

Parametric study on the structural forces and the moments of cylindrical shell roof using ANSYS

Ashique Jose¹, Ramadass S² and Jayasree Ramanujan¹

¹Civil Engineering Department, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

²Division of Civil Engineering, Cochin University of Science and Technology, Kochi-682 022, Kerala, India

Abstract: - This paper deals with the influence of various parameters on the structural forces and the moments developed on the surface of cylindrical shell roofs. The parameters considered in this study are thickness to radius ratio (t/R), length to radius ratio (l/R) of a single cylindrical shell roof. The radius is made constant and is equal to 9.0m. The length of the shell is varied between 26m and 46m. The thickness of the shell is varied from 65 mm to 85mm. The structural forces and the moments developed in cylindrical shell roof are predicted using the model proposed by ANSYS 12.0 software. The results of the study give an insight to the range for the magnitude of the various parameters to be considered for the optimum performance of single cylindrical shell roof.

Keywords: - Cylindrical shells, membrane forces, moments, parameters

I. INTRODUCTION

Shells are produced by a straight line generator, moving over a given curve (directrix) at its two ends. Different shapes can be made, namely, circular cylindrical shell, hyperbolic shell, elliptic shell and catenary shell etc. Circular cylindrical shells are widely used in practice for roof structures. A novel method of generating stiffness matrices for axisymmetric thin plate and shell elements with special reference to an annular plate element is introduced by Bhatia and Sekhon (1995). Donnell-type of shell equations had been applied by Batdorf (2004) to predict the critical loads of cylindrical shell structures. Angalekar and Kulkarni (2011) conducted parametric studies on the linear elastic behavior of concrete cylindrical shell roofs using finite element analysis, wherein, 4 noded flat plate elements with increment load technique had been used. Limited studies have been reported on the influence of length of cylindrical shell, radius of the shell, and thickness of the shell on the membrane forces and the moments developed on the surface of cylindrical shell roofs.

Cylindrical shells can be analyzed by classical methods, namely membrane theory and bending theory. The cylindrical shells can also be analyzed by numerical methods. The classical methods proposed by bending theory have been considered for the manual analysis. The numerical method proposed by ANSYS software has been considered for the computer analysis.

In this paper, a typical cylindrical shell roof of standard dimension adopted in practice has been considered. The structural shell forces and the moments developed on the surface of cylindrical shell roof are predicted using the model proposed by bending theory. The numerical analysis is carried out using ANSYS 12.0 software. The results obtained from the classical method are compared with the corresponding results obtained from the numerical method. The comparison is done to check the degree of accuracy of the application of ANSYS software for further parametric study. In this paper, the influence of various parameters, namely, length to radius ratio (l/R) and thickness to radius ratio (t/R) of a single cylindrical shell roof on the structural shell forces and the moments developed on the surface of cylindrical shell roofs have been reported. The parametric study is carried out using ANSYS software.

II. ANALYTICAL MODEL

2.1 Bending theory

The bending theory of analysis of cylindrical shell is considered. Shell parameters are calculated using the general equations for bending analysis. Particular integral and complementary functions involved in the analysis of shell are calculated for computing the structural shell forces acting per unit length (N_x , N_y and N_{xy}) and the moments developed per unit length (M_x , M_y , M_{xy}) over the surface of the shell.

$$N_x = \left\{ \frac{2DR\alpha_m^4}{\epsilon^3} \cos \alpha_m x \right\} + \left\{ -\frac{1}{\alpha^2 R} (H3 + 2)g1 \right\} \quad (1)$$

$$N_y = \left\{ -\frac{2DC}{\epsilon^2} \cos \alpha_m x \right\} + \left\{ -\frac{1}{\alpha^2 R} (H3 + 2)g - R(H3 + 2)g1 \right\} \quad (2)$$

$$M_x = \left\{ -D\alpha_m^2 \cos \alpha_m x \right\} + \left\{ -D \left[\alpha^2 + \frac{\nu}{r^2} \right] Cg1 \right\} \quad (3)$$

$$M_y = \left\{ \frac{D}{R^2} \cos \alpha_m x \right\} + \left\{ -D \left[\nu\alpha^2 + \frac{1}{r^2} \right] Cg1 \right\} \quad (4)$$

$$D = \left\{ \frac{Eh^3}{12(1 - \nu^2)} \right\} \quad (5)$$

$$C = \left\{ \frac{(\alpha_m R)^4 + (4 + \nu)\alpha^2 R^2 + 2}{(1 + \alpha_m^2 R^2)^4 + (R^6[1 - \nu^2]) \left(\frac{12\alpha_m^4}{h^2} \right)} \right\} \quad (6)$$

$$H_3 = \frac{CD}{R^4} \{ (1 + \alpha_m^2 R^2)^4 \} \quad (7)$$

Where R is the radius of the shell, α_m , ν , ν are the shell parameters, g is the dead load of the shell.

2.2 ANSYS software model

ANSYS provides solutions to many types of analyses problems including structural, thermal, linear buckling and shape optimization studies. ANSYS is an intuitive mechanical analysis tool that allows geometry to be imported from a number of different CAD systems. It can be used to verify product performance and integrity from the concept phase through the various product design and development phases. Detail of the shell element used is given. In this paper, ANSYS12.0 is used for the analysis.

2.2.1 Element details, shell 63

Shell 63 has been used as the element in the computer analysis. It has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. Stress stiffening and large deflection capabilities are included. The geometry, node locations and the coordinate system for Shell 63 are given in Fig.1. The element is defined by four nodes, four thicknesses, elastic foundation stiffness, and the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in coordinate Systems. The element x-axis may be rotated by an angle THETA (in degrees). The thickness is assumed to vary smoothly over the area of the element, with the thickness input at the four nodes. If the element has a constant thickness, only TK(I) need be input. If the thickness is not constant, all four thicknesses must be input.

