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LINEAR AND NONLINEAR BUCKLING ANALYSIS OF BASALT LAMINATED COMPOSITE PRESSURE HULL

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ABSTRACT

Pressure hull is the inner hull of a submarine; it holds the difference between outside and inside pressure. It is the main load carrying structure of a submarine. Submarine is a pressure vessel operating in deep waters. The objective of this work is to study the feasibility of using basalt composites as an ideal material for the construction of submarine pressure hull. The linear and nonlinear buckling analysis of the basalt laminated stiffened cylindrical pressure hull subjected to very high hydrostatic pressure is conducted.Comparative study of steel and basalt is also conducted to study the weight criteria.Finite element package ANSYS is used for modelling and analysis of the submarine pressure hull.

KEYWORDS: Pressure Hull, Submarine, Basalt

INTRODUCTION

A pressure hull is a structure that is designed to withstand the compressive forces associated with hydrostatic pressure. The most efficient geometries for resisting these compressive forces are thin walled circular cross-sections, and thus pressure hulls are typically composed of a combination of ring-stiffened cylinders and cones. Under uniform external hydrostatic pressure, a submarine pressure hull can buckle through shell instability as shown in Figure 1. Thus the design of thin cylindrical shell should be based on the buckling criteria .This mode of failure is undesirable, as it is structurally inefficient and one way of increasing its efficiency is to stiffen it with suitable ring stiffeners, spaced at suitable distance apart. If the ring stiffeners are not strong enough the entire ring-shell combination can buckle through general instability as shown in Figure 2. The hull must be able to withstand high water pressure at the desired depth; usually around 350 m. Stiffeners in circumferential and longitudinal directions considerably increase the resistance of the shell.

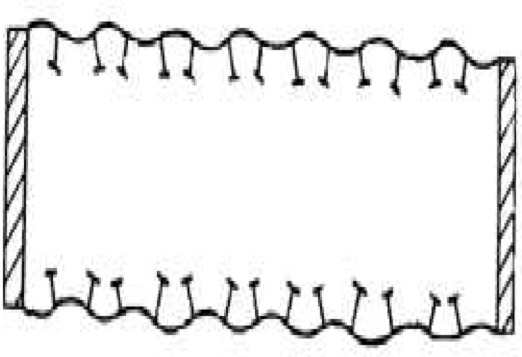

Figure 1: Shell Instability

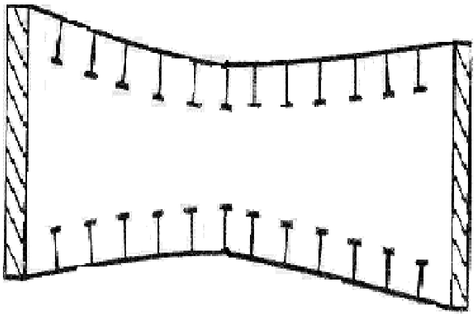

Figure 2: General Instability

GEOMETRIC DESCRIPTION OF MODEL

The composite pressure hull in this study is the modified version of the trial design model published by C.S Smith on “Design of submersible pressure hulls in composite materials” in 1991 [1], shown in Figure 3. Modifications are done based on ply orientation, lamina thickness, depth of stiffener and the use of unidirectional properties of fibers.

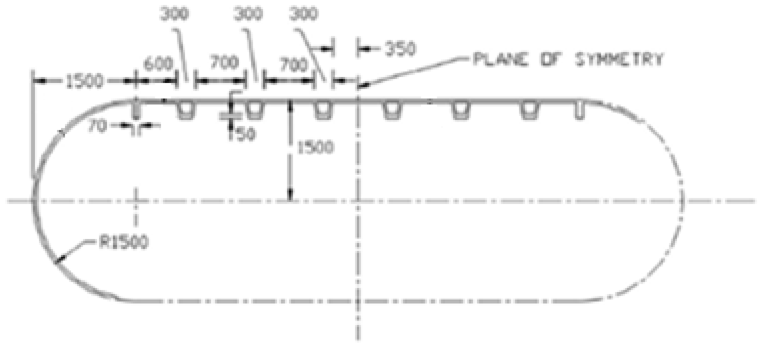

Figure 3: Geometry of the composite Pressure Hull (Dimensions in Millimeters)

The basalt laminates are built using angle ply layers with($0^\circ/90^\circ$) fiber orientation for each layers. The total thickness of the shell is 45mm.The section details of the submarine model are shown in Table 1.

