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STUDY THE BEHAVIOR OF SINGLY CURVED CONCRETE SHELL STRUCTURE FOR DIFFERENT LOADING CONDITIONS

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Abstract — *From the perspective of structural engineering, shells due to their spatial curvature, possess a structurally efficient way of carrying loads acting perpendicular to their surfaces. However, the nature and geometry of shells makes them complicated to understand or predict their structural behavior. The structural analysis of thin concrete shells can be conducted numerically (i.e. derivation) or by using computer software. In numerical solutions very complicated stress problems can be obtained regularly using Finite element analysis. So main study of this paper is analysis and design singly curved concrete shell structure by STAAD.Pro software. For analysis of singly curved concrete shell structure applying some loads and its combinations.*

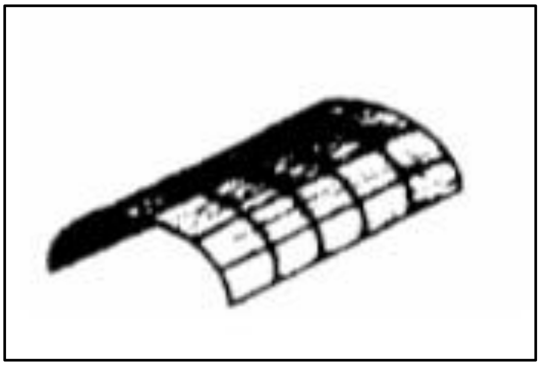
Keywords- *Singly Curved Shell, Thin Concrete Shell, Roof, Staad.Pro, F.E.M Method.*

I. INTRODUCTION

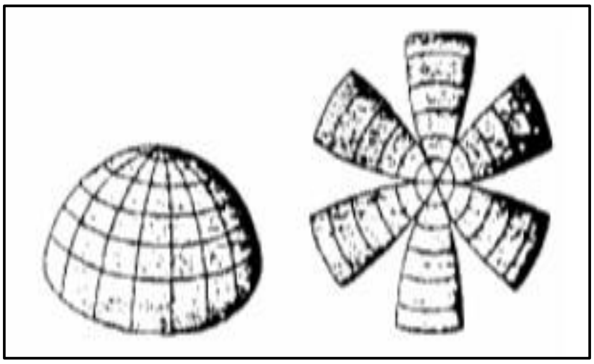
Concrete shell structures, often referred to as ‘thin shells’ are suitable structural elements for building spacious infrastructures. They are often economical and suitable solution for different facility structures such as water tanks, large-span roofs, containment buildings, auditorium building and silos. Loads acting on the surface of shell structures are mainly carried by the so called membrane action. This is a general state of stress consists of the in-plane normal and shear stress resultants only. In comparison, other structural forms such as beams and plates carry loads acting on their surfaces by bending action, which can be said is structurally less efficient. Usually the in-plane stresses in shells are low such that with a relatively small thickness it is possible to span over large distances. In addition, concrete shell structures can have various shapes and geometries and that has contributed to them often considered as visually attractive.

The term “shell” is used to represent and describe the structures provided with durability, strength and rigidity due to its low depth i.e. thickness, with respect to its other dimensions such as radius of curvature and span.

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

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.

