Comparative Structural Analysis of Clarifier In Various Seismic Zones: A Review

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Abstract- *Clarifiers play a crucial role in water and wastewater treatment plants, and their failure during earthquakes can pose significant threats to public health and the environment. Therefore, ensuring their seismic resilience is essential for maintaining operational functionality during such events. This review analyzes how seismic activity affects clarifier structures, with a focus on structural design across different seismic risk zones. It investigates the dynamic forces—including both lateral and vertical loads—that act on these structures during earthquakes and the resulting engineering challenges. The review outlines effective design strategies aimed at improving performance under seismic stress. Clarifiers typically consist of two main functional zones: the clarification zone, where sedimentation by gravity occurs, and the thickening zone, where solids settle and form a concentrated sludge blanket. The review concludes by underscoring the importance of ongoing research to improve the seismic durability of clarifiers and other essential components of water infrastructure in earthquake-prone areas*

Keywords- Seismic performance, Clarifiers, Earthquake-resistant design, Seismic zones, Dynamic loading,Base isolators,multi-hazard analysis, Soil-structure interaction,Energy dissipation, Water treatment infrastructure.

I. INTRODUCTION

Clarifiers are essential components of wastewater treatment plants, designed to remove solids from wastewater through gravity sedimentation under calm conditions. Each clarifier includes two key zones: a clarification zone for sedimentation and a thickening zone where solids accumulate into a sludge blanket. As mechanically built settling tanks, clarifiers enable continuous solid removal. Evaluating their performance under seismic loading is crucial, as it affects their design, material selection, and structural stability in various seismic environments Seismic events pose a substantial threat to infrastructural integrity, especially for essential public utilities like water treatment facilities. In earthquake-prone regions, structural stability under seismic loading becomes a key design consideration. The Indian seismic code, IS 1893 (Part 1): 2016, classifies the country into four seismic zones (II to V), based on expected ground motion intensity. Zone II represents low seismic risk, while Zone V indicates very high seismic activity.

Studying the structural response of clarifiers in different seismic zones is crucial for several reasons. First, these structures store large volumes of liquid, leading to complex fluid-structure interaction under seismic loading, including sloshing effects that can amplify structural stress. Second, the failure of clarifiers during an earthquake can interrupt water supply or wastewater treatment, leading to severe public health and environmental consequences.

1.1 Types of Clarifier

Clarifiers, also known as sedimentation basins or settling tanks, are integral components in water and wastewater treatment processes, used to remove suspended solids from liquid through gravitational settling. The design and configuration of clarifiers vary based on application, flow requirements, and available space, but the most commonly employed types are circular and rectangular clarifiers.

1.1.1 Circular Clarifiers

Circular clarifiers are widely used due to their structural efficiency and uniform flow distribution. In these systems, influent water typically enters through a central inlet and flows radially outward toward the periphery, where clarified water is collected by a launder. A centrally located rotating sludge scraper moves settled solids toward a central hopper for removal. Circular clarifiers are especially common in secondary sedimentation following biological treatment due to their operational simplicity and low maintenance requirements.Tank diameter ranges from 3 meters (10 ft) to over 100 meters (300 ft). Circular clarifiers are typically built in pairs of 2 or 4 to simplify the influent flow distribution between the individual units. Circular tank sidewater depth varies from 2.5 to 5 meters (8 to 16 feet). Depending on the configuration of the tank inlet, circular clarifiers are classified as center feed and peripheral feed. Currently, the most widely used circular tanks are center feed type

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1.1.2 Rectangular Clarifiers

Rectangular clarifiers, on the other hand, are generally used when space constraints or process layout favor linear arrangements. These clarifiers have a longer travel path for solids to settle and usually include chain-and-flight mechanisms to scrape sludge along the tank bottom. Although they may require more mechanical components compared to circular designs, they can be easily expanded and integrated into modular treatment plant configurations.The length-to-width ratio of individual clarifier tank basins typically ranges from 3:1 to 15:1. The shortest allowable length from the inlet to the outlet is generally around 3 meters (10 feet). The depth of the tank commonly falls between 2 and 6 meters (approximately 6.6 to 20 feet). For rectangular clarifiers, the width is often determined by the standard sizes of sludge removal equipment and usually ranges from 2 to 6 meters (6.6 to 20 feet).

