JURNAL TEKNIK SIPIL DAN LINGKUNGAN | EISSN:2549-1407
https://journal.ipb.ac.id/index.php/jsil

Vol. 10 No. 02 October 2025
DOI: 10.29244/jsil.10.2.307-318

Evaluation of the Seismic Performance of The X Building Structure in West Jakarta Using Nonlinear Pushover Static Analysis

Nafisha Faradhilla*, **Erizal, and Sekar Mentari**

Department of Civil and Environmental Engineering, IPB University, Bogor 16680, Indonesia
***Correspondence author: nafishafaradhilla@apps.ipb.ac.id

Abstract: Jakarta, which is close to the earthquake path, has a high potential for seismic hazards, so building structures must be designed to withstand earthquakes. The X Building, located in West Jakarta, is expected to have an earthquake-resistant structure, evaluated using *pushover analysis*. This study aims to assess the performance of the X Building structure against earthquake loads using pushover analysis with ETAS software. X Building underwent translation in patterns 1 and 2, followed by rotation in pattern 3. The value of the structure period in the X direction is 2.578 seconds, and in the Y direction is 2.252 seconds. The mass participation requirement has been met, with a participation rate of 90% or higher in all three directions. There is torsional irregularity in the Y direction. The dynamic shear force after scaling is 10,503.93 kN (X) and 10,503.94 kN (Y). When the performance point is reached, the roof displacement is 623.182 mm (X) and 513.267 mm (Y). The total number of plastic hinges is 2774 in the X direction and 2330 in the Y direction. The structural performance level obtained is Damage Control (DC). The ductility value in the X direction is 1.31, and in the Y direction is 1.12.

Keywords: ATC-40, push over analysis, spectrum response, structure performance, torsion

Submitted: 29 Aug 2025
Revised: 12 Oct 2025
Accepted: 21 Oct 2025

1. Introduction

Tall buildings are becoming a crucial element in the development of architecture and urban planning worldwide. Along with the rapid increase in population and urbanization in Indonesia, big cities face land limitations that encourage the development of vertical spaces to meet the needs of residential, office, commercial, and public facilities. Tall buildings are no longer just a symbol of modernization and economic progress, but also a solution to the demands of land-use efficiency in urban areas. Indonesia is ranked 9th among countries with the highest number of high-rise buildings in the world [1]. Indonesia has 136 buildings with a height of more than 150 m, 50 buildings with a height of more than 200 m, and 2 buildings with a height of more than 300 m. However, Indonesia's geological conditions, which are prone to earthquakes, can be a challenge to infrastructure security, including high-rise buildings.

DKI Jakarta is a high-risk area because it is close to the earthquake path in West Java [2]. Building construction in Jakarta must be planned to account for the ability to withstand the axial and lateral forces that occur during an earthquake. X Building, located in West Jakarta, is a 12-storey high-rise apartment in the shape of the letter L. This building will be used as a residence, so it has a risk category II. Given the earthquake-prone state of DKI Jakarta, it is expected that this building will have an earthquake-resistant structure, especially since it is asymmetrical, making it more prone to collapse. Linear analysis is a method often used to analyze the strength of structures against earthquakes. Still, it is considered less accurate because earthquake loads can produce inelastic properties in the building structure. Therefore, it is necessary to carry out a nonlinear analysis [3]. Pushover analysis is one of the nonlinear analyses used to evaluate the strength of building structures against earthquake loads. This analysis employs a performance-based engineering method, utilizing nonlinear static analysis, to assess the structural strength against earthquakes. Along with the development of technology, pushover analysis can now be performed using ETABS software. Therefore, this study aims to evaluate the performance of the X Building structure against earthquake loads using *pushover* analysis carried out with ETABS software.

2. Method

2.1. Time and Location

The research, titled "Evaluation of the Seismic Performance of X Building Structure using Nonlinear Pushover Static Analysis," was conducted from February to April 2025. This research was conducted at the Department of Civil and Environmental Engineering, Faculty of Agricultural Technology, IPB University. Meanwhile, the research object, in the form of X Building, is located on Jalan Sakti Raya, Kemanggisan Village, Palmerah District, West Jakarta.

2.2. Tools and Materials

The tools used in this study are laptops equipped with Extended Three-Dimensional Analysis of Building Systems (ETABS) software, Microsoft Office 2021, and the 2021 Indonesian Design Response Spectrum Application. Meanwhile, the materials used are shop drawing data, soil investigation data, material specification data, and 2017 earthquake maps. This research refers to regulations such as SNI 1726-2019 concerning Earthquake Resilience Planning Procedures for Building and Non-Building Structures, SNI 1727-2020 concerning Minimum Design Load and Related Criteria for Buildings and Other Structures, and ATC-40 concerning Seismic Evaluation and Retrofit of Concrete Buildings.

