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Numerical Investigation on Buckling Behavior of Non-prismatic Steel Columns with different Taper Ratio and Hollow Flanges

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Abstract: Buckling analysis is particularly important for steel structures because they are slender sections. Buckling occurs suddenly and cause system to collapse. Now a days tapered structural members are used for the stability purpose. Non-prismatic members are popular for civil engineering structures and certain benefits in terms of efficiency in material consumption and better steel utilization can be achieved by using tapered members. This study deals with the axial load performance of web tapered I-section steel column. The column is axially loaded by keeping overall weight of the column constant. The study focused on analysis of non-prismatic column with different taper ratio and the best model was fixed. Two different shape such as L-shape and V-shape were used for taper ratio study. The effect of using different hollow flange shapes such as rectangular, trapezoidal, and tubular on tapered steel column were also studied. A non-linear finite element model using ANSYS 16.1 has been adopted to investigate axial load behaviour of tapered column section. The result was analysed to determine buckling behaviour of tapered column section.
Keywords: Buckling, Non-prismatic members, tapered steel column, axially loaded, taper ratio, hollow flange

I. INTRODUCTION

Steel is an alloy of iron and carbon, and due to its high tensile strength and low cost, this material is widely used in buildings. Buckling of steel structure under axial compression load is described as bending of structure. Structures can be unstable due to many factors; as like when structural member reaches to their yield strength. Collapse of structure is due to maximum deflection or fracture of a member. Now a days, tapered structural elements are commonly used for stability purposes. Columns are one of the important parts of the structure, which transfer load of the structure to the surrounding soil through the foundations. So, it is important to build strong columns, otherwise failure will occur. Light steel structures have been extensively used in recent years, since it is most effective in practical applications. The major advantages of using such kind of structures are the effective usage of material and faster erection as well as their good service characteristics. Over the past three decades, building frames made with web tapered I-columns and web tapered I-beam, manufactured from high tensile steel have become a standard practice. Fabrication cost of such tapered members can be minimized by using automatic welding techniques. Tapered members are used in buildings mainly due to their strucural efficiency, at the same time it also provides aesthetical appearance.

Web tapered I section steel column have become very popular in construction field. Tapered steel column are type of reduced sections as shown in Fig. 1. They are non uniform in nature with more width at one end and tapered at the other end. They are popular in modern building construction due to its material effeciency and the convinience in construction. Metal building system builders have an option to use straight column or tapered column to built up a structure. A tapered column design can reduce cost and amount of steel required in many ways. Tapered columns are commonly used in telephone towers, post towers, Steel frame such as industrial halls, warehouses etc. Now a days it is also used in buildings as diagonal members. The design considered for tapered column is minimum weight design of columns with varying web area but constant flange area. The web will be of uniform thickness and is tapered linearly. The most recent studies of tapered steel members are mostly based on analytical work which is validated by advanced non-linear numerical simulations. Although there are several advantages for tapered steel members, In any other structural solutions these advantages depends directly upon use of suitable tools (analytical, numerical or code) by the designer. In this sense, it is found that there is lack of design rules, guidance and validated solution for non-uniform members.

This Paper aims to study the buckling behaviour of web tapered I-section steel column under different taper ratios and different shapes of hollow flanges. The taper ratio of a tapered member is defined as the ratio of maximum height to minimum height of a section.

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Two different shapes such as L-shape (Inclination of flange is different with respect to centroidal axis) and V-shape (Inclination of flange is equal with respect to centroidal axis) is used for taper ratio study. There are lot of advantages by keeping flange of a I-section as hollow. Several studies were done on hollow flange effect in beams, girders etc. So, with the importance to check how it effect in small portions like column, the effect of different shapes of hollow flanges on buckling behavior of tapered steel column are also investigated.

