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Dynamic and Parametric Analysis of Membrane Structures

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Abstract

This study presents the Dynamic Analysis of thin membranes with different parameters. Membranes are used in various fields like aerospace, medicine, etc. It is essential to study their vibration characteristics. Modal analysis of flat pre-stressed membranes is carried out using finite element analysis tool ANSYS and the results are compared with Theoretical Calculations. A Good match between the two solutions was observed. Furthermore, vibration analysis of membranes with varying parameters was carried out, the results are studied and significant conclusions are drawn.

Keywords— Mode shapes, Vibrations, Modal Analysis, Natural Frequency.

Introduction

A membrane is thin shell structure with no bending stiffness. Hence a membrane cannot resist any compression at all. However, membrane theory accounts for tension and compression stresses. In membrane theory only the in-plane stress resultants are taken into account. This study presents the modal analysis for predicting the behavior of various shaped thin membranes of various materials which are optimally subjected to pre-stress to render them to behave as structural members rather than bending or moments.

Membrane materials

Table1: Properties of membrane materials (Ruggiereo etal 2003, Srivastava et al 2008).

Sl no	Name of the Material	Mass Density [kg/m^3]	Young's Modulus [N/m^2]	Poisson's ratio
1	Kevlar	790	11.9x10^9	0.3
2	Kapton	1420	2.5 x 10^9	0.34
3	Mylar	1390	8.81 x 0^9	0.38
4	PVDF	1780	2.8x10^9	0.32

Free Vibrations of Rectangular Membranes

A rectangular membrane with plane form dimensions $a \times b$ is shown in Figure. 1. Assume that uniform tension is applied to it in all directions, so that free vibrations are governed by the equation of motion. To determine the natural frequencies and mode shapes, we will proceed in the usual manner, that is, a solution to will first be found, and then the boundary conditions will be applied.

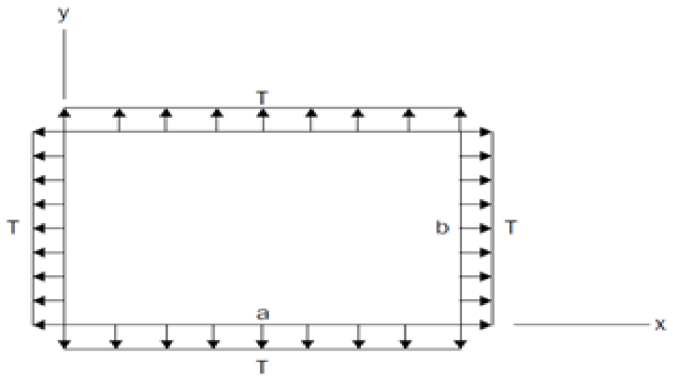


Figure: .1 Rectangular membrane subjected to equal tension in all directions.

Using the method of separation of variables, a solution to is assumed in the form

$w(x, y,t) = X(x) * Y(y) * \Phi(t)$

Substituting this into wave equation, and dividing by $XY\Phi$ results in

$$\frac{X''}{X} + \frac{Y''}{Y} = \left(\frac{\rho h}{T}\right)\frac{\Phi''}{\Phi}$$

Each of the three terms is a function of a different variable (x,y, or t), therefore, the only way in which this equation may be valid is if each term is equal to a constant. Let these constants be $-\alpha^2$, $-\beta^2$, and $-\gamma^2$. Then

$$X'' + \alpha^2 X = 0$$

$$Y'' + \beta^2 X = 0$$

$$\Phi'' + \left(\frac{T}{\rho h}\right)\gamma^2\Phi = 0$$

And

$$\alpha^2 + \beta^2 = \gamma^2$$

In anticipation of the solution form, replace $(T/\rho h)\gamma^2$ by the constant ω^2, which will be, of course, the circular frequency. Solutions are then

$$X = A\sin\alpha x + B\cos\alpha x$$

$$Y = C\sin\beta y + D\cos\beta y$$

$$\Phi = E\sin\omega t + F\cos\omega t \qquad \text{where} \qquad \alpha^2 + \beta^2 = \left(\frac{\rho h}{T}\right)\omega^2$$

Boundary conditions where all edges are fixed will be considered.

The boundary conditions are therefore

$w(0, y,t) = w(a, y,t) = w(x,0,t) = w(x,b,t) = 0$

hence

$X(0) = X(a) = Y(0) = Y(b) = 0$

Substituting this into solution, gives $B = D = 0$ and In non-dimensional form,

$$\lambda = \omega a\sqrt{\frac{\rho h}{T}} = \pi\sqrt{m^2 + \left(\frac{a}{b}\right)^2 n^2} \qquad (m, n = 1,\ 2,\ 3, \ldots, \infty)$$

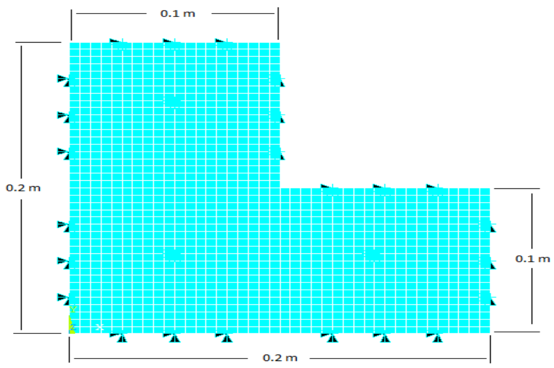
It is seen that the non-dimensional frequency parameter λ, depends on the aspect ratio (*a*/*b*) of the membrane and that, for any *a*/*b*, there is a doubly infinite set of frequencies depending on the choices of m and n. Different analytical methods can be used for membranes of different shapes.

