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Evaluation of the Effectiveness of Swimming Pool Position as a Tuned Liquid Damper in Reducing the Drift Rasio Due to Earthquake Excitation with Response Spectrum Analysis

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ABSTRACT

Swimming pools integrated with the main structure are increasingly popular in modern high-rise buildings due to their aesthetic appeal and recreational value. As a result, there has been much research into the influence of swimming pools, which were previously considered as additional masses, now function as passive dampers, Tuned Liquid Dampers (TLD). The focus of the research is the optimal placement of the swimming pool position because the swimming pool can increase the eccentricity to the center of mass, which affects the dynamic behavior of the building. This study analyzes the position of the swimming pool to affect the TLD's effectiveness in reducing the drift ratio. The study was conducted numerically with ETABS at a 10-story hotel with two basements and a total building height of 39.6 meters. The swimming pool measuring 16.25 x 4.85 x 1.5 meters was analyzed in empty conditions and two positions, namely Pool P1 (existing pool) with a mass eccentricity of 20.679 m. In contrast, pool P2 is a pool with a position that is moved closer to the center of mass, with a mass eccentricity of 10.650 m. The swimming pool is modeled with a spring-mass model as a dynamic load, and the damping ratio is 5%. The analysis used the mass spectrum response method based on SNI 1726:2019.

Keywords: tuned liquid damper; spring mass mode; swimming pool; sloshing; passive control.

INTRODUCTION

When planning high-rise buildings with swimming pool facilities on the rooftop, it is often assumed that the pool's mass can be treated as a static load. However, swimming pools have the potential to cause structural damage if not calculated properly (Widyarsana et al., 2020). Therefore, planning high-rise buildings with swimming pool facilities must be carried out with an appropriate approach.

This is becoming increasingly important considering the current construction trend of designing lighter and more flexible buildings. This trend makes these buildings have low natural damping, making them more vulnerable to earthquakes. Therefore, the strategy that is often used is to control the seismic response by modifying stiffness, mass, damping, or implementing passive or active control systems (Davidson & Kumar, 2018).

In this context, swimming pools on the rooftop can be used as passive controls, namely Tuned Liquid Damper (TLD), to increase the seismic damping of the structure. Nanda (2010) and Banerji et al. (2000) revealed that proper placement and design of TLDs, with proper parameters such as tuning ratio, depth ratio, and mass ratio, will effectively reduce structural response. Sorkhabi et al. (2024) conducted a large-scale TLD study in real time and showed that TLDs could dampen structural vibrations due to earthquakes and reduce peak displacement, RMS value, and FFT spectrum amplitude. Tejas & Srinivas (2022) explained that water tanks as TLDs can reduce base shear forces and improve structural performance, while Suja & Subha (2016) stated that the sloshing effect on swimming pools can reduce earthquake loads. Therefore, swimming pools such as TLDs can be an innovative solution for designing earthquake-resistant buildings.

However, it should be noted that the placement of swimming pools on rooftops also needs to be analyzed and evaluated in depth to identify their impact on the eccentricity of the building and its efficiency in reducing earthquake forces. This is because the position of the swimming pool affects the center of mass of the building, if the center of mass of the pool and the center of mass of the building have a large eccentricity, it will cause a moment imbalance and will affect the structural response when an earthquake occurs.

Considering the impact of the swimming pool position on the building's center of mass, the analysis shows that the most effective placement of the swimming pool is the one closest to the building's center of mass. Ishak et al. (2021) found that multiple-tuned liquid dampers will work effectively if the TLD distribution is evenly distributed around the building's center of mass, significantly reducing the structural response during an earthquake. Davidson & Kumar (2018) also showed that a swimming pool placed in the middle of a building is more effective as a Tuned Mass Damper (TMD) because this position produces a more optimal frequency and period of the structure. The study supports that the effectiveness of placing a pool close to the building's center of mass will have a better structural response in reducing earthquake loads.

