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STATIC, DYNAMIC AND BUCKLING ANALYSES OF CYLINDRICAL BODIES WITH VARIOUS STIFFENERS

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ABSTRACT

In this study, cylindrical bodies with various stiffeners which were subjected to shear, compression force and bending moment are compared in terms of their structural integrity by using finite element method (FEM). Firstly, static structural, free vibrational and buckling analyses of the baseline cylinder which do not have any stiffener are carried out. After that, the same FEM analysis on cylinders which are reinforced with various stiffener designs like I,L,Γ,T,U,C and Z type profiles are carried out by using commercial finite element solver ABAQUS. As a result of the structural analyses; total displacement, maximum von Mises stress, natural frequencies and buckling loads are obtained and the results are given for comparison of the stiffeners.

INTRODUCTION

Cylindrical bodies are simple geometric shapes with a wide range of applications. Areas of use include; bridges, building supports, pressure tanks, pipelines; submarine, aircraft and rocket bodies. Such wide use of cylindrical bodies has been the main reason why researchers have carried out many studies on this subject throughout history. [Smith,1992]

[Eswara,2017] et al. analyzed pressure vessels with various types of outer stiffeners under internal pressure loading and compared them. While [Erturk,2018] et al. conducted an stiffener optimization study on cylindrical hulls exposed to lateral external pressure. [Sinha,2014] et al. showed the effect of using proper fiber orientation on composite pressure vessels. [Pandey ,2018] et al. studied the effect of various types of stiffener designs for pressure vessels in the view of static and free vibrational analysis. [Reddy,2018] estimates the influence of an explosion shock pressure loading on the ring stiffened submersible hull using finite element analysis. [Saunders,1931] et al. worked on strength of thin cylindrical shells under external pressure and give suggestions to designer and engineer. [Tomislav,2014] et al. presented a Typhoon class submarine structure’s graphical optimization which includes stiffeners on its hull.

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Many of the cylindrical bodies are differ from each other by their operating conditions and so exposed loading conditions. While a submarine hull exposed to external pressure most of its operation life, a pressure tank is mostly exposed to internal pressure and a rocket or aircraft body exposed to inertial loads mostly.

In cases where cylindrical bodies are subjected to combined loading conditions, the damage to the structure is usually caused by the phenomena of yielding, buckling and resonance. Although these cylindrical bodies can be reinforced with various types of stiffener profiles which reduces the weight of the structure [Eswara, 2017], the damage phenomena of the structures remain the same. Generally, the bodies with short and thick or the ones thick and close reinforcements tend to be damaged by yielding, whereas the thin shells with delicate bodies and distal reinforcements tend to be fail by buckling. Figure 1 shows the possible damage modes of a reinforced cylindrical shell structure subject to this loading condition. [Robertson,1990].

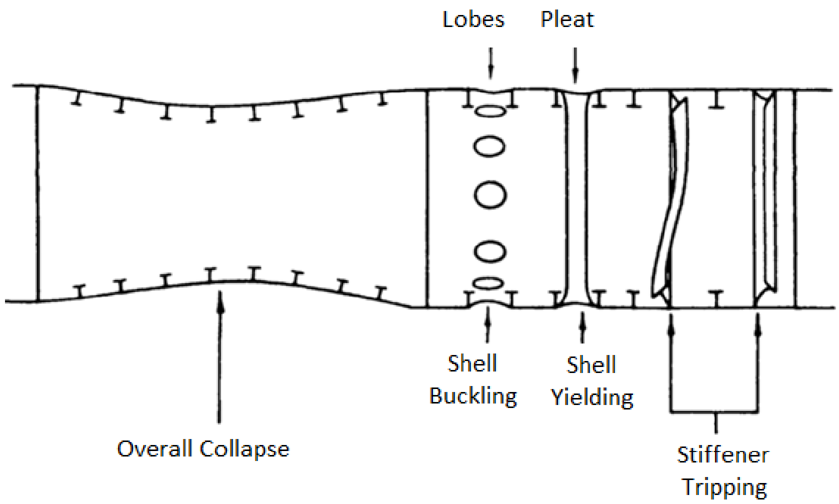


Figure 1. Modes of Collapse of a Ring-Stiffened Cylinder [Roberts and Smith,1988]

In this study, combined loading of compression, shear load and bending moment are considered as the main loads for cylinders. So the given results in this study are only valid for the cylinders which have parameters given in this study.

