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The Influence Of Slenderness Ratio On High-Rise Building Seismic Performance Across US Seismic

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Abstract:The construction of high-rise buildings with increasing slenderness ratios presents both economic and engineering challenges. This study investigates the effect of slenderness ratio on the seismic performance of high-rise buildings in various seismic zones across the United States. This research aims to contribute to the development of safer, more resilient, and cost-effective high-rise construction practices in earthquake-prone regions. The research employs non-linear and linear static analysis to assess the seismic response of slender high-rises subjected to ground motions representative of different US seismic zones. Key parameters such as lateral drift and inter-story drift ratio will be evaluated to understand how slenderness influences building behavior under seismic loads. The findings aim to improve seismic design guidelines, optimize structural systems for slender high-rises, and inform performance-based design approaches that consider the specific seismic threats of each zone. In this study, seismic lateral loading on flat slab structures with high-column inertia, with or without edge beams, was applied. The study considered six different width high-rise building models having the same area and column distribution but different slenderness ratios due to the height of the building: 20, 30, and 40 story buildings. Numerous seismic zones were taken into account to study the behavior of high-rise concrete buildings in various zip codes throughout the USA. Linear and nonlinear static analyses were carried out according to ACI 318-14 and ASCE 7-10 using ETABS software. The performed numerical study presented a design chart applicable for any building dimensions (length and width) to guide the designer to the maximum height that can be achieved in any seismic zone.

Keywords: : High-rise, seismic, non-linear analysis, slenderness, building width, drift, time period.

1. INTRODUCTION

The skylines of modern cities are increasingly dominated by high-rise buildings. These structures offer numerous advantages, including efficient land use and maximization of valuable urban space. However, the pursuit of ever-greater heights and slender profiles for aesthetic or economic reasons necessitates careful consideration of their seismic performance.

Earthquakes pose a significant threat to high-rise buildings, and their slenderness ratio – the ratio of a building's height to its base width – is a critical factor influencing seismic vulnerability. Slender buildings are more susceptible to lateral sway under seismic loads. This can lead to excessive lateral drift, inter-story drift ratio, and potential structural damage or collapse.

Fig 1 High-rise building models studied having the same area and different plan aspect ratios.

The United States encompasses a diverse range of seismic zones, with varying levels of ground motion intensity. Understanding how slenderness ratio interacts with seismic forces specific to different seismic zones is crucial for ensuring the safety and resilience of high-rise buildings.

This research investigates the influence of slenderness ratio on the seismic performance of high-rise buildings across various US seismic zones. By employing advanced analytical techniques and considering the seismic characteristics of each zone, this study aims to provide valuable insights for:

- Improved Seismic Design Guidelines: Developing more comprehensive design codes that account for the specific vulnerabilities of slender buildings in different seismic threat levels.
- Optimized Structural Systems: Designing more efficient structural systems that mitigate the negative effects of slenderness under seismic loads.
- Performance-Based Design Approach: Informing a performance-based design approach where slenderness ratio is explicitly considered in seismic assessments.

In this study, the width and slenderness of the structures are the main topics that are taken into account. The dimensions of the area of the building determine the maximum height to be considered to overcome the load cases of either earthquake or wind load as lateral loading.

Due to the rapid growth of the high-rise building system all over the world and the major benefits of using any land dimensions from an economic point of view, the behavior of flat slabs was studied in different storey's height levels (10, 20, 30, and 40) and at different types of regular -plan buildings. The study investigates the case of columns with flat slabs with edge beams as shown in Figure 1. The study was done according to ACI 318-14[1] design code and ASCE 7-10 [2]. Linear and pushover nonlinear static analysis were carried out using ETABS [3] software.

2. LITERATURE REVIEW

The width and slenderness ratio of high-rise buildings is the most important issue in the behavior of multi-storey structures. Recently, there have been a lot of pencil buildings that have an aspect ratio (height/width) of 12 to 24. An example is the high-rise building at 111 West 57 Street in New York, its aspect ratio is 24 and its height is 438 m with 82 floors, as shown in Figure 2.

Fig 2: The Most-Slender Building in New York 24:1 slenderness

Many studies investigated the slenderness of building concrete structures, while this study presented a design strategy to evaluate in choosing the maximum height for the concrete structure according to the width of the building structure considered. Fawzy, [4] investigated the influence of using edge beams in high rise buildings structures. Ilgın, [5] in this study investigates how a building's slenderness ratio (height to base width) affects design choices for super tall towers (>300m). Analyzing 75 buildings worldwide, the research pointed out trends in slenderness based on height, function, and structural system and offered valuable insights into designing these high-performance structures.

Awida, [6] examined how a building's slenderness ratio impacts residential concrete high-rises in Kuwait City, focusing on wind and seismic loads he analyzed two 30-story towers with varying slenderness ratios and offers design recommendations for engineers and architects. JSzołomicki, and Szołomicka, [7] explored the new trend of super-tall, slender residential towers. They examined two types: ultra-luxury with few apartments per floor and those with more typical layouts. The paper analyzed structural advancements needed for these buildings.

Pechorskaya at alcompared [8] compared two software programs (ETABS and RSA) for analyzing high-rise buildings under gravity and wind loads and found that RSA produces higher forces and moments than ETABS, suggesting potential differences in analysis methods Walsh et al., [9] explored ways to build taller, thinner skyscrapers in crowded cities using different buildings plan sections and found that square buildings and those with connected towers can reach greater heights than traditional designs, while minimizing side-to-side sway under wind and weight. Meanwhile Alex et al, [10] compared a simplified method for estimating a building's ability to withstand future earthquakes (residual capacity) after damage, with a more precise method. They found the simple method works well for minor damage but can be overly cautious for buildings with more significant damage. Ahmed et al, [11] developed a new computer model to analyze complex concrete walls used in buildings. The model can handle walls with unusual shapes, openings, and features, unlike most existing models. This will help engineers better understand how these walls behave in earthquakes and wind. Ghosh ,S. K.,[12] discussed changes made to the seismic design provisions of ASCE 7-10 (referenced by the 2012 IBC)[13] compared to ASCE 7-05.[14] It excludes changes to wind design, other provisions, non-structural components, and non-building structures.

