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Enhancing Structural Stability of Submerged Cylindrical Shell with Stiffeners

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Abstract*: An extensive study is made on the buckling types and conditions of various types cylindrical shells based on their design and material properties. Based on those, numerical analysis is done on a submerged type of cylindrical shell. This analysis is done based on two different conditions. The first one includes design with the addition of stiffeners and the other is based on the design which has no stiffeners. A comparative study is performed between these two and the results are analyzed. Two cylindrical shells, one including stringer and the other without a stringer are modeled using CATIA with specific dimensions. These models are imported into ANSYS to perform an explicit dynamic analysis. Parameters such as equivalent stress, equivalent elastic strain, shear stress, shear elastic strain and total deformation are calculated. The end results are obtained using ANSYS and the graphs are plotted using the values obtained. Based on the results obtained, it is concluded that the use of stiffeners makes the structure widely enviable to bear compressive types of loads. Also, it gives additional strength to the structure with sturdiness at the top and bottom layers. Based on the study, it can be concluded that the use of rectangular type stringer is preferred much more than the other types.

***Keywords:* Buckling, cylindrical shell, depth, pressure, stiffener, submerged.**

I. INTRODUCTION

Buckling is a measured volatility that causes failure. Stiffness of the material or the structure is a major parameter which defines the amount of buckling. Though the value of stress is below the value causing failure, buckling can occur in a typical structure. When any structure under compression undergoes a force applied transversely to the load, the object gets buckled. Buckling may occur due to compressive stress acting on the structure. Therefore, a sudden deformation in a high scale due to the increase in the applied load causes buckling.

Hoff made numerical analysis on buckling of thin shells and proved that thin shells were sufficient to withstand high loads and 3% reduction in material weight can withstand the same loads [1]. Seide *et al.* [2] carried out experimental analysis of elastic stability on thin shell structures and validated the results with numerically published results. Ohira [3] carried out buckling analysis of compressed cylinders and compared the results with curved thin structures. The author found 4% increment in load carrying capacity. John Hutchinson [4] carried out experimental analysis on cylinders that are pressurized. Thin pressurized cylinders could withstand only minimal loads due to its high loadings on both the sides.

Sadeghifar *et al.* [5] performed analysis over stiffened laminated cylindrical shells and validated results with numerical analysis. Van der Neut [6] made stability analysis over stiffened plates under yield load conditions. Singer *et al.* [7] carried out similar kind of analysis but the concentration of load was made at the centre as eccentric points were crucial for buckling. Rosen and Singer [8] tested the elastic nature of stiffened plates up to yield limit loads. Jarmai *et al.* [9] improved the load carrying capacity of thin shells by orthogonally welding them and found that the performance of thin panels can be improved by 5% due to orthogonal loading. Simoes *et al.* [10] optimized the design of welded stringer plates under axial compression loads. Recently, researchers [11-23] reported works on using stiffeners for cylindrical structures for a variety of applications.

Buckling can occur in several conditions depending on the type of structure and design. The point where all the equilibrium parameters of a structure fail leads to buckling. This makes the structure unstable. The buckling occurring in plates is known to be local buckling. The buckling of columns is called Euler buckling. These are super-critical phenomena which are considered to be safe to an extent. The buckling of shells is considered a sub-critical factor which is dangerous compared to the others. Buckling of cylindrical shells with or without stiffeners is caused mainly due to compressive loads. Therefore, these must be taken into serious consideration. Stiffeners are small structures which provide strength to the material. They are connected to the webs to avoid the loss of strength when buckling occurs.

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Therefore, this study deals with analyzing the buckling strength of shells with and without stiffeners. The focus is to analyze buckling of submerged cylindrical shell with stiffeners at various depths of sea by applying corresponding hydro pressure to the shell at various depths (1000 feet to 4000 feet in step of 1000 feet). This analysis is carried out to find out which type of cylindrical shell configuration has better load carrying capacity. It is carried on two different shell configurations, one with stiffener and the other without stiffener.

II. NUMERICAL APPROACH

The cylindrical shells of thickness 3mm is created using CATIA. In order to perform a comparative study, cylindrical shells with and without stiffener are made. These geometries are studied by analysing the effects of varied applied pressures and stresses conditions. Figure 1 shows the finite element model of the cylindrical shell. The geometrical details are listed in Table 1.

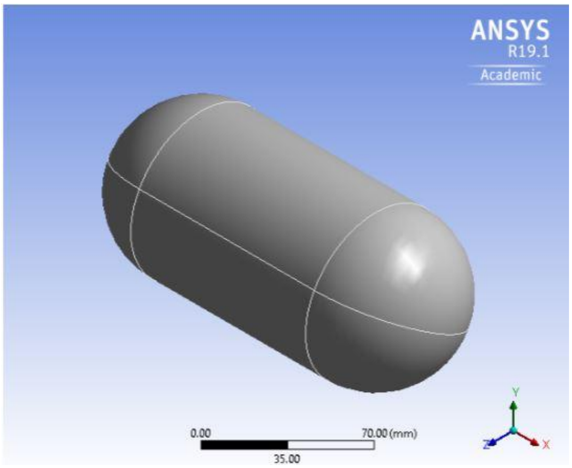

Fig. 1. Cylindrical shell

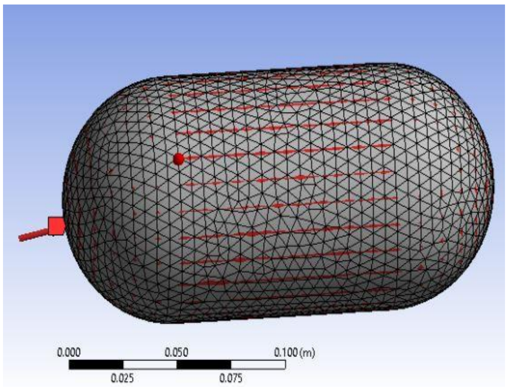

Fig. 2. Generated mesh

The cylindrical shells designed in CATIA are imported to ANSYS software for meshing and analysis. The cylindrical shell is meshed and Fig. 2 depicts the meshed model of the shell. ANSYS explicit dynamic mesh parameters are given in Table 2. The analysis settings given are listed in Table 3.

