

Influence of Building Height on seismic behaviour of RC structure under multi-component Ground Motion

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Abstract - Earthquakes occur due to the sudden release of energy inside the Earth's crust, producing seismic waves that cause ground shaking and damage to structures. These events can lead to loss of life, property damage, and environmental destruction. To reduce such risks, engineers study important seismic parameters such as Peak Ground Acceleration (PGA), frequency of ground motion, and duration of shaking. This study focuses on how different earthquake frequencies affect reinforced concrete (RC) buildings. Using ETABS software, linear time-history analysis is carried out on three types of buildings: low-rise (2-story), medium-rise (8-story), and high-rise (20-story) structures. The buildings are tested under low, medium, and high-frequency earthquake motions to understand their behavior during seismic events. The performance of the structures is evaluated using parameters such as floor acceleration, floor displacement, inter-story drift, and base shear. By comparing these results, the study helps identify how different buildings respond to earthquakes and supports the development of safer and more earthquake-resistant structures.

Key Words: Earthquake, ETABS, Linear Time-History Analysis, Peak Ground Acceleration, Inter-Story Drift

1. INTRODUCTION

An earthquake is a sudden shaking of the Earth's surface caused by the release of stored energy within the lithosphere due to tectonic plate movements, volcanic activity, mining, or other geological processes. Engineers and seismologists use instruments such as seismographs and accelerographs to study earthquake behavior and measure parameters like acceleration, velocity, and displacement. The most important factors affecting structures during earthquakes are Peak Ground Acceleration, duration of shaking, and frequency content. Local soil conditions also influence seismic response, as soft soils can amplify seismic waves and increase structural damage. When the frequency of ground motion matches the natural frequency of a building, resonance occurs, causing excessive vibrations and possible structural failure.

1.1 Basics of Seismic Action and Structural Response

Earthquakes are natural disasters caused by the sudden

release of energy inside the Earth's crust, producing seismic waves that create vibrations on the ground surface. These vibrations act in both horizontal and vertical directions and affect structures depending on the intensity, duration, and frequency of shaking. Important seismic parameters such as Peak Ground Acceleration, frequency content, and duration of shaking greatly influence structural behavior. Reinforced concrete (RC) structures are commonly used in earthquake-resistant construction because they combine the strength of concrete with the ductility of steel reinforcement. This study focuses on the seismic response of 2-story, 8-story, and 20-story RC buildings using ETABS software and Linear Time-History Analysis under low, medium, and high-frequency earthquake motions to evaluate displacement, drift, acceleration, and stress distribution.

1.2 A Journey through the Evolution of Seismic Analysis

The field of earthquake engineering has developed over time through lessons learned from destructive earthquakes such as the 1908 Messina earthquake in Italy, which highlighted the need for better seismic design methods. This led to the development of the Equivalent Static Method of Analysis (ESMA), where seismic forces were considered as horizontal forces acting on structures. Later, the installation of accelerographs and the availability of real earthquake records improved the understanding of structural behavior during earthquakes. With advancements in computer technology, more advanced methods such as Linear Dynamic Analysis and nonlinear analysis were developed to study multiple vibration modes and inelastic structural behavior. Today, modern seismic design combines advanced analysis techniques and performance-based engineering concepts to create safer and more earthquake-resistant structures.

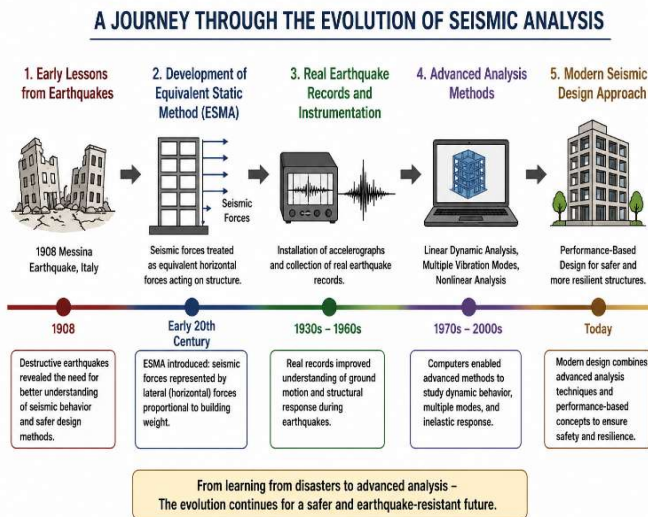


Figure 1. 1 A Journey through the Evolution of Seismic Analysis

1.3 Significance of Research – The Symphony of Seismic Resilience

Earthquakes release large amounts of stored energy in the form of seismic waves, and the severity of ground motion is mainly defined by acceleration, duration, and frequency content. The interaction between these seismic frequencies and the natural frequency of reinforced concrete (RC) buildings plays an important role in determining structural performance and safety. High-frequency earthquake motions mainly affect low-rise buildings because of their stiffness, causing rapid vibrations that may damage foundations and shear walls. Medium-frequency motions strongly influence mid-rise structures, creating internal stresses and structural deformation, while low-frequency ground motions greatly affect high-rise buildings by producing large sway movements and increasing ductility demands. Therefore, understanding how different building heights respond to different earthquake frequencies is very important for improving seismic design, reducing structural damage, and developing safer and more earthquake-resistant structures.

2. AIM AND OBJECTIVES

1. To study the seismic behavior of reinforced concrete (RC) buildings.
2. To compare the response of low-rise, mid-rise, and high-rise structures during earthquakes.
3. To analyze the effect of earthquake frequency on different building types.
4. To perform Linear Time-History Analysis using

ETABS software.

