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Optimizing Elevated Water Tank Design Focusing on Structural Integrity on Sloping Ground

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ABSTRACT

Elevated water tanks, because of their unusual mass distribution, are unexpectedly prone to enhanced seismic forces in the course of earthquakes. This vulnerability can lead to structural failure or significant damage, threatening public safety and water supply system reliability, particularly in seismically active regions. Appropriate seismic design and detailing are essential to minimize those threats and ensure reliable water delivery. Vessels of top and mass distribution benefit through giant lateral loads for the duration of seismic occasions because of their top and mass distribution. Ignoring SSI in seismic assessment can lead to completely wrong evaluation of the structural overall performance, and can consequently result in unsafe layout decisions. This survey examines the seismic response of elevated water storage tanks on two narratives and slopping floor, taking into account constant and supple base situations. Numerical analysis indicates excellent variations in structural response under seismic loading. The sloped terrain and uneven loads on the top of tanks lead higher forces on one side and lower forces on the other side, resulting in differential settlement. The findings underscore the importance of accounting for SSI in seismic analysis to obtain a more faithful representation of tank behavior. The consideration of SSI reflects the active interaction between the tank and sub-soil and provides a complete understanding of seismic response.

Key Words:- Elevated water tanks, earthquake-prone regions, Sloping ground, Numerical analysis, load distribution

Introduction

Water storage systems serve an important role in providing continuous drinking water supply in all residential, commercial and industrial sectors. Water tanks are one of the most commonly used solutions among the water garage options for credit due to their versatility and convenience. After an earthquake, maintaining an adequate flow of water is a critical needed to extinguish raging fires, distressed additional destruction, and protect the public. Due to the importance of water tanks in disaster-prone areas, it is imperative to incorporate seismic performance aspects in the design and construction of water tanks.

Different types of water tanks are used according to specific site requirements and operational demands. These include the ground-based tanks, underground tanks and the multiplied tanks. In particular, elevated tanks are very widely employed due to their capability to maintain generally steady water stress and supply coverage over an intensive region. But their prolonged functionality also exposes them to a greater chance of seismic forces, making good structural design measures critical to enhance their earthquake resistance.

Everybody relies upon these elevated water storage containers for water maintainability, augmentation vitality economy. In other words, the structural stability of those tanks is very important, as failure at sure seismic occasions does trigger monumental harm, water loss and capacity hazards. The design and production of increased water tanks must be governed by strict protection and performance requirements to erbody these problems. Many national and international codes offer detailed guidance on their design, build, and maintenance.

Key standards governing the seismic design of elevated water tanks include:

IS 1893 (Part 2): 2014 – Indian Standard Code for the seismic design of liquid storage tanks, outlining seismic analysis methods and safety factors for elevated and ground-supported tanks.

ACI 350.3-06 – American Concrete Institute guidelines for seismic design of liquid-containing concrete structures, ensuring adequate strength and stability under dynamic loading.

ASCE 7-22 – American Society of Civil Engineers standard providing minimum design loads for buildings and other structures, including elevated water tanks.

Eurocode 8 (EN 1998-4) – European standard for the seismic design of silos, tanks, and pipelines, addressing dynamic response and safety considerations.

AWWA D100-11 – American Water Works Association standard for welded steel tanks, emphasizing structural integrity under seismic and wind loads.

In seismic design, key considerations include:

Sloshing Effects: Water movement within the tank during an earthquake can generate dynamic forces that affect stability.

Base Shear and Overturning Moments: The forces acting on the tank due to ground motion must be accurately analyzed to prevent structural failure.

Ductile Behavior: The tank and supporting structure must be designed to absorb and dissipate seismic energy without catastrophic failure.

Foundation Design: Proper foundation design is critical to prevent differential settlement or tilting due to seismic shaking.

By incorporating these seismic performance criteria and adhering to established codes, the resilience and reliability of elevated water tanks can be significantly enhanced, ensuring uninterrupted water supply during and after seismic events. This proactive approach is essential for safeguarding critical infrastructure and minimizing risks in disaster-prone regions.

Figure 1 Water tank resting on sloping ground

Literature Review

Sangeetha et al (2024) Elevated water tanks have an irregular mass distribution, making them vulnerable to amplified seismic forces during earthquakes, which can lead to structural damage or failure. To mitigate these risks and ensure reliable water distribution, proper reinforcement and seismic design are essential. The seismic performance of elevated water tanks is critical for public safety and water supply resilience, especially in earthquake-prone regions.

