Comparison of energy absorption of various section steel tubes under axial compression and bending loading

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Abstract

Thin-walled cylindrical tubes are widely used as structure members in engineering applications. Therefore, its' collapse behavior has been studied for many decades, focusing on its energy absorption characteristics. This paper is also aimed to compare the energy absorption of various section steel tubes under axial compression and bending loading by using a commercial explicit finite element programs code of ABAQUS. The various cross-sectional shapes include square, hexagonal, octagonal and circular cross-sections. The effects of wall thickness and plastic collapse mode are also investigated. For axial compression load, the energy absorption increases as the initial wall thickness increases. Nevertheless, the concertina mode of circular tube has the highest mean load and hence energy absorption capacity. Furthermore, the energy absorption for square cross-section is lower than for circular, hexagonal and octagonal cross-sectional tubes, respectively. For bending load, the energy absorption of square cross-section is the higher than that of the hexagonal, octagonal and the circular cross-section is the lowest.

Keywords: Plastic collapse, Cylindrical Tube, Thin-walled structure, Polygonal

1. Introduction

Thin-walled cylindrical tubes are widely used as structural members such as in a car body, offshore pipeline and platforms, land-based pipelines, aircraft, support structure and energy absorbing devices. Many researches investigated the experiment and theoretical of circular tube subjected to static axial compression. Alexander [1] analysed the axisymmetric concertina mode (see Figure. 1a.) of deformation by considering the formation of stationary hinges and assuming the tube length between the hinges as rigid. The region between the extreme hinges was assumed to buckle outward only. He obtained an expression for the fold length by minimizing the total energy respected to the membrane strain and plastic bending moments at the hinges. The investigation also proposed an equation for predicting the mean collapse load. Abramowicz and Jones [2] later modified Alexander's model by introducing curvature in the deformation fold length, Fig 1 (b). They used ultimate stress instead of yield stress to account the strain hardening. Only the calculation of the collapsed load was addressed in their analysis.

In general two modes of deformation may be observed when circular tubes collapse, which include axisymmetric (also called concertina modes), see Figure.1 and non-symmetric (diamond mode). Andrew et al. [3] shown that thick cylinders (small D/t ratio, D/t<80-90) buckle in the concertina mode of deformation, whereas thin cylinders (high D/t ratio) buckle in the diamond modes. The number of lobes increases with increasing of D/t ratio. For a given tube, it was found that the absorbed energy of the mode concertina is more than that in the diamond mode.

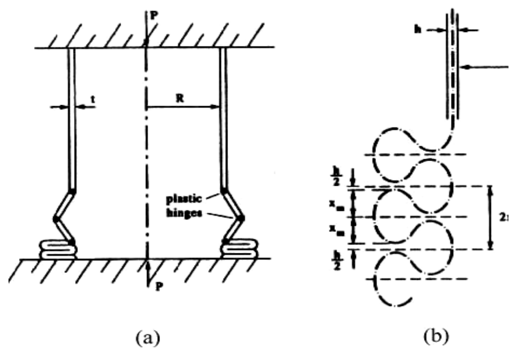

Figure 1. The plastic collapse mechanism of tube for concertina mode [1]-[2]

Yamashita et al. [4] studies on the crush behaviors of hollow cylindrical structures with various regular polygonal cross-sections under axial compression. They found that the crush strength increases as the number of corners of the cross-section increases, though it almost saturates for the number of corners beyond 11. G.M. Nagel et al. [5] compared the energy absorption response of straight and tapered thin-walled rectangular tubes under both quasi-static and dynamic axial impact loading. It was found that the dynamic response of tapered tubes is more sensitive to impact velocity and wall thickness than taper angle at lower impact velocities. G.M. Nagel et al. [6] compared the energy absorption response of straight and tapered thin-walled rectangular tubes under quasi-static axial loading, for variations of their wall thickness, taper angle and number of tapered side. The results shown that the initial peak load increases with increasing wall thickness, yet decreases with increasing taper angle. Furthermore, the triple-tapered tube and frusta have the highest mean load and hence energy absorption. N.K.Gupta et al. [7] studied of the collapse of aluminum cylindrical shells of different diameter to thickness ratios when subjected to quasi-static axial compression and the impact of a drop hammer. The results shown that the energy absorption capacity of the tested tubes in impact test is higher by 1.56-2.3% in comparison with the corresponding value obtained in quasi-static test. The load-deformation and energy compression curves for the set of shells of different thickness and same diameter increases with increase thickness and these curves for the set of shells of different diameter and same thickness increases with increase in diameter.

