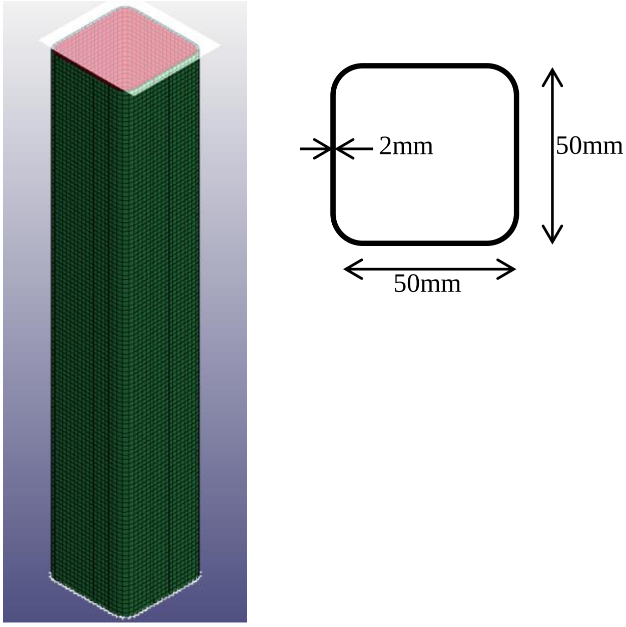


Figure 1. Geometry and mesh

MAT024_PIECEWISE_LINEAR_PLASTICITY material model is used to model the steel with Cowper-Symonds strain rate parameters and MAT054_ENHANCED_COMPOSITE_DAMAGE is used for the CFRP. Dynamic crushing analysis is performed on FE models and during the analysis; the top of the tube model is subjected to axial impact with 574kg in mass and 6ms^{-1} velocity. The impactor was modelled as a rigid wall. All the material properties, geometry and impact conditions (Bambach et al. 2009) are listed in Table 1.

Table 1. Properties and impact conditions

	Material properties	
	steel	CFRP
Density	7850 kg/m^3	1700 kg/m^3
Poisson's ratio	0.3	0.2
Young's modulus	210 GPa	230 GPa
Strength	360 MPa	3790 MPa
	Geometries	
Thickness	2mm	0.176mm
	Impact conditions	
Mass	574 kg	
Impact velocity	6ms^{-1}	
Simulation time	120ms	

Bottom of the tube was modelled as built in section providing all the nodes are restrained in all the directions and rotations about all three axes. Interface of the steel-CFRP and within the CFRP layers was modelled using AUTOMATIC_SURFACE_TO_SURFACE_TIE_BREAK contact with failure criteria. Failure between the two layers was defined using the following Equation 1.

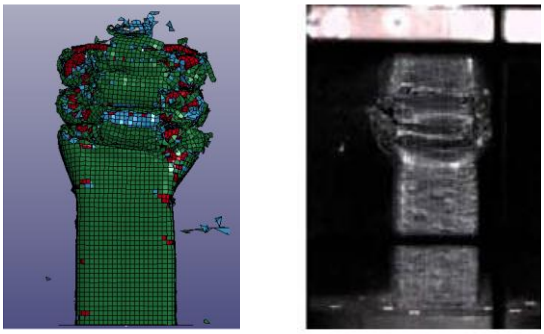
$$\left(\frac{|\sigma_n|}{NFLS}\right)^2 + \left(\frac{|\sigma_s|}{SFLS}\right)^2 \geq 1 \tag{1}$$

Where *NFLS* is tensile failure strength and *SFLS* is shear failure strength of the adhesive (LS-DYNA manual 2003).

An adhesive material with properties of *NFLS* = 35 MPa and *SFLS* = 40 MPa has been used to define the tiebreak contact failure.

RESULTS AND DISCUSSIONS

Results obtained from the finite element analysis are shown below compared with experimental results. The finite element results are in good agreement with the experimental results. Failure modes of the FE and the experiment are shown in Figure 2 and FE failure mode followed the similar behaviour as the experimental failure mode. Figure 3 shows the comparison of impact force vs axial deformation of axially impacted steel tube.



(a) (b)