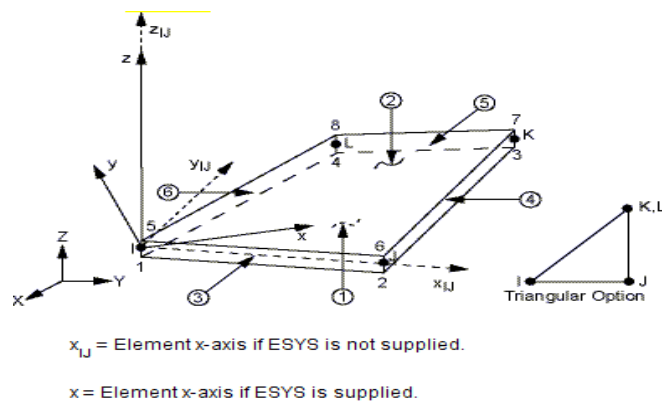


Fig.1 Shell 63

III. DETAILS OF CYLINDRICAL SHELL ROOF FOR THE ANALYSIS

A circular cylindrical shell roof of standard dimension adopted in practice has been considered and is given in Fig.2. All dimensions given in Fig. 2 are in meters. The length (l) of the shell is assumed as 36m. The radius of the shell assumed is 9m. The thickness of the shell assumed is 75mm. The semi central angle is assumed as 40 degrees. The live load on the roof is assumed as 2500 kN/m². The grade of concrete assumed is M25. The structural shell forces per unit length and the moments developed per unit length on the concrete shell roof are predicted using the models proposed by bending theory of analysis(classical method) and by the numerical method using ANSYS software. The results obtained from the bending theory of analysis are compared with the corresponding results obtained from the numerical analysis.. The structural forces and the moments developed on the concrete shell roof are computed at various sections of the shell roof ranging from zero to 18m measured from the mid span location of the shell roof. From the theoretical study, it is observed that the computed structural forces and moments are almost found to be equal in magnitude at the location of 15 m measured from the mid span location. The comparison of results at this location of 15 m is given in Table 1. The comparison indicates that the prediction by the numerical model is in agreement with limited variations when compared with the prediction proposed by bending theory of analysis. This indicates that the application of shell element 63 in ANSYS software is valid for further parametric studies at the cross section of shell roof at 15m measured from the mid span location Table.2. Transverse moments at joints using Simpson’s method and numerical method

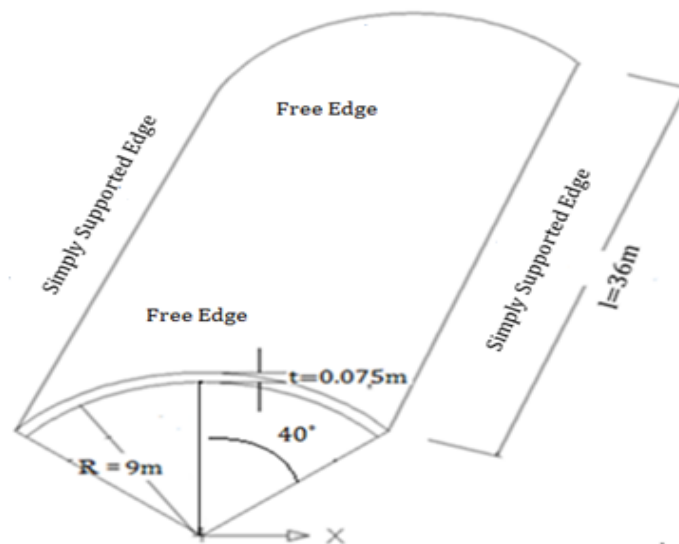


Fig.2. Details of cylindrical shell roof

Table 1. Structural forces and the moments computed using classical method and numerical method

Final stresses and moments (Classical method)						
Angle in Degrees	Forces(kN)			Moments(kNm)		
	N _x	N _y	N _{xy}	M _x	M _y	M _{xy}
0	-11280	6825	486	19.26	-.2569	-290.81
10	-10920	6105	-836.45	-78.56	44.536	98.65
20	-9826	5219	-632.56	-93.65	42.39	140.69
30	11056	-2820	250.8	-119.24	36.89	60.98
40	13497	0	124.86	-104.36	0	-110.68
Final stresses and moments (Numerical Method)						
Angle in Degrees	Forces(kN)			Moments(kNm)		
	N _x	N _y	N _{xy}	M _x	M _y	M _{xy}
0	-10180	7109	288.42	13.587	-0.11124	-255.57
10	-10306	5926.8	-620	-60.771	37.576	57.46
20	-11524	4708.2	-420.46	-83.269	35.864	110.95
30	12664	-2669	126.02	-94.325	23.284	18.692
40	12917	0.028	78.433	-89.998	0	-85.921
Ratio of variation of results(Numerical solution/Classical Solution)						
Angle in Degrees	Forces(kN)			Moments(kNm)		
	N _x	N _y	N _{xy}	M _x	M _y	M _{xy}
0	0.902482	1.041612	0.593457	0.705452	0.433009	0.878821
10	0.943773	0.970811	0.741228	0.773562	0.843722	0.582463
20	1.172807	0.902127	0.664696	0.889151	0.846049	0.788613
30	1.145441	0.946454	0.502472	0.791052	0.631174	0.306527
40	0.957027	1.289388	0.628168	0.86238	0.348885	0.776301

IV. PARAMETRIC STUDY

The parametric study is carried out by assuming a typical cylindrical shell roof given in Fig.2. In Fig 2, L is the length of the cylindrical shell roof, R is the radius of the shell, t is the thickness of the shell and θ is the semi central angle. The influence of various parameters, namely, length to radius ratio (L/R) and thickness to radius ratio (t/R) of a single cylindrical shell roof on the structural shell forces acting per unit length (N_x, N_y, N_{xy}) and the moments (M_x, M₀, M_y, M_{x0}) developed per unit length on the surface of cylindrical shell roofs have been reported. The parametric study is carried out using ANSYS software.

