Seismic Analysis of Elevated Water Tank with Variations of H/D Ratio and Container Shape using staad-pro v8i

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***Abstract*—** As known from very upsetting experiences, liquid storage tanks were collapsed or heavily damaged during the earthquakes all over the word. The economic lifetime of concrete or steel tanks is usually in the range of 40 to 75 years (ALA 2001).Damage or collapse of the tanks causes some unwanted events such as shortage of drinking and utilizing water, uncontrolled fires and spillage of dangerous fluids. Due to this reason numerous studies done for dynamic behavior of fluid containers; most of them are concerned with cylindrical tanks. In this study, Seismic forces acting on an Elevated water tank e.g. circular Tank and rectangular tank are studied with constant stagging height. Seismic forces acting on the tank are also calculated changing the Seismic Response Reduction Factor(R). IS: 1893-1984/2002 for seismic design and then checked the Design of Tanks by using the software STAAD PRO.

***Keywords:* -** *Water Tank, Stagging System, Staad Pro, Earthquake.*

I. INTRODUCTION

Water is life line for every kind of creature in this world. All around the world liquid storage tanks are used extensively by municipalities and industries for water supply, firefighting systems, inflammable liquids and other chemicals. Thus Water tanks plays a vital role for public utility as well as industrial structure having basic purpose to secure constant water supply from longer distance with sufficient static head to the desired location under the effect of gravitational force. Storage reservoirs and overhead tank are used to store water, liquid petroleum, petroleum products and similar liquids. The force analysis of the reservoirs or tanks is about the same irrespective of the chemical nature of the product. All tanks are designed as crack free structures to eliminate any leakage. Water or raw petroleum retaining slab and walls can be of reinforced concrete with adequate cover to the reinforcement. Water and petroleum and react with concrete and, therefore, no special treatment to the surface is required. Industrial wastes can also be collected and processed in concrete tanks with few exceptions. The petroleum product such as petrol, diesel oil, etc. are likely to leak through the concrete walls, therefore such tanks need special membranes to prevent leakage. Reservoir is a common term applied to liquid storage structure and it can be below or above the ground level. Reservoirs below the ground level are normally built to store large quantities of water whereas those of overhead type are built for direct distribution by gravity flow and are usually of smaller capacity. Elevated tanks should remain functional in the post-earthquake period to ensure water supply is available in earthquake-affected regions. Never the less, several elevated tanks were damaged or collapsed during past earthquakes Due to the fluid–structure–soil/foundation interactions, the seismic behavior of elevated tanks has the characteristics of complex phenomena. Therefore, the seismic behavior of elevated tanks should be known and understood, and they should be designed to be earthquake-resistant. Some general programs have been carried out, which cover large amounts of data; these programs include STAAD PRO etc. However, a general-purpose structural analysis program generally exists in every engineering office. So, the evaluation of the applicability of these structural analysis programs in the design of elevated tanks is important from an engineering point of view and it will be helpful to present the application and results to designers. There is a second important reason that should be considered. That is, simplified models are used for a straightforward estimate of the seismic hazard of existing elevated tanks. Only if the estimated risk is high, it is convenient to measure all the data (e.g. geometry of the tank, material properties) that are required by the general finite element codes and to spend time and money to prepare a reliable general model.

II. SEISMIC ANALYSIS OF ELEVATED WATER TANK

Seismic analysis of elevated water tank involved two types of analysis,

1. Equivalent Static analysis of elevated water tanks.
2. Dynamic analysis of elevated water tanks

Equivalent static analysis of elevated water tanks is the conventional analysis based on the conversion of seismic load in equivalent static load. IS: 1893- 2002 has provided the method of analysis of elevated water tank for seismic loading. Historically, seismic loads were taken as equivalent static accelerations which were modified by various factors, depending on the location's seismicity, its soil properties, the natural frequency of the structure, and its intended use. Elevated water tank can be analyzed for both the condition i.e. tank full condition and tank empty condition. For both the condition, the tank can be idealized by one- mass structure. For equivalent static analysis, water-structure interaction shows, both water and structure achieve a pick at the same time due to the assumption that water is stuck to the container and acts as a structure itself and both water and structure has same stiffness. The response of elevated water tanks obtained from static analysis shows the high scale value. That's why for large capacities of tanks, static response are not precise. If we analyzed the elevated water tank by static method and design by the same, we get over stabilized or say over reinforced section but it will be uneconomical. That's why static systems of designing of elevated water tanks is not useful in seismic zones. And hence, IS code provision for static analysis is restricted for small capacities of tanks only.