These models are imported into ANSYS software to perform an explicit dynamic analysis. The required input parameters are specified to perform the analysis. To make a comparison of the two conditions, the obtained results from ANSYS are plotted. Parameters such as equivalent stress, equivalent elastic strain, shear stress, shear elastic strain and total deformation are calculated. The end results are obtained in ANSYS and the graphs are plotted using the values obtained. These graphs are obtained using TeraPlot graphing software. Also, the use of rectangular type stringer is preferred much more than the other types. Also, a wide research for the type of material to be used is also done. The present analysis is done considering using structural steel. Being tensile and having high strength to weight ratio, structural steel can meet all the requirements. Also, aluminium is proved to be an ideal material.

Table- I: Geometry parameters

PARAMETERS	VALUE
Length X	200 mm
Length Y	100 mm
Length Z	100 mm
Volume	1.7246e+005 mm^3
Mass	1.3538 kg
Analysis	3D

Table- II: Explicit dynamics mesh parameters

PARAMETERS	VALUE
Physics preference	Explicit
Element order	Linear
Size function	Adaptive
Relevance center	Fine
Smoothing	High
Rigid body behaviour	Full Mesh
Nodes	11673
Elements	35798

Table- III: Analysis settings

PARAMETERS	VALUE
Maximum Number of Cycles	1e+07
End Time	1 s
Maximum Energy Error	0.1
Time Step Safety Factor	0.9
Solve Units	mm,mg,ms
Beam Solution Type	Bending
Shell Sub Layers	3
Beam Time Step Safety Factor	0.5
Shell Shear Correction Factor	0.8333
Shell Thickness Update	Nodal

III. RESULTS AND DISCUSSION

The varying characteristics of cylindrical shell of different configurations (i.e., with and without stiffeners) for different pressure values over a time span of one second is studied and discussed here. On both cylindrical shells, a varying external pressure is applied and studied to identify the type of cylindrical shell that can withstand the maximum load and do not buckle. Also, various other factors such as the stress, strain, shear stress, shear strain and total deformation of the shell are analyzed.

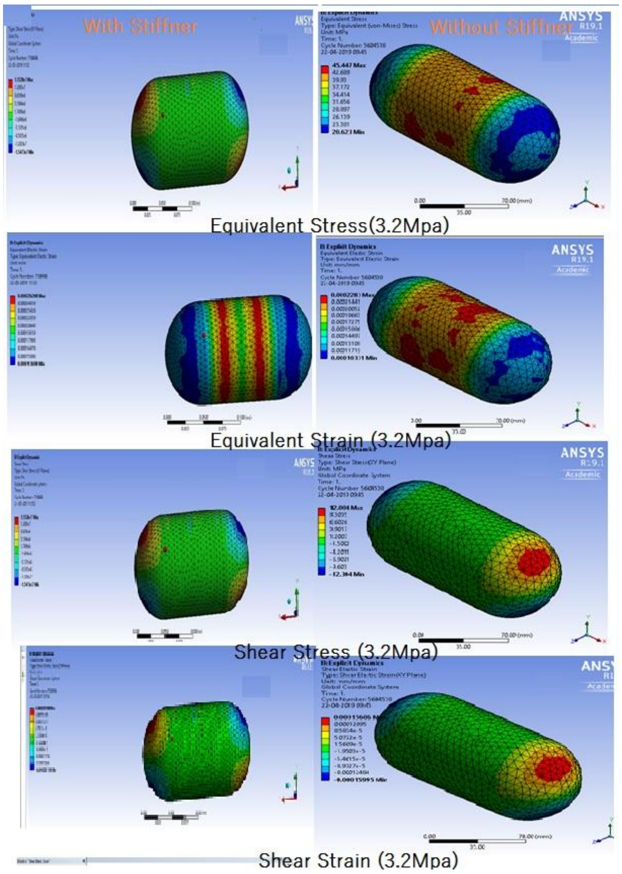

Fig. 3. At depth of 1000 feet (3.2 Mpa)

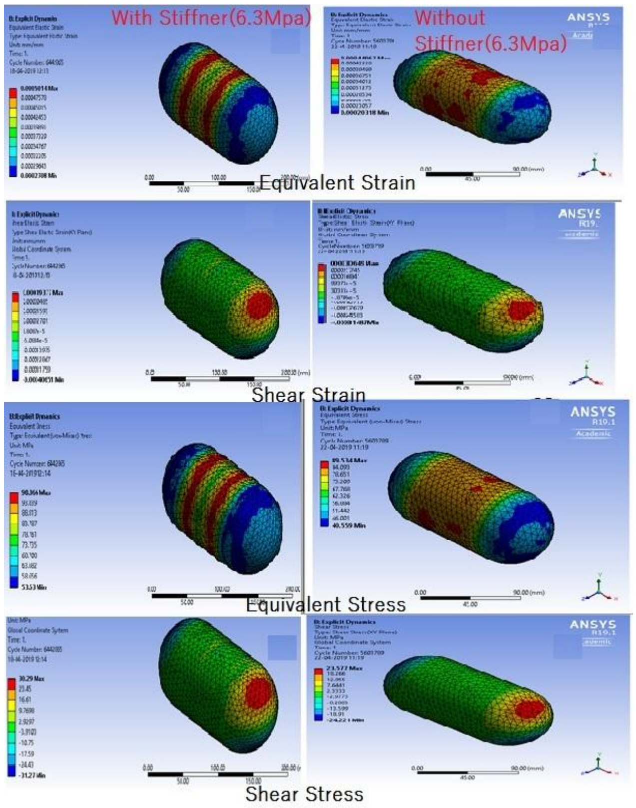

Fig. 4. At depth of 2000 feet (6.3 Mpa)