METHOD

In this study initially; in order to form the baseline, cylinder geometry with no reinforcements (stiffener-free) and with two open ends was selected. By using FEM on this geometry linear static, dynamic and buckling analyses were performed under the combination of three loads, namely axial compression loading (760kN), shear loading (50kN) and bending moment loading (100 kNm). As a result of analyses, the reference results of the cylinder without any reinforcement were obtained as total displacement, maximum stress, natural frequency and buckling loads. Figure 2 shows the cylinder geometry with boundary conditions and loads used in all FEM analyses in this study.

After obtaining the baseline (reference) results; in the next step, the cylinders inside are each individually reinforced by using I,L, Γ,T,U,C and Z type profiles each having an equal mass. Then the same analyses carried out on the body without reinforcement are then carried out for reinforced cylinders too.

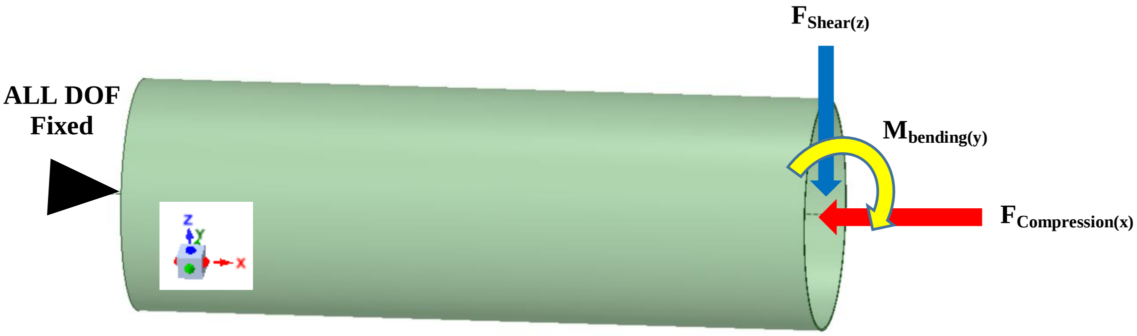


Figure 2. Cylindrical Body Geometry with Boundary Condition and Loads

After all of the analyses were completed and all the results were examined, the advantages of the reinforcements over the non-reinforced cylinder and advantages of the types of the profiles with respect to each other were compared.

Baseline Cylinder

Figure 3 shows the baseline (stiffener-free model) and dimensions of the geometry. The baseline cylinder has a material of steel and has a mass of 72.8 kg.

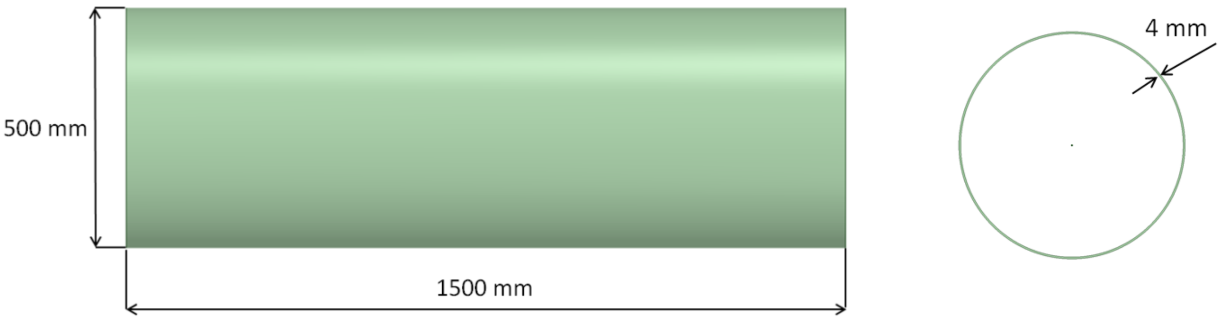


Figure 3. Schematic of Baseline Cylinder with Dimensions

Reinforced Cylinders

Figure 4 shows an example of general pattern view with 11x Z type reinforcements placed inside the cylinder along the cylinder axis. Each cylinder sample is reinforced with a total of 7 different profile types (Fig.5 a,b,c,d,e,f,g) with 11 uniform profile reinforcements. The geometry of each type of profile is chosen so that they have all equal masses. Each type of reinforced cylinders has a mass of 77.1 kg. A mass increase of about 6% is occurred with the insertion of reinforcements into the baseline cylinder. A more accurate comparison between stiffeners is aimed by keeping the inserted ones in equal masses.

