VIBRATION BUCKLING AND FRACTURE ANALYSIS OF CYLINDRICAL SHELL

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ABSTRACT

Shell structures are widely used in civil, mechanical, aerospace and marine engineering applications (e.g. offshore oil tanks, automotive industry, aircraft and submarines). Like other types of structures, they are susceptible to various types of defect and damage such as cracking, corrosion, chemical attack and time-dependent material degradation, which may impair their structural integrity and affect their service life. The presence of cracks in a cylindrical structure can considerably affect its behavior. The effects of these imperfections on load carrying capacity and safety are thus important considerations in the design of cylindrical shell structures. This present work presents a finite element study on the vibration, buckling and fracture behavior of a cracked cylindrical shell with clamped type supports and subject to a time varying rotating speed. Vibration, linear elastic buckling and fracture parameters of a cracked cylindrical shell with time-varying rotating speed are analyzed. The effects of constant rotating speed, crack length and orientation of crack and length-diameter ratio of the cylindrical shell on the free-vibration and buckling behaviors are investigated.

KEYWORDS: *Buckling of Cylinder, Buckling analysis Cylinder, Fracture Analysis of a Cylinder, Vibration Analysis of Cylinder*

I. INTRODUCTION

The cylindrical shell structures constitute main parts of jet engines, aero-transports, rockets, missiles and other aerospace vehicles, so the development of aerospace structures requires deep studies on the cylindrical shell which is one kind of thin-walled structures. Thin walled cylindrical shells are used in many Engineering applications. The shape and load carrying capability makes the cylindrical structures well-suited for aerospace and civil structures. Additionally, the cylinders are designed with minimum weight and maximum resistance to various load conditions. Aerospace structures rely on optimization to minimize weight; similarly, Civil engineering structures are designed with minimum material to reduce costs. Like other types of structures, these shells are susceptible to various types of defect and damage such as cracking, corrosion, chemical attack and time dependent material degradation, which may impair the structural integrity and affect the service life. Various cracks may develop in shell structures due to many reasons. Presence of these cracks may severely affect static and dynamic behavior of the shell structure. Unfortunately, the demand to design thinner cylindrical shells and support maximum design loads makes the shells more prone to buckling failure. Further, variations in a cylinder's manufactured dimensions from the design geometry greatly affect determination of the critical buckling load.

In Mechanical Engineering, shell forms are used in piping systems, turbine disks, and pressure vessels technology. Aircrafts, missiles, rockets, ships, and submarines are examples of the use of shells in Aeronautical and Marine Engineering. Another application of Shell Engineering is in the field of Bio

Mechanics: shells are found in various biological forms, such as the eye and the skull, and plant and animal shapes.
Contemporary engineers using scientifically justified methods of design tend to develop a structure that combines maximum strength, functional perfection, and economy during its lifetime. In addition, it is important that the best engineering solution ensues, other things being equal, at the expense of the selection of structural form and by not increasing the strength properties of the structure, e.g., by increasing its cross section. Note that the latter approach is easier.

II. TYPES OF ANALYSIS

2.1 Buckling Analysis:

Buckling is one of the main failure considerations when designing these structures. Presence of defects, such as cracks, may severely compromise their buckling behavior and jeopardize the structural integrity. The post-buckling analysis of cracked plates and shells indicated that the buckling deformation could cause a considerable amplification of the stress intensity around the crack tip. On the other hand, increasing the load can cause propagation of the local buckling leading to the catastrophic failure of the shell structure.

