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Review Study on Dynamic Behavior of RCC Circular Elevated Water Tank with Baffle Walls

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Abstract: *An elevated RCC water tanks are very important components of lifeline and are considered to be the critical elements in municipal water supply. The water tanks get heavily damaged during earthquakes due to sloshing effects. This fact necessitates to focus elevated water tanks by provision of baffle walls inside the tanks. This paper focuses on study of behavior of water tanks provided with the baffle walls by literature review. The study concludes that use of horizontal as well as vertical baffle walls inside the tank facilitates in reducing the responses viz., displacement and base shear. Further, by increasing height of vertical baffle walls causes reduction in the displacement by an approximate value of 15–20 %. There is a good scope to study the behavior of RCC elevated water tank considering the provision of annular horizontal baffle walls by positioning them at varying depths along the height of the tank*

Keywords: RCC elevated water tank, Dynamic behavior, Sloshing effect, Annular horizontal baffle walls

I. INTRODUCTION

An elevated water tank is a substantial structure specifically designed to store and provide water from a raised position, ensuring consistent supply and pressure. These tanks are engineered in a variety of shapes to suit different functional and structural needs. Among the various designs available, circular and rectangular tanks are the most frequently utilized due to their practicality and efficiency in construction and usage. [1]. During the earthquakes, violent liquid sloshing of water within the tank creates localized high impact forces on the tank roof and walls which may lead to damages. One effective method to reduce the intense sloshing of liquids in containers is by incorporating internal baffles or baffle walls. However, the exact damping behavior of these baffles is still not completely understood. Beyond marine transportation, liquid sloshing poses safety concerns in various systems such as storage tanks, land-based transport vehicles, elevated water towers, structures subjected to ground motion, and aircraft fuel tanks. Therefore, investigating the sloshing behavior of liquids in baffled tanks and the resulting structural responses holds significant importance across a wide range of engineering applications. [2]. The term "liquid sloshing" refers to the existence of a free fluid surface that permits container-related motions. The water tanks with partial filled water suffers from the damage due to the sloshing effect caused during earthquakes. In order to reduce such sloshing effect of the water use of baffle walls is commonly done [3]. To increase the performance of the circular water tanks, baffle walls can be effectively provided [2].

The water tanks are categorized based on the following parameters:

- Based on locations viz., resting on ground water tank, underground water tank, and elevated water tank.
- Based on shapes viz., circular water tank, rectangular water tank, and intze water tank.
- Based on material used viz., steel water tank, RCC water tank, masonry water tank, and plastic water tank.

1.1 Components of Elevated Water Tank

According to Monolithic, the circular tanks are stronger than rectangular-like alternatives. The key components of the water tank include: roof slab, side walls, bottom slab, bottom ring beams, column/staging and bracings. The various components of a circular elevated water tank are shown in the Fig.1.

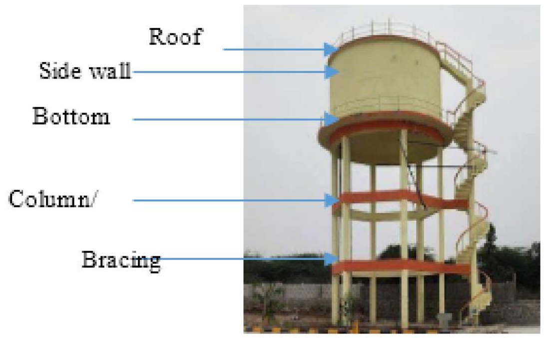

Fig. 1: Components of RCC elevated water tank
(Source: https://shorturl.at/gzvMX)

Structures can be protected from the damaging effects of strong earthquakes using either resistance-based methods or isolation techniques. In resistance design, it is assumed that seismic forces act directly on the structure, and each structural element must be capable of withstanding the highest possible loads, guided by ductility requirements. Conversely, in earthquake isolation, particularly in the seismic analysis and design of elevated water tanks, the goal is to minimize the structure's peak response. This is achieved by placing isolation devices between the structure's base and foundation, thereby reducing the transmission of seismic forces. [2].

1.2 Concept of Baffle Wall

The baffle walls are the panels which are used to obstruct direct flow of water in many industrial tanks such as heat exchanger and chemical reactor. Light weight panels are used as a baffle in industries whereas in civil engineering field baffle are used in the form of RCC concrete wall in water treatment and sewage plants. The baffle walls used in treatment plants are basically to increase the detention time period of water which causes settlement of particles. However, in water tanks, the baffle walls are mainly used to absorb the energy of sloshing. Fig.2 shows the vertical baffle wall in RCC elevated water tank and Fig.3 shows the horizontal ring baffle wall in RCC elevated water tank.