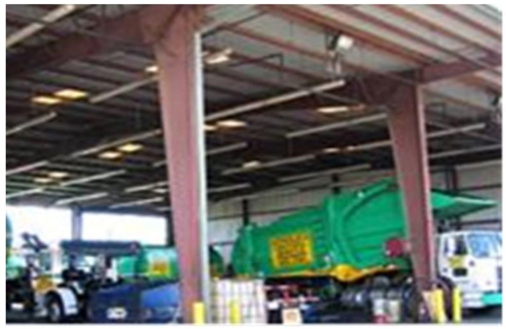


Fig. 1 Tapered steel column

II. OBJECTIVES

A. To study the buckling behaviour of non-prismatic steel column
B. To investigate non-prismatic steel column with different taper ratio
C. To investigate non-prismatic steel column with hollow flange effect and effect of different shapes of hollow flange

III. MODELLING OF TAPERED STEEL COLUMN

Steel columns provide better compressive strength, but it tends to buckle under extreme loading. To minimize the buckling effect and improving structure performance tapered steel columns are preferred and modelled. The tapered I-section steel column were designed for 6m height with various taper ratio. Both ends of the column are hinged and lateral supports are provided along the length of the column with 1 m spacing. Geometric properties of taper ratio 3 is fixed with reference to *Trayana Tankova et al*. FEA analysis is one of the best available method to analyse the behaviour of column. In this investigation, a commercial finite element software package, ANSYS 16.1 is used to perform non-linear FEA computations of tapered steel column under consideration. The non-linearities in each model can be easily considered by ANSYS. Solid 186 is the element type used for modelling tapered steel column. The material properties used for steel section of all the models is given in Table I and geometric properties of taper ratio 3 is given in Table II.

Table I Material Properties of Steel Section

Properties	Steel
Young’s modulus (MPa)	2×10^5
Poisson’s ratio	0.3
Yield strength of flange (MPa)	345
Yield strength of web (MPa)	345
Density (Kg/m^3)	7860

Table II Geometrical Properties of Tapered Steel Column

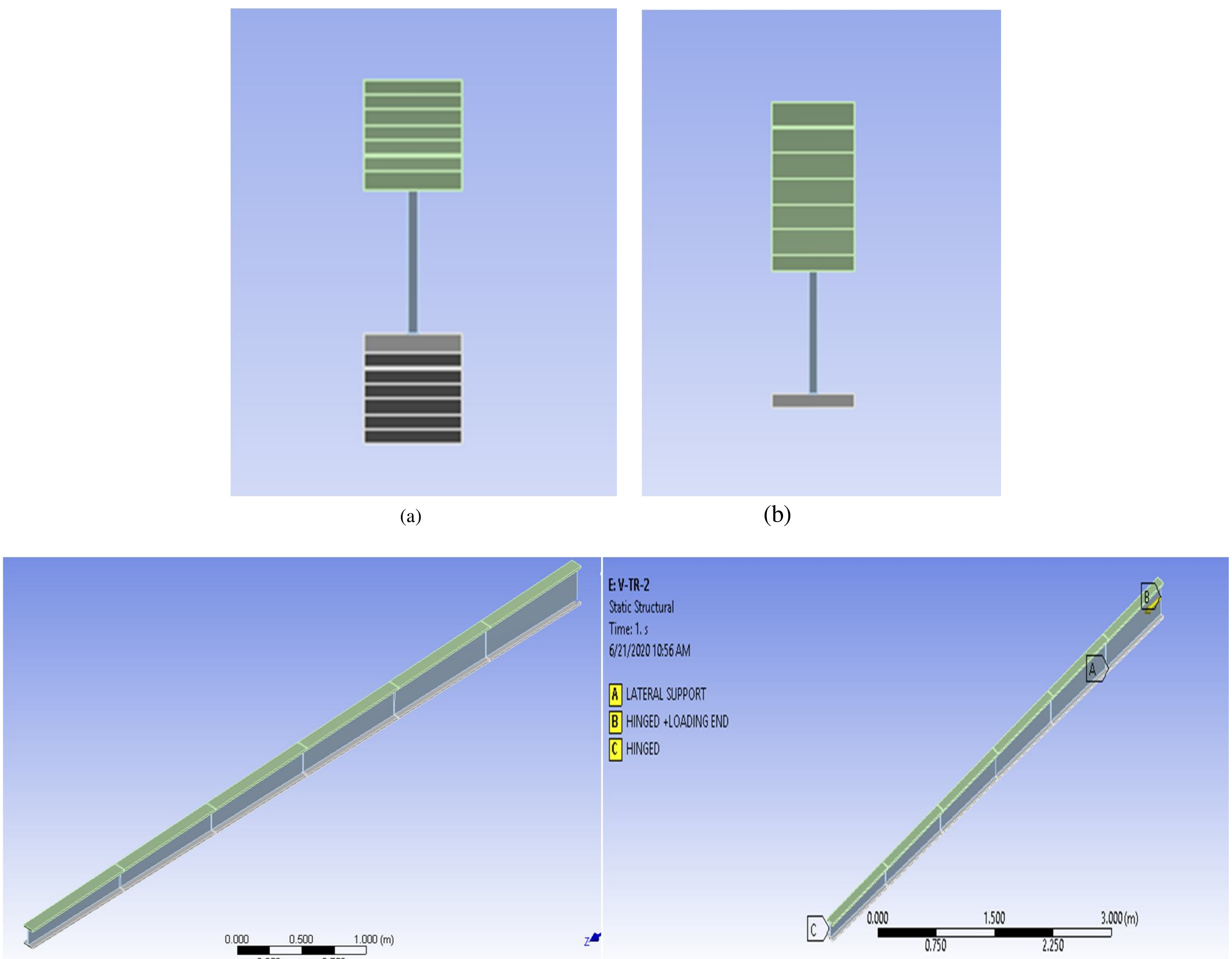
I-section steel column	Dimensions
Taper ratio	3
Shape	L
Minimum depth of section, h_{min}	120 mm
Maximum depth of section, h_{max}	360 mm
Breadth of flange, b_{bot} and b_{top}	100 mm
Thickness of web	10 mm
Thickness of flange, $b_{f, top}$ and $b_{f,bot}$	16 mm