2.3. 3D Modeling of Structures and Loading

3D modeling of the structure was carried out with ETABS V.22.5 software. The modeling of this structure is carried out based on the shop drawings obtained. The components of the modeled structure are columns, beams, and slabs. The foundations of the structure are modeled with a pinch base without the analysis and planning of the foundation. In modeling and analysis, soil-structure interactions are also not considered. Meanwhile, charging is carried out in accordance with SNI 1727:2020 and SNI 1726:2019. The combination of loading uses the ultimate method without considering the wind load, as shown in **Table 1.**

Table 1. Load combination

No.	Combination
ULS1	1.4D
ULS2	1.2D + 1.6L + 0.5 Lr 1.2D + 1.6L + 0.5 R
ULS3	1.2D + 1.6Lr + L 1.2D + 1.6R + L
ULS6	1.2D + Ev + Eh + L
ULS7	0.9D – Ev + Eh

Additionally, the structure is subjected to an additional dead load (SIDL). The dead load and live load are determined based on SNI 1726:2019 and SNI 1727:2020, while the building's load is calculated automatically by the ETABS software. The dead load and the living load of the structure are presented in **Table 2**. The spectrum response is used as an earthquake load by SNI 1726-2019. The X Building in West Jakarta City has a site class E with soft soil conditions. The results of the spectrum response graph are presented in **Figure 1**.

Table 2. Dead load and live load data

Load Type	Building Component	Load	Unit
Dead Load (DL)	Concrete	2.20	kN/m^2
	Mortar, per cm thick	0.21	kN/m^2
	Red brick wall	2.50	kN/m^2
	Lightweight concrete wall	1.59	kN/m^2
	Homogeneous ceramic tile	0.57	kN/m^2
	MEP Installation	0.25	kN/m^2
	Ceiling and hangers	0.18	kN/m^2
	Waterproofing	0.03	kN/m^2
	Glass Curtain wall + frame	0.60	kN/m^2
Live Load (LL)	Flat roof	0.96	kN/m^2
	All rooms except the stairs of the building	1.92	kN/m^2
	Stairs	4.79	kN/m^2

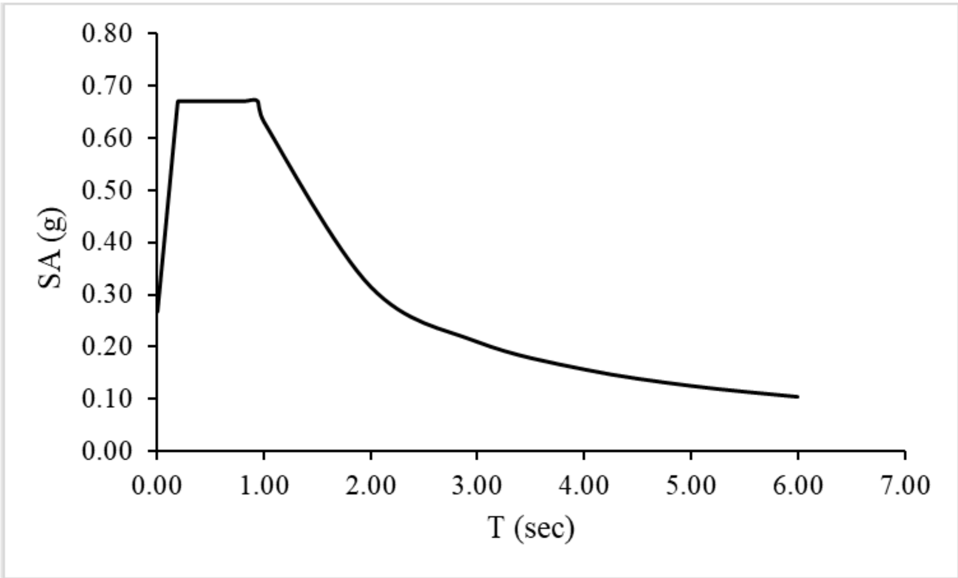


Figure 1. Spectrum response graph

2.4. Structural Suitability Analysis

SNI 1726:2019 requires several parameters to be met to obtain accurate spectrum response data. These parameters are the mass participation of the structure, the period of the structure, the irregularity of the torque, the shear force of the seismic base, the story drift, and the P-Delta effect. These parameters need to be reviewed to determine the suitability of the structure before conducting a pushover analysis.

2.5. Pushover Analysis

The pushover analysis will generate a capacity curve that will be used to determine the performance level of the structure. This analysis begins with the application of a gradually increased load at each story weight point until a displacement is achieved that causes the formation of at least one plastic joint. Each element is simulated to undergo the formation of a plastic joint by utilizing *the hinge properties* available in the ETABS software. The pushover analysis was conducted based on the ATC-40 reference using the capacity spectrum method (CSM).

2.6. Performance Level Evaluation Based on ATC-40

The performance level of the structure is evaluated based on the classification of the seismic performance level at ATC-40. From the evaluation results, it can be determined the ability of the structure to withstand earthquake loads. The results of the structural performance level can be determined based on **Table 3**.

Table 3. Structure performance level

Interstory drift limit	Immediate Occupancy	Damage Control	Life safety	Structural Stability
Maximum total *drift*	0.01	0.01 - 0.02	0.02	$0.33\frac{V_i}{P_i}$
Maximum *inelastic drift*	0.005	0.005-0.0015	No Restrictions	No Restrictions