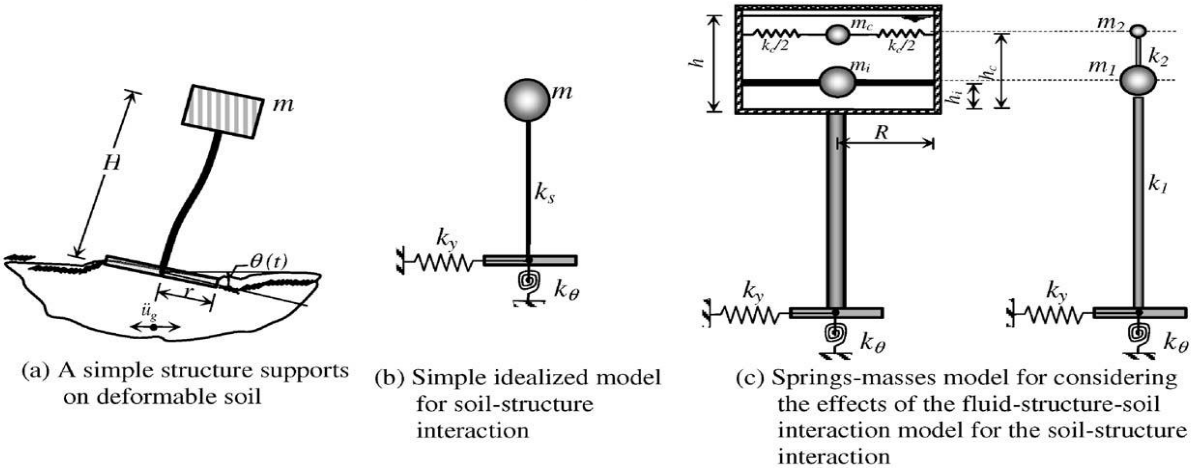

Fig. 1. Mechanical model for the fluid–structure–soil interaction of the elevated tank

A. Single lumped-mass model

The concept that enables analysis of elevated water tanks as a single lumped-mass model was suggested in the 1950s (Chandrasekaran and Krishna, 1954). Elevated tanks (Fig. 1) and the selected model for this concept can be seen in Fig. 1(e). Two significant points should be discussed for this concept. The first point is related to the behavior of the fluid. If the container is completely full of water, this prevents the vertical motion of water sloshing, so the elevated tank may be treated as a single-degree-of-freedom system in such a case. When the fluid in the container (vessel) oscillates, this concept fails to characterize the real behavior. The other point is related to the supporting structures. As the ductility and the energy-absorbing capacities are mainly regulated by the supporting structure, this is important for the seismic design of elevated tanks. In this model, it is assumed that the supporting structure has a uniform rigidity along the height. The elevated tanks can have different types of supporting structures, which could be in the form of a steel frame, a reinforced concrete shell, a reinforced concrete frame or a masonry pedestal. Under seismic loads, the supporting structures that act as a cantilever of uniform rigidity along the height cannot represent all the supporting structure types. But it may be that these are more suitable for the reinforced concrete shell supporting structure.

The Indian seismic code, IS:1893, requires elevated tanks to be analyzed as a single-degree-of-freedom system—that is, a one-mass system—which suggests that all fluid mass participates in the impulsive mode of vibration and moves with the container wall (Rai, 2002). It must be stated that this can be a realistic assumption for long and slender tank containers with a height-to-radius ratio exceeding four. Also, the ACI 371R-98 (1995) suggests that the single lumped mass model should be used when the water load (Ww) is 80% or more of the total gravity load (WG) that includes: the total dead load above the base, water load and a minimum of 25% of the floor live load in areas that are used for storage. For this model, the lateral flexural stiffness of the supporting structure (ks) is determined by the deflection of the concrete supporting structure acting as a cantilever beam.

