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Seismic Performance Assessment of Regular and Irregular RC Buildings Under BNBC 2020 Using ETABS

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ABSTRACT

Seismic performance analysis is crucial to guaranteeing the structural safety of buildings, particularly in seismic-prone locations. This study examines the seismic performance of reinforced concrete (RC) structures with regular and irregular plan forms using ETABS v17 and the Equivalent Static Force Procedure (ESFP) based on the Bangladesh National Building Code (BNBC) 2020. This study focuses on the major earthquake characteristics such lateral displacement, story drift, base shear, torsional irregularity, and overturning moment. Seven alternative plan forms, including rectangle, square, T, U, W, H, and L-shaped structures, were examined to assess the impact of geometric imperfections on seismic response. The results demonstrate that irregular structures endure substantially greater lateral displacement and story drift than regular designs, particularly above the seventh story, which renders them more sensitive to seismic activity. The W-shaped structure maintained the largest base shear, but torsional irregularity was more noticeable in T, U, and H-shaped structures, showing their sensitivity to rotational impacts. Overturning moment study also suggested that irregular structures are more sensitive to instability induced by non-uniform distribution of pressures. All these discoveries underscore the requirement of optimal structural design, superior lateral load-resisting systems, and suitable reinforcing to limit seismic threats. The study emphasizes the need for compliance with seismic design codes and recommends that the incorporation of shear walls, bracing systems, and moment-resisting frames would be able to improve seismic strength. Future research should take into account sophisticated nonlinear dynamic analysis and retrofitting solutions to further increase the seismic resilience of irregular high-rise buildings.

Keywords: Seismic Load, Plan Irregularity, Lateral Load, BNBC, ETABS

INTRODUCTION

Seismic performance is governed by structural stiffness, lateral strength, ductility, and geometric regularity [1]. Irregular constructions with plan and vertical irregularities interfere with the continuity of the load path, leading to stress concentrations and torsional effects, therefore becoming more sensitive to earthquake-induced damage [2], [3]. Irregular constructions, as stated by Chopra [4], have uneven mass distribution, which results in higher torsional response and displacement demand. The Bangladesh National Building Code (BNBC) [5] gives recommendations to avoid these consequences by adopting more strict seismic design guidelines for irregular structures.

There are several investigations that have evaluated the dynamic performance of irregular structures. Valmundsson and Nau [6] established that stiffness and mass eccentricities in buildings contribute to higher base shear and inter-story drift. Herrera and Soberon [2] have proved that asymmetric floor layouts have a large influence on the distribution of the lateral stress, such that specific parts become more prone to seismic collapse. These findings underscore the necessity for robust lateral-load-resisting devices in irregular buildings.

Irregular designs such as T, L, H, U, and W-shaped structures increase torsional irregularity, which leads to larger lateral displacements and inter-story drifts compared to regular designs [7]. Mohod [8] revealed that irregular structures have bigger overturning moments; ergo, they are more prone to collapse. Similarly, Kabir et al. [9] evaluated the seismic performance of regular and irregular multi-story structures, revealing that regular, symmetrical structures had higher energy dissipation.

Research by Sreenath et al. [10] measured the stress concentration impact at reentrant corners and suggested ideal placement of shear walls for maximal performance. This research collectively proves that irregular structures require greater lateral bracing in order to lessen seismic risk.

Torsional effects emerge when the center of mass and center of stiffness do not coincide, causing unequal displacements across the building design [4]. The BNBC [5] deems a building to be torsionally irregular when its greatest inter-story drift is larger than 1.2 times the average drift. Gaurav Kumar et al. [7] showed that base shear demand is larger with increasing mass-stiffness eccentricity, thereby demanding the strategic deployment of lateral resisting components.

Rathi and Raut [11] evaluated the influence of re-entrant corners and setbacks on seismic performance, showing that torsional abnormalities can be avoided by bracing and shear walls. Similarly, ASCE/SEI 7-16 [12] gives solutions to decrease torsional impacts using robust diaphragm connections and mass balance methods.

Seismic analysis methodologies vary from linear static to nonlinear dynamic studies. The Equivalent Static Force Procedure (ESFP) is one well-accepted approach for estimating base shear and lateral displacement in low- to mid-rise buildings [13]. However, the research suggests that ESFP cannot capture complicated dynamic responses in irregular structures [14].

Research integrating response spectrum analysis (RSA) and time-history analysis (THA) suggests that nonlinear deformations and higher-mode effects considerably damage irregular buildings [15]. Sullivan et al. [16] demonstrated that THA delivers a more accurate depiction of torsional effects and inter-story drifts, underlining its potential in appraising irregular structures.

Even with substantial study on plan faults and seismic performance, few data are available on irregular RC structures under BNBC 2020 rules. Most research depends on basic static approaches, whereas sophisticated dynamic analysis utilizing recent software (ETABSv17) is not yet completely investigated. The aim of this study is to make an effort in comparing the seismic response of T, L, H, U, and W-shaped irregular and regular buildings, approximating significant parameters such as lateral displacement, drift, base shear, and torsional irregularity, and providing design ideas in an effort to enhance seismic resistance for BNBC 2020. By the combination of BNBC 2020 criteria with analysis using ETABS, this study helps seismically secure Bangladesh, particularly irregular tall structures.

MATERIALS AND METHODS

METHODS OF SEISMIC ANALYSIS

This study employs the Equivalent Static Force Procedure (ESFP) as prescribed in the Bangladesh National Building Code (BNBC) [5] to assess the seismic performance of regular and irregular building layouts. The ESFP is a simplified linear static technique ideal for low to medium-rise buildings, allowing a realistic computation of seismic forces. While more advanced methodologies like as response spectrum analysis and time history analysis can provide more complete insights into dynamic behavior, the ESFP offers a practical means for comparative study, particularly in the context of initial design stages and code compliance checks.

The ESFP involves the computation of the base shear force dependent on the seismic zone, site class, building period, and response modification factor. This base shear is then extended vertically across the building height to determine the lateral pressures at each floor level. The displacement requirement is later assessed and checked against the code-specified constraints to preserve structural integrity.

