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The Dynamic Response of Cylindrical Roof Shell under the Effect of Direct Damping Model

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Abstract: - One of the major and repeatedly occurring disasters in the globe is earthquake. Civil engineers especially structural engineers are more concerned with its effects on their buildings, bridges and so on. In structures, the peak of earthquake response was known to be at the roof level. Therefore, studies on how roof structures would behave under such dynamic response need to be taken into account in design. However, one of the most popular roofs that cover large column space especially in seismically active regions is thin shells and the most commonly used thin shells for roofing is the cylindrical form due to their aesthetic background and strength to weight ratio. The present research describes different investigations that were carried out in modelling and analysis of earthquake loadings on a simply supported cylindrical roof shell using ABAQUS (FE) program. The study; that was conducted is the applications of such loadings under the effect of direct damping model using different damping ratios. Results from the analyses were presented and compared for various responses that include displacement, acceleration and stresses. Also, the mode convergence studies results for the direct damping model were also presented.

***Keywords**: - Cylindrical, Damping, Dynamic, Response, Roof, Shell,*

I. INTRODUCTION

Shell structures are considerably more complicated when it comes to vibration analysis problems as compared to their counterparts for beams or plates. The effect of curvature on the shell equations and on the dynamic behaviour are the primarily cause of their complexity. In shell structures membrane and flexural deformations are coupled; and because of that three mutually perpendicular components of displacement must be considered during such analysis. Also, three equations can be derived in respect to the displacement. Many different sets of equations exist because there is no universally accepted set of equations on it [1]. Moreover, Warburton [1] claims that there are no additional simplified equations made so far in predicting their natural frequencies that agree very closely from the results obtained in research carried out by Novozhilov, Flugge or Sandres.

Authors [2] investigated the dynamic behaviour of cylindrical shell roofs with two different boundary conditions; one with free edges and the other with fixed edges which are subjected to 1940 E1 Centro-Earthquake record. The Rayleigh-Ritz method was outlined in obtaining the natural frequencies and mode shapes. However, not only that, the response to an arbitrary earthquake acceleration history was also carried out by a superposition of normal mode response method. The analysis of cylindrical roof shell subjected to earthquake loadings recorded in Landers measured in June 28th 1992 at Lucerne station was carried out by Shadi [3]. A shell model of a simply supported boundary condition was developed and analysed using finite element packages (ABAQUS) and a newly developed analytical method to investigate the spectra of normal vibration modes and the forced vibration response when the shell is subject to synchronous vertical motions using a constant damping ratio of 5%. The contribution of each mode to displacement, acceleration, and stress responses were also investigated. Moreover, Shadi [4] in another publication; "Interpretation of seismic response of cylindrical roof shells", with the same parameter stated in her previous research mentioned above included the effect of in-plane forces which was neglected in her previous publication. The relative significance of both the horizontal and vertical components was also investigated.

1.2.1 Aims of the Research:

- To investigate the effect of different damping ratios on thin reinforced concrete cylindrical roof shell under earthquake loading.

1.2.2 Objectives of the Research:

- To use ABAQUS (FE) program in analysing the dynamic responses.
- To investigate the adequate number of mesh required for a converged frequency.
- To investigate the effect of different damping ratios on the dynamic response.

Very little has been documented to date about responses of roof shells under earthquake loading; Carr et al. [2] considered only one boundary condition with a constant Rayleigh damping model, and the only responses that were investigated are acceleration and displacement without the consideration of stresses. Shadi [3] also considered one boundary condition with a constant damping ratio of 5% but have considered almost all the responses that are supposed to be determined in seismic analysis. However, the effect of different damping ratios, different damping models and different boundary conditions of roof shells under earthquake loading also needs to be investigated.

This particular research aims to study the responses due to the effect of different damping ratios using the direct damping models with the consideration of concrete material. However, the geometry and boundary condition remain same as that of authors [3]. ABAQUS Finite element software package was used in the analyses of the cylindrical roof shell when subjected to earthquake loading.

II. MATERIALS AND METHOD

The problem regarding earthquake response on structures requires powerful tools and techniques in their analysis that can handle thousand degrees of freedom. The technique found to be efficient in solving such problem was finite element method and the most available finite element program with the author was ABAQUS (FE) program. ABAQUS software was used to model the reinforced concrete cylindrical roof shell in order to extract the natural frequencies, mode shapes and the modal dynamic analysis for the earthquake responses that include displacements, accelerations and the stresses. However, the efficient use of the program depends on the sound understanding of finite element analysis, modal analysis and the theories of shells.

Two different analyses were performed in this study:

a. The extraction of natural frequency and
b. Modal analysis of the earthquake responses.

These will be explained in detail in the following sections.

2.2.1 Extraction of Natural Frequency and Mode Shapes

Extraction of natural frequency and mode shapes in ABAQUS/CAE requires various procedures and steps before the results are being actualised for visualisation and actions. However, in the frequency extraction analysis, damping and loads were neglected. Thereafter, the results were collected and analysed as fully explained in the next chapters.

2.2.2 Modal Dynamic Analysis in ABAQUS/CAE

The modal dynamic analysis is always built upon the frequency extraction step. In other words, the analysis is only performed after the extraction of frequency; therefore, no creation of new model was involved in the process. However, the modal analysis was performed with respect to the available literatures and data given by authors [3], different damping ratios were used ranging from 0.5%, 1%, 2% and 5% and the vertical component of Landers earthquake measured on June 28th 1992 at the Lucerne station with duration of 48.12s, peak Ground Acceleration (PGA) of 0.818 g and 0.005 s time interval data of recorded data were used in the analysis.

