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Buckling Analysis of Orthotropic Composite Shell With and Without Cutouts Using Fem

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Abstract

Composite thin cylindrical shells are most widely used structural forms in aerospace and missile applications. In missile and airframe, the composite cylindrical shell structures are generally provided with cut-outs for accessing internal components during integration. The cut-outs invariably reduce the strength of the composite cylindrical shell and more specifically the buckling load. It has been a design practice to improve strength by addition of stiffener around cut-out. The cut-out not only introduces stress concentration but also significantly reduces buckling load.

The stiffener can be designed easily from stress criterion using standard design charts. But based on buckling criterion, not much literature is available to designer to fix stiffening parameters, unless detailed finite element analysis is attempted. Not to gain say the buckling behaviour could best be simplified to a great extent if provided with tools like design charts or empirical relations to handle buckling based shell design with cut-outs.

The present study is aimed at finding elaborate data on buckling load, normal, shear, principal and von misses stresses and deformations with different layers, different cut-outs sizes and strengthening effect by providing stiffener around cut-out. In this work an attempt has been made to study the behaviour of composite shells with and without cut-out using Finite Element Analysis.

Keywords*: Bending buckling, Cylinderical shell, Cutout, FEM.*

1. Introduction:

Thin-walled cylindrical shells are found in many aerospace structural applications because of their high load carrying capacity and low structural weight. Many of these aerospace shell structures have cut-outs or openings that serve as doors, windows, or access ports and these cut-outs or openings often require some type of reinforcing structure to control local structural deformations and stresses near the cut-out. In addition, these structures may experience compression loads during operation, and thus their buckling response characteristics must be understood and accurately predicted in order to determine effective designs and safe operating conditions for these structures.

A review of the results presented in the literature indicates that the response of a compression-loaded cylindrical shell with an unreinforced cut-out is, for the most part, understood. In contrast, the effects of cut-out reinforcement on the buckling behaviour of compression-loaded composite cylindrical shells, is not well understood. The objective of the present study is to identify typical linear response characteristics of a compression-loaded, thin-walled, quasi-isotropic, laminated, cylindrical shell with a square cut-out and to illustrate the effects of several cut-out reinforcement configurations on the response. Toward this objective, numerically predicted results that show the effects of change in material properties of Graphite/Epoxy composite shell with reinforcement configurations on the response of these shell structures are presented.

The cut-out reinforcement configurations considered were used to study the effects of reinforcement isotropy on the response of the shell. In addition, the results are used to illustrate the feasibility of structurally tailoring cut-out reinforcement to control shell-wall deformations and stress concentrations near a cut-out in a compression-loaded shell, and to increase the load carrying capacity of the shell.

Next results illustrating the response of a compression-loaded cylinder with an unreinforced cut-out are presented. Then, results illustrating the effects of with and without cut-out, with and without reinforcement on the response of the shell are presented. Lastly, response trends are identified and discussed. Results include the variation of Buckling Factor, Deformation, Interlaminar shear stresses change in E_t/E_l, G_{xy}/E_l, and G_{yz}/E_l.

2. Buckling of Cylindrical Shell:

If the cylindrical shell is uniformly compressed in the axial direction, buckling symmetrical with respect to the axis of the cylinder. The critical value of the compressive force N_{cr} per unit length of the edge of the shell can be obtained by using the energy method. As long as the shell remains cylindrical, the total strain energy is the energy of axial compression. When buckling begins, we must consider in addition to axial compression, the strain of the middle surface in the circumferential direction and also bending of the shell. Thus strain energy of the shell is increased, at the critical value of the load; this increase in the energy must be equal to the work done by the compressive load as the cylinder shortens owing to buckling.