RESEARCH METHOD

Material

This study obtained data from as-built drawings and modeled in 3D using the ETABS program. Technical data and material data used in modeling were adjusted in detail to the available technical documents and other parameters based on SNI 1726:2019 which regulates earthquake-resistant building structure planning, to ensure the accuracy of the resulting structural model. Details regarding structural engineering data and materials, as well as seismic parameters used, are shown in Tables 1 and 2. This study also includes a 3D model, as shown in Figure 1, and a research flow diagram, as shown in Figure 1. To describe the systematic analysis process.

Table 1. Technical dan and materials

Specification	Detail
Building Function	Hotel
Building Type	Reinforced Concrete
Number of Floors	B-2 & G+10
Total Building Height	39.6 meter
Concrete Strength (Columns)	35 MPa
Concrete Strength (Other Structures)	25 MPa
Plain Rebar Strength	BJTP 24
Deformed Rebar Strength	BJTD 40

Table 2. Seismic parameters

Parameters	Value	Parameters	Value
Soil Class	SD – Medium Soil	TS (s)	0.772
SS MCEr (g)	1.1259	SDS (s)	0.788
S1 MCEr (g)	0.5093	SD1 (s)	0.608
TL (s)	6	Ie	1.0
T0 (s)	0.154	R	7
TS (s)	0.772		

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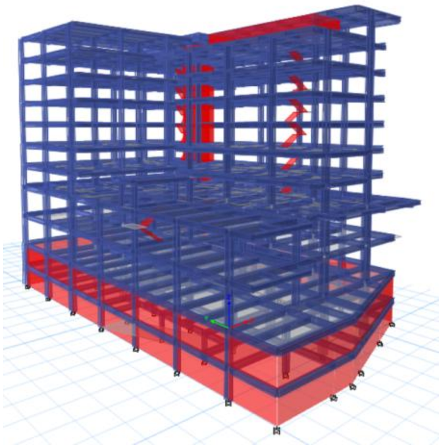

