Thin-Walled Structures 92 (2015) 48–54

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Plastic buckling of dented steel circular tubes under axial compression: An experimental study

Tohid Ghanbari Ghazijahani*, Hui Jiao, Damien Holloway

School of Engineering and ICT, University of Tasmania, Hobart, Australia

ARTICLE INFO

Article history:
Received 22 December 2014
Received in revised form
17 February 2015
Accepted 18 February 2015
Available online 16 March 2015

Keywords:
Steel CHS tubes
Plastic buckling
Dent imperfection
Axial compression

ABSTRACT

This paper examines the effect of large local imperfections, known as *dents*, on the plastic buckling capacity of short steel tubes under axial compression. A total of 11 tests on such short columns were carried out. The specimens were indented through a separate process and the ultimate axial capacity was subsequently obtained through compression tests. Dent imperfections with various depths were introduced to different locations on the body of the specimens. Plastic buckling modes as well as the ultimate capacity of the specimens were thoroughly investigated. The adverse effect of such a local damage on the load carrying capacity was quantified for different values and types of imperfections.

1. Introduction

The very popular usage of CHS members as structural elements has stimulated many researchers to investigate the structural behavior of such elements. Many researches have focused on these elements under compression. Copious papers have also looked into the sensitivity of such structures to geometrical irregularities, also known as geometric imperfections. In some cases these elements are highly prone to physical contacts caused by collisions such as columns in car a parking, tubular members in offshore structures collided by supply boats and so forth.

A limited number of papers have, however, studied the dent imperfections in hollow sections. Most recently, Ghanbari Ghazijahani studied the buckling behavior of very thin cylindrical shells subject to axial stresses [1]. 27 specimens were tested in this study with different dents. It appeared that the capacity of such structures decreased due to the effect of the damaged areas. Buckling of dented short carbon steel cylindrical shells under axial loading was studied parametrically by Prabu et al. [2]. Angle, size and inclination of the local dent imperfection were investigated in this research. The effect of dent imperfections was examined by Ghanbari Ghazijahani et al. for slender shell specimens under pressure loading, which similarly led to the capacity reduction [3–5]. Bending capacity of dented CHS tubes was investigated through two respective studies by the authors [6,7], and the failure modes as well as the ultimate capacity were thoroughly assessed for locally imperfect specimens. Indentation of ring-stiffened cylinders using wedge-shaped indenters was studied by Karroum et al. through both FE and an experimental research [8]. The failure location for all specimens was identified to be at a bulkhead of the specimens, where the plastic strain values were also evaluated.

Eyvazinejad Firouzsalari and Showkati studied steel dented tubes with D/t ratio of around 55 [9–11]. It was found that axial compression had a significant effect in some tests on the behavior of pipes against local lateral loading. Residual strength of dented structures was studied by Paik [12], which addressed the mechanics of dented members based on test observations and FE computations. An indentation process employing wedge-shaped indenters and a single spherical indenter was adopted to investigate tubular members [13]. The conducted tests were presented along with simplified analytical models which yielded closed-form expressions.

Despite the mentioned studies, relevant papers on local large imperfections seem insufficient to cover all aspects of structural behavior of shells with damaged geometries. To that end, this study aims to address the plastic buckling of steel CHS tubes under pure compression. The key aims of this study are to: (i) conduct the indentation by a proper V-shaped indenter, (ii) perform the main tests on the tubes under axial compression, (iii) evaluate the failure modes considering the presence of dent shape pre-deformation, (iv) discuss the load carrying capacity of the dented tubes considering different local imperfections, and (v) evaluate the results against previous data.

2. Experimental protocol

2.1. Specimens

All specimens were cold formed mild steel CHS tubes. The geometry of the specimens and the properties of the material used

* Corresponding author. Tel.: +61 469 311 896.
E-mail addresses: tohid.ghanbari@utas.edu.au, tohidghanbari@gmail.com (T. Ghanbari Ghazijahani).

http://dx.doi.org/10.1016/j.tws.2015.02.018
0263-8231/

for fabrication of the tubes are given in Fig. 1 and Table 1. The material properties were obtained from tensile coupon tests and a stress strain curve obtained from this test is available in Ref. [14]. In Tables 1 and 2 L_{tube} and D_{tube} are the length and the diameter of the tubes. Additionally, d_e, L_e and W_d are the depth of the dent, distance of the dent from the bottom end and width of the dent respectively.

2.2. Indentation

As seen in Fig. 2, indentation was conducted using a V-shape 90° angled indenter. Fig. 2(a) and (b) shows the indentation process of an unsupported specimen, wherein the ovalization of cross sections was achieved along the whole length. Fig. 2(c) shows a tube specimen before indentation, with end supports inserted into both ends to prevent the ovalization of the end sections. Fig. 3 displays different specimens with horizontal and inclined dents. The load displacement behavior of the specimens under concentrated indenting loads was recorded throughout the indentation. The curves out of this process are presented through Fig. 4. It is plainly seen that a nonlinear trend dominated the deformations from the initial stages of loading.

