Seismic Response Control of Elevated Water Tank using Base Isolation: A Review

Sanket Nimbekar1, Dr. K. R. Dabhekar2, Prof. S. S. Solanke3, Dr Isha P Khedikar4, Er. Tushar H. Sonawane5
1Research Scholar, Civil Engineering Department, G H Raisoni College of Engineering, Nagpur, India
2,3,4Assistant Professor, Civil Engineering Department, G H Raisoni College of Engineering, Nagpur, India
5Director, Tushar Sonawane and Associates-Consulting Civil & Structural Engineers, Nashik, India
1nimbekar_sanket.mtechstr@ghrce.raisoni.net

Abstract: Earthquake events are not something which can be avoidable. The Indian subcontinent has a background marked by devasting quakes. Quakes are generally caused when the stone underground out of nowhere breaks along an issue. Ground shake is caused by seismic waves due to sudden release of energy. The Centre of earthquake vibration is known as epicenter. Due to earthquake millions of lives are lost which can never be affordable. Most of the structures are subjected to vibrations; it causes destruction of country’s infrastructure. In the recent earthquakes many well designed concrete structures have been severely damaged or collapsed. To protect structures from response reduction of structures and important harm under such serious earthquakes has become a vital theme in structural engineering. In this investigation, we evaluated seismic performance of staging system of elevated water storage tank with or without Base Isolation by using SAP2000. From this examination the powers following up on elevated water tank because of seismic powers are determined for zone IV.

Keywords: Seismic Analysis, Elevated Water Tank, SAP 2000, Base Shear.

1. Introduction

Most of the structures are subjected to vibrations; it causes destruction of country's infrastructure. These earthquakes have because severe damages to large scale infrastructures. As per seismic code IS 1893(Part 1):2002, 54% of Indian land is defenseless against earthquake. The observed damages in recent earthquakes shoes that it is necessary to choose new methods in improvement designing of structure.
To stay away from such basic harms, underlying designers are attempting to sort out various kinds of primary frameworks that are vigorous and can withstand solid movement.

The four levels of seismicity for India considered as zone factors is the latest transformation of seismic drafting guide of India given in quake safe arrangement code of India [IS 1893(Part1)2002]. Zone II, III, IV, and V are four seismic zones in India as per earthquake zoning map of India. From various natural calamities Earthquake acquires first place in vulnerability. The life can’t be recovered but property losses are often recovered to some extent after an earthquake. The fundamental explanation of life misfortune is breakdown of structures. During course of history, it has been seen that high raised structure are most prone to seismic damages like communication towers, tall building and elevated water tank.[18]

1.1. Water Tank

Among various structures elevated water storage reservoirs are the structure which needs to be remains functional after major earthquake event for relief operations and to control fire break outs. Elevated water tank may be a colossal raised water accumulating compartment created to carry water system at a height satisfactory to pack water dissemination system. Water supply is a daily existence life line that should stay useful in catastrophe. Water supply system in most districts of India depends upon elevated tanks for limit. Accordingly, the seismic conduct of raised tanks ought to be known and perceived and they ought to be plan quake safe. [4]

A disappointment of capacity tanks immediately disquotes fundamental framework as well as purpose fires or natural pollution when combustible materials or risky synthetic compounds spill. These tanks ought to be stayed practical during post-tremor. Seismic analysis of water tanks contrasts from structures twoly; during seismic excitation, liquid inside the tank applies hydrodynamic power on base and tank wall. While designing the elevated water tank, first we have to know in which zone that water will be designed. The designing of water tank is also depending upon the soil type of that locality. Elevated water tank is generally design in two steps, the staging is provided at the base and water tank at the top. Staging generally has structural system compressing of column and horizontal braces which transmits the load to foundation.