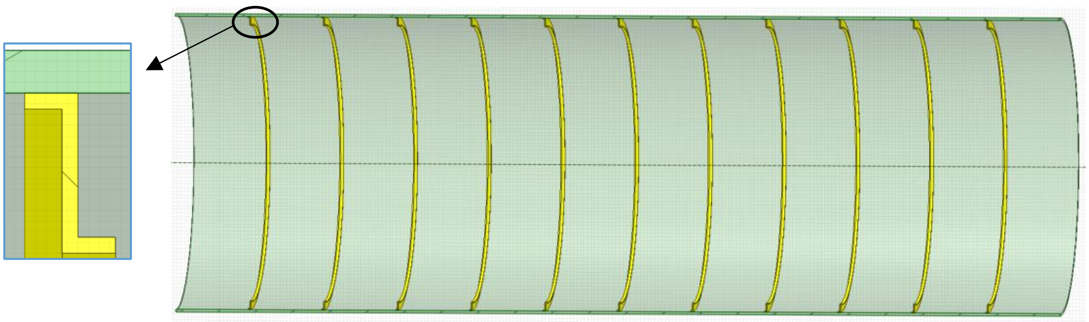


Figure 4. Half Section of a Cylindrical Body with Z type Stiffeners

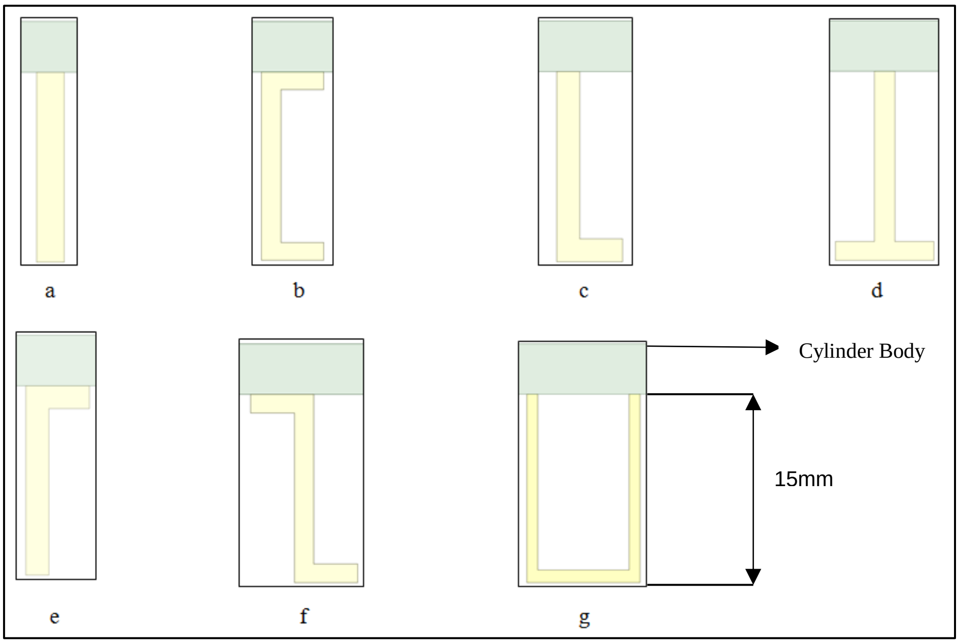


Figure 5. Schematic of Profile Section Types used Inside the Cylinders

Some cylindrical bodies exposed to external loads may have some other parts, mechanisms or cargo section in the interior region. Therefore, in such cases the boundary of the internal volume becomes important. So in this study, the diameter of the cylinder of the internal volume is assumed to be an important design factor and height of the profile sections is limited to 15mm as given in Figure 5-g.

