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A study on nested two-tube structures subjected to lateral crushing

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ABSTRACT

The paper studies on experimental and theoretical investigations into the crushing response of the nested rectangular-square tube structures under lateral loading. Lateral crushing behavior of these nested tube structures is described in this work. The effect of peak crushing load on mean crushing load is pointed out for each nested tube structure. The theoretical formula is proposed based on the simple superposition principle and the modification of the simplified super folding element theory. The mean crushing load depends on the length of the plastic hinge line, wall thickness, and flow stress of material. The value of the mean crushing load obtained from calculation is compared with the results of the tests, resulting in good agreement with acceptable errors.

1. Introduction

Energy absorber takes an important role in different engineering fields. Tubular structures in energy absorption components are commonly composed of thin-walled members of closed cross-sections, either circular or rectangular in shape because of their high energy absorption capacity, high effective crush performance, and their low cost [1,2]. Papers of the plastic response or the energy absorber behavior related to the thin-walled structure under crushing load have been done in the last two decades involving experiment, simulation, and theoretical analysis [3–12]. Nevertheless, with the soaring requirement of the specifically designed energy absorber, the compressive load-extension curve based on tubular structure's investigation did not reach the design demand of some energy absorbers because of its limited energy absorption capacity. Energy absorption capacity of the multi-cell tubes depends on the number of angle elements in tube's cross-section [13,14]. Nested tube system can be regarded as a type of multi-cell tubes. However, the creation of the nested system is easily compared to multi-cell tube. For that reason, nested tube structures including various types were introduced. Such energy absorbing components can not only enhance the absorbed energy stroke, but also rise the energy absorption capacities by forming the load-displacement so as to apply to different purposes.

Gupta et al. [15] introduced experimental and computational analyses of circular tube under lateral compression. In this paper, authors discussed the basic deformation mechanism and effects of process parameters on deformation behavior of the structures. Olabi et al. [16] researched both experimentally and numerically the behavior of the nested tube structures under lateral crushing with and without side constraints. Their works show that the numerical results behaved well and were quite adequate compared with those of experiments. Eyvazian et al. [17] reported the energy absorption characteristics of tubes with corrugations under lateral loading. They pointed out that the tube with corrugations can absorb approximately four times more energy than the tube without corrugations in the same sizes and weights. Wang et al. [18] carried out the theoretical, numerical, and experiment investigation of the internally nested tube system under lateral impact loading. An analytical solution based on rigid, perfectly plastic material idealization was developed, in which the effects of strain-hardening and strain-rate were considered. Baroutaji et al. [19] investigated the energy absorption behavior and crashworthiness optimization of short length circular tubes under quasi-static lateral loading. Their work showed that the crush force is greater in the smaller tube. In addition, the tubes with smaller width (W) and diameter (D), and higher thickness are more suitable for use as energy absorbing components. Another paper of Baroutaji et al. [20] addressed the responses of nested tube systems under quasi-static and dynamic lateral loading. They revealed that the force-displacement response from the dynamic cases was similar to their quasi-static counterparts under a low impact velocity due to unimportant strain rate and inertia effects of the nested systems.

The nested structure energy absorber is used to absorb the energy via plastic deformation of the layered structure. Nevertheless, most of the previous papers on the nested structure energy absorption component were still limited to the simulation and experiment, and the theoretical analysis was rarely built so far. The present paper adopts experiments and theoretical analyses to investigate the crushing response

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Fig. 1. Photographs of the experimental setup.

of the nested tube structures subjected to lateral loading. Based on the modification of the simplified super folding element theory and the simple superposition principle, the theoretical model of the mean crushing load is developed for these nested tube structures. The results obtained from prediction are compared with the experiments to verify the developed theoretical model.

2. Experimental procedure

The experimental setup is illustrated in Fig. 1. It includes a universal testing machine (INSTRON 3360), a computer, and test specimens. The nested two-tube structures tested are rectangular-rectangular tube type 1 (RRTT1), rectangular-rectangular tube type 2 (RRTT2), rectangular-rectangular tube type 3 (RRTT3), and rectangular-square tube (RST) as seen in Fig. 2. There are two groups in which Group 1 includes RRTT1 and RRTT2; while RRTT3 and RST belong to Group 2. All tests are performed on a universal testing machine at 3 mm/min. Whose upper limit of load is 50 kN. Totally, fifteen tests are conducted on four types of tubes. At first, RRTT 1, RRTT2, and RRTT3 are tested in order; then, RSTs are loaded. All compressive load - extension curves are revealed by the experiments. A series of photographs is taken at different deformation stages of the test specimens.