Due to their height and mass distribution, elevated tanks are subjected to significant lateral loads. Neglecting Soil-Structure Interaction (SSI) in seismic analysis can result in inaccurate assessments of structural behavior. This study examines the seismic response of elevated water tanks on both level and sloping ground, considering fixed and flexible bases using the Response Spectrum Method (RSM) in accordance with IS 1893 (Part 1): 2016 for seismic zones II and III. Finite Element Analysis (FEA) software SAP2000 v22 is used to evaluate SSI effects. Three soil types—soft, medium, and hard—are analyzed, considering both full and empty tank conditions.

The numerical analysis reveals variations in structural response under seismic loading, with different slope angles highlighting vulnerabilities associated with sloping ground. Results emphasize the importance of incorporating SSI effects in seismic analysis to achieve realistic assessments of water tank performance. Including SSI captures the dynamic interaction between the tank and the underlying soil, offering a more comprehensive understanding of structural behavior during seismic events. This study underscores the necessity of considering SSI in the design and evaluation of elevated water tanks, particularly in earthquake-prone regions. By accounting for SSI, engineers can enhance the seismic resilience of water supply infrastructure and better mitigate risks.

Aayush Mehta et al (2023) Elevated water tanks are essential components of water distribution systems, making sure a constant water deliver to groups. However, their structural balance during seismic activities is important for public protection. To cope with this difficulty, various layout codes and tips were established globally to provide seismic design issues for multiplied water tanks. This paper gives a comprehensive assessment evaluating and comparing the seismic analysis strategies prescribed by one of a kind design codes, which includes IS, ACI, EN, and NZS. The primary goal of this assessment is to assess and compare the seismic analysis tactics outlined in those codes. By analyzing those methodologies, their respective strengths and obstacles may be identified. This assessment is crucial for expertise the effectiveness and applicability of various layout codes in ensuring the seismic resilience of extended water tanks. Additionally, the overview highlights potential regions for development in seismic analysis strategies. By identifying existing limitations and aspects that require similarly research, this observe contributes to the continuing enhancement and improvement of seismic design recommendations for expanded water tanks. Engineers and researchers can leverage those findings to optimize design strategies and improve the know-how of seismic conduct in those important structures.

Methodology

This thorough analysis consists of inspecting the tank's behavior in each full and empty situations, evaluating its seismic reaction across different soil kinds (smooth, medium, and hard), and assessing modal parameters, base shear, and displacements for each fixed and flexible base situations. Additionally, the examine considers the tank's placement on leveled and sloped ground, factoring in the effect of ground inclination on structural reaction. Adherence to relevant codes and standards guarantees the water tank's integrity and safety beneath seismic loading. Analyzing the dynamic conduct of a liquid garage tank at some point of seismic occasions. Your technique of modeling the tank as a two-mass system, considering both impulsive and convective results, aligns properly with IS 1893 (Part 2): 2014 and IITK-GSDMA suggestions.

Study analyzed the seismic reaction of an open extended water tank on both stage and sloped floor. A few key aspects that might be exciting to discover in addition consist of:

Effect of Ground Slope on Base Shear & Overturning Moment: How does the seismic force distribution change because the ground slope will increase?

Dynamic Response & Mode Shapes: Did you study big variations in the tank’s essential duration or mode shapes due to sloped floor situations?

Soil-Structure Interaction (SSI): Was SSI taken into consideration, and how did one-of-a-kind ground slopes effect the tank’s balance?

Comparison of Sloped vs. Level Ground: At what slope angle did the seismic vulnerability significantly increase?

Seismic Design Considerations: Based on the findings, what recommendations could be made for the safe design of elevated water tanks on sloped ground.

Results and Discussion

Study on the seismic response of a water tank on leveled and sloped ground sounds interesting. You're analyzing how the ground slope (0° to 15° in 5° increments) affects the tank's seismic behavior under full and empty conditions with a fixed base**.** Since base shear is a critical design factor, do you observe a significant increase for higher slopes? Is the effect more pronounced in Zone II due to higher seismic intensity how does the height-wise displacement vary across different slopes? Does the empty tank show more displacement compared to the full tank due to reduced mass.