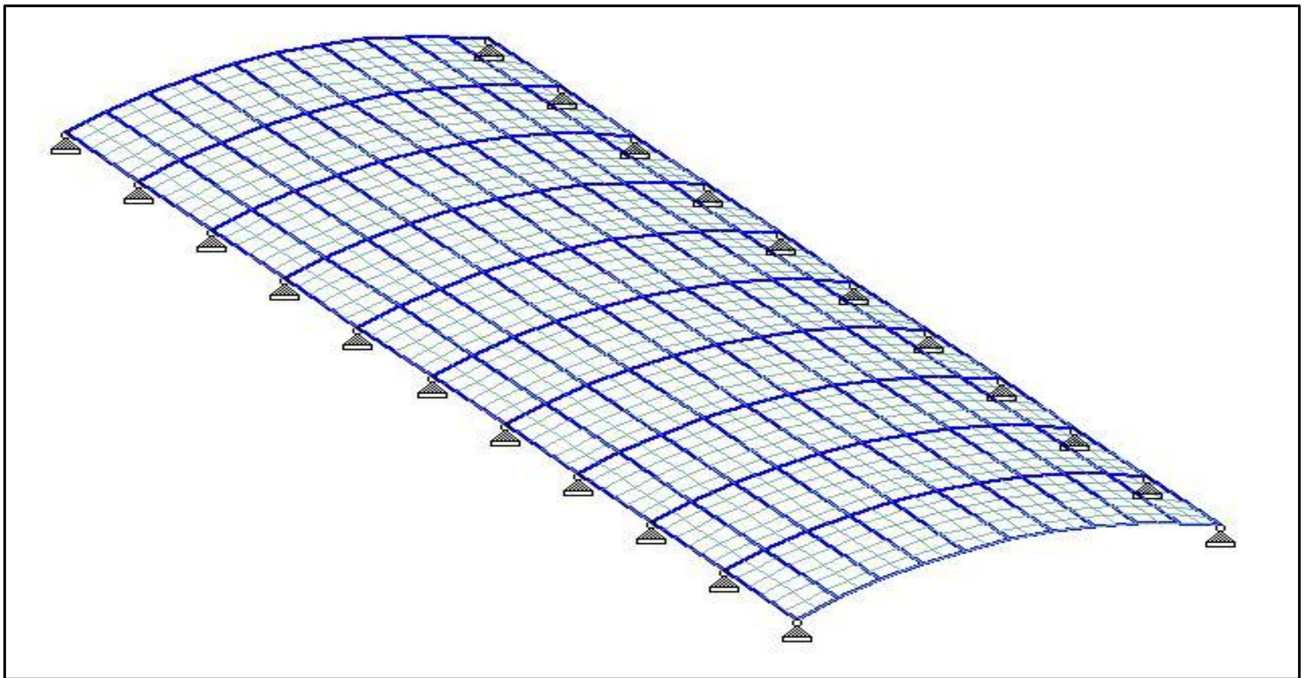
II. OBJECTIVE OF THE STUDY

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 to 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 analyze 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 = 2m
Continuous Column supports at 6 m interval along width 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: 0.8 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 = 2 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 50 mm if singly 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.

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. 1.5 (DL+LL)
2. 1.2 (DL+LL+WL(+X direction))
3. 1.2 (DL+LL+WL(-X direction))
4. 1.2 (DL+LL+WL(+Z direction))
5. 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	134	101 1.5 (DL+	**0.032**	-0.019	-1.418	-0.011	-0.443	0.304	0.264	0.198
Min Qx	263	101 1.5 (DL+	**-0.032**	-0.019	-1.418	-0.011	0.443	0.304	0.264	-0.198
Max Qy	1292	101 1.5 (DL+	0.031	**0.020**	-1.384	0.181	0.351	0.249	0.450	-0.117
Min Qy	302	101 1.5 (DL+	0.031	**-0.020**	-1.384	0.181	-0.351	0.249	0.450	0.117
Max Sx	1429	104 0.9 LL	-0.004	-0.001	**-0.008**	-0.048	0.038	-0.072	-0.043	-0.019
Min Sx	280	101 1.5 (DL+	-0.002	0.003	**-2.633**	-0.327	-1.239	-0.548	0.061	0.077
Max Sy	582	101 1.5 (DL+	0.030	-0.020	-1.329	**0.213**	-0.353	0.169	0.410	0.101
Min Sy	1431	101 1.5 (DL+	0.004	0.005	-2.434	**-1.057**	1.262	-0.613	0.050	-0.143
Max Sx	265	101 1.5 (DL+	-0.004	-0.005	-2.434	-1.057	**1.262**	-0.613	0.050	-0.143
Min Sx	133	101 1.5 (DL+	0.004	-0.005	-2.434	-1.057	**-1.262**	-0.613	0.050	0.143
Max Mx	151	101 1.5 (DL+	-0.023	-0.018	-0.972	-0.051	-0.127	**0.592**	0.323	-0.100
Min Mx	1431	101 1.5 (DL+	0.004	0.005	-2.434	-1.057	1.262	**-0.613**	0.050	-0.143
Max My	1433	101 1.5 (DL+	-0.022	-0.019	-0.943	0.040	-0.073	0.511	**0.578**	-0.039
Min My	1483	101 1.5 (DL+	-0.017	-0.000	-0.867	-0.012	-0.000	-0.448	**-0.540**	-0.004
Max Mx	134	101 1.5 (DL+	0.032	-0.019	-1.418	-0.011	-0.443	0.304	0.264	**0.198**
Min Mx	1432	101 1.5 (DL+	0.032	0.019	-1.418	-0.011	0.443	0.304	0.264	**-0.198**