3. LITERATURE REVIEW

Wei-Ping Zhang et al. has studied the effect of chloride-induced corrosion on the seismic performance of RCC structures. The study explained that corrosion reduces the strength, stiffness, and durability of reinforcement, which negatively affects structural behavior during earthquakes. The research highlighted the importance of considering material deterioration, structural uncertainty, and earthquake loading for accurate seismic analysis and safer structural design.

Ali Bigdeli et al. has investigated probabilistic seismic demand models and intensity measures for modular steel buildings subjected to near-field earthquakes. The study used nonlinear time history analysis to evaluate structural response under different ground motions. The research showed that intensity measures and fragility curves are important for predicting seismic vulnerability and performance of structures.

Haixu Yang et al. has studied the seismic performance of RC frame structures equipped with nonlinear energy sink (NES) damping devices. The study found that the damping system effectively reduced displacement, acceleration, and crack formation during earthquakes. The research concluded that NES devices improve energy dissipation and enhance the seismic resistance of RC frame structures.

Guiling Wang et al. has investigated the seismic behavior of integrated wall-RC frame systems in multi-storey grain warehouse structures. The study showed that masonry walls improved stiffness, load-bearing capacity, and energy dissipation during seismic loading. However, increased damage reduced wall contribution, affecting ductility and deformation capacity of the structure.

Jiaxu Shen et al. has examined the effect of sequential earthquakes and aftershocks on the reliability of frame structures using nonlinear finite element analysis. The study found that repeated aftershocks significantly increased cumulative damage and reduced structural reliability, especially in lower storeys. The research emphasized the importance of considering aftershock effects in seismic design and safety evaluation.

Zhenshan Wang et al. has studied the seismic performance of RC columns strengthened with prestressed lattice steel reinforcement under cyclic loading. The research showed improvements in stiffness, ductility, load-bearing capacity, and energy dissipation compared to conventional reinforcement methods. The study concluded that the proposed strengthening technique can effectively enhance the seismic resistance of RC structures.

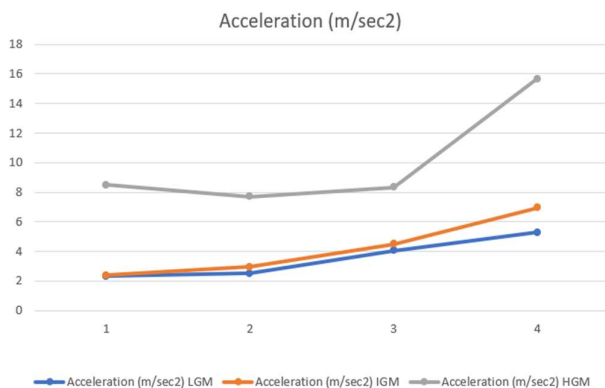
4. SYSTEM DEVELOPMENT

The present study involves the seismic analysis of three reinforced concrete (RC) buildings of different heights, namely 2-story, 8-story, and 20-story structures, using ETABS software. Three-dimensional models were developed by defining beams, columns, slabs, material properties, and loading conditions according to Indian Standard codes. Gravity loads such as dead load, live load, wall load, and floor finish load were applied to the structures, while fixed supports and rigid diaphragm conditions were assigned to simulate realistic structural behavior. The buildings were modeled as bare frame structures to study their seismic response accurately under earthquake loading.

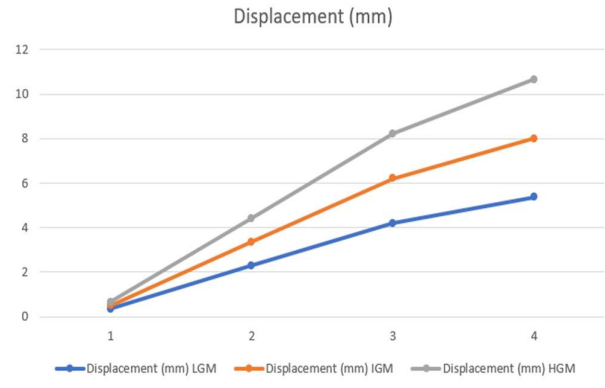
The seismic analysis was carried out using Linear Time-History Analysis based on IS 1893 (Part 1): 2002 guidelines. Three different earthquake ground motion records representing low-frequency, intermediate-frequency, and high-frequency motions were applied to the models to evaluate their seismic performance. Parameters such as displacement, inter-story drift, acceleration, and base shear were studied to compare the behavior of low-rise, mid-rise, and high-rise RC buildings under different earthquake frequencies. The analysis helped in understanding the influence of building height and ground motion frequency on structural stability and earthquake resistance.

5. RESULTS AND DISCUSSION

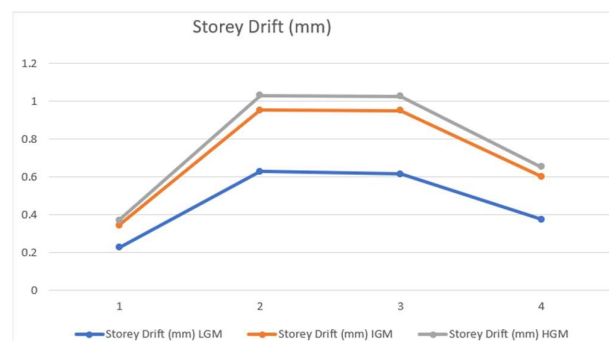
5.1 Seismic Response of Two-Story RC Building.