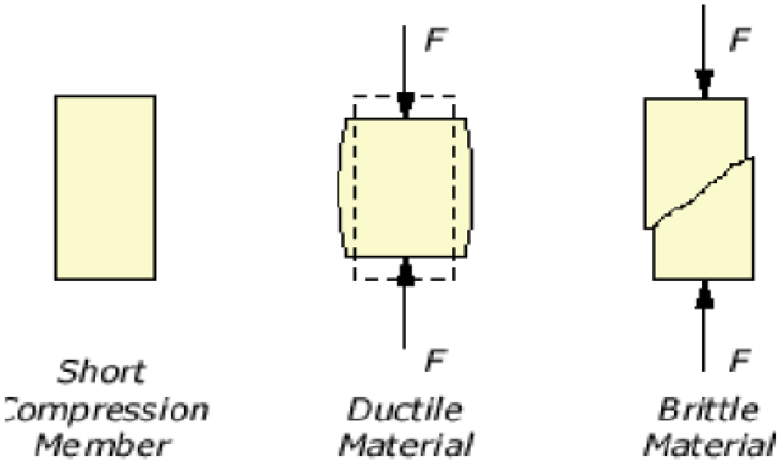


Figure1.Failure of short columns due to material failure

2.2 Vibration Analysis:

Vibration is another important consideration in the design of cylindrical structures because the natural frequencies of the cylindrical shells are clustered in a very narrow band and thus are more prone to be involved in resonant vibrations. To control the amplitudes of these vibrations, it is necessary to know the distribution of natural frequencies, since this allows us to design the cylindrical structures from the view point of optimum vibration control.
Traditional concepts do not anticipate the elevated stress levels due to the existence of cracks. The presence of such stresses can lead to catastrophic failure of the structure. Including the effect of flaws with fracture mechanics approaches is becoming common practice in many industries. Fracture mechanics accounts for the cracks or flaws in a structure and describes crack behavior using concepts from both applied mechanics and material science, because cracks propagate by the combined effect of stress and flaws.

2.3 Time-Varying Rotating Speed:

The time-varying rotating speed, which mainly exists in rotor machines such as turbo machine, should also be considered. The rotating speed of a turbo machine which contains blades, disk and shell will not always remain constant, and it may be strongly affected by the fluctuations of the density, velocity, pressure of the surrounding fluid and the working state. Thus, it would be more general and physically realistic to consider a time-varying rotational speed for these structures.

To the best of our knowledge, there is little research on the buckling and vibration behavior of the cracked cylindrical shell with rotating speed. Also a little research had been reported on fracture analysis of the cracked cylindrical shell with rotating speed. Inspired by the works carried out in the area of cylindrical shells, the aim of the present work is to investigate the vibration, linear elastic buckling and fracture parameters of a cracked cylindrical shell with rotating speed.

III. FINITE ELEMENT MODELLING

3.1. Finite Element Modeling of Cylindrical Shell

Specifications of a Cylindrical Shell:

Table 1. Specifications of a cylindrical shell

S.No	Parameter	Value
1	Radius (R)	242.3 mm
2	Length (L)	609.6 mm
3	Thickness (h)	0.648 mm
4	Young's modulus (E)	68950 MPa
5	Density	2714.5 Kg/m^3
6	Poison's ratio	0.315

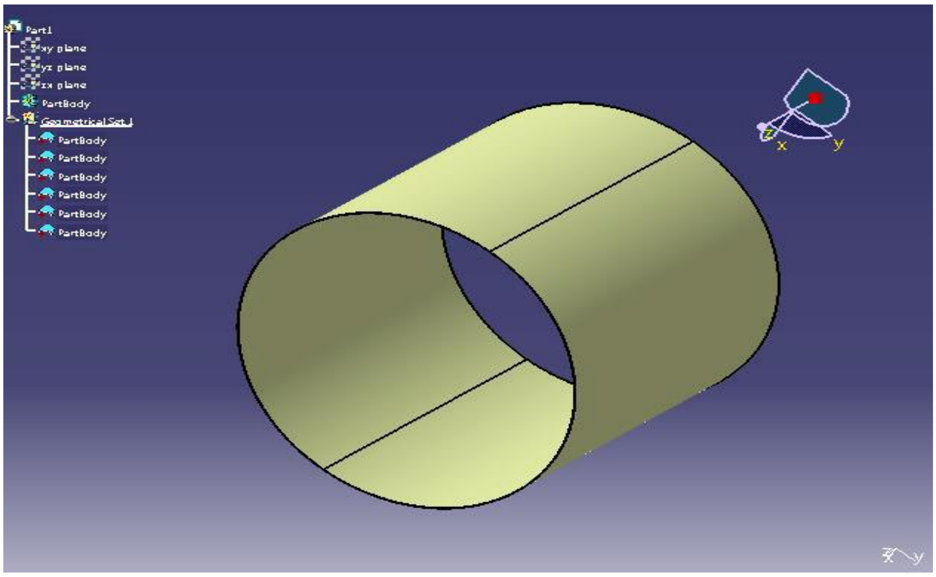


Figure2. Finite Element Modeling of Cylindrical shell

Meshing of Cylindrical Shell:

Table2. Isotropic Elastic Properties for cylinder material

Young's Modulus (Mpa)	Poisson's Ratio	Bulk Modulus (Mpa)	Shear Modulus (Mpa)	Density (Kg/mm3)
68950	0.315	62117	26217	2714.5

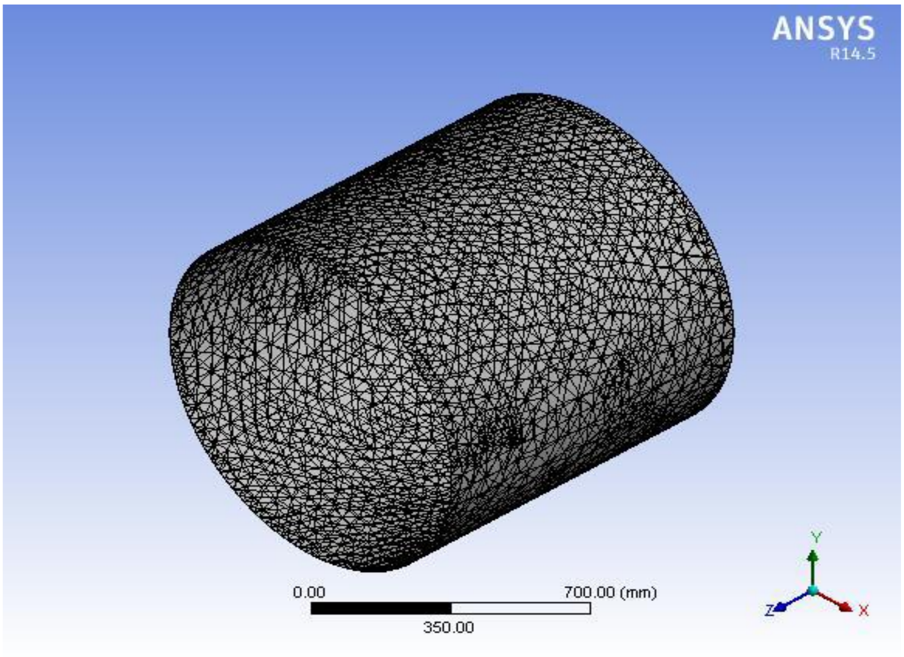


Figure 3: Meshed Model of Cylindrical Shell in ANSYS 14.5

3.2 Modal analysis of perfect cylindrical shell

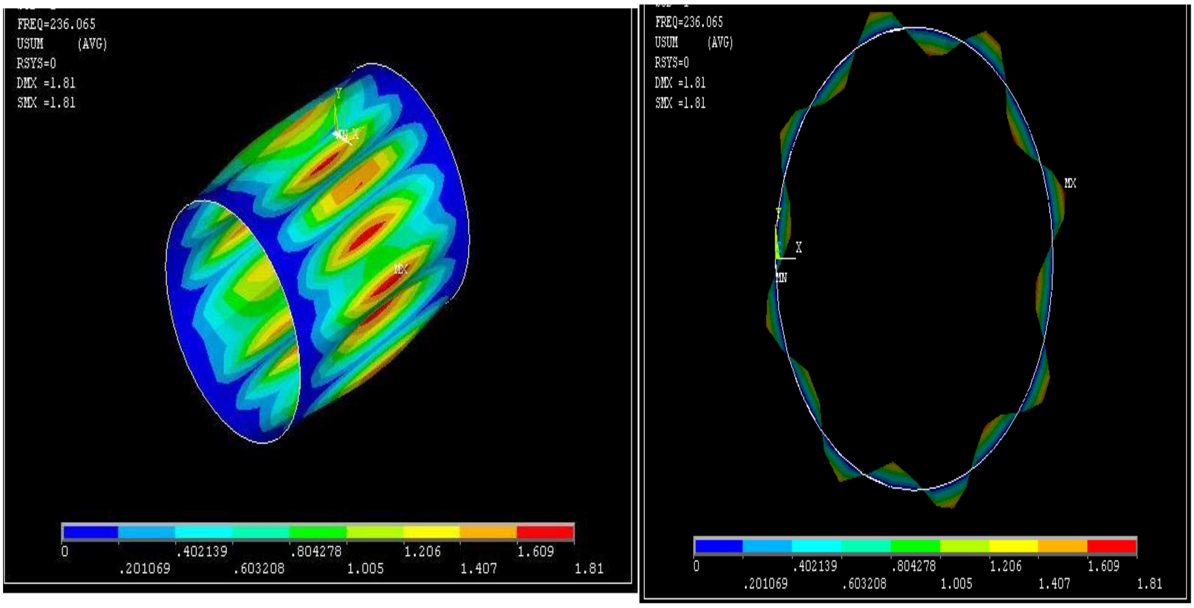


Figure4. Mode Shape 1 of Perfect Cylindrical Shell

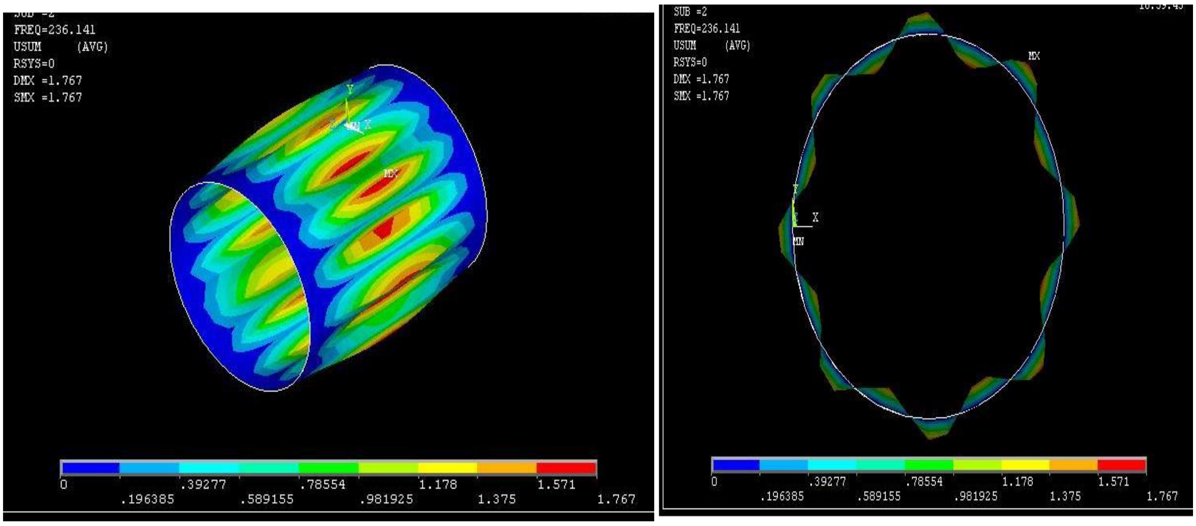


Figure5. Mode Shape 2 of Perfect Cylindrical Shell

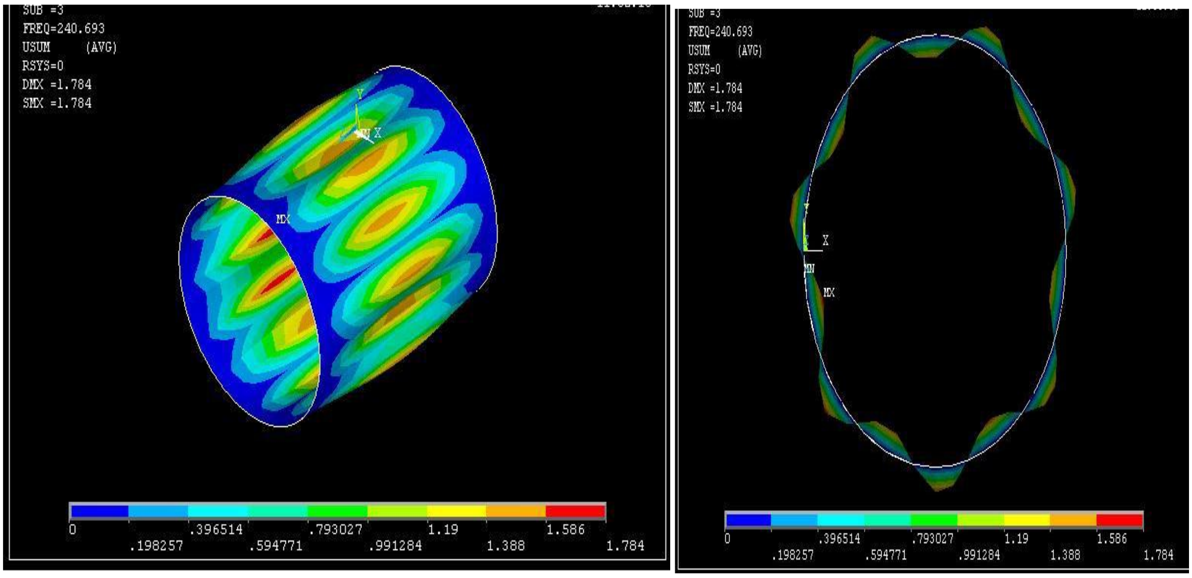


Figure6. Mode Shape 3 of Perfect Cylindrical Shell

3.2 Results obtained from modal analysis of perfect cylindrical shell

Table3. Frequency of perfect cylindrical shell

Mode Number	Frequency (Hz)	Maximum Deformation(mm)
1	236.07	1.81
2	236.14	1.767
3	240.69	1.784
4	241.53	1.921
5	245.32	1.647
6	247.16	1.593

3.3 Free Vibration analysis of cracked cylindrical shell

To investigate the vibration characteristics of a Clamped Cylinder (C–C) type cylindrical shell with a longitudinal crack, the dimensions and the properties of the cylindrical shell considered are listed as below

Table4. Dimensions and Properties of Cylindrical Shell

S.No	Parameter	Value
1	Radius (R)	500 mm
2	Length (L)	1000 mm
3	Thickness (h)	1mm
4	Young's Modulus (E)	68590 MPa
5	Poison's ratio (μ)	0.315
6	Density (ρ)	2714.5 Kg/m3

In order to know the effect of crack length on the natural frequency a longitudinal cracked cylindrical shell with zero crack angle and with zero rotating speed is studied considering the effect of the crack length. The figure below shows the isometric view of pre-meshed cracked models of the cracked cylindrical shell with different crack length i.e. C= 0.15L, C= 0.25L and C= 0.35L where C is the crack length and L is the length of the cylinder. The next three subsections deals with the effect of different crack lengths on the natural frequency of the cracked cylindrical shell.