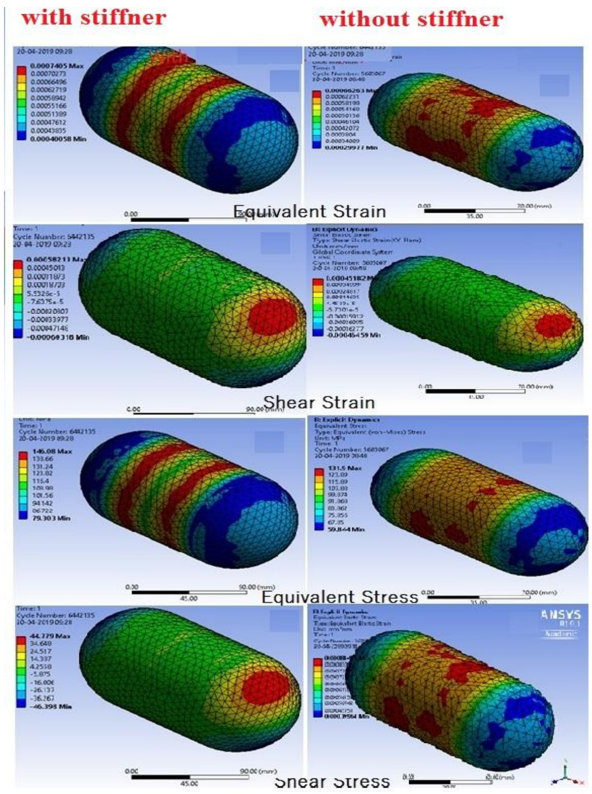

Fig. 5. At depth of 3000 feet (9.3 MPa)

Figure 3 depict the equivalent stress induced in the cylindrical shell due to the applied pressure load at 1000 feet (3.2 MPa). As can be seen in Figure, it is clear that stiffeners takes more stress and produce a uniform low stress region in the surface of the shell in contrast to the shell without stiffener which shows more stress distribution throughout the sections. Figure 3 also depicts the equivalent strain distribution. As can be seen in Figure, the stiffener takes more deformation and holds the shell surface. In contrast the shell without stiffener, distributes the induced strain due to applied pressure load throughout the section. Figure 3depicts the shear stress distribution of the shell with and without stiffener. It is common observation that the stiffeners resist the shearing effect of a cylindrical section. Figure 3 depicts the shear strain distribution of the shell with and without stiffener. It is a common observation that the stiffeners resist shearing effect of a cylindrical section. The deformation patterns of the shell with and without stiffeners are depicted in Fig. 3. It is common observation that the stiffeners resist shearing effect of a cylindrical section.

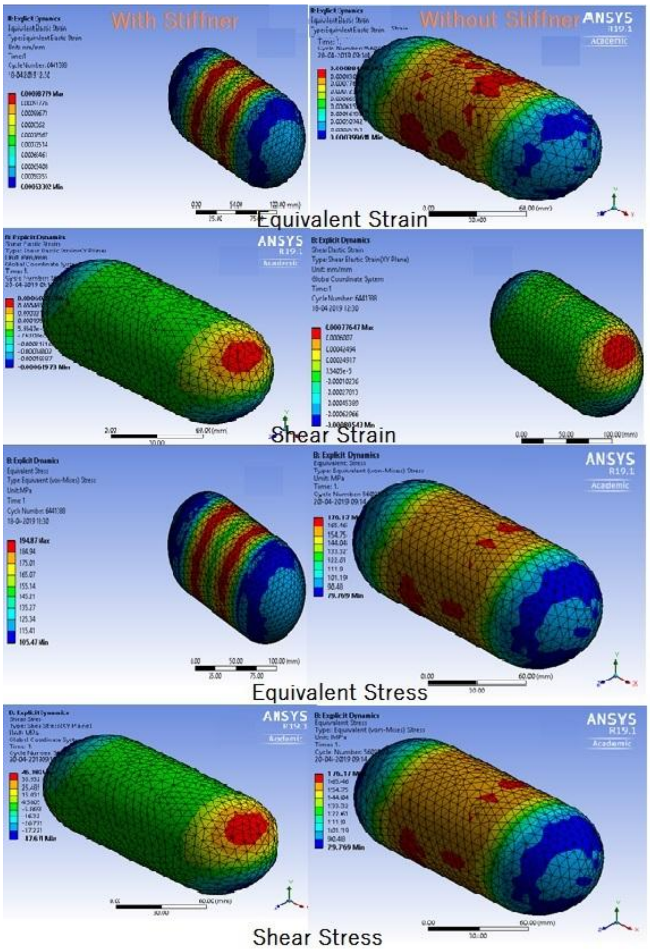

Fig. 6. At depth of 4000 feet (12 MPa)

Similar improved pattern is observed for the submerged cylindrical shell with stiffener for the cases involving 2000 feet (6.3 Mpa), 3000 feet (9.3 MPa) and 4000 feet depths (12 MPa)

Figure 7 and 9 shows the variation of equivalent stress as well as shear stress for both the sections respectively. Figure 8 and 10 represents the equivalent strain distribution as well as shear strain between cylindrical shell with and without stiffeners. .Figure 11 shows the variation of the deformation for both the sections. As can be seen in all these Figures, the cylindrical shell with stiffeners is observed to the best for the case involving 1000 feet (3.2 MPa).