Figure 1. Modeling the hotel structure using ETABS

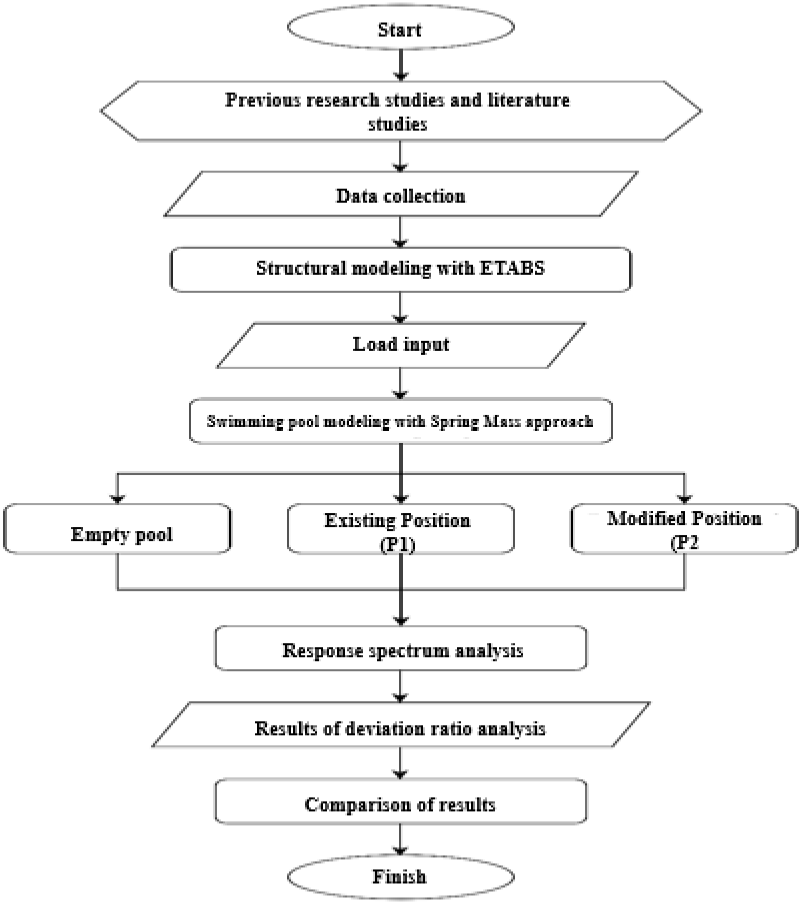

Figure 2. Flowchart

Method

This research method is focused on modeling swimming pools as dynamic loads in their role as TLDs modeled using the spring-mass approach. This approach will consider the dynamic behavior of water (sloshing) during the load application. Bhujel et al. (2023), Bikram Rana et al. (2018), Matsagar (2015) and Seleemah & El-Sharkawy (2011) explained that in modeling swimming pools as dynamic loads, water will be modeled as convective mass and impulsive mass which is modeled as lumped mass which is assigned as joint mass and linear link elements are used to represent stiffness, where this linear link is connected to the pool wall.

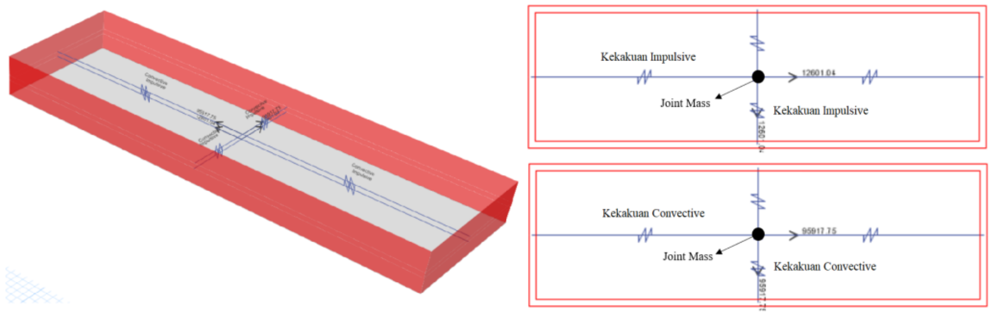

Figure 3. Modeling the swimming pool as a dynamic load using a spring-mass model in ETABS

The approach used is based on ACI-350 (2001), which adopts the basic principles of Housner (1963). The parameters used are as follows:

$$\frac{m_i}{m_w} = \frac{\tanh(0.866\, {}^{L}/_{h})}{0.866\, {}^{L}/_{h}}$$

$$\frac{h_i}{h} = 0.375 \qquad \text{for } \frac{h}{L} \leq 0.75$$

$$\frac{h_i}{h} = 0.5 - \frac{0.009375}{\frac{h}{L}} \qquad \text{for } \frac{h}{L} > 0.75$$

$$\frac{m_c}{m_w} = 0.264\frac{\tanh(3.16\, {}^{h}/_{L})}{{}^{h}/_{L}}$$

$$\frac{h_c}{h} = 1 - \frac{\cosh\left(3.16\frac{h}{L}\right) - 1.0}{3.16\frac{h}{L}\sinh\left(3.16\frac{h}{L}\right)}$$

$$k_c = 0.833\frac{mg}{h}\, tanh^2\left(3.16\frac{h}{L}\right)$$

The swimming pool with dimensions of 16.25 x 4.85 x 1.5 meters was analyzed in two positions, as shown in Figure 4, with a depth ratio of 5%. Position 1 (P1) is the pool's position in the existing model, which is located very far from the center of mass of the building, with a mass eccentricity of 20.679 m. In contrast, Position 2 (P2) is the swimming pool that is moved from the existing position so that it is closer to the center of mass, with an eccentricity of 10.650 m. This change in position does not change the parameters used in the analysis of the swimming pool as a TLD.