2.2.3 Research Model

A thin open cylindrical roof shell simply supported at four edges as shown in “Fig.” (2.2.3.1), as authors [3] model was used. However, in this model reinforced concrete material was chosen for the analysis. The following are the parameters for the model:

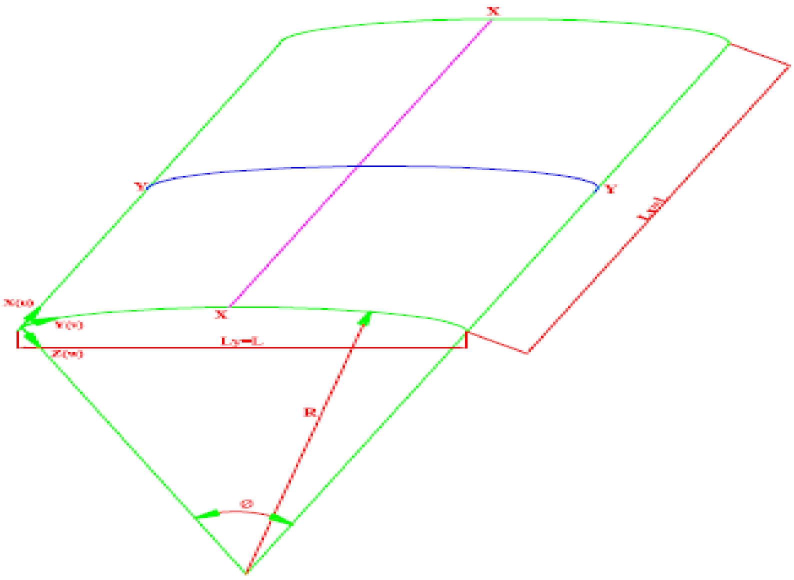

Figure (2.2.3.1): Shell Geometry (Source – The Author)

The radius of curvature R=104.8 m,
Longitudinal length Lx=Ly=L=104.8 m,
Thickness of R/h=500 =0.2096 m, and
$\phi = \pi/3$.
The material properties are taken to be reinforced concrete, with the following data:
Density, $\rho = 2450$ kg/m^3,
Poisons ratio = 0.18, and
Modulus of elasticity, E = 30 x 10^9 N/m^2.

2.2.4 Damping Ratio

The use of different damping ratios and direct damping model was applied on the shell structure when subjected to earthquake loading using the ABAQUS/CAE. The different damping ratios applied in the analysis include:

- 0.5% damping ratio
- 1% damping ratio
- 2% damping ratio, and
- 5% damping ratio

III. RESULTS, ANALYSIS, DISCUSSION AND CONCLUSIONS

Different analyses were performed in ABAQUS (FE) program which includes mesh convergence study, frequency extraction and mode convergence study. Also, the effect of different damping ratios for the response was investigated. Results were obtained and explained in detail in the following sections.
Mesh number convergence study of the frequency for the research model

This analysis was performed and results were obtained as shown in “Table” (3.1) and plotted in “Fig.” (3.1). As clearly shown in “Table” (3.1) and “Fig.” (3.1), the convergence begins from 40 x 40 mesh number with lowest frequency 0.58927 Hz and fully converges at 210 x 210 with lowest frequency 0.58455 Hz, but 50 x 50 mesh number with lowest frequency 0.58749 Hz was chosen for the analysis, in order to reduce the number of nodes and elements in the analyses.

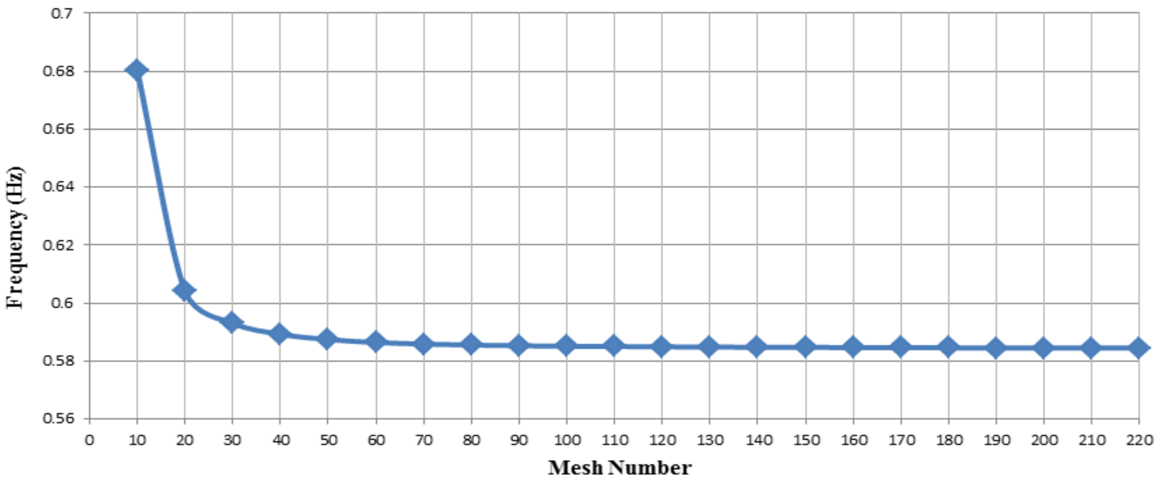

Figure (3.1): The natural frequency against mesh number (Source–The Author).

Table (3.1): Results of mesh number and frequencies of a cylindrical roof shell (Source – The Author).

