A Comprehensive Study for Economic and Sustainable Design of ThinShell 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. Basically the roof member are tried to build up by using light, durable and sustainable materials only considering dead load or self-weight along with or without live load. It is also equally viable to analyze the effect of other load cases such as wind and seismic loads for safety,durability, economic and sustainability consideration. The design of curved member is sophisticated in comparison to horizontal and sloping roofs due to non-linear stresses and bending moments. Shell is a thin, light weight and curved structuremay be used as side as well as top covering - roof memberwhich bearsupcoming loads, due to its curved shape and low flexural rigidity. The Design code specifications are provided for curved shell member in IS: 2210 – 1994, the load case criteria is to be as per IS: 875(2)– 2000 and RCC design specifications as per IS: 456 – 2000. The study has been carried out using STAAD.PRO software, the shell structure is having specific dimension such as width, radius of curvature, length of chord, span and thickness and is analyzed for various loading conditions. Design Analysisof shell roof member is based on2 different method,once assuming shell structure as a curved RCC beam member and then shell as a curved RCC grid panel slab.

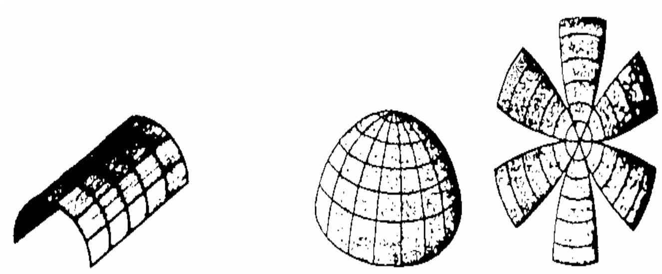
***Index Terms*— Shell, Roof, Flexural rigidity,Radius of curvature,STAAD.Pro, Sustainability.**

Introduction

Curved shape members like shell structures are naturally able to minimize the effect of stresses by distributing the load on the surface of structures.A shell structure is a thin curved membrane or slab usually of reinforced concrete that functions both as structure and covering.

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, 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.

Especially shell structure isefficiently able to bear direct bending stressesdue to its stressed skin structure As per IS 2210: 1988 in General - 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 synclastic or anticlastic according as their Gauss curvature is positive or negative.



Developed

Non- Developed

Fig. 1: **Forms of Curvature.**

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.

Smitha Gopinath[1], Nagesh Iyer[2], J. Rajasankar[3], Sandra D'Souza[4],et al [1] published workintegrates critical methodologies used for behaviormodeling of concrete and reinforcement with the physical interaction among them. The study is unique by considering interaction of tensile cracking and bond-slip which are the main contributors to nonlinearity in the nonlinear response of RC shell structures. *Another study by* Dr. Mrs. Mrudula S. Kulkarni1, Lakdawala Aliasgher[2]et al [2] presented a model of Analysis of tensile fabric structure using thin concrete doubly curved shell.Based on finite element method; models of varying complexity and precision shows that the simplest model, which represents shell with uniform thickness and no edge beams, yields conservative stress results. Yet these results indicate that the stresses are well within the strength limits.

For roofing system by shell is Rakul Bharatwaj.R[1], Jayashree.S.M[2], Dr. Helen Santhi. M[3]et al [3]found that the cost of Reinforced Inverted Umbrella and Pre-stressed Hyperboloid is lesser than grid roof. For smaller span, Inverted Umbrella can be used as roofing system. For spans more than 20 m where heavy reinforcement is required, pre-stressed Hyperbolic parabolic can be used which gives optimum use of steel and concrete and also the cost will be lesser than the conventional grid floor system.

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.

Objective of the study

The objective of this study is to carry out a comprehensive study for the economic and sustainable design of thin shell structure for different loading conditionbased on modeling and detailing done in Staad.pro software in form of shell having defined radius of curvature and chord length. For calculating the quantity of steel bars and concrete required to resist the stress due to assigned loads.

The study of various load combinations acting simultaneously will be comprehensively studied by the software profile for the data provided as per the forces and codal provision as per IS.2210:1988. “Criteria for design of reinforced concrete shell structures and folded plates” and IS.456:1988.and IS.875 (2):1988.

The purpose ofresearch carried out here is to design the shell, onceassuming it as curved beam member and once as grid plate panel slab structure, and analyzing the

***same single shell for different loading condition and combinations for getting economic* and sustain design.**

Structural Modeling of R.CShell member.