4.1 Influence of t/R ratio on the structural forces and the moments

The influence of the ratio of thickness (t) of the shell to the radius (R) of the shell, t/R of cylindrical shell roof is analyzed. The length of the shell (l) is made constant and is equal to 36m. The radius of the shell (R) is made constant and is equal to 9.0 m. The semi central angle is made constant and is equal to 40 degrees. The thickness of the shell (t) is varied from 65 mm to 85 mm. Hence the value of t/R ratios ranges from 0.0072 to 0.0094. The structural shell forces (N_x, N_y and N_{xy}) and the moments (M_x, M_y and M_x) developed on the surface of the shell are predicted at various locations of the angles ranging from zero degrees to 40 degrees using the model proposed by ANSYS software. The predicted values of structural forces N_x, N_y and N_{xy} and the moments M_x, M_y and M_{xy} are plotted and are given in Fig.3 and Fig. 4 respectively.

4.2 Influence of t/R on the structural forces (Nx,Ny and Nxy)

The influence of t/R ratio on the structural forces Nx,Ny and Nxy are discussed. The predicted values of structural forces Nx,Ny and Nxy are plotted and are given in Fig.3.

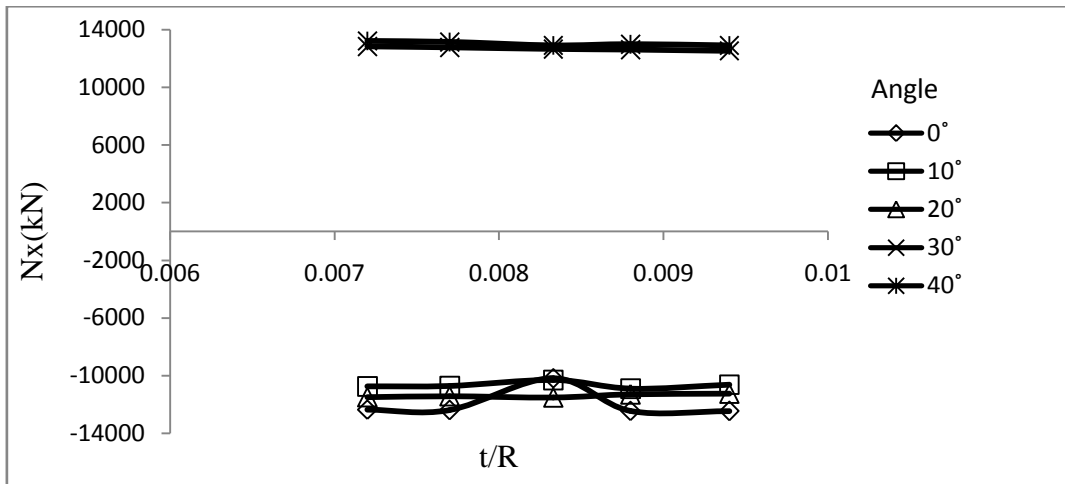


Fig.3 (a) Influence of t/R on Nx,Ny and Nxy

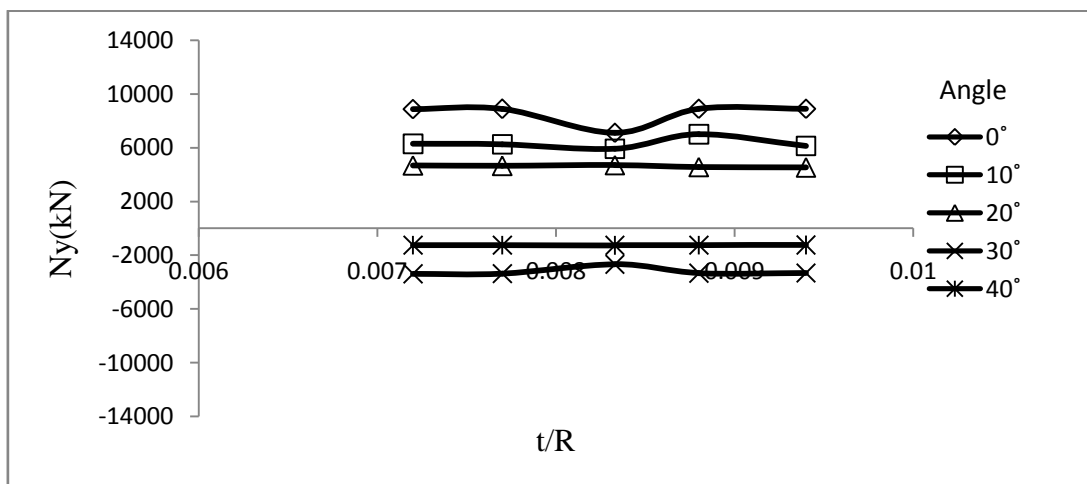


Fig.3 (b) Influence of t/R on Nx,Ny and Nxy

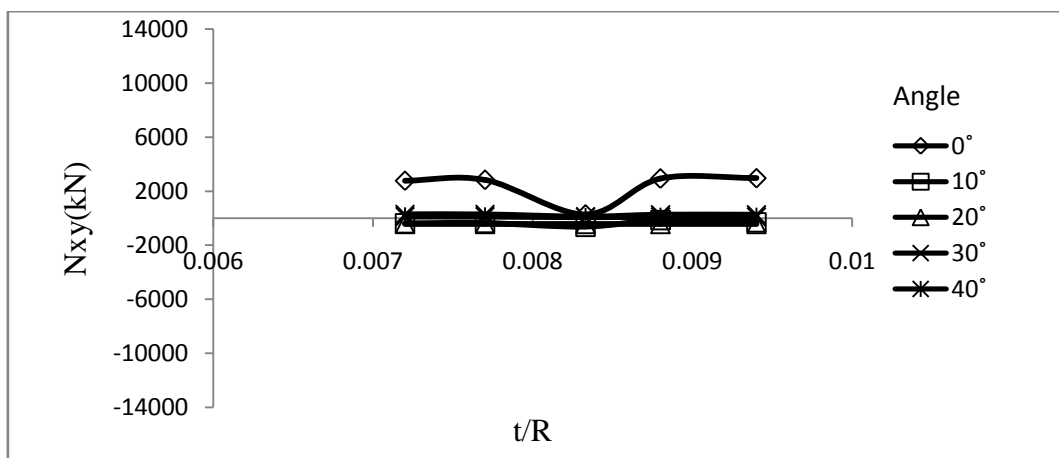


Fig.3(c) Influence of t/R on Nx,Ny and Nxy

4.2.1 Influence of t/R on N_x

The influence of t/R ratios ranging from 0.0072 to 0.0094 on the structural force N_x developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees (at center) are given in Fig 3(a). From Fig 3(a), it is found that when the values of t/R ratio increases, the value of N_x is found to be remains constant at each of the locations of the angles of shell roof except for the location of shell roof at zero degree (at the end). At the location of zero degree angle, the value of N_x is found to be constant for all values of t/R ratios except at t/R equal to 0.0085, where in the N_x value is found to be maximum. The value of N_x is found to be equal in magnitude and tensile in nature at the locations of 30 degrees and 40 degrees. The value of N_x is found to be compressive in nature at the locations of angles ranging from zero degree and 20 degrees. The value of N_x compressive in nature is found to be minimum at t/R equals 0.0085 at the location of angle equal to 10 degrees. When t/R equals 0.0085, the value of N_x compressive in nature is found to be minimum and equal in magnitude for zero degree and 10 degrees locations.

