VOL. 13, NO. 12, JUNE 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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COST ANALYSIS OF DOME STRUCTURE WITH RING BEAM

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ABSTRACT

Domes have been used throughout the ages as a housing form, or an element of a housing form (roof structure). Whenever large column free circular areas are to be covered with roof, domes become one of the easiest choices. Surface area required to cover huge space by a dome structure is minimal. Due to this, construction material usage becomes less and this feature leads to economy. In the present paper, an RCC dome with ring beam at the base has been analysed and designed through developing a C language computer program. Only dead and imposed loads are considered. Concentrated load acting at the apex is kept as further scope of study. Necessary input values in the program when given, the cost of construction of the dome is readily obtained.

Keywords: double curvature, shell of revolution, dome, ring beam, meridional, hoop, semi-central angle, construction cost.

INTRODUCTION

The dome element of the structure is predominant for its structural strength as well as the savings in cost of construction when replaced by a conventional roofing system with a monolithic element. A dome is a thin shell generated by the revolution of a regular curve about one of its axes. The shape of the dome depends on the type of the curve and the direction of the axis of revolution. In spherical domes, surface is defined by revolving an arc of a circle. The centre of the circle is on the axis of rotation. The edge of the dome around its base is provided with edge member cast integrally with the dome. Surfaces of doubly curved domes can take dead loads very effectively. Domes are used as roof of circular areas, in circular tanks, hangers, auditoriums, bins, bunkers, and many more. Reinforced concrete domes can be constructed over large spans [1]. Figure-1 shows the classification of Doubly Curved Non-Developable Shells [2].

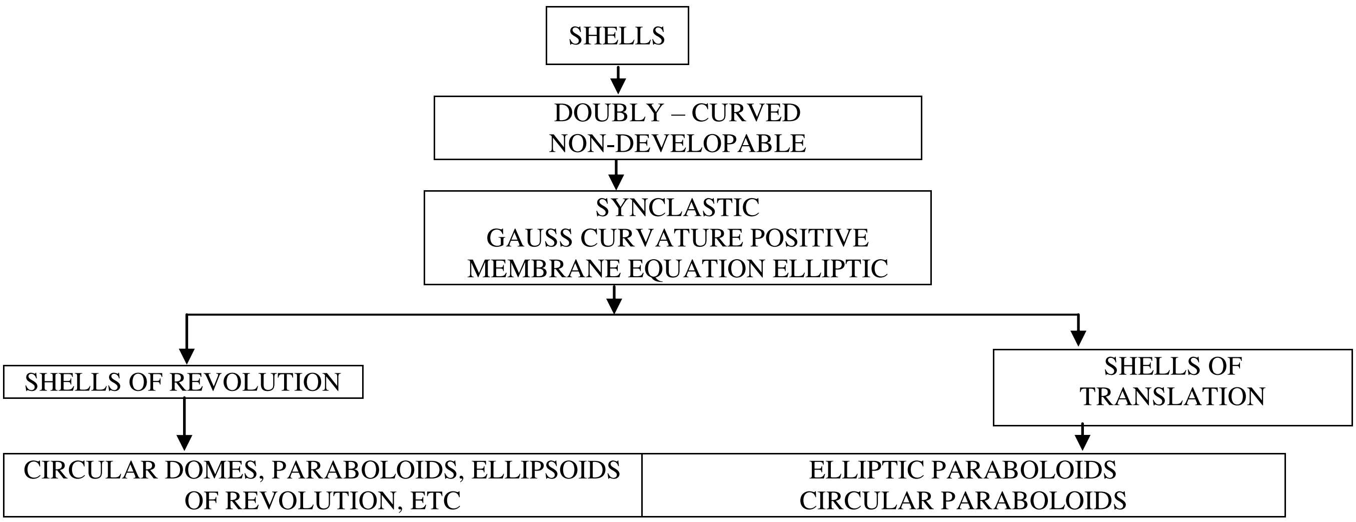

Figure-1. Classification of shells as per IS: 2210 – 1988.