A. Case 1 Non-Prismatic Steel Column with Various Taper Ratio

Taper ratio is the ratio of maximum depth to minimum depth of a section. Two different shapes are used for this study (L-shape and V-shape). For L-shaped column, the inclination of flange is different with respect to the centroidal axis and for V-shaped column, the inclination of flange is equal with respect to the centroidal axis. Various taper ratio chosen are 2,3 and 4. Taper ratio 3 is fixed with reference to Trayana Tankova et.al. The other taper ratios are fixed by keeping the overall weight of the column constant and by adjusting h_{max} and h_{min} of the column. The length of column is 6m. Table III represents maximum and minimum depth of sections. The cross-sectional view of L-shape and V-shape tapered column, isometric view and boundary conditions provided for tapered steel column are shown in Fig. 2.

Table III Maximum and Minimum Depth of Sections

Taper ratio	h_{max} (mm)	h_{min} (mm)
2	320	160
3	360	120
4	384	96



(a) (b)

(c) (d)

Fig. 2 (a) Cross-sectional view of V-shape (b) Cross-sectional view of L-shape (c) Isometric view (d) Boundary conditions of tapered column sections

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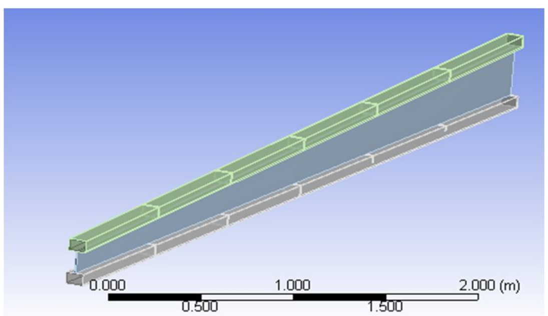
B. Case 2 Non-Prismatic steel column with different shapes of hollow flange