Walsh et al [15] investigated how well different skyscraper designs handle gravity and wind loading. They used (finite element analyses) to compare nine models. The buildings ranged in height from 80 meters to 460 meters. They found that square-shaped buildings could be built taller than rectangular ones with the same floor area. Additionally, connecting multiple towers together made them even stronger and allowed for even greater heights. Although their investigation missed the seismic performance for high-rise buildings.

Seismic Performance and Slenderness Ratio

Studies have shown that slenderness ratio plays a significant role in a high-rise building's seismic in terms of behavior.

- **Lateral Sway:** Buildings with higher slenderness ratios exhibit greater lateral sway during earthquakes. This can lead to increased occupant discomfort, potential damage to non-structural elements, and even structural failure in extreme cases.
- **P-Delta Effect:** In slender structures, lateral sway can induce additional bending moments (P-Delta effect) due to the building's own weight (P). This further amplifies lateral deformations and can lead to structural instability.
- **Dynamic Amplification:** Slender buildings are more susceptible to resonance with specific earthquake frequencies. This can significantly amplify the seismic forces acting on the structure.

US Seismic Zones and Design Considerations

The United States is divided into several seismic zones based on their historical earthquake activity. Building codes in these zones have specific provisions for seismic design, with considerations for slenderness ratio[2] .

- **High Seismic Zones:** In zones with high seismic risk, stricter code requirements exist for high-rise buildings. This may involve limitations on slenderness ratio, use of stiffer structural materials, or implementation of supplemental damping systems to mitigate lateral sway.
- **Moderate Seismic Zones:** In areas with moderate seismic risk, code provisions might allow for higher slenderness ratios compared to high seismic zones. However, engineers may still employ strategies to improve the seismic performance of slender structures.

Research and Knowledge Gaps

While the influence of slenderness ratio on seismic performance is well-established, ongoing research seeks to further refine our understanding:

- **Advanced Seismic Analysis Techniques:** The use of sophisticated computer modeling and finite element analysis can provide deeper insights into the complex behavior of slender high-rises under seismic loads.
- **Material Performance Under Seismic Events:** Understanding the behavior of high-performance concrete, steel, and composite materials used in modern high-rises under realistic seismic scenarios is crucial.
- **Seismic Zone Specific Design Optimization:** Optimizing design practices for high-rise buildings in different US seismic zones based on their unique ground motion characteristics can lead to more efficient and cost-effective structures.

2.1 RESEARCH SIGNIFICANCE:

The growing demand for urban space and architectural innovation has led to the construction of increasingly slender high-rise buildings in order to achieve the following.

- **Improved Seismic Design Guidelines:** This can lead to the creation of seismic design codes that account for the specific vulnerabilities of slender buildings in different threat levels, ultimately leading to safer high-rise construction.
- **Optimizing Structural Systems:** By quantifying the impact of slenderness ratio on seismic performance, engineers can design more efficient structural systems for slender high-rises.
- **Life-Cycle Cost Analysis:** Slenderness can be a cost-effective design choice for maximizing usable space.. Research can establish a clearer cost-benefit relationship between slenderness ratio and seismic performance in different zones. This will allow for informed decisions regarding life-cycle cost optimization during the design phase.
- **Performance-Based Design Approach:** Current seismic design practices often rely on prescriptive code requirements. This research can contribute to a performance-based design approach, where slenderness ratio is explicitly considered in seismic assessments. This allows for a more nuanced design process that optimizes building performance for the specific seismic threat of a given location.
- **Regional Seismic Hazard Mitigation:** The United States encompasses a diverse range of seismic zones. Understanding how slenderness interacts with seismic forces in different zones is crucial for developing targeted regional mitigation strategies. This can inform land-use planning decisions and guide the development of construction practices best suited for the specific seismic threats of a particular region.

3.MATERIALS AND METHODS

Forty, 30, 20, and 10-storey buildings of 3.0 meters in height, the dimensions of the building are variable according to the model case, but the total area is 400m^2 as shown in Figure 1. The material compressive strength of concrete and the yield of steel are f_c’ = 27.5 MPa and fy = 415 MPa, respectively. The Column size is 1200x1200 mm^2, constant for all heights of the model used, but depends on the number of floors. The beam size of 1200x300 mm^2 as an edge beam for the residential building, where Table 1 described the materials specifications and elements dimensions.

Loading Conditions

Total applied loads consist of (a) the self-weight of the slabs, considering the 300-mm slab thickness. (b) floor finish load of 1.5 kN/m^2, (c) wall load of 2.5 kN/m^2; (d) live load of 3 kN/m^2, (e) earthquake loads as per ASCE 7-10 (f) with a response modification factor depends on the system used; (g) importance factor of 1; and (h) damping of 5%.

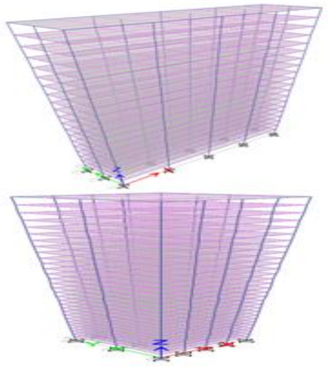

Fig 3: 3D model for models 1 and 4

Table 1: Materials specification and dimensions for members.