The figure 2shows the curved beam used as single shell, with following details,

- Radius of curvature(in x direction) = 12
- Gamma angle = 0^0 or 360^0
- Span of shell(in z direction) = 20 m
- Width of shell or length of chord = 12 m
- Thickness of shell = 0.08 m
- Depth of shell = 1.615 m
- Dead Load(factor) = -1
- Live load (imposed) = 0.4 kN/m
- Wind load = -1 KN/m

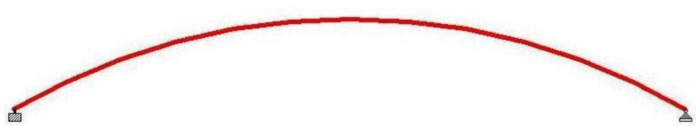


Figure – 2

The figure 3 shows the grid paneled curved slab used as single shell, with following details,

- Radius of curvature(in x direction) = 12
- Gamma angle = 0^0 or 360^0
- Span of shell(in z direction) = 20 m
- Width of shell or length of chord = 12 m
- Thickness of shell = 0.10 m
- Depth of shell = 1.615 m
- Dead Load(factor) = -1
- Live load (imposed) = 0.4 KN/m^2
- Size of grid panel element = 1m x 1m
- Wind load = -1 KN/m

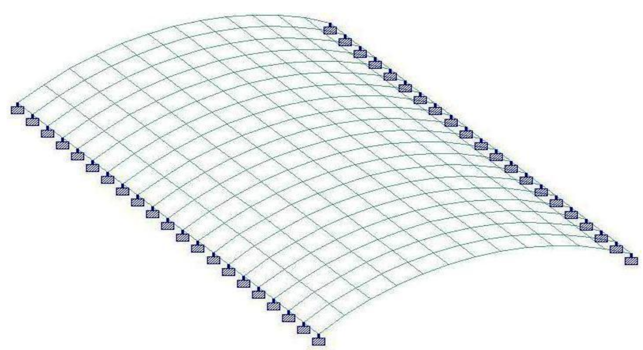


Figure - 3

Load calculation and its combination -

1. Unless otherwise specified, shells and folded plates shall be designed to resist the following load combinations:

a) Dead load,

b) Dead load + appropriate live load or snow load,

c) Dead load + appropriate live load + wind load, and

d) Dead load + appropriate live load + seismic load.

2.Dead loads is calculated on the basis of the unit weights taken in accordance with IS: 875 (Part I)-1987.

3. Live loads and wind loads is taken as specified in IS: 875 (Parts 2 to 4)-1987.

METHODOLOGY-

Thickness of shell member selected in accordance to clause 7.1.1 from IS 2210: 1988 i.e. Thickness of shells shall not normally be less than 50 mm if singlycurved 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.

Structure was analyzed for self-weight, live load, wind load and seismic loads. Analysis was performed in software based on IS code.

Dead Load: Automatically as multiplication f actor -1 as per structure.

Live Load: Calculated As per IS – 875 (part 3) – 1987.

Wind Load : For wind load analysis all data is taken from Indian standard code : IS – 875 (Part – 3) – 1987, since staad.pro software does not design directly for curved or inclined member.

Design Wind Speed = Vb * k1 * k2 * k3

Where;

Vb = Basic wind speed in m / s

k1 = risk coefficient = .92

k2 = THS Factor = 1.02

k3 = Topography Factor = 1

Vb = 39 m / s for Bhilai.

Terrain *Category 3* – Terrain with numerous closely spaced obstructions having the size of building-structures up to 10 m in height with or without a few isolated tall structures.

Class of Building: A (structures having maximum dimensions upto 10m) Wind intensities:

Design Wind Pressure = 0.6 * Vz^2

Exposure Factor At all Joints = 1

Wind load intensity at surface of shell = 0.7879 kN / m^2

The wind load on the building shall be calculated for the building as a whole. Wind Load on the Building = Cf * Ae * Pd

Where;

Cf = Force Coefficient

Ae = Effective Frontal Area

Pd = Design Wind Pressure

The value of Cf = 1 from Table – 20 of IS: 875 (Part – 3).

The semi-central angle shall preferably

be between 30 and 40".

Keeping the semi-central angle between these limits is advisable for the following reasons:

a) If the angle is below 40°, the effect of wind load on the shell produces only suction; and

b) With slopes steeper than 40".

Back forms may become necessary. Within these limits the semi-central angle shall be as high as

Load Combination: Auto generation by software under guidance of inbuilt Design Code data based on IS code specification in software.

ANALYSIS –

Analysis here done for the same dimensional and specification member with the help of software tool.

Table –1 Showing Reaction loads due to applied load cases on Shell Structure.

S.No	Type of SHELL	Load Case	Reaction of loads		
			x	y	z
1	Shell as beam	Dead Load	0	502.65	0
	Grid paneled Shell		0	502.43	0
2	Shell as beam	Live Load	0	125.66	0
	Grid paneled Shell		0	125.61	0
3	Shell as beam	Wind Load	198.02	0	0
	Grid paneled Shell		189.10	0	0

Table –2 Showing Displacement Data due to applied load cases on Shell (beam) Structure.