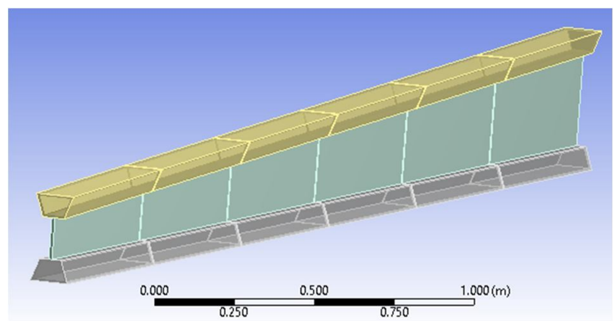
After fixing the best taper ratio (2) and best shape (V), the effect of hollow flange and different shapes of hollow flange on buckling behaviour of non-prismatic tapered column is studied. There are lot of advantages by making flange as hollow. So, it is necessary to check wheather it effects the buckling behaviour and structural performance of tapered steel column. The hollow flange flange can be provided in different shapes and inorder to check the shape effects, rectangular, trapezoidal and tubular hollow flanges are used in this study. Weight of flange and column is kept constant for all models. The thickness of hollow is 5mm for all models. In all these models, the web height is same as previous case, where the flange size varies. Size of hollow flanges is shown in Table IV. Fig 4 represents tapered steel column with rectangular, trapezoidal and tubular hollow flanges.

Table IV Size of Hollow Flanges

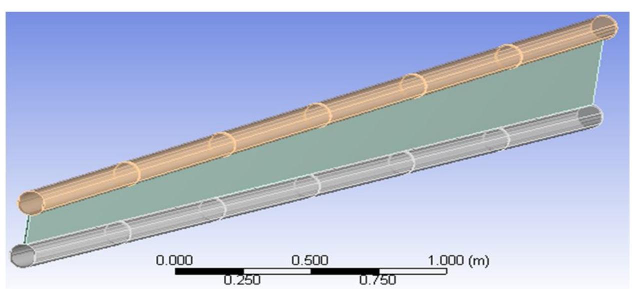
Hollow flange	Size
Rectangular	100×70 mm
Trapezoidal	100×70×70 mm
Tubular	53.2 mm diameter



(a)



(b)



(c)

Fig. 3 Tapered steel column with (a) Rectangular hollow flange (b) Trapezoidal hollow flange (c) Tubular hollow flange

IV. ANALYSIS AND RESULTS

V-Shaped and L-Shaped tapered steel column with taper ratio 2,3 and 4 are analysed. The load and corresponding deformation obtained for V-shaped and L-shaped columns with various taper ratios is given in Table V. The axial load given in table V is the maximum amount of axial load at which the column fails and the deformation given is corresponding to the failure load. Fig 4 and Fig.5 represents load-deformation curve for L-shape and V-shape tapered columns.

Table V Load and Deformations of Various Taper ratio

Taper ratio	Axial Load (kN)		Deformation (mm)	
	V-Shape	L-Shape	V-shape	L-Shape
2	1537	1511	8.93	9.02
3	1361	1358	8.3	8.43
4	1272	1229	7.74	7.63

