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A Survey on Dynamic Analysis of Elevated Water Tank for Different Staging Configuration

Aliakbar Qutubuddin Ali[1], Deepa P. Telang[2]
[1]Dept. of Civil Engg & G.H. Raisoni Academy of Engineering & Technology, Nagpur (MS), India
[2]Dept. of Civil Engg & G.H. Raisoni Academy of Engineering & Technology, Nagpur (MS), India
[1] aliakbarali72@gmail.com; [2] deepa.telang@raisoni.net

Abstract— This paper presents dynamic analysis of elevated water tanks supported on RC framed structure with different tank storage capacities. Effects of hydrodynamic forces on tank walls are calculated. History of earthquake reveals that it have caused numerous losses to the life of people in its active time, and also post earthquake time have let people suffer due to damages caused to the public utility services. Either in urban or rural areas elevated water tanks forms integral part of water supply scheme, so its functionality pre and post earthquake remains equally important. These structures have heavy mass concentrated at the top of slender supporting structure hence these structures are especially vulnerable to horizontal forces due to earthquakes. Objective paper is to understand the dynamic behavior of elevated water tanks under earthquake loading using latest Indian code IS 1893(part 2):2014. Parameters from seismic analysis of elevated water tanks and their comparison within different capacities including sloshing effects are calculated, lateral stiffness of frame staging is calculated using latest STAAD Pro V8i SS6 software. Results state that there is more threat of destruction to the tanks with higher capacities as compared to the tanks with lower capacities in a given zone.

Keywords:- Convective Hydrodynamic Pressure, Elevated Water Tank, Impulsive Hydrodynamic Pressure, Sloshing Wave Height, STAAD Pro V8i.

1. INTRODUCTION

Liquid storage tanks are essential structures in water, oil and gas industrials and the behavior of them during earthquake is more important than the economic value of the tanks and their contents. It is important that utility facilities remain operational following an earthquake to meet the emergency requirements such as firefighting water or meet the public demands as a source of water supply. For these reasons, serviceability becomes the prime design consideration in most of these structures. A good understanding of the seismic behavior of these structures is necessary in order to meet safety objectives while containing construction and maintenance costs. One of the problems that are important in analysis and designing of these structures is the interaction between fluid and structure. Prediction of analytical response of coupled field systems is very complex and approximately no available. So most of investigations are concerned about numerical methods such as finite element method. In this paper Numerical analysis of elevated concrete water tanks with central shaft is performed by using of finite element software which fluid- structure interaction is considered. 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.

A. Earthquakes:

The first seismic zone map was provided in 1962 by the Indian Standards, which was further revised in 1967 and once again in 1970. The map has been last revised in 2002, and it now has seismic zones – II, III, IV and V. The seismic zone I areas were merged with those of seismic zone II in 1970. Seismic Zone Map presents a large scale view of the seismic zones. Hence soil variations and variations in the geology cannot be represented at that scale. Therefore, for major projects, such as large scale dams or a power plant, the seismic danger is investigated specifically in detail for that particular site. In general, the methods of seismic analysis can be classified as

(1) Static analysis and

(2) Dynamic analysis.

a) **Linear seismic Coefficient Method** (SCM)(IS:1893, Cl.7.5.3 & 7.7.1): Here the seismic base shear for the building is determined by using an emphatically determined time period, and distributed over the stories as lateral load proportional to an assumed mode shape, which is parabolic (but interestingly with 100% mass participation assumed). Here lateral load determination is all formula based, no modal analysis is required, and the method is therefore.

b) **Non-linear**: This is done by running a non-linear analysis on a non-linear building model. Non-linearity is incorporated in the analysis model in form of non-linear hinges inserted into an otherwise linear elastic model which one generates using a common analysis-design software package.For the purposes of urban planning, the area to be urbanized is again zoned further as smaller unit which is known as micro-zoning. By doing so, the local variations in soil profile, geology etc can also be considered. The important factors that affect the magnitude of earthquake forces are:

a. Seismic Zone Factor, Z

As mentioned earlier, India has been divided into four seismic zones as per IS 1893 (Part 1): 2002. There are different zone factors for different zones.

b. Importance Factor, I

It relies upon useful utilization of the structures, characterized by hazardous results of its collapse or failure and post-earthquake practical requirements or financial significance. Elevated water tanks are utilized for putting away consumable water and used during crisis for example, putting out fires and are of post earthquake significance. Importance factor is taken as 1.5 for elevated water tank.

c. Response Reduction Factor, R

It relies on the apparent earthquake hazard and harm caused on the building, described by brittle or ductile displacements. R values of tanks are not as much as buildings since tanks are less ductile and have low redundancy when compared with other building. For Special Moment Resisting Frame (SMRF), R value is 2.5.

