Study the Behavior of Singly Curved Concrete Shell Structure for Different Loading Conditions

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Abstract- *Ever since the construction of building has started in human history the construction of top over-head covering structure like roof is given priority for safety and from privacy point of view. The shape and dimension of roof structure used is different for different loading conditions and geographical locations such as horizontal, sloping or curved member such as dome and shell member. Shell is a thin, light weight and curved structure may be used as side as well as top covering - roof member which bears upcoming loads, due to its curved shape and low flexural rigidity. Main study of this paper is analyzed and design doubly curved concrete shell structure by using STAAD.Pro software. For analysis of doubly curved concrete shell structure applying some loads and its combinations as per IS code.*

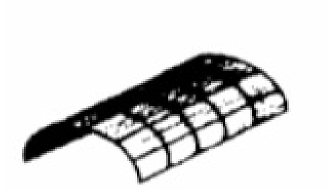
Keywords- Doubly curved shell, Flexural rigidity, Thin concrete shell, Staad.Pro, F.E.M Method.

I. INTRODUCTION

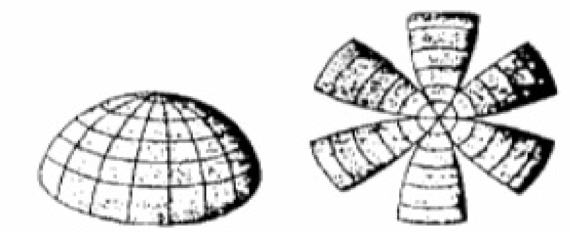
The term “shell” is used to represent and describe the structures provided with durability, strength and rigidity due to its low depth i.e. thinness, with respect to its other dimensions such as radius of curvature and span. There are various examples of curved mass shell structures adopted by nature in various forms of living and non – living things such as tortoise back, snails cover, human skull bone and caves top upper part. Shells belong to the class of stressed-skin structures which, because of their geometry and small flexural rigidity of the skin, tend to carry loads primarily by direct stresses acting in their plane.

Although shells of double curvature, with the exception of domes, have been introduced on a large scale comparatively recently into building construction, these are likely to be used more and more in future. Being non-developable surfaces, they are more resistant to buckling than cylindrical shells and in general, require less thickness. Shells are structurally continuous in the sense that they can transmit forces in a number of different directions in the surface of the shell, as required. Shell structures have quite a different mode of action from skeletal structures, of which simple examples are trusses, frameworks, and trees because other structures are only capable of transmitting forces along their discrete structural members.

Shells may be broadly classified as ‘singly-curved’ and ‘doubly curved’. This is based on Gauss curvature. The gauss curvature of singly curved shells is zero because one of their principal curvatures is zero. They are therefore, developable. Doubly-curved shells are non-developable and are classified as syn-clastic or anticlastic according as their Gauss curvature is positive or negative, respectively.



Developable forms



Non developable forms

A Shell is generally defined as a curved slab with very small thickness compared to the other dimensions like radius of curvature and span. They can be cast in any shape. It has sufficient strength and also has a body to cover space. The roof shell absorbs more pressure due to curved surface whereas the plain surface structures such as floor plate/membrane slab comparatively fails to do so due to horizontal alignment. Based on this review, it was concluded that shell is curved slab beam like member exposed to direct stresses due to loading, and may buckle infinitely.

As per IS: 2210 – 1994 the criteria for span and thickness of shells shell shall not normally be less than 50 mm if singly curved and 40 mm if doubly-curved. This requirement does not, however, apply to small precast concrete shell units in which the thickness may be less than that specified above but it shall in no case be less than 25 mm. The span should preferably be less than 30 m. Shells longer than 30 m will involve special design considerations, such as the application of pre-stressing techniques.

II. OBJECTIVE OF THE STUDY

The objective of the study is carrying out the economic and sustainable design of singly curved concrete shell for different loading conditions based on modeling and detailing done in STAAD.Pro software in form of shell having different parameter, i.e., t/r (thickness / radius), h/r (height / radius) and t/h (thickness / height) for singly curved concrete shell structure. And also determine the stress value of shell structure element when load and load combinations are applied.