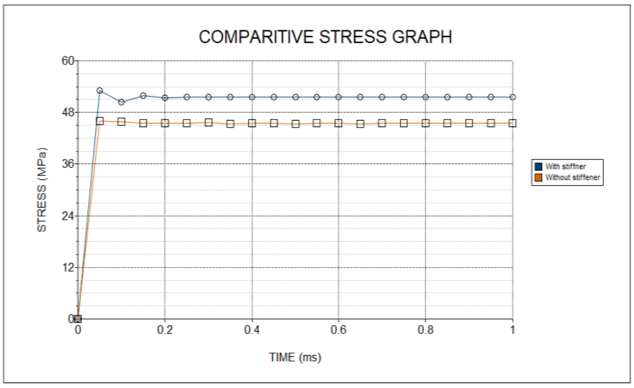

Fig. 7. Comparison of equivalent stress at 1,000ft

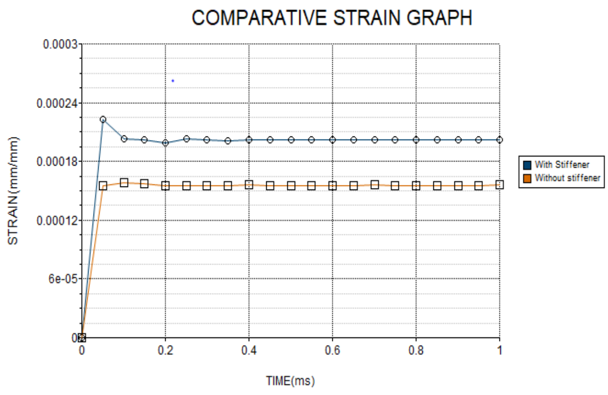

Fig. 8. Comparison of equivalent strain at 1,000ft

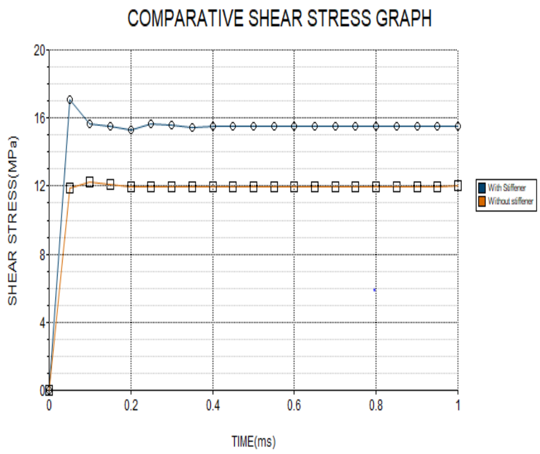

Fig. 9. Comparison of shear stress at 1,000ft

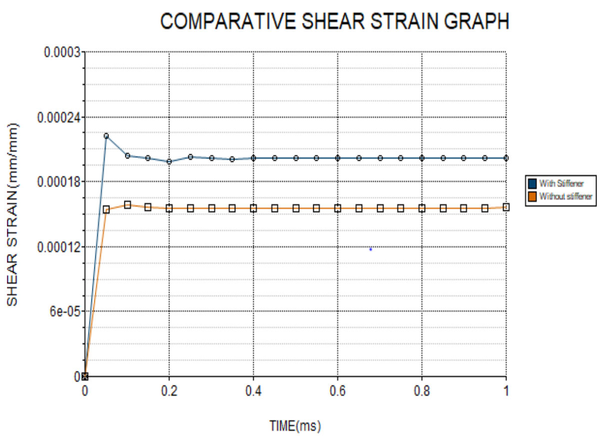

Fig. 10. Comparison of shear strain at 1,000ft

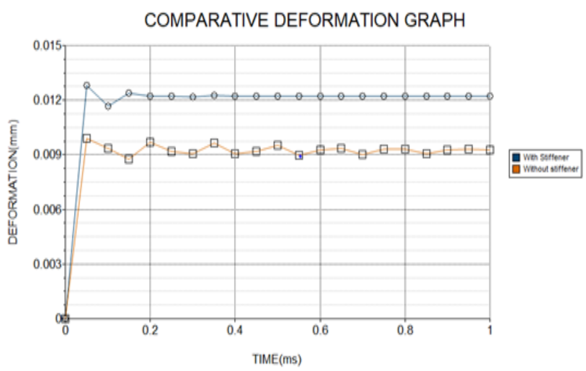

Fig. 11. Comparison of deformation at 1,000ft

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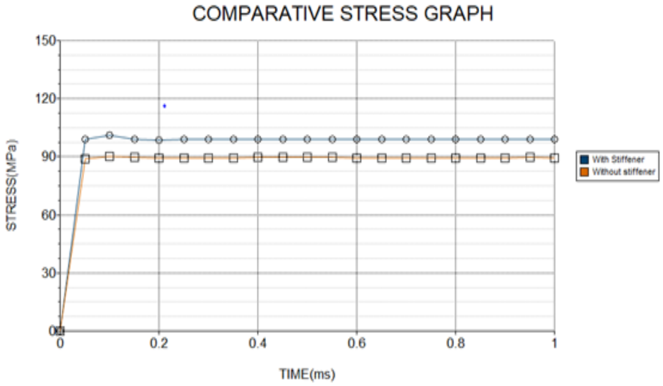