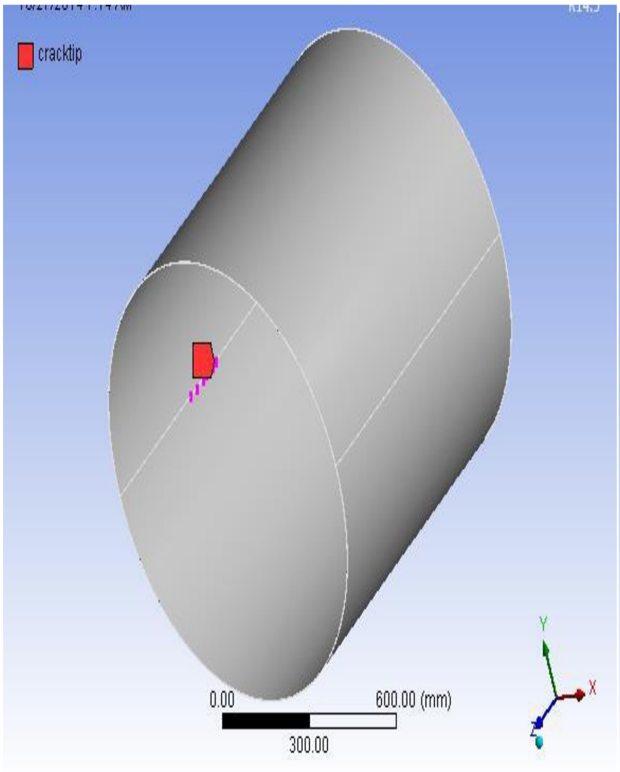


Fig7. Cylindrical shell with a Crack Length of 0.15L

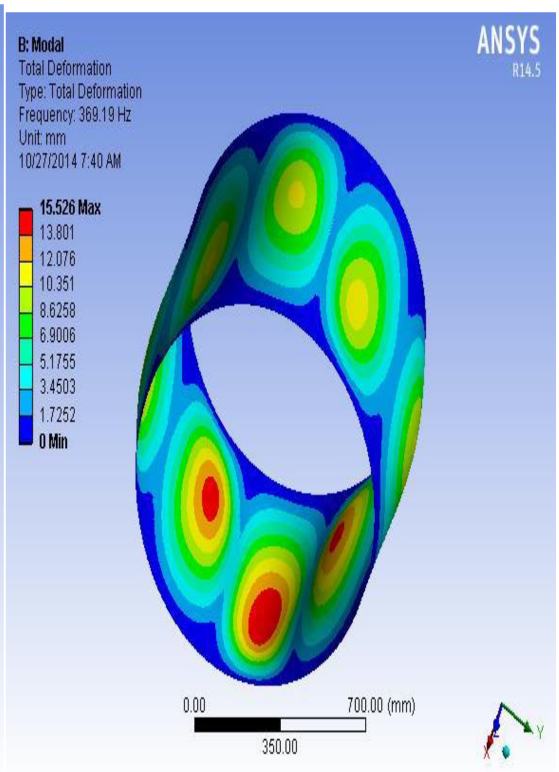
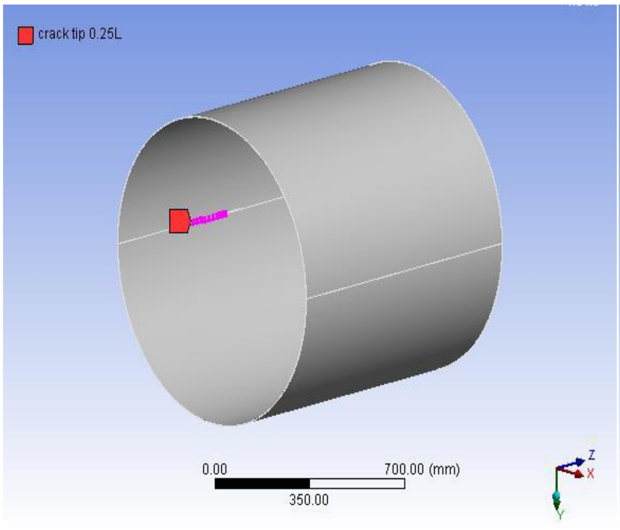


