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Abstract— Liquid storage tanks are considered essential lifeline structures. Water tanks, in particular , are important to the continued operation of water distribution system in event of earthquakes. Most of the failures of large tanks after earthquakes are suspected to have resulted from the dynamic buckling caused by overturning moments of seismically induced liquid inertia and surface slosh waves. Recent earthquakes have shown that liquid storage tanks are found to be vulnerable to damage. Current knowledge about the behaviour of liquid storage tank is extensive, but many of the analytical and theoretical results are for tanks without roof systems and include number of simplifying assumptions like small deformation and linear elastic material property. The nonlinear wave approach was not attempted at initial stage, in predicting the seismic response of tank structures because of its mathematical difficulties determining the elevation of the unknown moving free surface and in evaluating the geometrically non-linear boundary conditions on the liquid surface. It is noted that under nonlinear conditions, sloshing heights are larger than those calculated under linear condition.

In the present study sloshing effect in elevated water tank is studied by using Finite Element Method (FEM) based computer code. Various parameters have been considered such as height of container, depth of water in tank (30%, 50%, 70% and full) and height of staging etc.

Keywords*-Elevated Water tank; Finite Element Method, Response Spectrum, ANSYS, Modal Analysis,Sloshing*

I. INTRODUCTION

Seismic safety of ground based and elevated liquid filled containers is of great concern because of potential economic loss that might be incurred due to structural failure of the liquid container as well as the potential environmental impact the spilling of the contained liquid might have to surrounding area.

The nonlinear wave approach was not attempted at initial stage, in predicting the seismic response of tank structures because of its mathematical difficulties determining the elevation of the unknown moving free surface and in evaluating the geometrically non-linear boundary conditions on the liquid surface. However with the use of computers and finite element techniques, the studies have been started and carried out on the sloshing effect.(1,2)

Therefore in the present study an attempt has been made to study the effect of sloshing on the wall and roof of the elevated tanks considering nonlinearity by ANSYS software.

II. MODELING OF WATER TANK

Three capacities of elevated water tanks, viz. 200 m^3 , 160 m^3 and 120 m^3 are considered. The sizes of the tank and dimensions are practical. The staging height is varied from 25 m. to 5m. For each capacity of tank, the sloshing phenomenon is studied for 100%, 70% , 50%, 30% volume of the water

The details of models are tabulated in the Table no. 1 and are shown in Figure No.1 and Figure No.2 . The diameter of the tank is taken as 7.2m.

TABLE 1.GEOMETRIC DETAILS OF WATER TANK

Group	Capacity of the Tank m^3	Height of the container with free board 'h' (m)	Staging height 'H' m	% of water filled in the tank
A	200	5.7	24.25 ,20, 15.5, 11.2 and 6.85	30 ,50 ,70 ,100
B	160	4.7		
C	120	3.7		

III. SELECTION OF ELEMENTS

ANSYS (3) offers various elements for modeling and analysis, out of which three elements are used for present FEA model. The tank roof system is represented by shell and beam elements .Tank wall is modeled by elastic shell elements. The contents are represented by 3-D fluid elements.(3) The fluid element is particularly well suited for calculating hydrostatic pressures and fluid/solid interactions.

IV. MODAL ANALYSIS

Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a water tanks.

The basic equation solved in a typical undamped modal analysis is the classical eigenvalue problem:

$$[K]\{\square_i\} = \omega_i^2 [M]\{\square_i\} \qquad (1)$$

where:

[K] = stiffness matrix

$\{\Phi_i\}$ = mode shape vector (eigenvector) of mode i

ω_i^2 = natural circular frequency of mode i (ω_i^2 is the eigenvalue)

[M] = mass matrix

After application of boundary conditions the modal analysis was run using reduced method. About 241 modes were extracted and significant mode were chosen for the comparison of participation factors, modal coefficients, and mass distribution percentages. Larger mass distribution percentages usually indicate important modes in the corresponding dynamic response analysis.

Modal analysis study was carried out by changing the capacity of the tank, percentage of volume of water and height of the staging.

V. RESPONSE SPECTRUM ANALYSIS

A *response spectrum* represents is a graph of response versus frequency, where the response might be displacement, velocity, acceleration, or force.