Shear Force

The shear force on a water tank resting on sloping ground depends on several factors, including the inclination angle (θ) affects the horizontal and vertical components of forces acting on the tank. The self-weight (W) of the tank and the stored water creates both normal and tangential forces on the base. The shear resistance of the soil affects how much lateral movement or settlement may occur. Whether the tank is anchored or simply **resting** on the surface influences the shear force distribution. If the location is prone to earthquakes or strong winds, lateral forces can induce additional shear stresses. If groundwater or seepage exists, buoyancy can reduce effective weight and impact shear resistance.

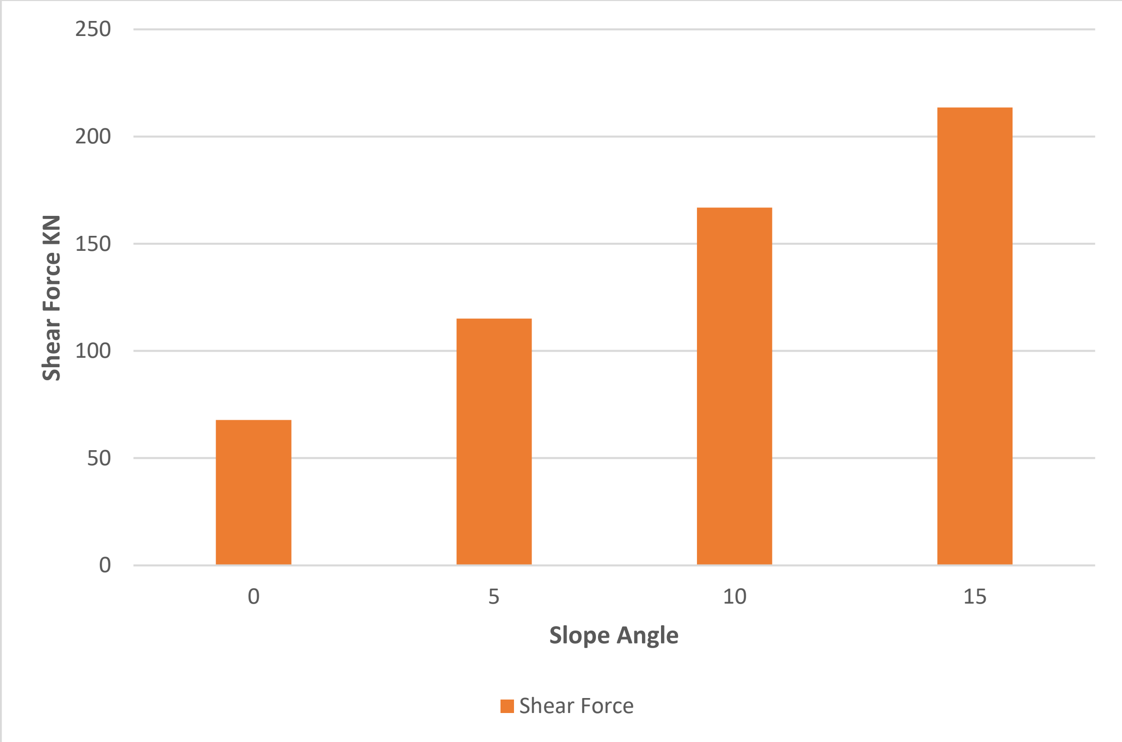

Figure 2 Shear force on water tank

Conclusion

Base shear increases in sloping ground conditions primarily due to stiffness irregularities, mass distribution asymmetry, and torsional effects. In a fixed base condition, this increased base shear suggests that the structure has greater resistance to seismic forces as it engages more of its structural strength to counteract earthquake-induced forces. However, special design considerations must be made to ensure stability and mitigate torsional effects when a structure is built on **sloping ground**, the Base Shear (V**b**) values generally increase compared to structures on flat ground. This occurs due to several factors related to mass distribution, stiffness variation, and dynamic response of the structure. Here's a detailed explanation. Buildings on slopes often have varying column heights (shorter on the uphill side and longer on the downhill side). As a result, the structure's center of rigidity shifts, leading to higher seismic force concentration on stiffer portions, increasing base shear. Due to different heights of columns, the building may undergo asymmetrical deformation, inducing torsion. This amplifies the lateral forces on certain structural elements, increasing total base shear. The interaction between soil movement and the structure can increase the dynamic response, leading to higher base shear values. The increased base shear indicates that more lateral force is resisted by the structure due to its increased stiffness. The stiffer portion (usually uphill) helps in anchoring the building, thereby enhancing resistance to seismic forces.

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