The displacement constraints defined in the BNBC 2020 [5] are as follows:

For fundamental period (T) < 0.7 seconds: $\Delta < 0.04h/R < 0.005h$

For fundamental period (T) ≥ 0.7 seconds: $\Delta < 0.03h/R < 0.004h$

Where:

- Δ = Design story drift
- h = Building height
- R = Response modification coefficient
- T = Fundamental period of vibration

This study employs ETABS v17 software for structural modeling and analysis. The input parameters for the ESFP are shown in Table 1.

Table 1. Necessary data for static load analysis

Parameters	Specification
Seismic Zone	Zone-01
Zone Coefficient	0.12
Site Class	SD
Response Modification, R	5.0
Occupancy importance	1

BUILDING PARAMETERS AND MODELLING

The structural models reflect 11-story (G+10) reinforced concrete structures situated in Rajshahi, Bangladesh, which falls inside seismic zone-I as per BNBC 2020 [5]. The site class is believed to be SD, suggesting a soil profile with loose to medium cohesionless or soft to firm cohesive soils up to 30 meters.

The study evaluates the seismic response of both regular and irregular building designs. Regular structures are represented by rectangular and square plan types, whereas irregular buildings include W, U, L, T, and H-shaped designs. The floor sizes of all models are preserved as closely as feasible to around 6400 sq. ft. to offer a fair comparison.

The structural models were created using reinforced concrete (RC), with material characteristics set based on BNBC 2020 requirements. The concrete employed in the analysis has a compressive strength (f'c) of 4000 psi, whereas the reinforcing steel has a yield strength (fy) of 60,000 psi. Slab components were developed with a thickness of 6 inches, while beam and column diameters were established to guarantee acceptable lateral and gravity load resistance. The material characteristics are presented in Table 3.

The structural dimensions and material qualities are similar across all models. The bay measurements are 20 ft in both the X and Y directions, with a floor height of 10 ft and a foundation bed level of 8 ft. The structural dimensions are as indicated in Table 2.

Table 2. Structural dimensions

Component	Specification
Lateral Dimension of Bay	20 ft
Number of Stories	G+10
Floor Height	10 ft
Foundation Bed Level	8 ft
Column Size	20 in x 20 in
Beam Size	18 in x 12 in
Slab Thickness	6 in

Table 3. Material properties and loads

Parameter	Specification
Concrete Strength (f'c)	4000 psi
Steel Yield Strength (fy)	60000 psi
Floor Finish	30 psf
Partition Wall Load	450 plf (5-inch)
Live Load	50 psf

LATERAL LOAD-RESISTING SYSTEM

To withstand seismic stresses, moment-resisting frames (MRFs) were adopted as the major lateral load-resisting mechanism in all models. The frames were built to offer ductility and energy dissipation, following BNBC 2020 seismic design criteria. Since irregular constructions are prone to torsional effects, additional lateral stiffness was supplied by inserting shear walls at important spots. The positioning of shear walls was improved to limit eccentricity and alleviate excessive lateral displacement.

In addition to moment frames and shear walls, column-beam joint design was carefully examined to optimize load transfer efficiency under seismic stresses. The frame parts were modeled as rigid connections, assuming complete moment transmission at joints.

GRAVITY LOAD-RESISTING SYSTEM

The gravity load-resisting system includes of slabs, beams, and columns intended to efficiently transmit vertical loads from the superstructure to the base. The floor system is represented as a two-way slab supported by beams, ensuring appropriate load distribution. The columns transmit axial loads down to the foundation, with their cross-sections optimized to resist buckling under combined gravity and lateral stresses.

The gravity load route is as follows:

- Slabs transfer living and dead loads to the supporting beams.
- Beams distribute the loads to the columns.
- Columns transmit the complete structural weight down to the foundation.

The foundation system was considered to be a rigid fixed base, omitting soil-structure interaction effects in this investigation. However, further investigation integrating soil flexibility might give further insights into the real earthquake reaction.

LOAD CONSIDERATIONS AND COMBINATION

The seismic analysis contains load combinations as required by BNBC 2020 [5], including dead load (DL), live load (LL), wind load (Wx, Wy), and earthquake load (EQx, EQy). The load combinations employed in this investigation are presented in Table 4.

Table 4. Material properties and loads

SL No.	Combination	SL No.	Combination
1.	1.4DL	17.	1.254D-EQx+0.30EQy+1.0L
2.	1.2DL+1.6L	18.	1.254D+EQy-0.30EQx+1.0L
3.	1.2DL+LL	19.	1.254D+EQy-0.30EQx+1.0L
4.	1.2DL +0.8Wx	20.	1.254D-EQy+0.30EQx+1.0L
5.	1.2DL-0.8Wx	21.	0.9DL+1.6Wx
6.	1.2DL+0.8Wy	22.	0.9DL-1.6Wx
7.	1.2DL-0.8Wy	23.	0.9DL+1.6Wy
8.	1.2 DL+1.6Wx+LL	24.	0.9DL-1.6Wy
9.	1.2 DL-1.6Wx+LL	25.	0.846D+EQx-0.30EQy
10.	1.2 DL+1.6Wy+LL	26.	0.846D-EQx+0.30EQy
11.	1.2 DL-1.6Wx+LL	27.	0.846D+EQy-0.30EQx
12.	1.254D+EQx+0.30EQy+1.0L	28.	0.846D-EQy+0.30EQx
13.	1.254D-EQx-0.30EQy+1.0L	29.	0.846D-EQx-0.30EQy
14.	1.254D+EQy+0.30EQx+1.0L	30.	0.846D+EQy+0.30EQx
15.	1.254D-EQy-0.30EQx+1.0L	31.	0.846D-EQy-0.30EQx
16.	1.254D+EQx-0.30EQy+1.0L		

MODELING AND VISUALIZATION

The structural models were developed and evaluated using ETABS v17. Plan views and 3D structural views of the models are provided in Figures 1 and 2, respectively.

