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Seismic Response Analysis of RC Shell Structures: A Parametric Study of Span and Rise Variations Across Different Seismic Zones

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Abstract

Concrete shells have been widely used for roofing large column-free areas and have been constructed in various countries for almost half a century. The objective of the present work is to compare the behaviour of RC shell structure having different geometrical parameters under seismic forces.

For this purpose a multi frame RC shell structure having single storey is considered. For analysis central rise and span of RC shell structure are considered having variations in parameters. The analysis is carried out with the help of software Staad.Pro. The total 12 models are to be compared in seismic zone III, zone IV and zone V.Details of the models considered for analysis are plan area A : 18m x 24m, column grid A : 6m x 4m, plan area B : 24m x 24m, column grid B : 8m x 4m, height : 6m, size of beams : 300mm x 600mm, size of columns : 400mm x 400mm, thickness of shell : 200mm. Shell is supported by columns through edge beams.Material properties for the analysis are density: 25 KN/m³, poisons ratio: 0.2, modulus of elasticity: 5000√fck, grade of concrete: M-20, grade of steel: Fe-500. To study the seismic behavior of RC shell structure the result parameters selected are maximum deflection, maximum moments and shear stresses. From the result analysis it is observed that in all the models deflection, moments and shear stress values are less for lower zones and it goes on increasing for higher zones because the magnitude of intensity will be the more for higher zones.In a RC shell structure if span is same but central rise is varying, then the deflection values increases with increase in rise when earthquake forces governs but in case of gravity forces deflection values decreases with increase in rise in all the zones considered, also the moment values and shear stress values decreases with increase in rise for all the load cases in all the zones considered.In a RC shell structure if central rise is same but span is varying, then the deflection values increases with increase in span for all the load cases, also the moment values and shear stress valuesincreases with increase in span for all the load cases in all the zones considered.

Keywords: Concrete Shells, Deflection, Moment, Shear Stress.

1. Introduction

Concrete shells have been widely used for roofing large column-free areas and have been constructed in various countries for almost half a century. The RC shells can be defined as curvedshape slabs whose thickness is extremely small as compared to their other dimensions. The curved structures resists more applied loads than flat structures with less deformation and stresses. In addition, shell structures are a lot efficient than other structures having the same span and dimensions because they have a high strength to weight ratio. There are a different type of shells that depends on their size, shape, type of load, material used etc. Because of this huge variation, many practical difficulties were occurring. To solve these difficulties many analysts presented their theory for design of shell. The very common type of shell used in field is cylindrical RC shell to cover large space. In general, long shells and short shells are the two different forms of cylindrical shells. Generally, long shells are used for roof factories and short shells for aircraft hangers.

Shell surfaces provide a structurally efficient solution to the problem of carrying roof loads over long spans. These three-dimensional forms owe their efficiency to the translation of applied loads into tensile and compressive stress, as well as shear stress, in the plane of their surface. These are termed as membrane stresses. Shell may be single curved in one direction, e.g. in the form of cylinder, or double curved, e.g. to form a dome or a saddle-shaped surface.

A shell can be defined as a curved slab whose thickness is very small compared to the other dimensions of the shell. Alternatively, a shell can also be defined as body that is bounded by two closely spaced curved surfaces. The middle surface, which is the locus of points that are equidistant from the two bounding surfaces, defines the shape of the shell. The thickness of the shell at a given point is the distance between the two bounding surfaces measured along the normal to the middle surface passing through a point.

PROBLEM IDENTIFICATION

After reviewing the literature papers, the effectiveness of different geometrical parameters under seismic forces will be carried out. The seismic analysis of RC shell structure for different rise and span will be examined.

OBJECTIVE

In the present dissertation or work a RC shell structure is considered to study its seismic behaviour with variation of geometric parameters. The objectives of the present work are:

1. To study the performance of RC shell structure with varying geometric parameters under seismic loading.
2. To study the effect on RC shell structure the result parameters considered are as maximum deflection, maximum moments and shear stresses.

