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HYSTERETIC BEHAVIOR OF COMPACT CIRCULAR STEEL TUBULAR COLUMNS

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INTRODUCTION: Hysteretic behavior of compact circular steel tubular columns of cantilever type subjected to combined constant axial load and cyclic lateral displacement are studied through finite element analysis employing the two-surface model[1] (2SM) for material nonlinearity. The effects of some important parameters, such as, column slenderness ratio, steel grade, axial load, and shape of cross-section on the hysteretic behavior and energy absorption capacity are pointed out and evaluated.

ANALYTICAL METHOD: An elastoplastic analysis based on the finite element method, using a conventional beam-column element of three displacements at each node, is employed in the analysis. In this approach, the member analyzed is divided into several beam-column elements along its length, and the cross-section is further subdivided into elemental areas, as shown in Fig. 1 for a hollow circular section. Each of the elemental areas is identified by, area dA_i, distance from the section centroid y_i, residual stress and strain, and stress-strain history. The incremental stress-strain relation for each elemental area is described by the 2SM[1]. The stress resultants of axial force and bending moment are calculated simply by summing the contribution of each elemental area over the cross-section[2]. The study has been confined to compact design and ignores local buckling. Initial geometrical imperfection and residual stress are not considered.

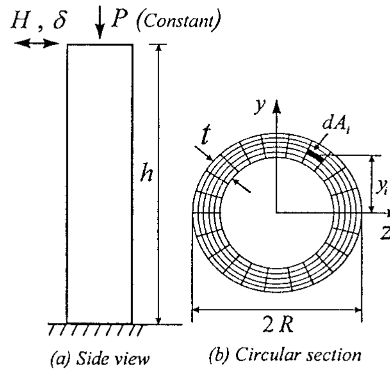

Fig. 1 Tubular column and subdivision of section.

COMPARISON WITH EXPERIMENT: Fig. 2 shows the normalized lateral load H/H_{y0} versus lateral displacement δ/δ_{y0} responses from the experiment(test C1[3]) and 2SM for a circular steel tubular column (see Fig. 1). The notations H_{y0} and δ_{y0} indicate, respectively, the yield load and yield displacement (neglecting shear deformation) corresponding to zero axial load[2]. The tested column had a slenderness ratio of $\bar{\lambda} = 0.38$ and the radius-to-thickness ratio of $R/t = 15$. The parameter $\bar{\lambda}$ controls the global instability and R/t ratio inhibits local buckling of the column. Owing to the smaller value of R/t ratio, local buckling did not occur until lateral displacement reaches at $\delta/\delta_{y0} = 0.6$, and the strength did not deteriorate until lateral displacement of $\delta/\delta_{y0} = 0.9$[3], see Fig. 2(a). Fig. 2 shows that the overall shape of the hysteresis loops from the developed formulation (2SM) are significantly closer to the experimental results mainly owing to the accuracy of the 2SM.

In order to account for the displacement history to which the inelastic performance of a structure is highly sensitive, a normalized cumulative energy absorption, $\bar{E}$, defined as

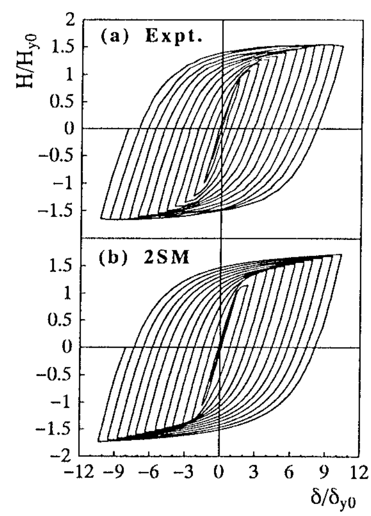

Fig. 2 H/H_{y0} versus δ/δ_{y0} (SS400, $\bar{\lambda} = 0.38$, $R/t = 30$, $P/P_y = 0.086$).

$$\bar{E} = \frac{1}{E_y}\sum_{i=1}^{n} E_i, \qquad E_y = \frac{1}{2}H_{y0}\delta_{y0} \tag{1}$$

is considered to be a more objective measure of the hysteretic behavior of a structure. In which, E_i =energy absorption in the i-th half-cycle, n = number of half-cycles[2]. Fig. 3 compares the value of $\bar{E}$ versus n obtained from the experiment and analysis using 2SM.