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	134	101 1.5 (DL+	**0.032**	-0.019	-1.418	-0.011	-0.443	0.304	0.264	0.198
Min Qx	263	101 1.5 (DL+	**-0.032**	-0.019	-1.418	-0.011	0.443	0.304	0.264	-0.198
Max Qy	1292	101 1.5 (DL+	0.031	**0.020**	-1.384	0.181	0.351	0.249	0.450	-0.117
Min Qy	302	101 1.5 (DL+	0.031	**-0.020**	-1.384	0.181	-0.351	0.249	0.450	0.117
Max Sx	1429	104 0.9 LL	-0.004	-0.001	**-0.008**	-0.048	0.038	-0.072	-0.043	-0.019
Min Sx	280	101 1.5 (DL+	-0.002	0.003	**-2.633**	-0.327	-1.239	-0.548	0.061	0.077
Max Sy	582	101 1.5 (DL+	0.030	-0.020	-1.329	**0.213**	-0.353	0.169	0.410	0.101
Min Sy	1431	101 1.5 (DL+	0.004	0.005	-2.434	**-1.057**	1.262	-0.613	0.050	-0.143
Max Sx	265	101 1.5 (DL+	-0.004	-0.005	-2.434	-1.057	**1.262**	-0.613	0.050	-0.143
Min Sx	133	101 1.5 (DL+	0.004	-0.005	-2.434	-1.057	**-1.262**	-0.613	0.050	0.143
Max Mx	151	101 1.5 (DL+	-0.023	-0.018	-0.972	-0.051	-0.127	**0.592**	0.323	-0.100
Min Mx	1431	101 1.5 (DL+	0.004	0.005	-2.434	-1.057	1.262	**-0.613**	0.050	-0.143
Max My	1433	101 1.5 (DL+	-0.022	-0.019	-0.943	0.040	-0.073	0.511	**0.578**	-0.039
Min My	1483	101 1.5 (DL+	-0.017	-0.000	-0.867	-0.012	-0.000	-0.448	**-0.540**	-0.004
Max Mx	134	101 1.5 (DL+	0.032	-0.019	-1.418	-0.011	-0.443	0.304	0.264	**0.198**
Min Mx	1432	101 1.5 (DL+	0.032	0.019	-1.418	-0.011	0.443	0.304	0.264	**-0.198**