STRUCTURAL ASPECTS

Due to the initial curvature of the domes, they transfer in-plane forces, which make its thickness small as compared to slabs to carry huge loads. Since dome is a double curvature structure, they are more secured for large areas. Bending moments and shear forces are developed only at the area around the base of the shell. Stiff horizontal ring beams around the shell limit the deformation in the meridian direction. Rise to span ratio for a dome may be taken as 1:7 to 1:8. For such shallow domes, the semi-central angle can be restricted to 52° so that the entire dome may be kept in compression under dead loads. If the semi-central angle exceeds 52°, tension forces are developed. Also, there is every possibility that during its construction, top forms may have to be provided. However, shallow domes transfer large thrusts to the wall or columns on which they are supported. Hence a ring beam is to be provided to absorb huge thrust that is transferred. Increase in the diameter of the dome, increases the ring beam size. [3].

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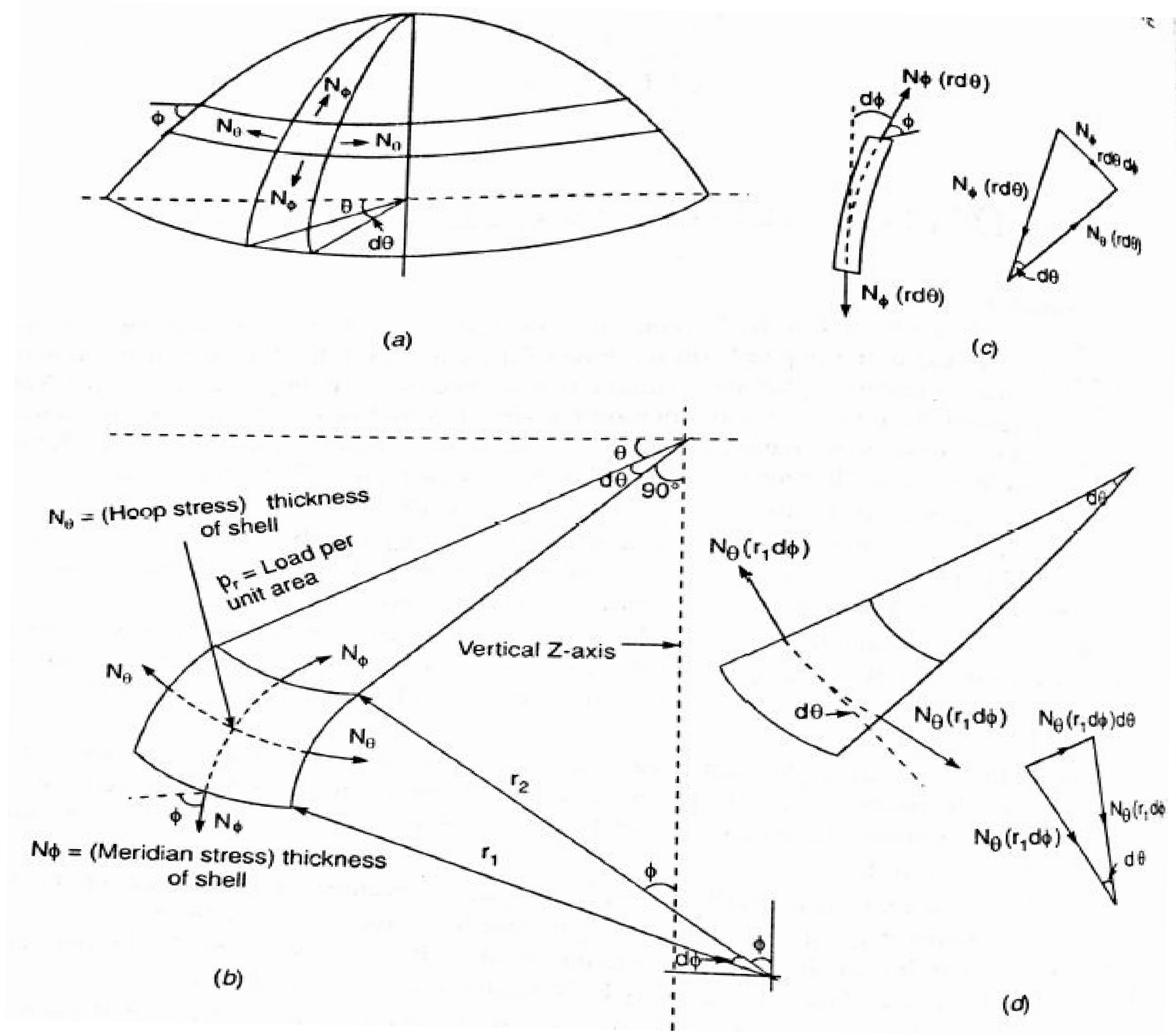

Figure-2. Stresses in shells of revolution [1].