Fig. 12. Comparison of equivalent stress at 2,000ft

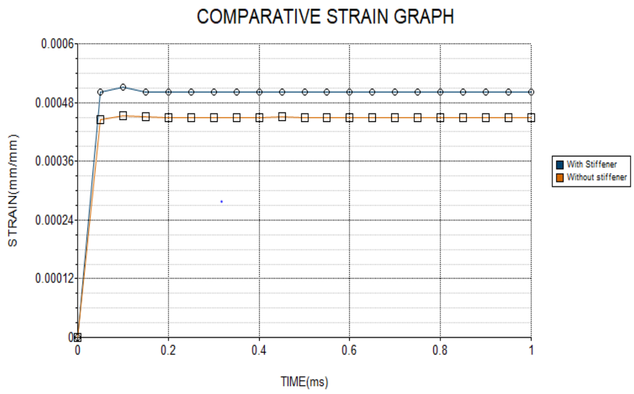
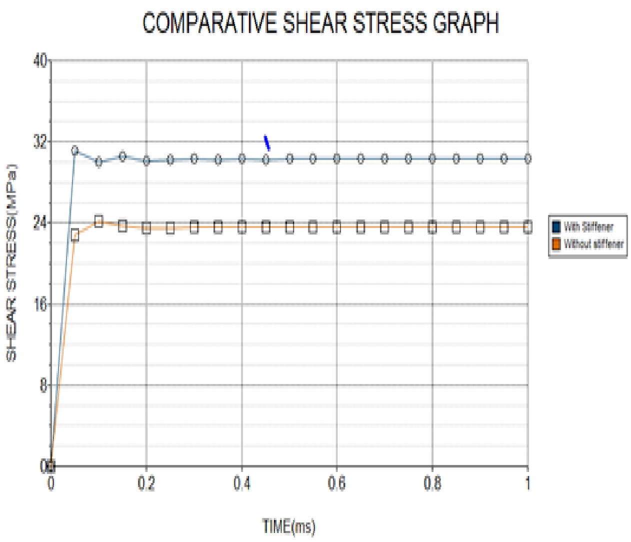


Fig. 13. Comparison of equivalent strain at 2,000ft



Fig, 14. Comparison of shear stress at 2000 ft

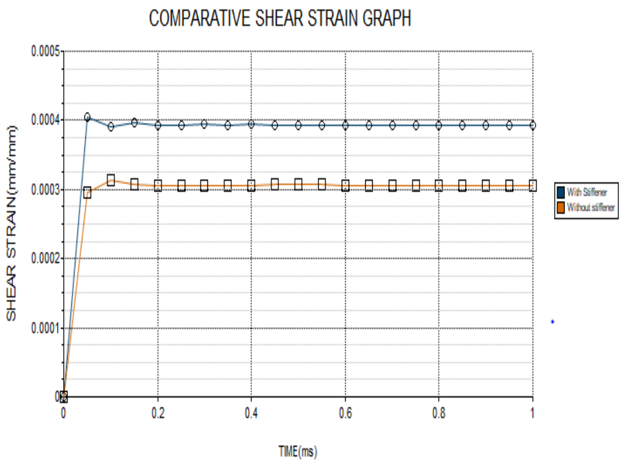


Fig. 15. Comparison of shear strain at 2000ft

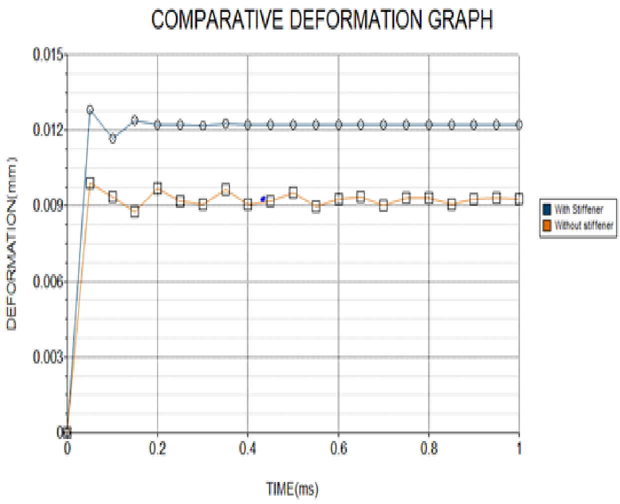


Fig. 16. Comparison of deformation at 2,000ft

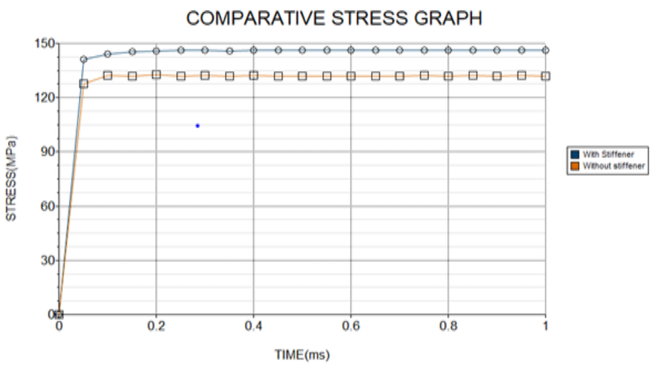


Fig. 17. Comparison of equivalent stress at 3000 ft

Figure 12 and 14 shows the variation of equivalent stress as well as shear stress for both the sections respectively. Figure 13 and 15 represents the equivalent strain distribution as well as shear strain between cylindrical shell with and without stiffeners. .Figure 16 shows the variation of the deformation for both the sections. As can be seen in all these Figures, the cylindrical shell with stiffeners is observed to the best for the case involving 2000 feet (6.3 MPa).

