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Behavior of thin-walled tubes with combined cross-sectional geometries under oblique loading

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***Abstract*—*Hollow tubes are the most important part of any structure because of their load-bearing capacity, lightweight and inexpensive manufacturing cost. One of the methods for improving the performance under quasi-static loading is to vary the cross-sectional shapes. In the real case, structures are seldom subjected to pure axial or pure bending rather they are subjected to a combination of two load cases i.e. oblique loading. In this paper, the circular cross-section was combined with four different polygonal cross-sections namely tetragon, hexagon, octagon and decagon and a total of 13 geometries were obtained. The buckling behavior of each tube was investigated numerically at various angles of inclination. Each tube was modeled in SOLIDWORKS and then was analyzed in ANSYS. Linear buckling code was used for finding the critical load at various angles ranging from 0° to 14°. The overall result was then compared and it was found that the proposed geometry can be a good alternative over conventional circular tubes in terms of load-bearing capacity at angular load.*

***Keywords*—buckling load; combined cross-section; oblique loading; finite element analysis.**

I. INTRODUCTION

In recent decades, the prime focus in the automobile industry is to ensure the vehicle crash safety without compromising the fuel efficiency in concern with the environment and sustainability. Aluminum alloys being 25% lighter than steel along with high energy absorption capacity are widely used in automotive industries. The lighter vehicle assures less fuel consumption contemporaneously making the environment cleaner [1]. Hollow metallic tubes are most efficient structures under axial loading [2]. In many publications, the energy absorption and initial peak load for the thin-walled tubes under axial or pure bending are presented. The performance of the tubular structure is solely dependent on either material or the geometrical shape. Studies show that the behavior is significantly affected by different geometrical features and modifications [3]. Cross section shapes such as circular, rectangular, hexagonal, polygonal and star-shaped have been investigated by many researchers [4-8]. The behavior of combined geometry tubes composing of plain, hemispherical and shallow spherical cap with cylinder segment is presented by A. Praveen Kumar and M. Nalla Mohamed [9]. In the real case, structures are infrequently subjected to axial loading, therefore, to comprehend the thin-walled metallic tubes there response under oblique loading is even more important. The response of square tubes under static and oblique loads was investigated [10].

This paper has numerically investigated the response of thin-walled tubes under oblique loading when polygonal cross-section was combined to circular cross-section to form combined cross-sectional geometries. The previous study shows that with combined cross section the increase in weight is minimal while the increase in buckling load is palpable [11].

NOMENCLATURE	
C – CIRCLE	O - OUTER PERIPHERY
F – FOUR SIDES	I - INNER PERIPHERY
S – SIX SIDES	
E – EIGHT SIDES	
T – TEN SIDES	

II. NUMERICAL SIMULATION

A. Material properties

The material for tubes is aluminum alloy with mass density $\rho = 2.7\times10^{-6}$ kg/mm^3 and having Young's modulus as 71000Mpa, the poisons ratio as 0.33 and ultimate strength is 310Mpa.

Specimen	Density (kg/m^3)	E (GPa)	Poisson's Ratio
Aluminum Alloy	2700	71	0.33

B. Finite element model

The finite element software ANSYS was used with Linear Buckling module to find the critical load of the geometries when subjected to oblique loading. Specific geometric dimensions were taken from the previous paper [11] which is shown in Figures below.

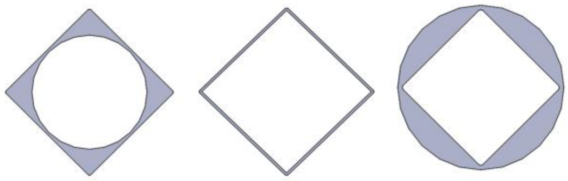

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Fig. 1. (a) FOCI, (b) FOFI, (c) COFI

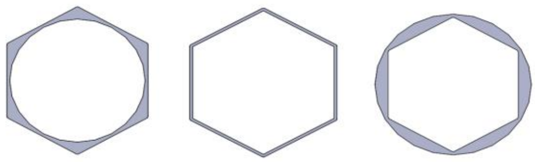

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Fig. 2. (a) SOCI, (b) SOSI, (c) COSI