The tested tubes are made of CT3 mild steel for which yield stress,

Table 1
Parameters of all types of nested tube structures.

Specimen	No.	Outer tube b(mm) - h (mm)	Inner tube b(mm) - h (mm)	L(mm)	t(mm)
RRTT1	1	40–80	25–50	70	1.4
	2				
	3				
	4				
RRTT2	1	40–80	30–60	70	1.4
	2				
	3				
	4				
RRTT3	1	60–120	40–80	70	1.4
	2				
	3				
RST	1	60–120	50–50	70	1.4
	2				
	3				
	4				

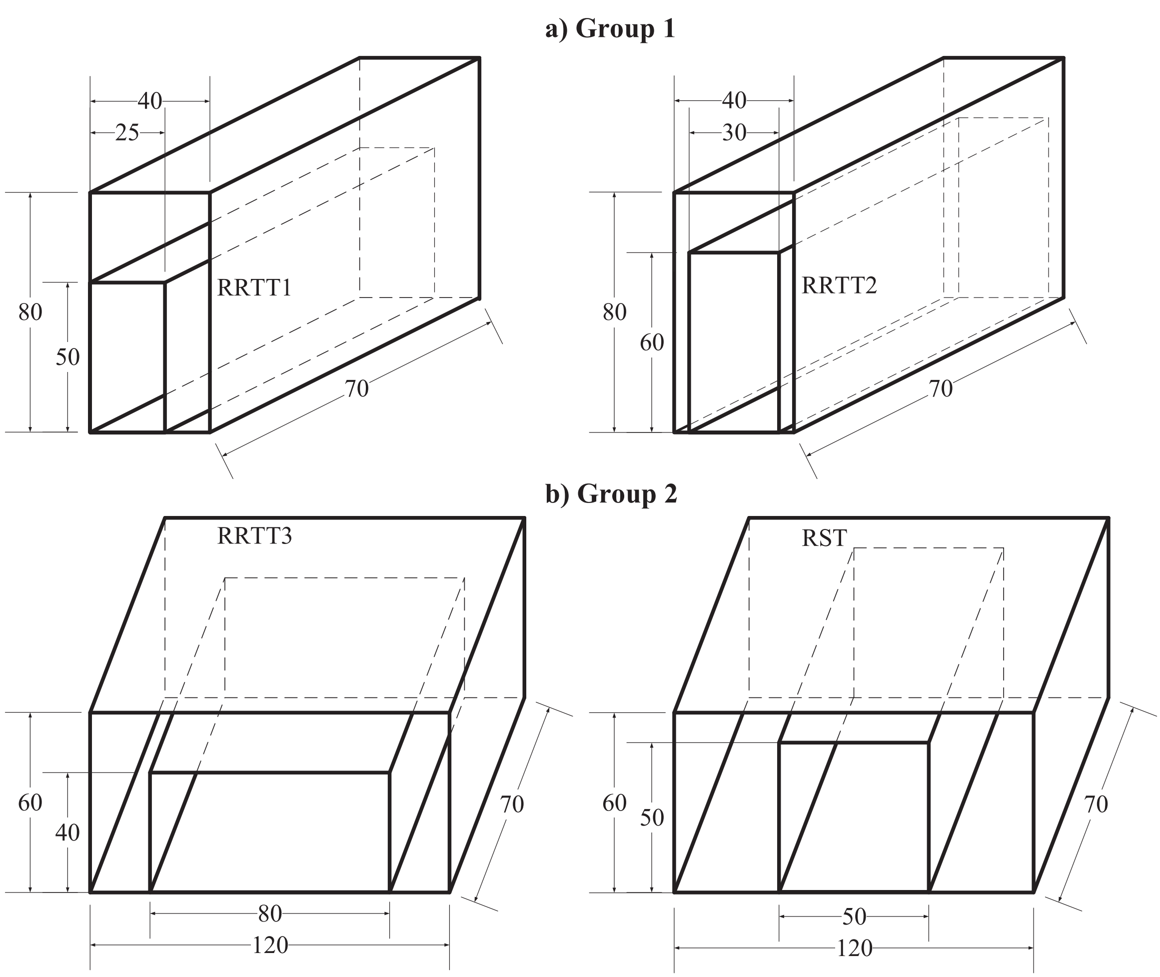

Fig. 2. Nested tube structure subjected to lateral compression load: a) Group 1 (RRTT1 and RRTT2) and b) Group 2 (RRTT3 and RST).