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BUCKLING SAFETY ANALYSIS OF CYLINDRICAL SHELL ROOF WITH EDGE BEAM

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ABSTRACT

Cylindrical shell roofs are usually constructed to cover large column free areas. In the present work, a single span cylindrical shell with edge beam has been analysed and designed. The Schorer Theory for long shells has been used for the analysis. A computer programme using C language is developed for analysis and design. The buckling safety of cylindrical shells is also incorporated in the analysis.

Key words: Cylindrical shell, stress resultants, semi-central angle, buckling of shells, principal tension, elastic stability, crushing strength, shell reinforcement, cost of construction.

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1. INTRODUCTION

The structures with curved shapes can be called shells. The geometry of the shell is defined by the form of the middle surface and the thickness at every point. Shell is one whose thickness is small compared to other dimensions and its radii of curvature. Cylindrical shells are widely constructed due to its economy. Figure 1. shows the classification of Singly Curved Developable Shells[1].

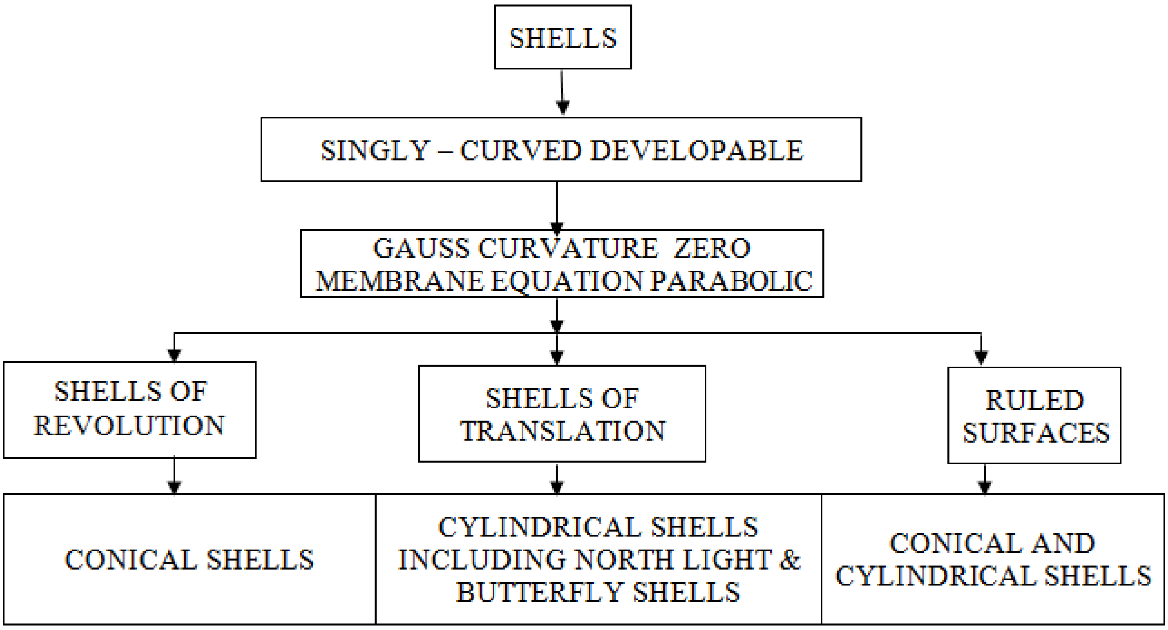

Figure 1 Classification of shells as per IS: 2210 – 1988

2. PRINCIPLE OBJECTIVE

The main objective of the present work is to design of a single span cylindrical shell roof with edge beams using The Schorer Theory, considering the shell buckling.

3. METHOD OF ANALYSIS AND DESIGN

Cylindrical shells with L/R ratio less than k will be analyzed using any of the accepted analytical methods listed in IS: 2210 – 1988. For long shells, The Schorer Theory is widely used analytical method. The Schorer Theory is applicable only to shells with $L/R \leq \pi$ [1].

The design part includes the design of shell, edge beams [2]. The design is done referring to the recommendations given in IS: 2210 – 1988 [1], IS: 2204-1962[4] and IS: 456 – 2000 [6]. A solid diaphragm traverse is also provided at the ends of the shell [5]. Loadings are considered as per IS: 875 (Part 2)-1987[7]. The detailing of the shell, edge beams and traverses may be done referring to SP: 34 – 1987 [8].