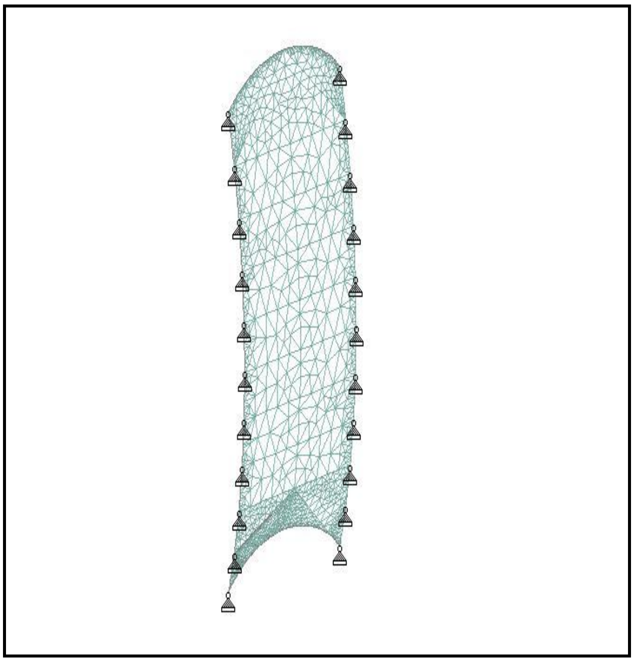
III. MODELING AND ANALYSIS OF R.C. SHELL ELEMENT

A sample shell is analyzed in STAAD.Pro whose dimensions are assumed similar to the ones found in the field as per the uses, requirements and most important IS: 2210 1988. Following are its dimensions:

Span of shell (X-direction) = 20m
No. of spans = 1
Width of shell (Z-direction) = 60m
Rise of shell;
Along X-direction = 2 m.
Along Z-direction = 1 m.
Continuous Column supports at 6 m interval along Z-direction of the shell

Initially for software analysis the continuous beams along the width are assumed to be of 230 mm * 300 mm
Thickness assumed for software analysis: 0.12 m
Load on the shell = Dead load, live load, wind load and load combinations.

Dead load is calculated on the basis of the unit weights taken in accordance with IS: 875 (Part I)-1987.
Live load is taken as specified in IS: 875 (Parts 2)-1987.
Wind load is taken as specified in IS: 875 (Parts 3)-2015.
Load combinations are use as per IS: 456 – 2000.
Dead load = 3 kN/sq m
Live load = 0.75 kN/sq m



STAAD model

IV. METHODOLOGY

Thickness of shell member selected in accordance to clause 7.1.1 from IS 2210: 1988 i.e. Thickness of shells shall not be less than 40 mm if doubly curved. This requirement does not, however, apply to small precast concrete shell units in which the thickness may be less than that specified above but it shall in no case be less than 25 mm.

Structure was analyzed for dead load, live load and wind load. Analysis was performed in software based on IS code.

Dead Load: Calculated As per IS: 875 (Part I) – 1987.
Live Load: Calculated As per IS: 875 (Part II) – 1987.
Wind Load: For wind load analysis all data is taken from Indian standard code IS: 875 (Part – 3) – 2015, since STAAD.Pro software does not design directly for curved or inclined member.

So, wind load calculation;

Design Wind Speed = $V_b * K_1 * K_2 * K_3 * K_4$
Where;
V_b = Basic wind speed (considering Vadodara region)
= 44 m/s
K_1= Risk coefficient factor (assuming 100 years of life)
= 1.07
K_2 = Terrains & height Factor (take height as 15 meter)

= 1.05

K_3 = Topography Factor (take plain terrain)

= 1

K_4 = Important factor for cyclonic region

No need to calculate this factor. Because our location is away from 60 km of sea bed.