Behaviour of water tank on staging is crucial and needs to be evaluated. Tanks are designed as crack free structure to avoid failure. [5]

During seismic excitation, liquid force acts on tank wall due to liquid inside the tank. Tank wall and liquid are exposed to flat speed increase when the tank carry water with a free surface is exposed to level quake ground movement. In the base space of the tank the liquid acts like a mass that is unbendingly connected with tank wall. The mass which accelerates close by the wall and incites impulsive hydrodynamic strain relatively on base and on the tank wall. In the higher area of the tank liquid mass goes through splashing movement. This mass which applies convective hydrodynamic tension on the base and tank wall is named as convective liquid mass. [8]

The two segments, impulsive mass and convective mass are isolated from complete liquid mass. These two liquid masses should be addressed appropriately in the spring mass model of liquid tank system. The boundary of spring mass model relies on the calculation which was initially proposed by Housner.

In this examination, we assessed seismic execution of raised water stockpiling tank by putting base separation framework utilizing SAP2000. The assessment of raised water is carried out on convective and impulsive mode utilizing the code IS1893 (Part2) and besides, we consider the forces inside the void condition tank and full condition tank. From this examination the powers following up on elevated water tank because of seismic powers are determined for zone IV. [9]

1.2. Method of Seismic Analysis

For seismic analysis purpose, both Response Spectrum Analysis and Equivalent Static Method are performed and results are presented separately.
1.2.1 Equivalent Static Method

The Equivalent Static Method is a managed technique to replace the impact of dynamic stacking of a common quake by a static power passed on at the edge on advancement for configuration purposes. The two horizontal directions parallel to the main axes of the tank is generally the assessment of total applied seismic force V. It acknowledges that the tank reacts in its crucial horizontal mode. To avoid torsional advancement underground developments the tank should be really symmetric and low rising. The design should have the choice to go against impacts achieved by seismic forces one or the other way, however not in the two ways at the same time. [19]

1.2.2 Response Spectrum Analysis

Response Spectrum Analysis (RSA) is an immediate one-of-a-kind authentic investigation technique which appraises the responsibility from each basic technique for quaking to present the most possible noteworthy seismic response of a fundamentally adaptable plan. RSA gives understanding of dynamic direct by assessing fake speed increment, speed, or on the other hand dislodging as a part of essential period for a level of damping and given time frame outline layout history. RSA is practical to cover response spectra along with ultimate objective by which a smooth curve tends to the apex response for each affirmation of fundamental time. Since RSA relates essential sort decision to dynamic execution, it is significant for plan dynamics. Developments of more restricted time experience for additional unmistakable speed increment; anyway, those of longer time experience more imperative removing. During starter plan and response-spectrum analysis essential accomplishment of targets should be considered. [19]

2. Objectives

- To study the impact of seismic forces on the water tank.
- To study the different techniques on seismic resistance of structures.
- To provide and compare staging using base isolation.

3. Methodology

3.1. Methods and Procedure

- Selection of R.C. Tank staging will be done in this step for analytical case study.
- Study of SAP2000 will be in model software.
- The staging of selected tank will be in model software.
- Study of base isolation system and design of rubber bearing will be carried out.
- Base shear utilizing Linear Static Method and Response Spectrum will be discovered for fixed base and secluded design.
- Comparison of fixed base structure and isolated structure will be done for base shear.

3.2. Plan and Elevation of water tank staging in SAP2000

A plan of R.C. Tank staging is designed. It consists container, slabs, beams and columns for elevated circular water tank.
The 2-D plan and 3-D model of elevated storage reservoir in SAP 2000 is as shown in above figure 1 and figure 2 respectively.

4. Details of the models and parameters provided

| Preliminary Data                  |       |
|-----------------------------------|-------|
| Roof slab diameter                | 14.4 m|
| Roof beam width                   | 0.25 m|
| Roof beam depth                   | 0.52 m|
| Wall thickness                    | 0.2 m |
| Depth of water                    | 7.7 m |
| Av. Thickness of balcony          | 0.13 m|
| Base slab thickness               | 0.20 m|
| Base beam width                   | 0.45 m|
| Base beam depth                   | 0.60 m|
| Span of bottom beam               | 4.00 m|
| Type of soil                      | Soft  |
| Depth of footing                  | 3 m   |
| Column diameter                   | 0.75 m|
| Brace width                       | 0.3 m |
| Brace depth                       | 0.4 m |
| Density of concrete               | 25 kN/m$^3$|
| Concrete Grade                    | M25   |
| Steel Grade                       | Fe415 |

| Seismic Data                      |       |
|-----------------------------------|-------|
| ZONE (Z)                          | 0.24  |
| IMPORTANCE FACTOR (I)             | 1.50  |
| RESPONSE REDUCTION (R)            | 2.50  |
5. Calculation