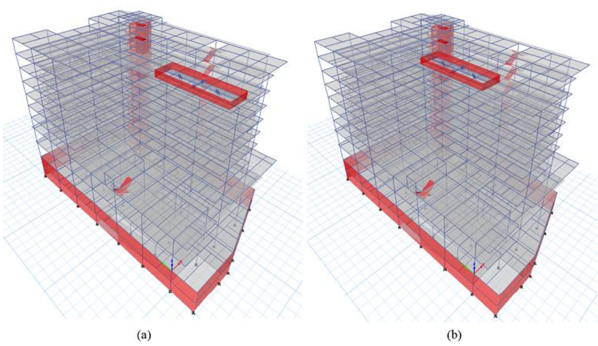

Figure 4. Swimming pool position (a) Position 1 dan (b) Position 2

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RESULT AND DISCUSSION

Before discussing the research results related to the swimming pool's position, it is important to first evaluate the swimming pool (P1) and swimming pool (P2) as passive dampers of TLD compared to the empty swimming pool.

In the analysis of the drift ratio, the research results show that the drift ratio in the P1 swimming pool and the empty swimming pool has a significant difference value, as seen in the graph below:

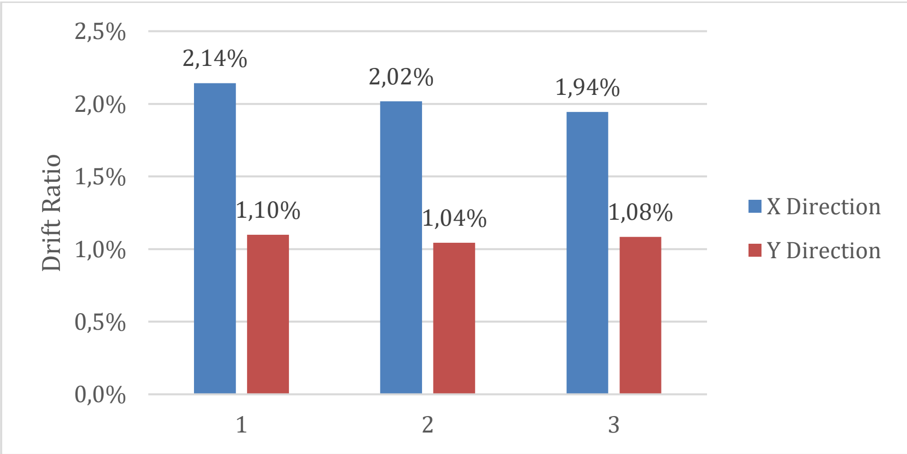

Figure 5. Graph of the roof drift ratio for (1) empty pool (2) P1 pool (3) P2 pool

Based on the graph above, it can be seen that the analysis of the roof drift ratio shows that the use of TLD in the swimming pool (P1) and swimming pool (P1) can significantly reduce the drift ratio compared to an empty pool. The graph shows that for pool P1 in the X direction, there is a decrease in the drift ratio of 5.61%, while in the Y direction, it is 5.45%. For swimming pool P2 in the X direction, there is a decrease in the drift ratio of 9.35%; in the Y direction, it is 1.82%.

As mentioned above, the placement of the swimming pool is one of the essential parameters because the mass eccentricity caused by the non-optimal position of the swimming pool can result in moment imbalance and will affect the structural response when an earthquake occurs. This eccentricity refers to the distance between the center of mass of the building and the center of mass of the swimming pool. The center of mass of the building looks like Figure. 6, and the mass eccentricity value is shown in Table 3.

Table 3. Mass eccentricity value

Pool Position	Center of Mass Building		Center of Mass Pool		Total Mass Eccentricity (m)
	X (m)	Y (m)	X (m)	Y (m)	
P1	17.640	29.301	15.001	8.800	20.679
P2	17.640	29.301	15.001	18.975	10.650