4.2.2 Influence of t/R on N_y

The influence of t/R ratios ranging from 0.0072 to 0.0094 on the structural force N_y developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees (at center) are given in Fig 3(b). From Fig 3(b), it is found that as the values of t/R ratio increases, the value of N_y is found to be remains constant at each of the locations of the angles of shell roof except for the location of shell roof at zero degree (at the end) and 30 degrees. The value of N_y is found to be constant for all values of t/R ratios, at the locations of zero degree and 30 degree angles, except at t/R equal to 0.0085, where in the N_x value is found to be minimum. The value of N_y is found to be tensile in nature at the locations of angles ranging from zero and 20 degrees. The value of N_y is found to be higher in magnitude and tensile in nature at the location of zero degree angle, when compared with the values of N_y at the locations of 10 degrees and 20 degrees. The value of N_y is found to be higher in magnitude and compressive in nature at the location of thirty degree angle, when compared with the values of N_y at the locations of 40 degree angle. The magnitude of tensile force N_y is found to be greater at the locations ranging from zero degree and 20 degrees when compared with the magnitude of compressive force N_y at the locations of 30 degrees and 40 degrees.

4.2.3 Influence of t/R on N_{xy}

The influence of t/R ratios ranging from 0.0072 to 0.0094 on the structural force N_{xy} developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees (at center) are given in Fig 3(c). From Fig 3(c), it is found that as the values of t/R ratio increases, the value of N_{xy} is found to be remains constant at each of the locations of the angles of shell roof except for the location of shell roof at zero degree (at the end). At the location of zero degree angle, the value of N_{xy} is found to be constant for all values of t/R ratios except at t/R equal to 0.0085, where in the N_x value is found to be minimum and is found to be zero. The value of N_{xy} is found to be equal in magnitude and almost found to be zero at the locations between 10 degrees and 40 degrees.

4.3 Influence of t/R on the moments M_x, M_y and M_{xy}

The influence of t/R ratio on the structural moments M_x, M_y and M_{xy} are discussed. The predicted values of structural moments M_x, M_y and M_{xy} are plotted and are given in Fig.4.