RESULTS

Total Displacement

For baseline and reinforced cylinders with seven different types of profile under the combined loading condition, max. total displacement values are calculated and plotted in the Figure 6.

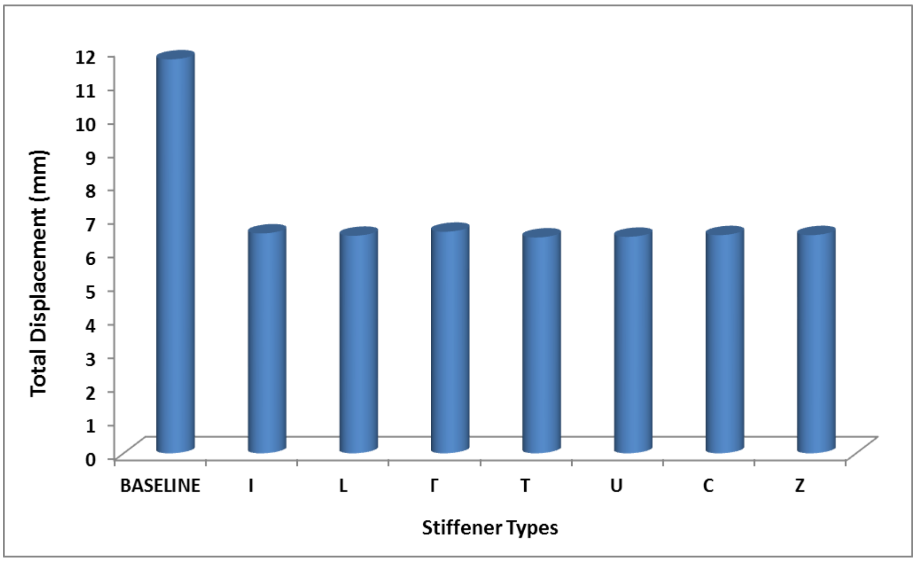


Figure 6. Variation of Max.Total Displacement With Respect to Different Stiffener Design

Cylinder von Mises Stresses

For baseline and reinforced cylinders with seven types of profile under the combined loading condition, von Mises stresses on the cylinder (for a zone of 125mm length) are calculated and plotted in the Figure 7.

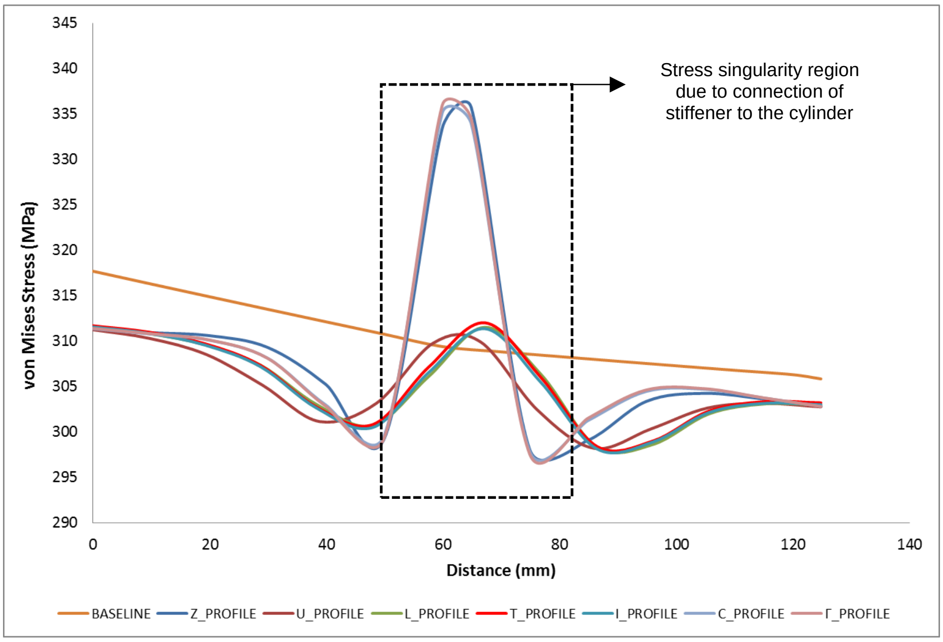


Figure 7. von Mises Stresses on the Cylinder With Respect to Different Stiffener Design