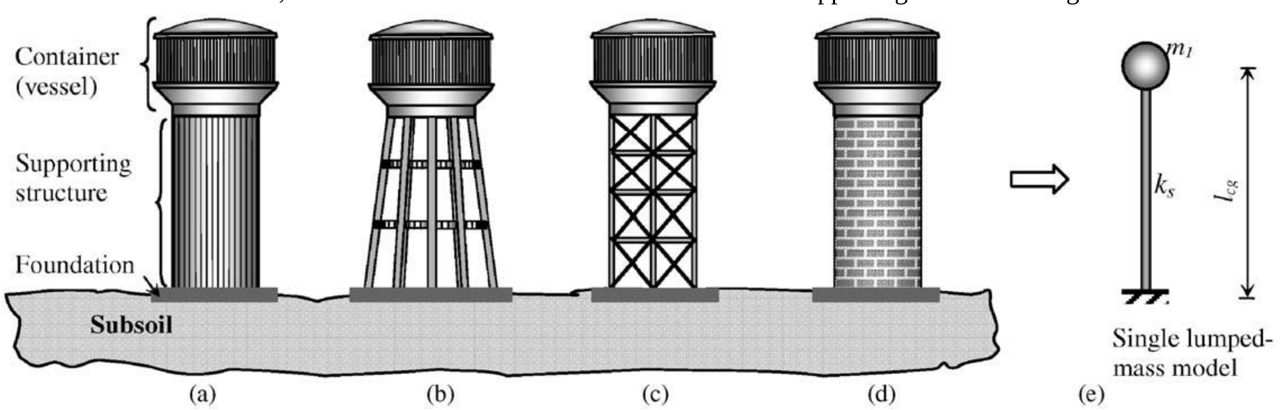

Fig. 2 Elevated tanks and the single lumped-mass model: (a) the tank with reinforced concrete shaft supporting structure, (b) the tank with reinforced concrete frame supporting structure, (c) the tank with reinforced concrete frame with diagonal braces or steel frame supporting structure, (d) the tank with masonry pedestal supporting structure, (e) single lumped-mass model.

B. Double lumped-mass model

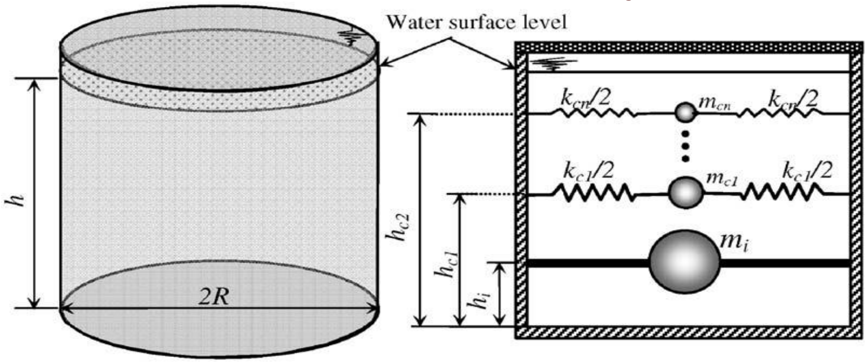

Fig.3 Spring-mass analogy for ground supported cylindrical tanks.

Most elevated tanks are never completely filled with liquid. Hence a two-mass idealization of the tank is more appropriate as compared to a one mass idealization, which was used in IS 1893: 1984. Two mass model for elevated tank was proposed by Housner (1963) and is being commonly used in most of the international codes.

III. METHODOLOGY

The methodology includes the selection of type of water tank, fixing the dimensions of components for the selected water tank and performing linear dynamic analysis (Response Spectrum Method of Analysis) by IS: 1893-1984 and IS: 1893-2002 (Part 2) draft code. In this study, various capacity circular and rectangular overhead water tank is considered for analysis. It is analyzed for four different zones (zone-II to V), and for two tank-fill conditions, i.e. tank full and tank empty conditions. Lastly, the results of the analysis of tanks performed on the basis of IS: 1893-1984 and IS: 1893-2002 (Part 2) draft code have been compared by using the software STAAD PRO software.

Step 1: Open STAAD.Pro and click on new project again click on space give file name and location, click on next add beam complete the task with proper directions.

Step 2: Now click on transalatinal circular repeat option make total no of steps =10 then click on link steps open base will apper select one refernce point axis of roatation Y and click on ok.

Step 3: Assigning Properties: click on property then property dialog box will opens and give the property of column and click on add close now select all the columns, assign to selected beams make a proper completion assign yes.