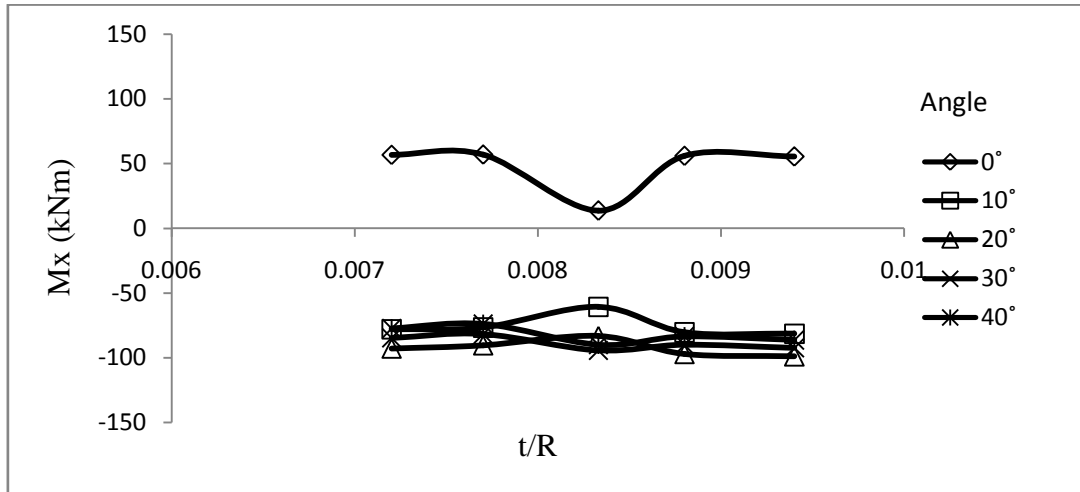


Fig.4 (a) Influence of t/R on M_x, M_y and M_{xy}

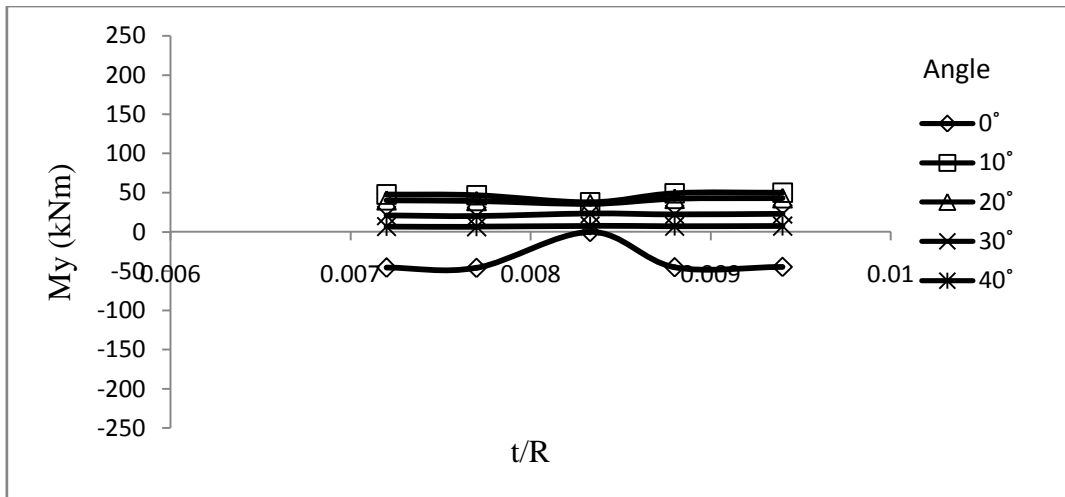


Fig.4 (b) Influence of t/R on M_x, M_y and M_{xy}

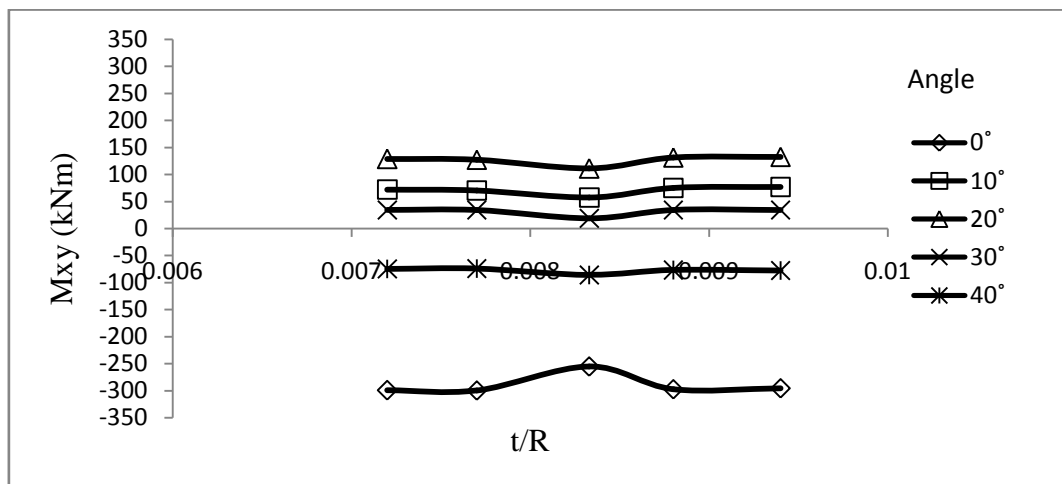


Fig.4 (c) Influence of t/R on M_x, M_y and M_{xy}

4.3.1 Influence of t/R on M_x

The influence of t/R ratios ranging from 0.0072 to 0.0094 on the structural moment M_x developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees(at center) are given in Fig

4(a). The value of M_x is found to be sagging in nature at the locations of zero degree. The value of M_x is found to be hogging in nature at the locations of angles ranging from ten degrees and 40 degrees. The value of M_x sagging in nature is found to be minimum when t/R is equal to 0.0085, at the location of zero degree. The value of M_x hogging in nature is found to be minimum when t/R is equal to 0.0085, at the location of 10 degrees and 20 degrees. The value of M_x hogging in nature is found to be maximum when t/R is equal to 0.0085 at the location of 30 degrees on the shell roof. The value of M_x sagging in nature at zero degree location and the value of M_x hogging in nature at 20 degrees locations are found to be higher in magnitude except at t/R equals 0.0085.

4.3.2 Influence of t/R on M_y

The influence of t/R ratios ranging from 0.0072 to 0.0094 on the structural moment M_y developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees (at center) are given in Fig 4(b). From Fig 4(b), it is found that when the values of t/R ratio increases, the value of M_y is found to be remains constant at each of the locations of the angles of shell roof except for the location of shell roof at ten degree. The values of M_y developed are found to be sagging for all the locations of angles ranging from zero degree and 40 degrees. The value of M_y is found to be higher in magnitude at the location of 10 degrees, when compared with values of M_y at the locations of other angles.

$W/D = 4.4$

4.3.3 Influence of t/R on M_{xy}

The influence of t/R ratios ranging from 0.0072 to 0.0094 on the structural moment M_{xy} developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees(at center) are given in Fig 4(c). From Fig 4(c), it is found that when the values of t/R ratio increases, the value of M_{xy} are found to be remains constant at thirty degrees. The value of M_{xy} is found to be higher in magnitude at the location of twenty degrees, when compared with values of M_{xy} at the locations of other angles. The value of M_{xy} is found to be less at the locations 10 degrees and 20 degrees when t/R equals 0.085. The value of M_{xy} is found to be more at the locations 40 degrees when t/R equals 0.085

4.4 Influence of l/R ratio on the structural forces and the moments

The influence of the ratio of length (l) of the shell to the radius (R) of the shell, l/R of cylindrical shell roof is analyzed. The length of the shell (l) is varied from 26 m and 46 m. The radius of the shell (R) is made constant and is equal to 9.0 m. The semi central angle is made constant and is equal to 40 degrees. The thickness of the shell (t) is made constant and is equal to 0.075mm. Hence the value of l/R ratios ranges from 2.88 to 5.11. The structural shell forces(N_x, N_y and N_{xy}) and the moments (M_x, M_y and M_{xy}) developed on the surface of the shell are predicted at various locations of the angles ranging from zero degrees to 40 degrees using the model proposed by ANSYS software. The predicted values of structural forces N_x, N_y and N_{xy} and the moments M_x, M_y and M_{xy} are plotted and are given in Fig.5 and Fig. 6 respectively.