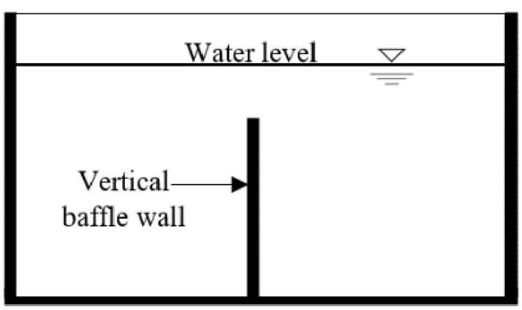

Fig. 2: Vertical baffle wall in RCC elevated water tank

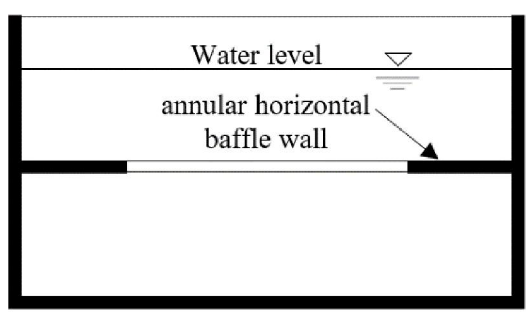

Fig. 3: Annular horizontal baffle wall in RCC elevated water tank

II. LITERATURE REVIEW

The research works published for several researchers in various national and international journals concerning the behavior of elevated RCC water tanks is rigorously studied and presented in the following section.

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Biswala et al., (2004) have studied the influence of annular baffle walls on the dynamic behavior of a partially liquid-filled cylindrical tank considering varying thicknesses and for different positions of baffle walls to determine natural frequencies of liquid. The baffle walls of rigid and flexible type are considered for the study. The analytical results of study for rigid and flexible baffle walls are compared. The study shows that as the thickness of rigid baffle wall increases, the natural frequency (sloshing frequency) of the liquid decreases by 0.013%. Authors conclude that the rigid baffle wall water tank system is effective as compared to flexible baffle wall system [1].

Mi-An Xue et al. (2011) conducted a study using a three-dimensional (3-D) numerical approach known as the Virtual Boundary Force (VBF) method to analyze viscous liquid sloshing in tanks equipped with internal baffles of varying shapes and configurations. The research compared sloshing behavior in tanks with and without ring baffles. Results revealed that the water beneath the ring baffle remains largely constrained, while only the liquid above it is free to move. This indicates that the ring baffle effectively limits vertical liquid motion and decreases the active sloshing mass by dividing the tank into smaller subregions. The researchers concluded that the developed 3-D model is reliable for fluid–structure interaction studies and that ring baffles significantly reduce the intensity of sloshing [2].

Aware et al., (2015) investigates the behavior of cylindrical elevated water tanks under earthquake loads, using the draft code of IS 1893:2002 (Part II). A 500 cubic meter tank was analyzed using finite element modeling techniques for various heights and different seismic zones in India. The study included 20 models to examine the effects of height and seismic zone on earthquake forces, with analyses conducted using STAAD-PRO. Results show that base shear increases peaking at a height of 10 meters by 33% and decreasing for heights between 10 to 25 meters by 12% from Zone II to Zone V. Investigator concluded that by increasing the heights of water tank decreases the base shear for Zone II to Zone V [3].

Dhumal et al., (2016) have carried out the finite element analysis of a rectangular elevated water tank without and with consideration of baffle wall by varying baffle wall parameters, such as thickness and spacing using ANYSIS 16.0 software. The openings in the baffle walls are considered for study. The results shows that the use of baffle walls in tank increases natural frequency and time period by 10% as compared to the corresponding values for the tank without baffle wall. From the results the investigators concluded that the use of baffle walls in tanks leads to an increase in natural frequency, time period, and also contribute in reducing deformation and shear stress along the long wall [5].

Chaudhary et al, (2017) studied the dynamic response of circular water tank resting on ground with two types of baffle walls (i.e., vertical and ring baffle wall) using ANSYS software. The analytical results of study for vertical baffle walls of different heights with single and multiple openings in vertical walls are compared. The results of the study indicate that the normal stress, shear stress and equivalent stresses at various locations of tank are lesser by more than 60 % in water tank with baffle wall than that of the tank without baffle wall. Furthermore, the findings show that a baffle wall with half the tank's height experiences approximately 32% less deformation and 60% to 80% lower stress compared to baffle walls that are either one-third or two-thirds the height of the tank. Authors concluded that the use of ring baffle wall and vertical baffle wall of one-half height in water tank are more effective [6].

