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Stress Analysis of Inflatable Cylinder

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Abstract: Any increment in buckling load and disturbances cause the structure to change from one equilibrium configuration to another. Hence, inflatable structural components become unbalanced under static loading. In this case, change in the character of deformation is indicated by buckling load at initial instant. Generally, significant load for analysis is the critical buckling load which is obtained at an instant when the material fails plastically or the structure collapses. In this research work, an inflatable cylinder is considered for numerical analysis. The cylinder is constrained as hinged at one end and simply supported at the other for studying buckling parameter. This study presents a numerical model made by using the commercial solver ABAQUS and solved for the same pattern of work, lastly, results obtained by both forms of analysis is to be correlated and inference is to be determined.

Keywords: Inflatable Cylinder; Buckling; ABAQUS

I. INTRODUCTION

In this paper, the buckling analysis of the beam is carried out using experimental setup. The result obtained by experimentation matched with the analytical results closely. It is a well-known fact that, due to unrealistic boundary conditions and unavoidable errors, the exact match between simulation results, analytical solution and experimental results could not be achieved. Therefore, an experimental model is set up and the detailed analysis of the same is performed. The comparison of experimental and analytical results will give a detailed insight into the behavior of inflatable beams. Finally, buckling load value obtained experimentally is used for finite element analysis and von mises stress is determined for inflatable cylinder.

II. OBSERVATION TABLE

Table I: Readings for Buckling Load Validation

Sr. No.	**Master Cylinder**		**Supporting Cylinder**		**Rotameter Reading (LPM)**
	Inlet (kgf/cm^2)	**Outlet (kgf/cm^2)**	**Inlet (kgf/cm^2)**	**Outlet (kgf/cm^2)**	
01.	8	3	6.2	0	30
02.	6	2	4	0	30
03.	8	3	5.2	0	30
04.	8	3	4.7	0	30
05.	8	3	3	0	30
06.	8	3	7	0	30
07.	8	3	6.7	0	30

A. Theoretical Analysis

- Discharge = Q = 30 LPM = 30 x 10^{-3} m^3/min

$$Q = \frac{30 * 10^{-3}}{60} \text{ m}^3/\text{sec}$$

$$Q = 0.5 * 10^{-3} \text{ m}^3/\text{sec}$$

- Density of air = 1 kg/m^3
- Mass flow rate = m = 1 * 0.5 * 10^{-3} kg/sec
- Flow of air is allowed for 10 sec
- Mass accumulated = m * t = (1 * 0.5 * 10^{-3})* 10 = 0.5 * 10^{-2} kg
- Assume, diameter and length of inflatable cylinder as 4 cm and 52 cm respectively.

We know that,

$$pV = mRT \qquad \text{Equation (1)}$$

Therefore, Volume is given by

$$V = (\pi/4) * (0.04)^2 * 0.52$$

$$V = 6.53 * 10^{-4} \text{ m}^3$$

$$T = 25\ {}^0\text{C} \qquad \text{(Ambient temperature)}$$

Substitute the value of volume and temperature in equation (1), therefore

$$p = \frac{0.5 * 10^{-2} * 287 * 298}{6.53 * 10^{-4}}$$

$$p = 654869.8 \text{ N/m}^2$$

$$p = 6.5487 \text{ kgf/cm}^2$$

Minimum tensile force

$$= 654869.8 * \frac{\pi}{4} * (0.04)^2$$

$$= 823.04 \text{ N} \qquad \text{Theoretical Buckling Load}$$

B. Experimental Analysis

Differential pressure = (8 – 3) kgf/cm^2

= 5 kgf/cm^2

= 50 N/cm^2

By measurement, pneumatic cylinder effective diameter = 3 cm

Therefore, force on main cylinder is given by,

$= 50 * \pi/4 * (3)^2$

= 353.42 N

Position of supporting cylinder = 40^o (Average)

Differential pressure = (6.2 – 0) kgf/cm^2

= 62 N/cm^2

Therefore, force on cylinder = $62 * \pi/4 * (3)2 = 438.25$ N

As the horizontal component of force is responsible for buckling, hence consider horizontal component of force for analysis.

Component of force in horizontal direction = 438.25 cos 40^o = 335.71 N

Total load = 438.25 + 335.71 = 773.96 N (Practical load at which buckling takes place)

III. NUMERICAL ANALYSIS

A. Cylinder Model

The geometry of the profile is created using key points which are marked which constitute for the first half of the cylinder profile. Using the ‘Extrude’ option, the straight line is revolved around its axis through 360 degrees. Hence, hollow cylinder of negligible thickness is obtained as shown in figure 1.

