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COMPARATIVE STUDY OF ELEVATED WATER TANK WITH DIAGRID SUPPORT SYSTEM

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Abstract—Present research attempts to study the response of elevated RC Elevated Water tank with Diagrid support system under earthquake load. With an objective to compare response of elevated water tank with frame staging and braced frame staging. The objective of the research is to carry parametric study for the response of overhead water tank under earthquake load for various staging patterns and to obtain the optimum diagonal angle for Diagrid support System. Time History Analysis are carried out of different staging patterns using SAP2000 to study the seismic behavior of EWT with Different Staging patterns. Seismic response of these structures in terms of Base Shear, Base Moment and Displacement will be evaluated and compared.

Keywords— Seismic Analysis, EWT, Diagrid System, Optimum Diagonal Angle, SAP2000

INTRODUCTION

Elevated water tanks (EWT) are the most efficient water system among all options. These structures store water at a sufficient height so enough pressure head is generated to supply the water purely based on hydrostatic pressure. This makes EWT able to supply water even during power-cuts. Thus elevated water tanks are considered as life line structures. Their safety performance during strong earthquakes is of critical concern. They should not fail after earthquake, so that they can be used in meeting essential needs like preparing drinking water and putting out fires. The failure of these structures and the subsiding of water may cause some hazards for the health of city due to the shortage of water or difficulty in putting out fire during critical conditions. These structures have a configuration that is especially vulnerable to horizontal forces like earthquake due to the large total mass concentrated at the top of slender supporting structure. So it is important to check the severity of these forces for particular region. The present study is to introduce diagrid staging of EWT and to study the seismic behaviour of EWT with different staging patterns using SAP2000 software. Diagrids are structural design strategy for constructing buildings that combine the resistance to gravity and lateral loads into triangulated system of members that eliminates the need for vertical columns. The system is comprised of diagonal members, normally fabricated from structural steel, that are joined at nodal points. The term "Diagrid" is a mixing of the words "diagonal" and "Grid" and states to a structural system which is single thickness in nature.

THE TWO MASS REPRESENTATION OF EWT

The two mass model of elevated tank was firstly proposed by Housner (1963) after the chileane earthquake of 1960, which is more appropriate and is being commonly used in most of the international codes including GSDMA guideline. When a tank containing liquid with a free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration. The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall. This mass is termed as impulsive liquid mass which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall and similarly on base. Liquid mass in the upper region of tank undergoes sloshing motion. This mass is termed as convective liquid mass and it exerts convective hydrodynamic pressure on tank wall and base. Thus, total liquid mass gets divided into two parts, i.e., impulsive mass and convective mass. In spring mass model of tank-liquid system, these two liquid masses are to be suitably represented.In spring mass model convective mass (mc) is attached to the tank wall by the spring having stiffness (Kc), whereas impulsive mass (mi) is rigidly attached to tank wall. Spring mass model can also be applied on elevated tanks, but two-mass model idealization is closer to reality

However, for most of elevated tanks it is observed that both the time periods are well separated. Hence, the two-mass idealization can be treated as two uncoupled single degree of freedom system as shown in Fig.1 (b). The stiffness (Ks) is lateral stiffness of staging. The mass (ms) is the structural mass and shall comprise of mass of tank container and one-third mass of staging as staging will acts like a lateral spring. Mass of container comprises of roof slab, container wall, gallery if any, floor slab, floor beams, ring beam, circular girder, and domes if provided. The two- mass model is shown in Fig. 1.