(a)



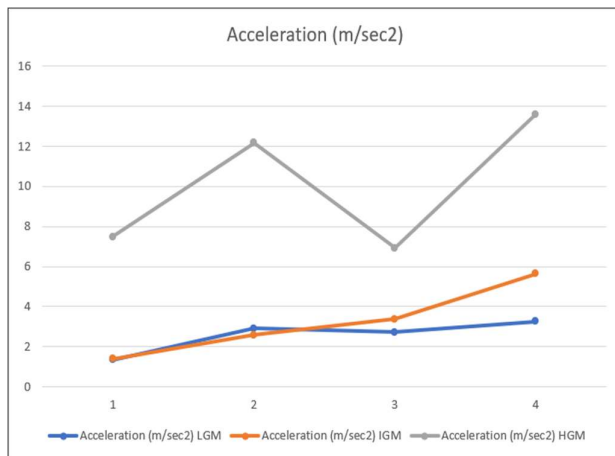
(b)



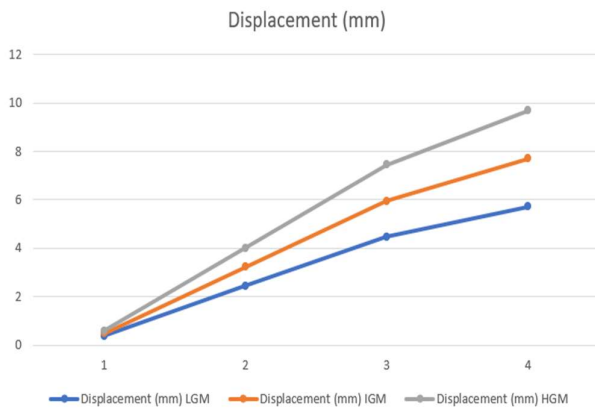
(c)

Figure 5.1: (a) Floor acceleration (b) Floor displacement and (c) Floor drift of Two Floor RC building under LGM, IGM and HGM in longitudinal direction

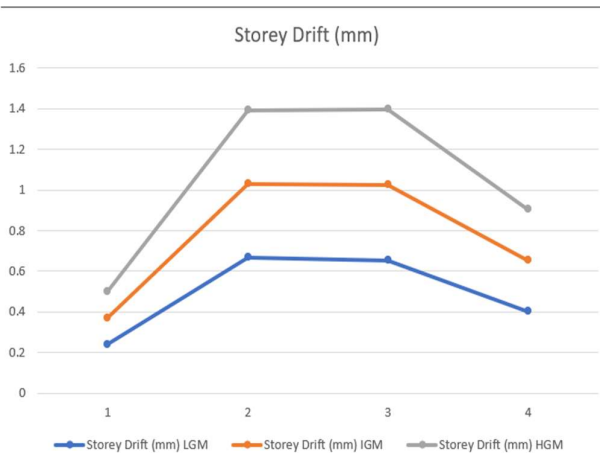
The analysis results of the two-floor RC building show that floor acceleration, displacement, and storey drift increase with the increase in earthquake frequency. High Ground Motion produces the maximum structural response, while Low Ground Motion (LGM) shows the minimum response. Floor acceleration and displacement increase towards the upper floors due to higher seismic effects. The storey drift values are also higher under HGM compared to IGM and LGM, indicating greater deformation in the structure during high-frequency earthquakes. Overall, the study shows that low-rise RC buildings are more sensitive to high-frequency ground motions, which significantly affect their seismic behavior and stability.



(a)



(b)



(c)

Figure 5.2: (a) Floor acceleration (b) Floor displacement and (c) Floor drift of Two Floor RC building under LGM, IGM and HGM in transverse direction

The transverse direction analysis of the two-floor RC building shows that floor acceleration, displacement, and storey drift increase as the earthquake frequency content increases. High Ground Motion produces the highest response values, while Low Ground Motion (LGM) gives the minimum structural response. Floor displacement gradually increases towards the upper floors, indicating larger lateral movement during seismic loading. The storey drift values are also maximum under HGM, showing greater deformation and stiffness demand on the structure during high-frequency earthquakes. Overall, the results indicate that the two-floor RC building is highly sensitive to high-frequency ground motions in the transverse direction, leading to increased acceleration, displacement, and drift responses.

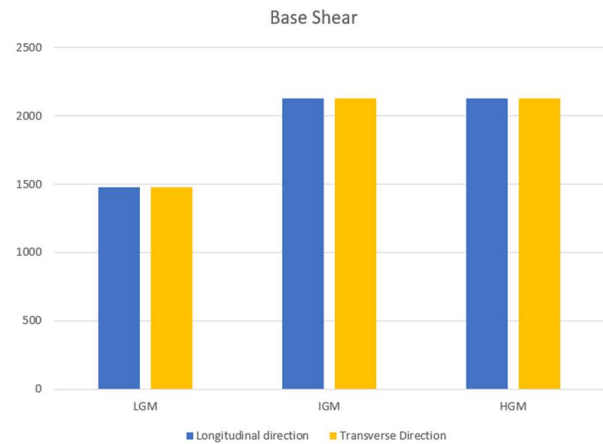
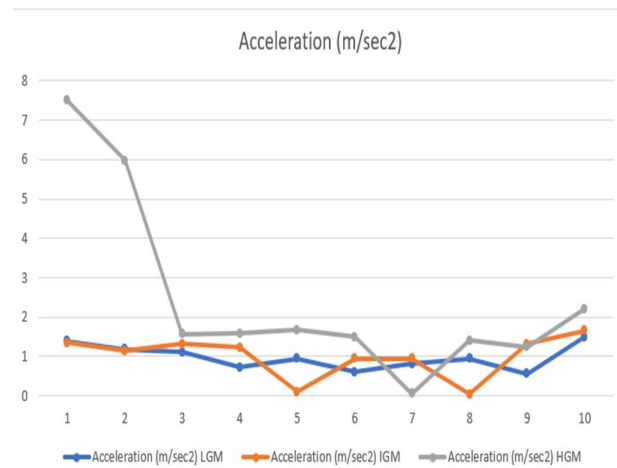