4.5 Influence of l/R on the structural forces (N_x, N_y and N_{xy})

The influence of l/R ratio on the structural forces N_x, N_y and N_{xy} are discussed. The predicted values of structural forces N_x, N_y and N_{xy} are plotted and are given in Fig.5.

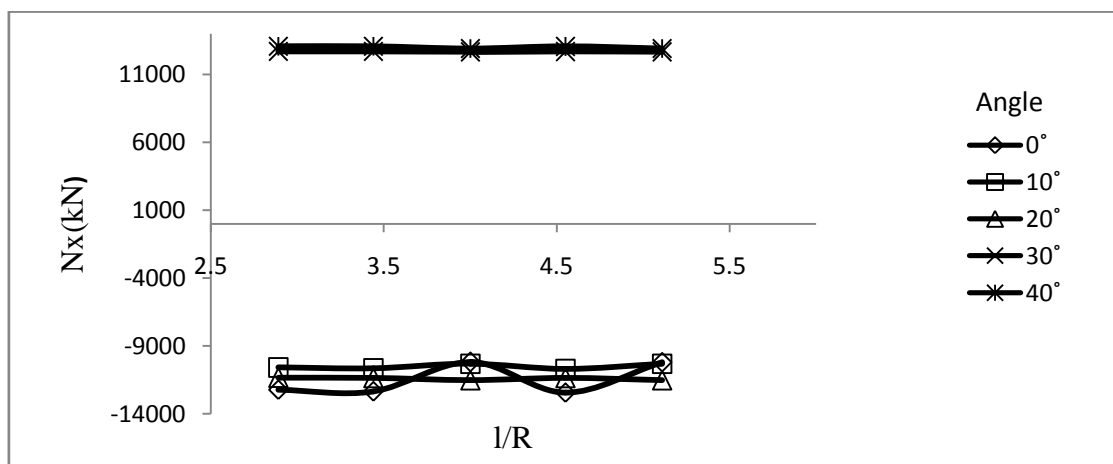


Fig.5 (a) Influence of l/R on N_x, N_y and N_{xy}

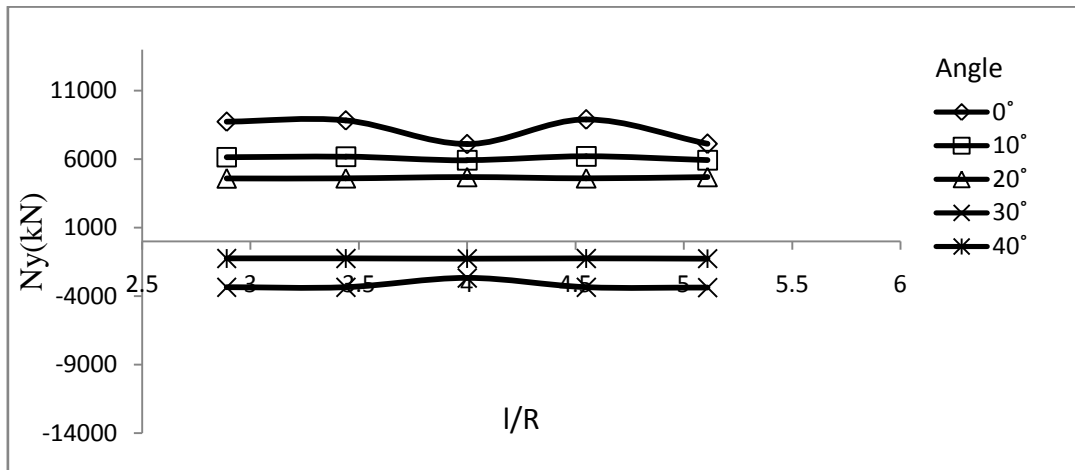


Fig.5 (b) Influence of l/R on Nx,Ny and Nxy

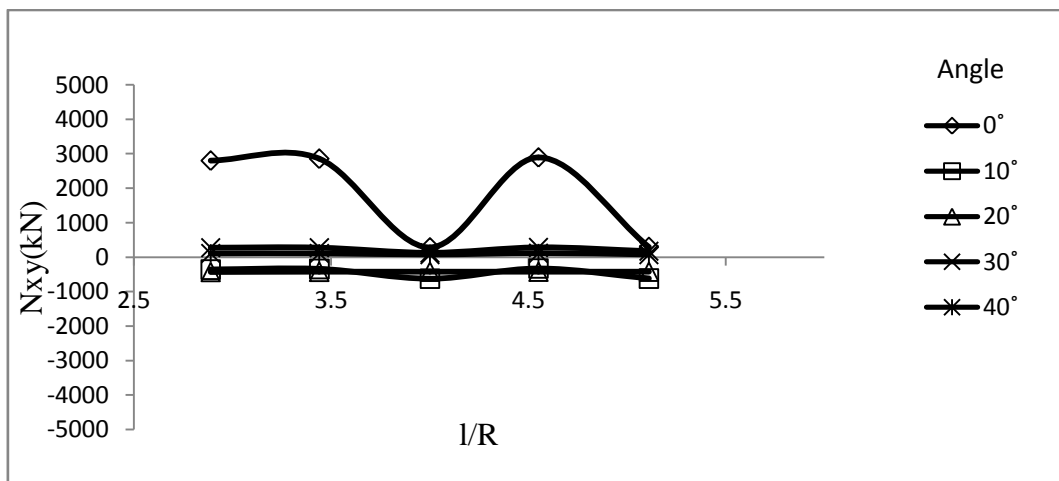


Fig.5(c) Influence of l/R on Nx,Ny and Nxy

4.5.1 Influence of l/R on Nx

The influence of l/R ratios ranging from 2.88 to 5.11 on the structural force Nx developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees(at center) are given in Fig 5(a). From Fig 5(a), it is found that as the values of l/R ratio increases, the value of Nx is found to be remains constant at each of the locations of the angles of shell roof except for the location of shell roof at zero degree(at the end). At the location of zero degree angle, the value of Nx is found be constant for all values of t/R ratios except at l/R equal to 4.0, where in the Nx value is found to be minimum. The value of Nx is found to be equal in magnitude and tensile in nature at the locations of 30 degrees and 40 degrees. The value of Nx is found to be compressive in nature at the locations of angles ranging from zero degree and 20 degrees.

4.5.2 Influence of l/R on Ny

The influence of l/R ratios ranging from 2.88 to 5.11 on the structural force Ny developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees(at center) are given in Fig 5(b). From Fig 5(b), it is found that as the values of l/R ratio increases, the value of Ny is found to be remains constant at each of the locations of the angles of shell roof except for the location of shell roof at zero degree(at the end) and 30 degrees. The value of Ny is found be minimum when l/R equals 4.0 for the locations at zero degrees and thirty degrees. The value of Ny is found to be tensile in nature at the locations of angles ranging from zero and 20 degrees. The value of Ny is found to be higher in magnitude and tensile in nature at the location of zero degree angle, when compared with the values of Ny at the locations of 10 degrees and 20 degrees. The value of Ny is found to be zero in magnitude at the location of forty degree angle. The value of Ny is found to be higher in magnitude and compressive in nature at the location of thirty degree angle.

4.5.3 Influence of I/R on Nxy

The influence of I/R ratios ranging from 2.88 to 5.11 on the structural force Nxy developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees(at center) are given in Fig 5(c). From Fig 5(c), it is found that when the values of I/R ratio increases, the value of Nxy is found to be remains constant at each of the locations of the angles of shell roof except for the location of shell roof at zero degree(at the end) and 40 degrees. At the location of zero degree angle, the value of Nxy is found be zero when I/R ratios is equal to 4.0. The value of Nxy is found to be equal in magnitude and almost found to be zero at the locations of 30 degrees and 40 degrees

4.6 Influence of I/R on the moments Mx, My and Mxy

The influence of I/R ratio on the structural moments Mx, My and Mxy are discussed. The predicted values of structural moments Mx, My and Mxy are plotted and are given in Fig.6.