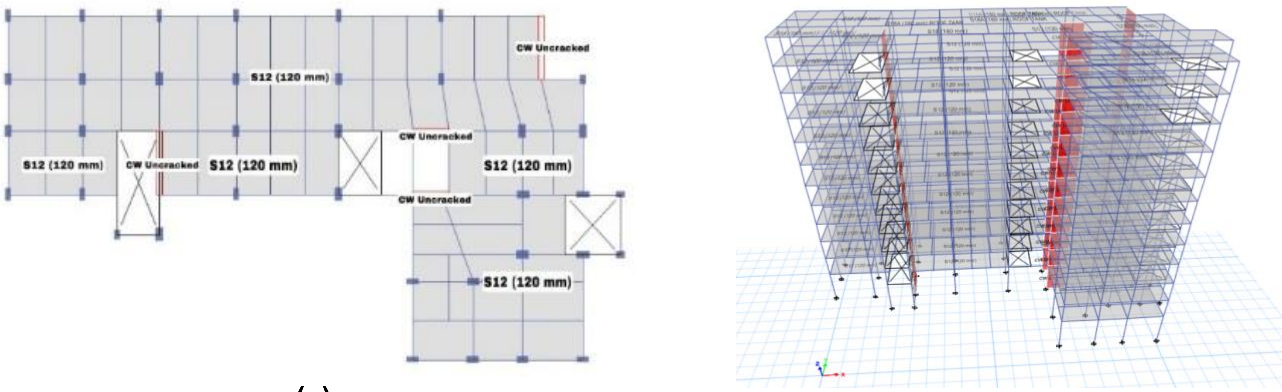
Source: ATC-40, Table 11-2

Information:
Vi : total lateral shear force on story x
Pi : total weight of the structure on the story x

3. Results and Discussion

3.1. Structural Modeling

The X Building's structure consists of 12 stories, with a roof story that is a concrete slab. The building has a total height of 45 meters, with a building shape like the letter L. The X Building will be used as a flat, so it has a risk category II based on SNI 1726:2019. Modeling was carried out using ETABS software, following the shop drawings obtained. The results of modeling the X Building's structure are presented in **Figure 2**. An L-shaped building is more vulnerable to earthquake loads [4]. Therefore, it is crucial to conduct a seismic analysis on Building X.



(a) **(b)**

Figure 2. X Building modeling results (a) structural plan (b) 3D model of the structure

3.2. Vibration Variety Patterns and Numbers

The vibration variety pattern represents the movement of the structure in response to the earthquake's vibration. The pattern of the mode shape is influenced by the building's geometric shape, material, and structural period. Based on the analysis results using ETABS, it was found that in the first variety, the building structure exhibited translational movement in the X direction, followed by translation in the Y direction in the second variety, and rotation in the Z direction in the third variety, as shown in **Figure 3**. Meanwhile, the number of varieties is determined based on mass participation, with a minimum participation rate of 90%. The number of varieties must be added if the requirements for mass involvement have not been met [5]. For the X Building, the number of varieties that meet the requirements for mass participation is 12. The vibration patterns in mode 1, mode 2, and mode 3 are important to analyze because they describe the direction of the dominant response, structural stiffness, high mode detection, and assist in model validation. Analysis of the first three modes can represent the dynamic response of the structure quite accurately.

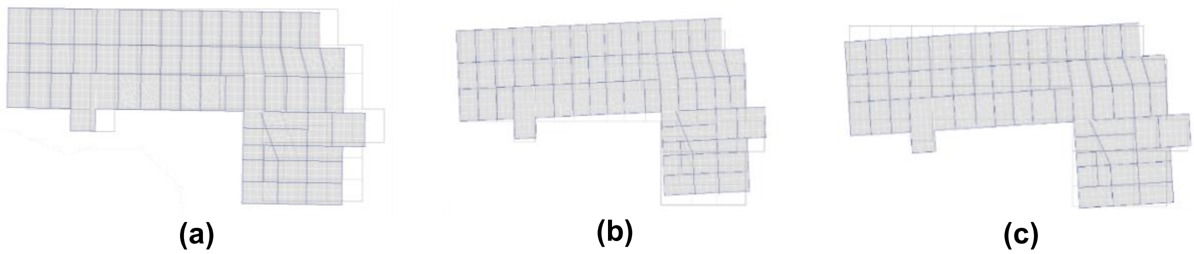


Figure 3. Vibration variety patterns (a) first (b) second and (c) third

3.3. Mass Participation

Mass participation shows a comparison between the mass of a building and its vibrational response [6]. Based on the results of the ETABS analysis in **Table 4**, the structure of X Building exhibits a mass participation of 90.3% for the X direction in the 4th mode, 90.2% for the Y direction in the 6th mode, and 90.6% for the Z direction in the 6th mode. The results of the mass participation in X Building show that the requirement of 90% mass participation in the three degrees of freedom has been met. The mass involvement of more than 90% indicates that most of the structural components of the building were shaken during an earthquake, which can cause the most significant damage. If the mass participation value is less than 90%, the calculated value of the basic force and *displacement* of the building will be smaller than it should be.

Table 4. Mass participation in X Building

Mode	Period (sec)	UX	UY	UZ	ΣUX	ΣUY	RZ	ΣRZ
1	2.578	0.781	0.004	0.000	0.781	0.004	0.005	0.005
2	2.252	0.010	0.553	0.000	0.790	0.557	0.204	0.208
3	1.847	0.001	0211	0.000	0.791	0.768	0.569	0.777
4	0.768	0.111	0.000	0.000	0.903	0.768	0.000	0.778
5	0.623	0.000	0.089	0.000	0.903	0.856	0.048	0.825
6	0.520	0.000	0.046	0.000	0.903	0.902	0.081	0.906
7	0.391	0.045	0.000	0.000	0.948	0.902	0.000	0.906
8	0.280	0.000	0.027	0.000	0.948	0.930	0.019	0.925
9	0.246	0.000	0.020	0.000	0.948	0.949	0.026	0.951
10	0.237	0.023	0.000	0.000	0.971	0.950	0.001	0.951
11	0.184	0.000	0.000	0.000	0.971	0.950	0.000	0.951
12	0.174	0.000	0.000	0.000	0.971	0.950	0.000	0.951