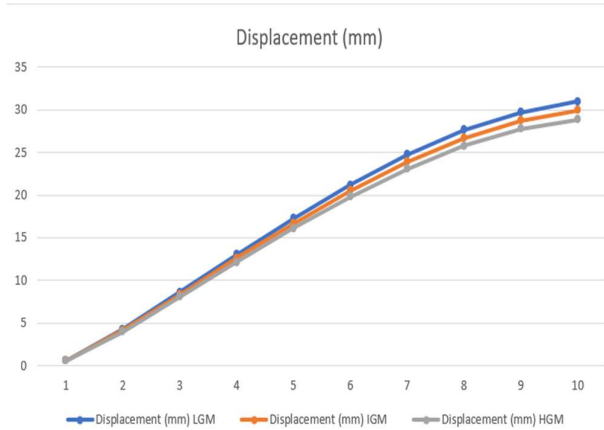
Figure 5.3: Base shear of two Floor RC building due to LGM, IGM and HGM in longitudinal and transverse direction

The base shear results of the two-floor RC building show that the base shear values increase from Low Ground Motion (LGM) to Intermediate Ground Motion (IGM) and High Ground Motion (HGM). The minimum base shear is observed under LGM, while the maximum base shear occurs under HGM due to higher seismic forces acting on the structure. The longitudinal and transverse directions show nearly similar base shear values, indicating a uniform structural response in both directions. Overall, the results indicate that higher-frequency earthquake motions generate greater lateral forces and increase the seismic demand on the two-floor RC building.

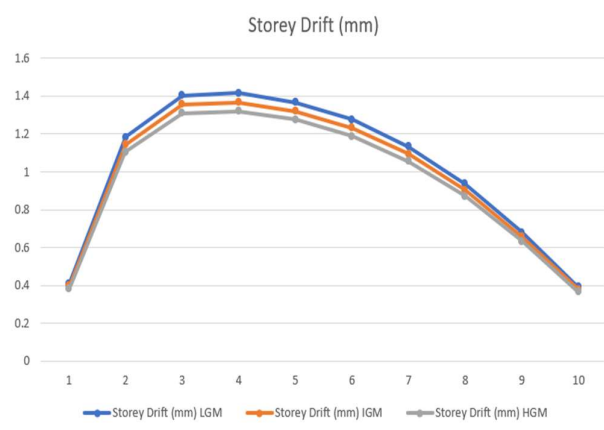
5.2 Eight story Reinforcement Building



(a)



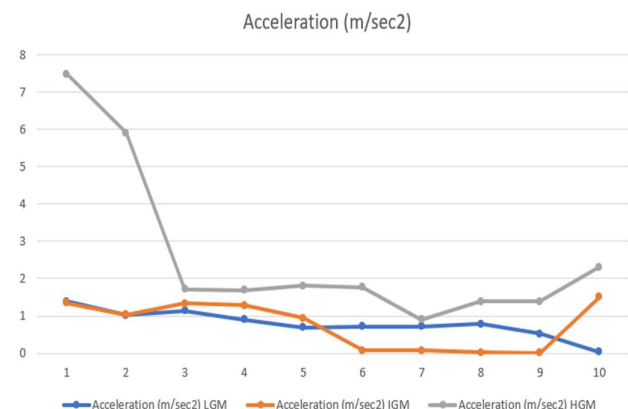
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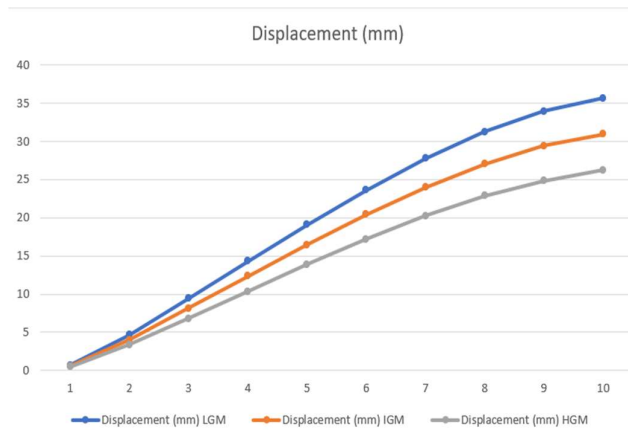
(c)

Figure 5.4: (a) Floor acceleration (b) Floor displacement and (c) Floor drift of Eight Floor RC building under LGM, IGM and HGM in longitudinal direction