An Earthquake is a phenomenon that results from and is powered by the sudden release of stored energy in the crust that propagates Seismic waves. At the Earth's surface, earthquakes may manifest themselves by a shaking or displacement of the ground and sometimes tsunamis, which may lead to loss of life and destruction of property. The word Earthquake is used to describe any seismic event whether a natural phenomenon or an event caused by humans—that generates seismic waves. Most naturally occurring earthquakes are related to the tectonic nature of the earth. Such earthquakes are called tectonic earthquakes. The Earth's lithosphere is a patchwork of plates in slow but constant motion caused by the heat in the Earth's mantle and core. Plate boundaries grind past each other, creating frictional stress. When the frictional stress exceeds a critical value, called local strength, a sudden failure occurs. The boundary of tectonic plates along which failure occurs is called the fault plane. When the failure at the fault plane results in a violent displacement of the Earth's crust, the elastic strain energy is released and seismic waves are radiated, thus causing an earthquake. Earthquakes occurring at boundaries of tectonic plates are called inter plate earthquakes, while the less frequent events that occur in the interior of the lithosphere plates are called inter plate earthquakes. The severity of an earthquake can be measured in terms of magnitude and intensity. For that seismologists use two fundamentally different but equally important types of scales.

B. Water Tanks:

In general there are three kind s of water tanks-tanks resting on ground, underground tanks and elevated tanks. The tanks resting on ground like clear water reservoirs, settling tanks, are ration tanks etc. are supported on the ground directly. The walls of these tanks are subjected to pressure and the base is subjected to weight of water and pressure of soil. The tanks may be covered on top. The tanks like purification tanks, Imhoff tanks, septic tanks, and gas holders are built underground. The walls of these tanks are subjected to water pressure from inside and the earth pressure from outside. The base is subjected to weight of water and soil pressure. These tanks may be covered at the top. Elevated tanks are supported on staging which may consist of masonry walls, R.C.C. tower or R.C.C. columns braced together. The walls are subjected to water pressure. The base has to carry the load of water and tank load. The staging has to carry load of water and tank. The staging is also designed for wind forces. From design point of view the tanks may be classified as per their shape- rectangular tanks, circular tanks, intze type tanks. Spherical tanks conical bottom tanks and suspended bottom tanks.

Sloshing Impact

Sloshing, the motion of the free liquid surface inside its container is one of the major concerns in design of liquid storage tanks, moving tankers fuel tank of space vehicles and also in ships. In major cities and also in rural areas elevated water tanks forms an integral part of water supply scheme and these tanks must remain functional to meet the demand in any extreme situation like earthquake, fire, etc. Seismic safety of liquid storage tanks is of considerable importance. Water storage tanks should remain functional in the post-earthquake period to ensure potable water supply to earthquake-affected regions and to cater the need for firefighting. Industrial liquid containing tanks may contain highly toxic and inflammable liquids and these tanks should not lose their contents during the earthquake.

The main concerns for failure of water tanks are

• Consideration is not given to sloshing effects of liquid and flexibility of container wall while evaluating the seismic forces on tanks.

• It is recognized that tanks are less ductile and have low energy absorbing capacity and redundancy compared to the conventional building systems which is not considered properly.

• Unsuitable design or wrong selection of supporting system and underestimated demand or overestimated strength of the tank.

The need for this study is that, Indian code needs inclusion of convective mode of vibration in the seismic analysis of tanks and more importance should be given to Sloshing, rather than considering it as a parameter to fix the free float of the tank.

2. LITERATURE REVIEW

For same capacity, same geometry, same height, with same staging system, in the same Zone, with same Importance Factor & response reduction factor; response by Equivalent Static Method to Dynamic method differ considerably. It also state that even if we consider two cases for same capacity of tank, change in geometric features of a container can show the considerable change in the response of elevated water tank. At the same time Static response shows high scale values that of the Dynamic response. It happens due to the different picks of time periods. For Static analysis water- structure interaction shows that 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 structure and water has same stiffness, while in Dynamic analysis we considered two mass model which shows two different stiffness for both water and structure hence pick of time for both the components are different hence fundamental time periods are different for both static and dynamic analysis. But secondary time period in dynamic analysis is greater than both fundamental time periods because water in the upper region (Convective region) remains in un damped condition (sloshing condition) for some more time.