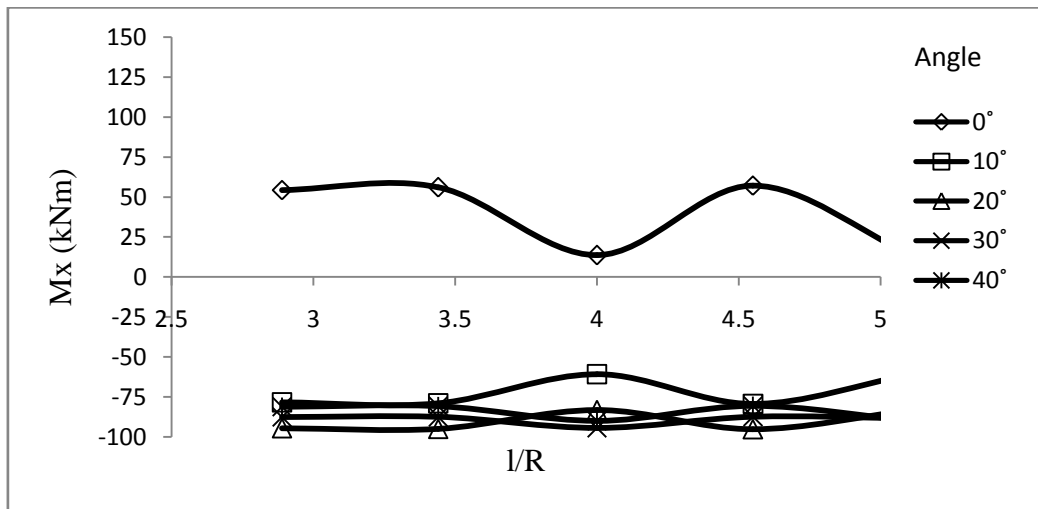


Fig.6 (a) Influence of I/R on Mx, My and Mxy

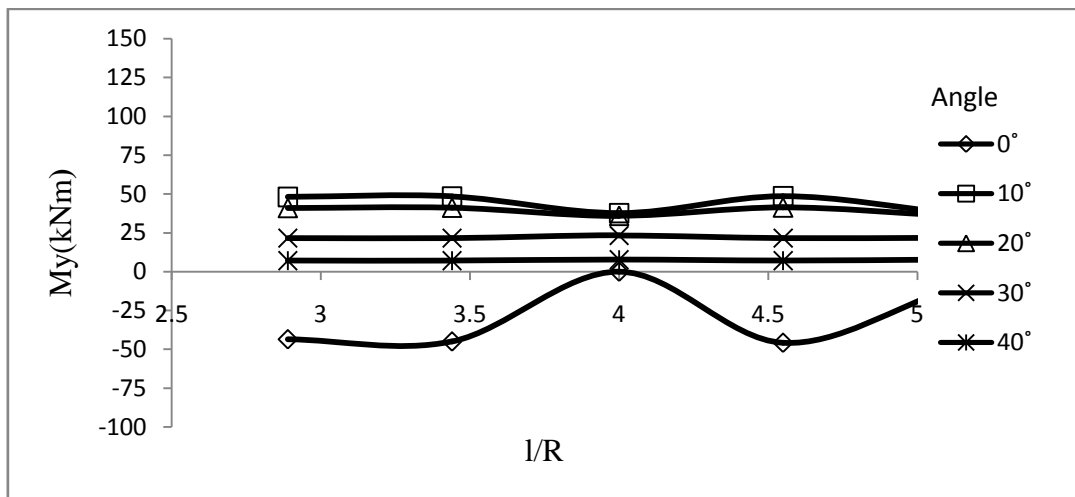


Fig.6 (b) Influence of I/R on Mx, My and Mxy

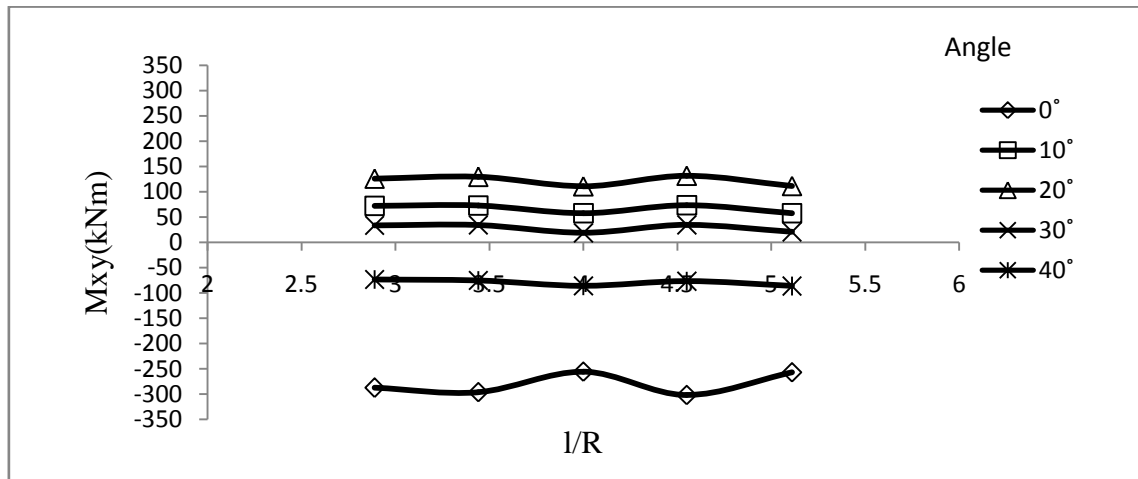


Fig.6 (c) Influence of l/R on Mx,My and Mxy

4.6.1 Influence of l/R on Mx

The influence of l/R ratios ranging from 2.88 to 5.11 on the structural moment Mx developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees(at center) are given in Fig 6(a). The value of Mx is found to be sagging in nature at the locations of zero degree. The value of Mx is found to be hogging in nature at the locations of angles ranging from ten degrees and 40 degrees. The value of Mx sagging in nature is found to be minimum when l/R is equal to 4.0 at the location of zero degree. The value of Mx hogging in nature is found to be minimum when l/R is equal to 4.0, at the location of 10 degrees and 20 degrees. The value of Mx hogging in nature is found to be maximum when l/R is equal to 4.0 at the location of 40 degrees on the shell roof. The value of Mx sagging in nature at zero degree location and the value of Mx hogging in nature at 40 degrees locations are found to be higher in magnitude except at l/R equals 4.0. The value of Mx hogging in nature is found to be in lower magnitude at ten degrees location.

4.6.2 Influence of l/R on My

The influence of l/R ratios ranging from 2.88 to 5.11 on the structural moment My developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees(at center) are given in Fig. 6(b). From Fig 6(b), it is found that when the values of l/R ratio increases, the value of My is found to be remains constant at each of the locations of the angles of shell roof except for the location of shell roof at zero degree and ten degree. The values of My developed are found to be sagging for all the locations of angles ranging from ten degree and 40 degrees. The value of My is found to be higher in magnitude at the location of 10 degrees, when compared with values of My at the locations of other angles, except at l/R equal to 4.0. The value of My is found to be zero in magnitude at the location of 40 degrees.

4.6.3 Influence of l/R on Mxy

