

SEISMIC ANALYSIS OF SHELL STRUCTURES BY USING LINEAR STATIC AND DYNAMIC ANALYSIS

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Abstract— Shells are the one of the different type of structural element which is characterized by its shape. Shell is a three-dimensional solid body whose thickness is very small when compared with other dimensions. Shells are very strong and durable. In a realistic situation would probably still be standing when all conventional structures had failed. Shells are among the most efficient structures available, especially as roof structures. The superiority of shells as roofs is in their stiffness and strength that they stand without the support of columns. Shell is a roof structure so, that the main force that a dome bears is its own weight. These conditions make analysing the structural behaviour for predicting its respond imprecise for investigating the dynamic response of shells to applied loads. The dynamic forces acting on a concrete shells generally do not control the design, however, in earthquake prone areas the most disastrous force that can be applied on a shell is seismic load. Many researchers have studied the vibration characteristics of shells and formulated three dimensional analytical solutions. This paper presents five different types of shell structures were designed such as spherical dome, parabolic shell, hyperbolic paraboloid, cylindrical shell, multi-bay shell. Study of dynamic behaviour of reinforced concrete shells and the dynamic characteristics such as Base shear, displacements, mode shapes and time periods.

Keywords— Shell, Response Spectrum analysis, Time periods, Mode shapes, Displacements, SAP2000 software.

I. INTRODUCTION

In the past and recent years, there have been an increasing number of structures using RCC domes as one of the most efficient shapes in the world. It covers the maximum volume with the minimum larger volumes with no interrupting columns in the middle with an efficient shapes would be more efficient and economic. Dome roofs are the lightest structure to cover circular shape. Shells are space structures which provide large column free net precious area for utilization. Domes enclose the maximum amount of space with minimum surface. This feature provides economy in terms of consumption of constructional material. The availability of high speed computational tools and numerical software for analysis in recent years has facilitated structural engineers to develop many economical designs of space structures. Esthetically looks good over others forms of construction.

II. MODELLING AND ANALYSIS

A. Loads Considered

Dead Loads

Gravity loads of constant magnitudes and fixed positions that act permanently on the structure. Such loads consist of the weights of the structural system itself and of all other material and equipment permanently attached to the structural system.

Live Loads

Structural (typically gravity) loads of varying magnitudes and positions caused by the use of the structure. Furthermore, the position of a live load may change, so each member of the structure must be designed for the position of the load that causes the maximum load that causes the maximum stress in that member.

Seismic Loads

An earthquake is a sudden undulation of a portion of the earth's surface. Although the ground surface moves in both horizontal and vertical directions during an earthquake, the magnitude of the vertical component of ground motion is usually small and does not have a significant impact on most structures.

B. Load Combinations:

- 1) $1.5(DL+IL)$
- 2) $1.2(DL+ZL\pm EL)$
- 3) $1.5(DL\pm EL)$
- 4) $0.9DL\pm 1.5EL$

Codes Followed:

SHELL STRUCTURE: IS2210 1988

DEAD LOAD : IS875 1987(PART-1)

LIVE LOAD : IS875 1987(PART-2)

SEISMIC LOAD : IS1893 2002

C. Types of Analysis

1) *Static Analysis:* A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. The loads and the structure's response are assumed to vary slowly with respect to time.

2) *Dynamic Analysis:* Structural analysis is mainly concerned with finding out the behaviour of a physical structure when subjected to force. This action can be in the form of load due to the weight of things such as people, furniture, wind, snow, etc. or some other kind of excitation such as an earthquake, shaking of the ground due to a blast nearby, etc.

3) *Equivalent Lateral Force Method:* Seismic analysis of most structures is still carried out on the assumption that the lateral force is equivalent to the actual (dynamic) loading. This method requires less effort because, except for the fundamental period, the periods and shapes of higher natural modes of vibration are not required. The base shear, which is the total horizontal force on the structure, is calculated on the basis of the structure's mass, its fundamental period of vibration, and corresponding shape. The base shear is distributed along the height of the structure, in terms of lateral forces, according to the code formula. Planar models appropriate for each of the two orthogonal lateral directions are analysed separately; the results of the two analyses and the various effects, including those due to torsional motions of the structure, are combined. This method is usually conservative for low- to medium-height buildings with a regular configuration.