From this comparison it is clear that the predicted energy absorption capacity agrees well with experimental results. The reason is the 2SM takes accurately into account the yield plateau, Bauschinger effect and cyclic strain hardening of the material[1].

Key Words: steel, tubular column, hysteretic behavior, energy absorption capacity, two surface model
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PARAMETRIC STUDY: Using the developed formulation(2SM), an extensive parametric study is carried out on hypothetical specimens having circular sections of outer radius $R = 300mm$; and thickness $t = 20mm$, see Fig. 1. The main parameters considered are: column slenderness ratio; steel grade; axial load; and cross-section shape. After applying the prescribed constant axial load, lateral displacement histories are applied for 10 half-cycles with a constant peak displacement of $\delta/\delta_{y0} = \pm 4$.

The results of parametric study regarding energy absorption capacity are summarized in Figs. 4 and 5. Fig. 4 shows that all the curves corresponding to a specific P/P_y, say $P/P_y = 0.2$, and various $\bar{\lambda}$ values almost coincide for SS400. It implies that the column slenderness ratio has almost no effect on the normalized cumulative energy absorption capacity. Also, an increase in axial load P/P_y decreases the energy absorption capacity, especially when the number of cycles increases. Similar results have been obtained for steel grades SM490 and SM570.

Fig. 5 shows that the normalized energy absorption capacities for steel grades SS400 and SM490 are very close to each other and are lower than that of steel grade SM570. These observations are mainly attributed to the fact that steel grades SS400 and SM490 exhibit yield plateau, conversely, it is not the case for steel grade SM570. Fig. 5 also shows that the normalized absorbed energy capacities regarding each steel grade are very close and almost coincide for both of the compact square box section[2] and circular section. This implies that the shape of cross-section to be taken as compact circular or compact square box, does not significantly affect the normalized absorbed energy capacity under the same loading history.

CONCLUSIONS: The present paper was concerned with the hysteretic behavior and energy absorption capacity of compact circular steel tubular columns. The 2SM is employed for material nonlinearity in the beam-column finite element formulation used in the analysis. The developed formulation, after being verified by the experiments, was used to carry out a series of parametric studies on compact circular steel tubular columns. It was shown that: 1) the column slenderness ratio, $\bar{\lambda}$, has almost no significant effect on the normalized cumulative energy absorption capacity; 2) the yield plateau has the effect of reducing the normalized energy absorption capacity; 3) the shape of cross-section, to be a compact circular section or a compact square box section, does not significantly affect the normalized absorbed energy capacity under the same loading history.

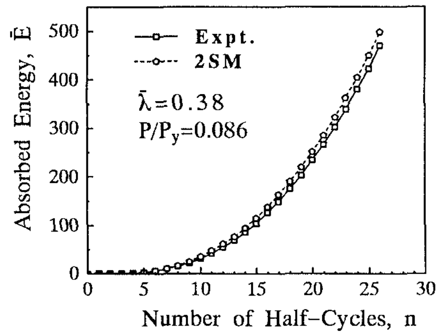

Fig. 3 Comparison of absorbed energy.

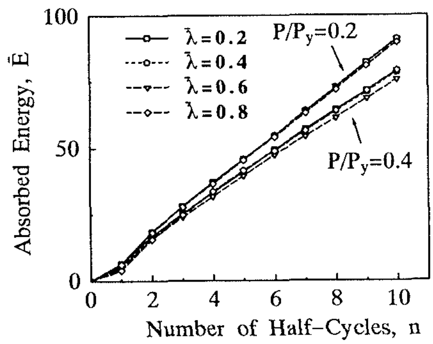

Fig. 4 Effect of column slenderness ratio and axial load on normalized absorbed energy.

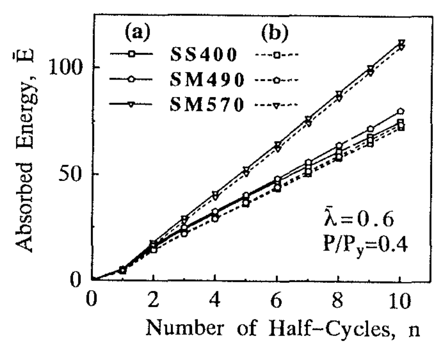

Fig. 5 Effect of steel grade and cross-section shape on normalized absorbed energy: (a) compact circular section; (b) compact square box section.

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