Structure	MR Fame-Column
Number of Storey	10-20-30 and 40
Type of building used	Residential
Storey Height	3 m
Grade of Concrete	fcu=27.5MPA
Grade of Steel	Fy=415 MPA
Young's Modulus of Concrete	24855 MPA
Density of Concrete	*25*
Slab Thickness	300mm
Beam Dimensions	300x1200 mm^2
Column Dimensions	1200x1200 mm^2
Bracing Dimensions	Not used
Floor Cover+wall load	4 kN/m^2
Live Load	3 kN/m^2
Seismic Zone	All
Importance Factor	1
Damping	5%
Site Class	D

Table 2: Different seismic zones according to zip code

Seismic Zones UBC 97	0	1	2A	2A	2B	3	4	4 =0.4g
Zip code	33111	80019	30309	2131	89110	98122	90009	94704
City	Miami	Denver	Atlanta	Boston	Las Vegas	Seattle	Los Angeles	Western California
Sa	0.041	0.163	0.188	0.2	0.499	1.34	1.673	2.281
S1	0.02	0.054	0.0904	0.0675	0.164	0.5222	0.6148	0.945
SDS	0.0441	0.17	0.2	0.21	0.46	0.89	1.1	1.52
SD1	0.032	0.087	0.14	0.108	0.23	0.52	0.61	0.945
Seismic Design Category	A	B	B	B	C	D	D	D & E

4.ANALYSIS OF THE RESULTS

As drift is the most important issue in the behavior of high-rise buildings, the study focuses on the relationship between the width and slenderness ratio of the building structure, especially the high-rise, and the allowable drift. Different parameters are also studied, such as base shear and time period, to get a full picture of the true behavior of slender-medium and high-rise building structures.

Table 3: The slenderness ratio for the studied models with different number of storeys.

Number of Stories	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	10x40 m	12x33.33 m	15x26.66 m	20x20 m	5x80 m	7.5x53.33 m
10	3	2.5	2	1.5	6	4
20	6	5	4	3	12	8
30	9	7.5	6	4.5	18	12
40	12	10	8	6	24	16

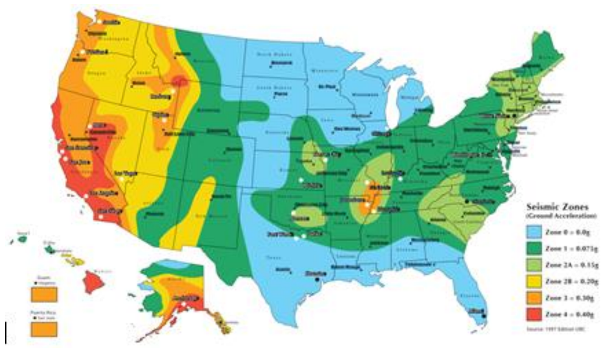

Fig 4.: The United States seismic zones [2]

The different seismic zones used in this study are given in Table 2., where the first row shows the seismic zones due to the Uniform Building Code 97[16}, the second row illustrates the Zip Code of various places and major cities in the United States, although the last row determines the seismic design category according to the ASCE 7-10 [2] from the calculation discussed in the rest rows due to the new calculation of the Seismic design categories, where Sa,S1,SDS,SD1 are factors in the ASCE 7-10 Code.

SD1 = the design spectral response acceleration at a one second period

S1 = the mapped MCE spectral acceleration for a one second period.

SDS = The design spectral response acceleration at short periods

Ss is the mapped maximum considered earthquak .

Seismic Zone 2A (Zip Code 02131 Boston) for 20 Storey, 30 storeys and 40 storeys

First, study the maximum displacement in the x directions for different six cases due to the slenderness ratio of the building, as given in Figure 5.

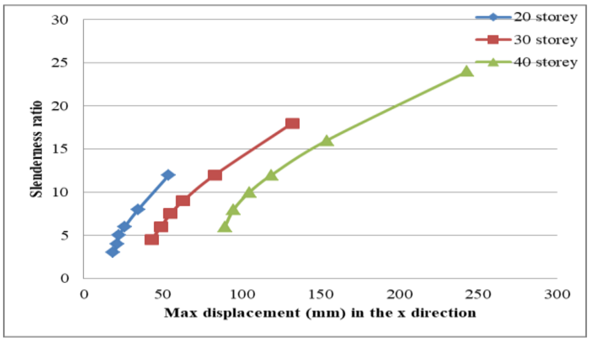

Fig 5: The relation between maximum displacement in the x direction in different storeys and the slenderness ratio

Then, in the Y direction, the values of displacement and drift increased in this axis, as given in Figures 6 and 7.

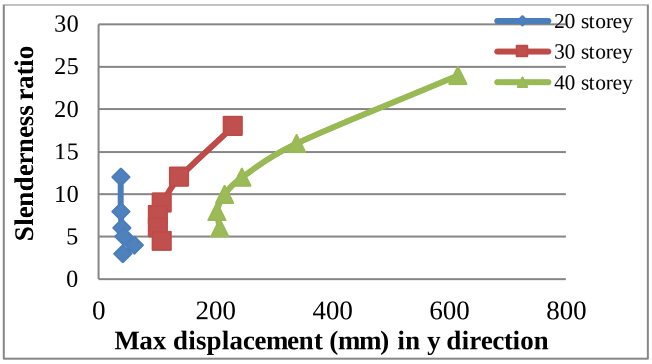

Fig 6: The relation between the maximum displacement in y direction in different storeys and the slenderness ratio

Thus, the maximum drift is in the Y direction and given in figure 6.

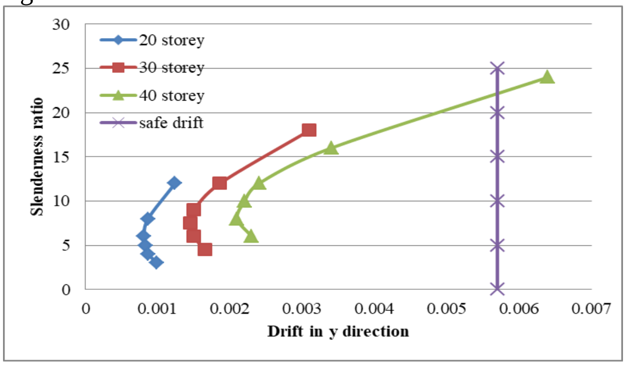

Fig 7: The relation between the maximum drift in the y direction in different storeys and the slenderness ratio

Also, Figure 7 illustrates the allowable drift per ASCE-7-10 [2], showing that, in this seismic zone (2A), all types of building structures from 20 to 40 storeys will be safe for a slenderness ratio of less than 22, although only model 5 will be unsafe in the 40-storey building as its slenderness ratio is 24 > 22. The slenderness ratio of the building structures is a major factor in the maximum drift, which is the main item to investigate the behavior of medium- and high-rise building structures affected by seismic loading.