Stiffener von Mises Stresses

For reinforced cylinders with seven different types of profile under the compound loading condition, max.von-Mises stresses on the stiffeners are calculated and plotted in the Figure 8

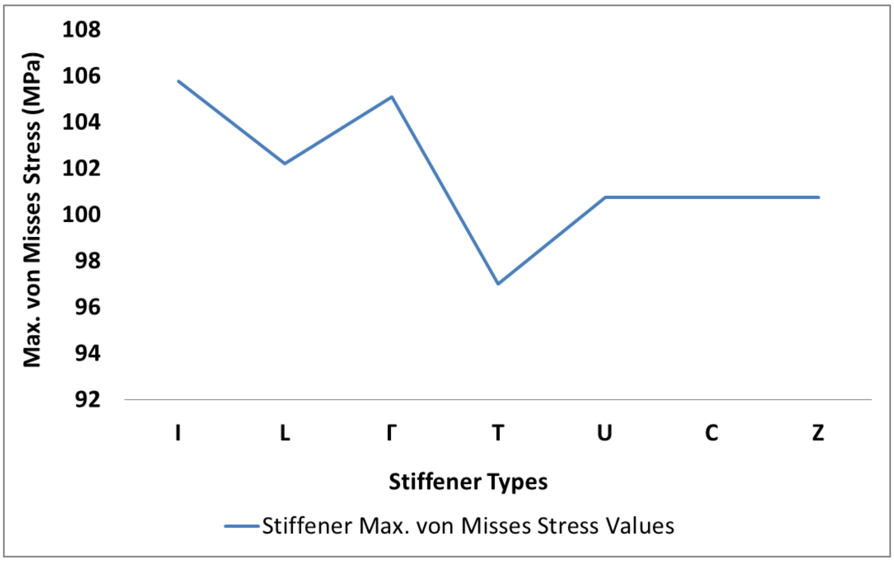


Figure 8. von Mises Stresses on the Stiffeners With Respect to Different Stiffener Designs

Natural Frequencies

For baseline and reinforced cylinders with seven different types of profile under the combined loading condition, the first three natural frequencies are calculated and plotted in the Figure 9

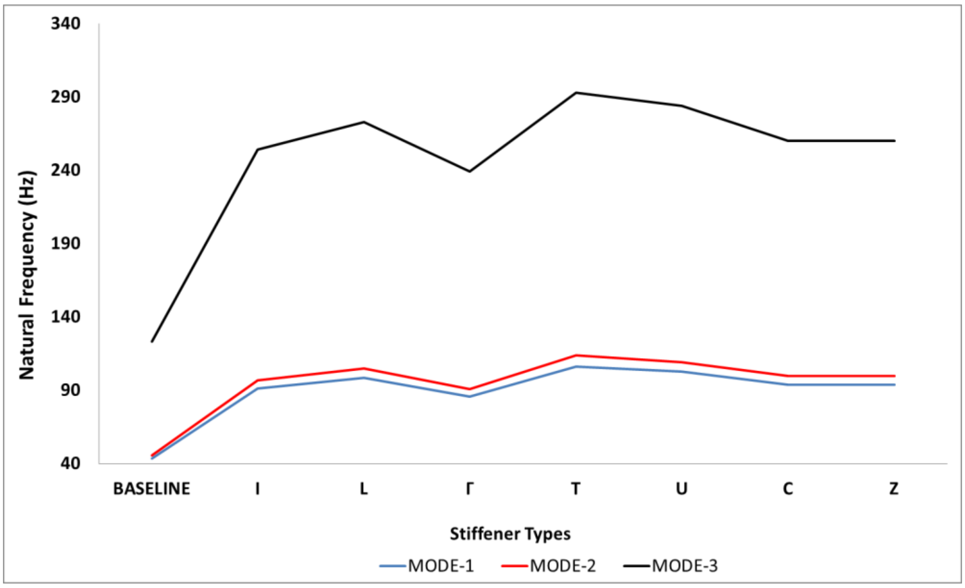


Figure 9. Variation of Natural Frequencies With Respect to Different Stiffener Design

Mode shapes for the first three frequencies are also plotted in the Figure 10. for Baseline cylinder and cylinder with Z type reinforcement. In addition to the Baseline results, only the mode shapes of cylinders with z-type reinforcement is given by way of example, because when the results are examined it is seen that the others had the same mode shapes.