Fig8. Mode Shape 1 of Cracked Cylindrical Shell With crack length 0.15L



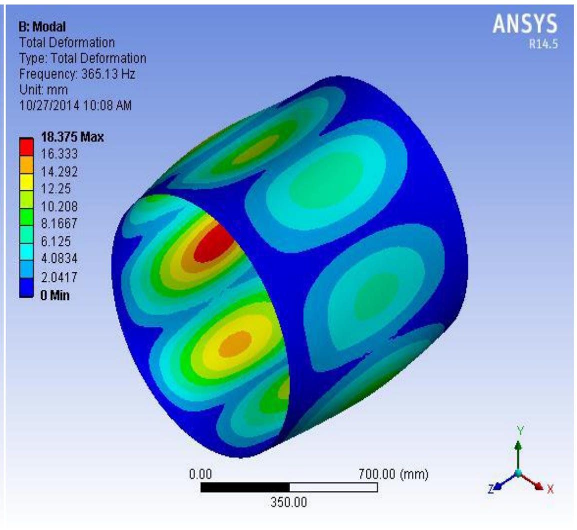
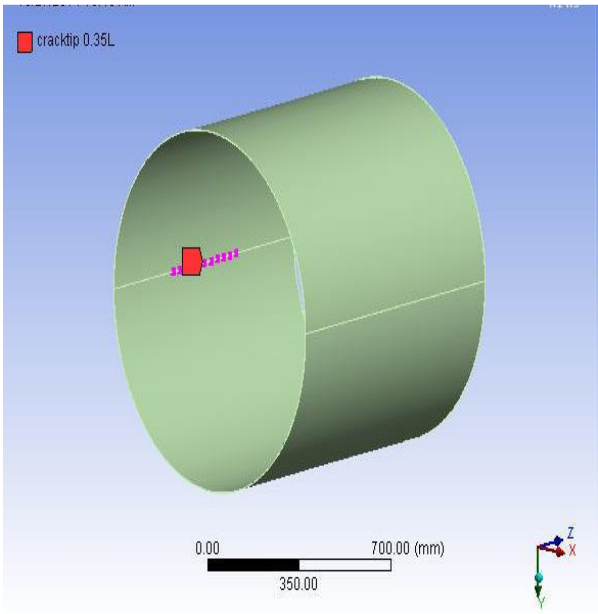