5.1. Calculation of parameters

| Weight of container  |   |
|----------------------|--|
| Weight of water      | 11853.23 kN |
| Weight of wall       | 1784.424 kN |
| Weight of roof slab  | 488.580 kN |
| Weight of roof beam  | 111.526 kN |
| Weight of gallery    | 157.236 kN |
| Weight of bottom slab| 814.300 kN |
| Weight of base slab  | 301.121 kN |

| Weight of staging    |   |
|----------------------|--|
| Weight of column     | 1325.359 kN |
| Weight of braces     | 535.327 kN |

| Live Load             |   |
|-----------------------|--|
| Roof slab             | 244.290 kN |
| Gallery               | 72.570 kN |
| 25% of Live load      | 79.215 kN |

| Total weight W/O weight of water | = 4256.258 kN |

Analysis

| Analysis                                      | With water in Tank                  | W/O water in tank                  |
|----------------------------------------------|-------------------------------------|------------------------------------|
| Time Period                                  | $T_I = 1.049 \text{ sec}, T_C = 3.9422 \text{ sec}$ | $T = 0.6530 \text{ sec}$          |
| Design Horizontal Seismic Coefficient        | $(A_h)_I = 0.117, (A_h)_C = 0.04788$ | $A_h = 0.117$                     |
| Base Shear                                   | $v_b = 1334.638 \text{ kN}$          | $V_b = 2508.82 \text{ kN}$        |
| Base Moment                                  | $m^* = 45032.062 \text{ kN-m}$       | $M^* = 10225.253 \text{ kN-m}$    |

5.2. Validation of SAP2000

DEAD WEIGHT OF TANK

| MANUAL CALCULATION | 17429.788 KN |
| SAP2000 V19.2.1    | 17549.02 KN |

From the above table we can compare dead weight of tank calculated by SAP2000 V19.2.1 with manual calculation of the same and it has been found that the results calculated by the software are considerably near to manually calculated results.
6. RESPONSE CONTROL OF STAGINGS

6.1. Study of Base Isolation

Base Isolation is quite possibly the most broadly acknowledged seismic assurance frameworks in quake inclined regions. Seismic confinement is a plan technique, which uncouples the construction for the harming impacts of the ground movement. The other motivation behind a disconnection framework is to give an extra method for energy dispersal, consequently lessening the sent speed increase into the superstructure. [3, 5]

Base isolation, as a procedure to shield structure from earthquake, spins around a couple of fundamental components of comprehension:

- **Period-shifting of structure**: Base isolator may be more adaptable gadget contrasted with the adaptability of the construction. Along these lines, coupling both the superstructure and an isolator together expands the adaptability of the all-out disengaged primary framework. Along these lines, this strategy stretches the constructions common time-frame away from the dominating recurrence of the ground movements, consequently sidestepping sad reactions caused because of reverberation.

- **Mode of vibration**: The significant technique for vibration is changed from nonstop cantilever type plan to an essentially inflexible superstructure with distortions amassed at the confinement level

- **Damping and cutting of load transmission path**: To ingest the energy of the ability to decrease the general redirection of the plan with respect to the ground, energy dissipater or a damper is utilized.

- **Minimum rigidity**: For base level service loads it gives least inflexibility, for example, minor earthquake loads or wind.