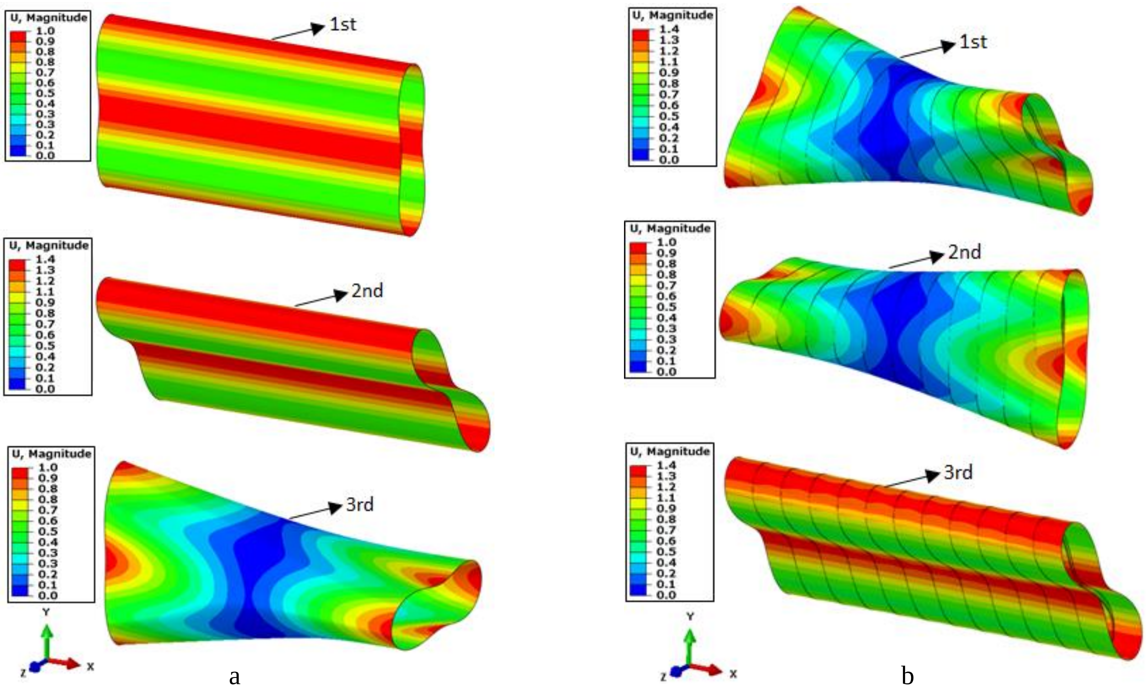


Figure 10. Baseline (a) and Z type reinforcement cylinder (b) first three mode shapes

Buckling Loads

For baseline and reinforced cylinders with seven different types of profile under the combined loading condition, buckling loads are calculated and plotted in the Figure 11.