S/No.	Mesh Number	Frequency (Hz)
1	10 x 10	0.68005
2	20 x 20	0.60410
3	30 x 30	0.59313
4	40 x 40	0.58927
5	50 x 50	0.58749
6	60 x 60	0.58646
7	70 x 70	0.58592
8	80 x 80	0.58555
9	90 x 90	0.58534
10	100 x 100	0.58513
11	110 x 110	0.58507
12	120 x 120	0.58496
13	130 x 130	0.58485
14	140 x 140	0.58480
15	150 x 150	0.58475
16	160 x 160	0.58470
17	170 x 170	0.58465
18	180 x 180	0.58460
19	190 x 190	0.58458
20	200 x 200	0.58456
21	210 x 210	0.58455
22	220 x 220	0.58455

3.2.1 Natural Frequency Extraction of the Research Model

In this phase the natural frequencies were extracted and the number of half waves in both the circumferential and longitudinal directions was also plotted in “Fig.” (3.2.1.1) and the number of circumferential half wave is represented by i, and the number of longitudinal half wave is represented by j as indicated in “Fig.” (3.2.1.1). it is also shown that, as the frequency increases the number of longitudinal half wave increases.
Therefore, the higher the number of longitudinal half waves the higher the frequency and subsequently, the lower the number of longitudinal half waves the lower the frequency.

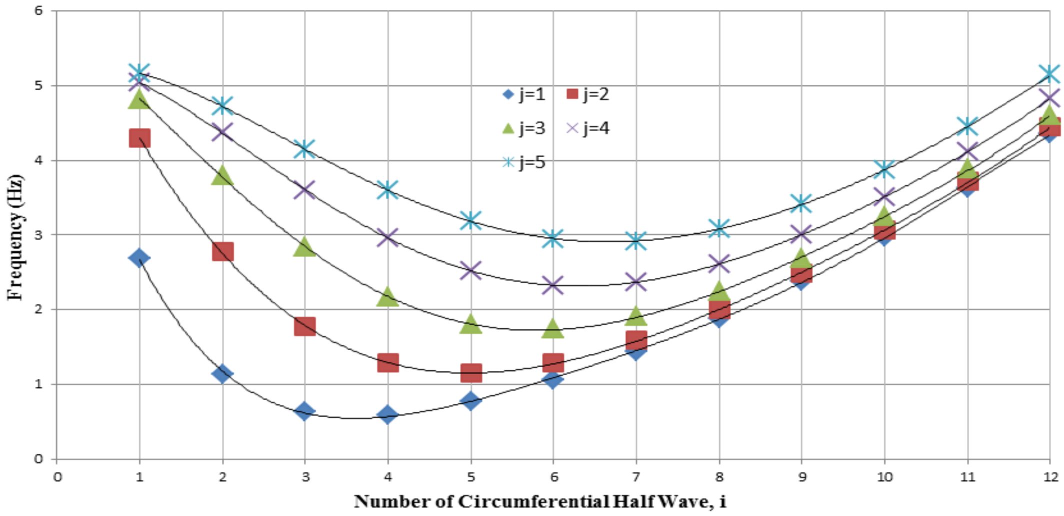

Figure (3.2.1.1): The natural frequency against the number of circumferential half wave, i (Source – The Author).

The graph of natural frequency against the mode number was also plotted as shown in "Fig." (3.2.1.2). The Figure typical shows that, as the mode number increases the natural frequency also increases, which give more insight on the relationship of frequency and mode number.

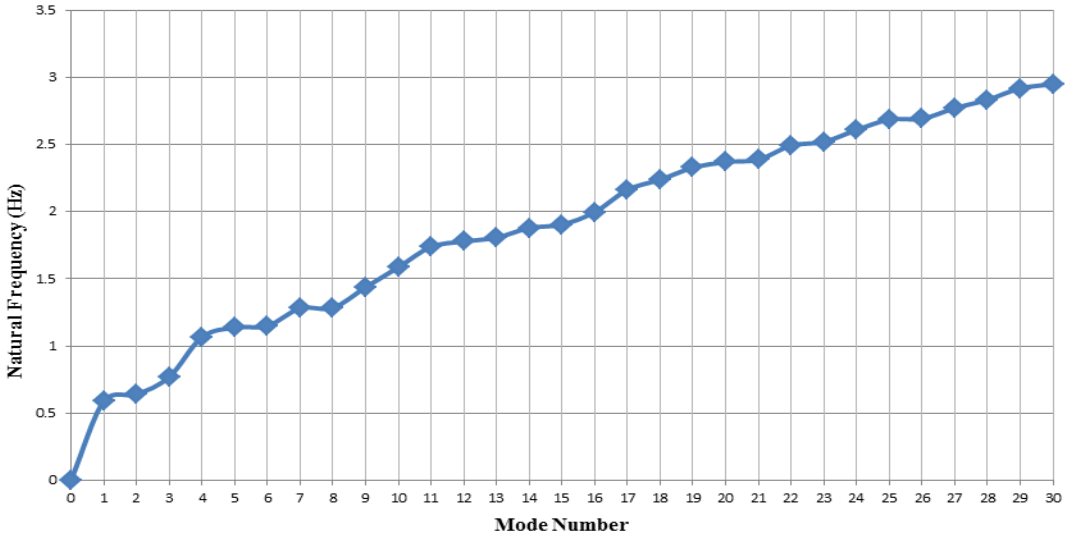

Figure (3.2.1.2): The natural frequency against the mode number (Source – The Author).