1.2 The structural engineering aspects regarding clarifiers

1.2.1 Construction Materials

- **Reinforced Concrete**: Clarifiers are usually constructed using reinforced concrete due to its ability to withstand the constant water pressure and the corrosive nature of wastewater. The concrete design must meet the required strength standards to handle both static and dynamic loads.
- **Steel Reinforcement**: Proper reinforcement is crucial for ensuring the durability and strength of the clarifier. The placement and type of steel bars (rebar) must be carefully designed to withstand the stresses from the weight of water, sludge, and seismic forces.

1.2.2 Seismic Design Considerations

- **Seismic Loading**: In seismic zones, clarifiers need to be designed to resist dynamic forces generated during an earthquake. This involves using seismic analysis to determine the forces acting on the structure and ensuring that the clarifier can safely absorb and dissipate these forces without failure.
  - **Damping Systems**: In earthquake-prone regions, clarifiers may need damping systems to reduce vibrations and prevent structural damage. These systems can be incorporated into the design of the tank or its components to enhance resilience.
  - **Seismic Zone Classification**: Different seismic zones impose varying levels of design criteria. Clarifiers in high seismic zones need to be more robustly designed, with stronger foundations, thicker walls, and reinforced connections to withstand stronger tremors.
  - **Foundation Design**: The foundation of a clarifier must be designed to resist seismic forces, including lateral forces and differential settlement that could arise during an earthquake. In high seismic zones, the foundation may need to be deeper or reinforced with additional structural elements like piles or caissons

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1.2.3 Hydrostatic Pressure

- **Water Load:** The clarifier must be designed to withstand the hydrostatic pressure, which increases with depth. The walls and bottom of the clarifier must be designed with adequate thickness and reinforcement to handle this constant pressure.
- **Sludge Load:** As solids settle in the clarifier, The structural design should account for potential variations in the sludge volume and weight

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1.2.4 Seismic Zone Classification

The design and structural safety of clarifiers in earthquake-prone areas depend significantly on the seismic zoning of the region. Seismic zoning categorizes regions based on the likelihood and potential intensity of earthquake ground motion, which directly influences design parameters such as base shear, response spectra, and structural ductility requirements.

In India, seismic zoning is governed by the Indian Standard IS 1893 (Part 1): 2016, which classifies the country into four seismic zones:

- Zone II – Low seismic risk
- Zone III – Moderate seismic risk
- Zone IV – High seismic risk
- Zone V – Very high seismic risk

Each zone is associated with a Zone Factor (Z) that influences the calculation of base shear. For instance, Zone II has a factor of 0.10, while Zone V has a factor of 0.36. The design horizontal seismic coefficient is derived from the zone factor, the importance factor of the structure, the response reduction factor, and the average acceleration spectrum.

1.3. Objectives of the Study

1) To Evaluate the Seismic Performance of Clarifiers in Various Seismic Zones.
2) To compare the Seismic Performance of Circular and Rectangular clarifiers.

II. LITERATURE REVIEW

Jayanti S. et al. (2004) studied issues regarding mathematical modeling of sedimentation process in secondary clarifiers Secondary clarifiers are equipment used in wastewater treatment plants for gravitational separation of solid particles from water. As this process is chemically activated by adding flocculants to improve the settling, a mathematical model may be developed considering a mixture model and taking into account the relative velocity between the solid phase and the liquid.

Loosedrecht M. et al (2008) studied various methods proposed by many researchers have been employed to increase the settling capacity in clarifiers, including using a double-deck clarifier. Similarly, a stack of tubes, installed horizontally in a clarifier, has proved to increase the settling capacity; however, several problems were associated with this method, such as the installation and operation of a system to remove settled solids at each tube. In particular, it has been reported that the removal of the settled solids without causing resuspension of the solids was problematic.

Ali Ghawi et al (2011) analysed three dimensional fully mass conservative clarifier model, based on modern computational fluid dynamics theory, was applied to evaluate the proposed tank modification and to estimate the maximum capacity of the existing and modified clarifiers. A Computational Fluid Dynamics model was formulated to describe the tank performance, and design parameters were obtained based on the experimental results .It also ravealed that velocity and suspended solid is a better parameter than total solids, biochemical oxygen demand, chemical oxygen demand to evaluate the performance of sedimentation tanks and that the removal efficiencies of the suspended solids.