2.3. Experimentation

An Avery Universal Testing Machine with the loading capacity of 1000 kN was utilized to apply the axial loading. The boundary condition of the specimens was simply supported such that rotation and axial translation were allowed during the loading. Loading was applied slowly so as to apply a quasi-static loading. Loading was initiated and monotonically increased until final failure of the specimens took place.

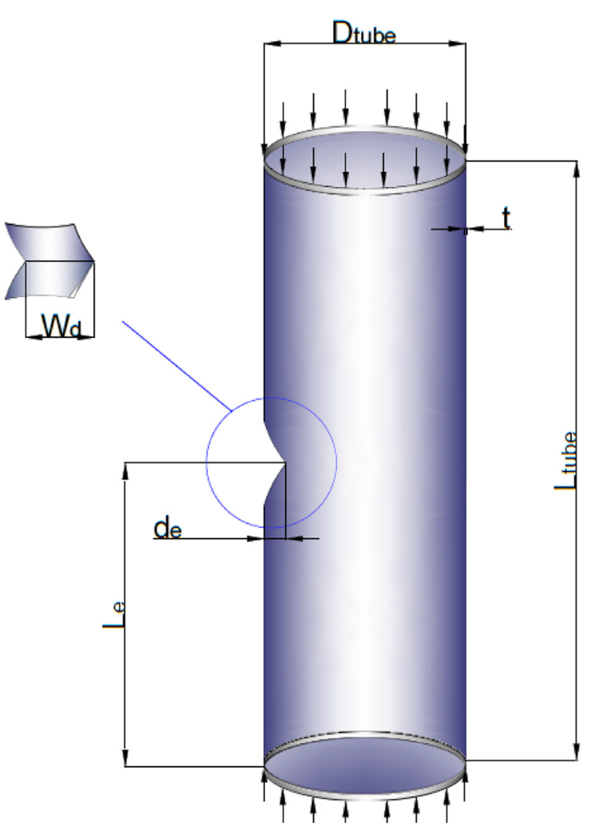

Fig. 1. Geometry of the dented specimens.

Table 1
Geometry of the specimens and material properties.

Specimen	L_{tube} (mm)	D_{tube} (mm)	D_{tube}/t
TUD.1–11	220	76.2	47.6
Yield stress (MPa)	Ultimate stress (MPa)	Young's modulus (GPa)	
307	360.2	216.3	

Table 2
Specimens and dent specifications.

Specimen	d_e (mm)	L_e (mm)	W_d (mm)	Orientation
TUD.1	0	0	0	–
TUD.2	4	45	37	Horizontal
TUD.3	8.5	45	56	Horizontal
TUD.4	19	45	85	Horizontal
TUD.5	5.7	73.3	46	Horizontal
TUD.6	11.5	73.3	62	Horizontal
TUD.7	16	73.3	71	Horizontal
TUD.8	9.5	210	53	Horizontal
TUD.9	18.3	210	77	Horizontal
TUD.10	9	73.3	79	Diagonal (45°)
TUD.11	17	73.3	105	Diagonal (45°)

3. Results and discussions

3.1. Observation of the test

The intact specimen, as expected, failed in *elephant foot* plastic buckling. The buckling bulge occurred approximately 15 mm from one end in a ring shape as an outward deformation. This end of the tubes deformed quite symmetrically.

Deformations for the dented specimens were initiated from the dented area such that the dents predominantly extended at the both ends towards the sides. This was further accompanied by the deepening of the dents. As deformations developed further, a U-shaped wave started in the side opposite the dent until it encompassed approximately half the circumference approaching the dent. Likewise, the same phenomenon, i.e. bulge, was seen at the top end of the specimens for some specimens. Deformations at the side opposite the dent occurred exactly at the same location at which the intact specimen buckled. However, the area underneath the dented zone remained unbuckled as seen in Fig. 5(c) and (d).

The same behavior was seen for CHS tubes with different shapes of cutout presented in Ref. [15], where the authors elucidated that the axial stress flow lines deflected to the sides upon approaching the cutout. The same response is verified for the present dented specimens through this study.

Fig. 6 shows the dent and the end section after failure, which was triangular for a medium size dent and quadrangular for a deeper dent. The end section was triangular which was rather closer to a round shape in the specimen with a medium size dent, whereas as the dent became deeper the end section approached a quadrangular which was certainly affected by the depth of the dent. This demonstrates that for deeper dents the final failure mode changed compared with the intact specimen. Fig. 7 shows the typical buckling progress in a dented specimen, through which the development of buckling around the dent and on the opposite side is schematically illustrated. The same phenomenon was observed for TUD.5 and TUD.2 as shown in Figs. 8 and 9.

3.2. Displacement and strain behavior

Fig. 10 shows end shortening of different specimens versus the axial load. It is quite obvious that TUD.1 (intact specimen) had a