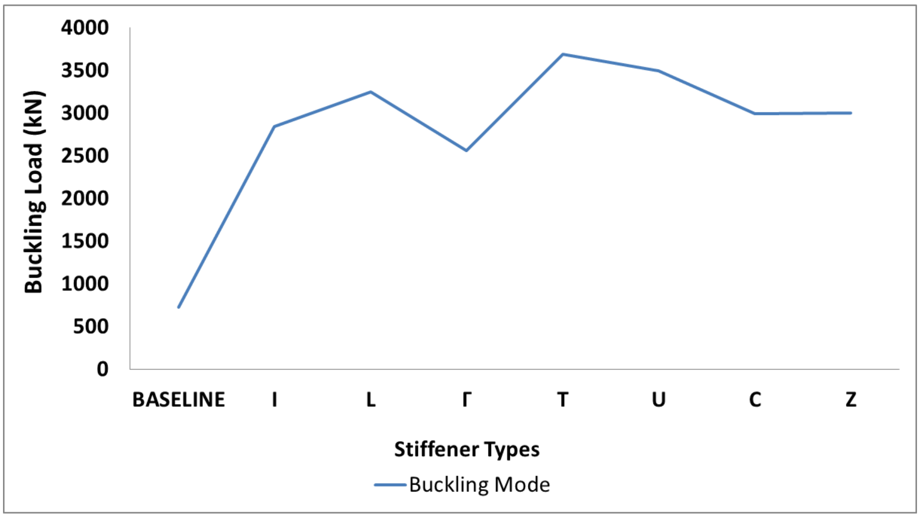
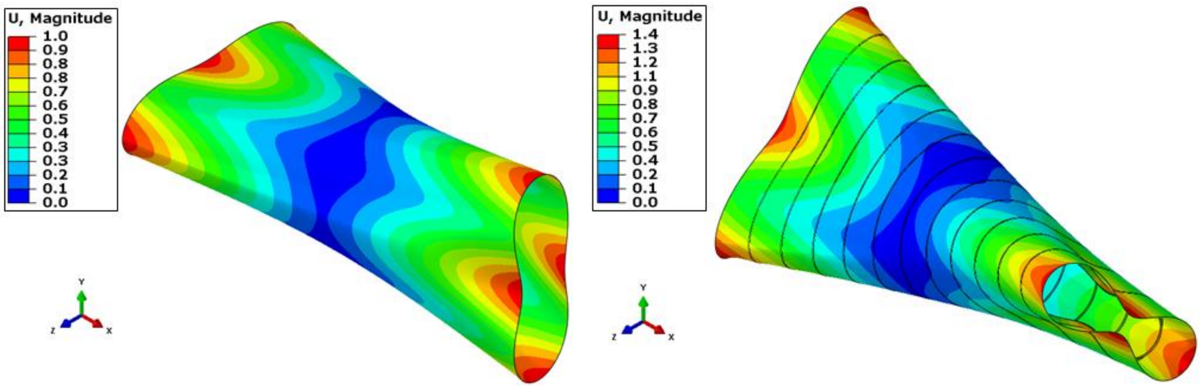


Figure 11. Variation of Buckling Loads With Respect to Different Stiffener Design

First buckling mode shapes are also plotted in the Figure 12. for Baseline cylinder and cylinder with Z type reinforcement. In addition to the Baseline results, only the buckling mode shapes of cylinders with z-type reinforcement is given by way of example, because when the results are examined it is seen that the others had the same mode shapes.



a b

Figure 12. Baseline (a) and Z type reinforcement cylinder (b) first buckling mode shapes

CONCLUSION

When the results are investigated; it is seen that the total displacement values occurring under the resultant loading are at least reduced by 44% in the stiffened cylinders with a total mass increase of about 6% by adding reinforcement. And when the stress values on the bodies are checked; there is a decrease of 5 MPa stress value in the reinforced cylinders when the stress singularity in the stiffener-cylinder connection region is ignored.

It has been seen that, again with a mass increase of about 6% by adding reinforcement, the baseline cylinders natural frequency increased by at least %109 and buckling load values also increased by at least %250.

As for compare the used stiffener profile types on cylinders with each other; it can be seen that the von Mises stresses on the cylinder body were close to each other, but the stresses on the reinforcement profiles were found to have the least stress on the T profile. Due to the higher values of natural frequency values and buckling load values compared to other reinforced cylinders the T profile has been observed to be the best within this study limits.

In summary, when all the results are examined; it has been observed that by the reinforcement with various profiles placed in the inner regions of the cylindrical bodies under shear, compression loading and bending moment load can be highly strengthened in terms of structural strength.

When it comes to compare the equal mass reinforcement profile types, it has been shown that the most efficient profile type with the used geometric dimensions, material data and a cylindrical body subject to the respective loading conditions is T shape.

If the geometric dimensions, material data and loading types and loading intensities are different from those given in this study, it is recommended that similar simulations be repeated and the most effective type of reinforcement profile should be selected for the relevant situation.

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