Figures 8 and 9 show the maximum displacement for the buildings in the x and y directions, although it is higher in the y direction. The displacement decreased from model 1 to model 4 and reached its maximum value with model 5.

Model 5 in Figure 7 illustrates the maximum drift in the y direction for all storey heights.

Seismic zone 2B, (Zip Code 89110, Las Vegas), 20, 30, and 40 storeys.

The second seismic zone is the moderate zone of 2B, which is represented by Las Vegas City buildings of different storeys .

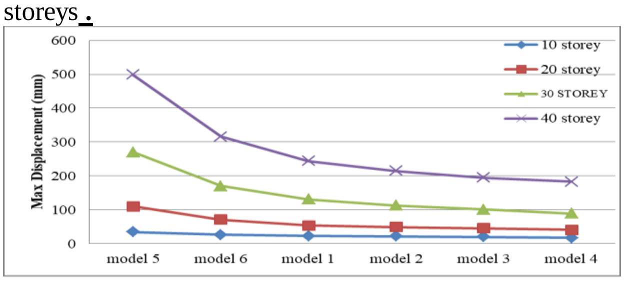

Fig 8: The relation between maximum displacement in the x direction with different models

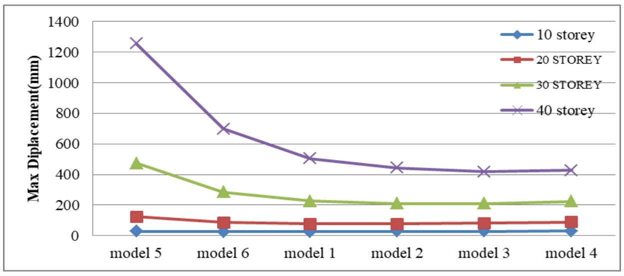

Fig 9: The relation between maximum displacement in the y direction with different models

The maximum displacement in zip code 89110 shows that model 5 has a minimum width of 5.0 m and a high slenderness ratio of 40x3/5 = 24 eq_y = 1257 mm. Also, model 6 has a width of 7.5 m and an eq_y of 707 mm, while models 3 and 4 give the least displacement in eq_x and eq_y of 428 mm. The relation in Figure 8 shows that the maximum displacement is associated with the highest slenderness ratio and the least width of the building structure.

The percentage increase in the maximum displacement and drift from the number of storeys to a higher one is for the maximum value in the case of model 5 with the highest slenderness ratio, as shown in Figures 8 and 9.

The number of storeys in the seismic zone 2A has values in maximum displacement and drift in the low range, although 30 storeys are in the medium range that is accepted for the slenderness ratio, except for the slenderness of 22, and 40 storeys are in the high range that is not accepted by the ASCE-07 for slenderness of less than 13.0.

Figure (10) illustrates that the maximum drift in y-direction is maximum with model 5 and 6 and decreased to be the least values in model 4.

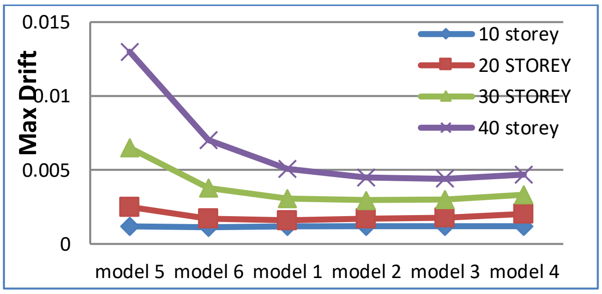

Fig 10: The relation between maximum drift in the y direction with different models

Figure 11 shows the allowable drift for the building structure of 10, 20, and most of the model cases except model 5 of slenderness 24 is within the allowable range, although the 40-storey buildings are within the allowable range for a slenderness ratio of less than 13.

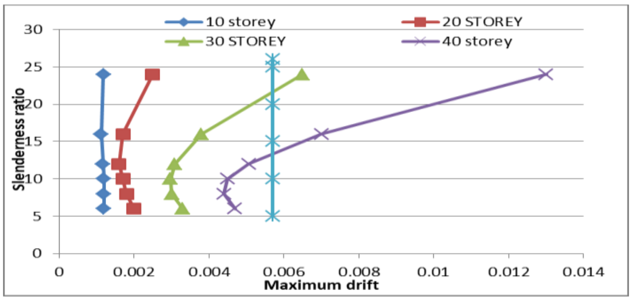

Figure 11: The relation between maximum drift and slenderness ratio for different storeys

Models 5 and 6 had the most displacements for all storey heights, and the values decreased from model 1 until they reached the least value of model 4.

The aspect ratio of the plan model plays an important role in reducing the maximum displacement and drift of the laterally loaded structures.

The maximum displacement in the x direction is nearly 0.4 to 0.8 times the maximum displacement in the y direction.

The ratio of the maximum displacement in the y direction for 4-storey buildings to 30-storey buildings is nearly twice that with all models and reached 2.6 for model 5 with the high aspect ratio.

The ratio of the maximum displacement in the y direction for 40-storey buildings to 20-storey buildings is nearly six times of all models and reached 10 for model 5 with the high aspect ratio.

The ratio of the maximum displacement in the y direction for 40-storey buildings with 10-storey buildings is nearly sixteen times that of most models, and it reached 44 for model 5 with the high aspect ratio.

The maximum displacement increased rapidly as the building increased in height to a value of forty- four times from a 10- to 40-storey building with a high aspect ratio and fourteen times for the best aspect ratio of model 4.

Seismic zone 3, zip code 98122 Seatle, 20, 30, and 40 Storeys

The maximum displacements increase rapidly in Model 5 for the x and y directions, as shown in Figures 12 and 13. The displacements are more in the y direction for all models' cases.