3.2.2 Modal Analysis of the Research Model

This analysis was performed in ABAQUS and responses of displacement, acceleration and stress resultant were all obtained with respect to the different damping ratios within a certain range of frequency. However, mode convergence studies were also carried out and details of each analysis were explained in the following sections.

3.3.1 The Effect of Different Damping Ratios on the Response of Shell.

Direct damping models were used in investigating the response of effect of different damping ratios within a certain range of frequency. However, this analysis was run on the ten lowest mode of the structure and the following sections will be explaining the details.

3.3.2 Response of Direct Damping Model

In this model ten different responses were analysed with four different damping ratios used and plotted as shown in "Fig." (3.3.2.1 – 3.3.2.10). The responses were plotted along centre line y-y of the earthquake duration in all the ten cases as shown in "Fig." (3.3.2.1 – 3.3.2.10). Maximum displacements and accelerations were obtained and plotted as in "Fig." (3.3.2.1 - 3.3.2.4), with respect to each node when subjected to earthquake loading. Each line in the horizontal direction of the graph represents a node on the roof shell structure.

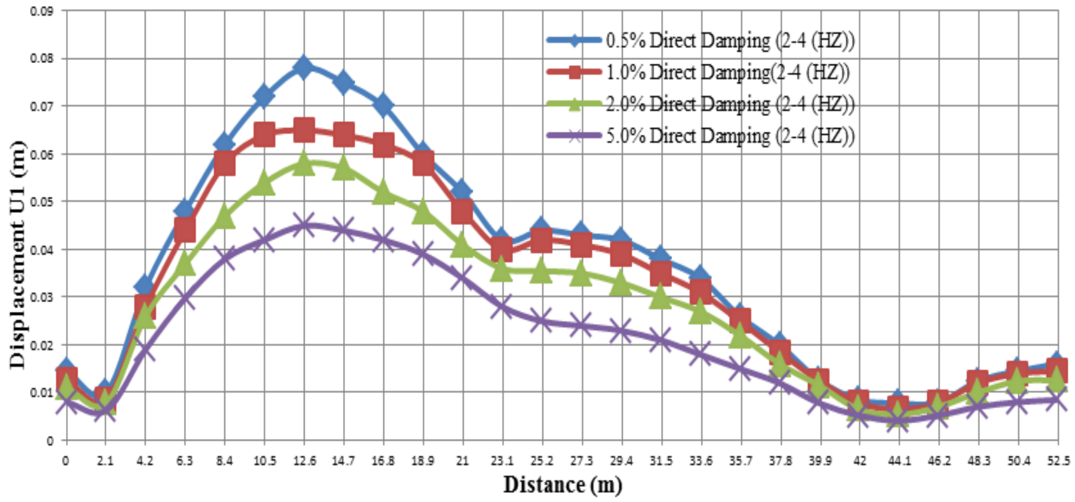

Figure (3.3.2.1): Circumferential displacement against geometry of shell along half width y-y (Source – The Author).

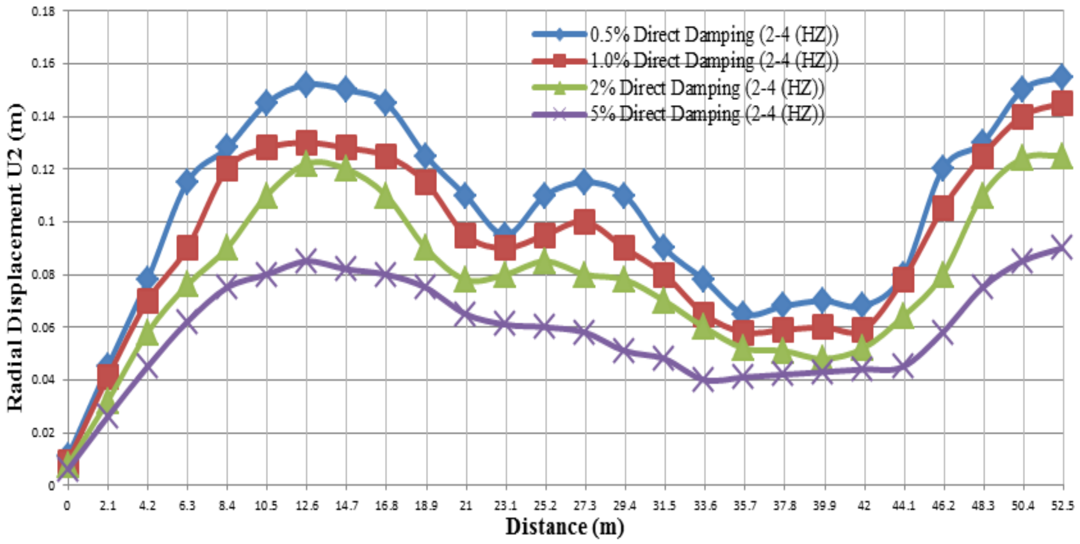

Figure (3.3.2.1): Radial displacement against geometry of shell along half width of y-y (Source – The Author).