4) *Response Spectrum Analysis:* This method is also known as modal method or mode superposition method. The method is applicable to those structures where modes other than the fundamental one significantly affect the response of the structure. This method is based on the fact that, for certain forms of damping which are reasonable models for many buildings the response in each natural mode of vibration can be computed independently of the others, and the modal responses can be combined to determine the total response. Each mode responds with its own particular pattern of deformation (mode shape), with its own frequency (the modal frequency), and with its own modal damping.

D. Software Used

SAP2000 is general-purpose civil-engineering SOFTWARE ideal for the analysis and design of any type of structural system. Created by engineers for effective engineering, SAP2000 is the ideal SOFTWARE tool for users of any experience level, designing any structural system.

- SAP2000 From a simple small 2D static frame analysis to a large complex 3D nonlinear dynamic analysis.
- SAP2000 is the easiest, Most productive solution for your structural analysis and design needs.
- Complex Models can be generated and meshed with powerful built in templates.
- Integrated design code features can automatically generate wind, wave, bridge, and seismic loads with comprehensive automatic steel and concrete.

III. DESCRIPTION OF STRUCTURAL MODEL

In these paper presents designing five different types of shell structures. compare the behaviour of structures using mode shapes, time periods, displacements. The shape of the dome depends upon the type of the curve and the direction of the axis of revolution. When the segment of a circular curve revolves about its vertical diameter, a spherical dome is obtained. Similarly, conical dome is obtained by the revolution of a right angled triangle about its vertical axis, while an elliptical dome is obtained by the revolution of an elliptical curve about one of its axes.

Model-1: Spherical dome shell structure

Model-2: Cylindrical shell structure

Model-3: Paraboloid shell structure

Model-4: Multi-bay cylindrical shell structure

Model-5: Hyperbolic paraboloid shell structure

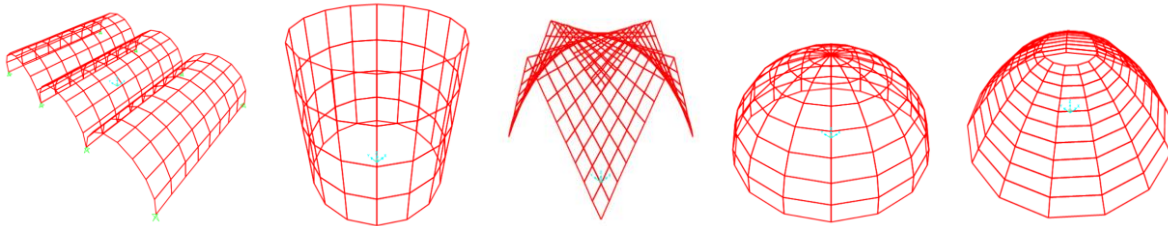


FIGURE 1 TYPES OF SHELLS

➤ Modelling and analysis has been done using SAP2000

A. Common Data Taken For All Shells

Live Load:

Live Load = 2kN/m^2

Seismic Data:

Seismic Zone	-	V
Seismic Intensity	-	Very High
Zone Factor (Z)	-	0.36
Importance Factor (I)	-	1.5
Soil condition	-	III

B. Models

1) Model 1:

TABLE I - DIMENSIONS OF MODEL-1

DIMENSIONS OF MODEL 1	
Foundation to Surface Level	1m
Support	Fixed Support
T beam	0.3x0.4m
Type of columns	Circular column
No. of Columns	8
Angle between columns	45°
Height of the columns	3m
Thickness of the plinth slab	0.4m
Thickness of the RCC slab	0.2m
Thickness of the dome	0.2m
Height of the wall	0.9m
Beam	0.4x0.2m
Type of the Shell	Spherical dome
Height of the dome	2m

Load Cases

Dead Load:

$$\begin{aligned}
 \text{Dead load for wall} &= \text{Height of wall} \times \text{Wall thickness} \times \text{Brick density} \\
 &= 0.9 \times 0.2 \times 20 \\
 &= 3.6 \text{ kN/m} \\
 \text{Dead load for Dome} &= \text{Height of dome} \times \text{Thickness} \times \text{Density} \\
 &= 2 \times 0.2 \times 25 \\
 &= 10 \text{ kN/m} \\
 \text{Dead load for slab RCC} &= \text{Slab thickness} \times \text{Concrete density} \\
 &= 0.2 \times 25 \\
 &= 5 \text{ kN/m}^2 \\
 \text{Dead load for slab PCC} &= \text{Slab thickness} \times \text{Concrete density} \\
 &= 0.4 \times 24 \\
 &= 9.6 \text{ kN/m}^2
 \end{aligned}$$