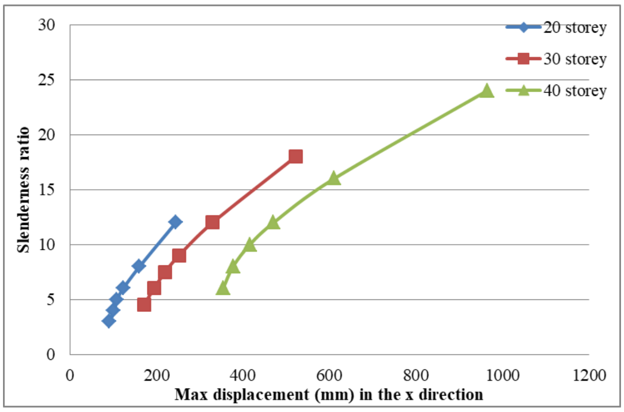

Fig 12: The relation between maximum displacement in the x direction in different storeys and the slenderness ratio.

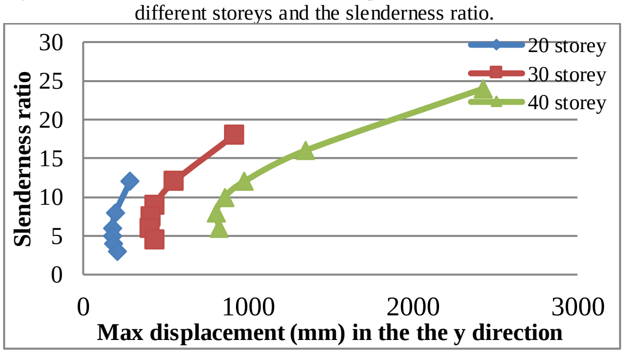

Fig 13: The relation between maximum displacement in the y direction in different storeys and the slenderness ratio

The 20-storey building structure is within the allowable range for all the model cases as shown in Figure 14 for the 20-storey building, although the 30-storey building is within the allowable range for only the slenderness ratio between 6 and 9. But the 40-storey building is out of the safe drift range.

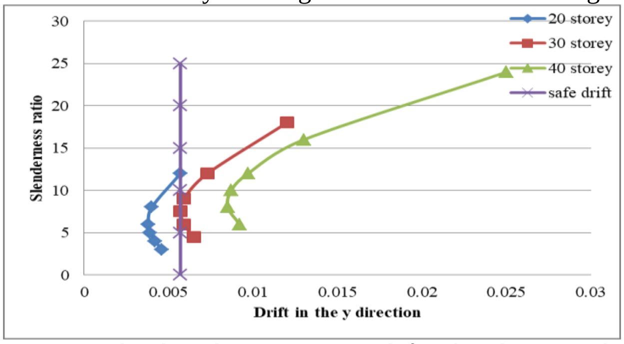

Fig 14: The relation between maximum drift in the y direction with slenderness ratio

The seismic zone 3 in the United States is represented by 4 different types and number of storeys: 10, 20, 30, and 40 storeys. The maximum displacements are computed for both the x and y directions and thus the drift for the y direction (the most critical) is calculated as shown in Figure 15.

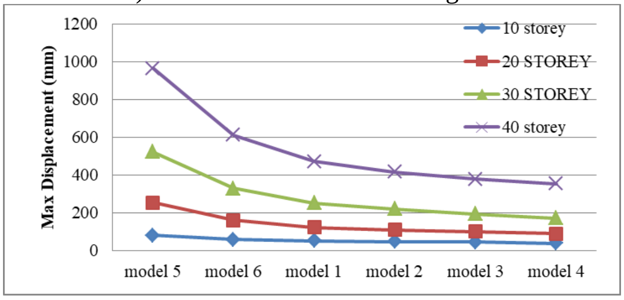

Fig 15: The relation between maximum displacement in x direction with different models

For zip code 9812, it was found that the aspect ratio of model three gives the least maximum displacement.

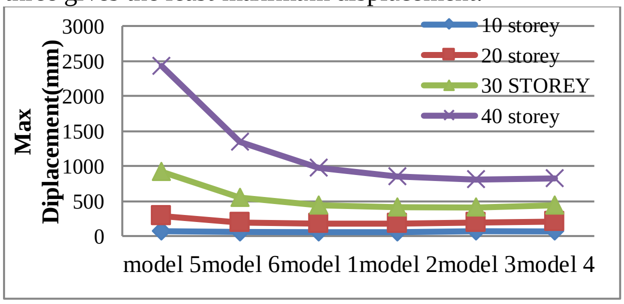

Fig 16: The relation between maximum displacement in the y direction with different models.

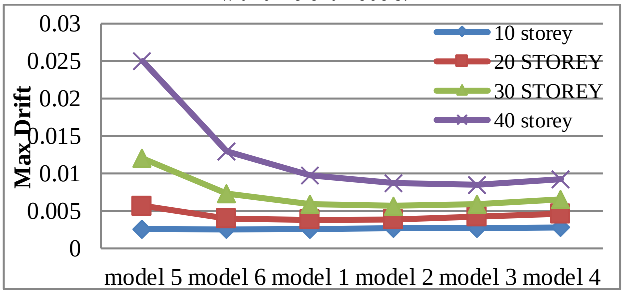

Fig 17: The relation between maximum drift in the y direction with different models

The drift behaves in the same manner as the maximum displacement; model 3 is the only safe drift model in both the

x and y directions, although model 5, with the maximum slenderness ratio, is the worst drift in both directions.
The drift in the y direction is safe in the 10-storey building and nearly in the 20-storey building, as is the case in Model 5 of the most slenderness ratio, while high-rise structures for 30 and 40-storeys are above the allowable drift limit, as shown in Figure 17.
If the maximum allowable displacement is considered to be height/500, then the 10-storey building is only less than the allowable, and the 20-storey building in the x direction only for models 1 until 4 is less than the allowable.
The maximum drift is shown very clearly for models 5 and 6 in Figure 3, and the divergence increases for 30- and 40-storey buildings The minimum drift is found in models 1 through 4.
As given in figure (16) ,the ratio of the maximum displacement in the y direction for 40-storey buildings to 30-storey buildings is nearly twice that with all models and reached 2.6 for model 5 with the high aspect ratio
The ratio of the maximum displacement in the y direction for 40-storey buildings to 20-storey buildings is nearly five times that of all models and reached 8.5 for model 5 with the high aspect ratio.
The ratio of the maximum displacement in the y direction for 40-storey buildings with 10-storey buildings is nearly fourteen times that of most models, and it reached 38 for model 5 with the high aspect ratio.
The maximum displacement increased rapidly as the building increased in height to a value of thirty-eight times from a 10- to 40-storey building with a high aspect ratio and 12.6 times for the best aspect ratio of model 4. Figure 6 shows that the slenderness ratio of 8 in model 3 gave the least drift for all types and heights of building structures.