To compare the RC shell structure with varying geometric parameters for above result parameters in zone III, zone IV and zone V.

ROOF

The topmost element of a constructed structure is said as roof which is provided to protect the building from rain, wind, snow, sun etc. and furthermore secures living creatures and materials kept inside the building. The roof should be **strong, stable, weather proof and safe against fire and calamity**.

FUNCTIONS OF ROOF

The major function of the roof is to be concerned for and deal with the weather elements, predominantly precipitation, thereby protecting the interior and structural elements of the home.

In addition to protecting the interior elements of the home the roof components should also be designed, related to the gutters and downspouts, to direct rainwater and runoff away from the foundation area, compaction and water entering the basement area.

CLASSIFICATIONS OF ROOF ACCORDING TO SHAPE

1. Flat Roofs
2. Pitched Roofs
3. Shell Roofs

1 Flat Roofs:

Flat roofs are fundamentally watertight membranes that should have just enough slopes to permit water to run off. The slope of flat roof is usually from 1 degree to 5 degrees. These roofs are constructed similarly as floor is. The roof acts much similarly as a level platform to support the load. This roof varies from intermediate floor in view of top finish known as ‘Terracing’**which protects the roof from unfavorable effects of rain, snow, and heat and so on.**

Advantages of Flat Roofs:

1. **It can be utilized for living purposes.**
2. **It is comparatively safer than other types of roofs.**
3. **Its construction and maintenance is simpler and more economical.**
4. **It provides better light, ventilation and architectural appearance.**
5. **The construction of upper floor can be taken up when desired in minimum time.**
6. **It is economical than pitched roof for normal residential and official buildings because false ceiling is required for thermal comfort.**

Disadvantages of Flat Roofs:

1. It cannot be used for industrial sheds without using intermediate columns.
2. These roofs are not suitable where rainfall or snowfall is heavy.

2 Pitched Roofs:

Pitched roofs are the roofs having a **slope of greater than 10 degrees to the horizontal surface**. Symmetrical pitched roof is the most common shape of roof. The slope of roof differs according to the span, climatic conditions, types of roof covering and so on. **In the heavy snowstorm areas, slopes provided are steeper as of 1: 1.5 or 1: 1 to decrease the frequency of snow load on roof**. Pitched roofs are usually constructed with material wood or steel. Pitched roofs are made of steel trusses (frames) and rolled steel sections.


Advantages of Pitched Roofs:

1. It is constructed in a very short time.
2. It **does not require weather covering and water proofing treatment**.
3. This roof has no problem of drainage, rainy water and snow.
4. It is useful for making for long span industrial sheds without intermediate columns, walls etc.

Disadvantages of Pitched Roofs:

1. It has more weather effects
2. It is not so durable.
3. It cannot be used for upper floor.
4. The roof has leakage problem.
5. When the roof is constructed with iron sheets, rusting problem may arise.

3. Shell Roofs:

As the shell roofs are constructed in consideration with functional and architectural requirements. These roofs are constructed in public**buildings such as recreation centers, theatres, libraries, factories or workshops** etc. Shell roofs are constructed where large floor areas are required to be covered without hindrance from columns.


Fig. 2.3Shell roofs (https://images.app.goo.gl/FHAruL4qfhVDr4qy5)

Advantages of Shell Roofs:

1. More area is covered without any intermediate columns etc.

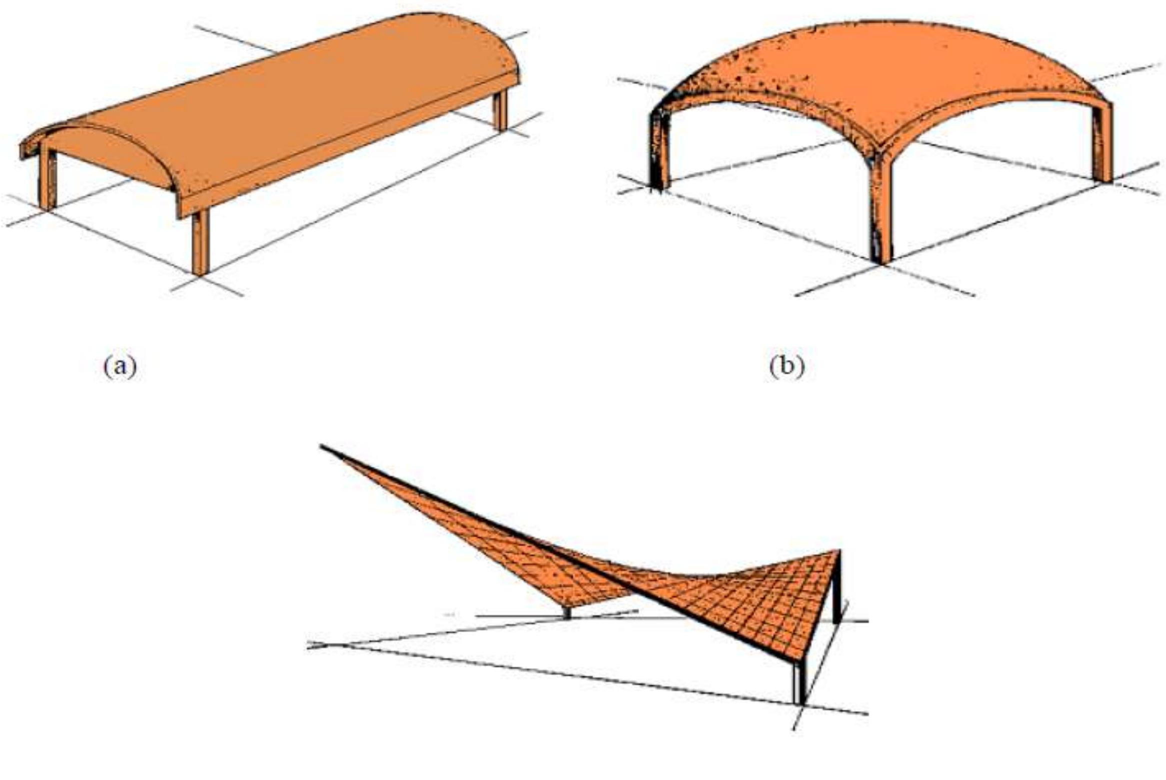
2. There is no leakage problem in this type of roof.
3. It gives architectural view to add beauty nearby area.
4. The area covered under this roof is used for conferences and big gathering.
5. Economical for very large span roofs as material consumption would be less.
6. Dead loading is much less compared to other alternatives.
7. Drainage may not be a problem and gutter formations at edges is natural.
8. Deflection for large spans not a problem.
9. Transversely, load transfer is through shell action requiring min steel/concrete.

Disadvantages of Shell Roofs:

1. It cannot be used to construct upper floor.
2. Shuttering is expensive.
3. Centering is also costly.
4. Mostly used for RCC roofing only.
5. Due to thin sections strict supervision required.

INTRODUCTION TO SHELL:

Shell surfaces provide a structurally efficient solution to the problem of carrying roof loads over long spans. These three-dimensional forms owe their efficiency to the translation of applied loads into tensile and compressive stress, as well as shear stress, in the plane of their surface. These are termed as membrane stresses. Shell may be single curved in one direction, e.g. in the form of cylinder, or double curved, e.g. to form a dome or a saddle-shaped surface.



(a) (b) (c)

Fig. Examples of shell roofs: a) Barrel vault, b) Dome, c) Saddle dome

A shell can be defined as a curved slab whose thickness is very small compared to the other dimensions of the shell. Alternatively, a shell can also be defined as body that is bounded by two closely spaced curved surfaces. The middle surface, which is the locus of points that are equidistant from the two bounding surfaces, defines the shape of the shell. The thickness of the shell at a given point is the distance between the two bounding surfaces measured along the normal to the middle surface passing through a point.