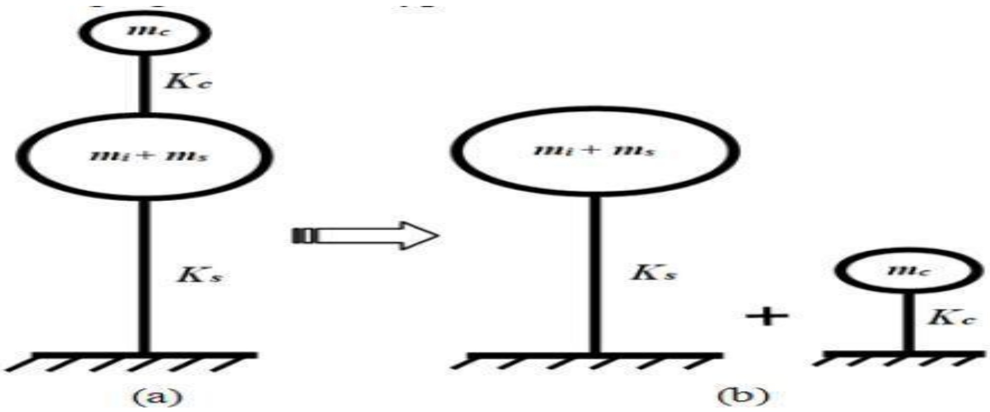

Figure 1. Two mass model for EWT

FLUID-STRUCTURE INTERACTION

During seismic events ground causes hydrodynamic pressure on the tank depends on the geometry of tank, height of liquid, properties of liquid and fluid-tank interaction.

In the mechanical analogue of tank-liquid system, the liquid is divided in two parts as, impulsive liquid and convective liquid. The impulsive liquid moves along with the tank wall, as it is rigidly connected and the convective and sloshing liquid moves relative to tank wall as it under goes sloshing motion. This mechanical model is quantified in terms of impulsive mass, convective mass, and flexibility of convective liquid. Housner (1963) developed the expressions for these parameters of mechanical analogue for circular and rectangular tanks. Fluid- structure interaction problems can be investigated by using different approaches such as added mass Westergaard approach, Lagrangian approach (Wilson and Khalvati), Eulerian approach (Zienkiewicz and Bettes), or the Eulerian-Lagrangian approach (Donea). The simplest method is added mass approach and can be investigated by using some of conventional Finite Element Method software such as SAP2000, STAAD Pro and LUSAS.

The general equation of motion for a system subjected to an earthquake excitation can be written as,

$$M^*\ddot{u} + C\dot{u} + Ku = -M^*\ddot{u}_g \tag{1}$$

In which M, C and K are mass, damping and stiffness matrices, $\ddot{u}$, $\dot{u}$ and u are the acceleration, velocity and displacement respectively, and the ground acceleration. M* is the new mass matrix after adding hydrodynamic mass to the structural mass.

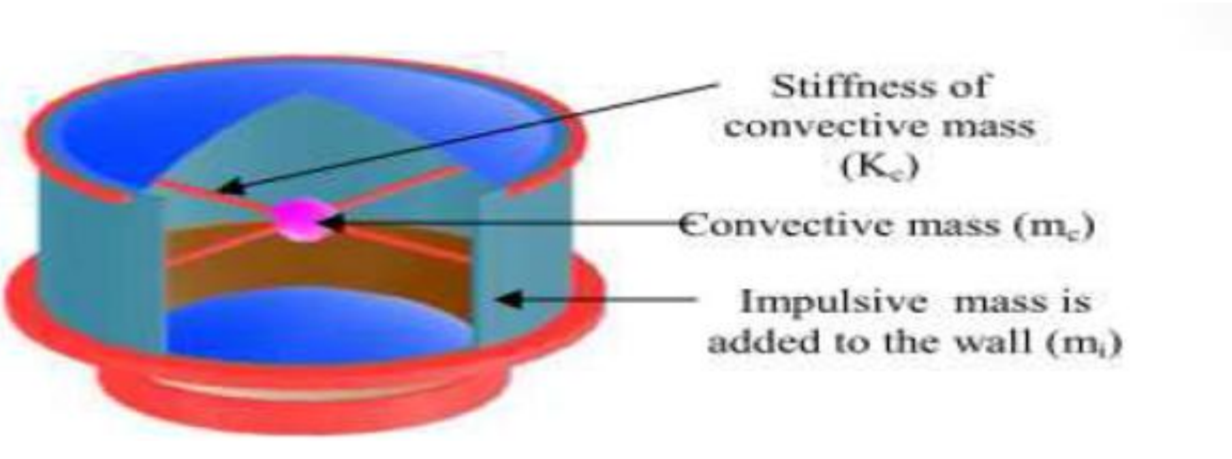

Figure 2. FEM fluid-structure-interaction Model

Westergaard Model's method was originally developed for the dams but it can be applied to other hydraulic structure, under earthquake loads i.e. tanks. The impulsive mass been obtained according to GSDMA guidelines technique and is added to the tanks walls according to Westergaard Approach.