Base shear

For 40-storey building structures, the base shear increases as the seismic zone increases, as the author has for zip code 02131. The base shear is 1885 kN and increases rapidly to 3863, nearly double for zone 89110, and 7464 for seismic zone 98122, nearly four times. This ratio is approximately equal in all six model cases. The author can conclude that the base shear value is doubled from a lower seismic zone to the next upper seismic zone. Figure 18 illustrated the base shear for the 40 storey buildings.

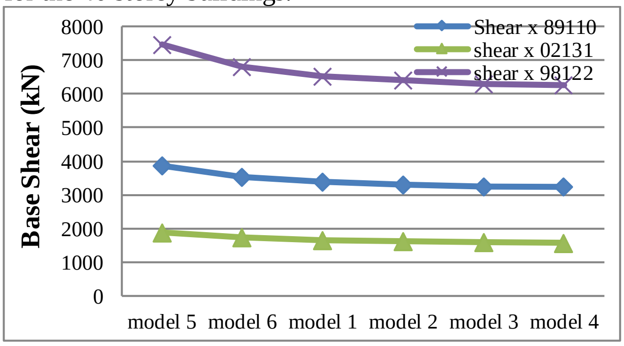

Fig 18: The relation between base shear and different models in various seismic zones (40-storey buildings)

Figure 19 shows the seismic zone (2A) zip code 02131, and the base shear is calculated for the model cases for the 20, 30, and 40-storey buildings. It is quite clear that model 5 with a high slenderness ratio has the highest base shear, and it decreases as the slenderness ratio decreases.
From Figure 18, it is clear that the base shear decreases as the width of the building increases in all seismic zones. As in Seismic Zone 2B, for model 5 (width 5.0 m), the base shear was 3863 kN, while for model 4 (with 20.0 m), the base shear was 3237 kN.

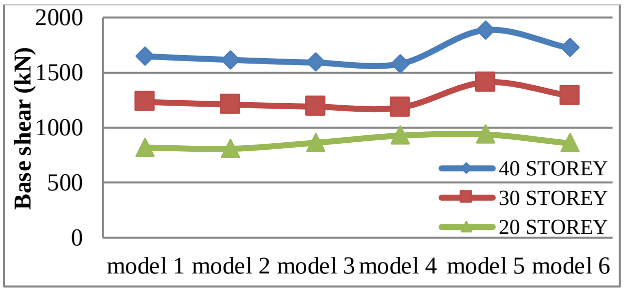

Fig 19: The base shear of different models and storeys

Time period

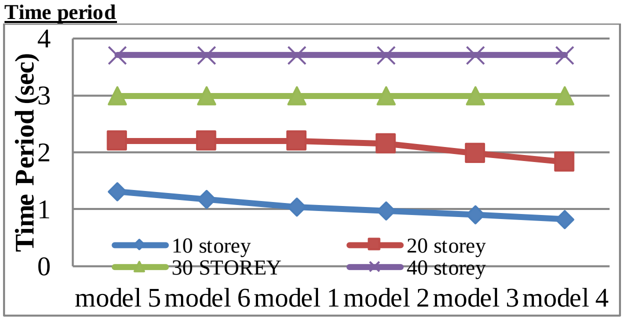

Fig 20: Time period Tx for different storeys with zip code 98112

The time period increases in Figure 20 as the height increases, as in the equation for calculating the time period. The time period decreases as the slenderness ratio decreases for the 10- and 20-storey buildings, although for the 30- and 40- storey buildings, it is kept constant for all model cases of different slenderness ratios.

Pushover analysis

Pushover analysis is a computational technique used to evaluate the **nonlinear** behavior of a structure subjected to lateral loads, typically earthquake forces. It's a static analysis, meaning it doesn't consider the dynamic effects of an earthquake, but provides valuable insights into a structure's capacity and potential failure mechanisms.

The results of the pushover analysis are typically presented as a pushover curve, which plots the **base shear** (total lateral force resisting collapse) against the **roof displacement** (horizontal movement of the top floor). The pushover curve provides valuable information about the structure's capacity, stiffness, and potential failure modes.

Moment Resisting Frame (MRF) Behavior

Moment resisting frames (MRFs) are structural systems where beams and columns are specifically designed to resist bending moments (moments that cause elements to bend). They achieve this resistance through rigid connections between beams and columns, allowing them to transfer moments effectively.
Here are some key characteristics of MRF behavior:

- **Lateral Load Resistance:** MRFs primarily resist lateral loads (wind, earthquake) through bending moments in beams and columns. Beams act like levers, transferring forces to columns, which ultimately transfer them to the foundation.
- **Ductility:** MRFs can exhibit a relatively ductile behavior under lateral loads. Beams and columns can develop plastic hinges at locations of high moment concentration. These hinges allow for controlled deformation (bending) before failure, providing some energy dissipation and warning signs of structural distress.
- **Stiffness and Strength:** The stiffness and strength of an MRF depend on the size and material properties of its beams and columns. Stronger and stiffer elements can resist larger loads and deformations.

In summary, pushover analysis helps us understand the overall behavior of a structure under lateral loads. MRFs offer good strength and some ductility,

Selecting the right combination of these elements in a building design depends on factors like seismic hazard, architectural requirements, and desired performance objectives.