3.4. Structure Period

The fundamental period of the structure (T) was obtained in *mode* 1 for the X direction and *mode* 2 for the Y direction. SNI 1726:2019 requires that the period of a structure obtained from the calculation must not exceed the maximum period value (upper limit). Based on **Table 5,** it is evident that the structure period of the ETABS calculation results exceeds the maximum period. Therefore, for the calculation of the seismic response coefficient (Cs) and subsequent analysis, the maximum period is used. The period of the X-directional structure is greater than the period of the Y-directional structure. This indicates that the Y direction has a more rigid structural nature than the X direction. L-shaped buildings have a center of mass and a center point of rotation that is not located directly in the center of the building, resulting in uneven mass distribution, which causes the structure to have different rigidity in each direction [4,7].

Table 5. Structure Period

Structure Period Parameters	ETABS Calculation Result Period		Fundamental Approach Period (sec)	Maximum Period (Sec)
	X-Direction	Y-Direction		
Nilai	2.578	2.252	0.848	1.187

3.5. Torsion Irregularities

Structures with seismic design categories C, D, E, or F that exhibit torsional irregularities (1a) and excessive torsional irregularities (1b) according to SNI 1726:2019 must multiply the inherent torsional moment by the torsional magnification factor [8]. Meanwhile, the unexpected torsion eccentricity is an additional eccentricity of 5% of the building's dimensions in the perpendicular direction of the earthquake force [9]. From the results in **Table 6**, it is evident that there is no torsional irregularity in the X direction for items 1a and 1b.

Table 6. Checking for torsional irregularities in the X-direction and the Y-direction

Story	X-Direction		Y-Direction	
	$\Delta_{max}/\Delta_{avg}$	Check	$\Delta_{max}/\Delta_{avg}$	Check
Roof story	1.118	OK	1.319	H.1a
12th story	1.096	OK	1.350	H.1a
11th story	1.081	OK	1.373	H.1a
10th story	1.072	OK	1.396	H.1a
9th story	1.067	OK	1.343	H.1a
8th story	1.062	OK	1.287	H.1a
7th story	1.058	OK	1.286	H.1a
6th story	1.053	OK	1.291	H.1a
5th story	1.046	OK	1.297	H.1a
4th story	1.039	OK	1.372	H.1a
3rd story	1.029	OK	1.339	H.1a
2nd story	1.039	OK	1.352	H.1a

According to SNI 1726:2019, the torsion magnification factor must be between 1 and 3. This torsion magnification factor is multiplied by the unexpected torsion eccentricity of 5%, resulting in an eccentricity ratio greater than 5% on each story. In X Building, only the Y direction experiences torsion irregularities, so that the torsion magnification factor and eccentricity value are only calculated in that direction. The results of the calculation of the torsion magnification factor and the Y-direction eccentricity value for each story of Building X are presented in **Table 7**.

Table 7. Torsion magnification factor and eccentricity value

Y-Direction	$\Delta_{max}/\Delta_{avg}$	A_x	%	Eccentricities (m)
Roof story	1.319	1.208	6.0	2.711
12th story	1.350	1.266	6.3	2.840
11th story	1.373	1.309	6.5	2.937
10th story	1.396	1.353	6.8	3.037
9th story	1.343	1.253	6.3	2.810
8th story	1.287	1.150	5.8	2.581
7th story	1.286	1.148	5.7	2.577
6th story	1.291	1.157	5.8	2.597
5th story	1.297	1.168	5.8	2.621
4th story	1.372	1.307	6.5	2.933
3rd story	1.339	1.245	6.2	2.794
2nd story	1.352	1.269	6.3	2.848

3.6. Basic Shear Forces

SNI 1726:2019 requires that the basic shear force of the dynamic spectrum must be greater than or equal to 100% of the static base shear force. Based on calculations, a static base shear force of 10503.93 kN was obtained. Meanwhile, the dynamic elemental shear forces were obtained from the results of ETABS analysis in the X direction and Y direction, with values of 4171.24 kN and 4006.22 kN, respectively, using an initial scale factor of 1400.95 mm/s². The value of the dynamic basic shear force does not meet the SNI requirements; therefore, force scaling is necessary.

Table 8. Force scaling and the result of the dynamic basic shear force

Base Shear Force	Static (kN)	Dynamic (kN)	Scale Factor	Dynamic Base Shear Force (*Scaled*) (kN)
X	10503.93	4171.24	2.52	10503.93
Y	10503.93	4006.22	2.62	10503.94

In **Table 8,** the scale factor for the basic shear force of the X direction is 2.52 and the Y direction is 2.62. With this scale factor, the dynamic basic shear force in the X direction was 10503.93 kN and the Y direction was 10503.94 kN. The basic dynamic shear force has met the requirements of SNI, namely $V_{dynamic} \geq V_{static}$. The larger the base *shear* force, the greater the lateral force that the structure must receive.

