Buckling behavior of straight slot tubes under oblique loading – A comparative study
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Abstract—Hollow tubes are the most important or crucial parts of the rapidly growing automobile and construction industry. The tube is subjected to pure buckling. In the analysis, one end is fixed and the force is applied to the other end and by application of different angles of inclinations ranging from 0° to 20° with different thickness of the range of 0.5 to 2.0. Linear buckling code was used for finding the critical buckling load. This research paper is about the effects of buckling under oblique loading. It is the process in which the tube is subjected to compressive oblique loading and the tube fails by the first increase in cross-sectional area and then bulging on any of the sides but in the case, oblique loading in hollow tube shell bulges internally or inside the perimeter of the tube.

Keywords—buckling load; straight slot; oblique loading; finite element analysis.

I. INTRODUCTION

In the age of globalization and advancement in technology, every automobile industry is focusing primarily to ensure the crash safety without compromising the comfort and fuel efficiency. A detailed study has been carried out for finding the optimal design of structures for so as to act as a safeguard for humans and their stuff. Columns being the preeminent part of any structural design plays the vital role in presaging the structural efficiency. Thin walled tubes due to their light weight, low price, high strength to weight ratio, ease of fabrication is globally preferred over comparable solid section. The behavior of thin-walled tubes is exclusively dependent upon cross-sectional shapes and material properties. The behavior of tubes changes when their cross-sectional shape is changed thereby making it an arduous task for finding an optimal design for a circumstantial exercise.

It is evident that the hollow tubes for the intrinsic part of any structure and a lot of attempts have been made by the researchers previously for finding the individualized characteristics of a different cross-section such as rectangular, triangular, octagonal, 12 sided star, lateral corrugations to name a few [1-5]. The influence of geometrical features and modifications on the behavior of tubes is presented by Z Fan [6]. The buckling response of tubes can be further enhanced by foam fillers [7]. The behavior of tubes is predominantly determined under axial loading conditions however in real case situation the structures are seldom subjected to pure axial or pure bending, rather a combination of two. Therefore in order to apprehend the buckling characteristics of the tubes, the reaction under oblique loading is even more important. The behavior of hollow tubes under static and oblique loading was investigated [8]. The previous study shows that the response of tubes under oblique loading can be improved by combining the cross-sectional shapes [9]. The present study has numerically investigated the buckling response of straight slot tube at various angles of inclinations for getting an insight of the effect of oblique loading.

II. NUMERICAL SIMULATION

A. Material properties

The material for tubes is aluminum alloy with mass density \( \rho = 2.7 \times 10^3 \text{ kg/m}^3 \) and having Young’s modulus as 7100Mpa, the poisons ratio as 0.33 and Ultimate tensile strength as 310Mpa and steel is having the mass density \( \rho = 7800 \text{ kg/m}^3 \) and the poisons ratio as 0.26 and the ultimate tensile strength as 250 Mpa.

B. Finite element model

In this analysis, we use ANSYS with linear buckling module under oblique loading. The specific dimensions of the tube are presented in Table 1. CAD modeling was done in Solidworks. One end is fixed and the other end is free too which load is applied (100 N). The inclinations angles were taken as 0°, 5°, 10°, 15°, 20° as shown in Fig.1.
The thickness of the tube was taken as 0.5, 1.0, 1.5, and 2.0 while the length of the tubes was kept constant as 100 mm. A detailed geometric specification is presented in Table 1.

| Specimen | Thickness (mm) | Length (mm) |
|----------|----------------|-------------|
| SS-T1    | 0.5            | 100         |
| SS-T2    | 1.0            | 100         |
| SS-T3    | 1.5            | 100         |
| SS-T4    | 2.0            | 100         |

C. Meshing of geometric profiles
The meshing of the tubes were done in such a manner that the number of elements were almost same in all the different configurations which was corresponding to thousand on an average. A detailed description of the mass of slot tubes as a function of element is given in Table 2.

| Specimen | Mass (Kg) | Elements |
|----------|-----------|----------|
| SS-S-T1  | 5.5347e-002 | 1116     |
| SS-S-T2  | 0.10947   | 1080     |
| SS-S-T3  | 0.16235   | 1044     |
| SS-S-T4  | 0.214     | 1044     |
| SS-A-T1  | 1.953e-002 | 1116     |
| SS-A-T2  | 3.8627e-002 | 1080 |
| SS-A-T3  | 5.7287e-002 | 1044 |
| SS-A-T4  | 7.5512e-002 | 1044 |

III. RESULTS AND DISCUSSION
The objective of this ongoing analysis is to find out about the buckling behavior of straight slot tube under oblique loading. The straight slot geometry with a different angle of inclinations and different thickness with a constant length (100 mm) is taken for the analysis. The geometry is tested under 5 angles of inclination ranging from 0˚ to 20˚ with the same load of 100 N and further analysis is being made by considering several results like in case of steel maximum peak load are at 0˚ which is 2980.5 and thickness of (2.0) mm while the maximum peak load in case of Aluminum is 1047.8 which is at 0˚ inclination and thickness of (2.0) mm respectively.

| Specimen | Load Multiplier |
|----------|-----------------|
|          | 0˚  | 5˚  | 10˚ | 15˚ | 20˚ |
| SS-S-T1  | 64.29 | 53.41 | 43.30 | 35.02 | 28.29 |
| SS-S-T2  | 448.7 | 406.71 | 349.1 | 293.2 | 241.7 |
| SS-S-T3  | 1355. | 1277.5 | 1127. | 961.7 | 798.57 |
| SS-S-T4  | 2980.5 | 2860.5 | 2569. | 2220. | 1852.1 |
| SS-A-T1  | 22.66 | 18.79 | 15.23 | 338.4 | 9.9727 |
| SS-A-T2  | 157.9 | 143.05 | 122.8 | 103.2 | 85.222 |
| SS-A-T3  | 476.7 | 449. | 396.4 | 338.4 | 281.19 |
| SS-A-T4  | 1047. | 1005.5 | 904.4 | 781.2 | 652.55 |
IV. CONCLUSION

The critical load of the straight slot thin-walled tubes was investigated at quasi-static axial and oblique loading numerically. The critical load changes with a change in the thickness and angle of loading. It was found that the value of the critical load may improve but limited to a certain extent. Based on the numerical observations following conclusions can be wrap up:

- Steel is more stable because its critical buckling load is more than that of aluminum as per this straight slot geometry is concerned.
- With the increase in the thickness of the slots, the buckling load was rising.
- Clearly further more comprehensive studies are needed to investigate this problem.

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