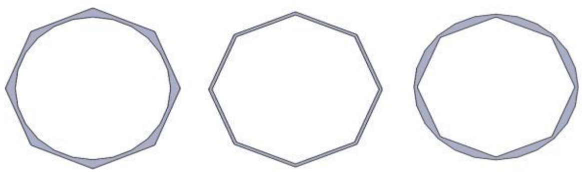

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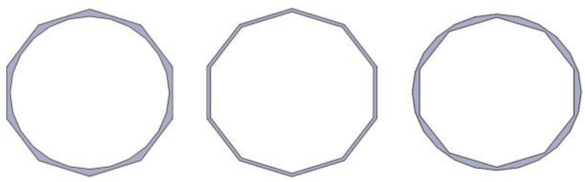
Fig. 3. (a) EOCI, (b) EOEI, (c) COEI



a b c

Fig. 4. (a) TOCI, (b) TOTI, (c) COTI

CAD model of the tubes was created using SOLIDWORKS. Fixed support was provided at one end while the load was applied at the antipodean end. The loads were applied at 0°, 3°, 7° and 14°.

III. RESULTS AND DISCUSSION

The present investigation aims to find the behavior of combined cross-sectional thin walled tubes when they are subjected to oblique loading. Four different cross-sectional shapes (i.e. tetragon, hexagon, octagon, and decagon) were combined with conventional tubular structure for finding the critical load for the first geometrical imperfection. In this section, detailed outcomes of the results of the finite element analysis of the tubes under quasi-static axial along with oblique loading conditions are presented. Each specimen was tested under four loading angles ranging from 0° to 14°. The buckling load for each were recorded and is listed in Table 1.

Table.1: Buckling load of specimen under oblique loading

Specimen	Mass (kg)	Buckling Load (N) 0°	3°	7°	14°
C	0.43	8080.5	8044.9	7888.5	7335.4
FOCI	1.91	45238	45109	44510	42319
FOFI	0.54	13608	13490	13309	12403
COFI	2.25	34355	34251	33784	32115
SOCI	0.98	20122	20054	19746	18653
SOSI	0.47	9901	9837	9279	8504
COSI	1.29	22789	22658	22495	21490
EOCI	0.72	16020	13467	13234	12837
EOEI	0.45	9005.1	8981.3	8793.8	8173
COEI	0.93	17023	16581	16345	16070
TOCI	0.61	15508	11388	11269	10725
TOTI	0.44	8658.5	8621	8452	7857
COTI	0.75	13737	14019	13498	12788

The result obtained from the circular tube was kept as a benchmark for comparing the behavior of the other specimen under oblique loads.

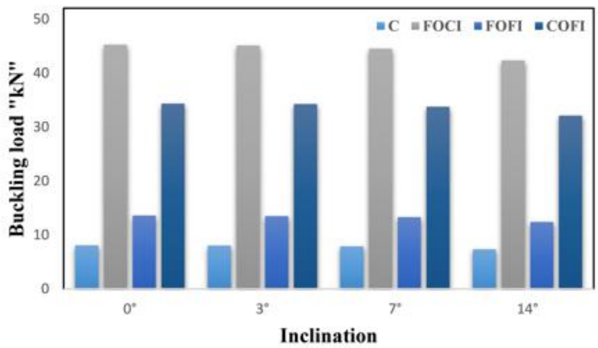


Fig. 5: Buckling behaviour for tetragonal combination under oblique load

The reduction in buckling load for a circular tube with the increase in inclination of loading was recorded as 9.22% at 14°. Fig. 5 shows the behavior of tetragonal combinations in comparison with the circular ones at similar loading conditions. It was found that the buckling load was highest for FOCI [Fig. 1.a] in all the cases while for the circular tube it was minimum. The reduction in buckling load for FOCI under oblique load was only by 6.4% at 14 degrees which were the minimum in tetragonal combinations, however, there was an increase in mass by 4.44 times. The response for hexagonal combinations is represented in Fig. 6. Specimen COSI here shows some good response as the buckling load was increased by 182.02% when loaded axially along with a good stability on oblique loading as the critical load was decreased by only 0.57% and 5.70%

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at 3 and 14 degrees respectively. Specimen SOSI [Fig. 2. b] was the least stable in hexagonal combinations as the stability was decreased by almost 14%.

