Buckling Analysis of Inflatable Cylinder by using Experimental Setup

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Abstract: Inflatable structures belong to the family of tensile structures. Tensile structures are membrane like structures which require pre-stressing in order to sustain externally applied compressive loads. The pre-stressing is achieved by means of a pressure differential over the skin. In this paper, an inflatable cylinder is considered for analytical and experimental analysis and the cylinder is studied for its behavior for different cases of load application. In past, MATLAB codes were developed considering the beam to be constrained as hinged at one end and simply supported at the other. Parameters like buckling, deflection, wrinkling and stress-strain relationships of the cylinder were studied. In this paper buckling analysis of inflatable cylinder is carried out. The result obtained by experimental method is compared with the analytical results.

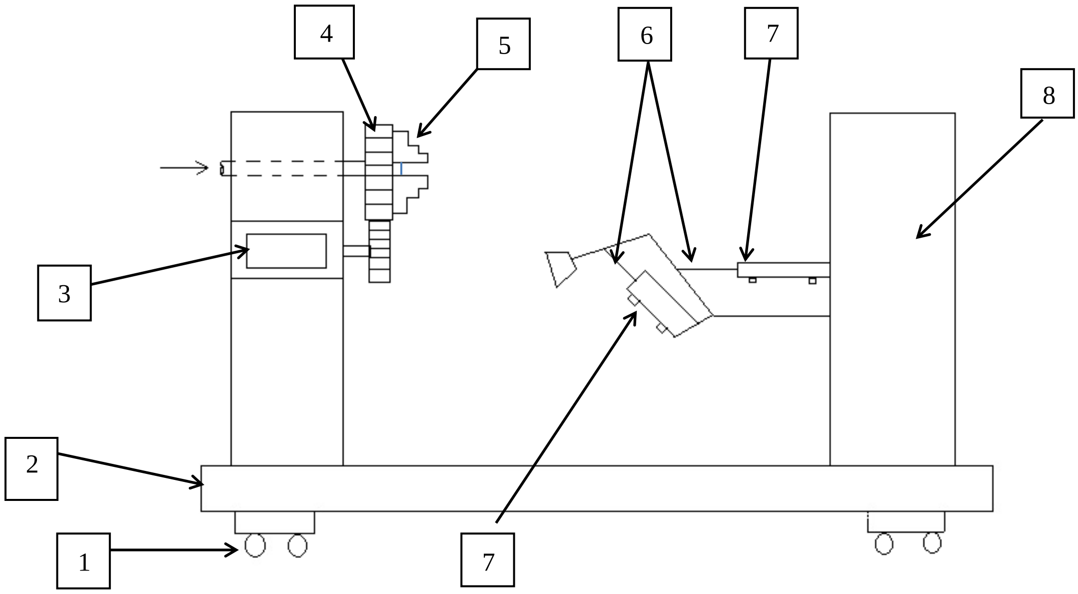
Keywords: Inflatable cylinder; Buckling; MATLAB; Stress; Experimental method

I. INTRODUCTION

In this paper, the buckling analysis of the beam is carried out using experimental setup. The results 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. In this research work experimentation is carried out to demonstrate the buckling of an inflatable cylinder which can also be used to demonstrate the twisting, torsion, elongation, compression and bending of the cylinder. Finally, the results are validated and comparison is made with the analytical results.

II. WORKING OF EXPERIMENTAL SETUP

From Figure 1 it can be seen that the left driver is used for twisting through stepper motor drive which will drive a chuck through gears in predefined steps to demonstrate the twisting effects on an inflatable cylinder. As a result of this twisting, torsional stress effects will be developed in the membrane and can be studied for maximum and minimum stresses that the material can handle. Right driver is used for the application of tension and compression on the inflatable cylinder with the help of the top pneumatic cylinder that will be run by a compressor and the one below it, is used for bending.