The influence of l/R ratios ranging from 2.88 to 5.11 on the structural force Mxy developed at various locations of the shell ranging from zero degree (at the end) to 40 degrees(at center) are given in Fig 6(c). From Fig 6(c), it is found that when the values of l/R ratio increases, the value of Mxy is found to be almost remains constant at each of the locations of the angles of shell roof except for the location of shell roof at zero degree(at the end). At the location of zero degree angle, the value of Nx is found be constant for all values of l/R ratios except at t/R equal to 4.0, where in the Nx value is found to be maximum. The value of Mxy is found to be higher in magnitude at the location of twenty degree. The value of Mxy is found to be less when l/R is equal to 4.0 for all the locations ranging from zero degree and 40 degrees

V. CONCLUSIONS

Based on the parametric study, following conclusions are arrived at.

On the structural forces and the moments developed on the surface of cylindrical shell roofs. The parameters considered in this study are length to radius ratio (l/R) and thickness to radius ratio (t/R) of a single cylindrical shell roof. The radius is made constant and is equal to 9.0m. The length of the shell is varied between 26m and 46m. The thickness of the shell is varied from 65 mm to 85mm.

- The length, the radius and the thickness of the concrete cylindrical shell roof greatly influences the structural forces and the moments developed on the surface of cylindrical shell roofs.
- It is found that when the ratio of thickness of shell to the radius of the shell is equal to 0.0085, the structural forces and the moments developed on the surface of cylindrical shell roofs are found to be significant.
- It is found that when the ratio of length of the cylindrical shell to the radius of the shell is equal to 4.0, the structural forces and the moments developed on the surface of cylindrical shell roofs are found to be significant.
- When width to depth ratio is equal to 4.54, the longitudinal moment is found to be reduced and remains constant at all the joints.

The parametric study made in this paper is useful for the design engineers to arrive at economical sections of cylindrical shell roofs made of concrete.

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