The models which were used for modal analysis were again run using Single Point Response Spectrum method. The tank was excited by response spectrum in X-direction and Z-direction. The real data Bhuj earthquake 2001(India) is given in the form of response spectrum. The response spectrum is applied at the nodes where all the degrees of freedom are fixed i.e. at the bottom-most nodes of the tank staging and damping is used as 5%. Then modes are expanded and mode combination is done using SRSS method of mode combination. Figure 1 shows the model with application of response spectrum and Figure 2 shows the response spectra of Bhuj Earthquake 2001(India)

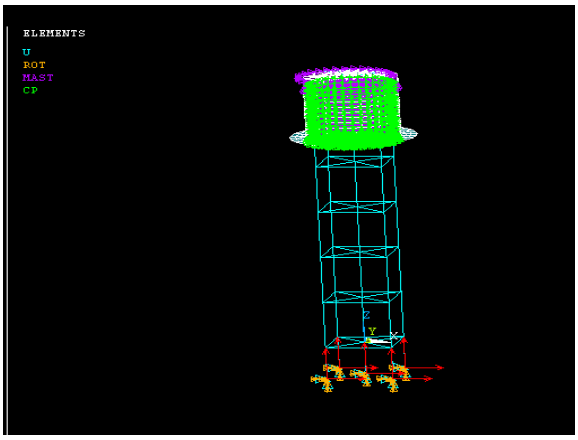


Figure1. Application of response Spectrum

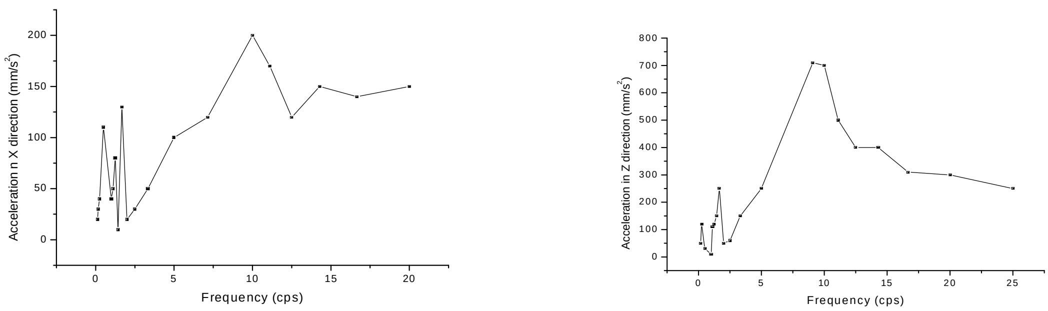


Figure. 2 Response Spectrum of Bhuj Earthquake (2001) in X direction and Z direction

VI. RESULTS OF RESPONSE SPECTRA ANALYSIS

The results obtained after Response Spectrum Analysis are the displacement of water i.e. sloshing of water. The results for all 60 cases are tabulated in the form of charts from Table II to Table VI.

TABLE 2. DISPLACEMENT OF WATER – STAGING HEIGHT 24.25M

Volume of water in %	Staging Height 24.25 m. Displacement of water in mm Tank 200 m^3 capacity	Tank 160 m^3 capacity	Tank 120 m^3 capacity
100	170.395	160.611	212.394
70	168.907	143.244	147.964
50	202.082	223.764	280.672
30	170.453	152.602	164.415

TABLE 3. DISPLACEMENT OF WATER – STAGING HEIGHT 20M

Volume of water in %	Staging Height 20 m. Displacement of water in mm Tank 200 m^3 capacity	Tank 160 m^3 capacity	Tank 120 m^3 capacity
100	309.354	190.981	104.452
70	200.674	166.443	296.928
50	197.54	179.085	281.592
30	215.964	160.516	213.963

TABLE 4. DISPLACEMENT OF WATER – STAGING HEIGHT 15.5 M

Volume of water in %	Staging Height 15.5 m. Displacement of water in mm Tank 200 m^3 capacity	Tank 160 m^3 capacity	Tank 120 m^3 capacity
100	303.541	217.86	163.718
70	262.745	252.96	286.993
50	249.367	243.327	213.928
30	224.545	209.304	202.291

TABLE 5. DISPLACEMENT OF WATER – STAGING HEIGHT 11.2M

Volume of water in %	Staging Height 11.2 m. Displacement of water in mm		
	Tank 200 m^3 capacity	Tank 160m^3 capacity	Tank120m^3 capacity
100	374.936	262.634	185.426
70	301.889	193.066	239.301
50	274.185	254.734	285.507
30	281.246	249.146	234.546

TABLE 6. DISPLACEMENT OF WATER – STAGING HEIGHT 6.85

Volume of water in %	Staging Height 6.85 m. Displacement of water in mm		
	Tank 200 m^3 capacity	Tank 160m^3 capacity	Tank 120 m^3 capacity
100	450.242	327.029	249.049
70	347.326	272.841	177.122
50	399.282	316.067	288.341
30	368.717	310.496	234.252

VII. RESULT ANALYSIS AND DISCUSSION

The results that are tabulated through Table II to Table VI are presented in form of graphs figure 3 (a) to figure 3(e) and figure 4.Figure 3(a) shows that for staging height 24.25m response of water to the earthquake excitation for all capacities of tank is same. Displacement of water is maximum when volume of water in tank is 50% of its capacity. Interesting sloshing is maximum in 120 m^3 capacity tank.