Figure 2. Failure modes (a) - FE model (b) - Experiment

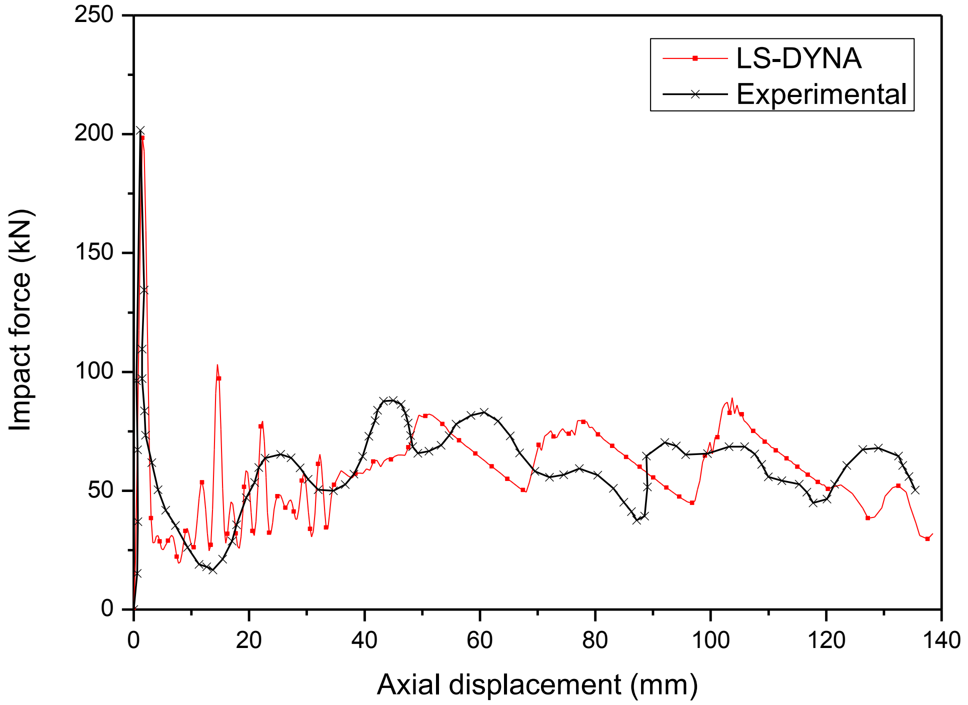


Figure 3. Impact force vs axial displacement of steel tube

From the experiment maximum peak impact force was obtained as 203kN and the peak impact force obtained from the FE model is 193kN. It is observed that FE results and the experimental results are in a good agreement throughout the analysis.

Figure 4 shows the comparison of impact force vs axial deformation of axially impacted steel tube strengthened with CFRP. It can be concluded by comparing Figure 3 and 4 that the deflection of the CFRP strengthened tube is lesser than the bare steel tube.

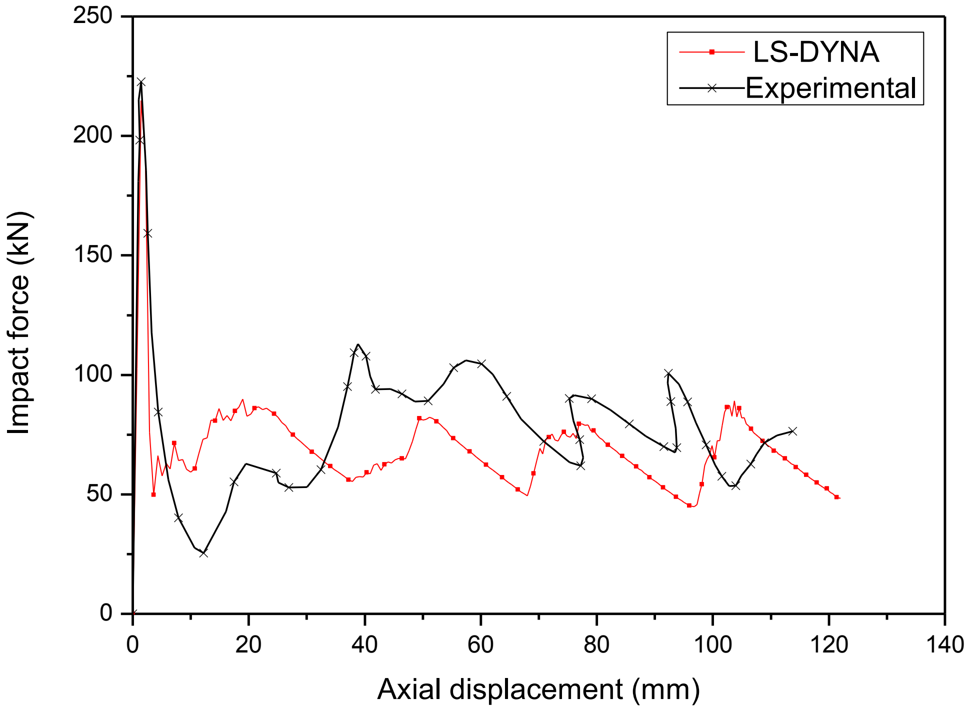


Figure 4. Impact force vs axial displacement of CFRP strengthened steel tube

The peak impact force obtained from the experiment was 218kN and the obtained peak impact force from finite element model was 215kN. In the experiment it was observed some force spikes after the first impact and the finite element analysis results also showed similar impact force variation around 60kN after the initial peak.

The impact force vs time and Impact velocity vs time graphs are shown in Figures 5 and 6.