Column moment in bracing increases by increasing height of staging of water tank. Column moment is minimum for radial bracing. Shear force in bracing increases by increasing height of staging. Shear force in bracing is minimum for radial bracing. Comparison of base shear value by manual and software method is in permissible limit that is 1.17% less value in software analysis as compare to manual. Axial column force and base shear is not much affected by height of staging. Bending moment in bracing increases by increasing height of staging. Maximum displacement increases by increasing staging height for zone IV. Cross bracing gives minimum value for base shear for all zone and staging height. Maximum displacement value is minimum for radial bracing. Maximum displacement is greater in cross bracing. Overturning moment is minimum for cross bracing. By considering results of analysis radial bracing performs better in all manner as compared to cross bracing and normal bracing.

Seismic analysis and performance of elevated RC circular water tank have been presented in this study for frame type of staging pattern. Generally, when earthquake occur major failures of elevated water tank take place due to failure of supporting systems, as they are to take care for seismic forces. Therefore supporting structures of elevated water tanks are extremely vulnerable under lateral forces due to an earthquake. Modeling and static analysis is performed using STAAD PRO software. Further, the behavior of elevated water tank with staging pattern is analyzed using two mass model methods. Seismic analysis of overhead circular water tank carried out in accordance with IS: 1893- 1984 and IS: 1893-2002 (Part-2) draft code. The analysis is carried out for elevated circular tank of 1000 Culm capacity, located in four seismic zones (Zone-II, Zone -III, Zone-IV, Zone-V) and on three different soil types (Hard rock, Medium soil, Soft soil). Further, three different tank-fill conditions - tank full, tank 50% full, tank empty are also considered in this study. The seismic responses of circular tanks are computed and compared based on the theoretical procedures of IS: 1893-1984 and IS: 1893-2002(Part-2) draft code. The analysis was performed using SAP-2000 software package also. The parameters of comparison include base shears, base moments, impulsive and convective hydrodynamic pressures on tank wall and base slab. The results of the analysis showed an increase in base shear, base moment, hydrodynamic pressure and time period with increasing zone factor for all soil types and tank fill conditions considered.

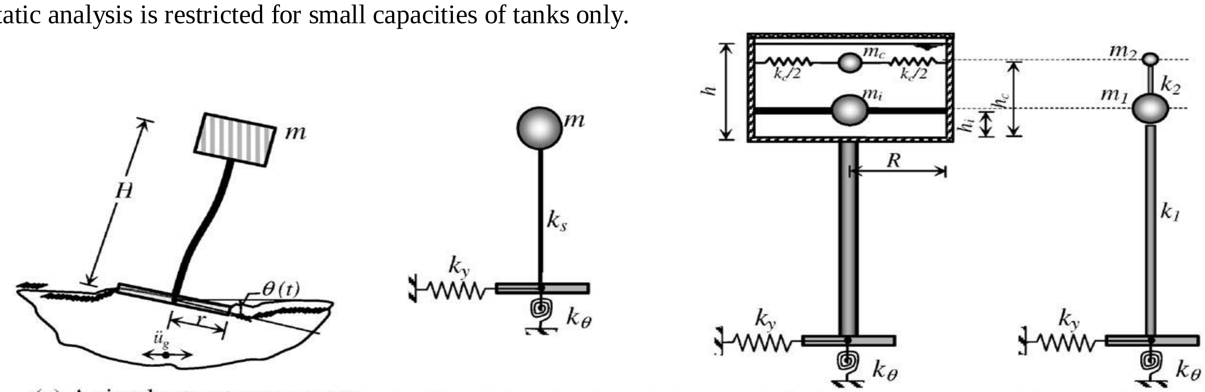
depict the variation of base shear with seismic zone i.e. Zone factor and it could be observed that the base shear increased with increasing zone factor, which increases from zone II to V, for all types of soils (hard rock, medium soil and soft soil) and also for different tank-fill conditions i.e. tank full condition, tank 50% full condition and tank empty condition. In the analysis of 1000 Cu.m overhead circular tank, as per IS:1893-1984 Provisions, base shear increased by 100%, 150% and 300% as the zone changed from II to III, IV and V respectively in case of hard rock. The corresponding values are found to be 100%, 150% & 300% and 100%, 108% & 147% respectively in medium and soft soil for tank full condition. On the other hand, the values have been 100%, 150% & 300% and 100%, 150% & 300% for tank 50% full and tank empty conditions in hard rock, medium soil and soft soil respectively. As per IS:1893- 2002 (Part -2) draft code Provisions, base shear increased by 56%, 135% and 253% with zone changing from II to III, IV and V respectively in hard rock. The corresponding values are 56%, 135% and 253% and 54%, 131% & 246% respectively for medium and soft soil with tank full condition. The base shear values have been 60%, 140% & 260% and 54%, 131% & 246% for tank 50% full and tank empty conditions in hard rock, medium soil and soft soil respectively.