Zhao et al, (2017) studied a fluid-structure interaction algorithm by employing finite element technique to investigate the seismic response of water tank with internal baffles of various parameters, such as vertical baffle height, arrangements, and length of baffle. The analytical results indicate that the optimal design scheme is the case 1 with vertical ring baffle placed near the bottom of tank has the smallest peak acceleration under different earthquake loads. From the results investigator concluded that the seismic response of water tank effectively reduces due to the presence of vertical and ring baffles placed near the bottom of tank [7].

Mane et al, (2019) examined a time history analysis of rectangular and circular elevated water storage tanks by considering empty and full conditions. Also, the analysis is performed using SAP 2000 software by incorporating a vertical baffle wall to mitigate sloshing effects. The results show that the inclusion of a baffle wall in rectangular water tanks leads to the reduction in displacement by 14.55% for empty condition while for water tank with full condition it reduces by 6.24%. for full condition and increases base shear by 19.36 for empty condition 19.78% for full condition and circular water tanks having less displacement by 8.05% for empty condition 9.10% for full condition and increases base shear by 13.02 for empty condition 20.88% for full condition and higher base shear compared to tanks without baffles. Authors concluded that decreases displacement and increases time period and base shear by using baffle wall is effective in rectangular and circular water tanks as compared to without baffle wall [9].

Philip et al., (2020) have analyzed the behavior of a circular elevated water tank of identical capacity by varying staging heights using ETABS software. This study examines two staging heights (10m and 15m) for water tanks of same capacity, analyzing conditions for both empty and full tanks on level ground as well as 50 and 100-degree sloping grounds. The analytical results show that both base shear and displacement are higher for full tanks, with a nearly 10% increase. Displacement is greatest at the top storey, while base shear is lowest. Additionally, base shear rises with increased staging height, showing a 10% to 20% increase. Base shear also increases with slope angle, with a 3% to 5% rise. Investigator concluded that the displacement slightly decreases as slope angle increases as compared to level ground [10].

Anjum et al., (2021) performed non-linear time history analysis on models of circular and intze type water tank with empty, half and full conditions. The results show that the natural frequency of a structure decreases by 10% as water storage increases, with variations in the time period observed between empty, half-full, and full tank conditions due to sloshing and hydrodynamic pressure. The values of base shear and nodal displacement increased by 4.95% and 23% respectively as water levels increased. Authors concluded that critical responses in elevated water tanks can occur not only for full but also for empty or half-full conditions depending on the specific characteristics of the earthquake [11].

Devi et al., (2021) investigates the structural behavior of water tanks across different seismic zones using ETABS 18.0.0 software. The analysis incorporates static loads, including earthquake loads in both x and y directions, and wind loads. Additionally, the design of structural is also carried out. The results show that the Zone II exhibits lower displacement by 38% and story shear by 37% as compared to zones III, IV, and V. Overturning moment is greater in Zone V by 73% as compared to Zone II. Consequently, reinforcement in columns and beams is greater in Zone V than in the other zones. Authors concluded that the construction of elevated water tank in Zone II is effective when compared to Zone V [12].

Kaul et al., (2024) carried out free vibration modal analysis of various elevated water tanks with different shapes and staging models. Using finite element-based ETABS software, the analysis identified natural frequencies, periods, and mode shapes for tanks with cross and standard staging. The results reveal that rectangular tanks with cross-staging have higher natural frequencies compared to those with standard staging. Conversely, circular and square tanks showed greater natural frequencies in standard staging than in cross-staging configurations. Investigator concluded that the provision of cross staging is effective as compared to standard staging for rectangular type water [15].

III. RESEARCH GAP

Following are the research gaps identified through the rigorous literature review:

Major research work focuses on the study of sloshing effect of water on the dynamic behavior of water tanks provided without and with vertical baffle walls for determining the various responses (viz. displacement, base shear, natural frequency, time period, and bending moments) using time history method.

Limited studies are carried out for analyzing the behavior of water tank provided with horizontal annular baffle walls. Few research studies have been carried out to study the behavior of RCC water tanks by introducing annular horizontal baffle walls in order to reduce the effect of sloshing on water tank.

IV. CONCLUSION

From the review study following conclusion can be drawn:

The use of baffle walls inside the water tank contributes in reducing the responses namely viz., displacement and base shear. Increasing the height of vertical baffle walls causes reduction in the displacement by an approximate value of 15–20 %. Further, the study needs to be carried out for understanding the behavior of elevated water tank considering the provision of annular horizontal baffle walls by locating them at varying depths along the height of the tank.

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