Classification of shell surfaces:

1 Gaussian Curvature:

Shell surfaces are usually classified based on their gaussian curvatures. For a threedimensionalsurface, the product of the maximum and minimum principal curvatures gives us the Gaussian curvature. They are orthogonal to each other and can be found out by intersecting infiniteplanes with the surface at any point. Based on the product of the principal curvatures wecan further classify the gaussian surfaces as discussed below.

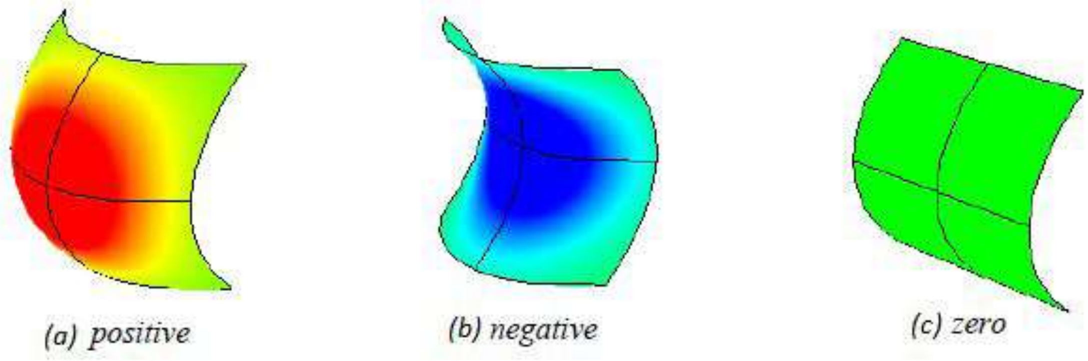


Fig. 2.5Types of Gaussian curvatures (https://images.app.goo.gl/aLUXAu43RUhPqzar6)

Synclastic: A Synclastic surface has a positive gaussian curvature and is shown in figure 2.5 (a).Both the principal curvatures have the same sign. They generally exhibit in-planemeridional and circumferential stresses to carry loads. Spheres and elliptical paraboloidsare common examples of this kind of surface.

Anticlastic: In this type of surface both the principal curvatures have different signs resulting in anegative gaussian curvature (figure 2.5 (b)). Having opposite signed principal curvatureenables these surfaces to act with a combination of compressive and tensile arch behavior under perpendicular loads. Hypars are good examples of anticlastic surfaces.

Monoclastic: In this type of structures if one of the principal curvatures is zero then it is said tomonoclastic surfaces. Theyhave zero gaussian curvature as seen in figure 2.5 (c). Cylindrical shells are the mostcommon examples of this type of surface.

SOFTWARE USED

Analysis of all the cases is done with the help of software STAAD Pro v8i for windows XP. This is comprehensive software that shows all the aspects of Structural Engineering-model development, analysis, design, verification and visualization. This is based on the principles of "concurrent engineering". After building model it is verified then analysis and design is performed and then create a report on basis of results obtained. The main options available from the concurrent graphics' environment are:

1. STAAD Pro Analysis and Design
2. STAAD Pre Graphics Input Generation
3. STAAD Post Graphical Post-Processing

Utilities of Software:

Separately from a variety of windows facilities as temporary exit to other programs running concurrently with STAAD Pro v8i, this software also offers the following utilities within its Graphical User Interface Environment.

1. **Text Editor –** For creating/editing the input file
2. **View Facility –** For viewing the output file
3. **Facility of Print/Plot –** For output file's and graphics screen's printing and plotting
4. **Data Exchange with CAD Program –** For import/export of drawing data
5. **On Screen Calculator –** For interactive arithmetical calculations
6. **On Line Manual –** For detailed information, STAAD Pro v8i which commands as explained in the reference manual.

In the main menu text editor is available as well as from the STAAD Pre facility. It is also available as an independent application from the REI applications group. This can be used for creating new input file. The STAAD Pre graphics input generator creates viewing/editing an existing input file and viewing/editing an input file. The view facility is accessible from the main menu as well as from the STAAD Post facility. This facility can be utilized to view the complete output file on the screen. On this both numerical data and graphics output can be viewed.