3. DYNAMIC 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.



(a) A simple structure supports on deformable soil (b) Simple idealized model for soil-structure interaction (c) Springs-masses model for considering the effects of the fluid-structure-soil interaction model for the soil-structure interaction

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

A. Single lumped-mass model

The equivalent spring-mass models have been proposed by some researchers to consider the dynamic behavior of the fluid inside a container as shown in Fig. 2. The fluid is replaced by an impulsive mass mi that is rigidly attached to the tank container wall and by the convective masses mcn that are connected to the walls through the springs of stiffness (kcn). According to the literature, although only the first convective mass may be considered (Housner, 1963), additional higher-mode convective masses may also be included (Chen and Barber, 1976; Bauer, 1964) for the ground-supported tanks. A single convective mass is generally used for the practical design of the elevated tanks (Haroun and Housner, 1981; Livaog˘ lu and Dog˘angu¨ n, 2005) and higher modes of sloshing have negligible influence on the forces exerted on the container even if the fundamental frequency of the structure is in the vicinity of one of the natural frequencies of sloshing (Haroun and Ellaithy, 1985).

As practical analyses are presented in this study, only one convective mass is taken into consideration in the numerical examples. Haroun and Housner (1981) have also developed a three-mass model of ground-supported tanks that takes tank-wall flexibility into account. Here, as the elevated tanks are considered to be reinforced concrete, the flexibility of the walls is ignored and the third-mass is not considered for the simplified models that were used in this project.

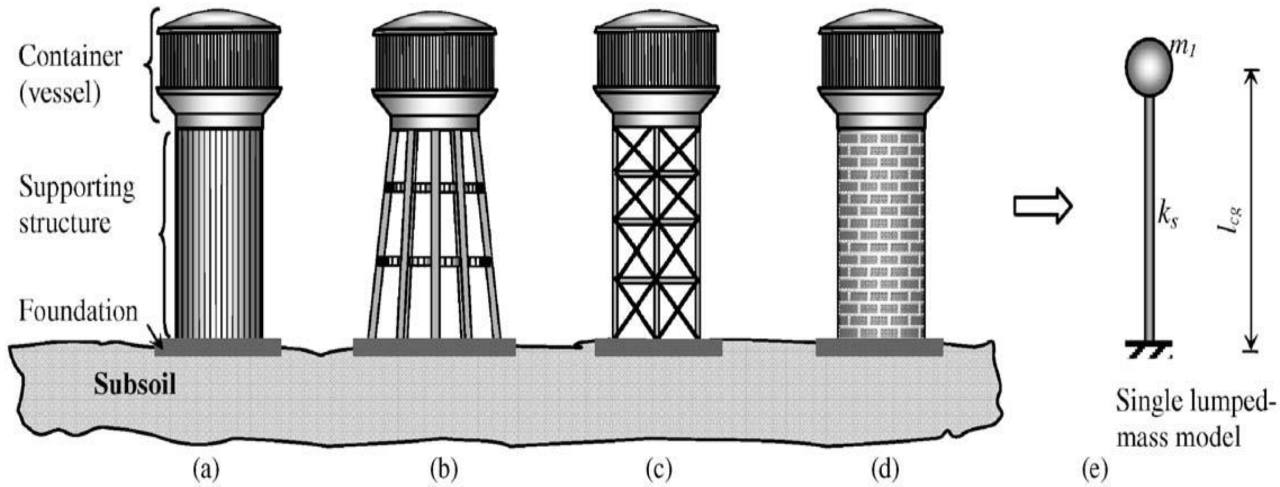


Fig. 2 Elevated tanks and the single lumped-mass model: (a) the tank with reinforced concrete shaft supporting structure, (b) the tank with reinforced concrete frame supporting structure, (c) the tank with reinforced concrete frame with diagonal braces or steel frame supporting structure, (d) the tank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

