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# INVESTIGATING THE SEISMIC RESPONSE OF THE HIGH-RISE BUILDINGS HAVING SWIMMING POOLS AT VARYING ELEVATIONS USING ETABS

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*Abstract :* This study aims to examine the seismic response of high-rise buildings with swimming pools at varying elevations using ETABS. The dynamic analysis of high-rise buildings is crucial due to their vulnerability to seismic loads, which can cause substantial damage and loss of life. Swimming pools add an additional mass to the structure, which can notably affect the building's seismic response. In this study, we will analyze the impact of varying elevations of swimming pools on the seismic response of high-rise buildings using ETABS. The aim of the current study is to determine the optimal height at which a swimming pool should be situated in a multi-storey building.

## 1. INTRODUCTION

High-rise buildings with swimming pools are often coupled with luxury and prestige. Including a swimming pool can enhance the overall image of the building and attract upscale residents or tenants who are willing to pay a premium for exclusive amenities. The incorporation of a swimming pool within a tall edifice has the potential to enhance the overall visual allure of the framework. The shimmering water and unique design of a pool can serve as a focal point and contribute to the building's architectural identity. Earthquakes possess the capacity to inflict substantial damage upon towering edifices, leading to a loss of both human life and property. Hence, it is crucial to conduct a thorough examination of the response of tall buildings to seismic activities to ensure their protection in the event of such incidents. Swimming pools are ubiquitous amenities in lofty structures, and it is essential to scrutinize their influence on the response of a building to earthquakes. The addition of a swimming pool introduces extra weight to the building, which can notably influence the building's natural vibration frequency and how it moves. Furthermore, where the swimming pool is placed within the building can also affect how the building reacts to seismic forces. Therefore, it's essential to investigate how different pool locations at various heights affect how a tall building responds to seismic events. Our study will adopt a systematic approach to explore how varying the elevation of the swimming pool impacts the building's response to seismic forces. The outcomes of this study will offer great insights to designers and engineers, helping them gain a deeper understanding of how tall buildings with swimming pools behave during earthquakes. This learning will help them to make well-informed decisions when designing and constructing such buildings.

## 2. OBJECTIVES

In our study, we aim to reveal the ideal elevation for construction of swimming pools within high-rise buildings while considering their response to seismic activity. Our approach involves utilizing the ETABS software for analysis and simulation,

(I) To assess the seismic performance of high-rise buildings with swimming pools at varying levels using numerical analysis tools such as ETABS.
(II) To determine the impact of swimming pools on the overall seismic response of the building.
(III) To investigate the impact of different seismic hazard levels on the performance of high-rise buildings with swimming pools at varying elevations.
(IV) To identify the optimum elevation to incorporate swimming pools.

## 3. METHODOLOGY

### 3.1 Seismic Analysis and Design Data of Structure

During an earthquake, the various factors leading to the structural damage are vertical irregularities, irregularity in strength and stiffness, torsional irregularity, mass irregularity etc. Ground and structures supported on ground are subjected to vibration when earthquake occurs. Thus, during an earthquake the dynamic loading on the structure is not external loading, but because of the motion of support. Earthquake ground vibration may be small, temperate, or strong and their happening may be regular for small, seldom for temperate and not often for strong ground vibration.

### 3.2 Lateral Design Forces

In the IS: 1893-2016(Part 1) code, method suggested for finding the lateral force is based on the computation that result of yielding can be reported for linear analysis of the structure by means of design spectrum. In IS: 1893-2016(part1), modal analysis procedure and dynamic analysis procedure are given. Main difference between these two procedures is that magnitude and lateral load distribution over the height of the building. Lateral forces in the dynamic analysis methods are based on the characteristics of the natural vibration modes of the structure, which are found by allocation of mass and stiffness over the height. Distribution of lateral forces in the equivalent lateral force method is given by a simple formula which is suitable only for normal structures and magnitude of force is based on an evaluation of the fundamental period. In this study only equivalent static method is considered.

