Advances in Engineering Software 000 (2015) 1–12

Contents lists available at ScienceDirect

Advances in Engineering Software

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

Computer analysis of impact behavior of concrete filled steel tube columns

S. Aghdamy[a,*], D.P. Thambiratnam[a], M. Dhanasekar[a], S. Saiedi[b]

[a] School of Civil Engineering and Built Environment, Queensland University of Technology, Brisbane, Australia
[b] Hatch Ltd., Vancouver, Canada

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Numerical modeling
Concrete filled steel tube column
Lateral impact
Sensitivity analysis

ABSTRACT

This paper presents a numerical study of the response of axially loaded concrete filled steel tube (CFST) columns under lateral impact loading using explicit non-linear finite element techniques. The aims of this paper are to evaluate the vulnerability of existing columns to credible impact events as well as to contribute new information towards the safe design of such vulnerable columns. The model incorporates concrete confinement, strain rate effects of steel and concrete, contact between the steel tube and concrete and dynamic relaxation for pre-loading, which is a relatively recent method for applying a pre-loading in the explicit solver. The finite element model was first verified by comparing results with existing experimental results and then employed to conduct a parametric sensitivity analysis. The effects of various structural and load parameters on the impact response of the CFST column were evaluated to identify the key controlling factors. Overall, the major parameters which influence the impact response of the column are the steel tube thickness to diameter ratio, the slenderness ratio and the impact velocity. The findings of this study will enhance the current state of knowledge in this area and can serve as a benchmark reference for future analysis and design of CFST columns under lateral impact.

1. Introduction

Concrete filled steel tubes (CFST's) are used increasingly as structural columns due to their excellent structural and constructional advantages. These members are often used at the frontage of buildings, in car parks and airports, or as bridge piers. Therefore, they are exposed to accidental or intentional lateral impacts from vessel/vehicle traffic. The resulting damage can lead to structural collapse with human injury or fatality risks. The damage can also be very costly to repair. Therefore, it is prudent to investigate the performance of this type of columns under lateral impact loading to assess their vulnerability in order to provide appropriate retrofitting, if necessary and to provide information for the new design of such vulnerable columns.

The lateral impact behavior of the CFST beams has recently been studied by some researchers [1-6]. Wang [1] conducted tests on simply supported CFST beams impacted at mid-span, with identical outer-diameter and different values for tube thicknesses. The results showed that reducing the diameter-to-thickness ratio of CFST beams causes an increase in their energy absorption capacity. Bamchad et al. [2] experimentally investigated the response of fully clamped steel square hollow sections (SHS) and square CFST beams to low-velocity, large-mass, impacts at mid-span. The results indicated that non-compact CFST can sustain greater impact loads compared to SHS in which the local deformations in the vicinity of the impactor are restricted from forming. The effect was less pronounced for compact sections. Remennikov et al. [3] conducted a comparative study on the behavior of simply supported infilled SHS and unfilled SHS beams under low velocity impact at mid-span. They performed tests on mild steel and stainless steel SHS's for both filled and unfilled sections where the filler materials were either rigid polyurethane foam (RPF) or concrete. The results indicated that the concrete filled tubes had the highest impact resistance and energy absorption capacity, followed by the steel tubes filled with RPF and the hollow tubes. It was confirmed that stainless steel tubes, as opposed to mild steel tubes, have a higher impact resistance and energy absorption capacity. Yousuf et al. [4] performed an experimental study to investigate the impact behavior of simply supported structural steel SHS, both unfilled and filled with concrete. The dynamic moment capacity of hollow and concrete filled columns under impact loading indicated a significant increase, compared to the capacity associated with static loading. Deng et al. [5] tested the impact response of simply supported circular CFST's, circular steel post-tensioned concrete filled tubes (PTCFST's), and a circular steel fiber–reinforced

* Corresponding author. Tel: +61 401329846.
E-mail address: s.aghdamy@qut.edu.au, s.aghdamy@gmail.com (S. Aghdamy).

http://dx.doi.org/10.1016/j.advengsoft.2015.06.015
0965-9978/© 2015 Civil-Comp Ltd. and Elsevier Ltd. All rights reserved.

Table 1
Summary of research on impact behavior of CFST members.