The present paper is also aimed to compare the energy absorption of various section steel tubes under axial compression and bending loading by using a commercial explicit finite element programs code of ABAQUS. The various cross-sectional shapes include square, hexagonal, octagonal and circular cross-section.

2. Finite element modeling

In this study, numerical simulation of various cross-section tubes under axial compression and bending load was carried out using the commercial explicit finite element program code of ABAQUS. The model for the various cross-section tubes under axial compression was validated using an existing theoretical model [8] which predicted the quasi-static mean load response. The FE model for the bending loading of various cross-section tube was validated using a theoretical model derived in [9] which predicted the bending collapse of rectangular and square section tubes.

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2.1 Axial compression load

A model of the square hexagonal octagonal and circular tube under axial compression load was developed by using the FE code ABAQUS/Explicit. The structural member computed is a full model. The tube model was constructed with a number of 4 node shell elements. Mesh size effect was studied in order to maximize accuracy, an element size of 3 mm was found to produce suitable results. The tube was crushed by two rigid platens in axial direction. The top edge was compressed with constant velocity of 10 mm/s, as shown in figure 2.

The cross-section shapes used in this study were square, hexagonal, octagonal, and circular tube. The circumference of a circle was 200 mm, which was equal to the sum of peripheral length of square hexagonal and octagonal. The axial length was 150 mm for all cases and the wall thickness t was set to be 1.0, 2.0 and 3.0 mm. Therefore. The mass of all tubes have no effected.

The material was assumed homogeneous, isotopic, constant thickness and perfectly elastic-plastic. Young's modulus E = 300 GPa and Poisson's ratio υ = 0.3 and the density of the material ρ was 7800 kg/m^3. Their deformation shapes were recoded at different stages of compression and load-displacement response were plotted.

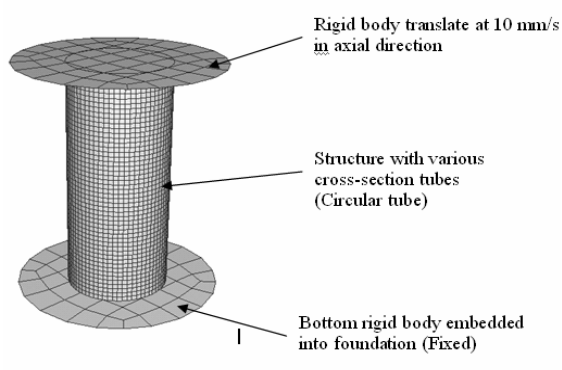

Figure 2 Illustration of axial compression model

2.2 Bending load

The FE model of the bending loading of various cross-section tubes was constructed by three points bending, as shown in figure 3. Each tube was modeled with a number of 4 node shell elements. Mesh size of 4 mm was found to produce suitable results. The load at rigid body was compressed with constant velocity of 10 mm/s and running time was 13 s.

Geometry and material properties of the cross-section dimensions for square hexagonal octagonal and circular were same as the case of axial compression load. The free length of each tube was 1500 mm. Their deformation mode and load-displacement response were plotted.

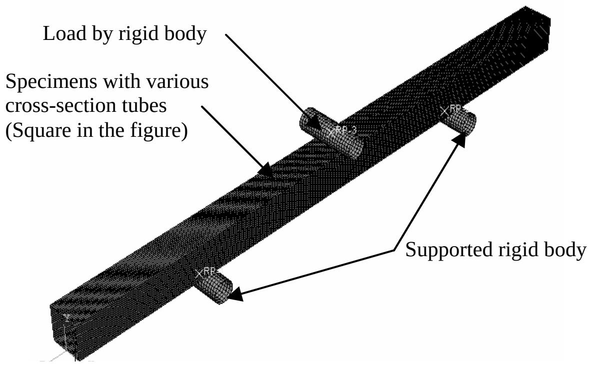

Figure 3 FE model of various cross-section tubes by using three points bending

3. Results and Discussions

This section compares the mean load-displacement and energy absorption response of various cross-section tubes under axial compression and bending loading, for variations in wall thickness.