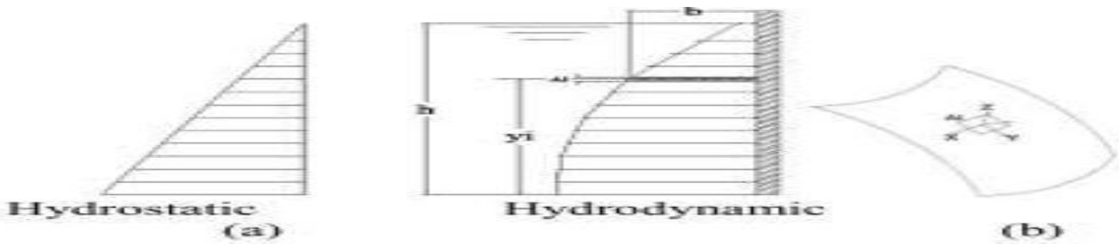

Figure 3. (a) Westergaard added mass concept (b) normal and Cartesian directions of curvilinear surface

$$m_{ai} = \left[\frac{7}{8}\rho\sqrt{h(h-y_i)}\right] A_i \qquad (2)$$

Where, ϱ is the mass density, h is the depth of water and Ai is the area of curvilinear surface.

OBJECTIVES

- The evaluation of response of elevated reservoirs on diagrid support system.
- To compare the response of elevated tank on diagrid support system with M-R frame type staging system under different ground motions in terms of Base Shear, Base Moment and Displacements .
- Linear Time history analysis of elevated tank on diagrid support system.
- To study the effect of various diagonal angles on response of ESR with diagrid support system.
- To study the effect of different tank size on response of ESR with diagrid support system.
- To study the effect of tank with different tank condition i.e. **(Full, Half, Empty)** on response of ESR with diagrid support system.

PROBLEM DESCRIPTION

A reinforced elevated water tank with Six Different staging patterns such as MR-Frame, MR-Frame with Cross bracing, and Diagrid Staging System with Four different Angles i.e.(70°,73°,75°,80°) with varying fluid level in the container have been considered for the present study. The storage capacity of water tank is 1000 m3 and elevated water tank is manually designed Finite element model is used to model the elevated tank system using SAP2000 structural software. Columns and beams in the frame type support system are modeled as frame elements .Conical part, bottom and top domes and container walls are modeled with thin shell elements .Other dimensions of the elevated tanks are shown in Table 1

Capacity of Tank	1000 m3
Unit wt. of Concrete	25 kN/m3
Thickness of Top Dome	0.15 m
Rise of Top Dome	2.4 m
Size of top Ring Beam	0.35 m x 0.35 m
Diameter of Tank	12.5 m
Height of cylindrical wall	7.5 m
Thickness of cylindrical wall	0.3 m
Size of Bottom Ring beam	1 m x 1.2 m
Size of Circular Ring Beam	1 m x 0.6 m
Rise of Conical Dome	3.75 m
Thickness of Conical Dome	0.5 m
Rise of Bottom Dome	2 m
Thickness of Bottom Dome	0.2 m
Diameter of Circular Columns	0.75 m
Bracings	0.5 m x 0.5 m

Table 1. Sizes of various components

In the present study six different staging patterns are modelled using SAP2000 and detailed time history analysis are carried out to study seismic behavior of EWT under different staging pattern.Total four numbers of earthquake records were used i.e Imperial Valley, Kobe, Loma Prieta, and Northridge.