Table 1: Section Details of Submarine Hull

Description	Dimension
Length of the shell between bulkhead	6500 mm
Diameter	3000 mm
Spacing of stiffener	700 mm
Thickness of cylinder	45 mm
Depth of stiffener	200 mm

The material properties of basalt composite used in this study is given below;

Young’s modulus (longitudinal) = 53.55GPa

Young’s modulus (transverse) = 15.15GPa

In plane shear modulus = 5.9GPa

Mass density = 2060Kg/m^3

Major Poisson’s ratio = 0.29

FINITE ELEMENT MODELING

Finite element package ANSYS was used for modeling and analysis of the structure. Composite materials can be modelled in ANSYS using elements like layered elements. The shells and stiffeners are modelled using shell elements. SHELL181 was used for modelling curved shell and ring stiffeners. This element is well-suited for linear, large rotation; large strain nonlinear applications .The element has six degree of freedom at each node, translations and rotations in *x*, *y*, *z* directions.

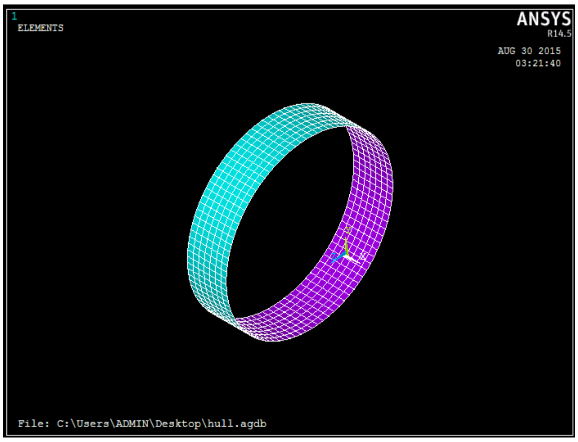

Figure 4: Shell between the Stiffeners

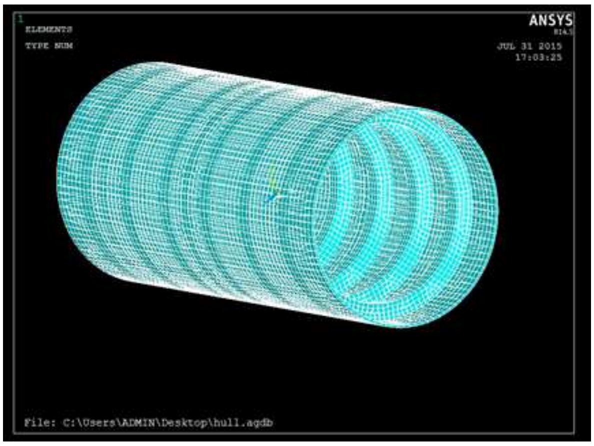

Figure 5: Full Model of Pressure Hull

LINEAR BUCKLING ANALYSIS

Buckling phenomenon is the major failure mode associated with thin walled cylindrical structures subjected to external pressure. In this study linear buckling analysis is used to predict the feasibility of basalt laminated composite pressure hull at deep waters. Analysis was conducted on interstiffener and inters bulkhead models with fixed-fixed and simply supported-simply supported boundary conditions.

Interstiffener Analysis

Interstiffener buckling analysis was carried out for the shell between the stiffeners. The type of analysis done was static and was carried out by incorporating fixed-fixed boundary condition and simply supported-supported boundary condition. Figure 6 shows the fixed boundary condition of the shell between the stiffeners.