Design Wind Speed $V_z = V_b * K_1 * K_2 * K_3 * K_4$

$$V_z = 49.43 \ {}^{m}/_{s}$$

Design Wind Pressure $p_z = 0.6 \ V_z^2$

$$p_z = 1.46 \ {}^{kN}/_{m^2}$$

The wind load on the building shall be calculated for the building as a whole. Wind Load on the Building,

F = $(C_{pe} - C_{pi}) * A * p_z$

C_{pe} = -0.7 (end of the roof)

= -0.5 (centre of the roof)

C_{pi} = -0.7 (opening > 20%)

Wind force from +X direction

F = -2.044 ${}^{kN}/_{m^2}$

Wind force from -X direction

F = -1.752 ${}^{kN}/_{m^2}$

Wind force from +Z direction

F = -2.77 ${}^{kN}/_{m^2}$

Wind force from -Z direction

F = -0.803 ${}^{kN}/_{m^2}$

Load combinations: As per IS: 456 - 2000

1.5 (DL+LL)

1.2 (DL+LL+WL(+X direction))

1.2 (DL+LL+WL(-X direction))

1.2 (DL+LL+WL(+Z direction))

1.2 (DL+LL+WL(-Z direction))

V. ANALYSIS

Analysis here done for the different parameters of the shell member with the help of software tool.

Table – 1 Showing Shear, Membrane and Bending Stresses on Shell Structure with t/h parameter

			Shear		Membrane			Bending Moment		
	Plate	L/C	SQX (local) N/mm2	SQY (local) N/mm2	SX (local) N/mm2	SY (local) N/mm2	SXY (local) N/mm2	Mx kNm/m	My kNm/m	Mxy kNm/m
Max Qx	705	101 1.5 (DL+LL)	0.078	-0.030	0.251	-0.689	0.314	-0.100	-2.297	1.320
Min Qx	795	101 1.5 (DL+LL)	**-0.172**	-0.029	-0.591	0.051	0.265	1.501	-2.051	-1.350
Max Qy	51	101 1.5 (DL+LL)	0.016	**0.069**	-2.446	-6.105	-3.560	-0.123	2.726	0.170
Min Qy	706	101 1.5 (DL+LL)	0.050	**-0.091**	-2.221	-0.330	0.622	-4.483	1.435	-0.565
Max Sx	1124	101 1.5 (DL+LL)	0.004	-0.007	**1.652**	0.110	-0.189	-1.321	0.334	0.067
Min Sx	83	101 1.5 (DL+LL)	0.024	-0.010	**-5.476**	-1.017	1.205	1.261	0.644	0.789
Max Sy	909	101 1.5 (DL+LL)	-0.005	-0.012	0.353	**1.787**	-0.356	0.676	-1.294	0.266
Min Sy	198	101 1.5 (DL+LL)	0.005	-0.085	-3.510	**-7.287**	2.985	-1.895	-1.206	1.177
Max Sx	198	101 1.5 (DL+LL)	0.005	-0.085	-3.510	-7.287	**2.985**	-1.895	-1.206	1.177
Min Sx	51	101 1.5 (DL+LL)	0.016	0.069	-2.446	-6.105	**-3.560**	-0.123	2.726	0.170
Max Mx	502	101 1.5 (DL+LL)	-0.008	-0.021	-3.623	-1.071	-1.910	**6.245**	1.144	3.055
Min Mx	166	101 1.5 (DL+LL)	0.003	0.002	-0.646	-0.034	-0.071	**-5.724**	-0.239	-0.944
Max My	501	101 1.5 (DL+LL)	-0.014	-0.053	-0.116	-3.449	0.098	0.373	**6.766**	1.165
Min My	160	101 1.5 (DL+LL)	0.002	0.002	-0.020	-0.680	0.050	-0.142	**-6.196**	0.389
Max Mx	502	101 1.5 (DL+LL)	-0.008	-0.021	-3.623	-1.071	-1.910	6.245	1.144	**3.055**
Min Mx	133	101 1.5 (DL+LL)	0.001	-0.002	-0.432	-0.254	-0.312	-3.871	-2.418	**-2.956**

Table – 2 Showing Shear, Membrane and Bending Stresses on Shell Structure with t/r parameter