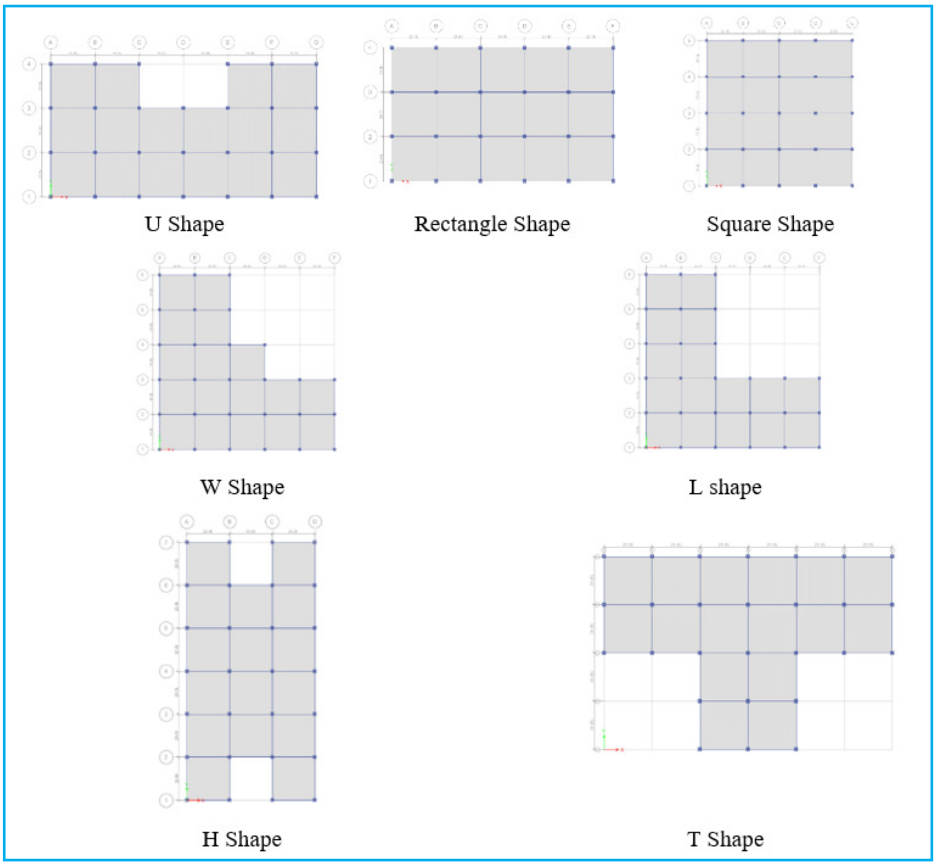
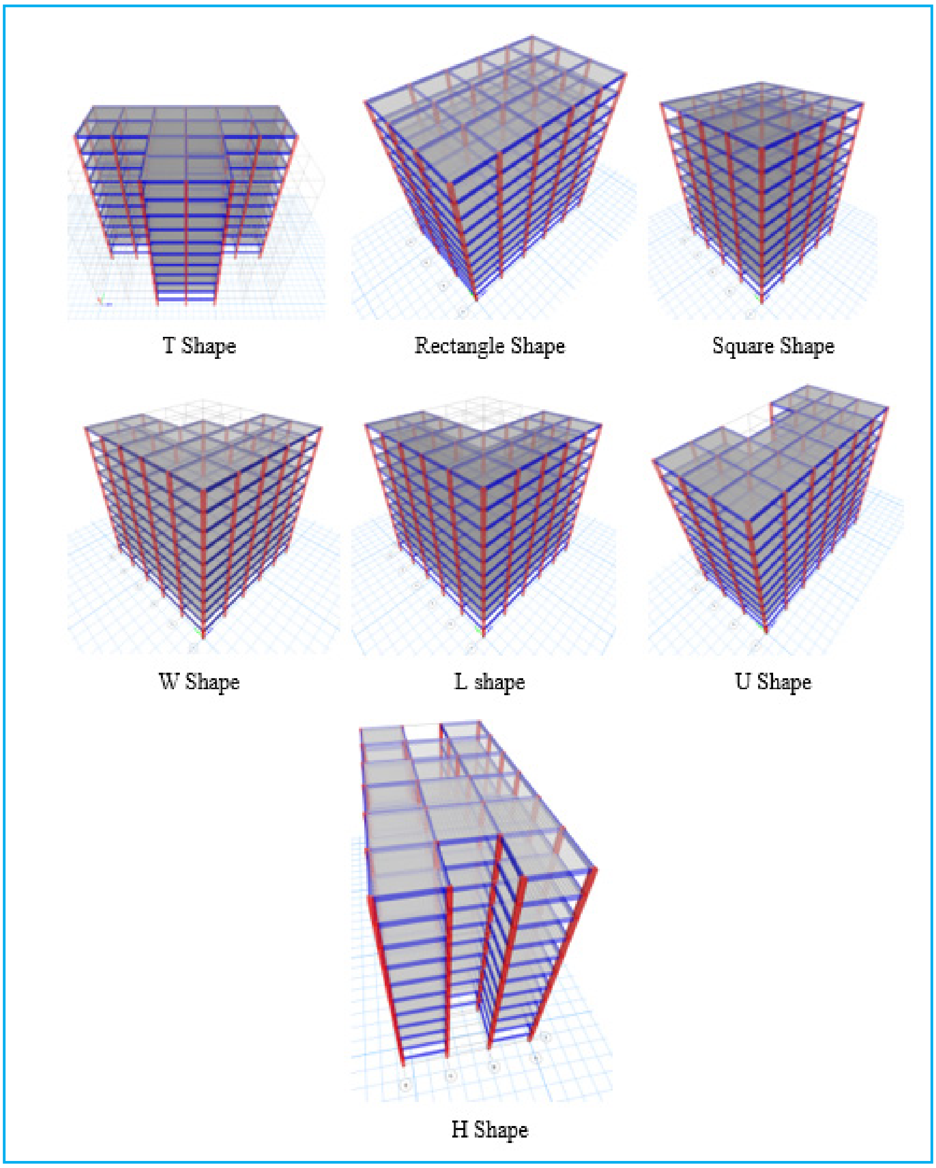

U Shape
Rectangle Shape
Square Shape
W Shape
L shape
H Shape
T Shape

Figure 1. Plan view of the models



T Shape Rectangle Shape Square Shape

W Shape L shape U Shape

H Shape

Figure 2. 3D Structural view of the models from ETABS

RESULT AND DISCUSSION

LATERAL STOREY DISPLACEMENT

Lateral story displacement, which measures the horizontal movement of building levels under seismic loads, is a critical factor in evaluating structural performance and stability. Seismic forces induce inertia-driven displacements, causing relative movement between adjacent stories. This research examines lateral displacements along both the X and Y axes for different structural configurations, as illustrated in Figures 3 and 4.