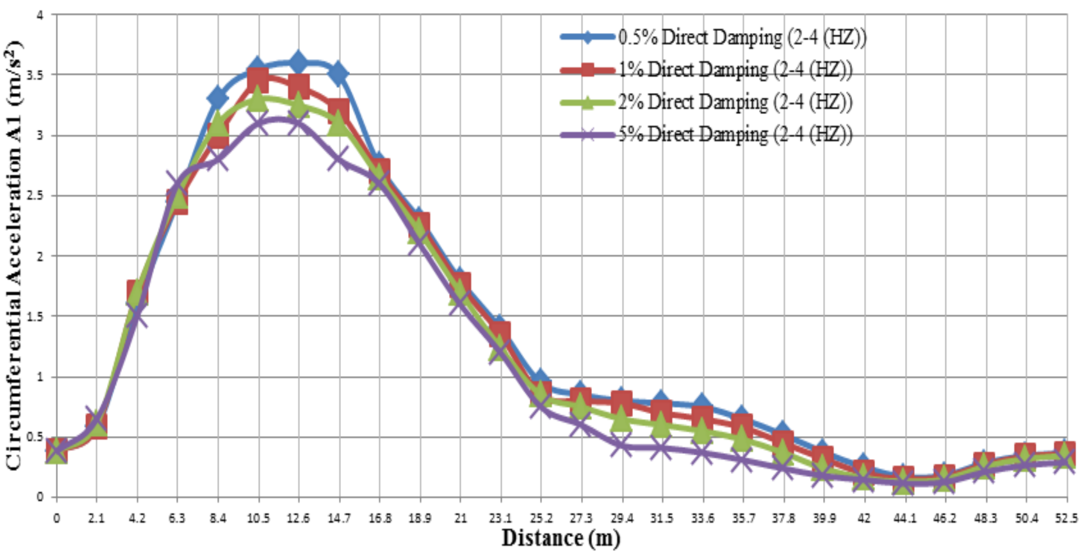

Figure (3.3.2.3): Circumferential acceleration against geometry of shell along half width of y-y (Source – The Author).

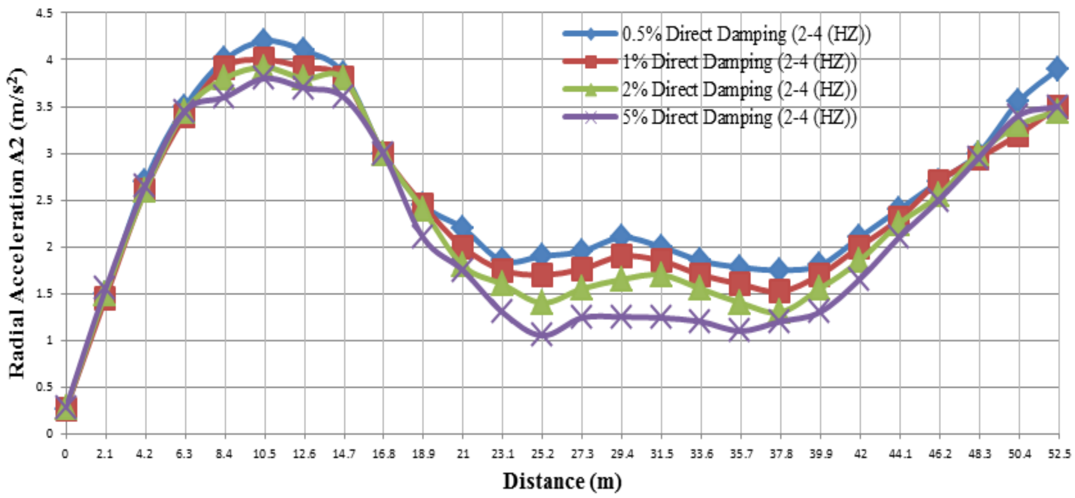

Figure (3.3.2.4): Radial acceleration against geometry of shell along half width of y-y (Source – The Author).

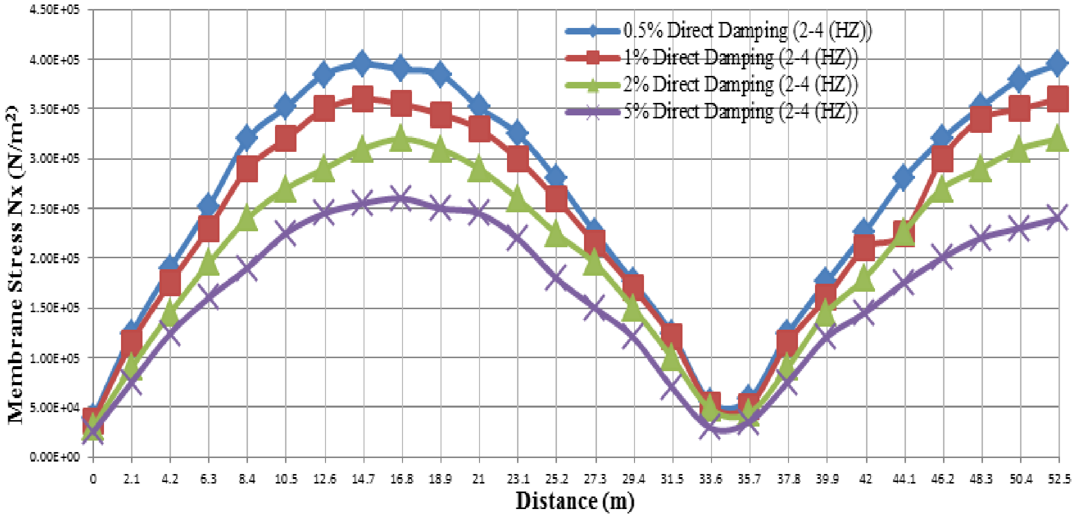

Figure (3.3.2.5): Membrane stress *Nx* against geometry of shell along half width of y-y (Source – The Author).