			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Min X	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max Y	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Min Y	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max Z	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Min Z	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max rX	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Min rX	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max rY	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Min rY	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max rZ	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Min rZ	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max Rs	1	1 LOAD CAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000

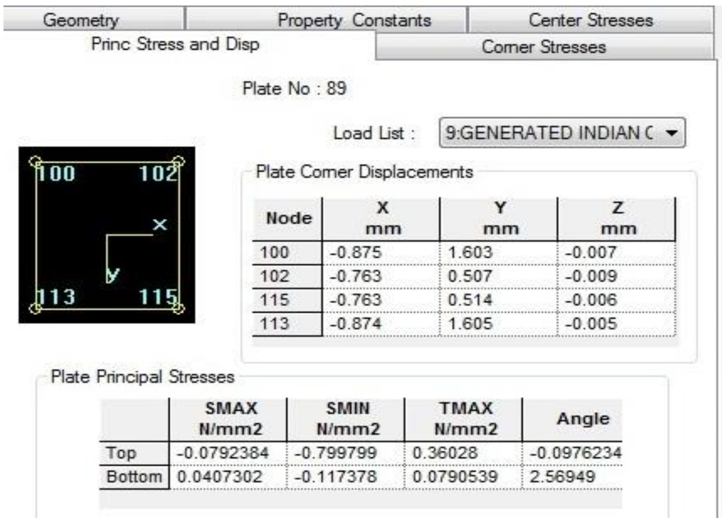
Table –3 Showing Displacement Data due to applied load cases on Shell (Grid) Structure.

			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	21	8 GENERATE	0.977	2.097	-0.021	2.314	-0.000	-0.000	0.000
Min X	20	9 GENERATE	-0.977	2.097	-0.021	2.314	-0.000	0.000	-0.000
Max Y	21	8 GENERATE	0.977	2.097	-0.021	2.314	-0.000	-0.000	0.000
Min Y	9	8 GENERATE	0.891	-2.658	-0.030	2.803	-0.000	-0.000	0.000
Max Z	273	4 GENERATE	0.000	-1.001	0.035	1.001	0.000	0.000	0.000
Min Z	13	4 GENERATE	0.000	-1.001	-0.035	1.001	-0.000	-0.000	0.000
Max rX	272	9 GENERATE	-0.805	-2.171	0.033	2.316	0.000	-0.000	-0.001
Min rX	12	9 GENERATE	-0.805	-2.171	-0.033	2.316	-0.000	0.000	-0.001
Max rY	265	8 GENERATE	0.641	-1.596	0.017	1.720	0.000	0.000	-0.001
Min rY	5	8 GENERATE	0.641	-1.596	-0.017	1.720	-0.000	-0.000	-0.001
Max rZ	12	8 GENERATE	0.758	0.298	-0.033	0.815	-0.000	0.000	0.001
Min rZ	11	9 GENERATE	-0.758	0.298	-0.033	0.815	-0.000	-0.000	-0.001
Max Rs	9	8 GENERATE	0.891	-2.658	-0.030	2.803	-0.000	-0.000	0.000

Table – 4 Showing Shear, Membrane and Bending Stresses due to applied load cases on Shell (Grid) Structure

			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	228	8 GENERATE	0.024	-0.000	-0.564	-0.072	-0.053	1.006	0.169	-0.008
Min Qx	13	9 GENERATE	-0.024	0.000	-0.564	-0.072	-0.053	1.006	0.169	-0.008
Max Qy	4	8 GENERATE	0.002	0.003	-0.435	0.001	0.001	0.584	-0.138	0.015
Min Qy	232	8 GENERATE	0.002	-0.003	-0.435	0.001	-0.001	0.584	-0.138	-0.015
Max Sx	1	3 LOAD CAS	0.010	-0.000	0.057	0.008	0.006	-0.592	-0.088	-0.004
Min Sx	12	8 GENERATE	0.024	0.001	-0.638	-0.065	0.051	0.991	0.079	-0.030
Max Sy	109	3 LOAD CAS	0.010	0.000	0.056	0.009	0.000	-0.595	-0.101	0.000
Min Sy	120	8 GENERATE	0.021	-0.000	-0.554	-0.089	0.002	0.950	0.162	0.000
Max Sx	24	8 GENERATE	0.024	0.000	-0.564	-0.072	0.053	1.006	0.169	0.008
Min Sx	13	9 GENERATE	-0.024	0.000	-0.564	-0.072	-0.053	1.006	0.169	-0.008
Max Mx	24	8 GENERATE	0.024	0.000	-0.564	-0.072	0.053	1.006	0.169	0.008
Min Mx	109	8 GENERATE	0.010	-0.000	-0.387	-0.061	-0.002	-0.835	-0.142	-0.000
Max My	36	8 GENERATE	0.022	-0.000	-0.559	-0.081	0.041	0.995	0.173	0.009
Min My	237	8 GENERATE	-0.003	-0.001	-0.492	-0.001	0.003	-0.811	-0.214	0.017
Max Mx	2	8 GENERATE	0.009	0.002	-0.434	-0.003	-0.000	-0.121	-0.175	0.032
Min Mx	230	8 GENERATE	0.009	-0.002	-0.434	-0.003	0.000	-0.121	-0.175	-0.032