			Shear		Membrane			Bending Moment		
	Plate	L/C	SQX (local) N/mm2	SQY (local) N/mm2	SX (local) N/mm2	SY (local) N/mm2	SXY (local) N/mm2	Mx kNm/m	My kNm/m	Mxy kNm/m
Max Qx	1355	101 1.5 (DL+LL)	**0.038**	-0.071	-1.202	0.222	-0.578	2.558	-0.312	1.442
Min Qx	1267	101 1.5 (DL+LL)	**-0.119**	-0.032	-0.571	-3.688	-0.197	-0.112	7.632	-2.614
Max Qy	1430	101 1.5 (DL+LL)	-0.040	**0.100**	-1.786	-0.568	0.831	4.234	-2.158	0.428
Min Qy	1355	101 1.5 (DL+LL)	0.038	**-0.071**	-1.202	0.222	-0.578	2.558	-0.312	1.442
Max Sx	880	101 1.5 (DL+LL)	-0.000	-0.001	**1.707**	-0.390	0.185	-0.662	0.558	-0.471
Min Sx	83	101 1.5 (DL+LL)	0.024	-0.010	**-5.490**	-1.028	1.230	1.380	0.684	0.832
Max Sy	886	101 1.5 (DL+LL)	-0.000	-0.000	-0.443	**1.462**	-0.040	0.662	-0.779	-0.280
Min Sy	297	101 1.5 (DL+LL)	0.013	0.060	-2.212	**-8.583**	-1.387	-0.461	-2.774	0.676
Max Sx	110	101 1.5 (DL+LL)	-0.029	0.052	-1.480	-2.329	**1.864**	1.263	-0.441	-0.355
Min Sx	68	101 1.5 (DL+LL)	0.016	0.070	-2.452	-6.094	**-3.561**	-0.107	2.871	0.214
Max Mx	1389	101 1.5 (DL+LL)	-0.008	0.005	-2.263	-0.005	-0.011	**4.804**	0.216	-0.252
Min Mx	166	101 1.5 (DL+LL)	0.003	0.002	-0.616	-0.034	-0.069	**-5.669**	-0.237	-0.939
Max My	1267	101 1.5 (DL+LL)	-0.119	-0.032	-0.571	-3.688	-0.197	-0.112	**7.632**	-2.614
Min My	160	101 1.5 (DL+LL)	0.002	0.002	-0.021	-0.650	0.047	-0.141	**-6.137**	0.376
Max Mx	130	101 1.5 (DL+LL)	0.005	-0.005	-0.301	-0.360	0.329	-3.005	-3.128	**3.013**
Min Mx	133	101 1.5 (DL+LL)	0.001	-0.002	-0.412	-0.243	-0.296	-3.838	-2.394	**-2.927**

Table – 3 Showing Shear, Membrane and Bending Stresses on Shell Structure with h/r parameter

			Shear		Membrane			Bending Moment		
	Plate	L/C	SQX (local) N/mm2	SQY (local) N/mm2	SX (local) N/mm2	SY (local) N/mm2	SXY (local) N/mm2	Mx kNm/m	My kNm/m	Mxy kNm/m
Max Qx	1260	101 1.5 (DL+LL)	0.103	-0.018	0.279	-0.207	0.201	4.348	0.456	-2.021
Min Qx	1573	101 1.5 (DL+LL)	-0.064	-0.007	0.265	-0.019	0.126	-0.608	0.314	1.013
Max Qy	51	101 1.5 (DL+LL)	-0.005	0.093	-2.484	-4.847	2.182	1.971	1.234	-1.225
Min Qy	1346	101 1.5 (DL+LL)	0.055	-0.092	0.392	1.047	-0.359	-1.235	3.390	1.856
Max Sx	1180	101 1.5 (DL+LL)	-0.001	-0.001	1.868	-0.587	-0.214	-1.001	0.771	-0.170
Min Sx	200	101 1.5 (DL+LL)	0.005	-0.092	-2.618	-5.208	2.292	-1.998	-1.274	1.247
Max Sy	702	101 1.5 (DL+LL)	0.005	-0.039	0.446	3.042	-0.433	-0.419	0.040	1.505
Min Sy	200	101 1.5 (DL+LL)	0.005	-0.092	-2.618	-5.208	2.292	-1.998	-1.274	1.247
Max Sx	200	101 1.5 (DL+LL)	0.005	-0.092	-2.618	-5.208	2.292	-1.998	-1.274	1.247
Min Sx	646	101 1.5 (DL+LL)	-0.006	0.030	0.691	1.503	-1.573	0.666	-1.257	0.430
Max Mx	1380	101 1.5 (DL+LL)	-0.012	-0.029	-0.605	-0.581	0.620	5.737	-0.016	1.003
Min Mx	166	101 1.5 (DL+LL)	0.003	0.001	-0.634	-0.022	-0.036	-5.336	-0.209	-0.872
Max My	501	101 1.5 (DL+LL)	0.037	0.066	-0.346	-0.864	-0.429	0.463	5.312	1.626
Min My	160	101 1.5 (DL+LL)	0.001	0.002	-0.022	-0.667	0.045	-0.130	-5.730	0.368
Max Mx	130	101 1.5 (DL+LL)	0.004	-0.004	-0.281	-0.357	0.324	-2.815	-2.933	2.825
Min Mx	1384	101 1.5 (DL+LL)	-0.018	-0.072	-0.279	-1.983	0.572	1.954	0.870	-4.068