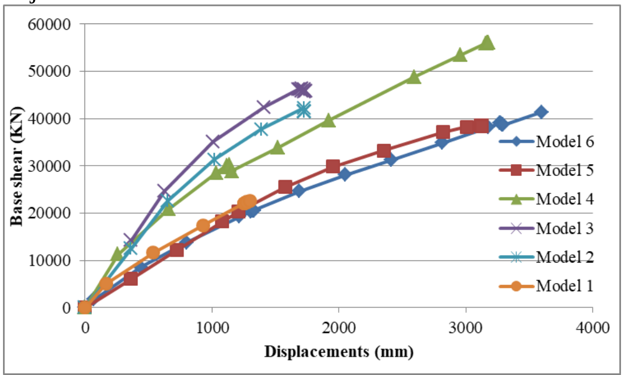

Fig 21: The relation between base shear and maximum displacements in Pushover analysis in X direction.

Pushover in x direction model 3 and model 2 in Figure21 had the least displacements of about 1700 mm although the rest models the displacements ia about from 3200-3600.

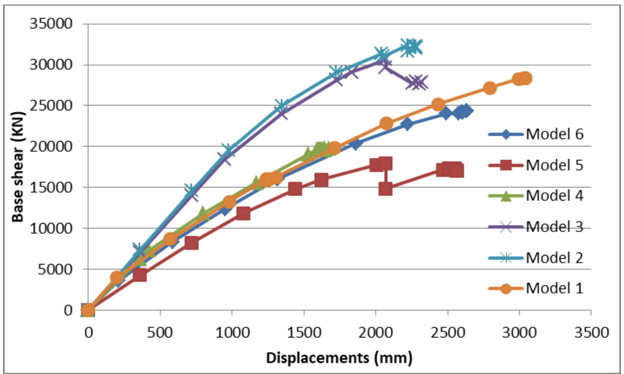

Fig 22: The relation between base shear and maximum displacements in Pushover analysis in Y direction.

Pushover in Figure 22 in y direction is least in base shear for model 5 of maximum plan aspect ratio of 16 and maximum slenderness ratio and the model 6 is next. Although the displacements were in between 2300mm and 3000 mm.

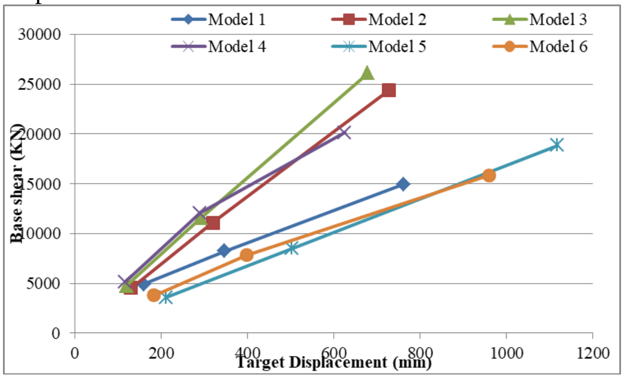

Fig 23: The relation between base shear and Target displacements in Pushover analysis in X direction in various seismic Zones.

The relation between the base shear and the target displacement is nearly linear in most cases for the three seismic zones studied in Figures 23 and 24. Model 5 &6 had the least base shear in all seismic zones.

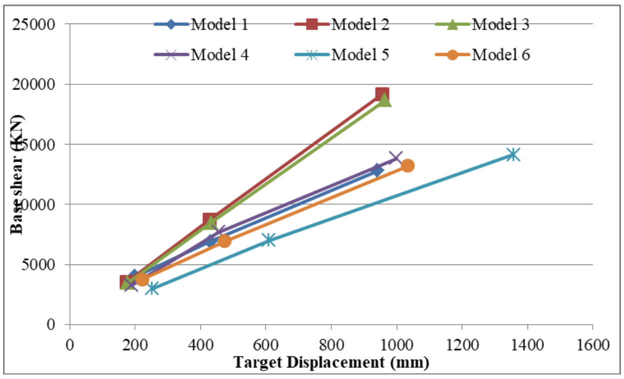

Fig 24: The relation between base shear and Target displacements in Pushover analysis in Y direction in various seismic Zones.

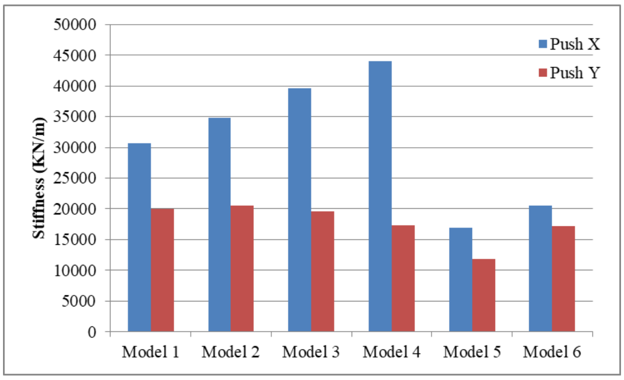

Fig 25: The effective stiffness for all models in Pushover in both X and Y directions.

The effective stiffness increases in x direction from the least from model 5 till model 4 as the slenderness ratio decreased. Although the y direction the same manner but of less values. Figure 25 illustrated this stiffness.

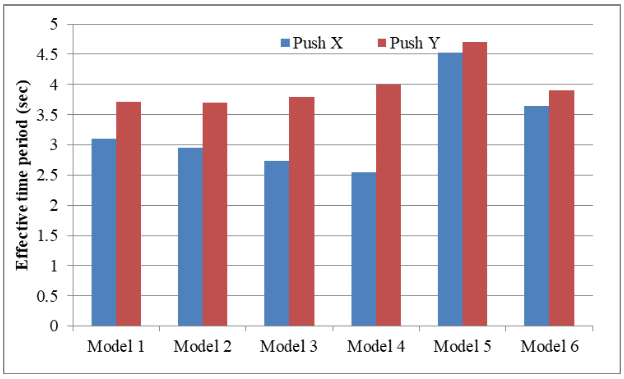

Fig 26: The effective Time period for all models in Pushover in both X and Y directions

The effective time period is plotted in Figure 26 in both direction is maximum in the case of model 5 of maximum slenderness ratio and decreases with the decrease of aspect ratio in plan .