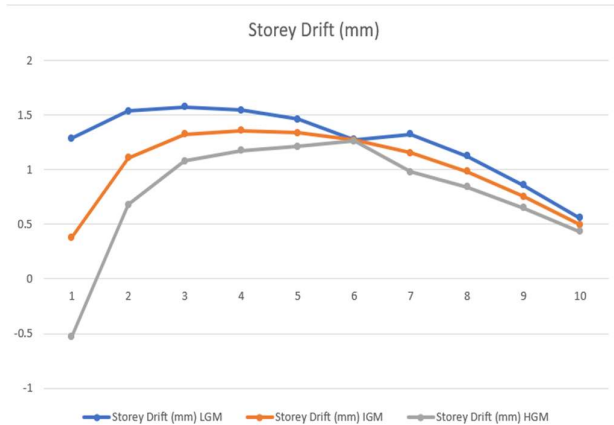
The results of the eight-floor RC building in the longitudinal direction show that floor displacement and storey drift gradually increase with building height under all earthquake motions. High Ground Motion produces higher acceleration values at the lower floors, while displacement continuously increases towards the upper floors due to greater lateral movement of the structure. The maximum storey drift occurs at the intermediate floors and then gradually decreases towards the top floors. The differences between LGM, IGM, and HGM responses are comparatively smaller in displacement and drift, indicating that the mid-rise RC building shows a more stable seismic response compared to low-rise structures. Overall, the results show that the eight-floor RC building experiences significant lateral displacement and moderate drift under seismic loading conditions.



(a)



(b)



(c)

Figure 5.5: (a) Floor acceleration (b) Floor displacement and (c) Floor drift of Eight Floor RC building under LGM, IGM and HGM in transverse direction

The transverse direction results of the eight-floor RC building show that floor displacement increases continuously from the lower floors to the upper floors under all earthquake motions. High Ground Motion produces higher acceleration values at the lower floors, while LGM shows comparatively larger displacement values at the top floors. The storey drift values increase at the intermediate floors and then gradually decrease towards the top floors. The maximum drift occurs in the middle storeys, indicating greater lateral deformation in that region of the building. Overall, the results show that the eight-floor RC building experiences significant displacement and moderate drift under seismic loading in the transverse direction.

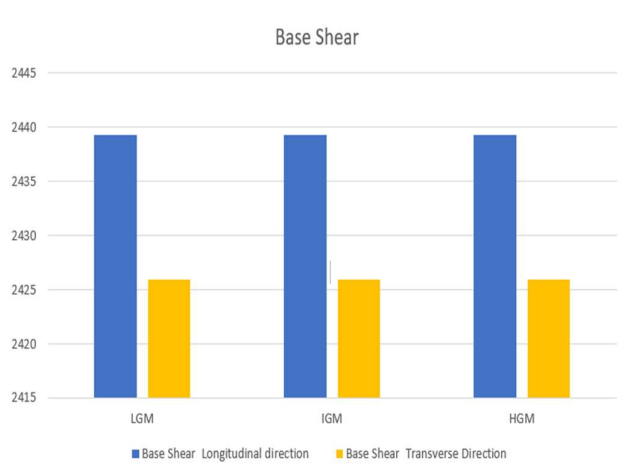
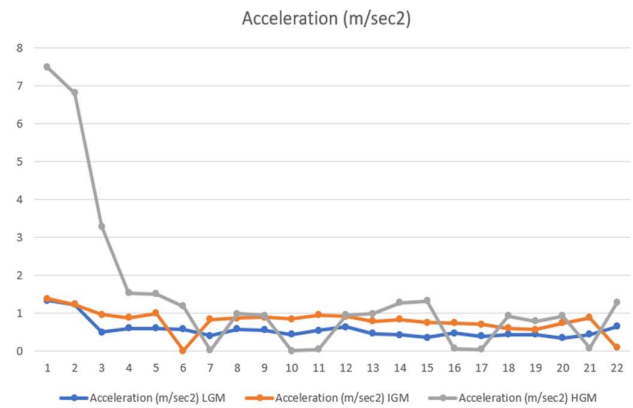


Figure 5.6: Base shear of Eight Floor RC building due to LGM, IGM and HGM in longitudinal and transverse

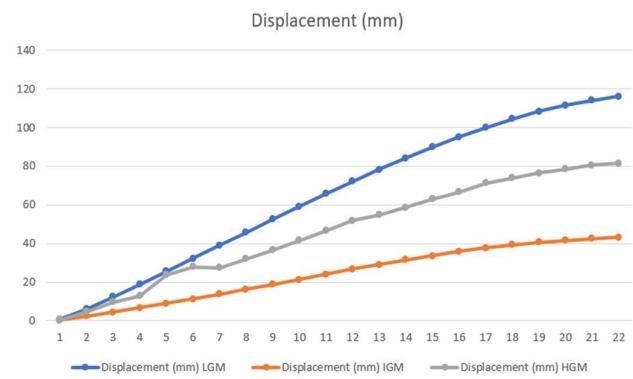
direction

The base shear results of the eight-floor RC building show that the longitudinal direction experiences slightly higher base shear values compared to the transverse direction under LGM, IGM, and HGM conditions. However, the variation in base shear due to different ground motions is very small, indicating a nearly stable seismic response of the mid-rise structure. The results also indicate that the eight-floor RC building distributes seismic forces more uniformly in both directions because of its structural stiffness and regular configuration. Overall, the building shows moderate seismic demand and good lateral load resistance under different earthquake frequency motions.