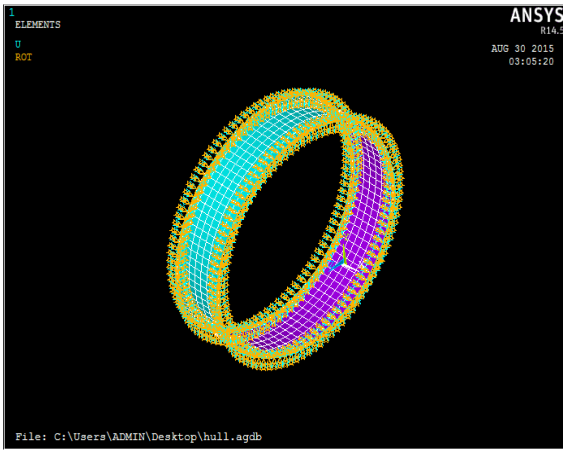

Figure 6: Inter Stiffener Model with Fixed Boundary Condition

The buckling mode shapes and the circumferential wave pattern for different boundary conditions;

Fixed – Fixed

The results obtained from the analysis of inter stiffener model with fixed-fixed boundary condition is shown in Figure 7 and Figure 8.

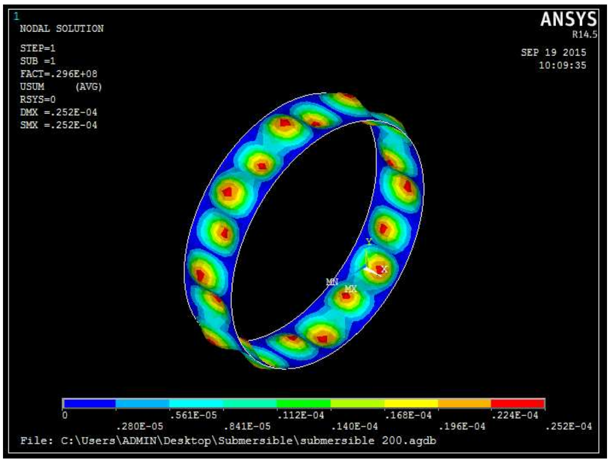

Figure 7: 1st Buckling Mode Shape

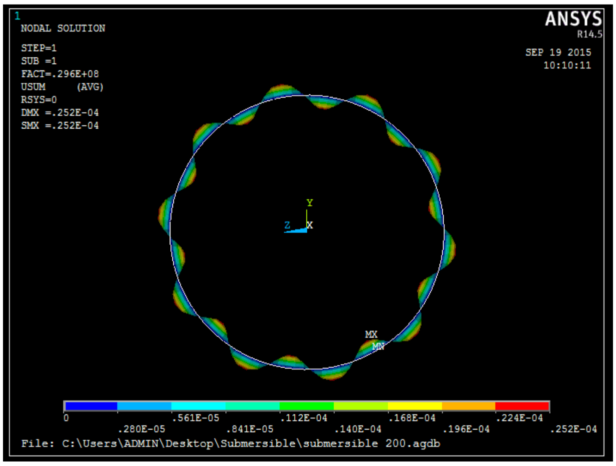

Figure 8: Circumferential Wave Pattern (n=10)

The critical buckling pressure obtained for fixed-fixed boundary condition was 29.6N/mm^2, the circumferential wave pattern of the 1st buckling mode shape shows that the pressure hull deforms with 10number of lobs in the circumferential direction.

Simply Supported-Simply Supported

The results obtained from the buckling analysis of inter stiffener model with simply supported-simply supported boundary conditions is shown in Figure 9 and Figure 10.