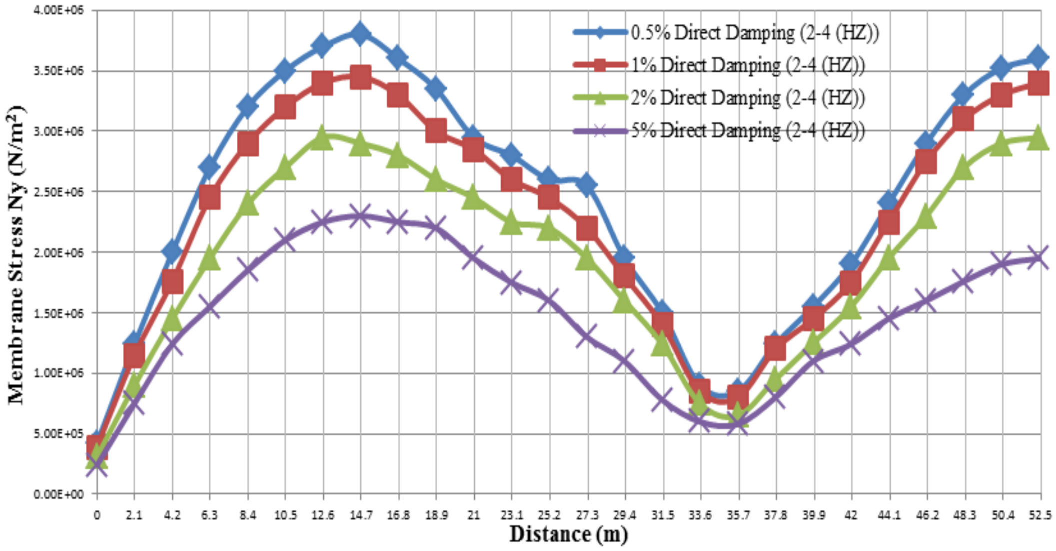

Figure (3.3.2.6): Membrane stress *Ny* against geometry of shell along half width of y-y (Source – The Author).

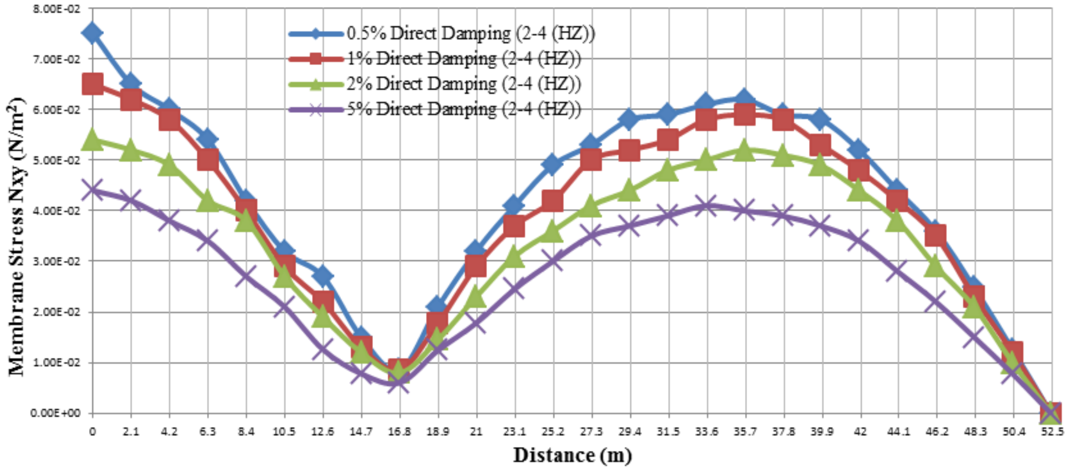

Figure (3.3.2.7): Membrane stress *Nxy* against geometry of shell along half width of y-y (Source – The Author).

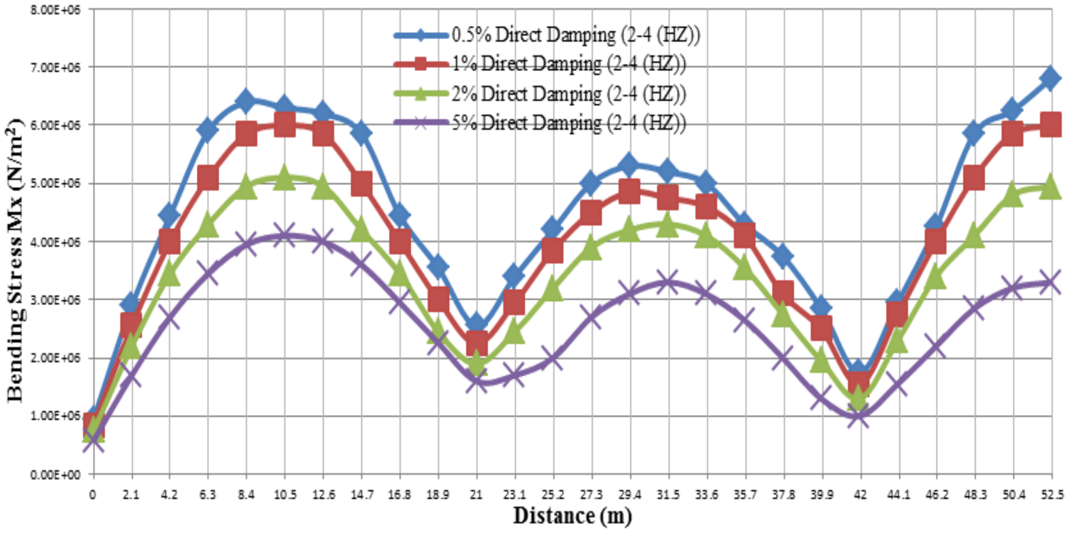

Figure (3.3.2.8): Bending stress *Mx* against geometry of shell along half width of y-y (Source – The Author).