Fig. 7 and 8 represent the response of octagonal and decagonal combinations respectively. The combination COEI shows the most promising structure under oblique as well as axial loading. The increase in buckling load under axial and oblique loading was 111% and 11.41% respectively.

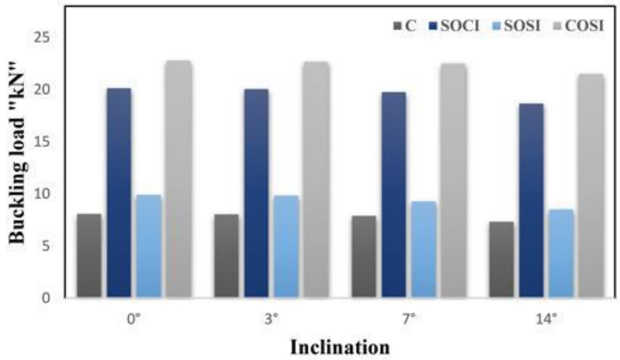

Fig. 6: Buckling behavior for hexagonal combination under oblique load

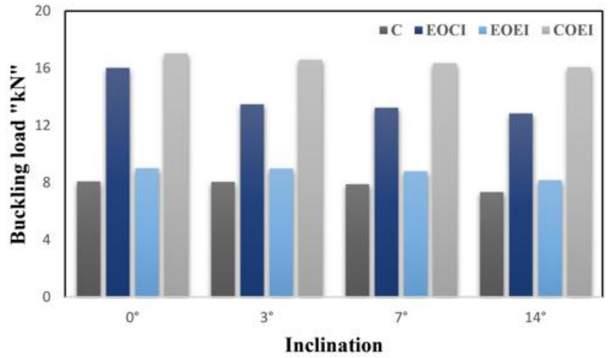

Fig. 7: Buckling behavior for octagonal combination under oblique load

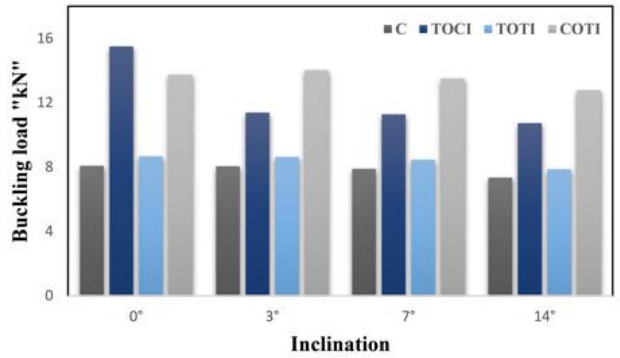

Fig. 8: Buckling behavior for decagonal combination under oblique load

The specimens TOCI and COTI displayed some interesting behavior. Introduction of decagonal shape on the outer periphery of the circular tube [Fig. 4. a] led to a minimal increase in weight but a considerable rise in buckling load by 92%, However, the stability of the specimen was decreased by 31% which was highest in the table. Considering the antipodean case when the decagonal cross section was introduced in the inner periphery the specimen was found to be well balanced, the stability increased by 25% along with the increase in buckling load by 70%.

IV. CONCLUSION

The critical load of the combined cross-sectional thin-walled tubes was investigated at quasi-static axial and oblique loading numerically. The critical load changes with a change in the cross-section shapes. 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:

- Buckling load and mass for the conventional circular tube was minimum.
- The highest buckling load under axial and oblique load was for FOCI.
- The two most stable configurations under oblique loading were COSI and COEI.
- With the minimum increase in mass, COTI showed an increase in buckling load under axial loading and maintaining stability with changing the inclination angle.
- Since the combined cross-sectional geometries look a promising structure in terms of buckling load over the comparable cylindrical tube with minimal increase in weight, these tubes can be used as a substitute over cylindrical tubes.
- Clearly further more comprehensive studies are needed to investigate this problem

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