Step 4: Go to define and rectangle finally give the property of lower beams and click on add close and select lower beams for assign to selected beams

Step 5: Go to define and select rectangle shape give the property of lower ring beam and click on add close to select lower beam assign to selected beams and assign.

Step 6: Go to define and rectangle arrangement give the property of upper ring beam and click on add close to select upper ring beam and assign to selected beams and assign.

Step 7: Go to define and thickness to give the property of plates and click on add close the select plates and assign to selected plates and assign.

Step 8: Assigning Loads, Click on load and definition then loads dialog box will opens click on load case details add give load or self weight to water tank assign to view assign yes.

Step 9: Go to load case details Add seismic load items dialog box will opens click on seismic load select type 1 Go to load case details add live load give name as hydrostatic load click on hydrostatic load items dialog box will opens click on plate loads select trapezoidal plate load direction of pressure Global Z Variation along element Y Give intensity as per height of the water tank multiplied by unit weight of water select required plates for hydrostatic force Assigned to selected plates Assign yes select lower plates of water tank give intensity according to its height assign hydrostatic load on lower portion of water tank.

Step 10: Go to load case details click on auto load combination select load combination type-Indian select load combination category –general structures click on generate loads add now go to analyze Run analysis go to post processing mode for required results. The same procedure will be followed to create models for different seismic loads.

IV. DESIGN AND ANALYSIS OF WATER TANK

I. Circular Water Tank (Capacity 100m3)
II. Rectangular Water Tank (Capacity 100m3

Problem Statement: A RC circular and rectangular water container of 100 m3 capacity has internal diameter of 6 m for circular and (7m x 4m) for rectangular with height of 3.9 m (including freeboard of 0.3 m). It is supported on RC staging consisting of 4 columns of 500 mm diameter with horizontal bracings of 500 x 250 mm at four levels, also Top ring beam 250 x 350 mm & bottom ring beam 250 x 500mm. The lowest supply level is 12 m above ground level. Staging conforms to ductile detailing as per IS13920. Staging columns have isolated rectangular footings at a depth of 2m from ground level. Tank is located on medium soil for all seismic zone. Grade of staging concrete and steel are M20 and Fe415, respectively. Density of concrete is 25 kN/m3. Analyze the tank for seismic loads. (Tank must be analysed for tank full and empty conditions).

Circular Water Tank 100m3

Full Tank condition

Nodal Displacement

Zone	Horizontal		Vertical		Horizontal	
	Max X	Min X	Max Y	Min Y	Max Z	Min Z
II	4.818	-4.818	0.138	-5.908	4.819	-4.819
III	7.709	-7.709	0.221	-5.908	7.711	-7.711
IV	11.563	-11.563	0.331	-5.908	11.567	-11.567
V	17.344	-17.344	0.496	-5.908	17.35	-17.35

Base Shear

Zone			
	Fx kN	Fy kN	Fz kN
II	9.705	433.205	9.705
III	15.528	433.205	15.527
IV	23.292	433.205	23.291
V	34.939	433.205	34.937

Base Moment

Zone			
	Mx kNm	My kNm	Mz kNm
II	21.623	-0.001	21.623
III	34.596	-0.001	34.597
IV	51.894	-0.001	51.896
V	77.841	-0.001	77.844

Shear Force

Zone			
	Fx kN	Fy kN	Fz kN
II	**38.812**	**-1070.67**	**38.812**
III	62.099	-1070.67	62.099
IV	93.148	-1070.67	93.148
V	139.722	-1070.67	139.722

Bending Moment

Zone			
	Mx kNm	My kNm	Mz kNm
II	**52.992**	**116.435**	**52.992**
III	84.787	186.296	84.787
IV	127.181	279.444	127.181
V	190.771	419.166	190.771

Empty Tank condition

Base Shear

Zone			
	Fx kN	Fy kN	Fz kN
II	9.705	267.721	9.705
III	15.528	267.721	15.527
IV	23.292	267.721	23.291
V	34.939	267.721	34.937

Nodal Displacement

Zone	Horizontal		Vertical		Horizontal	
	Max X	Min X	Max Y	Min Y	Max Z	Min Z
II	4.818	-4.818	0.138	-4.06	4.819	-4.819
III	7.709	-7.709	0.221	-4.06	7.711	-7.711
IV	11.563	-11.563	0.331	-4.06	11.567	-11.567
V	17.344	-17.344	0.496	-4.06	17.35	-17.35