From figure 3(b) and 3(d) we can see that all three tanks will have different behavior and surprisingly tank of 120 m^3 capacity is showing max displacement of water at volume of 70% while the other two tanks show maximum sloshing when they are full.

Figure 3(c) shows that maximum sloshing occurs when 120 m^3 and 160 m^3 tanks are filled up to 70% of their capacity and 200 m^3 tank is full.

Figure 3(e) represents that for 200 m^3 and 160 m^3 capacity tank maximum displacement of water occurs when volume of water was 100% but for 120 m^3 capacity tank sloshing is maximum at 50 % volume of water.

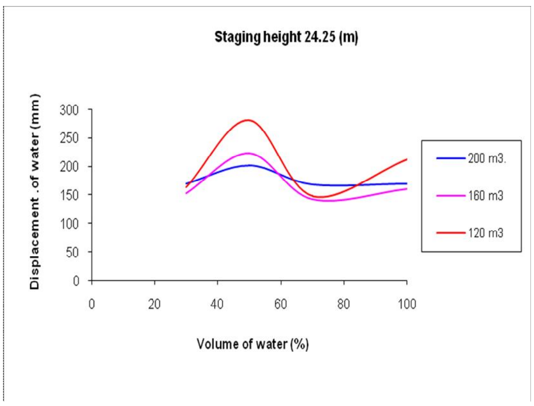


Figure. 3(a) Displacement of water – Staging height 24.25m

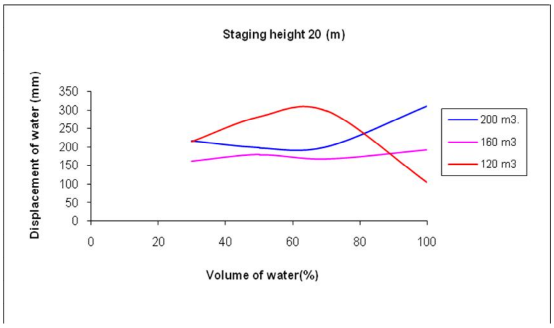


Figure. 3(b) Displacement of water – Staging height 20m

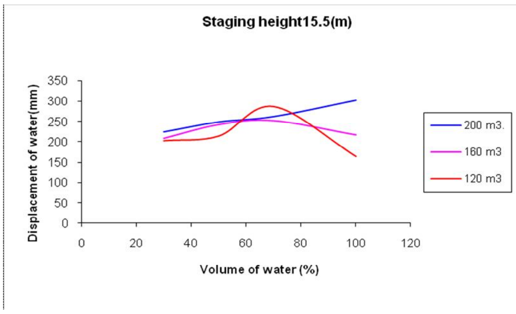


Figure. 3(c) Displacement of water – Staging height 15.5m

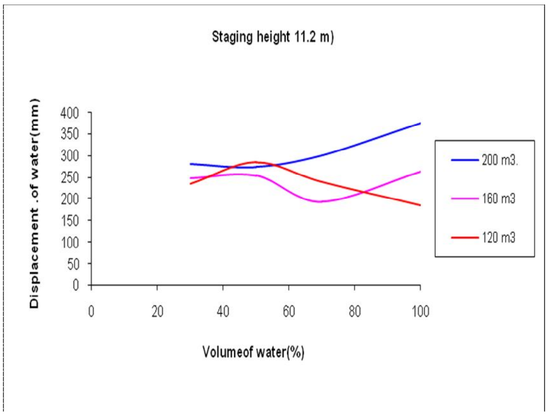


Figure. 3(d) Displacement of water – Staging height 11.2m

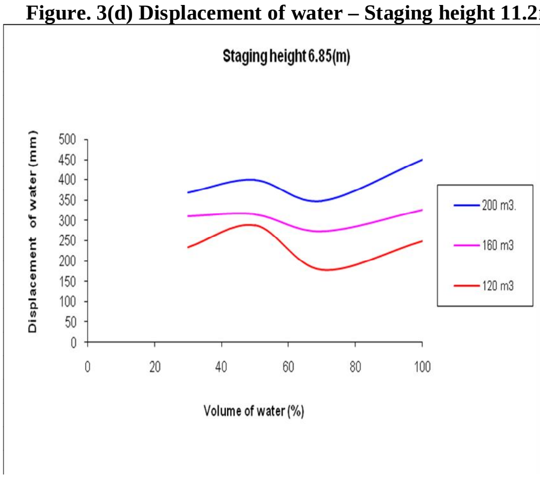


Figure. 3(e) Displacement of water – Staging height 6.85m

Figure 3 Maximum displacement of water in container of Tank for different staging heights