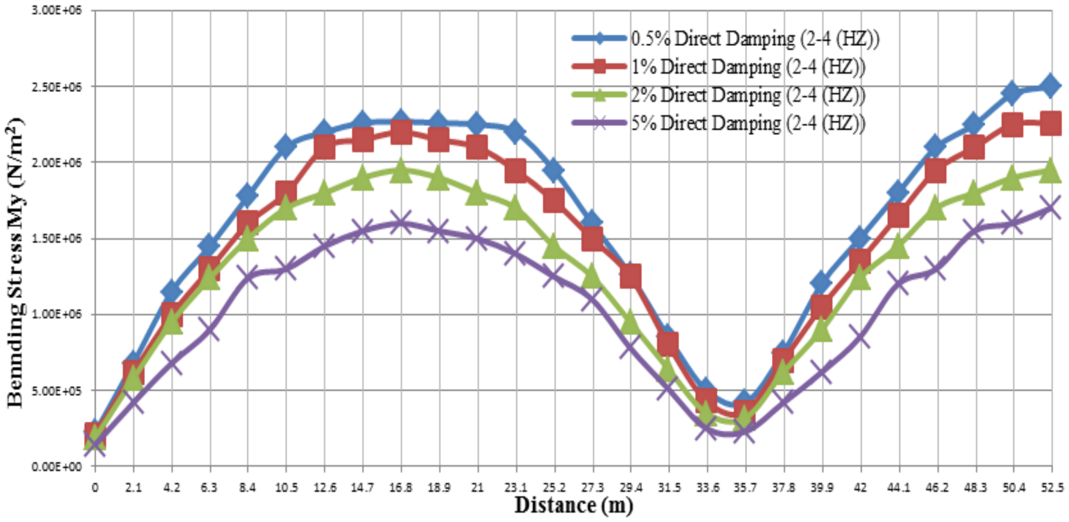

Figure (3.3.2.9): Bending stress *My* against geometry of shell along half width of y-y (Source – The Author).

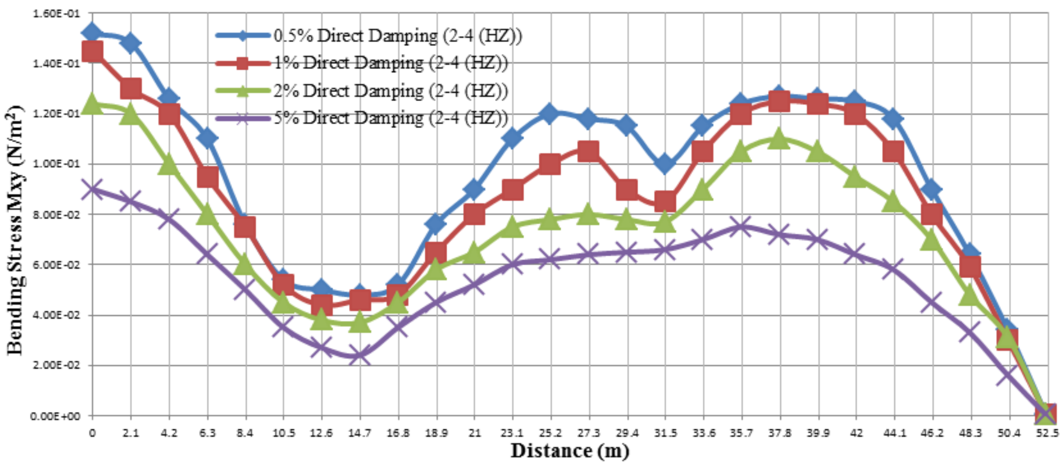

Figure (3.3.2.10): Bending stress *Mxy* against geometry of shell along half width of y-y (Source – The Author).

Maximum stresses were also obtained and plotted as in "Fig." (3.3.2.5 – 3.3.2.10), with respect to each element when subjected to the earthquake loading. Each box in the horizontal direction of the graph represents an element on the roof shell structure.

However, the entire plots were carried out only on the half part of the roof shell structure; because the results were found to be the same in the remaining section of the structure. Moreover, it was observed from "Fig." (3.3.2.1 - 3.3.2.10), in all the ten cases of the response, the higher the damping ratio the lower the response. Subsequently, the lower the damping ratio the higher the response of the shell structure towards the vibration. This observation was found to be different for the acceleration response in few nodes at the beginning and it was found to be the same in majority of the nodes up to the end of the response.

Moreover, the difference of lowest damping ratio (0.5%) to highest damping ratio (5%) for the maximum value of each response were obtained as shown in "Table" (3.2). it will be observed that in all the remaining cases the responses to half per cent damping is higher than the five per cent damping with minimum percentage difference of 10.53% and maximum percentage difference of 78.82%. Therefore, the higher the damping ratio the lower the vibration of the structures and the lesser the displacement/accelerations and stress resultant components.

Figures (3.3.2.11 – 3.3.2.12) are the response spectrum of acceleration and displacement for Landers earthquake data that was used in the analysis. The damping ratios of the spectrum shows that, the lower the ratio the higher the response in both the acceleration and displacement cases and which also confirms the results obtained in "Fig." (3.3.2.1 – 3.3.2.10).