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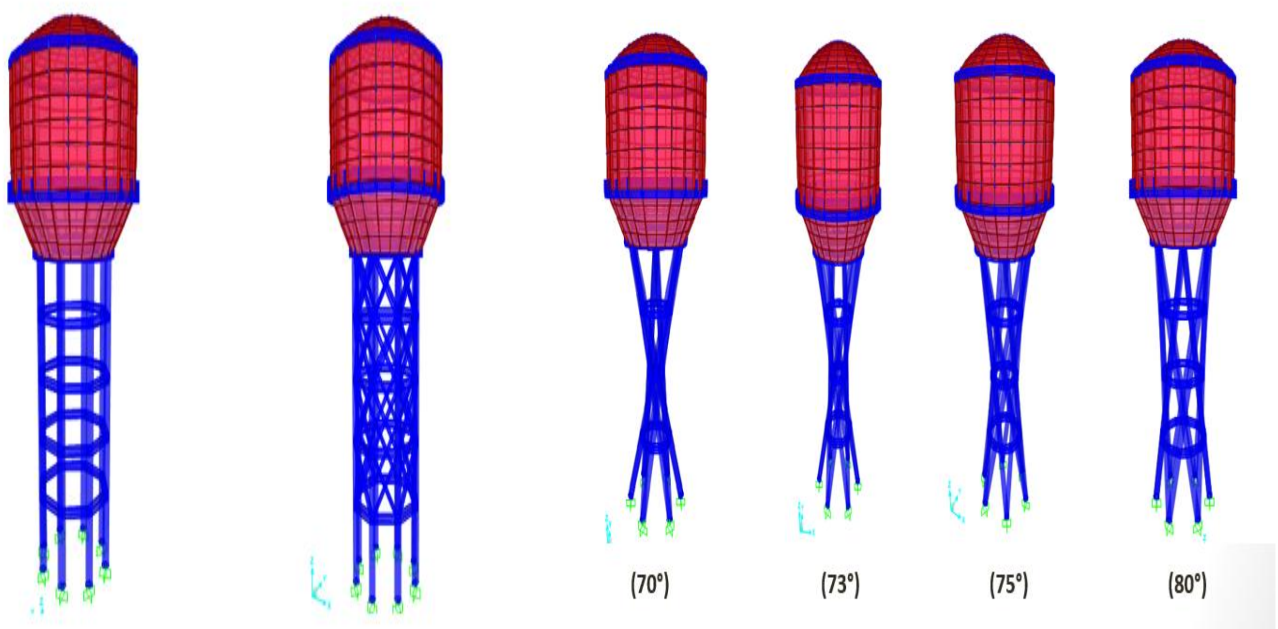
Six Different Staging Configuration are shown in the figure below



MR-Frame

MR-Frame with X-Bracing

EWT with Diagrid Support System

Figure 4 EWT with Different Staging Patterns

V.CONCLUSION AND RESULTS

Results for different important properties of this study are shown in tabular form. It has been also, displayed in graphical form for base shear, overturning moment and roof displacement as shown in fig,

1. Base Shear (kN)

Tank Water Level	Staging Type / Time History	MR Frame with X Bracing	MR Frame	Diagrid Staging 70°	Diagrid Staging 73°	Diagrid Staging 75°	Diagrid Staging 80°
Empty	Imperial Valley	7831.30	2619.68	2294.78	2288.46	4352.36	7258.53
	Kobe	6699.28	2269.87	2031.69	2020.89	4259.40	6363.11
	Loma Prieta	10630.64	1949.30	1964.82	2350.45	4255.00	6205.38
	NorthRidge	6022.54	2100.72	1973.46	2152.23	3207.78	6882.48
Half Full	Imperial Valley	8511.13	2997.40	2651.31	2584.66	4241.62	7799.94
	Kobe	6946.73	2214.71	2247.06	2165.02	4223.42	6698.02
	Loma Prieta	11909.75	2306.25	1867.68	2246.17	4076.57	10183.39
	NorthRidge	6294.00	2287.93	2790.06	2229.46	3725.77	5916.03
Full	Imperial Valley	6442.55	5834.98	4901.24	5263.98	8610.88	8351.38
	Kobe	4248.79	2369.98	3395.26	3675.26	7511.81	7693.44
	Loma Prieta	8225.47	3466.14	3535.38	3695.08	7995.66	7407.95
	NorthRidge	5670.33	6051.74	5203.70	5834.48	9902.74	7666.68