DOME STRESSES USING MEMBRANE ANALYSIS [4]

In domes, equilibrium of an element is obtained by intersection of meridian and latitude. Meridional Stresses ($N_\emptyset$) are the forces acting along the circumference and the forces acting right angles to the meridian plane and along the latitude are Hoop Stresses(N_θ). Neglecting the effect of bending moment, twisting moment and shear, membrane analysis is adopted to determine these stresses. The loads are acting along the length of the shell and the imposed loads act on the plan area. Dead load [5], imposed load [6], finishing loads [5] are considered from IS : 875 Part 1 and 2.

The meridional force per unit length is calculated using:

$$N_\emptyset = \frac{wR}{1+\cos\emptyset}$$

The hoop force per unit length is calculated using:

$$N_\theta = wRcos\emptyset - N_\emptyset$$

where:

w = weight per unit area

$\emptyset$ = semi-central angle measured from the crown

R = radius of the dome

ANALYSIS OF RING BEAM [4]

Shear force is developed at the junction of the shell and the ring beam due to the vertical component of the thrust between the shell and the ring beams at the bottom.

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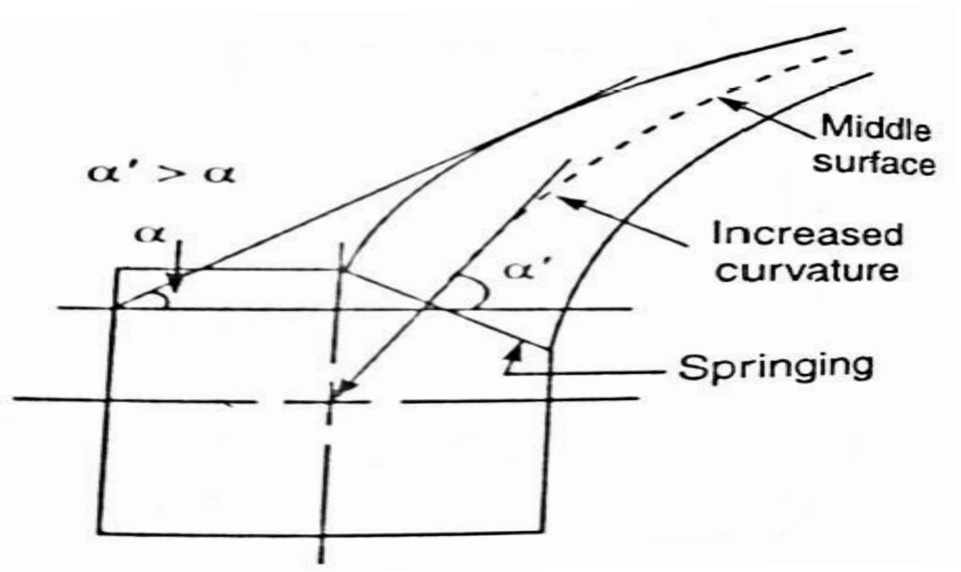

Figure-3. Ring beam in shell [1].

Total hoop tension on the ring beam is calculated using:

$H_T = N_{\emptyset max} x \cos\emptyset \, xR \sin\emptyset$

The shear force per meter length of circumference is calculated using:

$V = \left(\frac{R}{r}\right) hw$

Total tension in the ring beam is calculated using:

$T = V \cos\emptyset \, (0.5L)$

where:

$N_{\emptyset max}$ = meridional stress at maximum semi-central angle
r = one half span of the dome
h = rise of the dome
L = span of the dome

DESIGN OF THE DOME WITH RING BEAM [4]

Structural Design of the dome with ring beam is done in accordance to IS:456 - 2000 [7] and IS: 2204 - 1962 [8]. The detailing of the reinforcement is done referring to Indian Standard SP: 34 [9].Working Stress method of design is used in designing the dome and the ring beam.