VI. DESIGN SUMMARY

1. Reinforcement for Membrane Stress SX :

SX = -5.490 N/mm²

- Membrane force F_x = SX * b * d
  = 5.490 * 1000 * 120
  = 658.8 kN

Now, Capacity of single 16 mm dia. HYSD Fe-415 bars can be given as,

= 0.87 $F_y A_{st}$

= 0.87 * 415 * $\frac{\pi}{4}$ * 20^2

= 113.42 kN

- Total number of bars required for 1m width,

= $\frac{658.8}{113.42}$ = 5.8 ≈ 6 Bars.

2. Reinforcement for Local Bending Moment MX :

MX = 6.245 kN.m

With reference to Chart 13, IS: 456, 1978 (SP 16),

P_t= 0.12 %

- Area of reinforcement required A_{st},

= $\frac{0.12 * 1000 * 120}{100}$ = 144 mm²

Now, Area of a single 10 mm dia. Fe-415 bars,

= $\frac{\pi}{4}$ * 10² = 78.54 mm²

- Total number of bars required for 1m width,

= $\frac{144}{78.54}$ = 1.83 ≈ 2 Bars.

So, in X-direction, Membrane Stress SX is governing.

3. Reinforcement for Membrane Stress SY :

SY = -8.583 N/mm²

- Membrane Force F_y = SY * b * d
  = 8.583 * 1000 * 120
  = 1029.96 kN

Now, Capacity of single 20 mm dia. HYSD Fe-415 bars can be given as,

= 0.87 $F_y A_{st}$

= 0.87 * 415 * $\frac{\pi}{4}$* 20^2

= 133.42 kN

- Total number of bars required for 1m width,

= $\frac{1029.96}{133.42}$ = 7.6 ≈ 8 Bars.

4. Reinforcement for Local Bending Moment MY :

MY = 7.632 kN.m

With reference to Chart 13, IS: 456, 1978 (SP 16),

P_t = 0.15 %

- Area of reinforcement required A_{st},

= $\frac{0.15 * 1000 * 120}{100}$ = 180 mm²

Now, Area of a single 10 mm dia. Fe-415 bars,

= $\frac{\pi}{4}$ * 10² = 78.54 mm²

- Total number of bars required for 1m width,

= $\frac{180}{78.54}$ = 2.28 ≈ 3 Bars.

So, in Y- direction Membrane Stress SY is governing.

5. Shear reinforcement for the shear stresses SQ_x and SQ_y

For the prevailing $SQ_x > SQ_y$,

The reinforcement provided for the governing Membrane stresses SX and SY, whose magnitude is greater than that of Shear Stresses SQ_x and SQ_y, is sufficient to sustain the shear stresses and so, there is no need to provide extra Shear reinforcement.

VII. CONCLUSION

From the above research we can say that for doubly curved shell membrane stresses SY is more than the membrane stresses SX.

And the bending stresses are smaller than the membrane stresses. So, membrane reinforcement is enough to carry stresses.

VIII. ACKNOWLEDGMENT

I am very thankful to **Mr. Jainesh Bhavsar**, structural engineer at Vishwakarma consultancy, Vadodara. For guiding me towards my thesis. I am also very thankful for help me and giving her valuable time and guidance and continuous motivation.

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