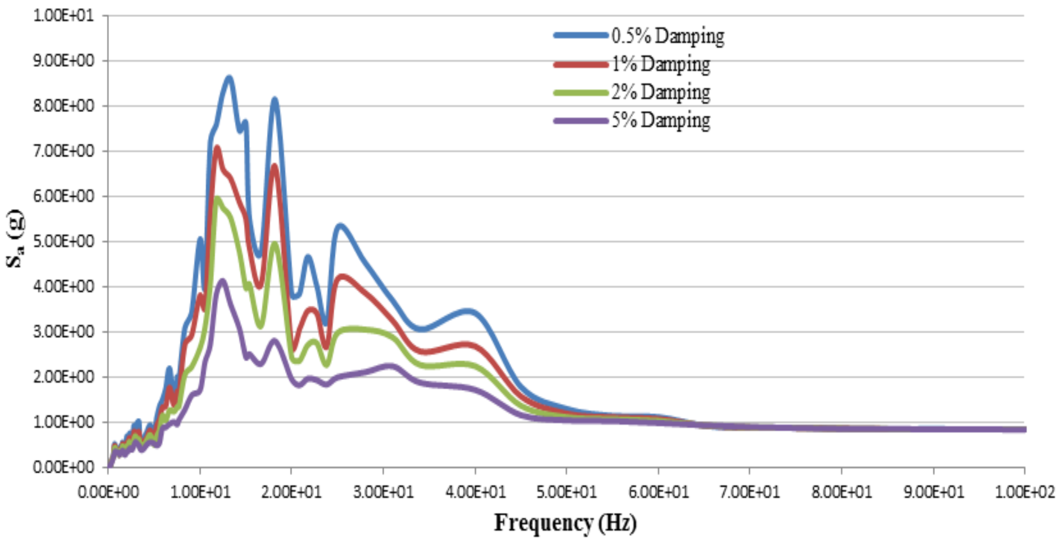

Figure (3.3.2.11): Acceleration response spectrum (Source - The Author).

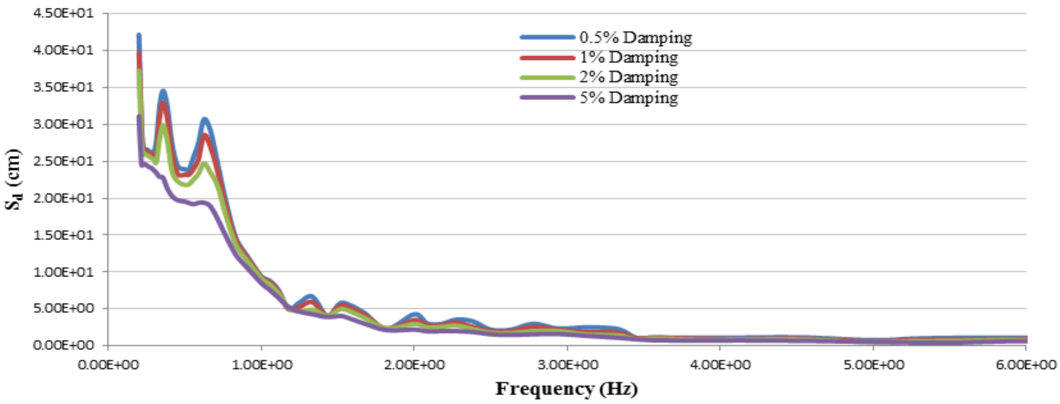

Figure (3.3.2.12): Displacement response spectrum (Source – The Author).

Therefore, the response of a structure under earthquake loading solely depends on the damping ratio used in the structure because the higher the damping ratio the lower the response of a structure.

IV. DISCUSSION

Reinforced concrete cylindrical roof shell was developed in ABAQUS using the direct damping model and using different damping ratios. The mesh number convergence study for natural frequency was carried out and plotted as shown in "Fig." (3.1) and "Table" (3.1). It clearly shows that, the frequency fully converges at 210 x 210 mesh numbers, but 50 x 50 mesh numbers was chosen for the research - though it was not fully converged, so as to minimise the number of nodes and elements involved in the analyses. The natural frequency of the shell was extracted first and plotted with respect to the circumferential and longitudinal half waves as shown in "Fig." (3.2.1.1). However, it was observed that, as the frequency increases the number of longitudinal half wave increases. Not only that, the frequency was also plotted with respect to the mode number as shown in "Fig." (3.2.1.1) and the result also shows that, as the mode number increases the frequency increases.

The modal analysis of earthquake loading was also carried out using the direct damping model with the application of 0.5%, 1%, 2% and 5% on each model and the responses were obtained. These results were plotted and compared in "Fig." (3.3.2.1 -3.3.2.10). In all the cases it was observed that, as the damping ratio increases, the responses decreases and this was compared with the response spectrum of the earthquake and found to be having the similar behaviour as shown in "Fig." (3.3.2.11 – 3.3.2.12). The results also show that, the number of half wave in the circumferential and longitudinal direction contributes to the convergence on the response of a cylindrical roof shell. Therefore, the lower the number of half waves in the circumferential and longitudinal directions the higher the response.

V. CONCLUSION

The purpose of the present research is study the effect of different damping ratios on a cylindrical roof shell subjected to earthquake loading using reinforced concrete material. The natural frequencies were firstly extracted and it was observed that as the frequency increases the number of half wave in the longitudinal direction also increases. The direct damping model was also used to model the effect of earthquake loading on the same reinforced concrete cylindrical roof shell, while different damping ratios were also applied on the damping model. By analysing the structure using ABAQUS (FE) program, the following conclusions have been obtained:

1. The direct model can be comfortably used in earthquake analysis of roof shells. The model can analyse, with a satisfactory accuracy, the damping ratios (those with higher values especially give lower response).
2. In all the four scenarios of the damping ratios; it was found that the response converges at the same mode number, which also gives more confidence in the use of direct damping model in earthquake analysis.

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