DESIGN OF THE DOME [4]

Since only compressive stresses are developed for the domes with $\emptyset < 52°$, minimum steel may be provided. The steel is placed at the centre of the dome thickness.Since domes are non-developable shells, a minimum of 4 mm thickness for domes is adequate from buckling consideration [6].Usually 0.3 % of steel is provided for mild steel and 0.2 to 0.24 % for HYSD bars.

DESIGN OF THE RING BEAM [4]

Ring beams are provided at the base of the dome and are designed to resist tension and shear force. Width and depth of the ring beam will not be less than twice the thickness of the dome. Shear design can also be done by providing extra tension steel in the ring beam provided the concrete should carry shear without vertical stirrups. Haunch should be provided at the junction of dome and ring beam.

The area of tension steel is calculated using:

$A_{st} = \frac{T}{f_s}$

The area of concrete is calculated using:

$\sigma_{ct} = \frac{T}{A_c + (m-1)A_{st}} \leq f_{ct}$

where:

f_s = allowable tension in steel
σ_{ct} = tension in concrete of the ring beam
f_{ct} = allowable tension in concrete
$m = \frac{280}{3\,\sigma_{cbc}}$ = modular ratio
σ_{cbc} = permissible compressive stress due to bending in concrete

C LANGUAGE CODE

A simple C language code is developed to quickly determine the stresses and reinforcement details of the dome with ring beam. The program is verified for standard numerical problems [4].Initial inputs like span of the dome, rise, imposed load, floor finish, grade of concrete, and grade of steel are to be given. The program tabulates meridional and hoop stress at specified increments of the semi-central angle. The maximum meridional and hoop stress is considered by the program for further analysis and the structural design of the dome with ring beam at the base. Finally the cost of construction of the dome can be obtained. Structural Engineers can also get the result of analysis and design along with the construction cost for various possible geometrical and

ARPN Journal of Engineering and Applied Sciences

structural properties. This avoids repeated calculations and facilitates quick decisions.

NUMERICALEXAMPLES

Three different data sets are considered to obtain the cost of construction of the dome with the ring beam. Rise of the span is considered as $\frac{Span}{6}$. M20 concrete is taken for first two cases and M25 for third case. Higher diameter bars considered for higher spans of the domes. The thickness of the dome and width of the ring beam are also considered higher, for higher spans. Other input data are shown in Table-1.

Table-1. Various input values for dome construction.

Inputs	Case 1	Case 2	Case 3
Span of the Dome (m)	10	20	30
Rise of the Dome (m)	1.5	3.4	5
Thickness of Dome (mm)	150	200	250
Density of Concrete (kN/m^3)	25	25	25
Live Load (kN/m^2)	2	2	2
Floor Finish (kN/m^2)	1	1	1
Grade of Concrete (kN/m^2)	20	20	25
Grade of Steel (kN/m^2)	415	415	415
Width of Ring Beam (mm)	250	350	600
Diameter of Reinforcement in Dome (mm)	8	12	16
Diameter of Main Steel in Ring Beam (mm)	16	25	25
Diameter of Shear Bars in Ring Beam (mm)	8	12	16
Cost of RCC including Shuttering (Rs. per m^3)	14,000.00	14,000.00	14,000.00
Cost of Steel (Rs. per kg)	50.00	50.00	50.00

RESULT OF NUMERICAL EXAMPLES

Table-2 shows meridional and hoop stresses for one degree increment in the semi-central angle for three different cases considered. Table-3 shows various structural design parameters and cost of construction of the dome with the ring beam. These results are obtained using C language program. Meridional Stress vs. Semi-central angle and Hoop Stress vs. Semi-central angle graphs are plotted for all the three different cases considered, as shown in Figure4 to Figure-9.

VOL. 13, NO. 12, JUNE 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-2. Meridional and Hoop stresses for semi-central angles.