We assure for radial displacements during buckling the expression, $\mathbf{W = A \sin (m\pi x)/l}$

Where l is the length of the cylinder

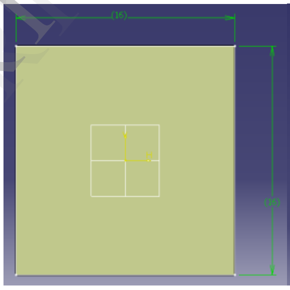
Critical stress (σ_{cr}) is found by using the expression,

$$\boldsymbol{\sigma_{cr} = Eh/ (r \sqrt{3} (1-v^2)}$$

2.1 FINITE ELEMENT MODEL:

The seven shells considered in this study were analyzed with the Structural analysis of linier shell. The 2-D diagrams of finite element model of a composite shell are shown in below fig1.1, fig1.2, fig1.3, fig1.4. A typical finite element model of a shell with centrally located square cutouts dimensions of a 1mm by 1mm. The shells have a length *L* of 16mm a radius *R* of 8mm.The shells were modeled as geometrically perfect, 8-ply-thick $[\pm45/0/90]_S$ quasi-isotropic graphite-epoxy laminates, in which each lamina ply had a thickness of 0.005mm. And shell wall thickness of 0.04mm. The cutout reinforcement consists of additional square-shaped lamina plies added to the shell-wall laminate at the shell-wall mid-surface that are aligned concentrically with respect to the square-shaped cutout in the shell. The square shaped reinforcement sizes included a2.4mm by 2.4mm.

2D-Drawings:



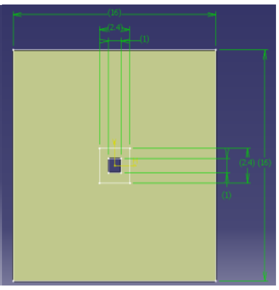
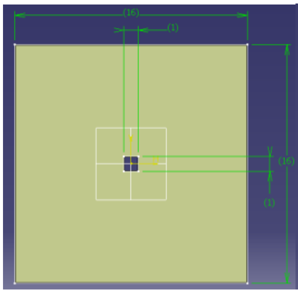


Fig1.1.Front view of composite shell
Fig1.2.Composite shell with hole



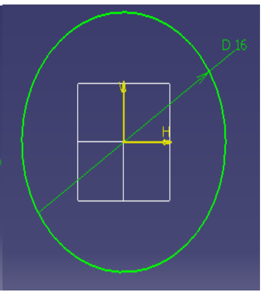


Fig1.3.Composite shell with reinforced hole
Fig1.4.Top view of composite shell

3.3. DIMENSIONS OF MODEL

Length of the shell =16mm

Radius of the shell =8mm

Thickness of shell =0.04mm

Thickness of ply =0.005mm

No of plies =8

Dimension of cutouts =1mm*1mm

3.4. PROPERTIES OF MATERIAL

Longitudinal modulus, E_l = $18.5e^6$Mpa

Transverse modulus, E_t = $1.64e^6$Mpa

In-plane shear modulus, G_{xy} = $0.87e^6$Mpa

In-plane shear modulus, G_{yz} = $0.51e^6$Mpa

Major Poisson's ratio, υ = 0.30.

3. Buckling of Shell with Square Cutouts:

The objectives of present study are to study the shell with square cutouts on the circumferential of the cylindrical shell with varies parameters when it is subjected to buckling load. Also this study aimed at finding elaborates strengthening effect by providing reinforcement around cutouts. With the advent of high speed computer and efficient general purpose finite element packages, parametric study of this nature is relatively inexpensive. However the applicability of finite element results for design is always appoint of debate so far as buckling failure concerned. The factor depends on the structure and nature of loading.

In carrying out of this parametric study, a symmetric approach has been followed in the first phase, geometric modelling of the shell and shell with cutout and reinforcement it has been developed. For this work finite element analysis package ansys10 on windows 2007 platform has been used for both geometric modelling. Meshing, static and item value of buckling analysis. Convergence study has been done on the complete shell without cutout by carrying out buckling analysis of shell. The necessary boundary conditions have been applied and bucking analysis carried out with varies conditions till acceptable finer mode shapes has been obtained. The cylindrical shell is subjected to axial compressive load. Initially only one cutouts is chosen on circumferential surface of the shell, at the mid span and solved for buckling analysis by varying material properties and at constant load of 2000N, the buckling factor and corresponding, mode shape is observed for the shell. Similarly buckling analysis has been carried with two and four cutouts placed diagonally opposite on circumference of shell, with same boundary conditions and also varying material properties at constant load of 2000N.It opted for buckling analysis of shell with cutout with reinforcement around cutout, with same boundary conditions and keeping the width of reinforcement and size of the cutout unchanged but varying the material properties, the improvement in buckling load is observed.

