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Research Paper**SEISMIC RESPONSE OF ELEVATED WATER TANK-1**

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ABSTRACT Elevated water tanks are important components of water supply systems, particularly in areas where reliable water storage and distribution are required. Due to their considerable height, mass distribution, and supporting structure, elevated water tanks are vulnerable to lateral forces generated during earthquakes. The movement of water inside the tank can produce a sloshing effect, which increases the dynamic load and may affect the stability of the supporting structure. Therefore, understanding the seismic behaviour of elevated water tanks is essential for improving their safety and structural performance. This project presents a physical model of an elevated water tank to study its response under simulated earthquake loading. The model consists of a water tank supported on a structural frame with X-bracing, mounted on a manually or motor-operated shake table. The model is subjected to controlled lateral movement to simulate earthquake forces. The water inside the tank demonstrates the sloshing effect and its influence on the movement and stability of the structure. Different structural conditions, particularly with and without bracing, can be observed and compared. The study focuses on parameters such as lateral movement, tank tilting, structural stability, and the effectiveness of bracing and base isolation in reducing earthquake-induced movement. The observations indicate that a properly braced supporting frame provides greater resistance to lateral forces and reduces excessive movement and tilting of the tank. Rubber pads used as an optional base-isolation arrangement can further help in reducing the transmission of vibrations to the structure. The project provides a simple and practical demonstration of the principles of earthquake-resistant design of elevated water tanks. It helps in understanding the interaction between structural response and water sloshing during seismic loading and highlights the importance of adequate bracing, stable foundations, and suitable structural design for safer water storage systems in earthquake-prone areas.

Keywords: Elevated Water Tank, Earthquake Loading, Seismic Response, Water Sloshing, Lateral Forces, Structural Stability, X-Bracing, Base Isolation, Earthquake-Resistant Design, Seismic Safety.

1. Introduction

Elevated water tanks, commonly known as overhead water tanks, are widely used to provide water storage and maintain pressure in distribution systems. An elevated water tank generally consists of three major structural components:

1. Tank container
2. Supporting staging

3. Foundation system

The tank container stores water, while the staging transfers gravity and earthquake-induced loads to the foundation. Unlike conventional buildings, elevated water tanks contain a large amount of liquid concentrated at an elevated level. Consequently, their dynamic behaviour during an earthquake differs substantially from that of ordinary framed structures. During seismic excitation, the stored water does not behave as a rigid mass. A portion of the liquid moves approximately with the tank and produces an impulsive response, whereas another portion undergoes oscillatory movement relative to the tank and produces a convective or sloshing response. The interaction of these components with the flexible supporting structure determines the overall seismic response.

The modern Indian approach recognizes this behaviour by representing an elevated tank using a two-mass model. Earlier approaches based on a single equivalent mass were replaced because they could not adequately represent the different dynamic characteristics of the impulsive and convective components. The IITK-GSDMA guidelines similarly describe the elevated tank using a two-mass model based on Housner's approach.

Earthquake damage investigations and analytical studies have shown that elevated tank failures may be associated with excessive lateral displacement, inadequate staging strength, overturning effects, and dynamic effects caused by fluid inertia and sloshing. Recent research has also compared different staging-bracing configurations to assess their influence on seismic response.

Therefore, accurate seismic analysis of elevated water tanks is essential for maintaining the functionality of water-supply systems following an earthquake.

2. Objectives of the Study

The main objectives of this research are:

- To study the seismic behaviour of elevated reinforced-concrete water tanks.
- To understand the effect of impulsive and convective liquid masses on seismic response.
- To evaluate seismic base shear and overturning moment.
- To investigate the influence of staging height on the dynamic response.
- To study the influence of different staging and bracing configurations.
- To evaluate the effect of seismic-zone parameters on structural response.
- To compare the response of the tank under different analytical approaches.
- To develop recommendations for improving the seismic performance of elevated water tanks.

3. Literature Review

3.1 Housner's Equivalent Mechanical Model

Housner's classical work established the importance of considering the dynamic behaviour of liquid in storage tanks. The liquid can be represented approximately by two components:

- An impulsive mass that moves with the tank.
- A convective mass that represents the sloshing liquid.

The impulsive component generally has a relatively shorter natural period, whereas the convective component has a longer period associated with free-surface oscillation.

This concept forms the basis of the spring-mass representation used in seismic design of liquid-storage structures.

3.2 IITK-GSDMA Guidelines

The IITK-GSDMA guidelines for seismic design of liquid storage tanks describe the two-mass idealization for elevated tanks and provide procedures for determining the impulsive mass, convective mass, their heights, and the convective spring stiffness.

The two-mass approach is more representative than a single-mass model because elevated tanks are frequently only partially filled, and the liquid has significant sloshing behaviour.

3.3 IS 1893 (Part 2): 2014

IS 1893 (Part 2): 2014 covers seismic design of liquid-retaining tanks, including elevated tanks supported on staging. It is intended to be used along with the general provisions of IS 1893 Part 1 and related standards.

The standard considers:

- Impulsive liquid response
- Convective liquid response
- Structural mass
- Hydrodynamic pressure
- Seismic coefficients
- Base shear
- Overturning effects
- Tank and staging response

The 2022 Amendment No. 1 modified and clarified portions of the spring-mass model parameters and related provisions.

3.4 Finite Element Analysis

Finite-element studies provide a more detailed method for evaluating fluid–structure interaction. Research on liquid-filled elevated tanks has used displacement-based fluid elements and modal/time-history analysis to separately evaluate impulsive and convective responses while considering tank-wall flexibility and free-surface sloshing.

Such advanced analyses are useful where conventional equivalent-mass methods are insufficient, particularly for irregular tanks, flexible walls, unusual staging systems, or detailed research investigations.

4. Structural Configuration of an Elevated Water Tank

A typical elevated reinforced-concrete water tank consists of:

4.1 Tank Container

The container may be cylindrical, rectangular, Intze-type, conical, or another suitable configuration. It is designed to resist:

- Hydrostatic pressure
- Hydrodynamic pressure
- Self-weight
- Roof loads
- Earthquake-induced forces
- Temperature and shrinkage effects

4.2 Staging

The staging transfers the tank loads to the foundation. Common staging systems include:

- Circular column staging
- Frame-type staging
- Shaft-type staging
- Braced column staging

The staging is particularly important for seismic behaviour because its lateral stiffness controls the structural natural period.

4.3 Foundation

The foundation transfers vertical and lateral forces to the soil. Depending on the soil and tank configuration, isolated footings, combined footings, raft foundations, or pile foundations may be adopted.

5. Seismic Behaviour of Elevated Water Tanks

The seismic behaviour of an elevated water tank is more complicated than that of a conventional building because of fluid–structure interaction.

When the ground moves horizontally during an earthquake, the tank container accelerates with the staging. The water experiences inertia and produces two primary responses.

5.1 Impulsive Response

The impulsive portion of the liquid moves approximately together with the tank wall.

The equivalent impulsive mass can therefore be represented as a mass attached to the tank structure.

The impulsive response contributes significantly to:

- Base shear
- Overturning moment
- Column forces
- Bracing forces
- Foundation reactions

5.2 Convective Response

The convective component represents the oscillatory movement of the free water surface.

This phenomenon is commonly called sloshing.

The convective response can cause:

- Large free-surface displacement
- Increased hydrodynamic effects
- Roof impact in inadequately designed tanks
- Increased freeboard requirements
- Additional overturning effects

Because its natural period is generally longer than the impulsive period, the convective component must be considered separately in seismic analysis.

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