3.1 Axial compression load of various cross-section tubes

Figure 4(a)-(d) demonstrate the mean load response of square, hexagonal, octagonal, and circular tube with variation wall thickness, respectively.

Table 1. Mean load with variation wall thickness

Thickness (mm)	Mean load (kN)			
	Square	hexagonal	Octagonal	Circular
1	11.23	13.53	14.36	14.51
2	37.44	42.34	43.10	44.07
3	69.57	75.84	76.0	78.87

From Table 1, it is also found that the mean load increases with increasing wall thickness. Furthermore, the mean load of circular tubes of all wall thickness is higher by 1.03-3.64%, 3.0-6.75%, and 11-22.61% in comparison with the corresponding value of octagonal, hexagonal and square cross-sectional tubes, respectively.

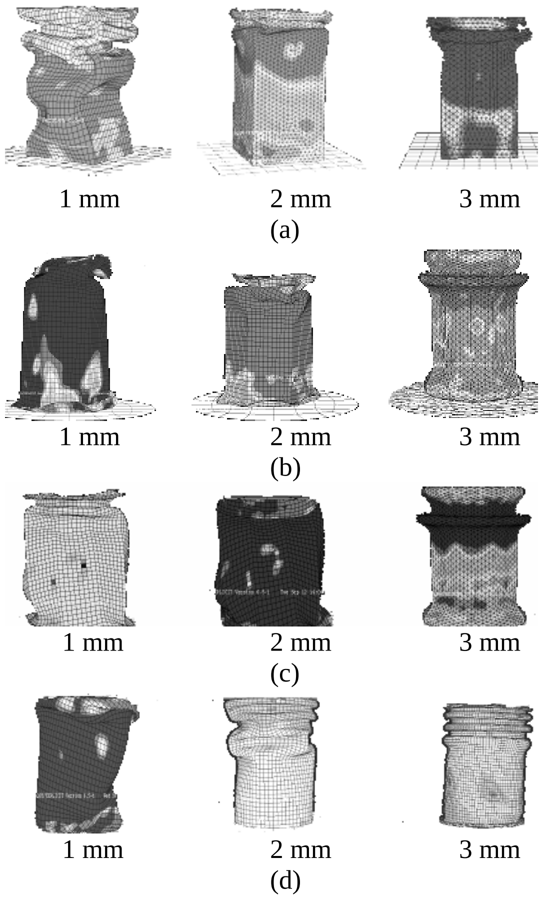

Figure 5 Axial collapse modes of various cross-section tubes with the wall thickness: (a) square (b) hexagonal (c) octagonal and (d) circular cross-section

Figure 5 demonstrates the axial collapse mode of various cross-section tubes with the initial wall thickness of 1, 2 and 3 mm. In figure 5, it was found that the axisymmetric concertina mode increases as the initial wall thickness increases. On the other hand, the diamond collapse mode appears as the initial wall thickness decreases.

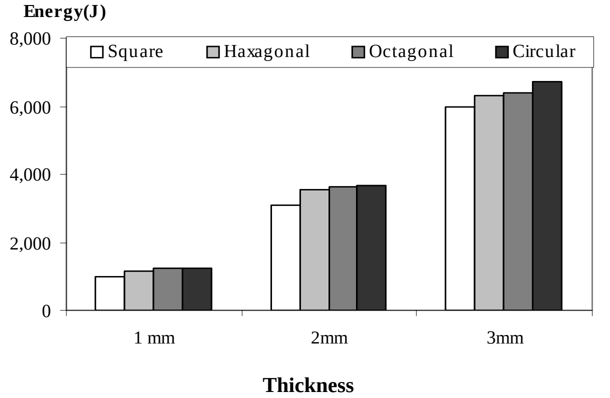

Figure 6 Comparative results the energy absorption with different wall thickness under axial loading

Figure 6 compares the energy absorbtion values for typical specimens obtained in quasi-static axial compression loading. The results show that the energy absorption increases as the initial wall thickness increases. In addition, the concertina mode of circular tube has the highest energy absorption capacity. Furthermore, the energy absorption for circular tube of all wall thickness is higher by 11-18.76%, 11.16-7.69%, and 1.01-5.03% in comparison with that of square, hexagonal, and octagonal cross-sectional tubes, respectively.