4. Introduction to Composite Material:

A composite material is defined as a material system which consists of a mixture or a combination of two or more distinctly differing materials which are insoluble are insoluble in each other and differ in form or chemical composition. Fiber reinforced composite materials consist of fibers of significant strength and stiffness embedded in a matrix with distinct boundaries between them. Both fibers and matrix maintain their physical and chemical identities, yet their combination performs a function which cannot be done by each constituent acting singly. Fibers of fiber reinforced plastic (FRP) may be short or continuous. It appears obvious that FRP having continuous fibers is indeed more efficient. Classification of FRP composite materials into four broad categories has been done according to the matrix used. They are polymer matrix composites, metal matrix composites, ceramic matrix composites and carbon/carbon composites, Polymer matrix composites are made of thermoplastic or thermo set resins reinforced with fibers such as glass, carbon or boron. Metal matrix composites consist of a matrix of metals or alloys reinforced with metal fibres such as boron or carbon.

Table4.1.Typical mechanical properties of selected fibres

Fiber Material	Density kg/m^3	Tensile strength Mpa	Tensile modulus Gpa	diameter
Glass	2550	3450-5000	69-84	7-14
Boron	2200-2700	2750-3600	400	50-200
Carbon	1500-2000	2000-5600	180-500	6-8
Kevler	1390	2750-3000	80-130	10-12
Silica	2200	5800	72	35
Boron carbide	2350	2690	425	102
Boron	1910	1380	90	6.9
Silicon carbide	2800	4500	480	10-12
Borsic/w	2770	2930	470	107-145
Borsic/c	2300	3170	415	107-145
Aluminia	3150	2070	210	17
Aluminia FP	3710	1380	345	15-25
Steel	7800	4140	210	127
Berylium	1830	1300	240	127
Molybdenum	1020	660	320	127
Quartz Whisker	2200	4135	76	92
Fe Whisker	7800	13800	310	12
Sic Whisker	3200	21000	840	5-10
Aluminia	4000	20700	427	5-10
Graphic Whisker	2100	20800	1000	5-10

5.0 RESULTS AND DISCUSSIONS:

The results are studied to understand the influence of cutouts on buckling strength of shell of same material and also the extent of improvement by proving reinforcement around cutouts. Numerically predicted results for selected compression-loaded quasi-isotropic laminated cylindrical shells with unreinforced and reinforced cutouts are presented in this section. The results were obtained from finite-element models of geometrically perfect shells subjected to a uniform axial end-shortening. These results are presented to illustrate the overall behaviour of a compression-loaded graphite-epoxy shell with a cutout and the effects of cutout reinforcement on the response. First, results illustrating the linear response of a compression-loaded geometrically perfect quasi-isotropic cylindrical shell with an unreinforced square-shaped cutout are presented. Then, results illustrating the predicted response of selected compression-loaded cylindrical shells with reinforced cutouts are presented and compared. Results include the variation of Buckling Factor, Deformation, Interlaminar shear stresses against E_t/E_l, G_{xy}/E_l, and G_{yz}/E_l.

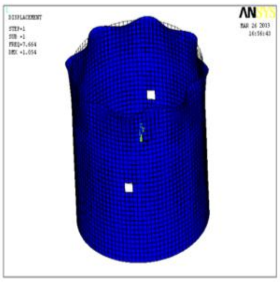
Fig5.1 shows the max buckling factor and deformation of without hole is 7.575, 1.008 respectively.

Fig5.2 shows the max buckling factor and deformation of with one hole is 7.570, 1.093 respectively.

Fig5.3 shows the max buckling factor and deformation of without hole is 7.664, 1.094 respectively.

Fig5.4 shows the max buckling factor and deformation of without hole is 7.637, 1.113 respectively.

Fig5.1Deformation without hole Fig5.2Deformation with one hole



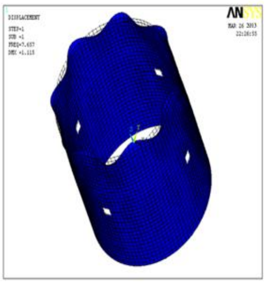


Fig5.3 Deformation with two holes Fig5.4 Deformation with four holes

Fig5.5 shows the interlaminar shear stress failure of without hole, the max, min stress is 4.134, -1.44 respectively. Maximum interlaminar shear stress is observed at bottom of composite shell.