Byonghi Lee (2015) investigated the performance of clarifiers equipped with inclined plates in wastewater treatment. The experiment involved constructing two laboratory scale rectangular clarifiers, one with inclined plates and one without, which served as a control. Only the first three out of seven slots in the clarifier with inclined plates received flow, indicating an uneven distribution. The study suggested that to maximize the Boycott effect and enhance settling efficiency, it was essential to ensure equalized inflow distribution across the inclined plate slots. Furthermore, it recommended designing the system to prevent the incoming flow from disturbing the settled sludge at the bottom of the clarifier.

Dahl Larsen et al (2016) developed a numerical model to analyze flow dynamics and settling behavior in activated sludge suspensions. The model simulated turbulent flow and the transport of suspended sludge, incorporating both free and hindered settling, along with the Bingham plastic characteristics of the sludge. However, the study emphasized the importance of precisely calibrating the rheological properties of activated sludge to improve model accuracy. This research contributed significantly to the optimization and design of secondary settling tanks in wastewater treatment.

Panico A. et al (2017) introduced a multidisciplinary methodology to assess the seismic vulnerability of wastewater treatment facilities. Recognizing that wastewater systems consisted of interconnected components, the study emphasized that failures in these elements during earthquakes could have led to environmental degradation and public health risks due to the release of untreated or inadequately treated wastewater. This methodology aligned with contemporary risk analysis tools and land-use planning strategies, facilitating the prioritization of structural improvements in wastewater treatment plants to enhance their earthquake resilience.

Brouckaert C.J. et al (2019) conducted Computational fluid dynamics analyses on a secondary clarifier at Durban's Northern Wastewater Treatment Works and a clarifier at the Umzinto potable water treatment plant in South Africa. Facing increased load demands due to population growth, the plants sought cost-effective ways to improve infrastructure. The Computational fluid dynamics simulations revealed similar flow patterns in both clarifiers, with concentrated up-flow near the outer walls around the clarified water overflow weirs. while those for the potable water clarifier had not yet been implemented.

Denny Parker et al (2019) examined the application of flocculator-detaniers in large-scale water treatment facilities. The authors shared insights gained from designing and operating these systems, highlighting their effectiveness in enhancing water treatment processes. The paper discussed the operational challenges encountered and the strategies implemented to optimize performance, providing valuable knowledge for engineers and professionals involved in the design and management of large water treatment plants.

Nital Patel et al (2021) investigated the efficiency of rectangular and circular primary clarifiers through both experimental and one-dimensional modeling approaches. They conducted experiments under three operating conditions—low, medium, and high solid concentrations—using lab-scale setups. The study found that the circular clarifier outperformed the rectangular clarifier in removing suspended solids. This research provided valuable insights into the design and operation of primary clarifiers, highlighting the superior performance of circular clarifiers in effectively reducing suspended solids in wastewater treatment processes.ammarahemad44

III. SYSTEM DEVELOPMENT

The different models are modeled using STAAD-Pro software and they are mentioned below.

Rectangular clarifier:-

1) Model-I : Rectangular Clarifier – Earthquake zone-II
2) Model-II : Rectangular Clarifier – Earthquake zone-III
3) Model-III : Rectangular Clarifier – Earthquake zone-IV
4) Model-IV : Rectangular Clarifier – Earthquake zone-V

Circular Clarifier:-

5) Model-V : Circular Clarifier – Earthquake zone-II
6) Model-VI : Circular Clarifier – Earthquake zone-III
7) Model-VII : Circular Clarifier – Earthquake zone-IV
8) Model-VIII : Circular Clarifier – Earthquake zone-V