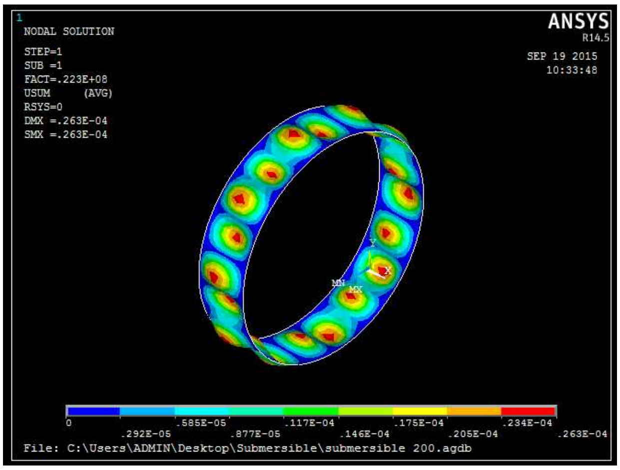

Figure 9: 1st Buckling Mode Shape

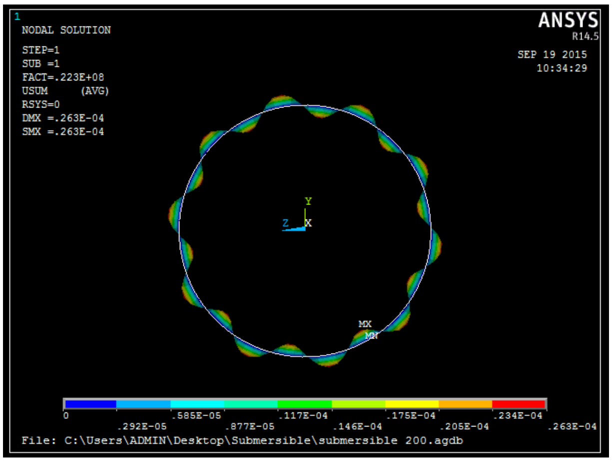

Figure 10: Circumferential Wave Pattern (n=10)

The critical buckling pressure obtained for simply supported-simply supported boundary condition was 22.3N/mm^2, the circumferential wave pattern of the 1st buckling mode shape shows that the pressure hull deforms with 10number of lobs in the circumferential direction.

Interbulkhead Analysis

The pressure hull was designed for a water depth of 350m.The uniform water pressure acting on the structure at the design depth is 3.5 N/mm^2. The interbulkhead model with boundary conditions is shown in Figure 11.

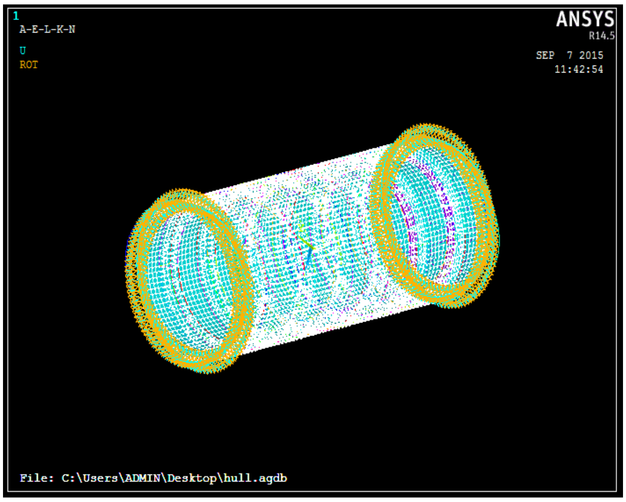

Figure 11: Model of the Cylindrical Shell with Boundary Conditions

The buckling mode shapes and the circumferential wave pattern for two different boundary conditions are as follows;

Fixed – Fixed

The 1st buckling mode obtained from the analysis is shown in Figure 12 and Figure 13, the buckling load value was obtained as 9.37 N/mm^2 .The inter bulkhead model buckles with 2 numbers of waves in the circumferential direction and it indicates the general instability