Fig5.6 shows the interlaminar shear stress failure of without hole, the max, min stress is 14.625, -9.208 respectively. maximum interlaminar shear stress is observed at free edge of the hole of composite shell.

Fig5.7 shows the interlaminar shear stress failure of without hole, the max, min stress is 30.51, -17.599 respectively. maximum interlaminar shear stress is observed at free edge of the hole of composite shell.

Fig5.8 shows the interlaminar shear stress failure of without hole, the max, min stress is 33.134, -21.413 respectively maximum interlaminar shear stress is observed at free edge of the hole of composite shell.

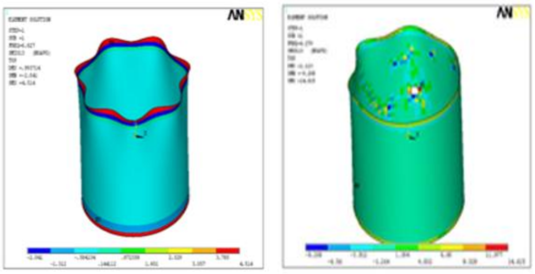


Fig5.5, Fig5.6 Interlaminar shear stress of without hole, with one hole

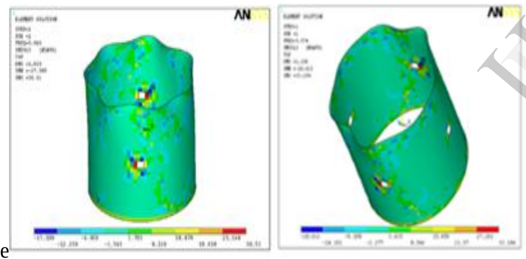


Fig.5.7, Fig5.8 Interlaminar shear stresses of with two hole, with four hole

Change in ratio of Et/El table

E_t/E_l	Without hole	With 1holes	With 2holes	With 4hole
0.02	7.181	7.186	7.287	7.212
0.04	7.298	7.302	7.398	7.325
0.06	7.413	7.416	7.508	7.437
0.08	7.575	7.578	7.664	7.595
0.10	7.639	7.641	7.725	7.657

Table5.1 Variation of buckling factor with change in ratio of E_t/E_l

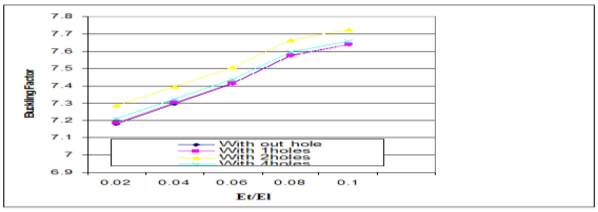


Fig5.9 Buckling factor Vs Change in ratio of E_t/E_l

Table5.2 Variation of inter laminar shear stress on S_{xz} with change in ratio of E_t/E_l

E_t/E_l	Without hole	With 1hole	With 2holes	With 4holes
0.02	11.412	12.753	13.381	13.586
0.04	11.843	12.878	12.801	13.377
0.06	12.256	13.582	13.511	13.24
0.08	12.831	14.137	14.068	13.791
0.10	13.062	14.36	14.293	13.985

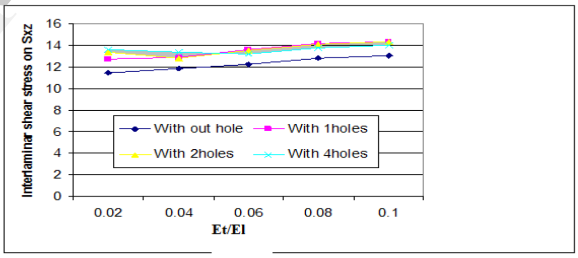


Fig5.10 Interlaminar shear stress on S_{xz} Vs Change in ratio of E_t/E_l

Table5.3 Variation of deformation with change in ratio of E_t/E_l

E_t/E_l	Without hole	With 1holes	With 2holes	With 4holes
0.02	1.011	1.102	1.069	1.138
0.04	1.008	1.099	1.065	1.136
0.06	1.007	1.096	1.059	1.131
0.08	1.006	1.093	1.054	1.122
0.10	1.010	1.091	1.053	1.115