3.7. Story Drift

SNI 1726:2019 requires that the story drift must not be greater than the permitted drift. The taller the building's structure, the greater the story drift. The story drifts of X Building is presented in **Figure 4**. X Building has a story drift that is classified as safe because no one exceeds the permissible drift. The most significant drift in the X direction is on the 5th story, while in the Y direction, it is on the 6th story. The most significant deviation in the middle story can be attributed to the L-shaped structure configuration, resulting in uneven mass and rigidity distribution. The story drift can be greater or smaller than the previous level due to the irregularity of the mass at a certain level [6]. The story drift between the X-direction levels is greater than that of the Y-direction, indicating a stiffer structure in the Y-direction, as evidenced by a smaller period and greater shear force.

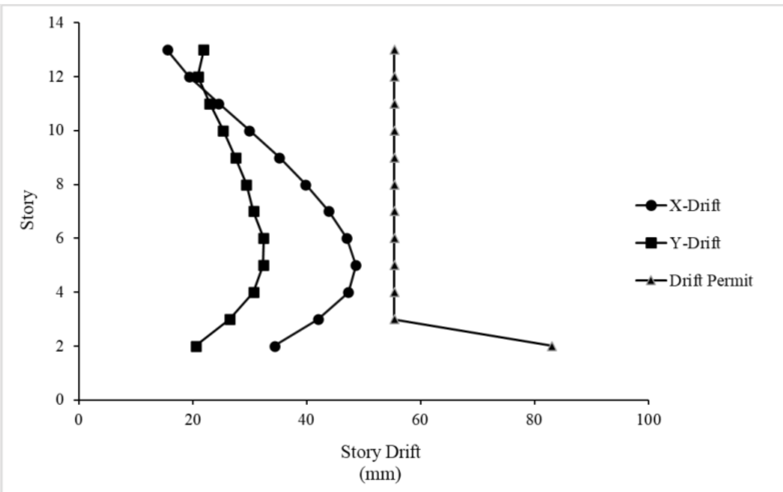


Figure 4. Story drifts of X Building

3.8. P-Delta Effect

The higher the number of stories in a building, the greater the effect of P-Delta should be considered in the analysis of earthquake-resistant structures [6]. The P-Delta effect was calculated to check the need for additional deviations. Based on SNI 1726:2019, the P-Delta effect must be considered if the stability coefficient (θ) is greater than 0.1, and the structure must be redesigned if the stability coefficient (θ) exceeds the structural stability limit (θ_{max}). In **Figure 5**, it can be seen that the P-Delta effect does not exceed the P-Delta effect limit of 0.1 and also does not exceed the structural stability limit (θ_{max}) in the X and Y directions. Therefore, it can be concluded that the P-Delta effect on the structure does not need to be considered. **Figure 5** also shows that the largest stability coefficient occurs on the 5th floor in both X and Y directions due to its large inter-story drift, which indicates lower stiffness. It also shows that the X direction has a higher stability coefficient than the Y direction, implying greater rigidity in the Y direction.

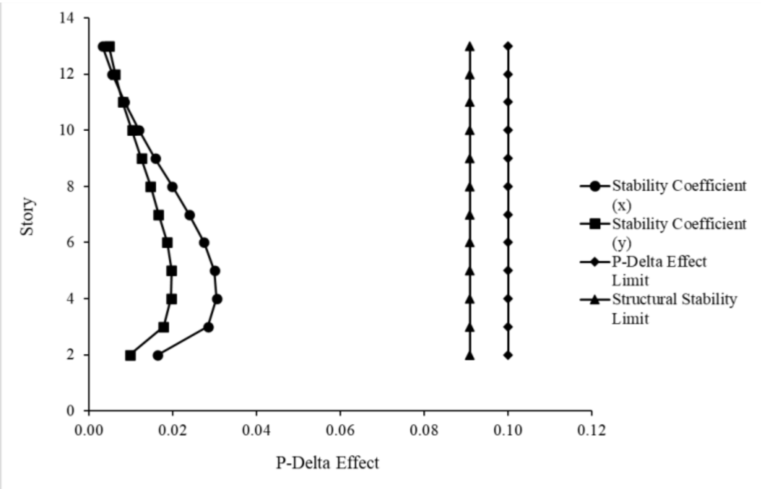


Figure 5. Effects of P-Delta on X Building

3.9. Results of Pushover Analysis

3.9.1. Capacity Curve

The capacity curve begins with a linear condition before transitioning to a melting state, which then continues with a nonlinear condition [10]. Based on the X directional capacity curve, the maximum acceptable base shear force of the structure is 30498.10 kN with a maximum displacement of 815.17 mm. Meanwhile, in the Y direction, the maximum base shear force acceptable to the structure is 30444.81 kN with a maximum displacement of 574.05 mm. In **Figure 7**, it can be seen that the capacity curve in the X direction is more sloping compared to the Y-direction capacity curve.