Case 1			Case 2			Case 3		
Semi-central angle (degrees)	**Meridional stress** (kN/m^2)	**Hoop stress** (kN/m^2)	**Semi-central angle** (degrees)	**Meridional stress** (kN/m^2)	**Hoop stress** (kN/m^2)	**Semi-central angle** (degrees)	**Meridional stress** (kN/m^2)	**Hoop stress** (kN/m^2)
0	30.64	52.73	0	65.64	54.15	0	115.62	115.86
1	30.65	30.63	1	65.64	65.62	1	115.63	115.58
2	30.65	30.6	2	65.66	65.54	2	115.66	115.45
3	30.67	30.54	3	65.69	65.41	3	115.7	115.23
4	30.68	30.46	4	65.72	65.24	4	115.77	114.92
5	30.7	30.36	5	65.77	65.01	5	115.85	114.52
6	30.73	30.22	6	65.82	64.74	6	115.94	114.04
7	30.76	30.07	7	65.89	64.41	7	116.06	113.47
8	30.79	29.9	8	65.96	64.04	8	116.19	112.81
9	30.83	29.71	9	66.05	63.61	9	116.34	112.06
10	30.88	29.48	10	66.14	63.15	10	116.51	111.23
11	30.93	29.23	11	66.25	62.62	11	116.7	110.3
12	30.98	28.97	12	66.37	62.04	12	116.9	109.3
13	31.04	28.68	13	66.49	61.43	13	117.13	108.19
14	31.11	28.36	14	66.63	60.75	14	117.37	107.01
15	31.18	28.02	15	66.78	60.03	15	117.63	105.74
16	31.25	27.67	16	66.94	59.25	16	117.91	104.38
17	31.33	27.28	17	67.11	58.43	17	118.21	102.94
18	31.41	26.88	18	67.29	57.56	18	118.53	101.4
19	31.5	26.45	19	67.48	56.65	19	118.86	99.79
20	31.6	25.99	20	67.68	55.68	20	119.22	98.08
21	31.7	25.52	21	67.89	54.67	21	119.6	96.29
22	31.8	25.03	22	68.12	53.6	22	119.99	94.42
23	31.91	24.51	23	68.36	52.48	23	120.41	92.46
24	32.03	23.96	24	68.61	51.32	24	120.85	90.41
25	32.15	23.4	25	68.87	50.11	25	121.31	88.27
26	32.28	22.81	26	69.14	48.85	26	121.79	86.06
27	32.41	22.2	27	69.42	47.55	27	122.29	83.76
28	32.55	21.57	28	69.72	46.19	28	122.81	81.37
29	32.69	20.92	29	70.03	44.79	29	123.36	78.9
30	32.85	20.23	30	70.35	43.34	30	123.93	76.34
31	33	19.54	31	70.69	41.84	31	124.52	73.7
32	33.16	18.82	32	71.04	40.29	32	125.13	70.98
33	33.33	18.07	33	71.4	38.7	33	125.77	68.17
33.41	33.41	17.75	34	71.78	37.06	34	126.43	65.28
			35	72.17	35.37	35	127.12	62.31
			36	72.57	33.64	36	127.83	59.26
			37	72.99	31.85	36.87	128.47	56.53
			37.55	73.23	30.85			

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ARPN Journal of Engineering and Applied Sciences

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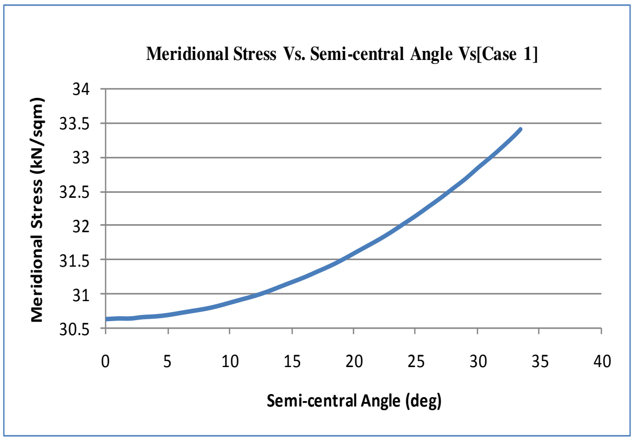

Figure-4. Meridional stress vs. semi-central angle [Case 1].