Figure 17 and 19 shows the variation of equivalent stress as well as shear stress for both the sections respectively. Figure 18 and 20 represents the equivalent strain distribution as well as shear strain between cylindrical shell with and without stiffeners. .Figure 21 shows the variation of the deformation for both the sections. As can be seen in all these Figures, the cylindrical shell with stiffeners is observed to the best for the case involving 3000 feet (9.3 MPa).

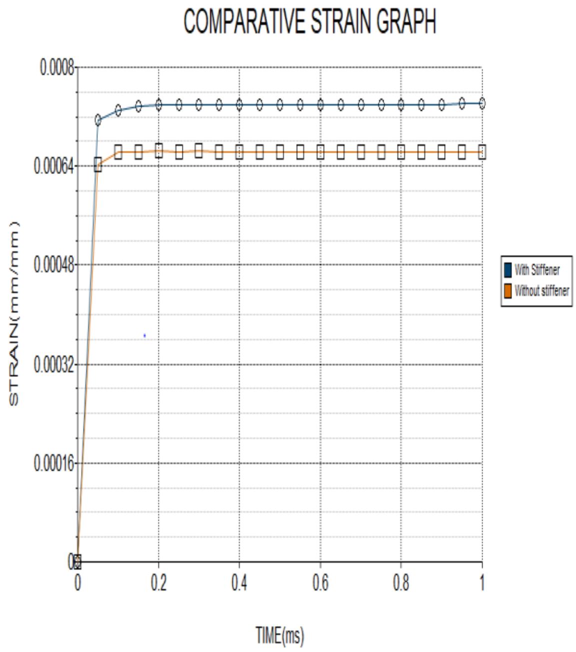


Fig. 18. Comparison of equivalent strain at 3000 ft

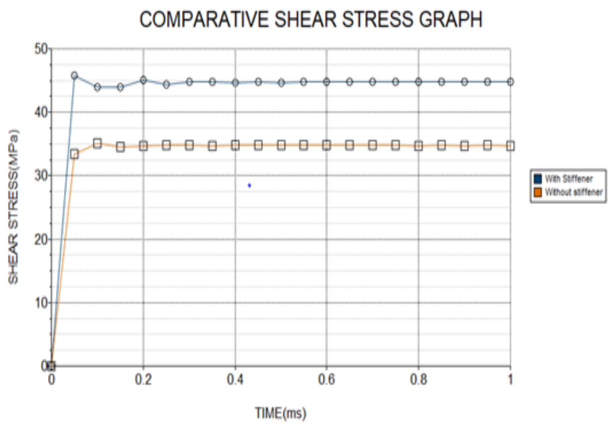


Fig. 19. Comparison of shear stress at 3000 ft

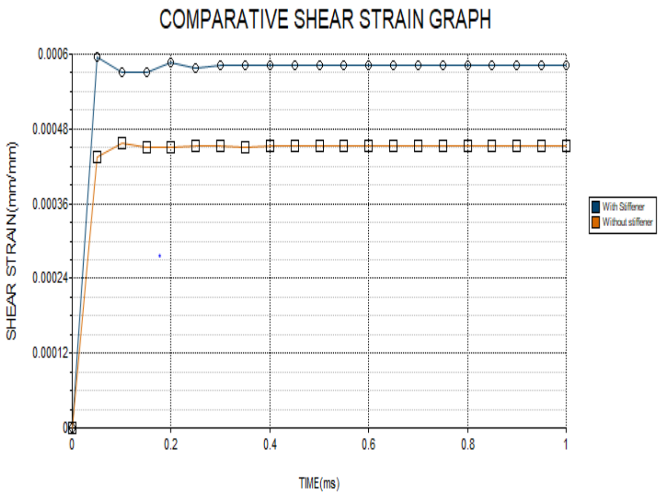
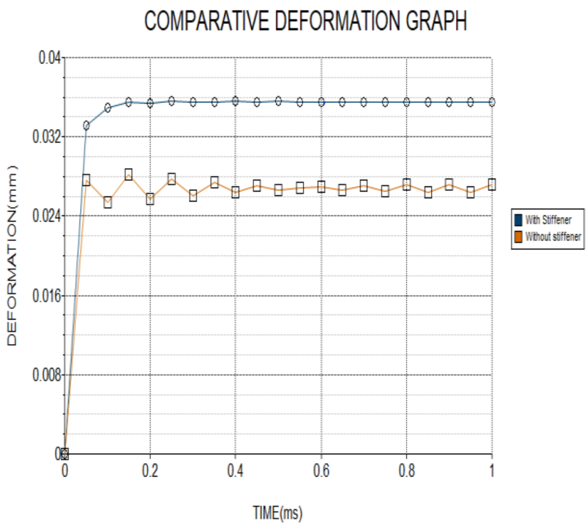