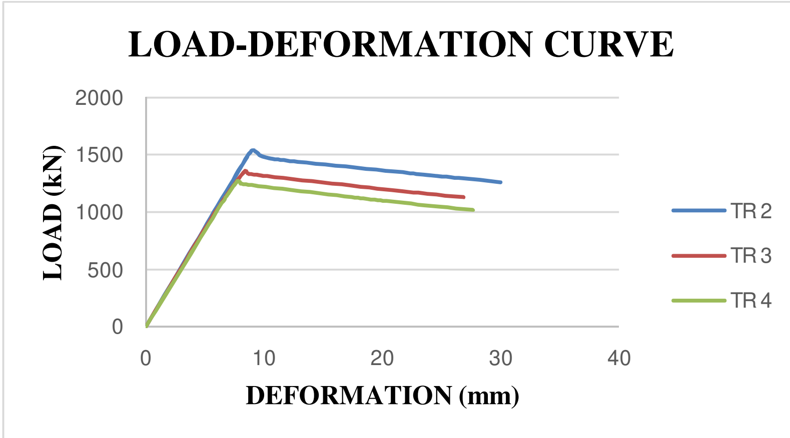


Fig. 4 Load deformation curve for V-shaped tapered column

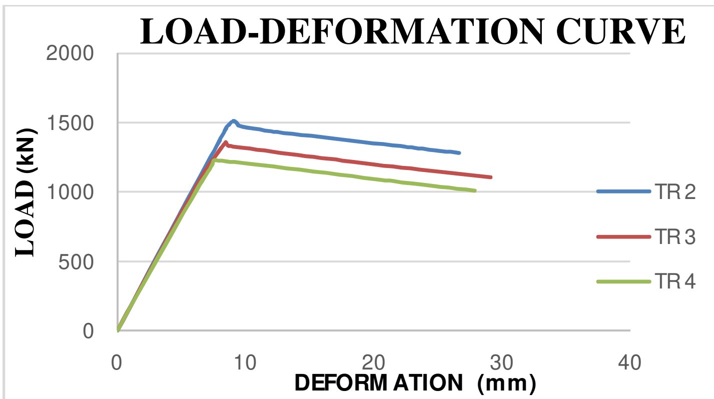


Fig. 5 Load deformation curve for L-shaped tapered column

From Fig. 4 and Fig. 5, It can be observed that load deformation curve for all models reaches a peak point and at that peak point, failure of the column occurs and load corresponds to that peak point is the maximum loading. Taper ratio 2 has the maximum load at failure. Out of L-Shape and V-Shape, V-Shaped tapered steel column with taper ratio 2 shows the best result. Since it has the maximum load carrying capacity, it is chosen as best model from case 1 and is the selected model for case 2. Fig. 6 shows Total deformation of V-Shaped tapered column with taper ratio 2. It was found that, all of the models with various taper ratio undergo local in-plane buckling.

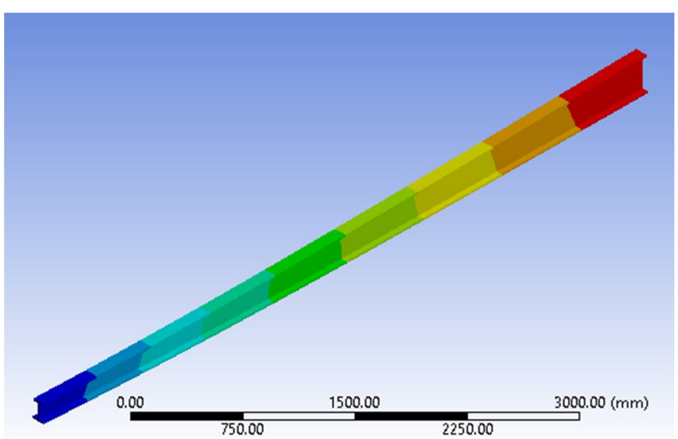


Fig. 6 Total deformation of V-shaped tapered column with TR 2

V-shaped tapered column having taper ratio 2 with different shape of hollow flange such as rectangle, trapezoid and circle are analysed. Table VI shows load and deformations of various hollow flange cases.

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Table VI Load and Deformation of Various Hollow Flange Cases

Hollow flange	Axial Load (kN)	Deformation (mm)
Rectangle	1574	10.2
Trapezoid	1579	13.68
Tubular	1561	10.3