B. Double lumped-mass model

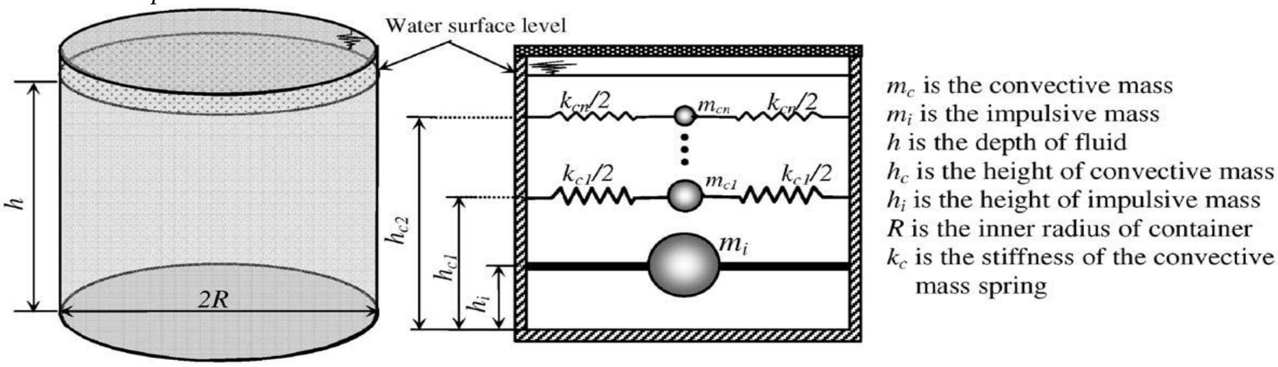


Fig.3 Spring-mass analogy for ground supported cylindrical tanks.

Simplified analysis procedure has been suggested by Housner (1963) for fixed-base elevated tanks. In this approach, the two masses (m1 and m2) are assumed to be uncoupled and the earthquake forces on the support are estimated by considering two separate single-degree-of-freedom systems: The mass of m2 represents only the sloshing of the convective mass; the mass of m1 consists of the impulsive mass of the fluid, the mass derived by the weight of container and by some parts of self-weight of the supporting structure (two-thirds of the supporting structure weight is recommended in ACI 371R also and the total weight of the supporting structure is recommended by Priestley et al., 1986).This two-mass model suggested by Housner has been commonly used for seismic design of elevated tanks.

4. METHODOLOGY

A. Structural Layouts

Each of the propped cantilevers was made rigid fixed to its base slab and was expected to be drawn inward at the top by the wall/top slab connecting reinforcements, in response to the outward hydrostatic loading on the wall. That was providing in view based on the fact that continuity reinforcement must be provided at corners and at member-junctions to prevent cracking. The base slabs was typically a double overhanging single-spanned continuous slab, with wall point load and its applied fixed end moment at each overhang end. And the top slabs was laid out to be either two-way spanning or simply supported as stated by Anchor (1992 and 1981). The tank dimensions was deduce by application related to the formula for solid shapes volume calculations, Therefore (π x R2 x H) for cylinder was applied for the circular water tank; where, H and R, Breadth, Height and Radius respectively.

B. Wall Loading

The average water force and load, P in kN / meter width of the rectangular tank walls under flexural tension was derived as a point concentrated load by calculating the areas of the pressure diagrams of the water tank content on the walls, to be (ρH) x H/2, where ρ is the water density. By the centroid consideration of loading of the pressure diagram, one-third distance from the base, up each wall, was chosen as the point of application of the concentrated load. The circular water tank wall would be clearly in a state of simple hoop tension and its amount in kN per meter height of wall would be (ρH) x D/2. And it would still act at one-third distance from the base up each wall. The wall total working loads for both options were assumed purely hydrostatic. And the inclusion of wind load in the working load was purely made to be dependent on tank elevation above the ground level, but would always be applicable in the design of its support. The wind loads application point, if considered, would be at one-half the tank"s height and acting against the lateral water force. Hence, the resultant lateral force, from the combination of the water force and wind force; if applicable, would be one-half way between the two forces, that is, five-twelfth of the tank"s height.

C. Base Slab Loading

For every of the elevated water tank options, the base slab characteristic serviceability uniformly distribute load in kN/m per meter was the sum of its dead load, thyself-weight concrete and its finish, and its live load, that is, the weight of water to be contained. And the serviceability point load in kN / meter, acting on each of the base slabs, at the extremes of the overhangs was derived by adding up the wall dead load that is the base projection weight and a calculated fraction of the top slab load. But some notice difference may be experience in the calculations of the fractions of the loads from the circular water tank top slabs.

D. Top Slab Loading

The top slab uniformly distributed load, in kN/m per meter run is calculate by adding up its combination of dead load, that is self weight concrete, waterproof finish and its live load, to derive the characteristic serviceability load. Factors of safety of 1.4 and 1.6 was apply to the combination of dead and live loads respectively before their sum is make to achieve the require ultimate design load of top slab.

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.

5. 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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