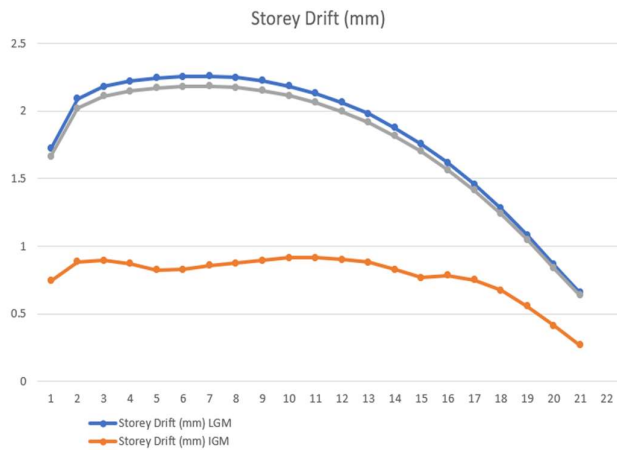
5.3 Twenty Floor RC Building



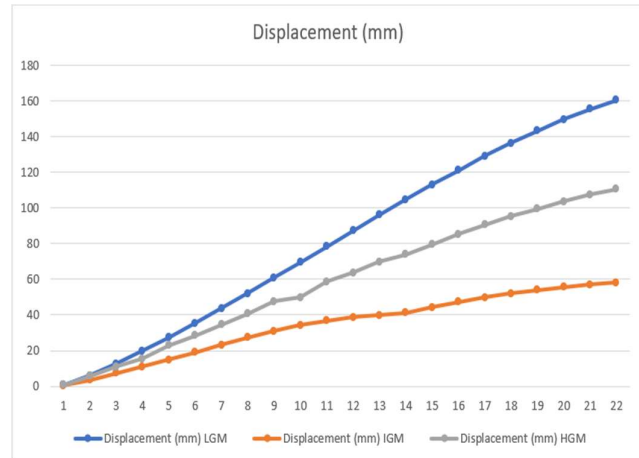
(a)



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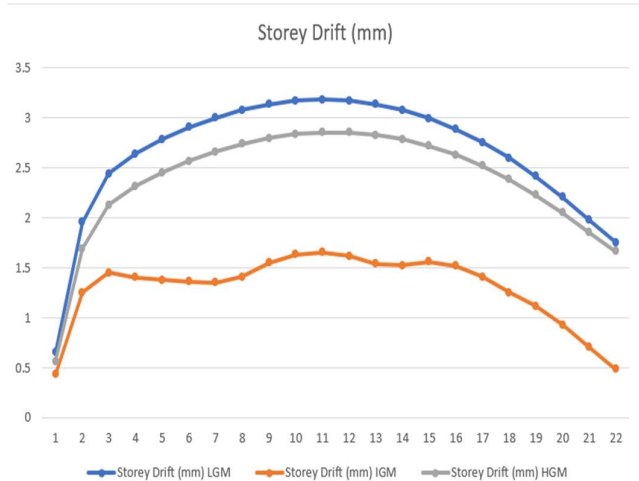
(c)



(b)

Figure 5.7: (a) Floor acceleration (b) Floor displacement and (c) Floor drift of Twenty Floor RC building under LGM, IGM and HGM in longitudinal direction

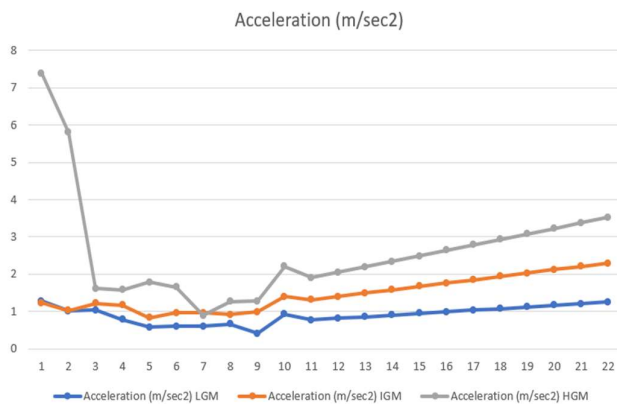
The longitudinal direction results of the twenty-floor RC building show that floor displacement increases significantly towards the upper floors under all earthquake motions due to the flexible behavior of the high-rise structure. Low Ground Motion produces the maximum displacement and storey drift values, indicating that high-rise buildings are more sensitive to low-frequency ground motions. The storey drift values are highest at the middle storeys and gradually decrease towards the top floors. Floor acceleration is comparatively higher at the lower floors under HGM and reduces along the height of the building. Overall, the results show that the twenty-floor RC building experiences large lateral displacement and drift under low-frequency seismic motions because of resonance effects and increased structural flexibility.



(c)

Figure 5.8: (a) Floor acceleration (b) Floor displacement and (c) Floor drift of Twenty Floor RC building under LGM, IGM and HGM in transverse direction

The transverse direction results of the twenty-floor RC building show that floor displacement and storey drift increase significantly with building height under all earthquake motions. Low Ground Motion produces the maximum displacement and drift values, showing that high-rise structures are highly sensitive to low-frequency ground motions due to their flexibility and longer natural period. The maximum storey drift occurs at the middle storeys and gradually decreases towards the top floors. Floor acceleration is highest under HGM at the lower floors and increases gradually towards the upper floors. Overall, the results indicate that the twenty-floor RC building



(a)

experiences large lateral movement and deformation in the transverse direction, especially under low-frequency seismic excitation.