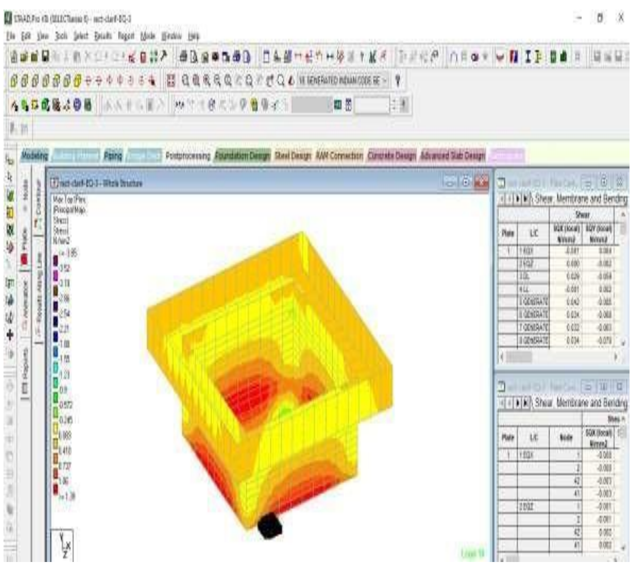

Figure 3.1 : Model- Rectangular Clarifier

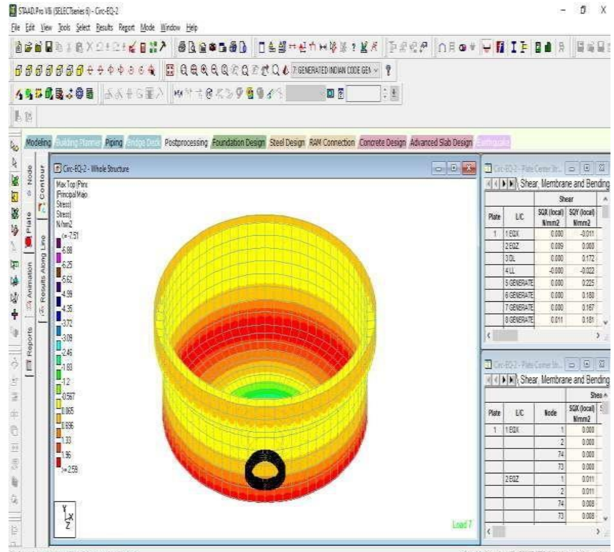

Figure 3.2 : Model- Circular Clarifier

IV. RESULT AND DISCUSSION

The output of the models using STADD-Pro for clarifiers under different seismic zones provides crucial insights into the structural behavior and stability of these systems when subjected to varying seismic intensities. These outputs are essential for optimizing the design, ensuring safety, and implementing necessary structural reinforcements in compliance with earthquake resistant design standards

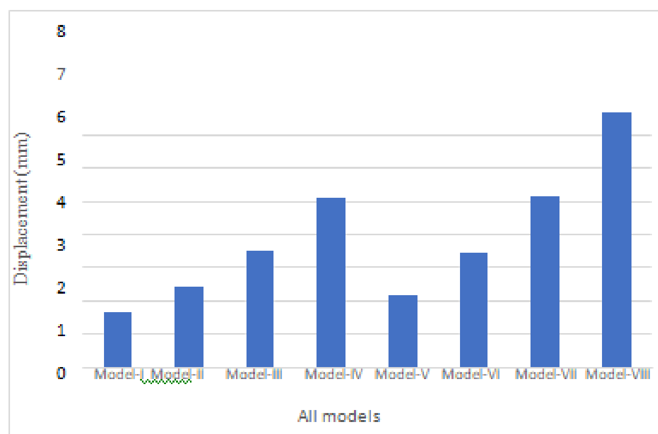

Figure 4.1: Horizontal Displacement for all the models

The Model-VIII (Circular Clarifier – Earthquake Zone-V) exhibits the greatest displacement among all the models analyzed. This model represents a circular clarifier located in the highest seismic risk area, in accordance with the Indian standard code IS 1893:2002.

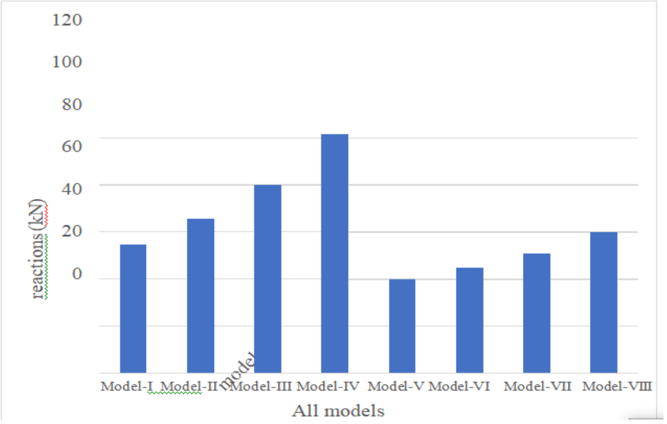

Figure 4.2: Vertical Reaction for all the models

Model-IV exhibits the highest vertical reaction force (Fy) among all the models, specifically for the rectangular clarifier.