According to the Bangladesh National Building Code (BNBC) [5], the maximum allowable lateral displacement for a structure is limited to 1/500th of the total building height. In this study, for a 10-story building (120 feet or 1440 inches high), the maximum permissible displacement is computed as 2.88 inches (1440 inches/500). However, considering the foundation bed level, this value is adjusted to approximately 2.4 inches. Table 5 presents the lateral displacement values at the 10th story for each building type in both X and Y directions.

Table 5. Lateral displacement at 10th storey in X and Y direction

Direction	Storey	TB	WB	LB	RB	SQB	UB	HB	Permissible Maximum Displacement
X	10th	2.772	2.785	2.986	0.388	1.675	2.798	2.993	2.4
Y	10th	2.966	2.785	2.986	0.822	1.675	2.398	2.569	2.4

As illustrated in Figure 3, irregular-shaped structures (T, W, L, H, and U-shaped buildings) exceed the permissible lateral displacement limit in the X direction, with deviation occurring from the 7th story onward. In the Y direction (Figure 4), the T, W, and L-shaped structures similarly exceed the limit from the 7th story, while the H-shaped structure surpasses it at the 8th story. Notably, the U-shaped structure remains within the allowable limit up to the 10th floor. The H-shaped structure experiences the highest displacement in the X direction, while the L-shaped structure undergoes the greatest displacement in the Y direction. Conversely, the rectangular building (RB) exhibits the least displacement in both directions, reinforcing the notion that regular structures perform better in resisting seismic loads.

These findings emphasize the significant influence of building geometry on lateral displacement during seismic events. Irregular structures, particularly those with re-entrant corners or asymmetrical mass distribution, tend to experience larger displacements due to enhanced torsional effects and stress concentrations [9], [7]. This aligns with previous research, which has demonstrated that buildings with plan irregularities experience greater lateral movement and deformation due to uneven stiffness distribution [4]. Chopra [4] highlighted that irregular structures exhibit larger torsional loads, resulting in increased lateral displacement and higher structural vulnerability.

Furthermore, Rathi and Raut [11] found that irregular mass and stiffness distributions in asymmetrical buildings exacerbate lateral displacement trends, making such buildings more susceptible to seismic forces. Similarly, Fajfar [17] emphasized the necessity of accounting for nonlinear behavior and displacement demands in seismic design, especially for irregular structures. Previous studies also highlight that stress concentrations at reentrant corners of L and T-shaped buildings create localized weaknesses, leading to increased displacement and drift [10], [6].

The fact that the U-shaped structure remains within permissible limits suggests that certain irregular geometries can still achieve acceptable seismic performance if properly designed with appropriate lateral load-resisting elements [2]. However, the overall trend underscores the need for a more careful evaluation of irregular shapes in seismic design, particularly in high-seismicity regions.

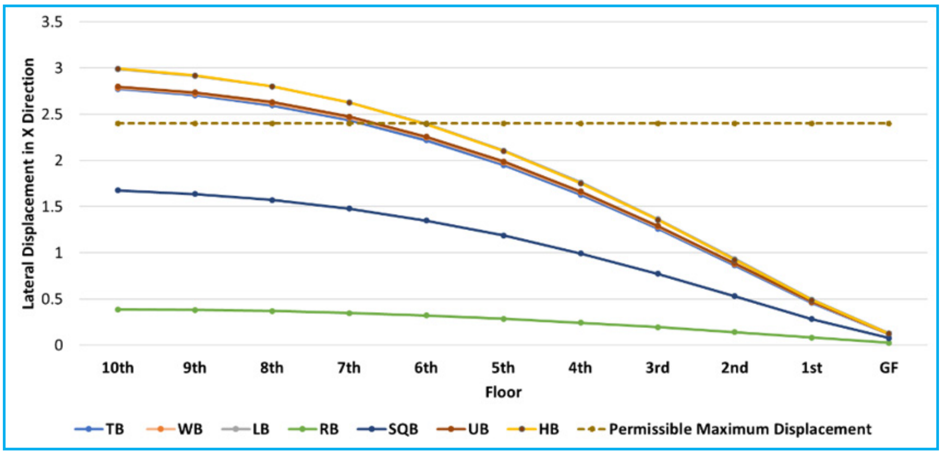


Figure 3. Lateral displacement in X direction

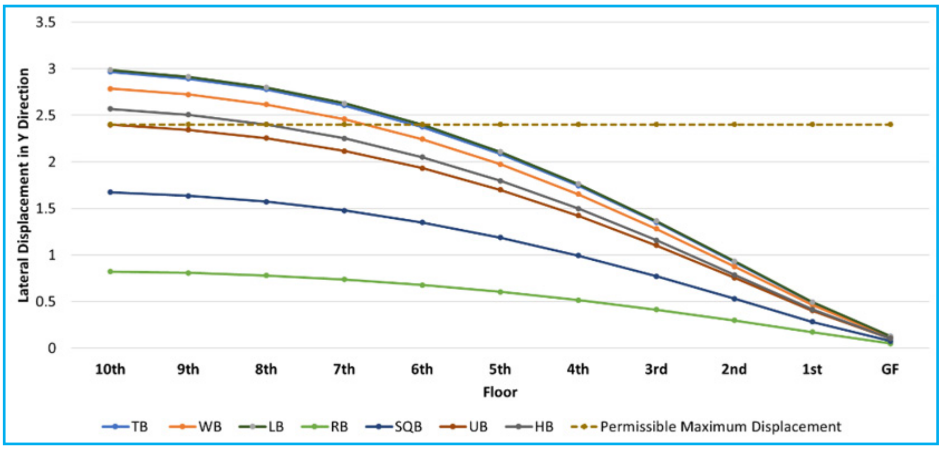


Figure 4. Lateral displacement in Y direction

STOREY DRIFT DUE TO SEISMIC LOAD

Story drift, defined as the relative displacement between adjacent floors during seismic or lateral loads, is a vital indication of structural performance and possible damage. It directly represents a building's ability to disperse seismic energy without incurring severe deformation. The amount of story drift is controlled by various elements, including the strength of seismic pressures, structural height, stiffness, plan design, and dynamic features such as natural frequency, damping, and mode shapes [17], [4].