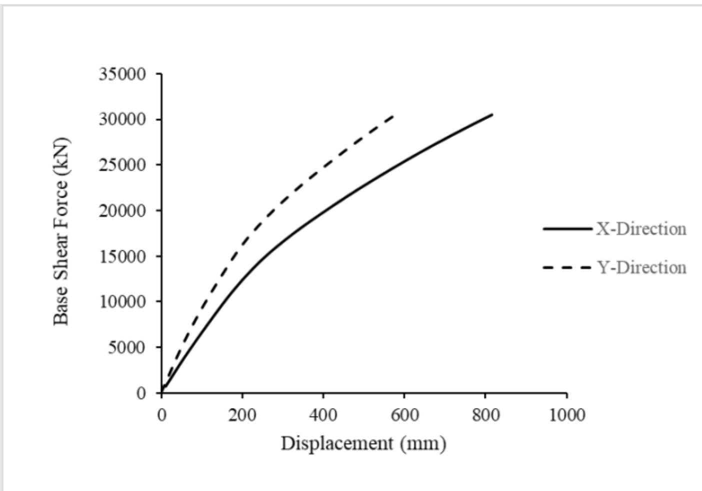
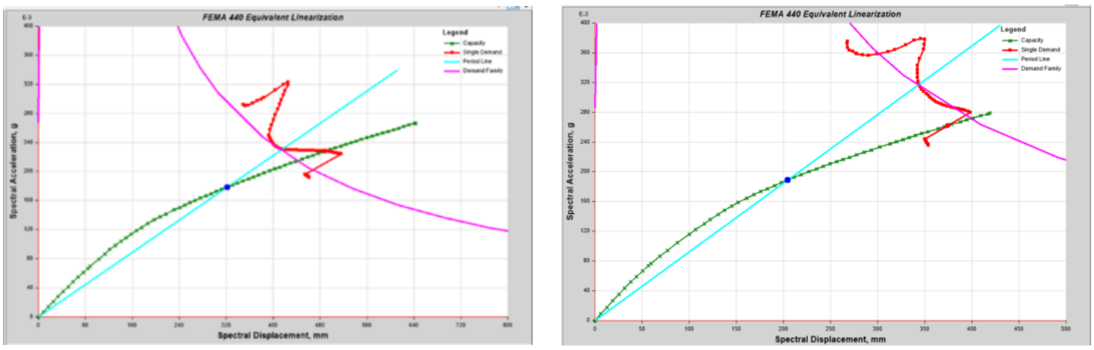


Figure 7. Building capacity curve X

3.9.2. Performance Points and Performance Levels of Structures



(a) **(b)**

Figure 8. Performance point (a) direction X (b) direction Y

Table 9. Results of the structural performance of the X Building structure

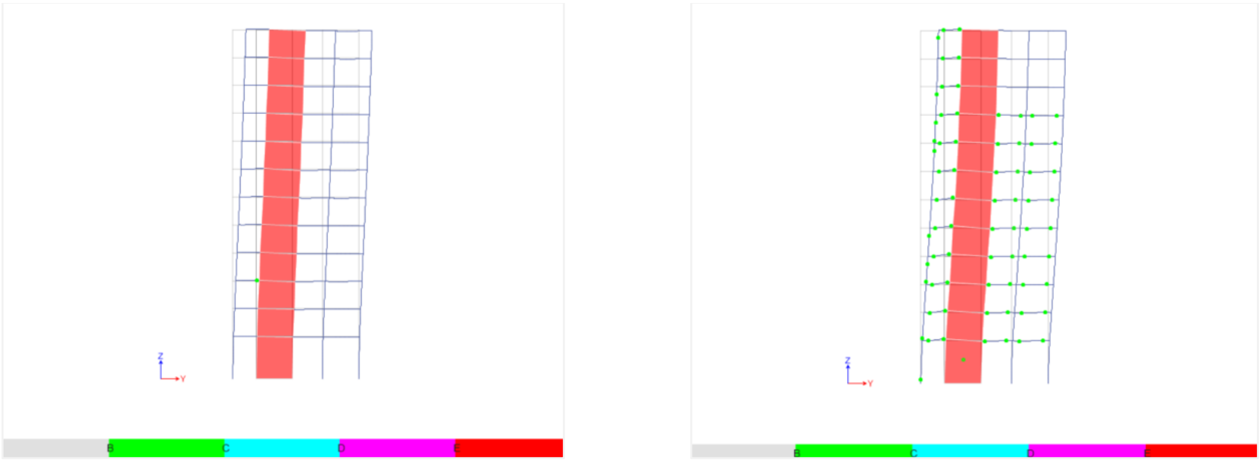
Direction	Inelastic Roof Displacement, D_1 (mm)	Roof Displacement Target, D_t (mm)	*Maximum Total Drift*	*Maximum Inelastic Drift*	Structure Performance
X	116.970	623.182	0.014	0.011	DC
Y	84.475	513.267	0.011	0.010	DC

Performance points are obtained from the intersection between the capacity curve and the spectrum response curve [11]. In **Figure 8**, a graph is presented showing the performance points of the structure for both the X and Y directions. The green curve is the capacity curve. The red curve is the single demand curve. Meanwhile, the light blue curve is the period curve and the pink curve is the spectrum response curve (demand family). The structural performance point is obtained from the intersection of the green curve and the red curve. From a performance point of view, the displacement target in the X direction was determined to be 623.182 mm, with a corresponding shear force of 26002.99 kN. Meanwhile, the target displacement in the Y direction was obtained at 513.267 mm with a shear force of 28571.07 kN. The results of the performance points are then used to determine the level of performance of the structure. The performance level of X Building was evaluated based on ATC-40 by calculating *the* maximum total drift and maximum inelastic drift values, which were then compared with the deformation limit values*.* According to the analysis in **Table 9**, the performance level of the X building structure in both the X and Y directions is classified as Damage Control (DC). Damage Control indicates that the building's structure remains capable of withstanding the earthquake's impact, and the risk of casualties is minimal.