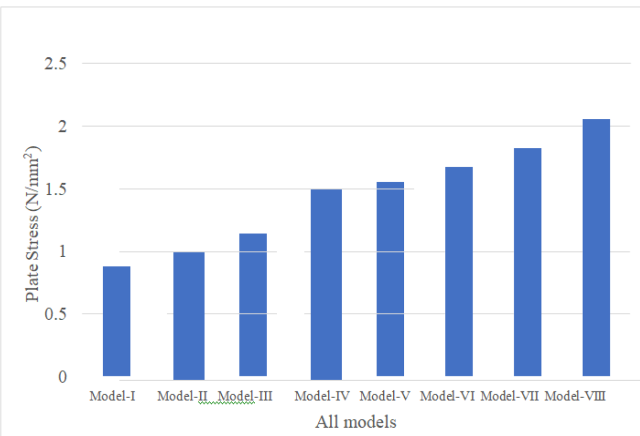

Figure 4.3 : Shear stress of all models

it is observed that the Model-VIII shows the maximum shear stress (SQY) as compared to other models and it is for the circular clarifier.

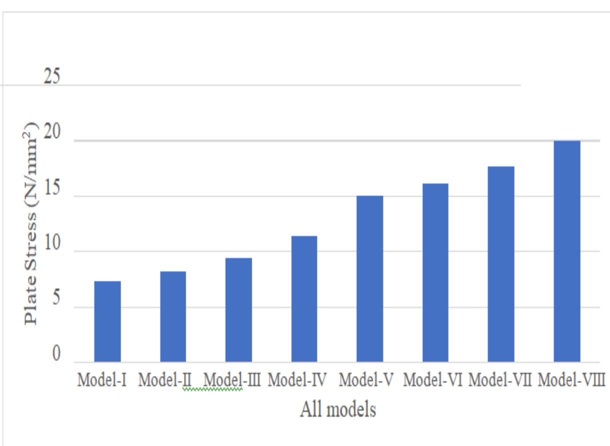

Figure 4.4: Principal (Top) Stresses for all the model

It is observed from the analysis that Model-VIII exhibits the highest values of principal (top) stresses among all the models, corresponding to the circular clarifier configuration

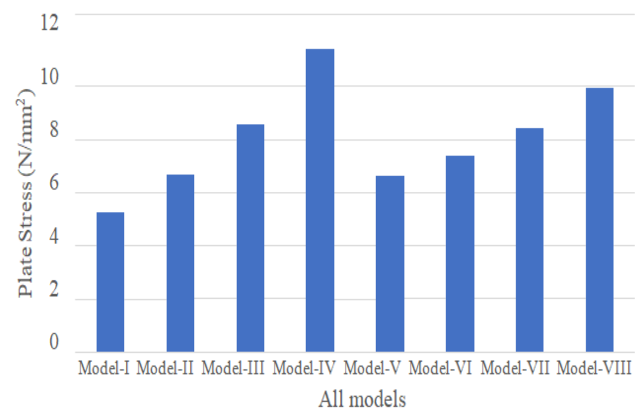

Figure 4.5: Principal (bottom) stresses for all the models

Model-IV is observed to produce the highest principal (bottom) stress among all the models, which corresponds to the rectangular clarifier configuration..

V. CONCLUSIONS

The following conclusions are obtained.

1) Seismic forces and displacement increased significantly from Zone II to Zone V. The fundamental frequency and mode shapes of the clarifier structure changed with varying zone intensities, affecting dynamic response. In Model-VIII, displacement and plate stress (shear) is observed maximum as compare to other models.
2) Base shear and bending moments were notably higher in high seismic zones. Vertical reaction in Model-IV is maximum while in the Model-V it is minimum.
3) Principal stress is observed maximum in Model-VIII while the minimum in Model-I. The study demonstrates that as the seismic intensity increases the lateral forces acting on the clarifier increase significantly. This result in higher base shears, greater displacement, and increased stresses on critical components like columns and base slabs.

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