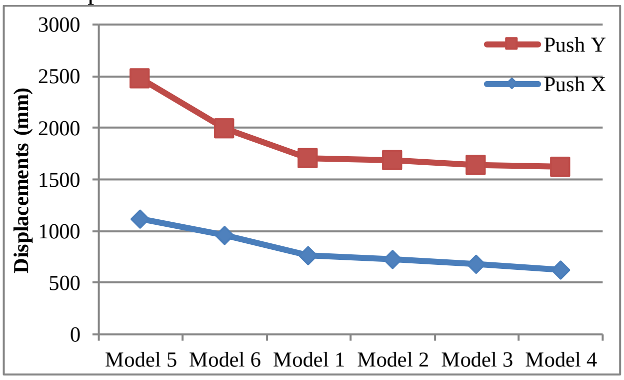

Fig 27: The displacements for all models in Pushover in both X and Y directions in seismic zone 3

For the seismic zone 3 the displacements are as shown in Figure 27 decreased from the maximum at model 5 of the most high slenderness value and decreased to model 4 of the least value.

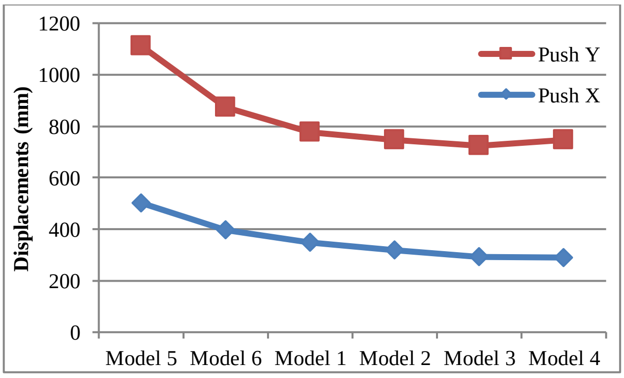

Fig 28: The displacements for all models in Pushover in both X and Y directions in seismic zone 2B

For the seismic zone 2B the displacements are as shown in Figure 28 decreased from the maximum at model 5 of the most high slenderness value and decreased to model 4 of the least value as the Zone 3.

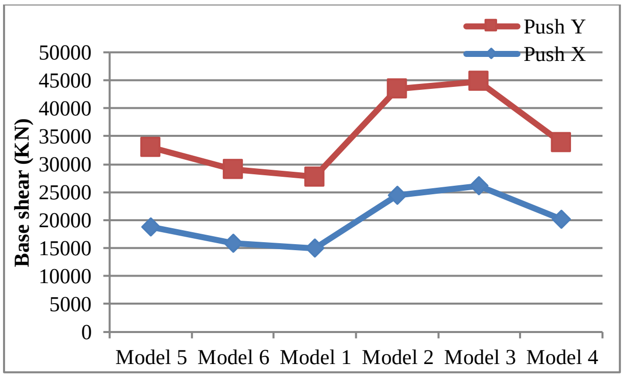

Fig 29: The Base shear for all models in Pushover in both X and Y directions in seismic zone 3.

Both seismic zones 3 and 2B had nearly the same behavior with respect to base shear as the base shear have a least value in the models of high slenderness ratio and increased as shown in Figures 29 and 30.

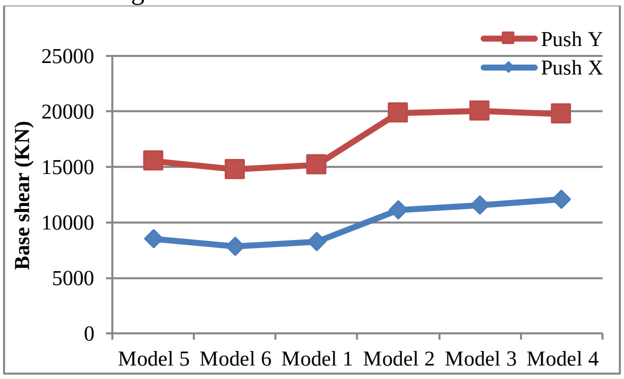

Fig 30.: The Base shear for all models in Pushover in both X and Y directions in seismic zone 2B.

5.CONCLUSIONS

<u>For zip codes 02131, 89110, and 98122</u>,

1-The 40-storey building with a slenderness ratio of 8 gave the smallest drift, while the 30-storey structure with a slenderness ratio of 10 gave the smallest drift, and the 20-storey reported 12 slenderness ratios, and the 10-storey monitored 16 slenderness.

2-The minimum drift for all models occurred at a 16-slenderness ratio with the 10-storey model and decreased up to 8 for the 40-storey structures, which means that the minimum drift at a certain slenderness ratio decreased as the height of the structure building increased.

3-From the previous analysis, it is clear that the seismic zone did not affect the relationship between the slenderness ratio and the number of storeys.

4-A relation between the height of the building structure and the slenderness ratio to achieve the least drift for any structure building for seismic zones 2A, 2B, and 3 is done in this study.

5-This study predicts the best width of any building structure to achieve the least drift and maximum displacement for the studied tall building structures. Drift and maximum displacement can be considered the main items in the analysis and design of any tall building.

6-Although the reduction of the drift is not essential for buildings of 10 storeys or less, the drift and displacement are within the acceptable range.

7-Seismic zone 2A, in the United States, is safe for building structures up to 40 storeys with 120 m in height due to a slenderness ratio of not more than 22. Exceeding the slenderness ratio of 22. The increase of the slenderness ratio greater than 22, gives maximum drift not permitted by ASCE-07.The base shear increased rapidly from low seismic zones to higher ones (2A-2B-3), and the increased values doubled from the seismic zone to the next one.
8-The base shear increases as the slenderness ratio increases in all seismic zones and building structures' heights.
9-Pushover analysis confirmed and verified the conclusions of this study by the nonlinear analysis technique.
10-Further studies should be implemented to investigate the behavior of steel and composite structures with different systems for both medium- and high-rise buildings.
11-Further investigations are required for the effect of wind loading on medium- and high-rise buildings and its relation to the slenderness ratios.

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