Fig9. Cylindrical shell with a Crack Length of 0.25L

Fig10. Mode Shape 1 of Cracked Cylindrical Shell With crack length 0.25L



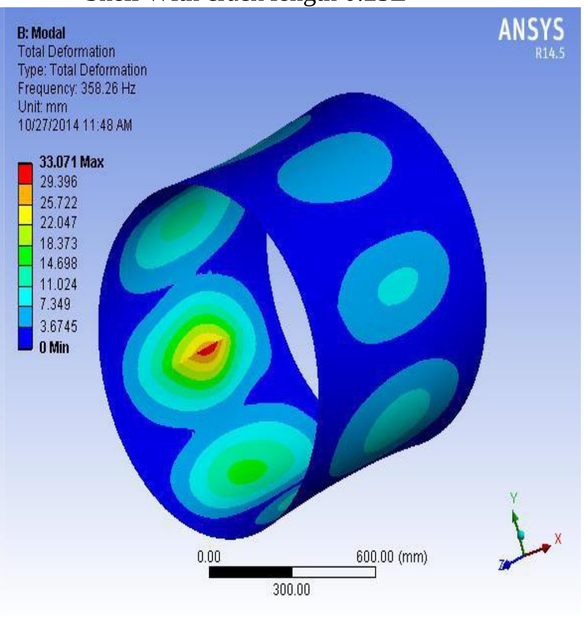


Fig11. Cylindrical shell with a Crack Length of 0.35L

Fig12. Mode Shape 1 of Cracked Cylindrical Shell With crack length 0.35L

IV. RESULTS AND DISCUSSION

Table5. Modal frequencies of cracked Cylindrical Shell with a crack length C =0.15L

Mode Number	Frequency (Hz)	Maximum Deformation(mm)
1	369.19	15.526
2	375.69	16.225
3	419.89	19.178
4	429.55	21.321
5	447.38	22.652
6	451.23	24.134

Table6. Modal frequencies of cracked cylindrical shell with C = 0.25L

Mode Number	Frequency (Hz)	Maximum Deformation(mm)
1	365.13	18.375
2	373.69	16.911
3	420.25	15.65
4	425.6	14.73
5	445.57	13.89
6	456.83	12.78

Table7. Modal frequencies of cracked cylindrical shell with C = 0.35L

Mode Number	Frequency (Hz)	Maximum Deformation(mm)
1	358.26	33.071
2	372.8	16.497
3	415.25	26.747
4	424.62	25.014
5	438.24	23.223
6	452.21	19.689

4.1 Graphs:

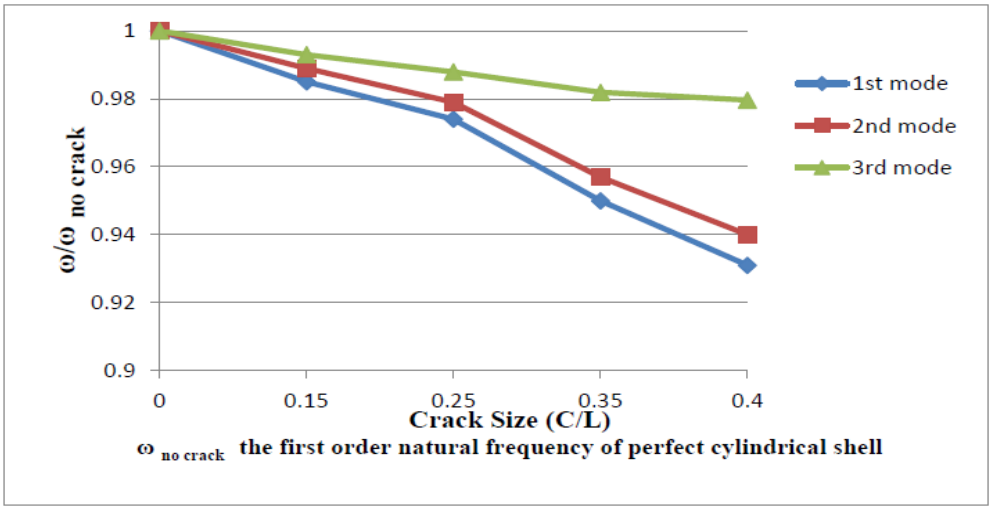


Figure13. Crack length vs. Frequency graph

From the graph above it is clear that the first and second order frequencies decrease obviously as the crack length increases, but the third frequency is hardly affected by the length of the crack. The curve of the first and second order frequencies decrease slowly when the crack size is small, but decrease very rapidly when the crack length reaches to0.2L.