4. ELASTIC STABILITY OF SHELLS [3]

Owing to the non-linear stress-strain relationship and low tensile strength of concrete, it becomes necessary to use the empirical formulae derived from the results of tests on different types of cylindrical shells. For the types of shells where the stresses are low, the deformation in concrete will follow Hooke’s Law, both in tension and compression. The effect of straight edges appear to have little effect on the buckling characteristics and the theoretical critical stress may used for the determination of the buckling load.

For shells of comparatively large thickness, the load carrying capacity will depend mostly on crushing strength of the concrete and the risk of buckling is negligible. For intermediate range of the above cases, the stresses are increased by the risk of buckling and the load carrying capacity is less than the theoretical critical stress and also is less than the load corresponding to the ultimate crushing strength of concrete.

5. BUCKLING IN SINGLY CURVED SHELLS [1]

The permissible buckling strength f_p in cylindrical shells can be calculated as follows:

$$f_p = \frac{0.25\, F_c}{\left(1+\frac{F_c}{F_{cr}}\right)}$$

where: F_c is the cube strength at 28 days, F_{cr} = critical buckling stress determined in accordance with (a) , (b) and (c) below:

- Shells with ρ<7 and k<0.12 – in such shells, buckling is caused by excessive longitudinal compression near the crown of the shell and the critical buckling stress F_{cr} can be calculated as $F_{cr} = \frac{0.2\, ET}{R}$
- Shells with ρ>10 and k>0.15 – in such shells, the transverse stresses tend to be critical from the point of view of buckling and the critical stress F_{cr} can be calculated as follows:
  (i) For shells with L < $2.3\sqrt{RT}$, F_{cr} = E[3.4 (T/L)^2 + 0.025 (L/R)^2]
  (ii) For shells with L > $2.3\sqrt{RT}$, F_{cr} = E{[0.89 T/2 $\sqrt{T/R}$]}/(1-1.18 $\sqrt{TR/L}$)
- Shells with ρ values between 7 and 10 and k values between 0.12 and 0.15, if such case exists, depending upon whether longitudinal stresses or transverse stresses are critical from elastic stability considerations, (a) and (b) as above can be used.

6. C LANGUAGE CODE

C language code is written to analyse and design a single span cylindrical shell roof with edge beam for span of the shell, chord width, imposed load, grade of concrete and grade of steel as input values. The program gives the cost of construction when the material cost is fed as input data. For the verification of the stress resultants given by the computer programme various standard problems are considered.

7. NUMERICAL EXAMPLE

In the present work, a single span cylindrical shell with edge beam for span of the shell = 25 m, chord width = 9 m and depth of the edge beam = 1.5 m, imposed load = 0.65 kN/mm^2 and a semi-central angle = 35° is considered. The stress resultants and principal tensions at mid-span and quarter span are obtained for every increment of 2.5° of semi-central angle. However, the results obtained using computer programme at mid-span for Nx, Np and Mp and at traverse for Nxp for a semi-central angles of values 0°, 5°, 10°, 15°, 20°, 25°, 30° and 35° only are presented in Table 1 and Table 2. The results obtained by manual procedure are presented in Table 3 and Table 4. Comparison of weight of reinforcement, volume of concrete, area of formwork and cost comparison is given in Table 5.

8. RESULTS

8.1. Stress Resultants and Principal Tensions at quarter span and mid span from C language programme

Table 1 Final Stress Resultants

Φ (degrees)	**Nx (N/m) (at mid-span)**	**Nxp (N/m) (at traverse)**	**Np (N/m) (at mid-span)**	**Mp (Nm/m) (at mid-span)**
0	-55876.27	97612.84	-1252.46	0.001
5	-110756.13	90645.44	-7922.79	717.30
10	-150729.45	79785.82	-14006.96	702.06
15	-177883.52	66179.31	-19240.18	250.77
20	-194820.16	50776.90	-23442.75	-379.64
25	-204323.63	34304.82	-26503.21	-981.84
30	-208876.53	17269.04	-28359.07	-1404.47
35	-210190.78	0	-28980.55	-1555.62

Table 2 Principal Tensions

Φ (degrees)	**σ_1 (N/m) (at mid-span)**	**σ_2 (N/m) (at mid-span)**	**σ_1 (N/m) (at quarter-span)**	**σ_2 (N/m) (at quarter-span)**
0	51475.54	-91871.65	97612.84	-97612.84
5	31730.11	-115648.78	90645.44	-90645.44
10	16050.35	-132536.58	79785.82	-79785.82
15	3352.95	-142740.41	66179.32	-66179.31
20	-6737.32	-14759.88	50776.91	-50776.89
25	-14223.24	-148995.97	34304.82	-34304.81
30	-18895.23	-148855.67	17269.04	-17269.03
35	-20492.34	-148627.33	0.009	0.001