6.2. Lead-Rubber Bearings

A Lead-Rubber bearing is the 2nd classification of elastomeric bearings. LRB lead-rubber bearing work on the rule of base disengagement and limits the energy moved from the base to the development inside the event of a quake. Lead Rubber Bearings (LRB) comprises of a steel holding and laminated rubber on for steel spine plates for mounting to the design. All isolators have an energy scattering lead center. In the isolator the rubber acts as a spring. It is extremely delicate along the side yet exceptionally firm upward. The high upward solidness is accomplished by having dainty layers of rubber supported by steel shims. The lead core gives damping by distorting plastically when the isolator moves horizontally in a quake. By giving lead core the isolation level displacement by ethicalness of its energy engrossing limit is reduced. The lead-rubber bearing likewise give an extra hysteretic damping through the yielding of the lead-core. The combined features of horizontal

![Figure 3. Deformed shape of model](image_url)
flexibility, damping during a single unit, vertical load support and restoring force provides during this seismic isolation system. [7, 16]

![Lead-Rubber Bearing](image)

**Figure 4. Lead-Rubber Bearing**

7. RESULT AND DISCUSSION

7.1. Manual calculation of base shear

From the time period given by the software we can manually calculate base shear for the respected seismic zone, soil type, importance factor and response reduction factor as given below

| Time period | Fixed Base | Isolated Base |
|-------------|------------|---------------|
| 2.51421     | 4.50404    |

| Seismic horizontal | Fixed Base | Isolated Base |
|--------------------|------------|---------------|
| $A_h = 0.0478$     |            | $A_h = 0.03$  |

| Base Shear | Fixed Base | Isolated Base |
|------------|------------|---------------|
| $V_B = 833.143 \text{ KN}$ | $V_B = 522.893 \text{ KN}$ |

7.2. Results found with manual calculations and SAP2000

| Base Shear | Manually calculated | SAP2000 |
|------------|---------------------|---------|
| EQX        | 833.143 KN          | 832.927 KN |
| EQY        | 833.143 KN          | 832.927 KN |

| Base Shear | Manually calculated | SAP2000 |
|------------|---------------------|---------|
| EQX        | 522.893 KN          | 527.521 KN |
| EQY        | 522.893 KN          | 527.521 KN |
Table 5. Results for response spectrum analysis.

| Base Shear | Manually calculated | SAP2000 |
|------------|---------------------|---------|
| RSAX       | 270.498 KN          | 176.574 KN |
| RSAY       | 270.498 KN          | 177.347 KN |

Table 6. Acceleration in X-direction

| Storey Level | Fixed | Isolated |
|--------------|-------|----------|
| 0            | 0     | 0.23858  |
| 1            | 0.07175 | 0.22409 |
| 2            | 0.22248 | 0.19207 |
| 3            | 0.27296 | 0.14312 |
| 4            | 0.19531 | 0.10356 |
| 5            | 0.15913 | 0.10315 |

Figure 5. Acceleration curves for X-direction
Acceleration in response spectrum analysis for Y-direction

Table 7: Acceleration in Y-direction

| Storey Level | Fixed  | Isolated |
|--------------|--------|----------|
| 0            | 0      | 0.23858  |
| 1            | 0.07175| 0.22409  |
| 2            | 0.22248| 0.19207  |
| 3            | 0.27296| 0.14312  |
| 4            | 0.19531| 0.10356  |
| 5            | 0.15913| 0.10315  |

![Acceleration in Y-direction graph](image)

**Figure 6.** Acceleration curves for Y-direction

7.3. Discussion

From above results we have observed that base shear resulting for manual calculation are considerably matching and also, we have observed that base shear in fixed is considerably decreased by providing the isolation at base.

In result from response spectrum method, we have observed that the acceleration of isolated base is more linear than the fixed base tank.
8. Conclusion

The seismic response of elevated water tank is isolated by lead rubber bearing (LRB) system is investigated under earthquake ground movement to research the viability of base isolation the response of the isolated tank and the tank without isolation system is compared by using the seismic analysis method i.e., response spectrum method and equivalent static method.