PROBLEM DEFINITION

The object of the present work is to compare the behavior of RC shell structure having different geometrical parameters under seismic forces. For this purpose a multi frame RC shell structure having single storey is considered. Geometric parameters considered for comparison are central rise and span. The number of bays considered for multi frame RC shell is 3, central rise 1m (R1) and 2m (R2), span 6m (S1) and 8m (S2). For the analysis models considered are:

Model 1: Rise 1m, span 6m (R1-S1)
Model 2: Rise 2m, span 6m (R2-S1)
Model 3: Rise 1m, span 8m (R1-S2)
Model 4: Rise 2m, span 8m (R2-S2)

The total 12 models are to be compared in seismic zone III, zone IV and zone V.

To study the seismic behavior of RC shell structure the result parameters selected are maximum deflection, maximum moments and shear stresses.

Details of the models considered for analysis are as follows:

Plan area A: 18m x 24m
Column grid A: 6m x 4m
Plan area B: 24m x 24m
Column grid B: 8m x 4m

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Height: 6m
Size of beams: 300mm x 600mm
Size of columns: 400mm x 400mm
Thickness of shell: 200mm
Shell is supported by columns through edge beams.

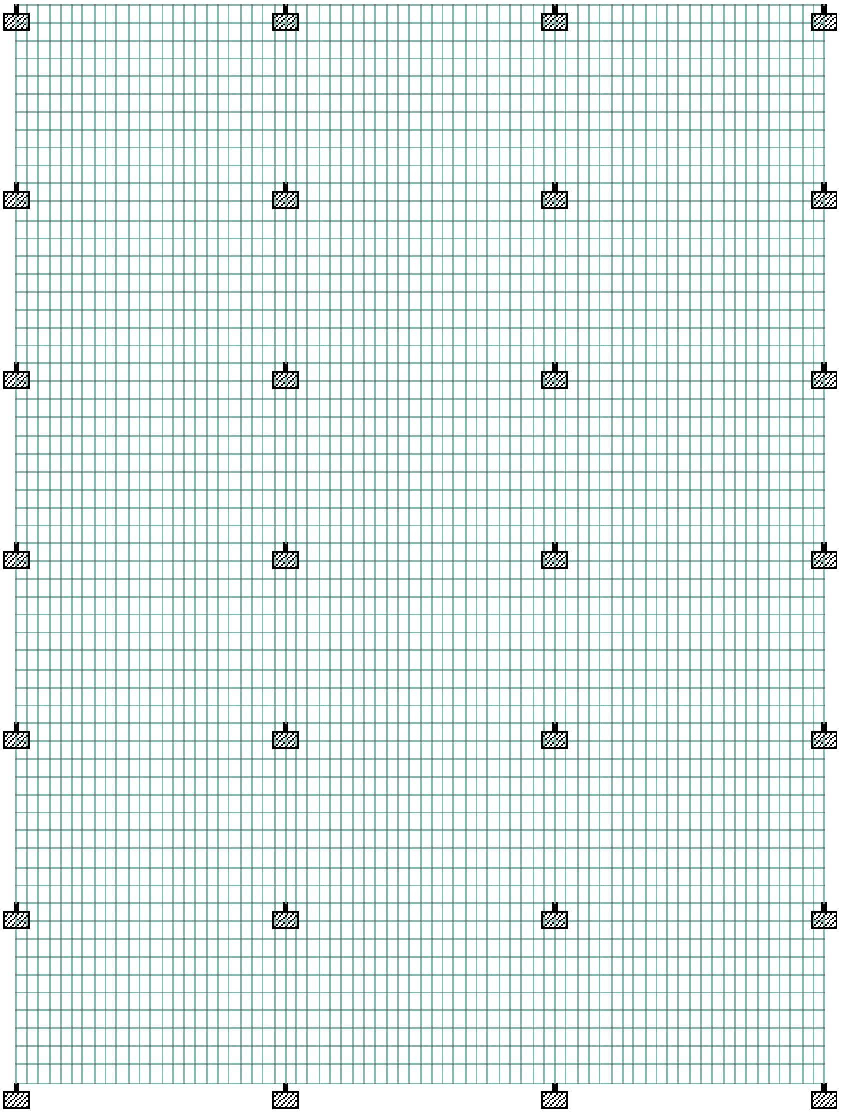


Fig. 4.1 Plan of RC shell structure

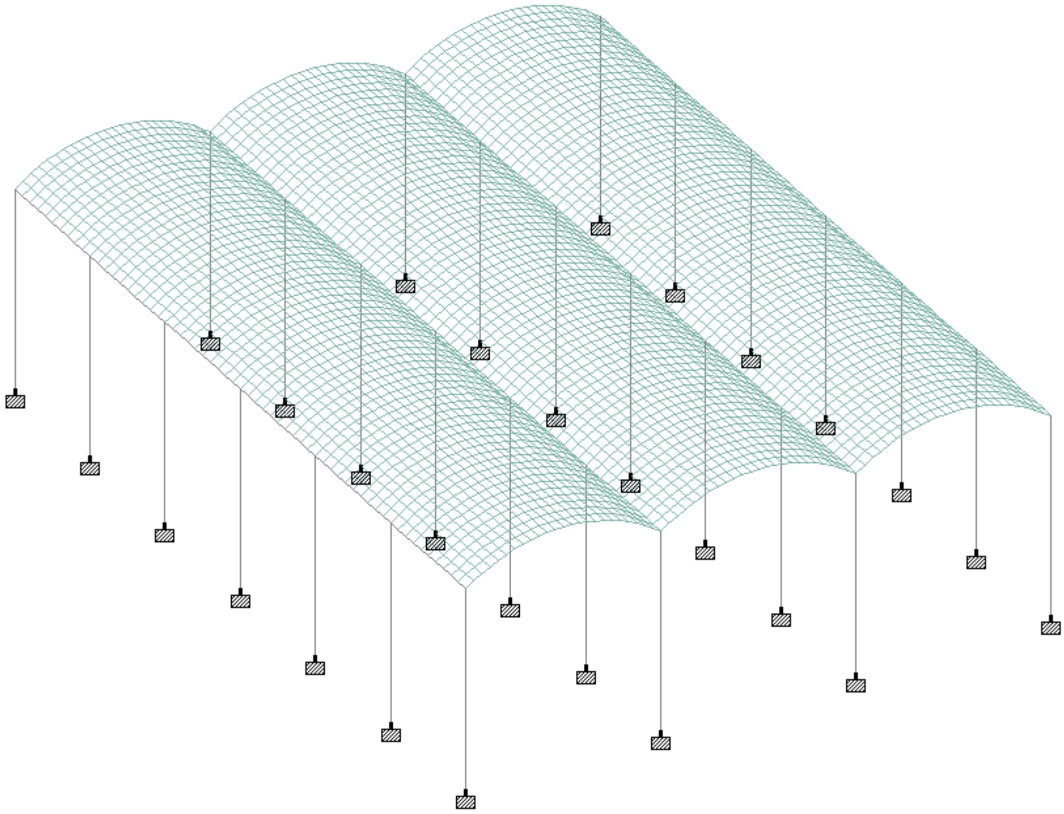


Fig. 4.2 3D view of RC shell rise 1m, span 6m

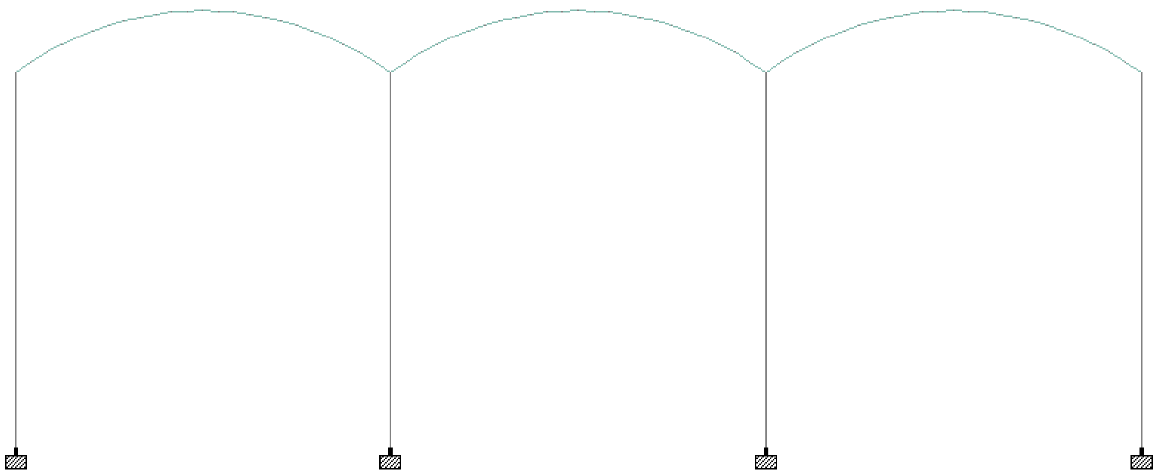