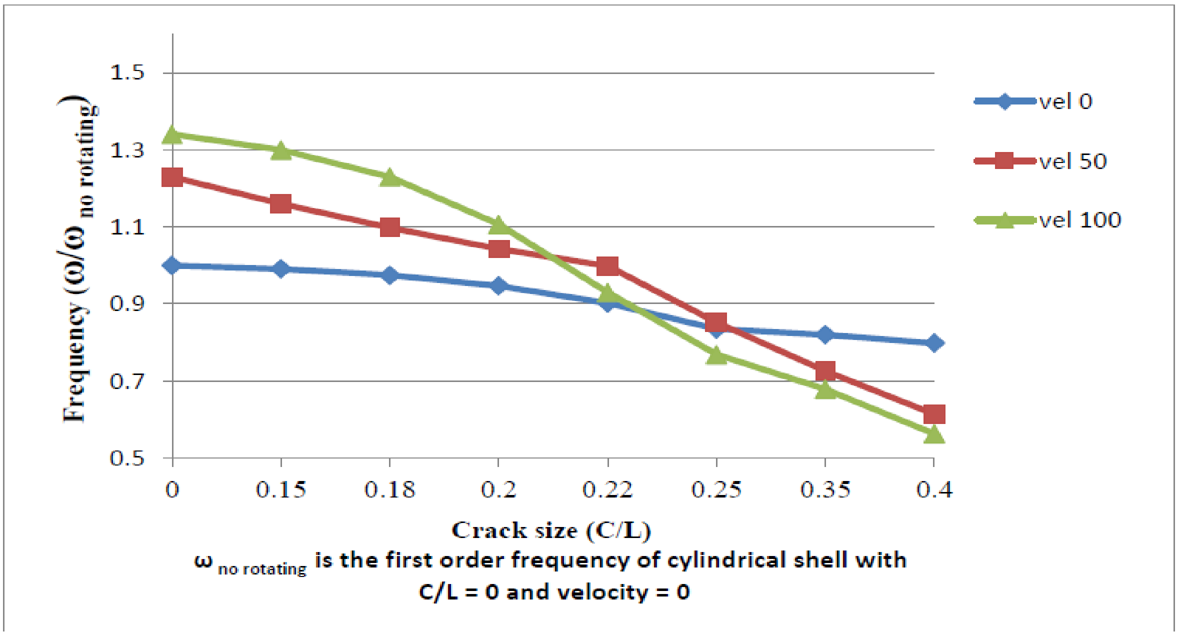


Figure14. Crack size vs. Frequency graph for rotating speeds

The Fig. above shows the effect of crack length on the first order natural frequency with different rotating speed 0, 50 rad /sec and100 rad /sec. ω no rotating is the first order frequency of cylindrical shell with C/L = 0 and velocity = 0. Curves in graph can be divided into two areas: flat area and steep area. In the flat area, the natural frequency decreases slowly with the growth of the crack length, and as the result of centrifugal or rotation stiffening effect, the higher the rotating speed is, the higher the natural frequency.

V. CONCLUSION

From the work carried out on the Vibration, Buckling and Fracture analysis of the cracked cylindrical shell it can be concluded that

The comparison of the perfect cylindrical shell vibration analysis results with experimental and analytical results are done and iIt shows that the variation between the results obtained from the literature and the present work is within the acceptable limits and thus the model is validated for further analysis in ANSYS.

- The first and second order frequencies decrease obviously as the crack length increase, but the third frequency is hardly affected by the length of the crack.
- The effect of crack angle on the cylindrical shell is that the frequency is hardly affected when the crack angle is greater than 20^{o}, however, it will be affected significantly when the crack angle is smaller than 20˚.
- The buckling load is lower with lower L/R value, because the centrifugal force is bigger with higher R value when L and C are constant.

Future Scope of the Work

- The analysis can be extended on the cracked cylindrical shell by taking the temperature effects into consideration and analyzing the effect of various fluids in the cracked cylindrical shell in CFD analysis.
- There is a scope of work for carrying out fracture analysis for the energy release rate by using Virtual Crack Closure Technique (VCCT) in ANSYS.
- It can also be investigated for the flow stresses by using Computational Fluid Dynamics.

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