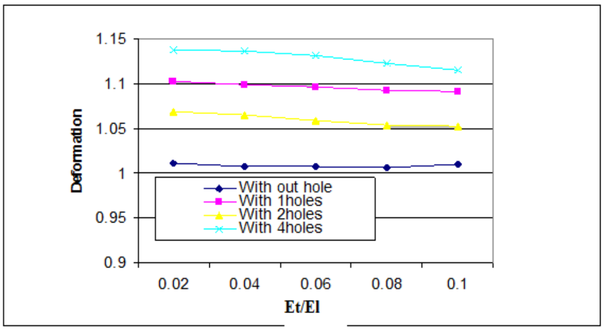


Fig5.11 Deformation Vs Change in ratio of E_t/E_l

5.2 WITH REINFORCEMENT OF COMPOSITE SHELL

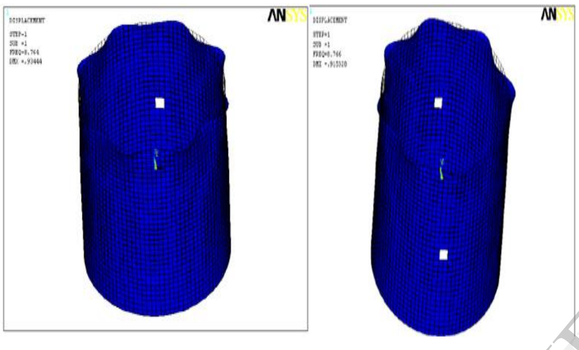


Fig5.12 Deformation of reinforcement with one and two holes

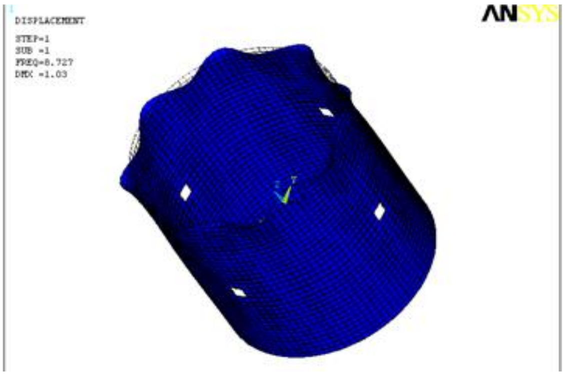
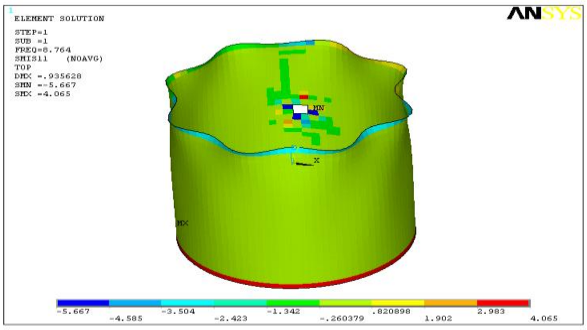


Fig5.30 Deformation of reinforcement with four holes

Fig5.12 Interlaminar shear stress with two hole



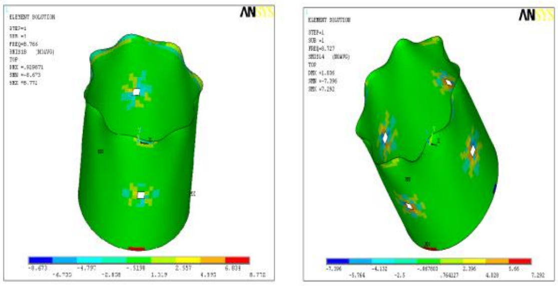


Fig5.12 Interlaminar shear stress with two and four holes

Table5.4 Variation of buckling factor with change in ratio of E_t/E_l

E_t/E_l	with one hole	with two holes	with four holes
0.02	7.112	7.059	7.055
0.04	7.231	7.177	7.169
0.06	7.347	7.294	7.281
0.08	7.511	7.458	7.439
0.10	7.575	7.522	7.501