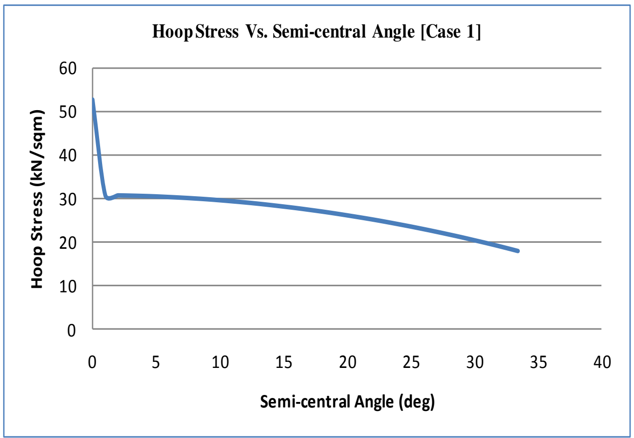

Figure-5. Hoop stress vs. semi-central angle [Case 1].

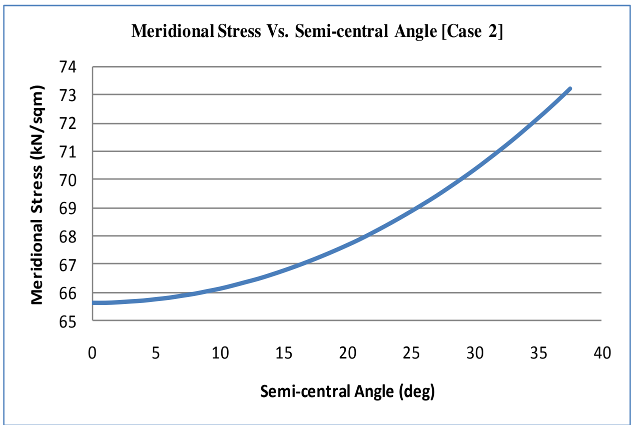

Figure-6. Meridional stress vs. semi-central angle [Case 2].

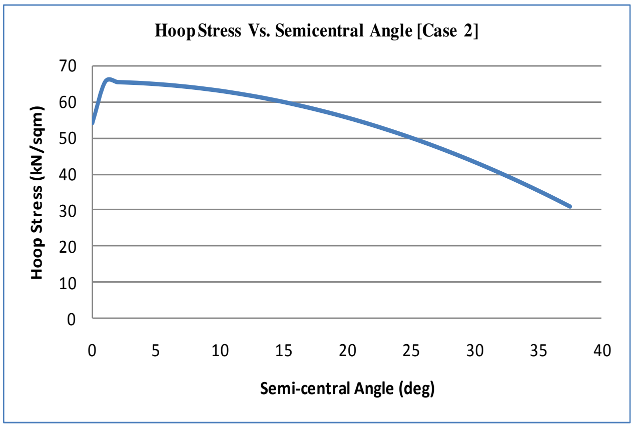

Figure-7. Hoop stress vs. semi-central angle [Case 2].

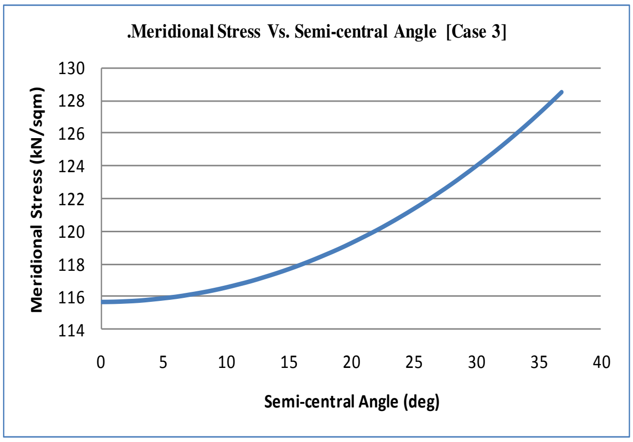

Figure-8. Meridional stress vs. semi-central angle [Case 3].