Fig. 4.3Elevation of RC shell rise 1m, span 6m

MATERIAL PROPERTIES

Material properties for the analysis are as follows:

Density: 25 KN/m³

Poisson's ratio: 0.2

Modulus of elasticity: 5000√fck

Grade of concrete: M-20

Grade of steel: Fe-500

LOADINGS CONSIDERED

1. Dead Load- Thickness x unit weight (it is taken by software itself).
2. Imposed Load- 0.75 KN/m^2.
3. Earthquake Load- As perIS 1893 (part-I):2002.

Load Combinations:

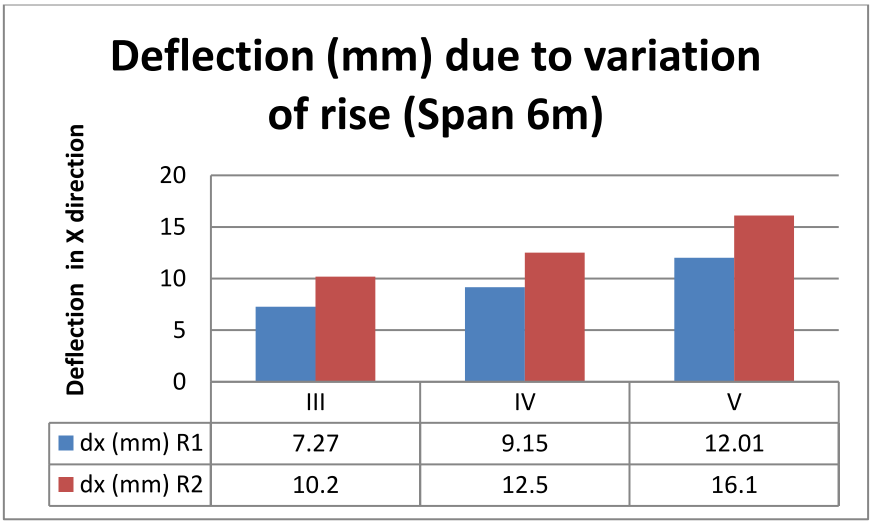
Load combinations considered are as follows:

1. 1.0(DL + IL)
2. 1.0(DL + EQ+X)
3. 1.0(DL + EQ-X)
4. 1.0(DL + EQ+Z)
5. 1.0(DL + EQ-Z)
6. 1.0DL + 0.8IL + 0.8EQ+X
7. 1.0DL + 0.8IL + 0.8EQ-X
8. 1.0DL + 0.8IL + 0.8EQ+Z
9. 1.0DL + 0.8IL + 0.8EQ-Z