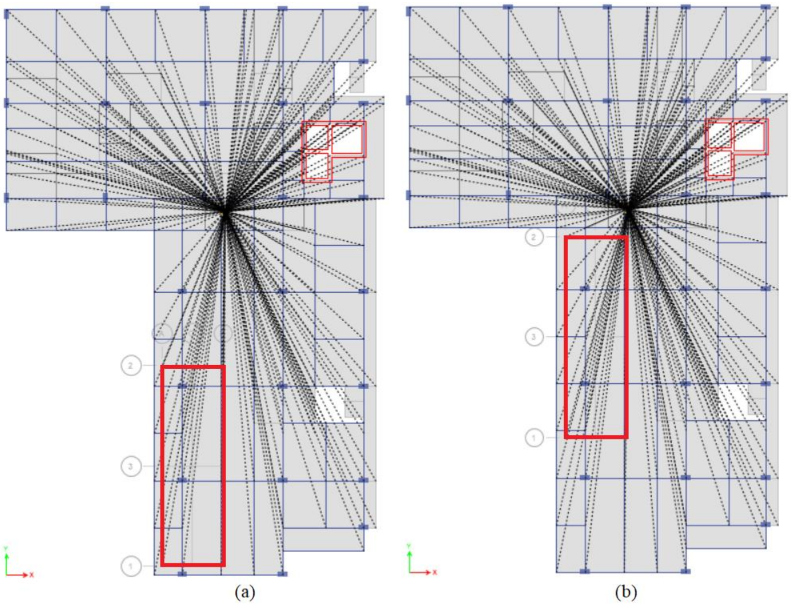

Figure 6. Center of mass (a) P1 pool (b) P2 pool

The impact of mass eccentricity on the center of mass of a building can significantly affect the structure's performance, mainly when an earthquake occurs. In Table. 3, it can be seen that swimming pool P2 has a smaller mass eccentricity value of 10.650 meters. This position can minimize imbalance and torsional moments that can affect building performance during an earthquake. Conversely, higher mass eccentricity, as seen in the position of pool P1, which is the original pool position, has the potential to cause a more significant imbalance so that it can increase the seismic response of the building.

Based on the deviation ratio graph in Figure 5, in the X direction, pool P1 has a deviation ratio of 2.02%, and P2 is 1.04%. This shows a reduction in the deviation ratio of 3.96%. However, in the Y direction, there is a difference in results that is opposite to the X direction, where pool P1 has a deviation ratio of 1.94%, and P2 is 1.08%; this means that in the Y direction, there is an increase in the deviation ratio of 3.85%.

This fact indicates that although the P2 pool is closer to the center of mass and theoretically more minor eccentricity can reduce the drift ratio, the results above show that the influence of P2 on P1 has not been able to reduce the drift ratio maximally in the Y direction. The difference in structural response in these two directions is reasonable, as Li et al., (2011)explained. Irregular structures can show a more robust response in one direction than in another when an earthquake occurs. However, due to differences in analysis with the response spectrum method, it is recommended to conduct further research using time history analysis to see the structure's dynamic behavior under actual earthquake conditions. According to Saputra & Priastiwi (2023), the time history analysis method provides better results in predicting displacement and internal forces than the response spectrum method, which often relies on simplified earthquake assumptions in the response spectrum curve. Therefore, further analysis using time history analysis is expected to produce different and more realistic results, especially in reducing the drift ratio, by considering the structure's overall response to the earthquake's variations and characteristics over time.

CONCLUSION

The study aims to analyze how the position of the swimming pool affects TLD's effectiveness in reducing the drift ratio in hotels in Yogyakarta. Based on the spectrum response analysis using the ETABS program with a spring-mass model approach, several conclusions can be drawn as follows: 1) pool P1 reduces the drift ratio by 3.96% compared to the empty column. This shows that the swimming pool (P1), which is an existing pool, is effective as a Tuned Liquid Damper (TLD) in reducing the drift ratio due to earthquake excitation, 2) pool P2, which is closer to the center of mass

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of the building, shows a better reduction in the drift ratio in the X direction compared to pool P1. However, in the Y direction, pool P2 shows less than optimal performance because the drift ratio increases by 3.85%, 3) position evaluation needs to be carried out in further analysis using the time history analysis method so that the structure's dynamic behavior can be seen in actual earthquake conditions.

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