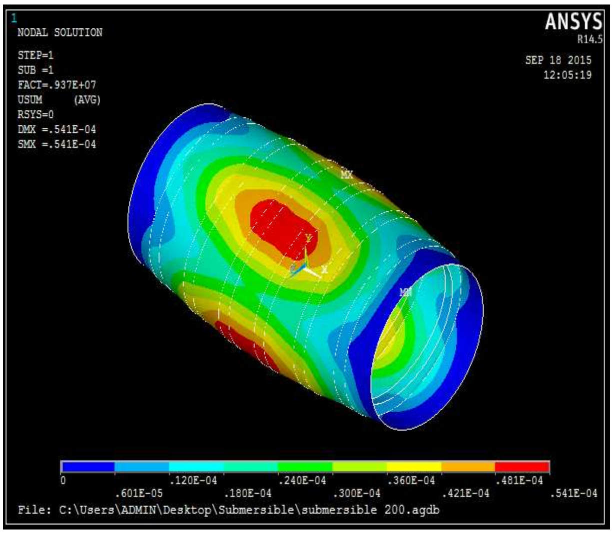

Figure 12: 1st Buckling Mode Shape

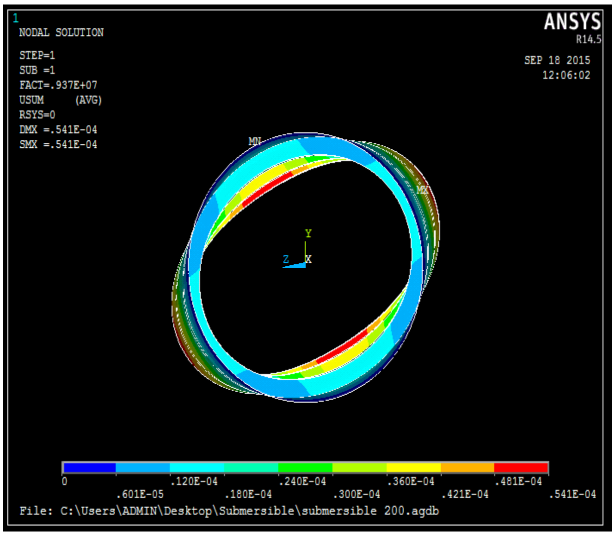

Figure 13: Circumferential Wave Pattern (n=2)

Simply Supported-Simply Supported

The 1st buckling mode obtained from the analysis is shown in Figure 14 and Figure 15, the buckling load value was obtained as 9.1 N/mm^2. The inter bulkhead model buckles with 2 numbers of waves in the circumferential direction.

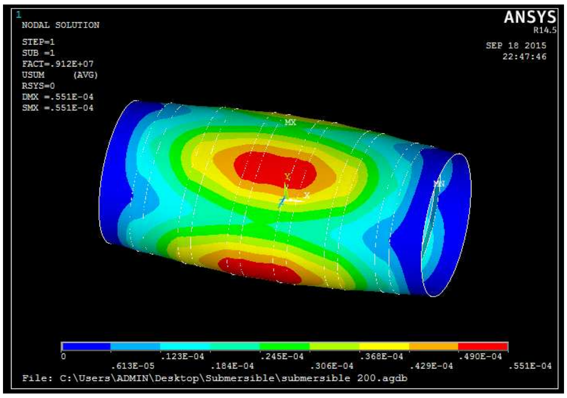

Figure 14: 1st Buckling Mode Shape

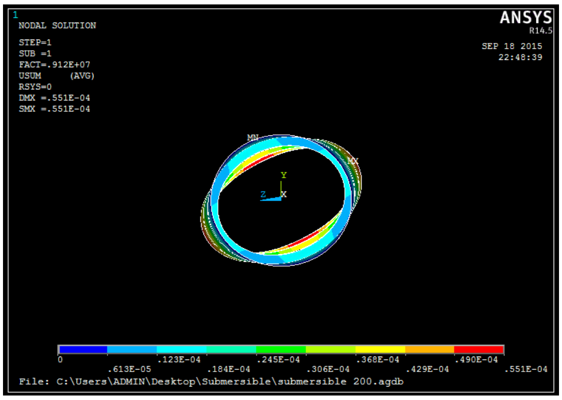

Figure 15: Circumferential Wave Pattern (n=2)

For both the boundary condition, the critical buckling pressure obtained was greater than the hydrostatic water pressure acting at the design depth, so the structure is safe for operating at the design depth.

The summary of results of interstiffener and interbulkhead buckling analysis is shown in Table 2.

Table 2: Comparison of Analysis Results

Configuration	Interstiffener		Interbulkhead	
Boundary condition	fixed	Simply supported	fixed	Simply supported
Linear buckling pressure (N/mm^2)	29.6	22.3	9.37	9.1
No of circumferential lobs	10	10	2	2

NONLINEAR BUCKLING ANALYSIS

ANSYS employs Newton Raphson approach to solve nonlinear problem in this problem the loads are subdivided into a series of load increments. The load increments are applied over several load steps. The iterative procedure continues until the problem converges. Nonlinearity arises when the load displacement graph is nonlinear. The nonlinear buckling analysis was performed on the pressure hull model to obtain the buckling pressure, stresses and displacement.The buckling pressure obtained for the fixed boundary condition is shown in Figure 16.