3.9.3. Distribution of Plastic Joints

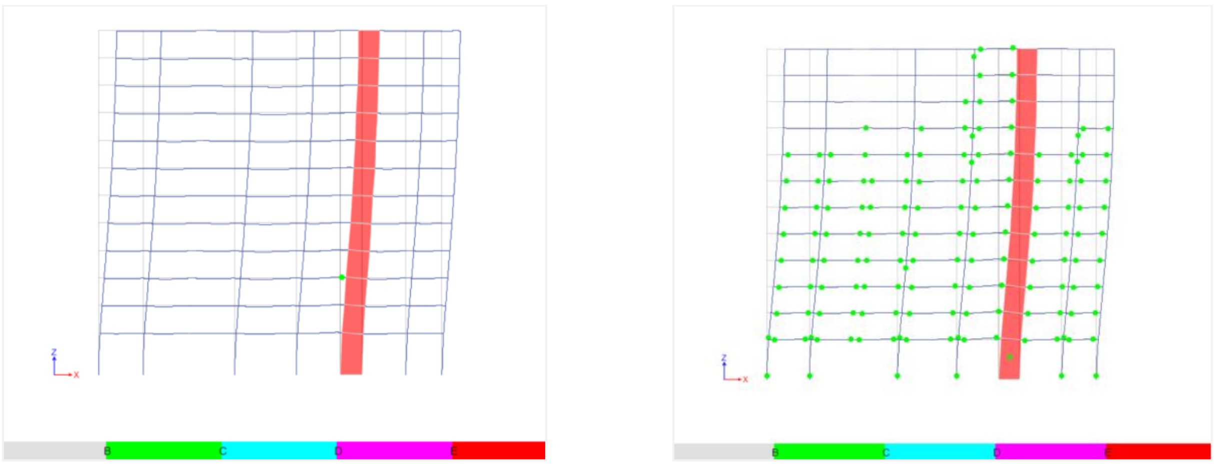
Based on the results of the ETABS analysis, there are 9456 joints (*hinges*) scattered in structural elements with a total of 2774 plastic joints in the X direction and 2330 in the Y direction. In the X direction, the first four plastic hinges appeared at step 11 with a roof displacement of 116.970 mm and a base shear force of 7700.260 kN. Meanwhile, in the Y direction, the first four plastic hinges appear at step 10 with a roof displacement of 84.475 mm and a base shear force of 7989.785 kN. ETABS iterations stop at step 71 for the X direction and step 58 for the Y direction. The final step resulted in the roof shifting in the X direction by 815.169 mm and in the Y direction by 574.052 mm.

Based on **Figures 9 and 10,** the plastic joint first appears on the beam and then extends to the column. The plastic joints in the column appear in *step* 21 for the X direction and *step* 18 for the Y direction. Plastic joints are expected to form on the beam elements first at the time of structural collapse, because the structure will immediately collapse if the column that first collapses [12]. The X Building has more plastic joints in the X direction than in the Y direction. This indicates that the X direction exhibits higher ductility than the Y direction and absorbs more energy [13].



(a) **(b)**

Figure 9. X-directional plastic joints (a) early stage (b) final stage



(a) **(b)**

Figure 10. Y-directional plastic joints (a) early stage (b) final stage

3.9.4. Story Shear Force

The story shear force is the shear force after the *performance point* is reached. The shear force at the performance point is obtained as 623.182 kN in the X direction and 513.267 kN in the Y direction. Based on **Figure 11**, it can be seen that the shear force of the level in the Y direction is greater than in the X direction, which indicates that the Y direction is more rigid. These results align with the findings of the structural period and the capacity curve in the Y direction, which yields a greater result than the X direction. This is because the lower story holds the largest gravity load and lateral base shear *load*. The shear force of the story is also influenced by the size of the columns, so that the larger the size of the columns in the structure, the greater the shear force [14].

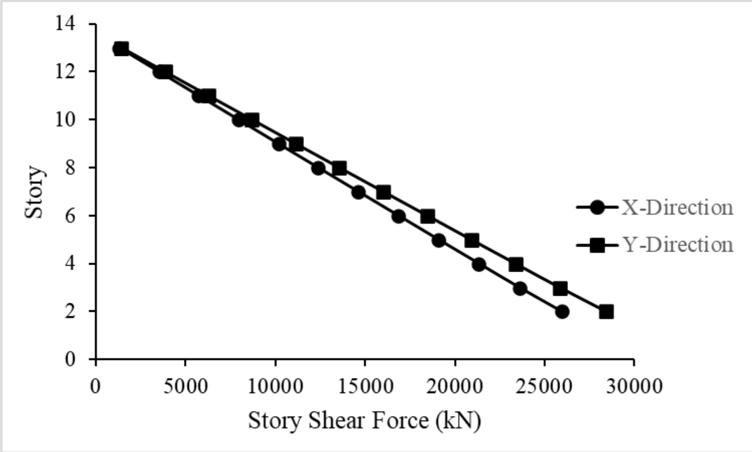


Figure 11. Story shear force after the *performance point*

3.9.5. Ductility

The ductility value is obtained from the ratio between the maximum deflection at the point of collapse (Δ_{max}) and the deflection at the point of initial yielding Δ_{yield}) [15]. From the ETABS analysis results, Δ_{max} In the X direction was 815.17 mm and in the Y direction was 574.05 mm. Meanwhile, Δ_{yield} In the X direction was 623.18 mm and in the Y direction was 513.27 mm. The ductility calculations for Building X in the X and Y directions are shown in equations (1) and (2). From the results of these ductility calculations, it is known that the ductility value in the X direction is greater than the ductility value in the Y direction. This is because the building structure is stiffer in the Y direction. Structures with higher stiffness tend to have low ductility because the deformation that occurs is smaller.