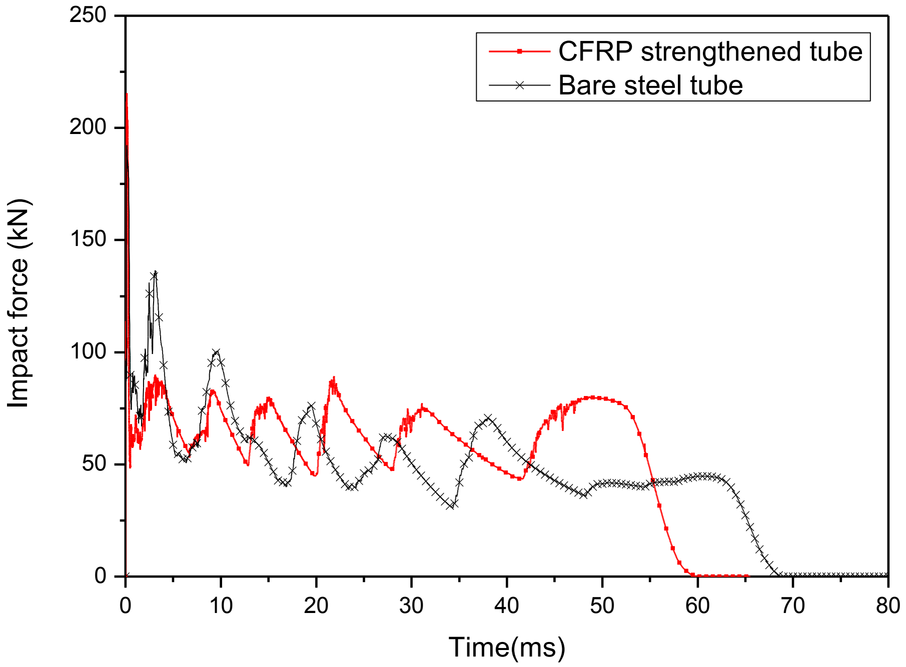


Figure 5. Impact force vs time comparison for bare steel tube with CFRP strengthened steel tube

CFRP strengthening caused increase the initial peak impact force from 193kN to 215kN compared to bare steel tube.

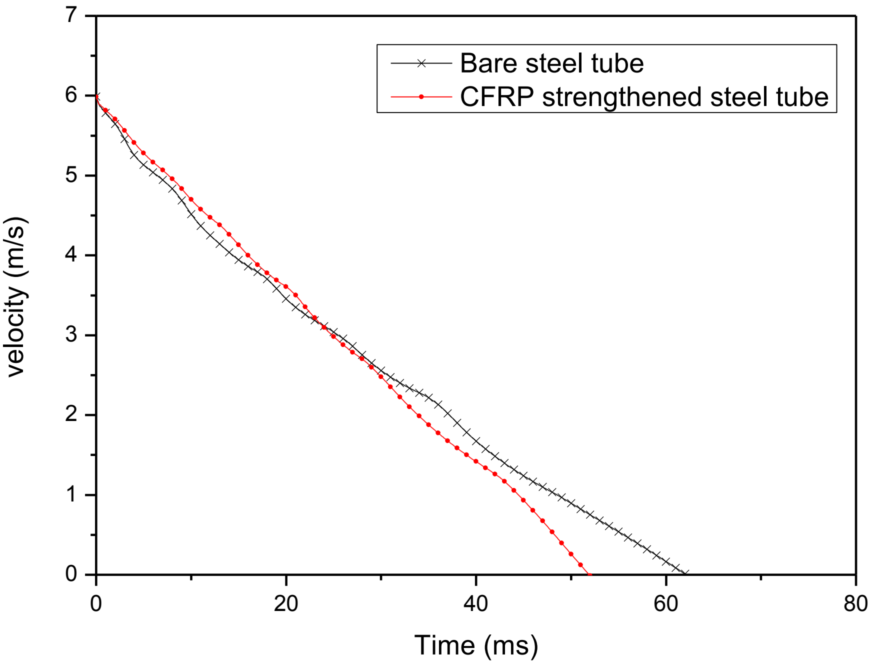


Figure 6. Impact velocity vs time comparison for bare steel tube with CFRP strengthened steel tube

Impact force vs time response illustrates that the CFRP strengthening caused to decrease the time of reaching impactor velocity to zero. The Impact force of bare steel specimen reached to zero at 69ms and in CFRP strengthened steel tube it was reached at 59ms. From the velocity vs time relationship obtained for the two specimens reflect the same behaviour. Impactor velocity reached to its minimum value in CFRP strengthened steel tube before the time it reached to zero in the bare steel specimen. This is because of the increase of the stiffness of the steel specimen wrapped with CFRP.

CONCLUSIONS

This paper has presented the finite element modelling of CFRP strengthened steel tubes under an axial impact loading with validation through experimental results. It was observed that the CFRP strengthening enhances structural performance of steel square hollow tubes by increasing the peak impact force up to 11%. With CFRP strengthening initial peak impact force can be increased and consequently the ultimate load carrying capacity is also increased. This is mainly due to the confinement effect of the CFRP wrapping which causes to increase the stiffness of the structural member. The relationships of impact force vs time, impact velocity vs time show that the CFRP strengthening is an efficient strengthening technique. The validated results also indicate that the developed finite element model can be used to predict the impact response of composite sections. However, since carbon fibre–epoxy composites have different material characteristics and failure modes, further studies will be needed to determine complete structural performance of CFRP strengthened steel tubes under an axial impact loading.

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