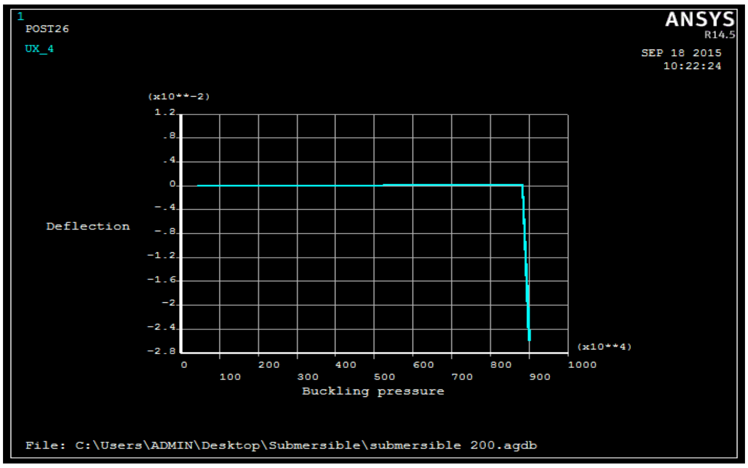

Figure 16: Graph Showing Nonlinear Buckling Pressure

The nonlinear buckling pressure obtained was 8.83N/mm^2, which was lower than that obtained for Eigen buckling analysis. The nonlinear buckling analysis is more accurate than Eigen buckling analysis as it taken into the effects of nonlinearities.

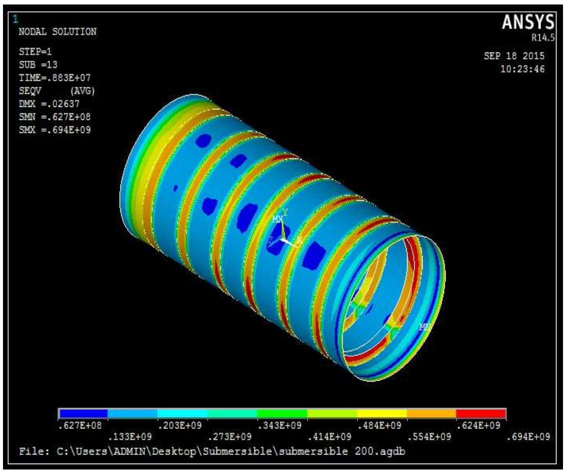

Figure 17: Vonmises Stress in Pressure Hull

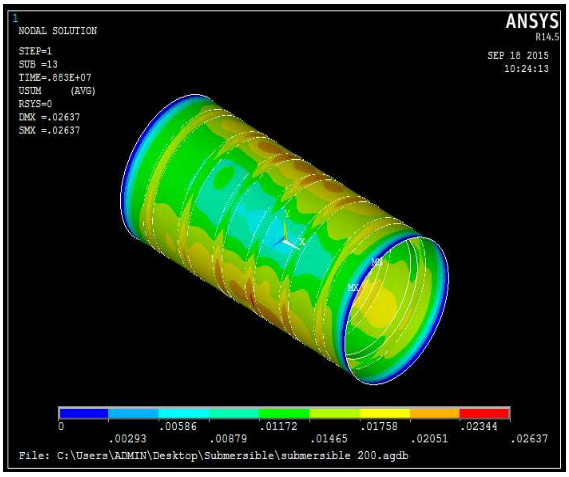

Figure 18: Displacement Vector Sum

The displacement vector sum obtained was 24.3mm, the von mises stress before buckling was 694 N/mm^2.The vonmises stress is less than the yield strength of the material so there is no possibility of material failure.