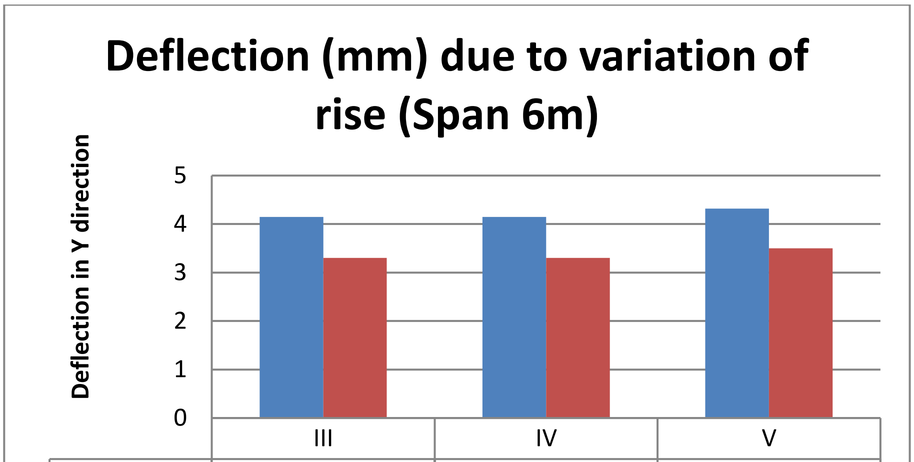
RESULT FOR DEFLECTION DUE TO VARIATION OF RISE

Table 6.1 Deflection for span 6m

Zone	dx (mm)		dy (mm)		dz (mm)	
	R1	R2	R1	R2	R1	R2
III	7.27	10.2	4.15	3.3	2.3	2.7
IV	9.15	12.5	4.15	3.3	3.5	4
V	12.01	16.1	4.32	3.5	5.12	5.9

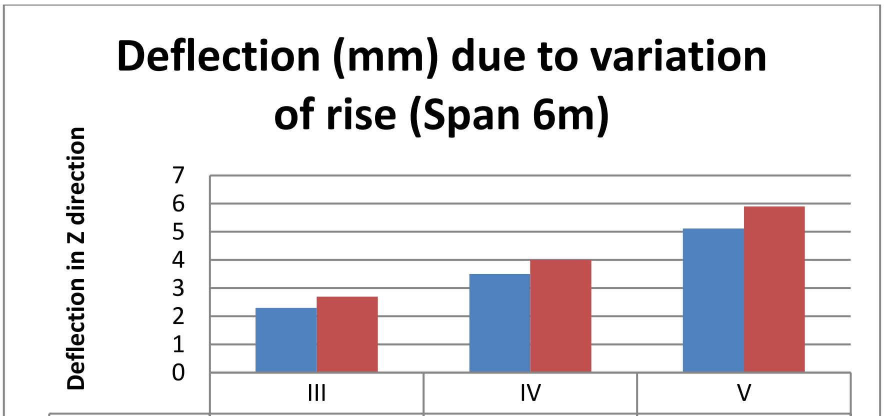


10. Fig.6.1 Deflection in X direction



	III	IV	V
dy (mm) R1	4.15	4.15	4.32
dy (mm) R2	3.3	3.3	3.5

Fig.6.2Deflection in Y direction



	III	IV	V
dz (mm) R1	2.3	3.5	5.12
dz (mm) R2	2.7	4	5.9

Fig.6.3Deflection in Z direction

CONCLUSION

Within the scope of present work following conclusions are drawn:

1. In all the models deflection, moments and shear stress values are less for lower zones and it goes on increases for higher zones because the magnitude of intensity will be the more for higher zones.
2. It is concluded that in a RC shell structure if span is same but central rise is varying, then the deflection values increases with increase in rise when earthquake forces governs but in case of gravity forces deflection values decreases with increase in risein all the zones considered.
3. From the result it is observed that in a RC shell structure if span is same but central rise is varying, then the moment values decreases with increase in rise for all the load casesin all the zones considered

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