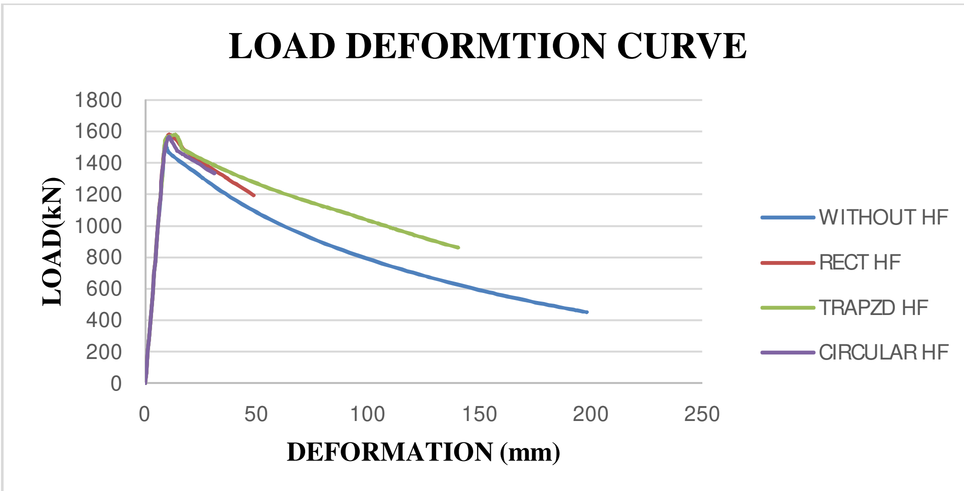

Fig 7 Load deformation curve of hollow flange effects

Fig. 7 shows load deformation curve obtained while comparing the hollow flange cases with tapered column without hollow flange From Fig. 7, tapered steel column with trapezoidal hollow flange has maximum load at failure. It is selected as the best model in this study, since it has more load carrying capacity while comparing with tapered column without hollow flange. Fig. 8 shows total deformation of tapered column with trapezoidal hollow flange. It was found that tapered column with, rectangular hollow flange undergoes local out-of-plane buckling, trapezoidal hollow flange undergoes local in-plane buckling and tubular hollow flange undergoes local in-plane buckling.

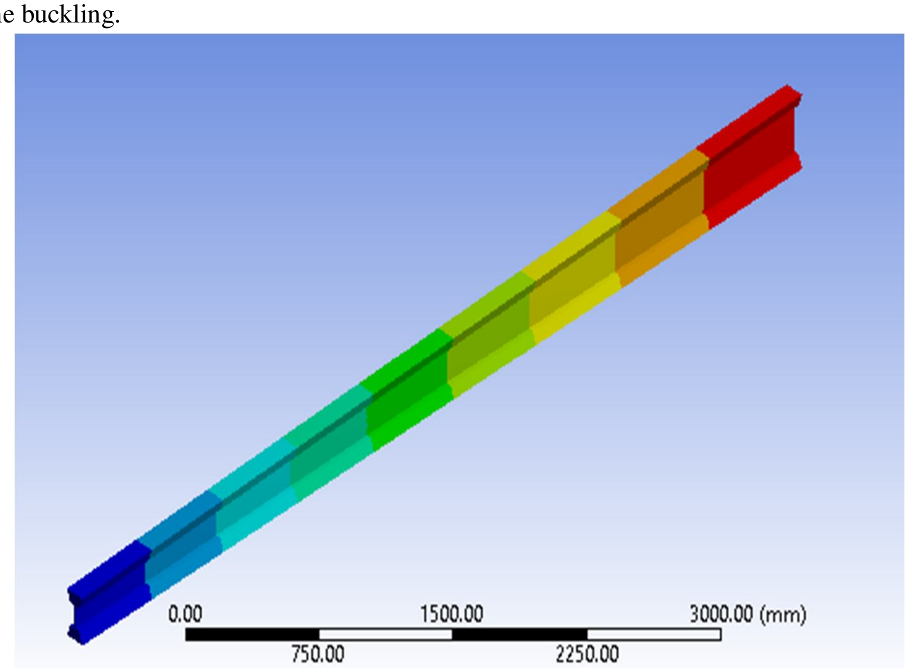

Fig. 8 Total deformation of tapered column with trapezoidal hollow flange

V. CONCLUSIONS

The aim of this paper is to investigate the buckling behaviour and load carrying capacity of various non prismatic steel columns using FEA modelling and analysis. The following conclusions are obtained from the analysis.

A. Taper ratio study on L-shape and V-shape tapered steel column shows that taper ratio 2 has the maximum load carrying capacity.
B. Further comparing L-shape and V-shape out of that, V-shape with taper ratio 2 gives the best result. It undergoes local-in-plane buckling.
C. Since hollow flange provision improves the stability of web, effect of different shapes of hollow flanges are studied and the result indicates that tapered steel column with trapezoidal hollow flange has the maximum load carrying capacity.
D. While comparing tapered steel column with trapezoidal hollow flange against tapered steel column without hollow flange (flat V), the axial load carrying capacity is higher for column with trapezoidal hollow flange.
E. Tapered steel column with trapezoidal hollow flange undergoes local-in-plane buckling.

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