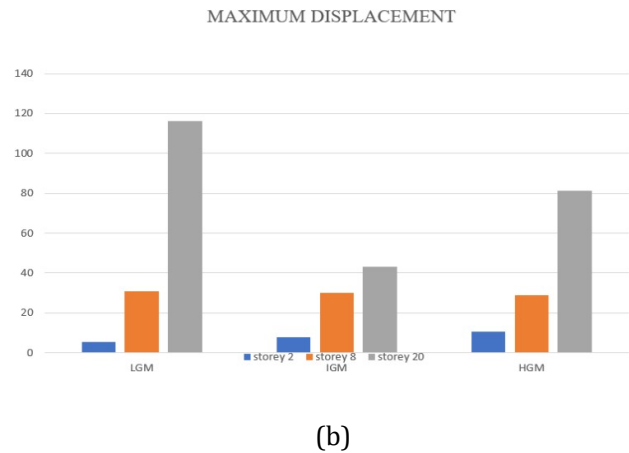
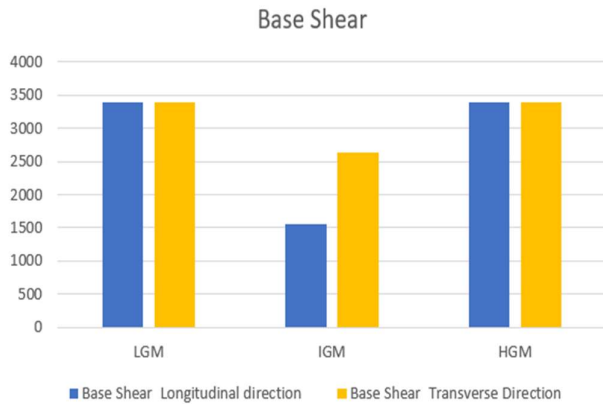
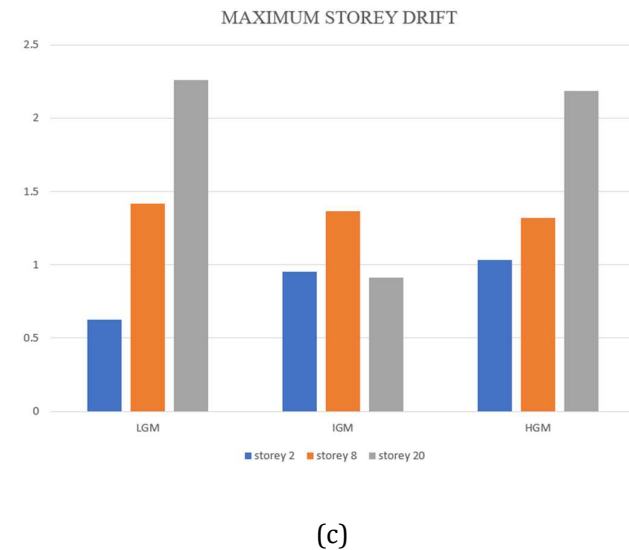


Figure 5.9: Base shear of Twenty Floor RC building due to LGM, IGM and HGM in longitudinal and transverse direction

The base shear results of the twenty-floor RC building show that the maximum base shear occurs under High Ground Motion and LGM conditions, while comparatively lower values are observed under IGM in the longitudinal direction. The transverse direction generally shows slightly higher base shear values compared to the longitudinal direction due to increased lateral flexibility of the structure. The results indicate that high-rise RC buildings experience large seismic forces because of their greater mass and height. Overall, the twenty-floor structure shows higher seismic demand and significant lateral force effects under different earthquake frequency motions, especially in the transverse direction.



5.4 Maximum Response in longitudinal direction(x)

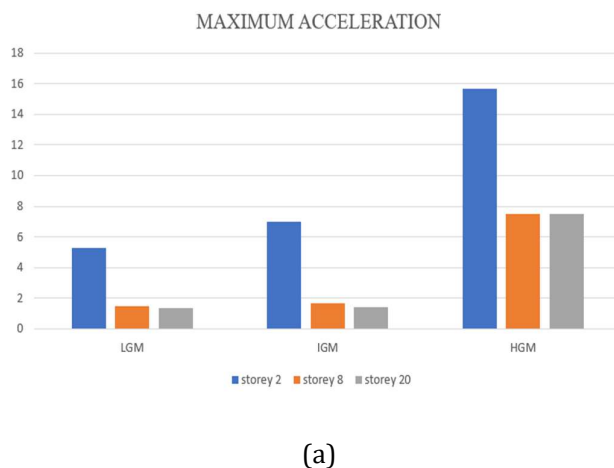
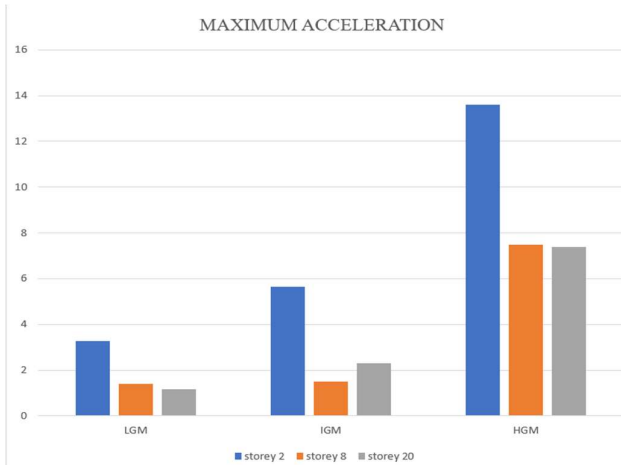


Figure 5.9: Maximum Responses in longitudinal direction for (a) Acceleration, (b) Displacement and (c) Floor Drift