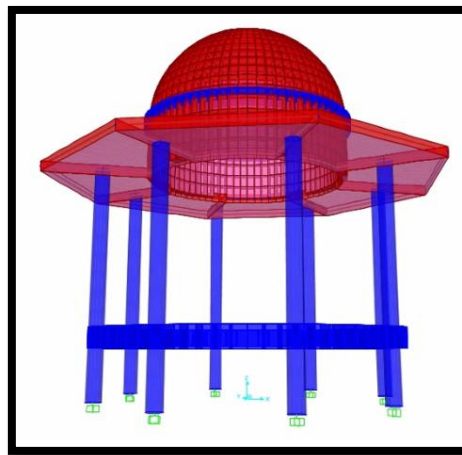


FIGURE 2: MODEL-1

Calculation of Lumped Masses to Various Floor Levels:

Roof:

Mass of infill + Mass of columns + Mass of beams in longitudinal and transverse direction of that floor + Mass of slab + Mass of shell+ Imposed load of that floor if permissible.

$$\begin{aligned}
 &= (0.9 \times 0.2 \times 20) + 0 + (0.4 \times 0.2 \times 25) + (2 \times 0.2 \times 25) + 0 + (2 \times 0.2 \times 25) \\
 &= 26.4 \text{ kN/m}
 \end{aligned}$$

Ground floor:

$$\begin{aligned}
 &= 0 + (8 \times 0.4 \times 0.2 \times 3 \times 25) + (0.4 \times 0.3 \times 24) + (0.3 \times 0.4 \times 25) + 2 \\
 &= 55.88 \text{ kN/m}
 \end{aligned}$$

$$\begin{aligned}
 \text{Seismic weight of building} &= \text{Seismic weight of all floor} &= M_1 + M_2 \\
 &= 26.4 + 55.88 \\
 &= 82.28 \text{ kN/m} \\
 \text{Determination of Fundamental Natural Period} &= T_a \\
 &= 0.075 \times h^{0.75} \\
 &= 0.075 \times 6^{0.75} \\
 &= 0.2875
 \end{aligned}$$

Design Seismic Base Shear

The total design lateral force or design seismic base shear (V_b) along any principal direction shall be determined by the following expression:

$$V_b = A_h W$$

$$A_h = \frac{ZI}{2R} \left(\frac{S_a}{g} \right) = 0.1836$$

Design seismic base shear, $V_b = 0.1836 \times 82.28 = 15.73 \text{ kN}$

2) Model 2:

TABLE II
 DIMENSIONS OF MODEL-2

DIMENSIONS OF MODEL 2	
Support	Fixed Support
Total height of tank	18m
Type of columns	Circular column
No. of Columns	8
Angle between columns	45°
Height of the columns	3m
Column	0.6x0.6
Beam	0.6x0.3m&0.6x0.4m
Gap between beam to beam	3m
Thickness of the dome	0.4m
Type of the Shell	cylindrical shell
Height of the dome	4m

Load Cases

Dead Load:

Dead load for Dome = Height of dome x Thickness x Density
 = 4x0.2x25
 = 20kN/m

Dead load for slab RCC = Slab thickness x Concrete density
 = 0.2x25
 = 5kN/m²

Live Load:

Hydrostatic pressure(p) = $\rho g h$
 = 1000x9.8x4
 = 39.2N/m²

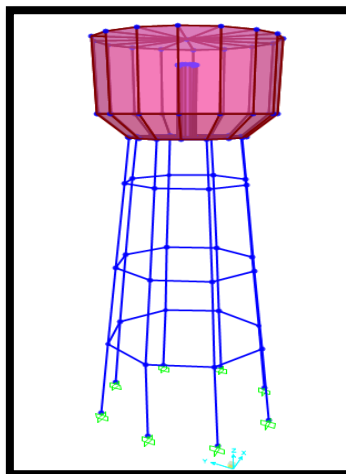


FIGURE 3 MODEL-2

Equivalent Static Lateral Force Method:

Calculation of Lumped Masses to Various Floor Levels:

Roof:

Mass of infill + Mass of columns + Mass of beams in longitudinal and transverse direction of that floor + Mass of slab + Mass of shell+ Imposed load of that floor if permissible.