### 3.3 Structural Details and Design Data of the Models

| PARTICULAR OF ITEMS | PROPERTIES |
|---|---|
| Total Built-Up Area | 625 sq. meter |
| Plan Area of Swimming Pool | 300 sq. meter |
| Number of Stories | G+10 |
| Column size | 500 mm X 500 mm |
| Height of Column | 3 meters |
| Depth of Swimming Pool | 3 meters |
| Beam Size | 400 mm X 350 mm |
| Slab Thickness | 150 mm |
| Swimming Pool Plate Thickness | 150 mm |

Table 1: Building Description

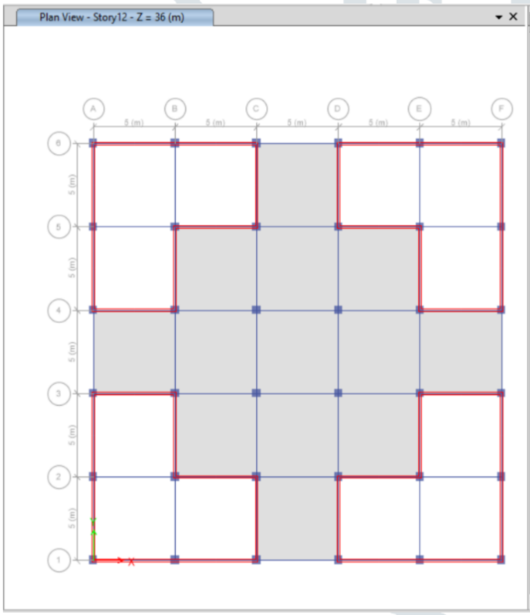



Fig 1. Floor plan with swimming pool

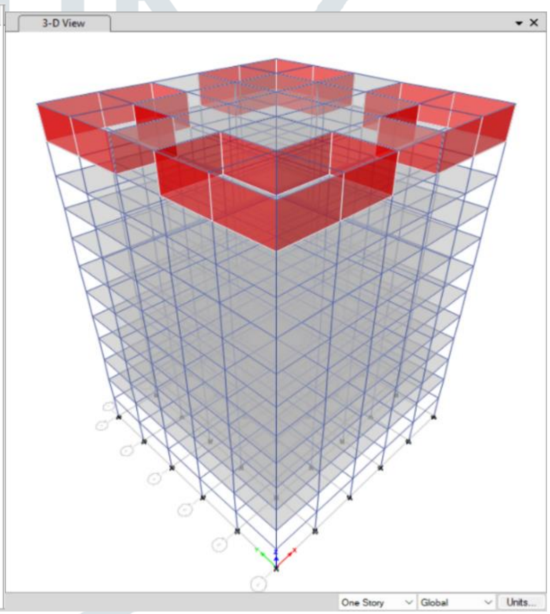



Fig 2. 3D view of with swimming pool

### 3.4 Seismic and Wind Parameters

| PARTICULARS | DETAILS | PARTICULARS | DETAILS |
|---|---|---|---|
| Seismic Zone | Zone – V | Windward co-efficient | 0.8 |
| Zone Factor Z | 0.36 | Leeward co-efficient | 0.5 |
| Response Reduction Factor R | 5.0 (SMRF) | Wind Speed | 50 m/s |
| Importance Factor I | All General Buildings (I =1) | Terrain Category | II |
| Rock/Soil Type | Medium Stiff Soil | | |
| Damping Ratio | 5% (Value = 0.05) | | |

### 3.5 Load Cases

| Load Case | Name | Load Type |
|---|---|---|
| 1. | Dead Load | Self-weight, Floor loads, Hydrostatic pressure, Member loadings |
| 2. | Live Load | Live load |
| 3. | EQX | Seismic load in X direction |
| 4. | EQY | Seismic load in Y direction |
| 5. | WLX | Wind load in X direction |
| 6. | WLY | Wind load in Y direction |

### 3.5.1 Load Case 1: Dead Load

The first load case is designated as Dead load in this analysis. The DEAD LOAD consists of self-weight of the reinforced concrete (RCC) frame, which comprised of slabs, beams, columns, and plate elements employed in the construction of the swimming pool. The unit weight of RCC is 25 KN/m³, as specified by IS 456: 2000. The self-weight for slabs, beam, columns, and plate element is applied in the vertical direction (Y direction) with a load factor of -1.