Table – 5 Showing Principal Stress on shell element due to applied load case on Shell (Grid) Structure



a) Concrete design of Shell as beam by software –

D E S I G N R E S U L T S
M30 Fe415 (Main) Fe415 (Sec.)
LENGTH: 12566.4 mm SIZE: 12566.4 mm X 80.0 mm

COVER: 25.0* mm (suggested by software)

Section fails while designing section: 9424.8 mm

Exceeds maximum. permissible tensile steel %

DESIGN LOAD SUMMARY (KN MET)

SECTION |FLEXURE (Maxm. Sagging/Hogging moments)| SHEAR

(in mm) | P MZ MX Load Case | VY MX Load Case

0.0 | 161.40 0.00 0.00 10 | 0.00 0.00 10
| 179.33 0.00 0.00 1 |
1047.2 | 161.40 0.00 0.00 10 | -10.00 0.00 2
| 44.83 -5.24 0.00 2 |
2094.4 | 161.40 0.00 0.00 10 | -20.00 0.00 2
| 44.83 -20.94 0.00 2 |
3141.6 | 161.40 0.00 0.00 10 | -30.00 0.00 2
| 44.83 -47.12 0.00 2 |
4188.8 | 161.40 0.00 0.00 10 | -40.00 0.00 2
| 44.83 -83.78 0.00 2 |
5236.0 | 161.40 0.00 0.00 10 | -50.00 0.00 2
| 44.83 -130.90 0.00 2 |
6283.2 | 161.40 0.00 0.00 10 | -60.00 0.00 2
| 44.83 -188.50 0.00 2 |
7330.4 | 161.40 0.00 0.00 10 | -70.00 0.00 2
| 44.83 -256.56 0.00 2 |
8377.6 | 161.40 0.00 0.00 10 | -80.00 0.00 2
| 44.83 -335.10 0.00 2 |
9424.8 | 161.40 0.00 0.00 10 | -90.00 0.00 2
| 44.83 -424.12 0.00 2 |
10472.0 | 161.40 0.00 0.00 10 | -100.00 0.00 2
| 44.83 -523.60 0.00 2 |
11519.2 | 161.40 0.00 0.00 10 | -110.00 0.00 2
| 44.83 -633.55 0.00 2 |
12566.4 | 161.40 0.00 0.00 10 | 0.00 0.00 10
| -179.33 0.00 0.00 1 |

b) Concrete design of Grid shell by software -

ELEMENT DESIGN SUMMARY

ELEMENT LONG. REINF MOM-X /LOAD TRANS. REINF MOM-Y /LOAD

(SQ.MM/ME) (KN-M/M) (SQ.MM/ME) (KN-M/M)

1 TOP :	72.	0.99 / 9	72.	0.08 / 9
BOTT:	72.	-0.78 / 8	72.	-0.18 / 8
2 TOP :	72.	0.09 / 3	72.	0.01 / 3
BOTT:	72.	-0.38 / 9	72.	-0.20 / 9

CONCLUSION –

The shell structure designed as a beam member fails for selected design specification whereas the shell as a grid paneled member passes for same specific condition.

Also both the beam and grid shell member is safe for dead and live load cases but with exception of wind load and combination of loads.

The designed beam shell structure requires more thickness (0.1 m) as compare to 0.08 m provided after application of wind load case as per load applied. The beam shell structure have no deflection but grid shell allows deflection for flexibility and sustainability.

The reason behind this failure is flexural failure and increase in tension reinforcement in beam shell member. The stress generated due to applied loads causes flexibility distortion.

The impact of this design is that the shell designed as beam structure collapse under load whereas the shell designed as grid paneled structure easily resist stress and safely act to counter the deformation.

It is also cost effective to use grid panel structural design specification for shell and slab like structure.

SCOPE FOR FUTURE STUDIES:

Further scope of study is in the calculation and visualisation in Effectiveness of shell structure along with the analytic study of non edged shell with edged beam member shell. Based on calculation of load due to dead load, live load and seismic forces, and their combination on similar structure or edged beam shell structure.

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