Story drift is often stated as a ratio of inter-story displacement to story height. For example, a drift ratio of 0.005 means that the relative displacement between two neighboring floors equals 0.5% of the story height. Building codes and seismic design standards, such as the Bangladesh National Building Code (BNBC) [5], prescribe maximum permitted drift restrictions to preserve structural integrity and prevent severe damage to non-structural components. According to BNBC [5], the maximum permissible story drift for this study is 0.020 × hsx, where hsx indicates the story height below level x.

Figures 5 and 6 depict the story drift profiles in the X and Y directions for various building layouts. The H- and L-shaped structures displayed the maximum drift at the second level in the X direction (Figure 5), while the L-shaped structure recorded the highest drift in the Y direction (Figure 6). In contrast, the rectangular building (RB) consistently demonstrated the lowest drift values in both directions. The reported results accord with prior studies, indicating that plan imperfections strongly impact lateral deformation patterns. Structures with re-entrant corners and asymmetric mass distribution display greater story drift due to the amplification of torsional effects and stress concentrations [6], [7]. Fajfar [17] highlights that irregular structures require particular seismic details to avoid excessive drift and torsional instability.

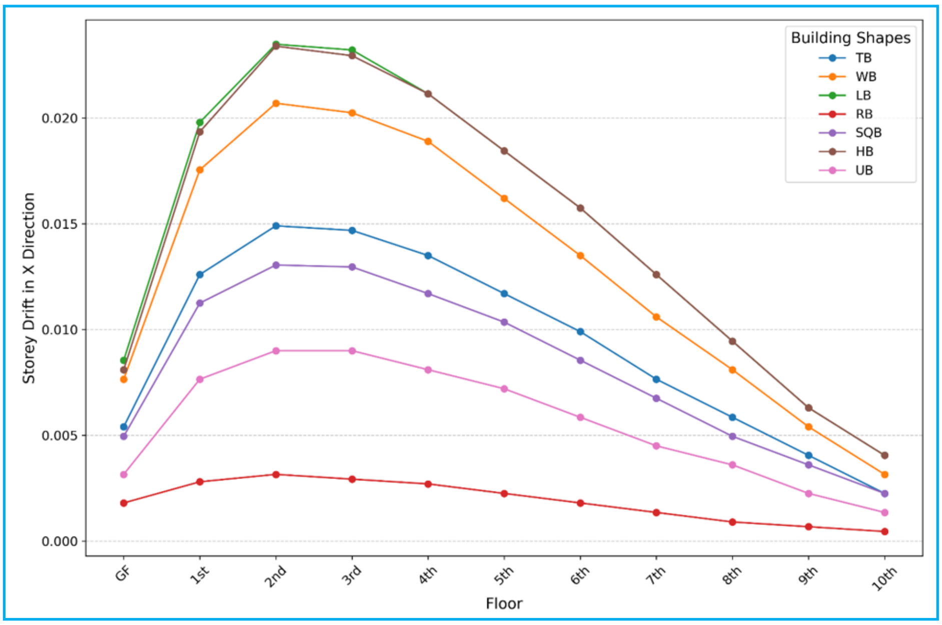


Figure 5. Storey drift in X direction due to seismic load

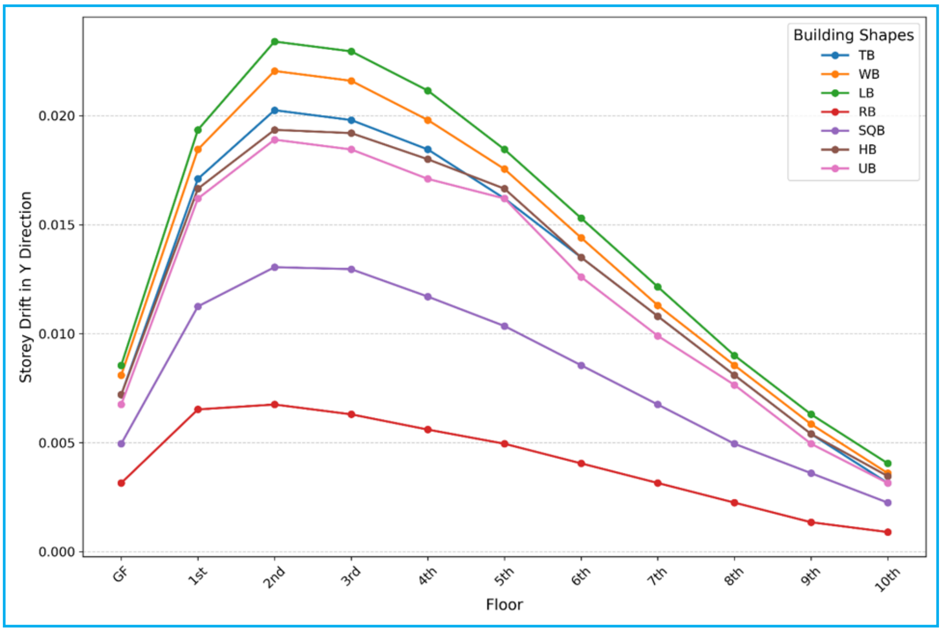


Figure 6. Storey drift in Y direction due to seismic load

Moreover, Rathi and Raut [11] discovered that structures with abrupt stiffness discontinuities are prone to large inter-story drifts, particularly in the lower levels. Similarly, Kabir et al. [9] revealed that L-shaped and H-shaped structures display enhanced drift values relative to regular-shaped buildings, emphasizing the susceptibility of irregular layouts. The concentration of maximum drift at the second story in the H- and L-shaped structures suggests a potential weak-story effect, which raises the chance of localized collapse during seismic events. This conclusion underlines the requirement for thorough structural details, appropriate lateral bracing, and homogeneous stiffness distribution to promote earthquake resistance.