Fig. 20. Comparison of shear strain at 3000 ft



Fig, 21. Comparison of deformation at 3000ft

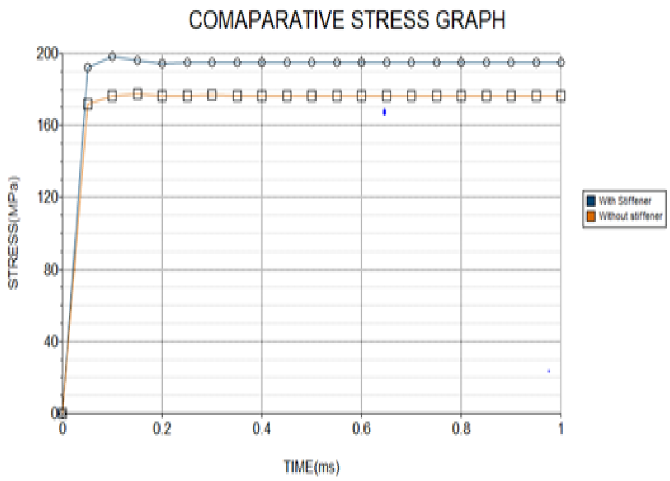


Fig. 22. Comparison of equivalent stress at 4000ft

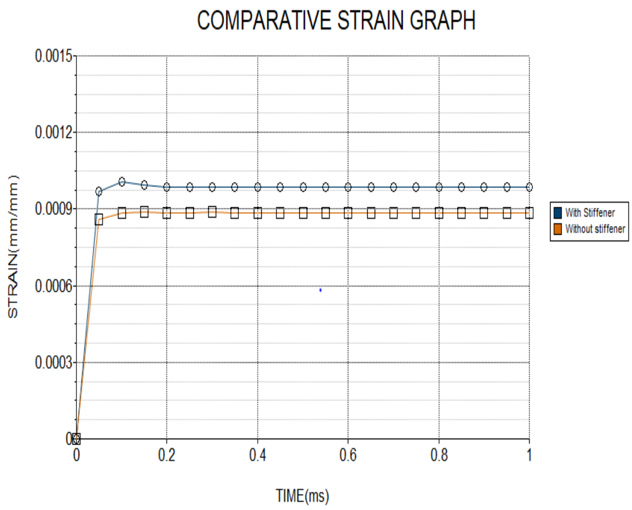


Fig. 23. Comparison of equivalent strain at 4000 ft

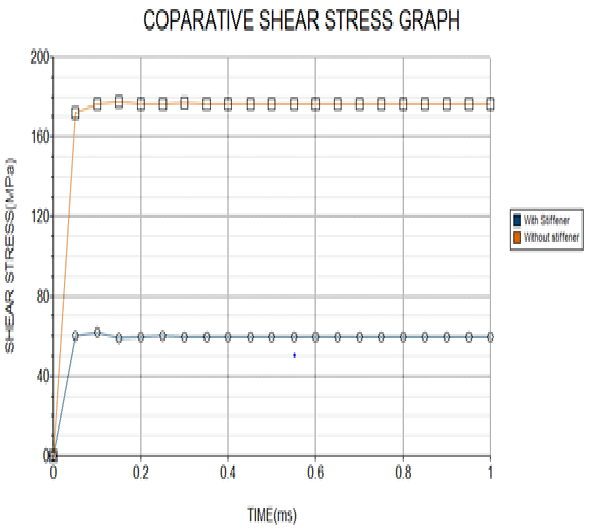


Fig. 24. Comparison of shear stress at 4000ft

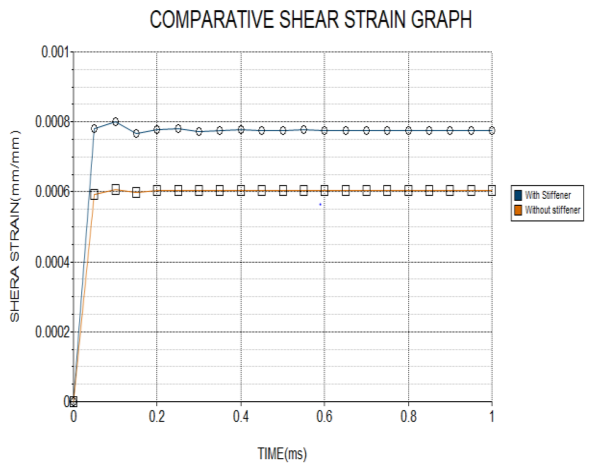


Fig. 25. Comparison of shear strain at 4000 ft

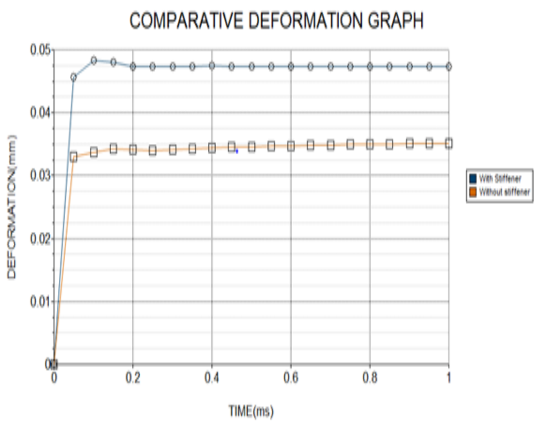


Fig. 26. Comparison of deformation at 4000 ft

Figure 22 and 24 shows the variation of equivalent stress as well as shear stress for both the sections respectively. Figure 23 and 25 represents the equivalent strain distribution as well as shear strain between cylindrical shell with and without stiffeners. .Figure 26 shows the variation of the deformation for both the sections. As can be seen in all these Figures, the cylindrical shell with stiffeners is observed to the best for the case involving 4000 feet (12 MPa).