Table 2. Base Shear (kN)

2. Overturning Moment (kN-m)

Tank Water Level	Staging Type / Time History	MR Frame with X Bracing	MR Frame	Diagrid Staging 70°	73°	75°	80°
Empty	Imperial Valley	190134.49	65231.95	64306.35	63060.91	120028.83	187093.56
	Kobe	166920.63	56861.45	45170.47	54617.97	113093.34	181419.54
	Loma Prieta	267042.46	48678.79	44722.00	68002.07	103383.42	161648.85
	NorthRidge	147825.96	52712.80	49582.34	52458.02	83462.04	183072.95
Half Full	Imperial Valley	209431.09	75073.83	73777.41	69308.32	113964.54	201915.08
	Kobe	172937.90	52080.73	51091.68	55555.19	118054.34	175634.40
	Loma Prieta	301211.36	60581.65	40033.81	50669.15	101528.77	275472.17
	NorthRidge	157616.18	56409.26	66416.82	56839.07	99256.96	156619.96
Full	Imperial Valley	164418.59	147378.10	128712.98	143521.99	206181.46	211638.43
	Kobe	112094.05	66491.96	90504.70	96705.79	193840.52	202812.41
	Loma Prieta	212867.40	88124.55	88604.02	87503.06	196414.82	206745.55
	NorthRidge	146356.44	144313.19	137862.75	145435.56	241532.80	199305.80

Table 3. Overturning Moment (kN-m)

3. Roof Displacement (m)

Tank Water Level	Staging Type / Time History	MR Frame with X Bracing	MR Frame	Diagrid Staging 70°	73°	75°	80°
Empty	Imperial Valley	0.13	0.13	0.17	0.11	0.14	0.12
	Kobe	0.11	0.11	0.13	0.14	0.12	0.12
	Loma Prieta	0.20	0.10	0.17	0.12	0.12	0.13
	NorthRidge	0.12	0.11	0.20	0.11	0.10	0.14
Half Full	Imperial Valley	0.13	0.13	0.20	0.15	0.13	0.13
	Kobe	0.12	0.11	0.17	0.12	0.13	0.12
	Loma Prieta	0.20	0.10	0.15	0.12	0.12	0.20
	NorthRidge	0.12	0.12	0.28	0.13	0.10	0.12
Full	Imperial Valley	0.10	0.26	0.40	0.25	0.20	0.10
	Kobe	0.10	0.12	0.30	0.22	0.15	0.10
	Loma Prieta	0.15	0.15	0.30	0.15	0.30	0.14
	NorthRidge	0.14	0.30	0.50	0.30	0.30	0.11

Table 4. Roof Displacement (m)

The above results are also represented in graphical form as shown in figure below,

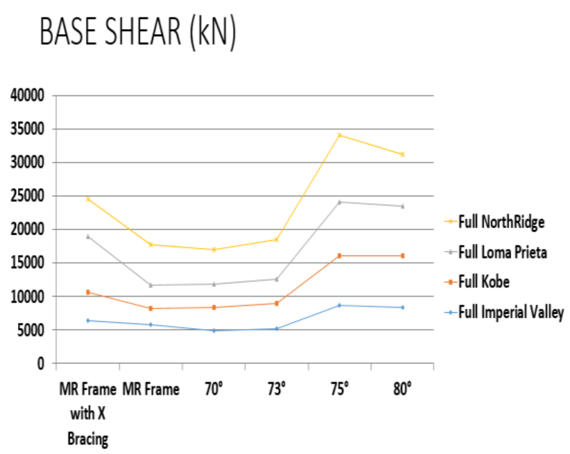


Figure (a)