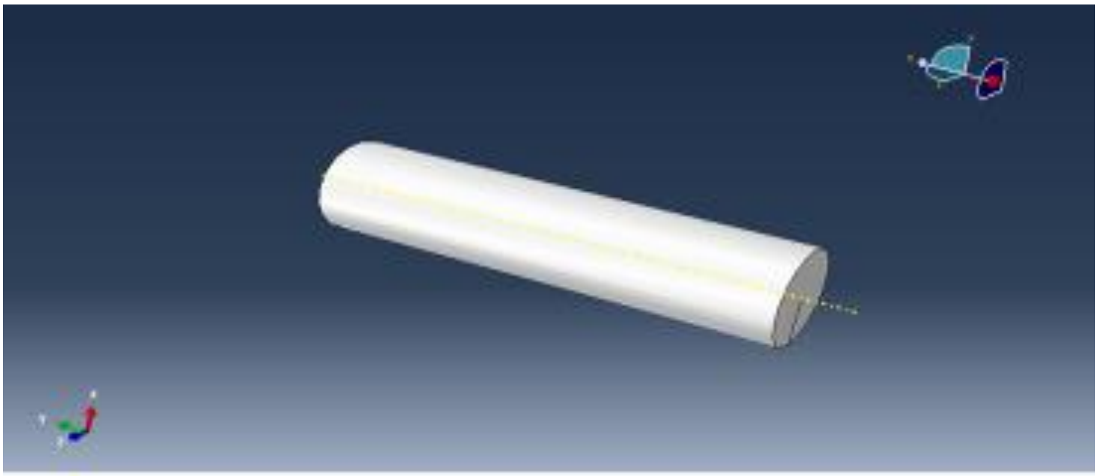

Figure 1: Cylinder Model

Table I: Dimensions of Inflatable Cylinder

Sr. No.	Parameters	Size
1	Diameter	4 cm
2	Length	52 cm

B. Meshing

Figure 2 shows meshed model of inflatable cylinder. Type of element selected for meshing is S4R (Shell element) and M3D4 (Membrane element). Plain strain condition is assumed, as thickness is not being varied as observed from the experiments on PVC. This has been tested on INSTRON type of flexible universal testing Machine at LTA Lab. Thickness of the shell is kept at 0.033mm, same as original thickness of the material. Coarse mesh is adopted with 621 numbers of elements as it resulted in less number of abortions due to distortions.

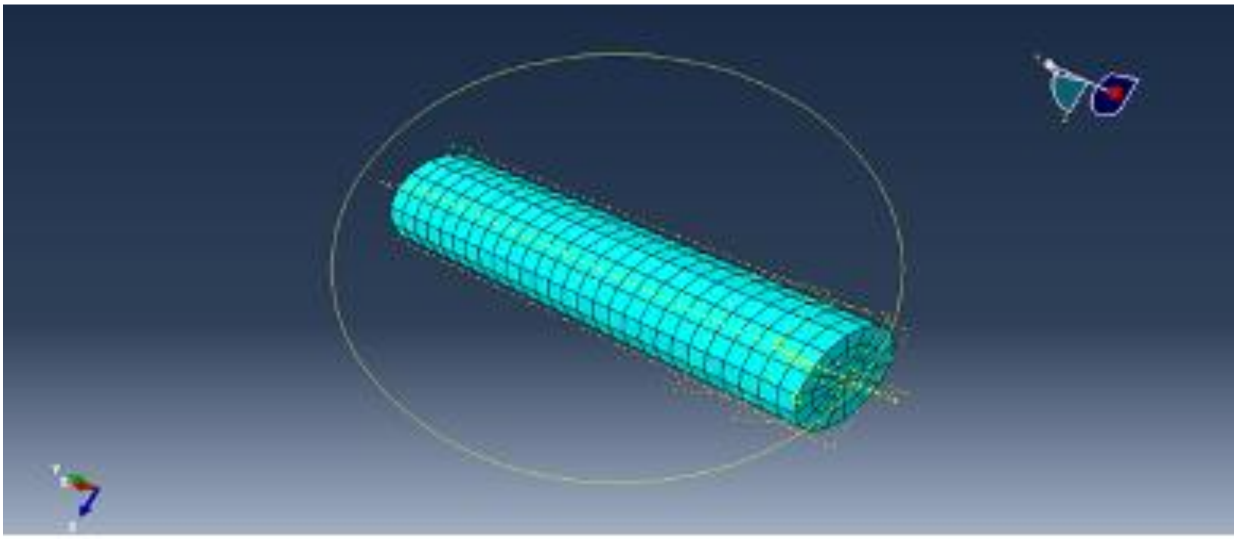

Figure 2: Meshed Model

C. Boundary Conditions

As shown in figure 3 uniform compressive load of magnitude 823 N is applied on right end face of inflatable cylinder. Cylinder has been inflated to a pressure of 6.2 bars as mentioned in experimental buckling analysis.