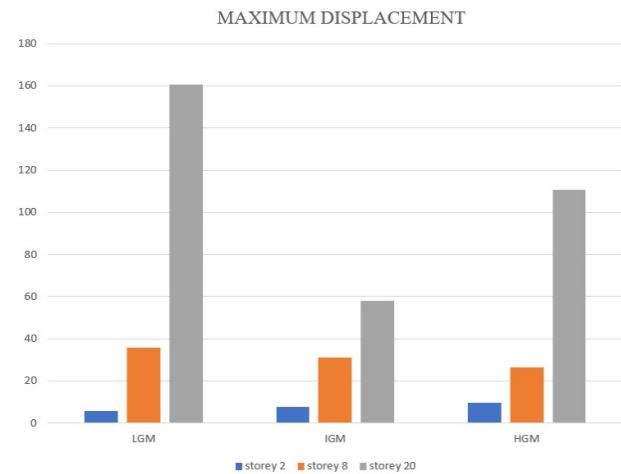
The maximum response results in the longitudinal direction show that the two-floor RC building experiences the highest acceleration values, especially under High Ground Motion, indicating that low-rise structures are more sensitive to high-frequency earthquakes. The eight-floor and twenty-floor buildings show comparatively lower acceleration responses because of their higher flexibility and longer natural periods. The displacement and storey drift results indicate that the twenty-floor RC building experiences the maximum lateral displacement and drift values, particularly under LGM conditions. This shows that high-rise buildings are more affected by low-frequency ground motions due to resonance effects and increased

structural flexibility.

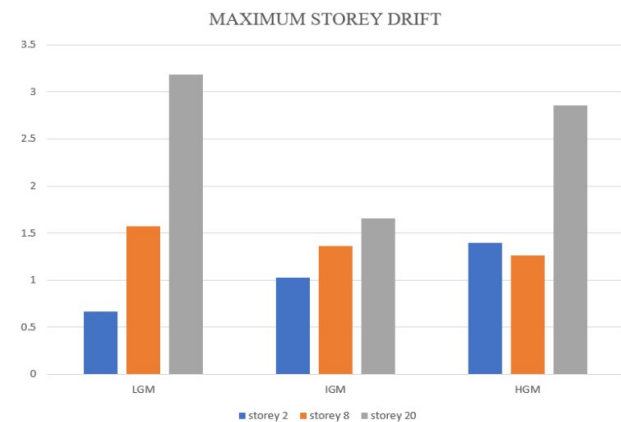
5.5 Maximum Response in transverse direction(y)



(a)



(b)



(c)

Figure 5.10: Maximum Responses in transverse direction for (a) Acceleration, (b) Displacement and (c) Floor Drift

The maximum response results in the transverse direction show that the two-floor RC building experiences the highest acceleration under High Ground Motion, indicating that low-rise buildings are more sensitive to high-frequency earthquakes. The eight-floor and twenty-floor buildings show lower acceleration values because of their greater flexibility and longer vibration periods. The maximum displacement and storey drift values are observed in the twenty-floor RC building, especially under Low Ground Motion. This indicates that high-rise structures are highly affected by low-frequency ground motions due to increased lateral flexibility and resonance effects. Overall, the results show that low-rise buildings are acceleration-dominant, while high-rise buildings are more vulnerable to displacement and drift in the transverse direction during earthquakes.

5.6 Maximum Response in longitudinal direction(x) and transverse direction(y) for Base Shear

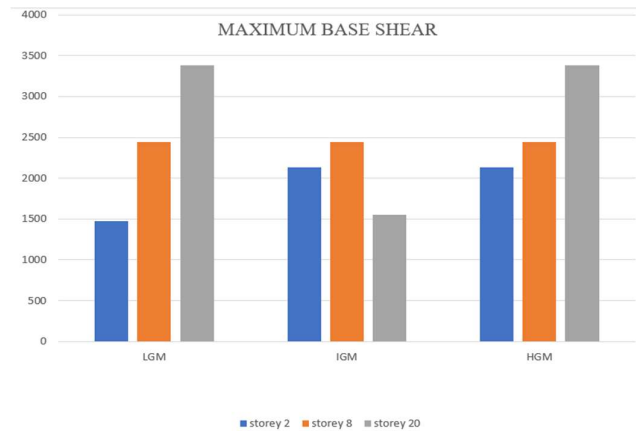


Figure 5.11: Maximum Responses in longitudinal direction(x) and transverse direction(y) for Base Shear

The maximum base shear results show that the twenty-floor RC building experiences the highest base shear values under Low Ground Motion and HGM conditions due to its larger mass and height. The eight-floor building shows moderate base shear values, while the two-floor building experiences the lowest base shear because of its smaller structural mass and lower seismic demand. The results indicate that base shear increases with building height, as taller structures attract greater seismic forces during earthquake excitation. Overall, the high-rise RC building is

subjected to higher lateral force effects in both longitudinal and transverse directions, showing greater seismic demand compared to low-rise and mid-rise structures.

6. CONCLUSIONS

1. The seismic response of RC buildings depends significantly on earthquake frequency and building height.
2. The **2-storey RC building** showed the highest acceleration under HGM, with responses increasing by approximately **40–60%** compared to LGM due to its short natural period and sensitivity to high-frequency motions.
3. The **8-storey RC building** exhibited a relatively stable response, with displacement and drift variations limited to about **10–20%**, indicating balanced seismic performance.
4. The **20-storey RC building** experienced the maximum displacement and drift under LGM, with values increasing by approximately **35–60%** compared to HGM because of resonance effects and greater structural flexibility.
5. Base shear increased with building height, with the 20-storey building developing approximately **40–70%** higher base shear than the 8-storey building and **80–120%** higher than the 2-storey building due to its larger mass.
6. Low-rise buildings are more sensitive to **high-frequency earthquakes**, while high-rise buildings are more affected by **low-frequency earthquakes** because of differences in their natural vibration periods.
7. Overall, earthquake frequency content plays a crucial role in seismic behavior, and considering frequency effects in design can improve the safety and performance of RC buildings.

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