1. Wheel, 2. Base, 3. Steeper Motor, 4. Gear, 5. Chuck, 6. Piston Rod, 7. Pneumatic Cylinder, 8. Column

Figure 1: Schematic Diagram of Experimental Setup

III. 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

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

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

- 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

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

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

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

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

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

$$p = 654869.8\ N/m^2$$

$$p = 6.5487\ kgf/cm^2$$

Minimum tensile force

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

$$= 823.04\ N \quad \text{................................ Theoretical Buckling Load}$$

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)

IV. COMPARISON OF RESULTS

Table II: Result Comparison

Sr. No.	*Parameters*	*Analytical (N)*	*Experimental (N)*	*Percentage Variation*
01.	Buckling Load	823.04	773.96	5.96%

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.

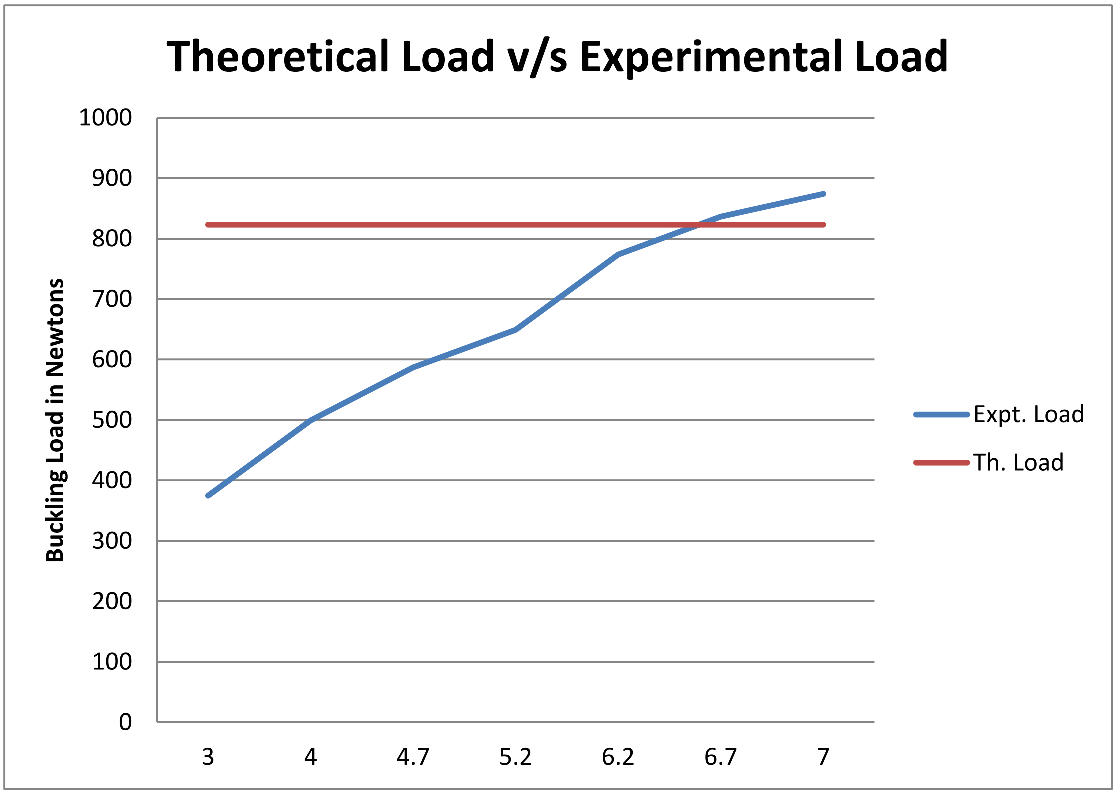


Figure 2: Comparison of Theoretical Buckling Load with Experimental Buckling Load

From figure 2 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.

V. CONCLUSIONS

From the literature survey it is concluded that enough experimental data is not available for inflatable structures. Therefore, validation in finite element analysis is not possible. Hence, study started with need of development of experimental setup for cylindrical inflatable structures. After developing an experimental setup for cylindrical inflatable structures, experimentation is carried out to determine the buckling load capacity. Finally, results obtained from experimentation for buckling load closely matches with analytical result with error less than 6%. This suggests that buckling load of magnitude 823 N initiates buckling.

VI. REFERENCES

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