The reduced drift values in the rectangular building (RB) illustrate the benefits of symmetrical design in seismic performance. Previous studies suggest that regularly shaped structures suffer more uniform lateral stress distribution, minimizing inter-story drift and enhancing overall stability [2], [8]. This reinforces the assumption that symmetrical structures perform more successfully under dynamic stresses, since their seismic reaction is more predictable [4].

BASE SHEAR

Base shear, a crucial metric in seismic design, indicates the entire horizontal force that a structure’s foundation must resist during an earthquake. It is closely connected to the inertial forces created by the building’s mass in reaction to ground motion [17], [4]. The precise computation of base shear is vital to guaranteeing structural stability and safety under seismic loading conditions. The Bangladesh National Building Code (BNBC) [5] gives detailed standards for base shear estimation depending on seismic intensity, structural layout, and site conditions.

The amount of base shear is determined by various factors, including:

- Seismic Zone Factor (Z): Represents the seismic hazard level of a region. Higher seismic zone values correspond to increased predicted ground shaking, resulting in higher base shear demands [12].
- Importance Factor (I): Adjusts the seismic load based on building function. Critical structures such as hospitals and emergency facilities have greater significance factors, assuring increased resistance for post-earthquake performance [14].
- Response Modification Factor (R): Defines the structure’s capacity to dissipate seismic energy through inelastic deformation. Higher ductility and energy absorption capacity minimize the total base shear demand [15].
- Building Weight (W): Includes the entire dead weight and a percentage of live loads operating on the building. Heavier structures create bigger inertial forces, resulting in increased base shear [9].
- Soil Type & Site Characteristics: Soft soils tend to enhance seismic waves, creating larger base shear stresses compared to rigid or rocky areas [8].

- Natural Period of Vibration (T): The building's height, stiffness, and mass distribution define its natural period. Flexible structures (longer period) often experience lesser base shear, while inflexible buildings with shorter periods are vulnerable to larger seismic stresses [16].

In this study, base shear values were estimated using the Equivalent Static Force Procedure (ESFP), as specified in BNBC 2020. The results for different structural layouts are presented in Table 6 and Figure 7.

Table 6. Base shear value of different building model

Building Shape	**TB**	**WB**	**LB**	**RB**	**SQB**	**UB**	**HB**
Base Shear (Kip)	600.8773	630.5855	598.003	550.431	583.014	577.784	605.497

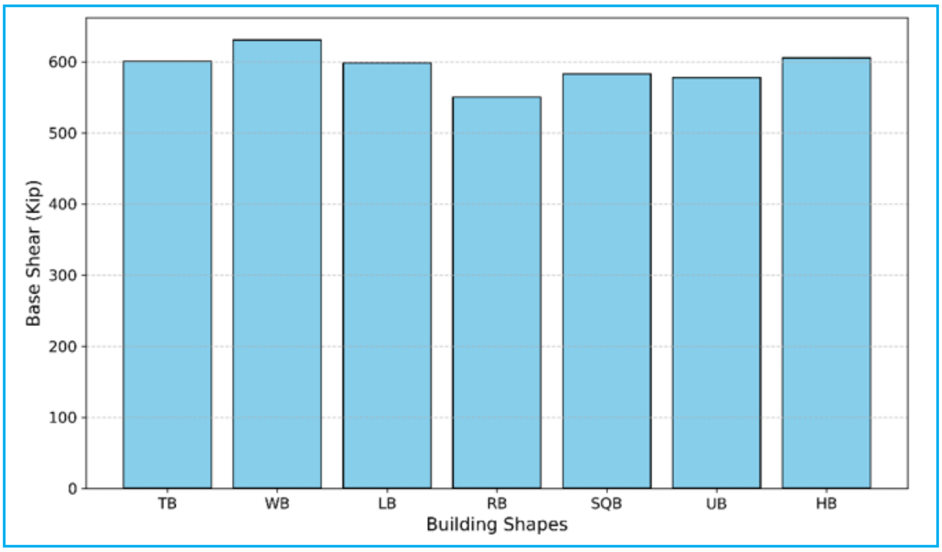


Figure 7. Base shear of the models

The W-shaped building displayed the greatest base shear (630.59 kip), roughly 12.72% greater than the rectangular structure (550.43 kip). This pattern coincides with earlier study findings, which show that irregular buildings incur higher seismic demands due to their unbalanced mass distribution and complicated load routes [6]. The increase in base shear for irregular forms is mostly owing to re-entrant corners, torsional irregularity, and mass eccentricity, which amplify stress concentrations and lateral force effects [7].

Conversely, the rectangular building recorded the lowest foundation shear, illustrating the intrinsic stability of symmetrical forms. Research by Herrera and Soberon [2] confirms this, suggesting that regular-shaped structures tend to transfer seismic pressures more uniformly, lowering localized stress concentrations and lateral displacements. The square-shaped construction (SQB) also performed satisfactorily, with base shear values similar to that of the standard rectangular building.

The increased base shear in irregular buildings such as W, T, and H-shaped structures implies that torsional factors considerably contribute to seismic reaction. This discovery agrees with ASCE/SEI 7-16 [12], which underlines that plan imperfections enhance base shear due to the unequal distribution of stiffness and mass across multiple axes. Similarly, FEMA P-750 [13] stresses that irregular buildings require additional lateral bracing and seismic-resistant detailing to mitigate the higher base shear impacts.