The weight of outer walls, partition wall is taken as member loading and are considered uniform force in the Y direction. The thickness of outer wall is considered as 230mm and unit weight of masonry to be 20KN/m³, hence we provide a member load of 0.23x20x3=13.8 KN/m to all the outer beams of the structure. As we have considered the partition wall thickness as 150mm, we will provide a member load of 0.15x20x3=9 KN/m on all inner beams. The floor finish for each floor is also considered as dead load of the magnitude 1.5 KN/m$^2$. Hydrostatic pressure, defined as the force that water exerts upon other objects when it is not in motion, is also a significant factor in this analysis. The depth of the swimming pool is considered 3 m. Therefore, the pressure on the floor of the swimming pool is 30 KN/m², and the magnitude of hydrostatic pressure on the wall is considered as uniformly varying shell load from 0 to 30 KN/m², depending on the orientation of the plate element, and is distributed in a horizontal shape.

### 3.5.2 Load Case 1: Live Load

The live load is referred here as load case 2. Live load includes imposed loads for all the floors, and they are considered as given in IS 875 Part -2 for residential buildings. A shell load of 2 KN/m$^2$ is considered as a live load.

### 3.5.3 Load Case 3 and 4: Seismic Load

Seismic or earthquake loads are denoted as EQX and EQY based on their direction of action. The complete seismic weight of each floor is the sum of its full dead load and an appropriate amount of imposed load, as specified in table 10 of IS 1893 (part 1) 2016. In calculating seismic loads of the structure, the imposed load on the roof is not deemed necessary. The floor live load is considered as 2 KN/m².

### 3.5.4 Load case 5 and 6: Wind Load

Wind loads are designated as WLX and WLY according to the direction in which they flow. In X and Y direction we will provide the angle of wind flow as zero degree and 90 degrees respectively. For this study, we have used design wind speed of 50m/s with a terrain category of 2. Both risk coefficient and topography factors are used as 1 as we are constructing the structure to have a design life period of 50 years. The diaphragms are provided to each storey to identify the center of weight of the floors. Windward and Leeward coefficients are 0.8 and 0.5 respectively.

## 4. RESULTS AND DISSCUSSION

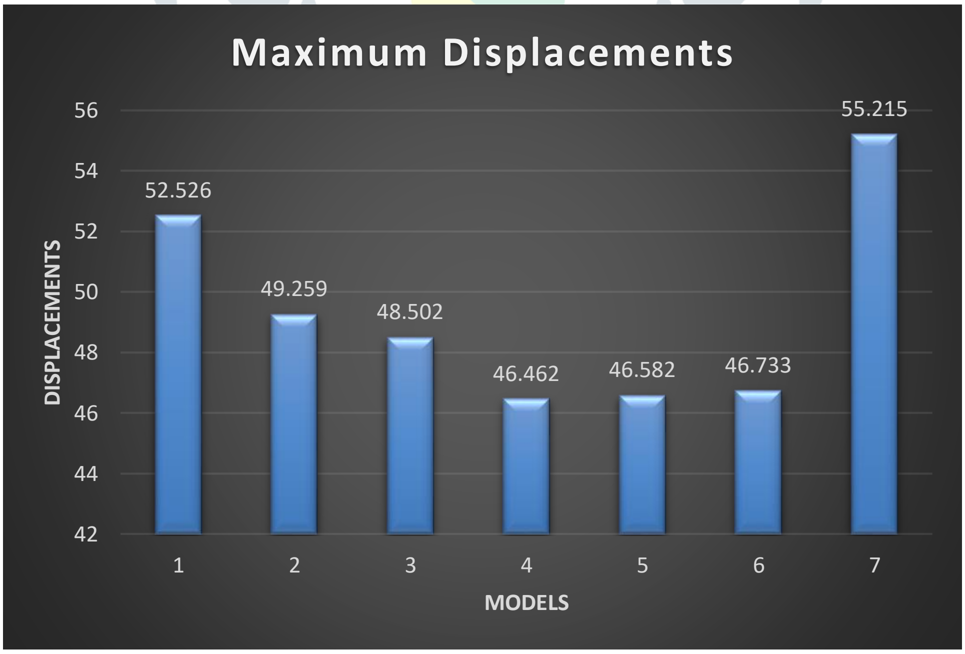
### 4.1 The Displacement values in X-directions for all the models:

| Story | Elevation | without | At GF | 2nd floor | 4th floor | 6th floor | 8th floor | 10th floor |
|---|---|---|---|---|---|---|---|---|
| | m | mm | mm | mm | mm | mm | mm | mm |
| 10 | 36 | 52.526 | 49.318 | 48.502 | 46.461 | 45.93 | 46.727 | 55.285 |
| 9 | 33 | 50.862 | 47.392 | 46.489 | 44.568 | 44.181 | 45.444 | 50.284 |
| 8 | 30 | 48.255 | 44.364 | 43.322 | 41.599 | 41.531 | 47.801 | 48.464 |
| 7 | 27 | 44.75 | 40.287 | 39.06 | 37.635 | 38.34 | 43.816 | 45.099 |
| 6 | 24 | 40.503 | 35.345 | 33.901 | 32.966 | 38.714 | 41.192 | 40.833 |
| 5 | 21 | 35.68 | 29.735 | 28.083 | 28.196 | 35.387 | 36.665 | 35.959 |
| 4 | 18 | 30.434 | 23.643 | 21.915 | 26.344 | 32.124 | 31.364 | 30.66 |
| 3 | 15 | 24.898 | 17.255 | 16.039 | 24.651 | 26.754 | 25.68 | 25.076 |
| 2 | 12 | 19.19 | 10.821 | 12.575 | 21.095 | 20.731 | 19.797 | 19.324 |
| 1 | 9 | 13.426 | 4.912 | 12.051 | 15.232 | 14.527 | 13.852 | 13.518 |
| GF | 6 | 7.782 | 1.695 | 8.496 | 8.922 | 8.424 | 8.03 | 7.835 |
| PL | 3 | 2.771 | 1.216 | 3.203 | 3.167 | 2.994 | 2.856 | 2.788 |
| Base | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |


Maximum Displacements observed in all models in direction X.

**4.2 The Displacement values in Y-directions for all the models:**

| Story | Elevation | without | At GF | 2nd floor | 4th floor | 6th floor | 8th floor | 10th floor |
|---|---|---|---|---|---|---|---|---|
| | m | mm | mm | mm | mm | mm | mm | mm |
| 10 | 36 | 52.526 | 49.259 | 48.502 | 46.462 | 46.582 | 46.733 | 55.215 |
| 9 | 33 | 50.862 | 47.344 | 46.489 | 44.568 | 44.736 | 45.45 | 50.217 |
| 8 | 30 | 48.255 | 44.327 | 43.322 | 41.599 | 41.992 | 47.804 | 48.407 |
| 7 | 27 | 44.75 | 40.261 | 39.06 | 37.635 | 38.716 | 43.821 | 45.051 |
| 6 | 24 | 40.503 | 35.33 | 33.901 | 32.965 | 39.039 | 41.193 | 40.795 |
| 5 | 21 | 35.68 | 29.729 | 28.082 | 28.195 | 35.67 | 36.665 | 35.93 |
| 4 | 18 | 30.434 | 23.645 | 21.914 | 26.343 | 32.363 | 31.364 | 30.639 |
| 3 | 15 | 24.898 | 17.264 | 16.037 | 24.649 | 26.931 | 25.68 | 25.061 |
| 2 | 12 | 19.19 | 10.836 | 12.572 | 21.095 | 20.849 | 19.797 | 19.314 |
| 1 | 9 | 13.426 | 4.93 | 12.048 | 15.232 | 14.596 | 13.852 | 13.512 |
| GF | 6 | 7.782 | 1.711 | 8.495 | 8.923 | 8.456 | 8.03 | 7.833 |
| PL | 3 | 2.755 | 1.215 | 3.203 | 3.168 | 3.001 | 2.856 | 2.787 |
| Base | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |




Maximum Displacements observed in all models in direction Y.