Results and Discussion

Modal analysis of membranes of various shapes

L-shaped membrane (S.C. Gajbhiye, S.H. Upadhyaye and S.P.Harsha)

Dimensions and Parameters



Young's Modulus : 11.9×10^9 N/m^2

Poisson's ratio : 0.3

Thickness : 0.1 mm

Density : 790 kg/m^3

Pre-stress Applied : 10 N/m^2

No. of Elements : 1600

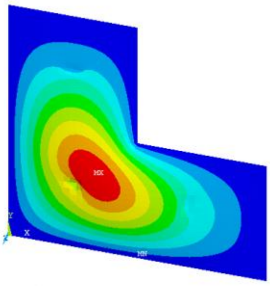
Boundary Conditions : The Membrane is fixed on all the edges.

Mode Frequencies and Shapes

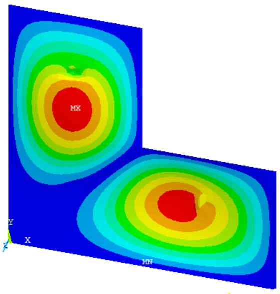
Table: 2 Natural frequencies of a L-shaped membrane

Mode No.	Natural Frequency (Hz)
1	54.210
2	67.610
3	75.682
4	90.057
5	91.584
6	108.150

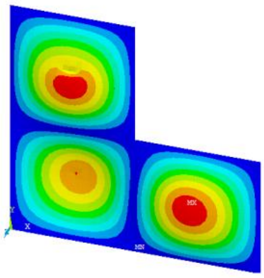
Mode I



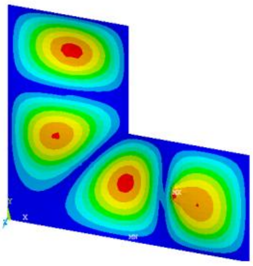
Mode II



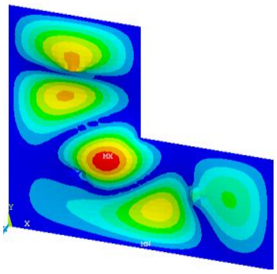
Mode III



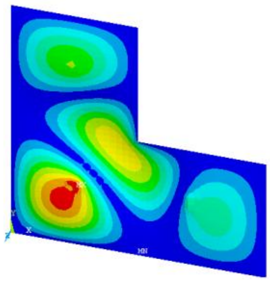
Mode IV



Mode V



Mode VI



Elliptical membrane

Dimensions and parameters

Major axis : 1.5 m

Width : 1.0m

Thickness : 0.1 mm

Young's Modulus : 11.9×10^{9} N/m^2

Poisson's ratio : 0.3

Density : 790 kg/m^3

Pre-stress Applied : 10 N/m^2

No. of Elements : 1600

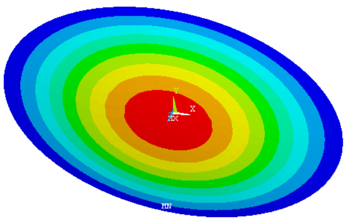
Boundary Conditions : The Membrane is fixed on all the edges.

Table:3 Natural frequencies of an elliptical membrane

ModeL No.	Natural frequency in Hz (Ansys)
1	18.284
2	28.181
3	31.771
4	34.530
5	39.002
6	43.145

Mode shapes obtained from ANSYS

Mode I



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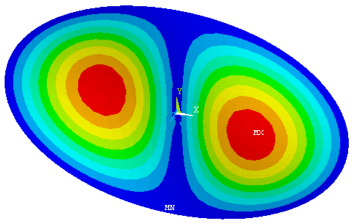
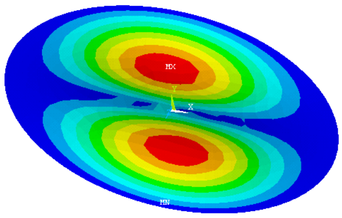
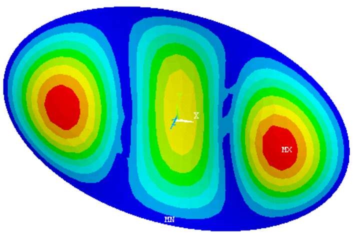


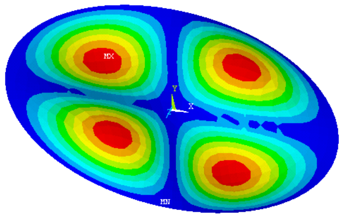
Mode III



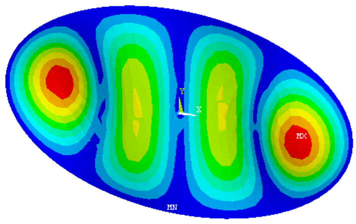
Mode IV



Mode V



Mode VI



Conclusions and Scope for future work

The geometric modeling and Analysis of inflatable structures *viz* membranes was carried out and variation of natural frequencies and mode shapes with respect to varying parameters were shown. In future, the harmonic analysis can be carried out. More studies can be made for specific applications. Different FEA tools like ABAQUS can be used for more dynamic visualization of modes. Based on the present work the membrane structures can be designed for optimal vibrations. Also, studies can be taken up for varying temperature conditions like cryogenic temperatures and very high temperatures.

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