TORSIONAL IRREGULARITY

Torsional irregularity in a building emerges when the structure undergoes uneven rotational reaction during seismic occurrences. This situation generally originates from eccentricity between the center of mass and the center of stiffness, resulting in torsional rotation along the vertical axis when subjected to lateral seismic stresses [4], [17]. The existence of torsional effects in a structure is typically amplified by irregular plan configurations, where the unequal distribution of stiffness and mass enhances stress concentrations, notably at re-entrant corners and edges [6], [7].

The causes of torsional irregularity are generally connected to asymmetrical building layouts, unequal mass distribution, and discontinuities in structural parts. Buildings with irregular plan forms, such as L-, T-, H-, and U-shaped layouts, automatically incorporate mass and stiffness eccentricities, making them more vulnerable to torsional effects [11]. Similarly, when structural mass is unevenly distributed over the floor plan, inertial forces created during seismic activity enhance the torsional response, resulting in differential displacements across the structure [9]. Additionally, discontinuities in shear walls, diaphragms, or braced frames contribute to uneven stiffness distribution, leading to additional torsional effects [2].

The repercussions of torsional irregularity might be significant, impacting the overall seismic performance of a structure. Unequal stress distribution across different areas of the structure might produce localized structural vulnerabilities, increasing the chance of damage or failure [8]. Excessive torsional effects can also contribute to enhanced inter-story drift, particularly in flexible structural components, rendering the structure highly sensitive to seismic pressures [14]. When torsional moments exceed the design limitations, the danger of progressive structural instability increases, which can result in partial or complete collapse [16].

According to the Bangladesh National Building Code (BNBC) [5], a building is categorized as torsionally irregular if the greatest inter-story drift at one end exceeds 1.2 times the average drift at both ends. Exceeding this threshold implies a large torsional response and demands extra design considerations such as strengthened shear walls, continuous diaphragms, or tuned mass dampers to increase torsional resistance [12].

In this work, the torsional irregularity ratio (TIR) was estimated for each structural model to examine torsional reaction under seismic stresses. Figure 8 provides a comparative analysis of TIR.

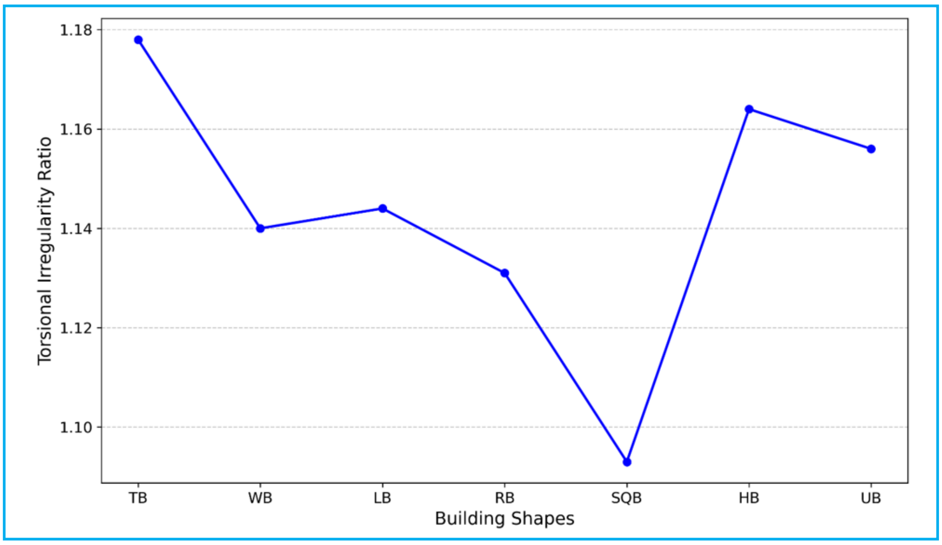


Figure 8. Torsional irregularity ratio (TIR) comparison

The data reveal that none of the constructions surpassed the BNBC 2020 torsional irregularity level (TIR > 1.2) [5]. However, T, U, and H-shaped structures had TIR values near the limit, suggesting an enhanced susceptibility to torsional impacts. These results accord with prior research, wherein irregular plan shapes were reported to endure considerable torsional amplification owing to mass and stiffness eccentricity [6]. The results also complement the study by Kumar et al. [7], which indicated that L and T-shaped structures experience more prominent torsional reactions to seismic loads, and that judicious placement of shear walls and moment-resisting frames is important to reduce rotations.

T, U, and H-shaped buildings being close to the TIR border implies that these structures may exhibit critical torsional behavior when subjected to earthquake loads stronger than designed for. The asymmetrical stiffness and mass distribution in such configurations necessitate further design considerations for optimal earthquake performance. ASCE/SEI 7-16 [12] provides guidelines for reducing torsional irregularity and emphasizes the importance of strategically positioning lateral load-resisting components to minimize stiffness eccentricity.

Additional research by Herrera and Soberon [2] reveals that continuous diaphragms and mass balancing procedures can make stress distribution more symmetrical, thereby reducing torsional response in irregular structures. Furthermore, FEMA P-750 [13] acknowledges the necessity of additional seismic damping devices and reinforced diaphragm connections to improve structural resilience in torsionally irregular structures.

OVERTURNING MOMENT

The overturning moment refers to the rotational force exerted on a structure due to lateral stresses such as seismic or wind forces. This moment induces rotation around the base of the structure, potentially leading to instability or even collapse if not properly accounted for in the design [4], [17]. Overturning moments primarily arise from seismic forces, where inertial loads generate lateral pressures that induce rotational movement, as well as wind loads, which exert sustained lateral stresses, increasing the likelihood of rotational effects [9]. Additionally, imbalanced loading caused by uneven mass distribution across the structure can contribute to overturning tendencies, particularly in high-rise or irregular buildings. Other contributing factors include hydrostatic pressure, which exerts significant rotational forces in structures such as retaining walls and dams, further increasing the likelihood of instability [12].

The implications of excessive overturning moments are severe and can result in structural instability, increased foundation stresses, overstressing of structural members, and significant damage to non-structural elements [15]. High overturning forces place extreme demands on the foundation and lateral load-resisting system, requiring careful structural detailing and reinforcement strategies to mitigate failure risks [6]. Proper seismic-resistant design considerations, such as reinforced shear walls, deep foundations, and moment-resisting frames, are crucial in limiting these effects, especially in irregularly shaped buildings that exhibit asymmetric force distribution [2].