COMPARATIVE STUDY OF STEEL AND BASALT COMPOSITES

Comparative study has been carried out between the steel and basalt composites to study the weight criteria. For the study, the interstiffener portion of the pressure hull was modelled in steel using the element shell 181 in ANSYS 14.5.A series of analysis has been carried out by varying the thickness of the steel pressure hull to obtain the same buckling pressure as that of basalt composite interstiffener model with fixed boundary condition.Fig.19 shows the 1st buckling mode and wave pattern for the steel model.

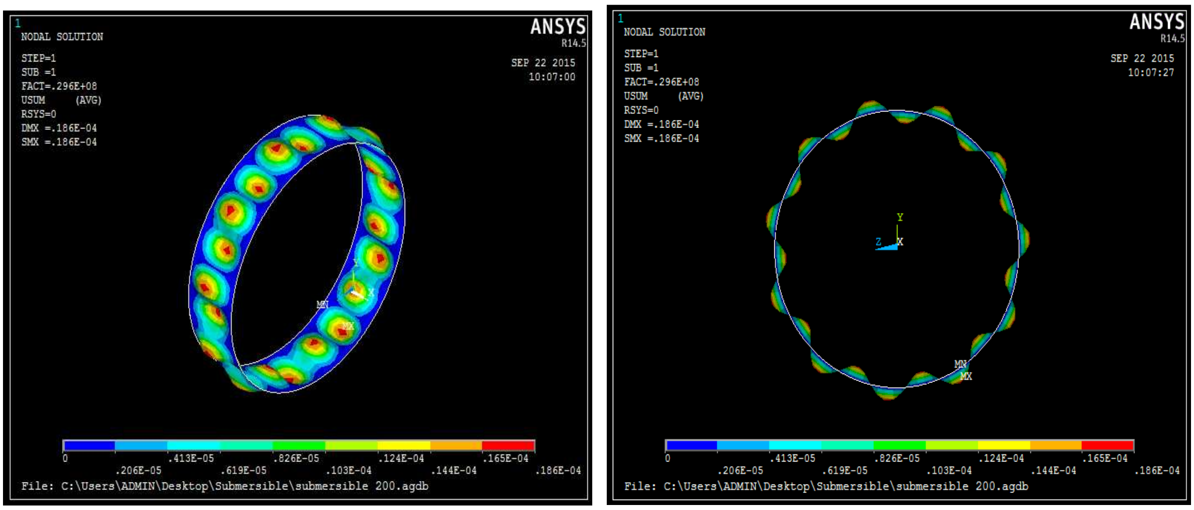

Figure 19: Buckling Mode and Circumferential Wave Pattern of 1st Buckling Mode (n=11)

The results of comparative study based on weight criteria between steel and basalt composite model is shown in Table 3.

Table 3: Comparative Study of Steel and Basalt

Material	Buckling Pressure (N/mm^2)	Density (Kg/m^3)	Thickness (mm)	Mass (Kg)	% wt. reduction
Steel	29.6	7500	24.12	1249.15	51
Basalt		2060	45	611.57	

The total weight of the interstiffener model of the pressure hull made with conventional material steel was found to be 1249.15 Kg while that replaced with basalt composite it got reduced to 611.57 Kg. Hence with the replacement of steel by basalt, the total weight of the pressure hull got reduced by 51 %.

CONCLUSIONS

Comparative study of linearbuckling has been done for two configurations, interstiffenerand interbulkhead model. Fixed-fixed and simply supported- simply supported boundary conditions were considered. For both configurations it was found that critical buckling pressure was higher for fixed boundary condition compared to simply supported boundary condition. Interstiffener model shows a reduction of 24 % in the buckling pressure for simply supported boundary condition as compared to fixed boundary condition. Whereas for interbulkhead model there is no much reduction in buckling pressure. Thus interstiffener model is more susceptible to the effect of rotational restraint. Between the bulkheads the shell buckles with less number of circumferential waves and it refers to general instability.

Critical buckling pressure obtained from the nonlinear buckling analysis was less compared to linear buckling pressure but it is within the design limit. Therefore the pressure hull is safe for operating at the design depth.

Comparative study has been done between the conventional steel material and basalt composites based on weight criteria. It was found that the total weight of the pressure hull got reduced by 51% when steel was replaced with basalt.

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