Ref.	[6]	[8]	[5]	[7]	[4]	[3]	[2]	[1]
No. of dynamic tests performed	9	12	9	1	1	1	6	16
Section type	Circular	Circular	Circular	Square	Square	Square	Square	Circular
Λ	30 45 62	42	58	87	87	87	41	42
$(D$ or $B)/t$	49.3	32.6	59.2	20	20	20	31.2 21.9 12.5	32.6 30.0 25.3
f'_c (Mpa)	60	39	46	13	45	41	88.4	37
f_y (Mpa)	247	298	340	349	441	440	455 485 480	274 298 387
N	0	0 0.3 0.6	0	0.58	0	0	0	0
M (Kg)	205–1115	229.8	525–625 675	592	592	600	600 300 120	203
V_o (m/sec)	465–920	4.4–11.7	7.7–14.1 10.8–16.8	3.6	3.6	3.6	6.2	4.4–11.1 4.4–11.7 4.4–14.4
Impact location	Mid-span	Mid-span	Mid-span	Mid-span	Mid-span	Mid-span	Mid-span	Mid-span
Indenter's shape and contact area (mm^2)	Square-N/A	Rectangular-2400	Circular-17671 Wedge-N/A	Circular-7854	Circular-7854	Circular-7854	N/A	Square-2400

concrete filled tube (FRCFST). The investigation showed that the use of pre-stressing strands and steel fibers significantly restrained tension cracks in the concrete. It also suggested that PTCFST's and steel FRCFST had superior impact resistance compared to regular CFST's. Han et al. [6] evaluated the impact behavior of high strength concrete filled steel circular hollow section (CHS) beams, experimentally and numerically. The high strength concrete filled steel tube beams deformed in a ductile manner and had good resistance under impact load.

Among the few investigations on behavior of axially loaded CFST members under transverse impact, Yousuf et al. [7] carried out an experimental investigation to assess the capacity of axially loaded concrete filled mild and stainless steel square sections subjected to impact load at mid-span. The results indicated adequate performance of CFST members in terms of energy absorption and ductility, with stainless steel performing at a noticeably higher capacity than mild steel. Additionally, Wang et al. [8] tested the impact performance of axially loaded CFST members. The results indicated that the critical failure energy of CFSTs subjected to impact load at mid-span increases with the confinement factor. The axial load and impact energy have also shown to have an effect on the residual lateral deflections of CFST members under lateral impact.

Table 1 summarizes the detailed features of these investigations on concrete filled mild steel tubes. It indicates that the response of CFST members when used as columns subjected to a combination of axial load induced by the live and dead loads of building slabs or bridge decks and lateral impact has been rarely investigated. Furthermore, a few studies, which have been conducted on axially loaded CFST members, are limited in scope and their conclusions are preliminary as they are among the first on this topic. Therefore, there is insufficient data to develop comprehensive understanding of the effects of various structural and load parameters on the structural response of CFST columns and determine the key factors accountable for the response of these columns which are required for the development of practical design methods.

The present study aims to bridge the knowledge gap, build on these preliminary research investigations, generate new information on effects of controlling parameters and develop a comprehensive database of column behavior under transverse impact. The enabling objectives of this paper are as follows:

i. To develop and validate finite element modeling (FEM) methods for simulating the lateral impact response of axially loaded CFST columns of different configurations.
ii. Using the validated numerical model, to evaluate the influence of various structural and load parameters on CFST response.
iii. Using the validated numerical model, to assess the sensitivity of CFST column behavior to various parameters.

The initial peak and residual impact force, impact duration and maximum and residual deflections are considered as the key response parameters in this study. The input load parameters are the impact mass, initial impact velocity, impact location, impact contact area and axial load level. The input structural parameters are concrete compressive strength, tube thickness-to-diameter ratio, slenderness ratio and CFST column's sectional configurations. The present paper is an enhanced version of a previous paper by authors [9] and it contains the following additional research:

- Verification of FEM techniques by comparing the results with those from different experiments reported in literature to ensure the adequacy and accuracy of the model with different column configurations.
- Evaluation of the sensitivity of CFST column response to changes in value of various structural and load parameters and determining key factors which control the major response of this column type.

2. Finite element model

2.1. Model development

In order to simulate the lateral impact response of CFST columns, the explicit dynamic nonlinear finite element code LS-DYNA [10] was employed. LS-PrePost software was used as the pre-processor and post-processor. Detailed model description has been given in [9]. A general description of the FEM follows.

2.1.1. Finite element types and meshes

The FEM consists of a concrete core, a steel tube, an impactor and end plates through which the axial load was applied.

Please cite this article as: S. Aghdamy et al., Computer analysis of impact behaviour of concrete filled steel tube columns, Advances in Engineering Software (2015), http://dx.doi.org/10.1016/j.advengsoft.2015.06.015