In this study, overturning moments for various structural configurations were evaluated using the Equivalent Static Force Procedure (ESFP) as specified by BNBC 2020. Figure 9 presents a comparative analysis of overturning moment values for different building models.

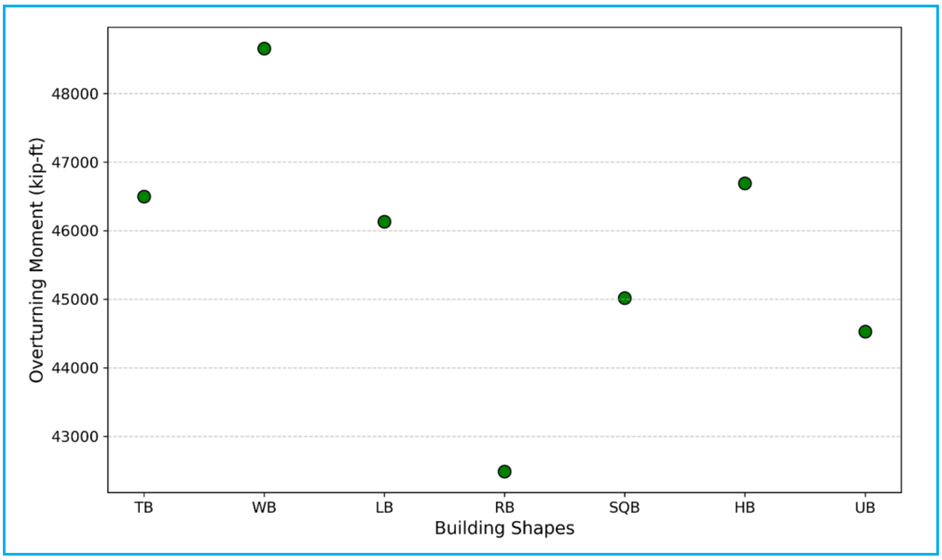


Figure 9. Overturning moment of different models

The results reveal that irregularly shaped buildings demonstrated considerably larger overturning moments than regular-shaped ones. The W-shaped, H-shaped, T-shaped, and L-shaped configurations suffered overturning moments of 48,658 kip-ft, 46,691 kip-ft, 46,498 kip-ft, and 46,133 kip-ft, respectively, while the rectangular structure recorded an overturning moment of 42,489 kip-ft. The W-shaped structure produced the maximum overturning moment, roughly 12.68% larger than the rectangular form, indicating the considerable influence of geometric irregularity on overturning effects.

These findings confirm the significant role of structural arrangement in influencing overturning resistance. Irregular structures inherently incur larger overturning moments due to their complicated mass distribution and asymmetric force routes, which contribute to unequal lateral force dissipation and elevated stress concentrations at certain structural points [8]. The increased overturning moment in the W-shaped structure is likely due to its unique plan layout, which magnifies torsional effects and lateral force imbalances, particularly under seismic loads. The reduced overturning moment seen in the rectangular structure demonstrates the value of symmetrical design in evenly distributing lateral stresses, minimizing rotational instability [16].

These findings align with ASCE/SEI 7-16 [12], which provides criteria for overturning moment estimation based on structural configuration and loading conditions. Research has shown that geometric regularity significantly enhances lateral stability, as pressures are more evenly distributed, preventing excessive moment amplification in certain locations [11]. Similarly, Kumar et al. [7] showed that T- and L-shaped structures tend to accumulate greater overturning moments due to abrupt stiffness fluctuations and mass irregularities, necessitating stronger reinforcement to reduce instability risks.

CONCLUSION

The seismic response of various plan configurations of the reinforced concrete structure was developed inside this research using metrics of essential relevance such as base shear, lateral displacement, story drift, torsional irregularity, and overturning moment. According to ETABS v17 and the Equivalent Static Force Procedure (ESFP) from BNBC 2020, the research gave a reflection on how designs of irregular structures effect seismic movement. The results demonstrate that irregular buildings contain substantially higher narrative drifts and lateral displacements compared to regular ones. Displacements were discovered to be in excess of allowed levels in a number of irregular configurations, notably after story number seven, indicating their sensitivity to seismic stresses. The observations underscore the importance of more effective lateral load-resisting systems, such as well-positioned shear walls, bracing, and moment-resisting frames, to restrict high-level deformations and assure ststability. ase shear study indicated that irregular structures had increased seismic force demands, with the most extreme base shear values for the W-shaped building. This stresses the necessity to regulate mass and stiffness distribution to allow for proper load transmission and prevent excessive forces on the structure. Torsionals distortion is revealed to be a key concern in some irregular shapes, suggesting the necessity of stronger diaphragms and efficiently distributed resisting lateral parts in order to reduce excessive torsional reactions. Moment of overturning studies also suggested that irregular structures are more prone to rotation instability. Asymmetrically designed structures demonstrated larger overturning moments, underlining the significance of extra strengthening and seismic-resistant details in such a configuration. Regularly shaped structures, however, usually demonstrated more symmetrical load distribution and greater structural performance. Outcomes of this study indicate the crucial relevance of building geometry in earthquake resistresistance. uneven constructions give architectural flexibility, they also demand meticulous structural details to assure safety and minimize seismic danger. installation of seismic design regulations, enhancement of the structural arrangement, and installation of innovative mitigation methods can be utilized to increase the resistance of irregular structures to earthquake loading. Advanced seismic analysis methodologies and genuine retrofitting solutions must be investigated in future studies to further enhance seismic the seismicance of high-rise structures.

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Conflicts of Interest

The authors declare no competing interest.

Author Contributions

Md. Saniul Haque Mahi: writing - original draft, resources. **Tanjun Ashravi Ridoy:** conceptualization, supervision. **Sakibul Hasan:** visualisation.

Data Availability Statement

The data used to support the findings of this study are included within the article.

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