### 4.3 The Drift values in X-directions for all the models

| Story | Elevation | without | At GF | 2nd floor | 4th floor | 6th floor | 8th floor | 10th floor |
|---|---|---|---|---|---|---|---|---|
| | m | mm | mm | mm | mm | mm | mm | mm |
| 10 | 36 | 0.000269 | 0.000642 | 0.000671 | 0.000265 | 0.000261 | 0.000191 | 0.001632 |
| 9 | 33 | 0.000482 | 0.001009 | 0.001056 | 0.000476 | 0.000448 | 0.001375 | 0.00035 |
| 8 | 30 | 0.000733 | 0.001359 | 0.001421 | 0.000717 | 0.000599 | 0.001282 | 0.000698 |
| 7 | 27 | 0.000989 | 0.001647 | 0.00172 | 0.000934 | 0.00135 | 0.000618 | 0.000979 |
| 6 | 24 | 0.00124 | 0.00187 | 0.00194 | 0.001039 | 0.001024 | 0.001141 | 0.001237 |
| 5 | 21 | 0.001483 | 0.002031 | 0.002056 | 0.001338 | 0.000865 | 0.001456 | 0.001482 |
| 4 | 18 | 0.001717 | 0.002129 | 0.001959 | 0.000784 | 0.001557 | 0.001709 | 0.001717 |
| 3 | 15 | 0.001937 | 0.002145 | 0.001289 | 0.001088 | 0.001897 | 0.001934 | 0.001936 |
| 2 | 12 | 0.002132 | 0.001969 | 0.000175 | 0.00191 | 0.002123 | 0.00213 | 0.002132 |
| 1 | 9 | 0.002261 | 0.001219 | 0.001185 | 0.002203 | 0.00226 | 0.00226 | 0.002261 |
| GF | 6 | 0.002169 | 0.00016 | 0.001784 | 0.002153 | 0.002168 | 0.002168 | 0.002168 |
| PL | 3 | 0.001205 | 0.000405 | 0.001068 | 0.001201 | 0.001205 | 0.001204 | 0.001205 |
| Base | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 4.4 The Drift values in Y-directions for all the models:

| Story | Elevation | without | At GF | 2nd floor | 4th floor | 6th floor | 8th floor | 10th floor |
|---|---|---|---|---|---|---|---|---|
| | m | mm | mm | mm | mm | mm | mm | mm |
| 10 | 36 | 0.000269 | 0.000642 | 0.000671 | 0.000265 | 0.000268 | 0.000195 | 0.001632 |
| 9 | 33 | 0.000481 | 0.001009 | 0.001056 | 0.000476 | 0.000452 | 0.001374 | 0.000375 |
| 8 | 30 | 0.000733 | 0.001359 | 0.001421 | 0.000715 | 0.000605 | 0.001286 | 0.000702 |
| 7 | 27 | 0.000989 | 0.001647 | 0.00172 | 0.000934 | 0.0014 | 0.00062 | 0.000979 |
| 6 | 24 | 0.00124 | 0.00187 | 0.00194 | 0.00104 | 0.001029 | 0.001148 | 0.001236 |
| 5 | 21 | 0.00148 | 0.002031 | 0.002056 | 0.001338 | 0.00087 | 0.001456 | 0.001483 |
| 4 | 18 | 0.001712 | 0.002129 | 0.001959 | 0.000788 | 0.001558 | 0.00171 | 0.001718 |
| 3 | 15 | 0.001934 | 0.002145 | 0.001289 | 0.001092 | 0.001897 | 0.001935 | 0.001937 |
| 2 | 12 | 0.002132 | 0.001969 | 0.000175 | 0.001915 | 0.002123 | 0.00214 | 0.002133 |
| 1 | 9 | 0.002261 | 0.001219 | 0.001184 | 0.002207 | 0.00226 | 0.00226 | 0.002264 |
| GF | 6 | 0.002169 | 0.00016 | 0.001783 | 0.00215 | 0.002168 | 0.002168 | 0.002167 |
| PL | 3 | 0.001205 | 0.000405 | 0.001068 | 0.001201 | 0.001205 | 0.001204 | 0.001206 |
| Base | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## 5. CONCLUSIONS:

Based on the above results from various model analysis we can come to following conclusions.

(a) It is observed from the analysis that the displacement and drift values are reduced in models with swimming pool in comparison with other models without swimming pool.

(b) The drift values of all the models are well within the IS defined limitations.

(c) The displacement in intermediate stories is less compared to the models.

(d) Finally, we can conclude that the optimum elevation to provide the swimming pool is intermediate storeys from $4^{th}$ to $6^{th}$ floors in case of G+10 building.

## 6. FUTURE SCOPE FOR THE STUDY

The present work can be extended to several areas of further research. The following points are suggested as further work. After identifying the optimum elevation for the swimming pool, we can continue the study for different shapes of the swimming pool.

(a) The study can also incorporate the position of the swimming pool within the specified floor.

(b) The assessment of seismic response can be done with buildings incorporating swimming pools at multiple levels.

(c) The study can also be conducted for irregularly shaped buildings.

(d) For further studies, the squashing effect of the water can also be taken into consideration.

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