3.2. Bending loading of various cross-section tubes

In figure 7 demonstrates the bending collapse mode of various cross-section tubes with the initial wall thickness. It was found that the collapse mode have less influence on the initial wall thickness in this case.

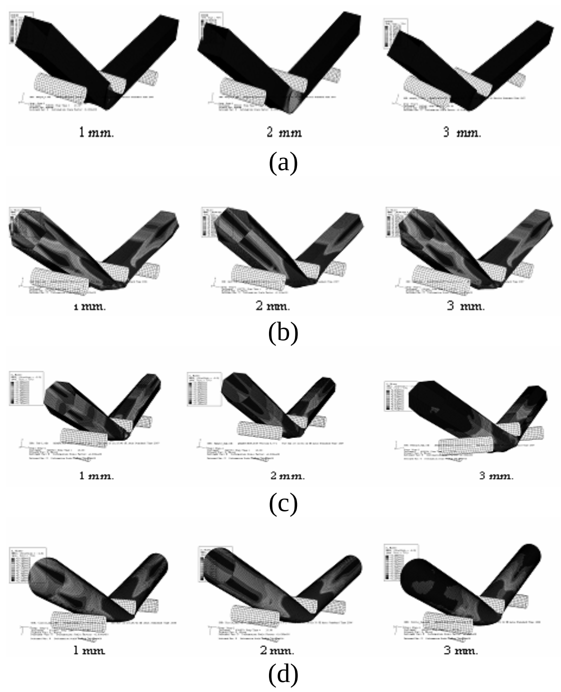

Figure 7 Bending collapse modes of various cross-section tubes with the initial wall thickness: (a) square (b) hexagonal (c) octagonal and (d) circular cross-section.

Table 1. Mean load with variation wall thickness

Thickness (mm)	Mean load (kN.m)			
	Square	hexagonal	Octagonal	Circular
1	1.99	1.83	1.51	1.56
2	5.66	5.58	5.27	4.98
3	12.10	11.77	11.01	9.95

From Table 2, it is also found that the mean load increases with increasing wall thickness. Furthermore, the mean load of square tubes of all wall thickness is higher by 1.33-8.58%, 6.85-24.57%, and 11.92-21.8% in comparison with the corresponding value of hexagonal, octagonal, and circular, respectively.

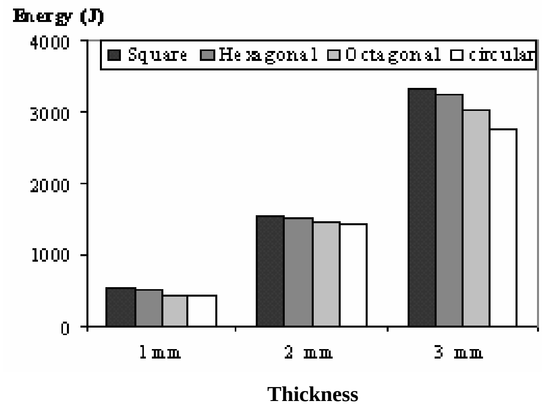

Figure 8 Comparative results of the energy absorption with various cross-section tubes under bending loading.

Figure 8 the results show that the energy absorption increases as the initial wall thickness increases. In addition, the energy absorption of square cross-section of all wall thickness is higher by 1.97-8.45%, 8.57-23.79%, and 7.39-22.39% in comparison with that of the hexagonal, octagonal and circular, respectively.

5. Conclusions

For the axial compression of various cross-section tubes, it was found that the mean load and energy absorption increases as the wall thickness increases. Furthermore, the mean load and energy absorption increases as the number of corner of cross-section tube increases. Therefore, the concertina mode of circular tube has the highest mean load and hence energy absorption capacity. , the energy absorption for square cross-section is lower than for circular, hexagonal and octagonal cross-sectional tubes, respectively.

For bending load, the mean load and energy absorption of various cross-section tubes increases with increasing the wall thickness. Nevertheless, the mean load and energy absorption decreases as the number of corner of cross-section tubes increases. Finally, the energy absorption of square cross-section has the higher than that of the hexagonal, octagonal and the circular cross-section is the lowest.

Acknowledgments

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