D. Von Mises Stress

Figure 4 shows Von Mises stress for inflatable cylinder. Blast type of appearance is due to excessive distortions towards end because of low stiffness of the elements. The stress value 0.052 N/mm^2 is less compared to 3 N/mm^2 which is at lower yield point. Hence, inflatable cylinder made of PVC is safe but its stability is affected badly.

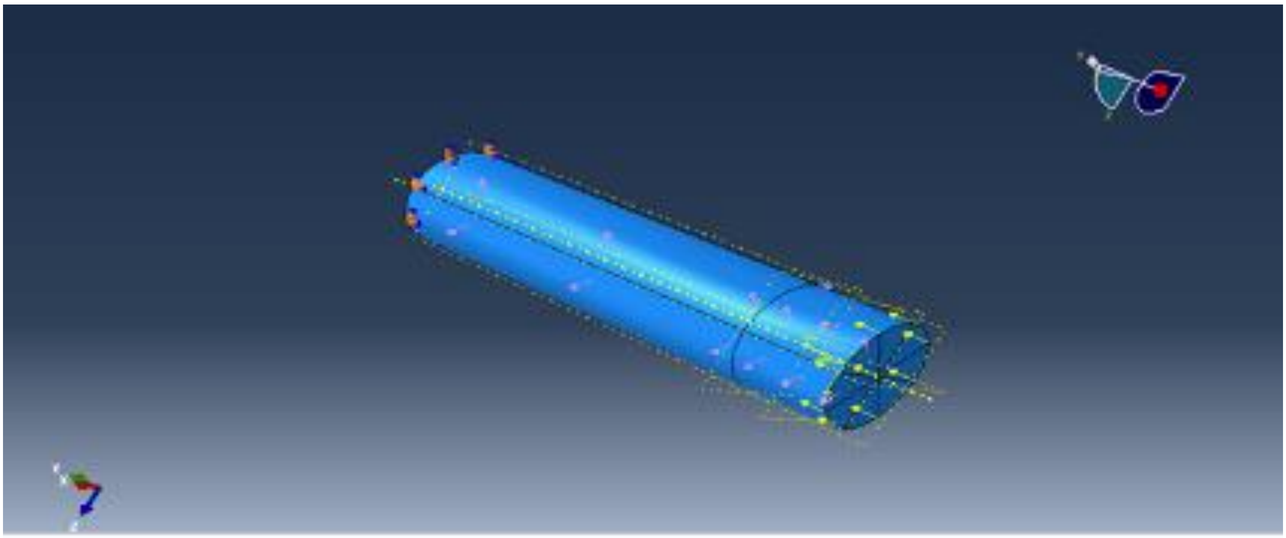

Figure 3: Boundary Conditions

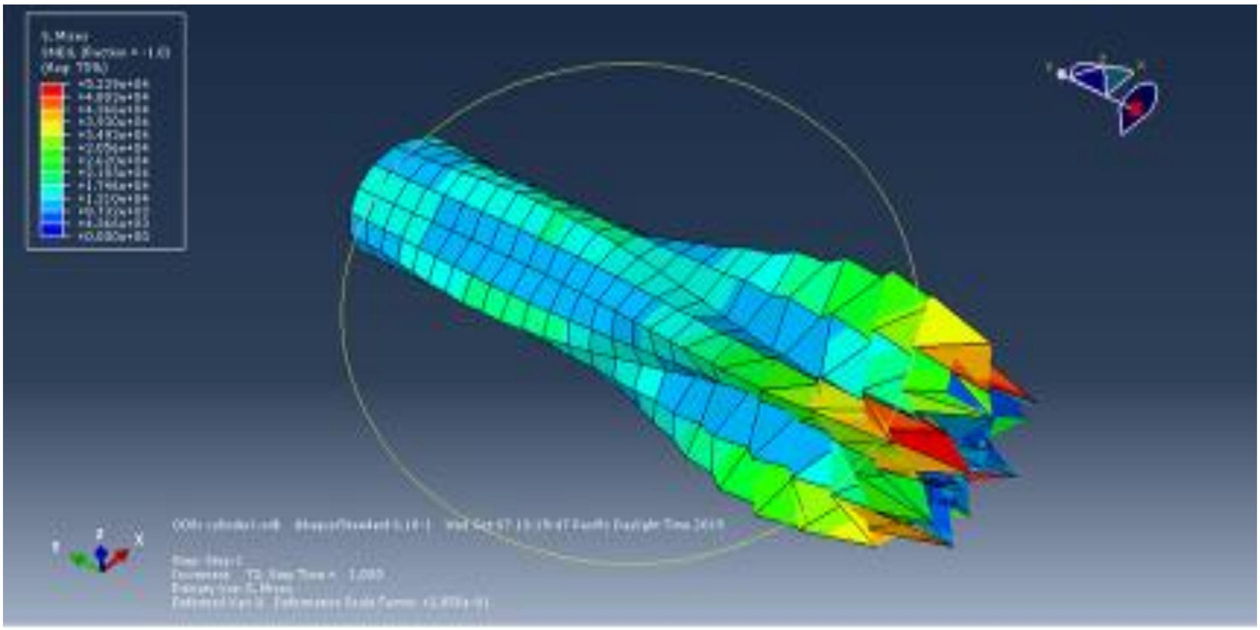

Figure 4: Von Mises Stress

IV. COMPARISON OF RESULTS

Experimental result obtained for buckling load is closely matching with analytical result. From this result it can be concluded that model with inflatable material properties can be solved with newly developed experimental setup. Small variation in result is obtained because of use of simplified boundary conditions in analytical solution.