Table- IV: Comparative deformation at 4000 ft

Time	With stiffener	Without stiffener
1.1755e-038	0.	0.
5.e-002	4.5685e-002	3.2958e-002
0.1	4.8312e-002	3.3715e-002
0.15	4.8035e-002	3.4215e-002
0.2	4.7292e-002	3.4099e-002
0.25	4.7273e-002	3.4003e-002
0.3	4.7399e-002	3.4158e-002
0.35	4.7328e-002	3.4293e-002
0.4	4.7404e-002	3.4433e-002
0.45	4.736e-002	3.4505e-002
0.5	4.7345e-002	3.4597e-002
0.55	4.734e-002	3.4647e-002
0.6	4.735e-002	3.4723e-002
0.65	4.7349e-002	3.4811e-002
0.7	4.7356e-002	3.4857e-002
0.75	4.7361e-002	3.4927e-002
0.8	4.7357e-002	3.498e-002
0.85	4.7357e-002	3.5016e-002
0.9	4.7353e-002	3.5078e-002
0.95	4.7348e-002	3.5121e-002
1	4.7356e-002	3.5156e-002

Table- V: Comparative equivalent stress at 4000 ft

Time	With stiffener	Without stiffener
1.1755e-038	0.	0.
5.e-002	192.01	171.75
0.1	198.23	176.27
0.15	196.27	177.32
0.2	194.6	176.66
0.25	194.89	176.53
0.3	194.9	176.71
0.35	194.8	176.51
0.4	194.92	176.61
0.45	194.83	176.44
0.5	194.83	176.34
0.55	194.87	176.31
0.6	194.85	176.25
0.65	194.86	176.22
0.7	194.86	176.24
0.75	194.86	176.23
0.8	194.87	176.2
0.85	194.87	176.22
0.9	194.87	176.21
0.95	194.86	176.17
1	194.87	176.17

Table- VI: Comparative equivalent strain at 4000ft

Time	With stiffener	Without stiffener
1.1755e-038	0.	0.
5.e-002	9.6935e-004	8.6161e-004
0.1	1.0053e-003	8.8435e-004
0.15	9.9308e-004	8.8996e-004
0.2	9.8627e-004	8.8684e-004
0.25	9.8788e-004	8.8629e-004
0.3	9.8764e-004	8.8716e-004
0.35	9.874e-004	8.8619e-004

0.4	9.8802e-004	8.8665e-004
0.45	9.8757e-004	8.8597e-004
0.5	9.8757e-004	8.8546e-004
0.55	9.8779e-004	8.8535e-004
0.6	9.8768e-004	8.8509e-004
0.65	9.8774e-004	8.8495e-004
0.7	9.8775e-004	8.8507e-004
0.75	9.8772e-004	8.8501e-004
0.8	9.8776e-004	8.8487e-004
0.85	9.8777e-004	8.8496e-004
0.9	9.8776e-004	8.8492e-004
0.95	9.8775e-004	8.8477e-004
1	9.8779e-004	8.8476e-004

Table- VII: Comparative shear stress at 4000ft

Time	With stiffener	Without stiffener
1.1755e-038	0.	0.
5.e-002	60.11	171.75
0.1	61.599	176.27
0.15	59.	177.32
0.2	59.765	176.66
0.25	59.962	176.53
0.3	59.521	176.71
0.35	59.708	176.51
0.4	59.815	176.61
0.45	59.669	176.44
0.5	59.719	176.34
0.55	59.747	176.31
0.6	59.707	176.25
0.65	59.73	176.22
0.7	59.731	176.24
0.75	59.726	176.23
0.8	59.732	176.2
0.85	59.727	176.22
0.9	59.725	176.21
0.95	59.727	176.17
1	59.729	176.17

For the sake of brevity, only the values pertaining to case of 4000 feet (12 MPa) is presented here. Table 4 to 8 lists the variations of deformation, equivalent stress, equivalent strain, shear stress, and shear strain over a time span of one second for the submerged cylindrical shell configurations involving with stiffener and without stiffener. The submerged cylindrical shell with stiffener configuration offers more resistance towards any kind of deformation. Thus, the impact caused due to buckling is reduced. Also, the use of a rectangular stringer gives additional strength to the structure.

Table- VIII: Comparative shear strain at 4000ft

Time	With stiffener	Without stiffener
1.1755e-038	0.	0.
5.e-002	7.8143e-004	5.9153e-004
0.1	8.0079e-004	6.0574e-004
0.15	7.6699e-004	5.9957e-004
0.2	7.7694e-004	6.0366e-004
0.25	7.7951e-004	6.0474e-004
0.3	7.7378e-004	6.0344e-004
0.35	7.7621e-004	6.0331e-004
0.4	7.7759e-004	6.0357e-004
0.45	7.7569e-004	6.0337e-004
0.5	7.7635e-004	6.0328e-004
0.55	7.7671e-004	6.0331e-004
0.6	7.7619e-004	6.0322e-004
0.65	7.7648e-004	6.0316e-004
0.7	7.765e-004	6.0317e-004
0.75	7.7644e-004	6.0311e-004
0.8	7.7651e-004	6.0307e-004
0.85	7.7646e-004	6.0307e-004
0.9	7.7642e-004	6.0301e-004
0.95	7.7645e-004	6.0298e-004
1	7.7647e-004	6.0297e-004

IV. CONCLUSION

A detailed comparative numerical study is performed on submerged cylindrical shell with stiffeners and without stiffeners by varying various pressure values. Stiffeners are short structures that provide better sturdiness to the top and bottom of structures. On application of compressive loading on any structure, rectangular stringer is found to be optimum. The results of total deformation, shear stress, equivalent stress, shear strain and equivalent strain are obtained. Based on the results, it is observed that the deformation caused due to the application of pressure is lessened with the addition of stiffeners. This shows that the structure offers more resistance towards any kind of deformation. Thus, the impact caused due to buckling is reduced. Also, the use of a rectangular stringer gives additional strength to the structure. It shows better properties in both elastic and non-elastic regions. Moreover, structural steel or aluminium can be a better choice as a material for stiffeners.

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