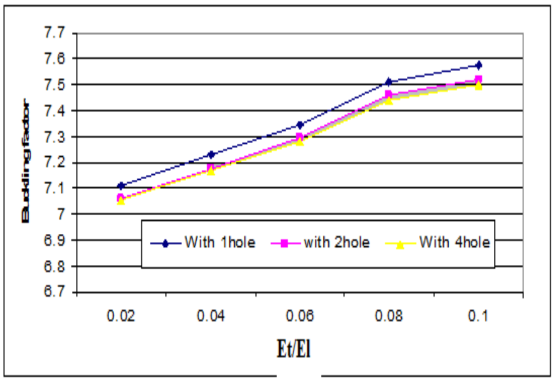


Fig5.13 Buckling factor Vs Change in ratio of E_t/E_l

Table5.5 Variation of deformation with change in ratio of E_t/E_l

E_t/E_l	with one hole	with two holes	with four holes
0.02	0.8979	0.7966	1.043
0.04	0.9055	0.8155	1.043
0.06	0.9122	0.8914	1.044
0.08	0.9206	0.9020	1.044
0.10	0.9235	0.9043	1.045

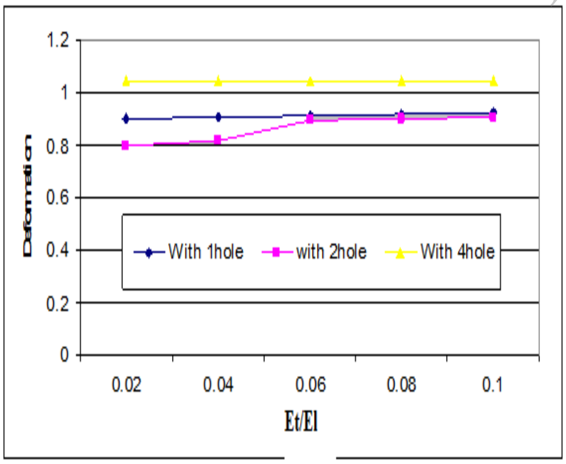


Fig5.14 Deformation Vs Change in ratio of E_t/E_l

Table 5.6 Variation of interlaminar shear stress on S_{xz} with change in ratio of E_t/E_l

E_t/E_l	with one hole	with two holes	with four holes
0.02	12.765	12.814	12.416
0.04	13.193	13.244	12.883
0.06	13.598	13.651	13.330
0.08	14.160	14.215	13.963
0.10	14.385	14.404	14.213

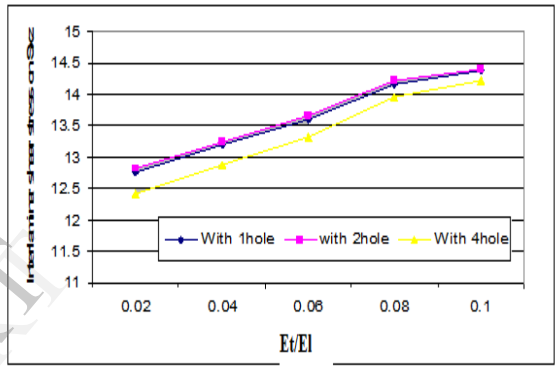


Fig5.15 Interlaminar shear stress on S_{xz} Vs Change in ratio of E_t/E_l

6.0 CONCLUSION:

Results from a numerical study of the response of thin-wall compression-loaded quasi-isotropic laminated composite cylindrical shells with reinforced and unreinforced square cutouts have been presented. The results identify some of the effects of cutout-reinforcement isotropic, size, and thickness on the linear response of the shells. A high-fidelity linear analysis procedure has been used to predict the linear response of the shells. In general, the addition of reinforcement around a cutout in a compression-loaded shell can have a significant effect on the shell response. Results have been presented that indicate that the reinforcement can affect the local deformations and stresses near the cutout and retard or suppress the onset of local buckling in the shell near the cutout.

1. Interlaminar failures are observed at bottom of shell without cutout.
2. Interlaminar failures are observed at free edge of cutout in case of without reinforcement.
3. Interlaminar failures are observed at away from cutout of shell with reinforcement.
4. Interlaminar failures are reduced by increasing the G_{xy}/E_l as compared with increasing the G_{yz}/E_l and Et/E_l.
5. Deformations are greatly reduced by adding reinforcement.
6. Critical loading also increased considerably by adding reinforcement.
7. It is observed that intra laminar failures like fibre cracking and matrix cracking with cutout are reduced considerably as compared to without reinforcement.

Future scope of work

- Buckling behaviour can be predicted by increasing number of layers in reinforcement.
- Buckling behaviour can be predicted by increasing the size of reinforcement.

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