From figure 5 it is found that experimental buckling load is very close to theoretical buckling load at differential pressure of 6.2 kgf/cm^2. If the value of differential pressure is taken below the 6.2 kgf/cm^2

then large difference between theoretical buckling load and experimental buckling load is observed. If the value of differential pressure is taken more than 6.2 kgf/cm^2 then experimental buckling load exceeds theoretical buckling load. Hence, 6.2 kgf/cm^2 pressure value is selected to obtain the various design parameters of interest of inflatable cylinder.

Table II: Result Comparison

	Analytical (N)	**Experimental (N)**	**Percentage Variation**
Buckling Load	823.04	773.96	5.96%

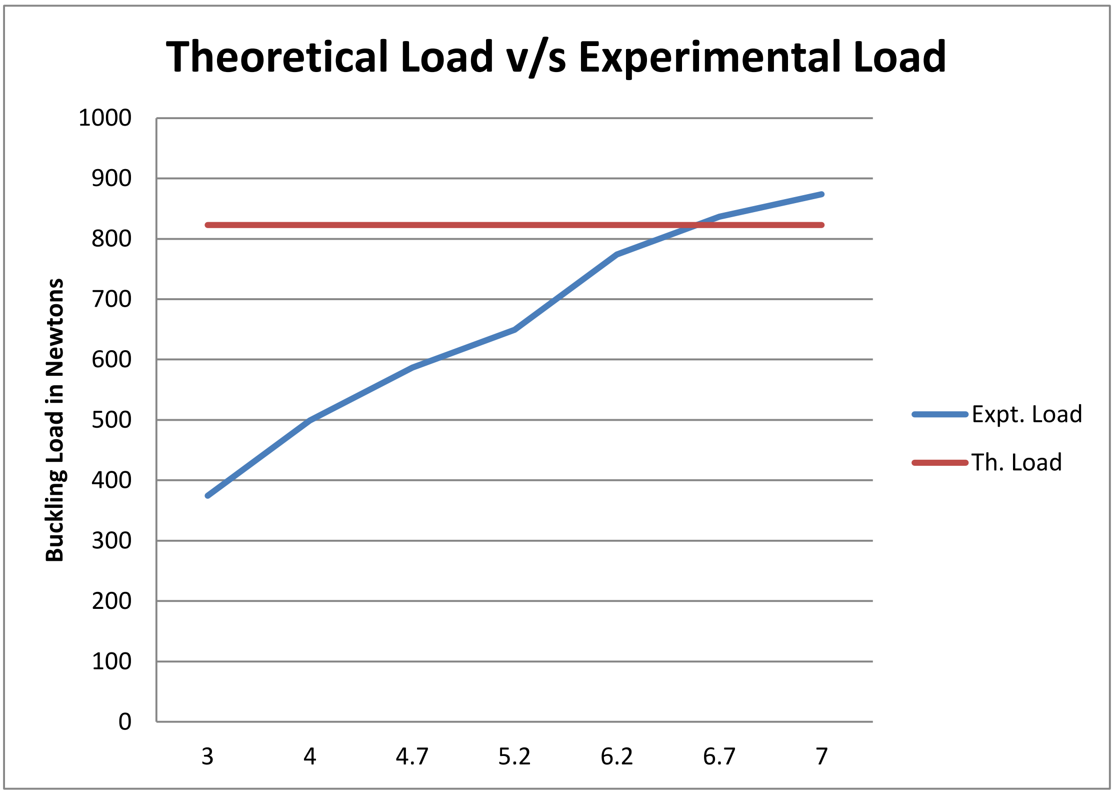

Figure 5: Comparison of Theoretical Buckling Load with Experimental Buckling Load

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Ethical statement: The authors declare that they have followed ethical responsibilities.

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