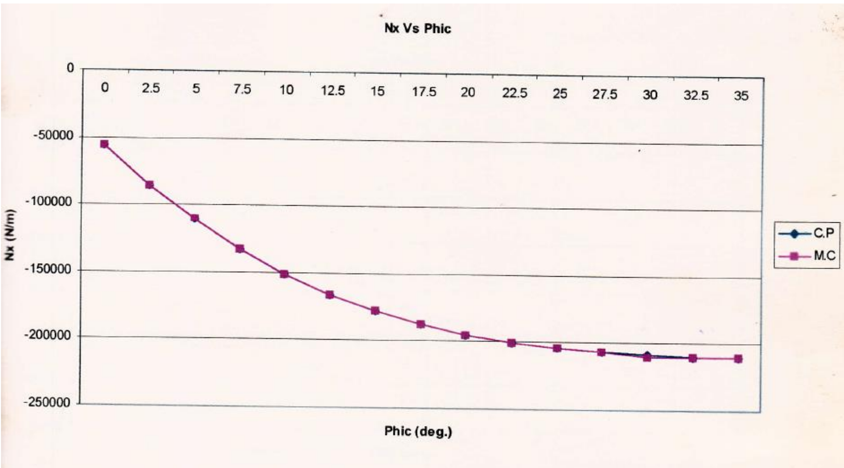

Figure 2 Variation of Longitudinal Stress Vs. Semi-central Angle

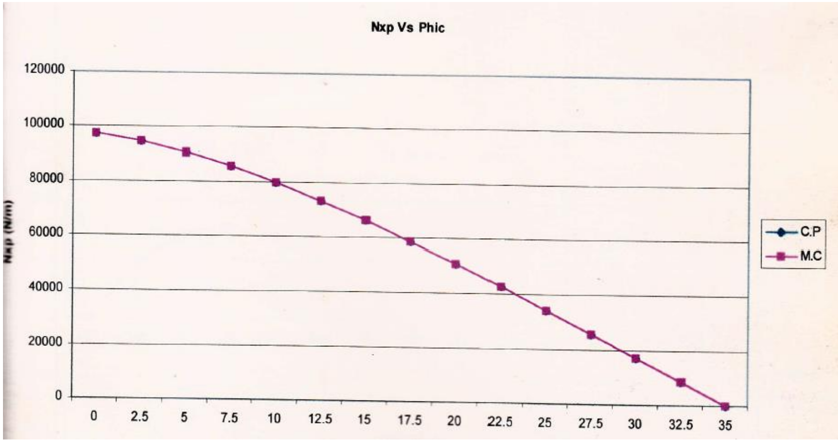

Figure 3 Variation of Shear Stress Vs. Semi-central Angle

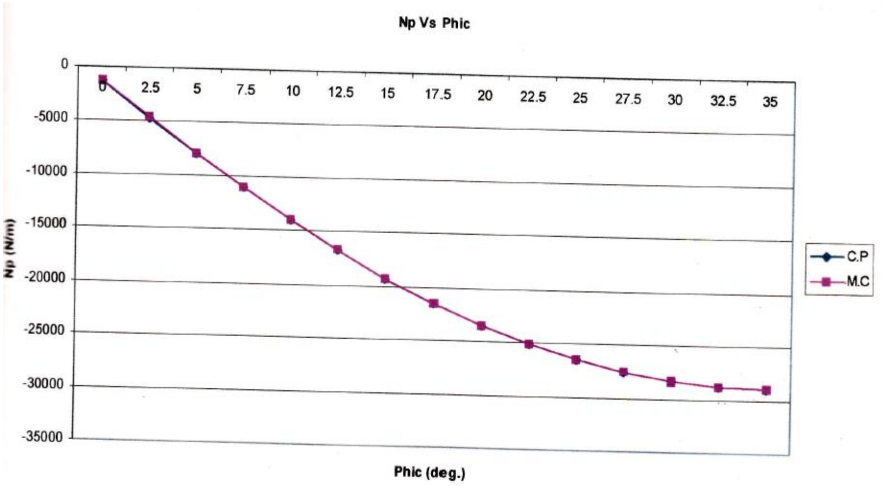

Figure 4 Variation of Transverse Stress Vs. Semi-central Angle

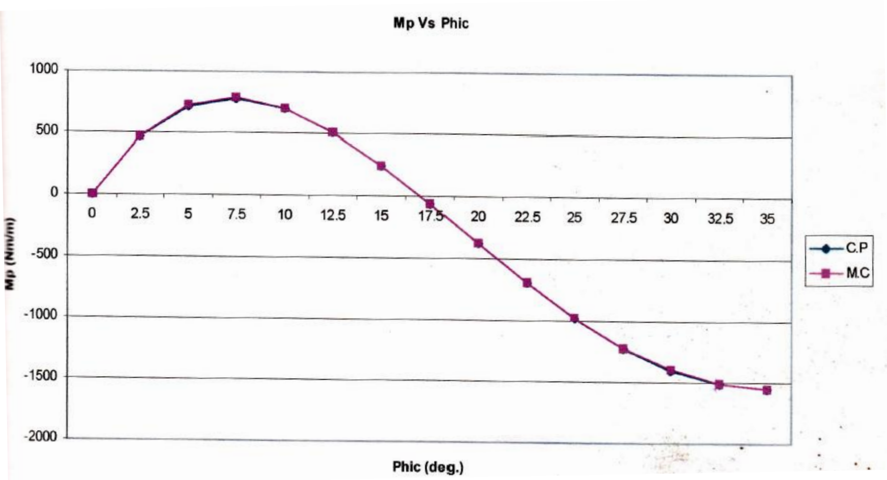

Figure 5 Variation of Transverse Moment Vs. Semi-central Angle

8.2. Stress Resultants and Principal Tensions at quarter span and mid span from manual calculations

Table 3 Final Stress Resultants

: Φ (degrees)	Nx (N/m) (at mid-span)	Nxp (N/m) (at traverse)	Np (N/m) (at mid-span)	Mp (Nm/m) (at mid-span)
0	-55866	97614	-1245	0
5	-110743	90643	-7913	721
10	-150731	79781	-14000	699
15	-177874	66168	-19248	251
20	-194818	50766	-23439	-376
25	-204319	34311	-26507	-982
30	-209869	17267	-28361	-1401
35	-210186	0	-28986	-1559

Table 4 Principal Tensions

Φ (degrees)	σ_1 (N/m) (at mid-span)	σ_2 (N/m) (at mid-span)	σ_1 (N/m) (at quarter-span)	σ_2 (N/m) (at quarter-span)
0	51481	-91866	97614	-97614
5	31733	-115645	90643	-90643
10	16048	-132540	79781	-79781
15	3353	-142742	66169	-66169
20	-6740	-147595	50766	-50766
25	-14225	-149011	34311	-34311
30	-18890	-148854	17267	-17267
35	-20495	-148630	0	0

8.3. Buckling Analysis Result

Maximum Compressive Force = 210190.78 N

Maximum Compressive Stress = 2.758 N/mm^2

Allowable Stress against Safe Buckling = 3.455 N/mm^2

Since Maximum Compressive Stress is less than Allowable Buckling Stress, the shell is safe against Buckling.

8.4. Comparison of weight of steel, volume of concrete, area of formwork and cost of construction

Table 5 Comparison of various items

Item	Member	Computer Programme	Manual Procedure