From the results of above investigation following conclusions have been made

I. The result obtained from the equivalent static analysis method by comparing elevated storage tank with and without isolation system in both X and Y direction is that the base shear obtained from non-isolated tank is significantly reduced in isolated tank.

II. The comparative results with equivalent static method for base shear by applying manual analysis calculation and analysis by SAP2000 are found to be approximately similar.

III. Analysis by using the response spectrum method it is found that the base shear of elevated storage tank is less for the isolated tank as compared with non-isolated tank.

IV. By the software computation for the acceleration at different story level in both X and Y direction by using response spectrum analysis it has been found that acceleration for isolated tank is changed as compared with non-isolated tank.

Reference

[1] Motwani, Mrs Meet. "Vibration Control of Elevated Water Tank Using Different Seismic Control Techniques–A Review."
[2] Dr..Pajgade P.S, Mr. Waghmare P. B., Dr. Kanhe N.M. "Seismic Response of Isolated Liquid Storage Tanks with Elastomeric Bearings."
[3] Dr. Potnis S.C., Ms. Sutar P. S. "Earthquake response of the liquid storage tank with various isolation systems."
[4] Mr. Birtharia A., Mr. Jain S. K. "Seismic response of elevated water tank."
[5] Mr. Deshmukh G. P., Mr. Patkar S. "Analysis of elevated water structure using staging system." [6].
[6] Dr. P.S.Pajgade, Pravin B. Waghmare and Dr. N.M.Kanhe, "Seismic Response of Isolated Liquid Storage Tanks with Elastomeric Bearings (2013)."
[7] Dr. S.C.Potnis, Poonam S. Sutar, "Earthquake response of the liquid storage tank with various isolation systems(2013)."
[8] Mr. Birtharia A., Mr. Jain S. K. "Seismic response of elevated water tanks: an overview."
[9] Neha N. Walde, Sakshi Manchalwar, Amey Khedikar, "Seismic Analysis of Water Tank Considering Effect on Time Period."
[10] G. P. Deshmukh, Ankush S. Patkar, "Analysis of elevated water storage Structure using Different staging system (2015)."
[11] Mor Vyankatesh K., More Varsha T. "Comparative study on dynamic analysis of elevated water tank frame staging and concrete shaft supported."
[12] Ankit Agarwal, "Department of Structure Engineering, Faculty of Technology UTU Dehradun, India ,Pooja Semwal."
[13] Asari Falguni P, Prof. M.G.Vanza, "Structural Control System For Elevated Water Tank."
[14] Mayank Gopal Manwani, Deepa P.Telang, "Review on seismic analysis of elevated water tank with variations of H/D ratio and container shape."
[15] Manish N. Gandhi, Ancy Rajan, "Earthquake resistant analysis of circular elevated tank with different bracings in staging."
[16] M.K. Shrimali, R.S. Jangid: "Seismic response of liquid storage tanks isolated by sliding bearings."

[17] M.B. Jadhav and R.S. Jangid: "Response of baseisolated liquid storage tanks."

[18] P.L.N.Saroja: "Comparative Study Of Analysis of Elevated Water Tank Due To Earthquake From Different Zones Of Earthquake."

[19] Tejaswini M.S., Sridhar. R-Comparative: "Study on Behaviour of Elevated Water Tank with Soil Structure Interaction Subjected to Seismic Load Using Sap 2000."

[20] Dr. R.B. Khadiranaikar, Abbas Ali Dhundasi: "Equition For Estimation of Fundamental Time Period for Elevated Water Tank."

[21] Chirag N.Patel and H.S. Patel: "Supporting System For Renforced Concrete Elevated Water Tank: A State- Of-The Art Liturature Review." 

[22] Suyash Nerkar, Chittaranjan Nayak: "Seismic Behavior Of Elevated Storage reservior By Finite Element Method."

[23] Atsushi MORI, Ryoichi Fujita, Kiyoshi Yasug, Ryoji Iso, Yuichi HAYASHI and Kenji NIWA: "A Study on a Seismic Verifcation and Retrofit Method for An Elevated Water Tank Against Strong Earthquakes.