X-Directional Ductility

$$\mu = \frac{\Delta_{U_X}}{\Delta_{Y_X}} = \frac{815.17\ mm}{623.18\ mm} = 1.31\ mm \quad (1)$$

Y-Directional Ductility

$$\mu = \frac{\Delta_{U_Y}}{\Delta_{Y_Y}} = \frac{574.05\ mm}{513.27\ mm} = 1.12\ mm \quad (2)$$

4. Conclusion

The results of the analysis of X Building indicate that in the first variety, the building structure exhibits translational movement in the direction of X, followed by translational movement in the direction of Y in the second variety, and rotational movement in the direction of Z in the third variety. The value of the structure period in the X direction is 2.578 seconds and in the Y direction is 2.252 seconds. The mass participation analysis has been fulfilled by more than 90% in all three directions. There is an irregularity of torsion in the Y direction, so that a torsion magnification factor is needed. The dynamic base shear force in the X direction was 10503.93 kN and the Y direction was 10503.94 kN after force scaling was performed. The story drift in X Building does not exceed the permitted drift limit, and the effect of P-Delta does not need to be considered. The results of the plastic joint pushover analysis initially appeared on the beam, which then extended to the column, thereby meeting the concept of a Strong Column Weak Beam. The performance level of the X building was characterized by Damage Control (DC), with ductility values of 1.31 mm in the X direction and 1.12 mm in the Y direction.

References

[1] The Council on Tall Buildings and Urban Habitat. 2023. Countries by Number of 150m+ Buildings Database. [diakses 2025 Feb 4]. https://www.skyscrapercenter.com/countries.

[2] Mataburu IB, Handawati R, Hijrawadi SN. 2023. Peningkatan kesiapsiagaan bencana gempa bumi bagi masyarakat Kelurahan Bukit Duri Jakarta Selatan. *Jurnal Pengabdian Kepada Masyarakat.* 6(2):234–241.

[3] Suwondo R, Mangindaan D, Cunningham L, Alama S. 2021. *Non-linear analysis of seismic performance of low-rise concrete buildings in Indonesia. IOP Conf Ser Earth Environ Sci.* 794(1):24.

[4] Lamia NWMT, Pandaleke RE, Handono BD. 2020. Perencanaan struktur gedung beton bertulang dengan denah bangunan berbentuk L. *Jurnal Sipil Statik.* 8(4):519-532.

[5] Hilmi M, Erizal, Febrita J. 2021. Analisis kinerja struktur pada bangunan bertingkat dengan metode analisis respon spektrum berdasarkan SNI 1726:2019. *Jurnal Teknik Sipil dan Lingkungan.* 6(3):143–158.

[6] Nursani R, Dheni D, Noor E. 2023. Analisis pengaruh penambahan dinding geser terhadap perilaku struktur gedung sistem ganda. *Jurnal Teknik Sipil dan Lingkungan.* 08(02):105–114.

[7] Ramadhani SF, Saputra J, Rosyidah A. 2022. Efek torsi bangunan terhadap respon struktur pada sistem rangka pemikul momen khusus dan sistem ganda. *Dinamika Rekayasa*. 18(1):1–11.

[8] Siajaya K, Windah RS, Handono BD. 2018. Respons struktur gedung bertingkat dengan variasi kekakuan kolom akibat gempa berdasarkan SNI 03-1726-2012. *Jurnal Sipil Statik.* 6(6):411-422.

[9] Tuwanakotta E, Bernard Y. 2022. Analisis torsi tak terduga dan ketidakberaturan torsi akibat gaya gempa. *Jurnal Karkasa.* 8(1):43–48.

[10] Pramudhita G, Buwono HK. 2019. Analisis nonlinier static pushover struktur gedung bertingkat soft story dengan menggunakan material beton bertulang dan beton prategang pada balok bentang panjang. *Konstruksia*. 10(2):95–106.

[11] Prasetya MA, Wirakusuma I, Sarya G. 2022. Kinerja struktur gedung perkuliahan 10 lantai berdasarkan analisis nonlinier pushover dan ATC-40 (studi kasus : Graha Wiyata UNTAG Surabaya). *Jurnal Extrapolasi.* 19(01):35–45.

[12] Monavari B, Massumi A. 2012. Estimating displacement demand in reinforced concrete frames using some failure criteria. *International Journal of Advanced Structural Engineering.* 4(4):1–6.

[13] Asmara KB, Isneini M, Niken C. 2021. Evaluasi kinerja struktur bangunan tinggi dengan analisis *pushover* menggunakan aplikasi pemodelan struktur (studi kasus: The Venetian Tower). *Jurnal Rekayasa Sipil dan Desain*. 9(1):177–188.

[14] Walujodjati E, Maulidan R, Kristalia R. 2024. Pengaruh perubahan dimensi kolom pada kapasitas struktur tahan gempa gedung beton Bertulang. *Jurnal Inter Tech*. 2(1):30–40.

[15] Nuraga K, Putri DAPAG, Antriksa K, Noni JFA. 2021. Analisis daktilitas struktur gedung rangka beton bertulang dengan metode analisis pushover (studi: Gedung Tugu Reasuransi Indonesia Jakarta). *Jurnal Ilmiah TELSINAS.* 4(2):34–41.