$$= (0 + (4 \times 0.2 \times 0.4 / 2 \times 25) + (0.2 \times 25) + 0 + (4 \times 0.4 \times 25) + 39.2)$$

$$= \mathbf{88.2}$$

Ground floor:

$$= 0 + (8 \times 0.6 \times 0.6 \times 3 / 2 \times 25) + (0.6 \times 0.4 \times 25) + (0.3 \times 0.4 \times 25) + 0$$

$$= \mathbf{117}$$

$$\text{Seismic weight of building} = \text{Seismic weight of all floor} = M_1 + M_2$$

$$= 88.2 + 117 = \mathbf{205.2}$$

$$\text{Determination of Fundamental Natural Period} = T_a$$

$$= 0.075 \times h^{0.75}$$

$$= 0.075 \times 18^{0.75}$$

$$= 0.655$$

Design Seismic Base Shear

The total design lateral force or design seismic base shear (V_b) along any principal direction shall be determined by the following expression:

$$V_b = A_{hw}$$

$$A_h = 0.081$$

$$\text{Design seismic base shear, } V_b = 0.081 \times 205.2$$

$$= \mathbf{16.62 \text{ kN}}$$

3) Model 3:

TABLE III
 DIMENSIONS OF MODEL 3

DIMENSIONS OF	MODEL 3
Support	Fixed Support
Height of the building	12m
Total Height of the building	16m
No. of floors	G+3
Height of the floor	4m
Beam	03x0.3m
Column	0.4x0.3m
Thickness of the slab	0.1m
Type of the Shell	Parabolic hyperboloid
No. of shells	5
Height of the middle shell	4m
Height of the corner shell	2m
Thickness of the dome	0.2m

Dead Load:

$$\text{Dead load for wall} = \text{Height of wall} \times \text{Wall thickness} \times \text{Brick density}$$

$$= 12 \times 0.2 \times 20$$

$$= 48 \text{ kN/m}$$

$$\text{Dead load for Dome} = \text{Height of dome} \times \text{Thickness} \times \text{Density}$$

$$= 9 \times 0.2 \times 25$$

$$= 45 \text{ kN/m}$$

$$\text{Dead load for slab RCC} = \text{Slab thickness} \times \text{Concrete density}$$

$$= 1 \times 25 = 25 \text{ kN/m}^2$$

$$\text{Dead load for slab PCC} = \text{slab thickness} \times \text{concrete density}$$

$$= 1 \times 24 = 24 \text{ kN/m}^2$$

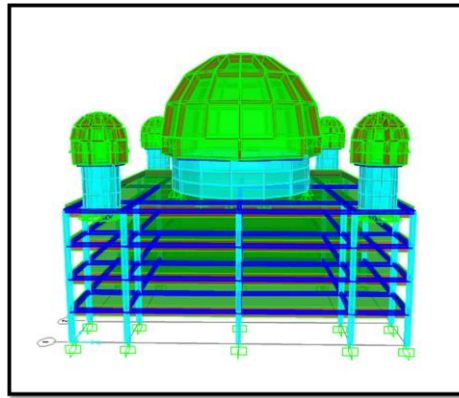


FIGURE 4 MODEL- 3

Calculation of Lumped Masses to Various Floor Levels:

Roof:

Mass of infill + Mass of columns + Mass of beams in longitudinal and transverse direction of that floor + Mass of slab + Mass of shell+ Imposed load of that floor if permissible.

$$= (12 \times 0.2 \times 20 \times 3/2) + (9 \times 0.2 \times 25 \times 3/2) + (1 \times 25 \times 3/2) + (1 \times 2 \times 0.4) + 0$$

$$= \mathbf{142.4}$$

Ground floor:

$$= (3 \times 25 \times 0.4 \times 0.3) + (3 \times 24 \times 1) + (3 \times 1 \times 25) + (0.3 \times 0.3 \times 25) + 2$$

$$= \mathbf{166}$$

$$\begin{aligned} \text{Seismic weight of building} &= \text{Seismic weight of all floor} &= M1 + M2 + M3 + M4 \\ & &= 142.4 + 3(166) \\ & &= \mathbf{640.4} \end{aligned}$$

$$\begin{aligned} \text{Determination of Fundamental Natural Period} &= T_a = 0.075 \times h^{0.75} \\ &= 0.075 \times 12^{0.75} \\ &= \mathbf{0.48} \end{aligned}$$

Design Seismic Base Shear

The total design lateral force or design seismic base shear (V_b) along any principal direction shall be determined by the following expression:

$$\begin{aligned} V_b &= A_h w \\ A_h &= 0.1132 \end{aligned}$$

$$\text{Design seismic base shear, } V_b = 0.1132 \times 640.4 = \mathbf{72.81 \text{ kN}}$$

4) Model 4:

TABLE 4
DIMENSIONS OF MODEL 4

DIMENSIONS OF	MODEL 4
Support	Fixed Support
Type of columns	Circular column
No. of Columns	8
Height of the columns	5m
Column	0.4x0.3m
Length	10m
Type of the Shell	multi bay cylindrical shell
Height of the shell	4m
Thickness of the shell	0.2m

Load Cases

Dead Load:

$$\begin{aligned} \text{Dead load for Dome} &= \text{Height of dome} \times \text{Thickness} \times \text{Density} \\ &= 4 \times 0.2 \times 25 \\ &= \mathbf{20 \text{ kN/m}} \end{aligned}$$

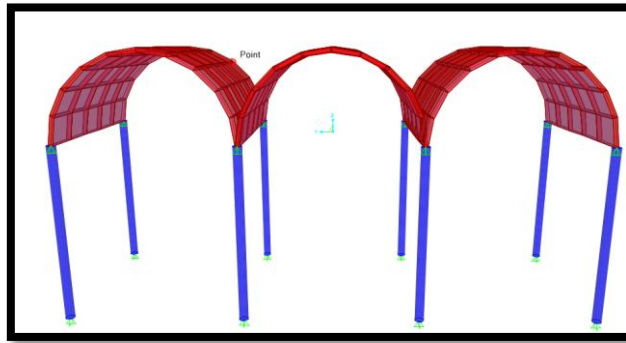


FIGURE.5 MODEL 4

Calculation of Lumped Masses to Various Floor Levels:

Roof:

Mass of infill + Mass of columns + Mass of beams in longitudinal and transverse direction of that floor + Mass of slab + Mass of shell+ Imposed load of that floor if permissible.

$$= 0 + (6 \times 0.2 \times 25) + 0$$

$$= 30$$

Ground floor:

$$= (0.4 \times 0.3 \times 8 \times 5) + 2$$

$$= 6.8$$

$$\text{Seismic weight of building} = \text{Seismic weight of all floor} = M1 + M2$$

$$= 30 + 6.8$$

$$= 36.8$$

Determination of Fundamental Natural Period

$$= T_a$$

$$= 0.075 \times h^{0.75}$$

$$= 0.075 \times 11^{0.75}$$

$$= 0.453$$

Design Seismic Base Shear

The total design lateral force or design seismic base shear (V_b) along any principal direction shall be determined by the following expression:

$$V_b = A_h w$$

$$= 0.135$$

$$\text{Design seismic base shear, } V_b = 0.135 \times 36.8 = 4.968 \text{ Kn}$$

5) Model 5:

TABLE 5
DIMENSIONS OF MODEL 5

DIMENSIONS OF	MODEL 5
Foundation to Surface Level	1.2m
Support	Fixed Support
T beam	0.3x0.4m
Type of columns	Circular column
No. of Columns	4
Angle between columns	90°
Height of the columns	2m
Column	0.4x0.4
Thickness of the plinth slab	0.4m
Thickness of the RCC slab	0.2m
Thickness of the dome	0.4m
Type of the Shell	Hyperbolic paraboloid
Height of the dome	5m

Load Cases

Dead Load

$$\begin{aligned}
 \text{Dead load for slab PCC} &= \text{Slab thickness} \times \text{Concrete density} \\
 &= 0.4 \times 24 \\
 &= 9.6 \text{ kN/m}^2 \\
 \text{Dead load for shell} &= \text{Height of shell} \times \text{Thickness} \times \text{Density} \\
 &= 5 \times 0.2 \times 25 \\
 &= 25 \text{ kN/m}
 \end{aligned}$$

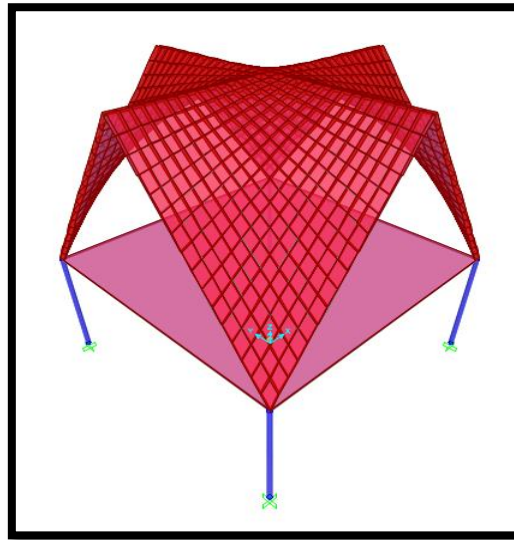


FIGURE. 6 MODEL 5

Calculation of Lumped Masses to Various Floor Levels:

Roof:

Mass of infill + Mass of columns + Mass of beams in longitudinal and transverse direction of that floor + Mass of slab + Mass of shell+ Imposed load of that floor if permissible.

$$= (5 \times 0.2 \times 25)$$

$$= 25$$

Ground floor:

$$= (4 \times 0.4 \times 0.4 \times 25) + (0.4 \times 24) + (0.3 \times 0.4 \times 25)$$

$$= 49.6$$

$$\begin{aligned}
 \text{Seismic weight of building} &= \text{Seismic weight of all floor} &= M_1 + M_2 \\
 & &= 25 + 49.6 \\
 & &= 74.6
 \end{aligned}$$

$$\begin{aligned}
 \text{Determination of Fundamental Natural Period} &= T_a = 0.075 \times h^{0.75} \\
 &= 0.075 \times 6^{0.75} \\
 &= 0.28
 \end{aligned}$$

Design Seismic Base Shear

The total design lateral force or design seismic base shear (V_b) along any principal direction shall be determined by the following expression:

$$\begin{aligned}
 V_b &= A_h w \\
 &= 0.135
 \end{aligned}$$

$$\text{Design seismic base shear, } V_b = 0.135 \times 74.6 = 10.07 \text{ kN}$$

IV. RESULTS

A. Displacements:

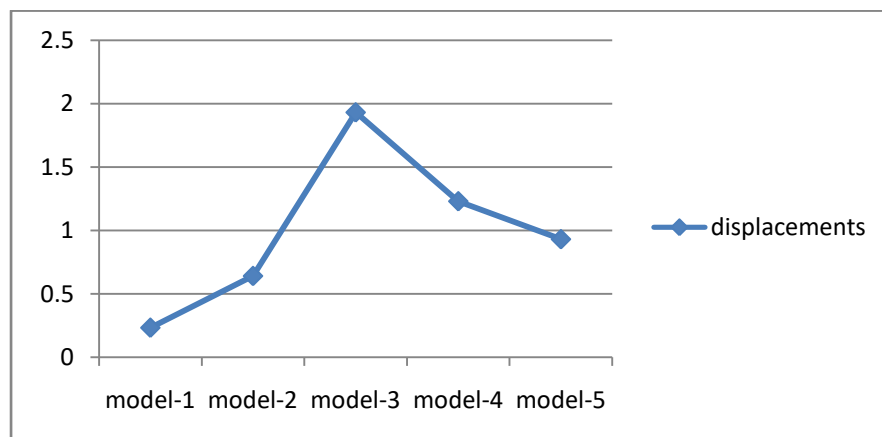


FIGURE 7:DISPLACEMENT OF SHELLS AT TOP POINT

B. Time Periods:

TABLE 6
TIME PERIOD FOR DIFFERENT SHELLS

S.No	Model Type	Natural or Fundamental Time period	Shape of the mode	Remarks
1	Spherical dome	0.232	longitudinal	Perform well
2	Cylindrical shell	0.932	Rotation	Complex
3	Paraboloid shell	4.973	longitudinal	Perform well
4	Multi-bay shell	2.324	Multi dynamic characteristics	Complex
5	Hyperbolic paraboloid	1.732	Multi dynamic characteristics	Complex

C. Base Shear

TABLE 7
BASE SHEAR FOR DIFFERENT MODELS

MODELS	LONGITUDINAL(U1)	LATERAL(U2)
MODEL-1	20.42	28.22
MODEL-2	16.14	14.32
MODEL-3	75.41	79.63
MODEL-4	4.329	9.841
MODEL-5	17.11	17.32

V. CONCLUSIONS

- From figure 7 we concluded that the displacement of spherical dome shell is less when compared to the other shells.
- If stiffness increases time period decreases, while comparing this shells from table 6 spherical dome and cylindrical shell structure has low time periods. So that they have more rigidity.
- Because of complex geometry and mass distribution shell structures are having critical and different characteristics.
- In multi-bay shell structure and hyperbolic paraboloid shells, they perform multi dynamic characteristics, so that it's not well performed shells.
- Due to base shear results table 7, we obtained that cylindrical shell and multi-bay shell structure perform well.
- While the shell designs comes to formwork the hyperbolic paraboloid and multi-bay shell structures are tough to get exact shapes we designed.
- Spherical domes perform well even in seismic conditions.

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