The behavior of all tanks with respect to staging heights is shown in figure 4. Response of three tanks with respect to staging height is shown in figure 4(a) to 4(c). From the figures it is clearly understood that displacement of water reduces as we go on increasing the staging height. But behavior of 120m3 tank is complex which may contribute to the h/D ratio

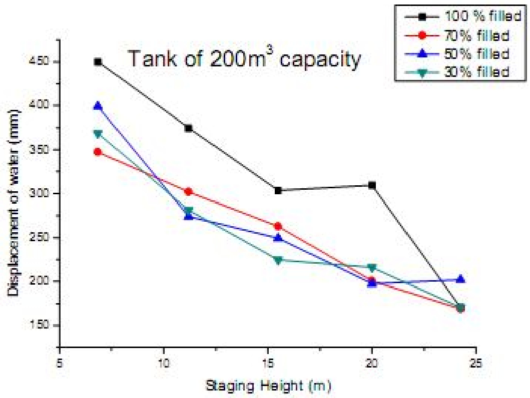


Figure. 4(a) Response of 200m^3 capacity tank

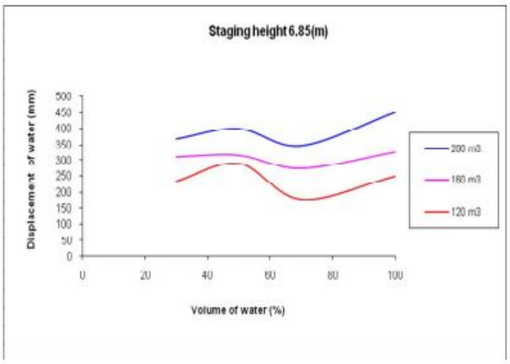
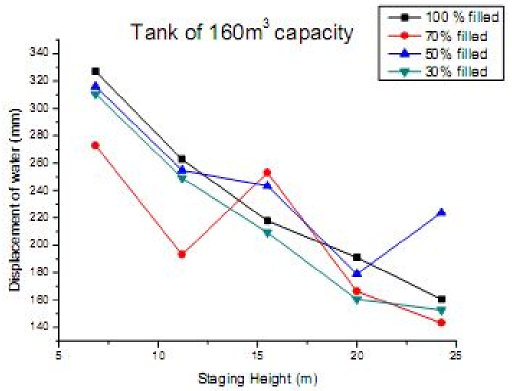


Figure. 4(b) Response of 160m3 capacity tank

VIII. CONCLUSION

On the basis of the results obtained in the study, although it is apparent that certain aspects of behavior of water tank are not yet clearly understood a number of conclusions may drawn .Following are the important conclusions:

1. Generally if the water tank is excited due to earthquake ground motion the displacement of water in the tank depends upon the volume of water contained in it.
2. Sloshing of water in tank depends not only on the volume of water in tank but also on staging height and h/D ratio
3. When 200m3 tank was filled 30%and given earthquake excitation at staging height of 6.85 m maximum displacement of water was noted as 450 mm , which emphasis the need of study of sloshing phenomenon.
4. It is observed that normally when tank was full maximum sloshing occurs at lower height but it it was not true when h/D ratio is small as in case of 120m3 capacity tank.



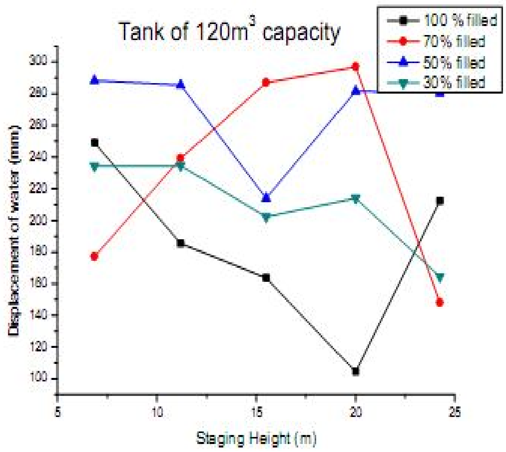


Figure. 4(c) Response of 120m3 capacity tank

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