Weight of Reinforcement (in kgs.)	Shell	3167.07	3166.93
	Edge Beam	2550.82	2549.84
	Traverse	750.50	750.91
	Total	6468.39	6467.68
Item	Member	Computer Programme	Manual Procedure
Volume of Concrete (in m^3)	Shell	18.00	18.00
	Edge Beam	17.68	17.68
	Traverse	7.00	6.99
	Total	42.68	42.37
Item	Member	Computer Programme	Manual Procedure
Area of Formwork (in m^2)	Shell	236.23	236.24
	Edge Beam	138.94	138.94
	Traverse	36.49	36.20
	Total	411.66	411.38

Item	Member	Computer Programme	Manual Procedure
Total Cost of Construction (Rs.)	Shell Edge Beam and Traverse	Rs. 7, 54, 611.00	Rs. 7, 54, 547.00

9. DISCUSSIONS

Variations of stress resultants for single span cylindrical shell roof with edge beams and with end traverses obtained using manual procedure and by computer programme are presented from Fig. 2 to 5. The following conclusions can be drawn:

- There is a good match in the graphs drawn for stress resultants and there is not much difference in the results obtained from manual procedure and computer programme.
- The principal tensions values at quarter span and mid span are almost the same obtained through manual procedure and computer programme.
- For any input data given the computer programme checks for the safety of the shell in buckling. The computer programme gives warning in case of shell failure due to buckling and suggests changing the input values. This reduces the effort put into laborious manual calculations and saves time of a practicing engineer.
- The difference in cost of construction is very small and is negligible.
- The cost of construction of single shell roof with edge beam can be easily obtained for various possibilities of shell geometry and client constraints.

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