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	157	101 1.5 (DL+	**0.078**	0.035	-2.416	0.070	0.298	0.614	0.638	-0.049
Min Qx	357	101 1.5 (DL+	**-0.078**	0.035	-2.416	0.070	-0.298	0.614	0.638	0.049
Max Qy	210	101 1.5 (DL+	-0.067	**0.037**	-1.522	0.028	-0.063	0.790	0.519	0.010
Min Qy	2190	101 1.5 (DL+	0.067	**-0.037**	-1.522	0.028	-0.063	0.790	0.519	0.010
Max Sx	2080	104 0.9 LL	-0.007	-0.000	**-0.001**	-0.055	-0.007	-0.179	-0.047	-0.000
Min Sx	154	101 1.5 (DL+	-0.039	-0.001	**-5.273**	-0.605	2.524	-1.166	-0.125	-0.012
Max Sy	617	101 1.5 (DL+	0.012	-0.001	-3.153	**0.308**	0.692	-2.455	-0.174	-0.115
Min Sy	133	101 1.5 (DL+	-0.043	-0.007	-5.095	**-2.191**	-2.590	-1.103	0.136	-0.050
Max Sx	339	101 1.5 (DL+	0.043	-0.007	-5.095	-2.191	**2.590**	-1.103	0.136	0.050
Min Sx	133	101 1.5 (DL+	-0.043	-0.007	-5.095	-2.191	**-2.590**	-1.103	0.136	-0.050
Max Mx	2208	101 1.5 (DL+	0.066	-0.036	-1.565	-0.012	-0.082	**0.973**	0.513	-0.018
Min Mx	1235	101 1.5 (DL+	0.001	-0.001	-1.575	-0.558	-1.079	**-2.493**	-0.667	0.086
Max My	333	101 1.5 (DL+	0.067	0.033	-1.804	-0.023	0.042	0.866	**0.691**	-0.089
Min My	164	101 1.5 (DL+	0.001	-0.000	-1.750	-0.062	-0.091	-1.325	**-0.781**	-0.142
Max Mx	135	101 1.5 (DL+	0.014	-0.000	-3.400	-0.154	-0.903	-2.393	0.036	**0.257**
Min Mx	337	101 1.5 (DL+	-0.014	-0.000	-3.400	-0.154	0.903	-2.393	0.036	**-0.257**

VI. DESIGN SUMMARY

1. Reinforcement for Membrane Stress SX :

SX = -5.273 N/mm²

- Membrane force F_x = SX * b * d

= 5.273 * 1000 * 80

= 421.84 kN

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

$= 0.87\, F_y A_{st}$

$= 0.87 * 415 * \frac{\pi}{4} * 16^2$

= 72.59 kN

- Total number of bars required for 1m width,

$= \frac{421.84}{72.59} = 5.81 \approx 6$ Bars.

2. Reinforcement for Local Bending Moment MX :

MX = 2.493 kN.m

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

P_t= 0.11 %

$P_{t\ lim}$= 0.12 %

- Area of reinforcement required A_{st},

$= \frac{0.12 * 1000 * 80}{100} = 96$ mm²

Now, Area of a single 12 mm dia. Fe-415 bars,

$= \frac{\pi}{4} * 12^2 = 113.09$ mm²

 Total number of bars required for 1m width,
$= \frac{96}{116.09} = 0.83 \approx 1$ Bars.

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

3. Reinforcement for Membrane Stress SY :
SY = -2.191 N/mm²
 Membrane Force F_y = SY * b * d
= 2.191 * 1000 * 80
= 175.28 kN

Now, Capacity of single 12 mm dia. HYSD Fe-415 bars can be given as,
$= 0.87\ F_y A_{st}$
$= 0.87 * 415 * \frac{\pi}{4} * 12^2$
= 40.83 kN

 Total number of bars required for 1m width,
$= \frac{175.28}{40.83} = 2.3 \approx 3$ Bars.

4. Reinforcement for Local Bending Moment MY :
MY = -0.781 kN.m
With reference to Chart 13, IS: 456, 1978 (SP 16),
$P_t = 0.03\ \%$
$P_{t\ lim} = 0.12\ \%$

 Area of reinforcement required A_{st},
$= \frac{0.12 * 1000 * 80}{100} = 96\ mm^2$

Now, Area of a single 10 mm dia. Fe-415 bars,
$= \frac{\pi}{4} * 10^2 = 78.54\ mm^2$

 Total number of bars required for 1m width,
$= \frac{96}{78.54} = 1.22 \approx 2$ 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 analysis conclude that;

a) For the base on different parameter:
   i. If we increase the thickness of singly curved shell the stress are decreases.
   ii. If we increase the height of singly curved shell the stresses are also increase.
   iii. And last if we increase the radius of singly curved shell the stresses are also increase.

b) For the base on different stress:

i. In membrane stress, for singly curved shell it governs only stress in direction of SX.

ii. For bending stress, it is less than membrane stress so it will not govern in design. Design is based on membrane stress only.

iii. For shear stress, it is less than membrane stress as well as bending stress so also it will not govern in design.

So, on the base of different stresses criteria conclude that for design of singly curved concrete shell structure only membrane stress (SX) governs.

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