Base Moment

Zone			
	Mx kNm	My kNm	Mz kNm
II	21.623	0	21.623
III	34.596	0	34.597
IV	51.894	0	51.896
V	77.841	0	77.844

Shear Force

Zone			
	Fx kN	Fy kN	Fz kN
II	**38.812**	-618.767	**38.812**
III	62.099	-618.767	62.099
IV	93.148	-618.767	93.148
V	139.722	-618.767	139.722

Bending Moment

Zone			
	Mx kNm	My kNm	Mz kNm
II	**52.992**	116.435	**52.992**
III	84.787	186.296	84.787
IV	127.181	279.444	127.181
V	190.771	419.166	190.771

Rectangular Water Tank 100m3 > Full Tank condition

Nodal Displacement

Zone	Horizontal		Vertical		Horizontal	
	Max X	Min X	Max Y	Min Y	Max Z	Min Z
II	6.382	-6.382	0.108	-3.497	5.124	-5.124
III	10.211	-10.211	0.173	-3.497	8.198	-8.198

IV	15.316	-15.316	0.26	-3.497	12.298	-12.298
V	22.974	-22.974	0.389	-3.497	18.447	-18.447

Base Shear

Zone			
	Fx kN	Fy kN	Fz kN
II	10.35	377.929	10.35
III	16.559	377.929	16.559
IV	24.839	377.929	24.839
V	37.259	377.929	37.259

Base Moment

Zone			
	Mx kNm	My kNm	Mz kNm
II	22.801	0.008	26.104
III	36.481	0.008	41.767
IV	54.722	0.008	62.65
V	82.082	0.008	93.976

Shear Force

Zone			
	Fx kN	Fy kN	Fz kN
II	41.398	-1142.025	41.398
III	66.237	-1142.025	66.237
IV	99.356	-1142.025	99.356
V	149.034	-1142.025	149.034

Bending Moment

Zone			
	Mx kNm	My kNm	Mz kNm
II	3023.428	144.894	59.34
III	3023.428	231.831	94.944
IV	3023.428	347.747	142.415
V	3023.428	521.62	213.623

Empty Tank condition

Nodal Displacement						
Zone	Horizontal		Vertical	Horizontal		
	Max X	Min X	Max Y	Min Y	Max Z	Min Z
II	6.382	-6.382	0.108	-1.351	5.124	-5.124
III	10.211	-10.211	0.173	-1.351	8.198	-8.198
IV	15.316	-15.316	0.26	-1.351	12.298	-12.298
V	22.974	-22.974	0.389	-1.351	18.447	-18.447

Base Shear

Zone			
	Fx kN	Fy kN	Fz kN
II	10.35	285.506	10.35
III	16.559	285.506	16.559
IV	24.839	285.506	24.839
V	37.259	285.506	37.259

Base Moment

Zone			
	Mx kNm	My kNm	Mz kNm
II	22.801	0.002	26.104
III	36.481	0.002	41.767
IV	54.722	0.002	62.65
V	82.082	0.002	93.976

Shear Force

Zone			
	Fx kN	Fy kN	Fz kN
II	41.398	-391.714	41.398
III	66.237	-391.714	66.237
IV	99.356	-391.714	99.356
V	149.034	-391.714	149.034

Bending Moment

Zone			
	Mx kNm	My kNm	Mz kNm
II	2284.051	144.894	59.34
III	2284.051	231.831	94.944
IV	2284.051	347.747	142.415
V	2284.051	521.62	213.623

CONCLUSION

Following are the conclusions based on the Seismic Analysis of Elevated Water Tank are as follows:

1. Base shear of full water tank and empty water tank are increased with seismic zone II-V because of zone factor, response reduction factor etc. while considering seismic analysis.
2. base shear in full condition tank is slightly higher than empty tank due to absence of water or hydro static pressure.
3. Displacement of full water tank and empty water tank are increased with seismic zone II-V because of zone factor, response reduction factor etc. while considering seismic analysis.
4. Maximum nodal displacement and minimum nodal displacement found at the wall of water tank when tank is full condition.
5. shear force and bending moment of full water tank and empty water tank are increased with seismic zone II-V because of zone factor, response reduction factor etc. while considering seismic analysis.
6. shear force and bending moment in full condition tank is slightly higher than empty tank due to absence of water or hydro static pressure.

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