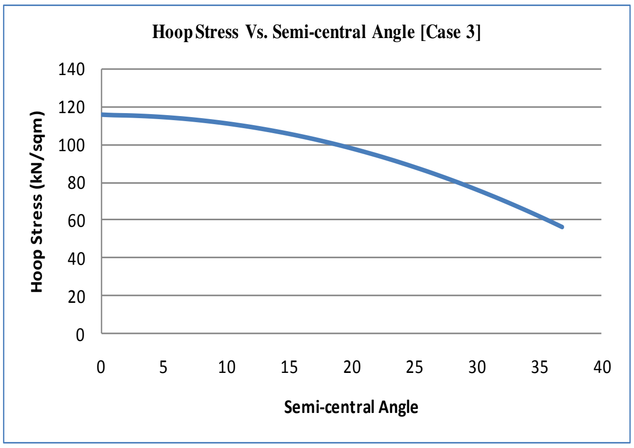

Figure-9. Hoop stress vs. semi-central angle [Case 3].

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Table-3. Output values for dome with ring beam.

Analysis and design	Value		
	Case 1	**Case 2**	**Case 3**
Radius of the Dome (m)	9.08	16.41	25
Semi-Central Angle (degrees)	33.41	37.55	36.87
Dead Load (kN/m^2)	3.75	5.00	6.25
Total Load (kN/m^2)	6.75	8.00	9.25
Maximum Compression Force due to Meridional Stress (kN)	33.41	73.23	128.47
Maximum Compression Force due to Hoop Stress (kN)	30.64	65.64	115.62
Maximum Compression Stress (N/m^2)	0.22 $<\sigma_{cbc}$ = 7 N/m^2 SAFE	0.37 $<\sigma_{cbc}$ = 7 N/m^2 SAFE	0.81 $<\sigma_{cbc}$ = 8.5 N/m^2 SAFE
Dome Reinforcement (m^2)	450.00	600.00	750.00
Dome Reinforcement for Meridional and Hoop Stress at the center of Dome thickness	8 @ 110	12 @ 180	16 @ 260
Hoop Stress in Ring Beam (kN)	139.45	580.58	1541.64
Tension Steel in Ring Beam (m^2)	606.30	2524.26	6702.78
Ring Beam Reinforcement at bottom	#4 of 16	#6 of 25	#14 of 25
Hanger Bars in Ring Beam	#2 of 16	#2 of 16	#2 of 16
Ring Beam Size	250 mm X 170 mm	510 mm X 350 mm	700 mm X 600 mm
Sheer Force (kN)	18.39	44.64	77.08
Sheer Reinforcement (m^2)	79.96	194.09	335.13
Sheer Reinforcement in Ring Beam c/c throughout the span	8 @120	12 @ 320	16 @ 400
Concrete in Dome (m^3)	76.42	334.29	971.97
Weight of Steel in Dome (kg)	18019.84	78825.58	229190.53
Concrete in Ring Beam (m^3)	44.02	431.40	1374.31
Weight of Steel in Ring Beam (kg)	183.36	2692.60	11721.66
Total Concrete (m^3)	120.44	765.69	1026.40
Total Steel (kg)	18203.20	81518.18	240912.19
Dome Shuttering (m^2)	501.05	1651.00	3848.84
Ring Beam Shuttering (m^2)	56.45	102.87	156.91
Total Shuttering Area (m^2)	557.50	1753.87	4005.75
Construction Cost of Dome with Ring Beam (Rs.)	20,46,820.00	91,19,549.00	2,64,15,210.00

CONCLUSIONS

The following conclusions are drawn:

a) For the input data shown in Table-1, manual calculations were done and verified with the results shown in Table-2 and Table-3. It is found that there are not many variations in the numerical values of the results.
b) Increase of meridional stress and decrease of hoop stress with the semi-central angle validates the example problems considered.
c) Semi-central angle need not increase for higher spans when rise-span ratio is kept constant.
d) Higher grades of concrete and larger diameter reinforcement bars are to be used invariably as the span is increased.

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