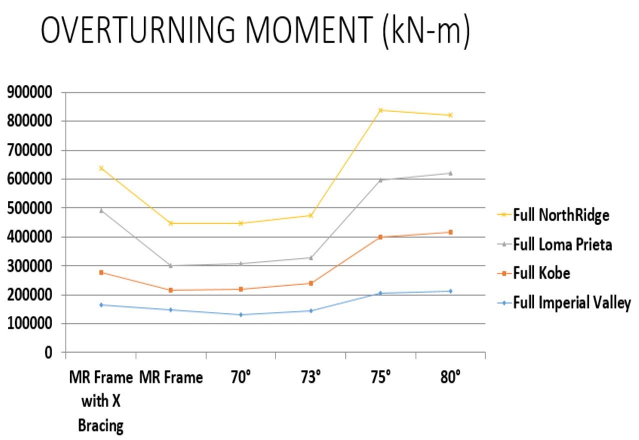


Figure (b)

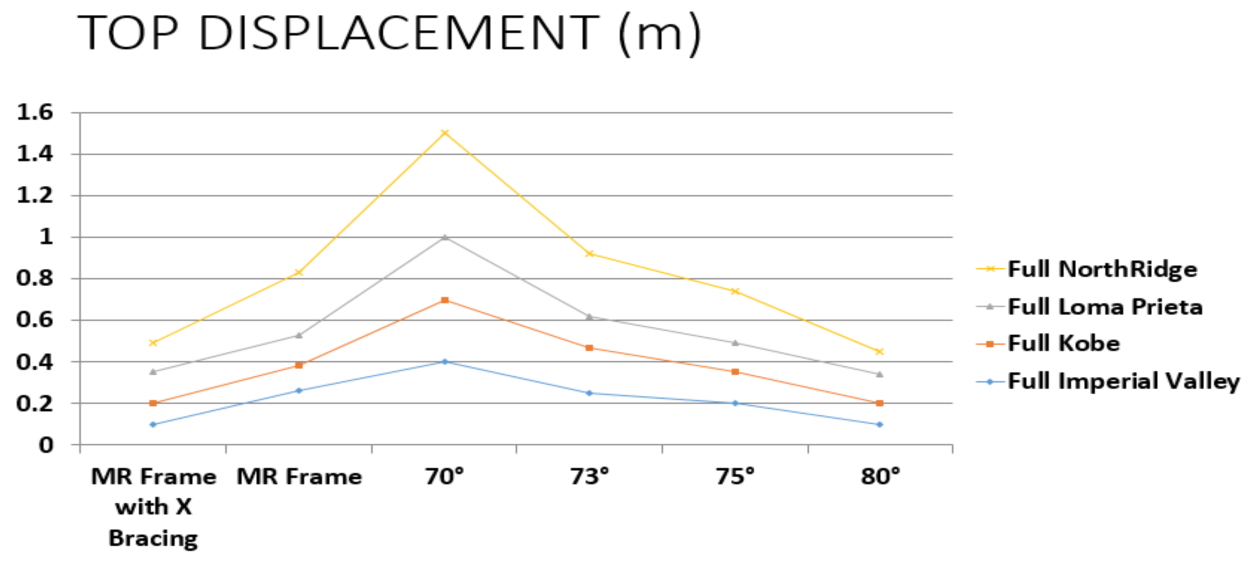


Figure (c)

From the analysis of Elevated Water Tank with Six Different Staging Patterns under tank Empty, Half, Full condition following observation and conclusions are deduced;

1. Base Shear and Base Moment are minimum in EWT with Diagrid Support System
2. MR frame with Cross Bracing shows highest Base Shear and Base Moment in comparison to other staging systems. And responds with least displacements amongst all the Staging system.
3. In case of Diagrid arrangement in present analysis of 70°,73°,75°,80° the 70° angle shows the least Base Shear and Base Moment , however Displacements are highest. Therefore 73° is observed to be best optimum configuration having almost least Base Shear and Base Moment as well as Displacement.
4. NorthRidge is observed to be most critical wherein Base Shear, Base Moment, and Displacement are observed to be Highest.
5. From Empty, Half Full, & Full condition analysis it is observed that as the lumped mass is highest in the Full Tank condition the Base Shear, Base Moment, and Displacement are highest.
6. Hence Diagrid Staging is proved to be economic and efficient staging system.

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