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# Structural Performance Analysis in 10-Storey and 2-Storey Basement Buildings Using the Pushover Method

**Muhammad Yaafi Fayyad *, Bangun Pasaribu, M. Husni Malik Hasibuan**
Faculty of Engineering, Universitas Islam Sumatera Utara
Jl. Sisingamangaraja No. 34, Teladan Barat, Kec. Medan Kota, Kota Medan, Sumatera Utara, Indonesia

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**ABSTRACT**

This study aims to evaluate the structural performance of a 10-story reinforced concrete residential building with two basement levels under seismic loading using the nonlinear static pushover analysis method. The research is motivated by the growing development of high-rise buildings with basement configurations in seismic zones, requiring a performance-based design approach to ensure structural safety. The theoretical foundation refers to ATC-40, FEMA 356, and the Indonesian seismic code SNI 1726:2019, which guide the determination of capacity curves, performance points, drift ratios, and structural damage levels. A quantitative analytical method was applied, and the structural model was developed using Robot Structural Analysis Professional. The loading considered includes dead load, live load, wind load, and equivalent static seismic load prior to conducting pushover analysis in both X and Y directions. The results show that the performance point in the X direction is achieved at a displacement of 179.29 mm with a base shear of 15,843.35 kN, while the Y direction reaches a displacement of 200.51 mm with a base shear of 15,479.03 kN. The maximum drift ratio of 0.004 in both directions satisfies the Immediate Occupancy (IO) performance level according to ATC-40.



***Corresponding Author:***

Muhammad Yaafi Fayyad
Universitas Islam Sumatera Utara
Email: mhdyaafi@gmail.com

## INTRODUCTION

The construction of multi-storey buildings in Indonesia continues to increase in line with population growth and land limitations, especially in big cities. Tall buildings with more than ten floors and basements are becoming a common choice, with BPS data (2024) showing an increase of 17% in urban areas. This condition demands a structural system that is not only efficient, but also able to withstand earthquake loads, considering that Indonesia is in an active seismic area.

Multi-storey buildings with basements have high complexity due to lateral loads of earthquakes and soil-structure interactions. Therefore, an analysis method that is able to realistically describe the behavior of the structure is needed. The pushover method as a nonlinear static analysis is used to evaluate the performance of the structure until it is close to collapse, including the identification of the plastic joint and the capacity of the structure.

Several previous studies have been conducted, such as by Arifin (2016) who examined the performance of steel structures using the pushover method, and Sintyawati (2018) who evaluated the structure of multi-storey buildings in Jakarta. In addition, Wiratmoko (2019) examined the influence of geometric shapes on the distribution of lateral forces. However, these studies have not considered the influence of basements in depth, so there is still a gap in the study of tall building structures with basements.

Based on this, this study aims to analyze the performance of the structure of a 10-storey building with 2 basements against earthquake load using the pushover method. The results of the research are expected to contribute to the planning and evaluation of earthquake-resistant buildings in Indonesia, especially in structures with complex basement configurations.

## METHOD

This study uses an analytical quantitative approach to evaluate the performance of the structure of a 10-storey building with 2 basements in a flats project in North Penajam Paser. The data used is in the form of building technical data, including structural dimensions, material quality, and loads working on the structure. The analysis was carried out by inputting structural loads consisting of dead loads, live loads, and earthquake loads, as well as a combination of loads according to standards. Structural modeling is carried out using structural analysis software to obtain the building's response to loads.

The analysis methods used include linear static analysis to determine the elastic response of the structure, as well as pushover analysis (nonlinear static) to evaluate the performance of the structure until the condition is close to collapse based on FEMA 356 and ATC-40 parameters. The research stages include literature study, data collection, structural modeling, analysis of results in the form of drift ratio, displacement, capacity curve, demand spectrum, performance points, and forces in the structure. Furthermore, the level of performance of the structure was determined based on the results of the analysis. The results of the study were used to draw conclusions about the ability of the structure to withstand earthquake loads and the level of performance achieved.

## RESULTS AND DISCUSSION

### 1. Building Structure Data

The building includes the typical building of each floor, building coordinate data, building element data. The floor plan of this building is a floor plan and is only displayed in a typical form, meaning that it only displays the outline. The building plan of each floor can be seen in Figures 1, 2 and 3 below.

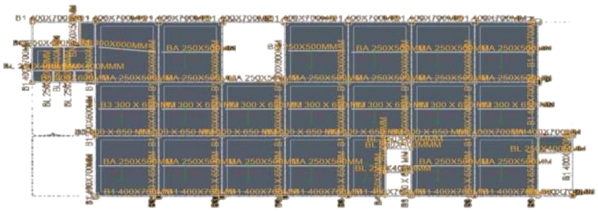

**Figure 1. Basement Floor Plan**
Source : Analysis on Structural Robots

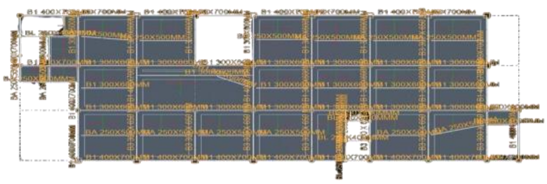

**Figure 2. 1-10 Floor Plans**
Source : Analysis on Structural Robots

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**Figure 3. 3D Building**
Source : Analysis on Structural Robots

**Table 1. X Direction Coordinates**

| No | Label | Distance (mm) | Coordinates (mm) |
|---|---|---|---|
| 1 | 1 | 6000 | 0 |
| 2 | 2 | 6000 | 6000 |
| 3 | 3 | 6000 | 12000 |
| 4 | 4 | 6000 | 18000 |
| 5 | 5 | 6000 | 24000 |
| 6 | 6 | 6000 | 30000 |
| 7 | 7 | 6000 | 36000 |
| 8 | 8 | 6000 | 42000 |
| 9 | 9 | 3300 | 48000 |
| 10 | 10 | 0 | 51300 |

Source: Field Data

**Table 2. Y-Direction Coordinates**

| No | Label | Distance (mm) | Coordinates (mm) |
|---|---|---|---|
| 1 | 1 | 7650 | 0 |
| 2 | 2 | 6850 | 7650 |
| 3 | 3 | 7650 | 14000 |
| 4 | 4 | 0 | 22150 |

Source: Field Data

**Table 3. Z directional coordinates**

| No | Label | Distance (mm) | Coordinates (mm) |
|---|---|---|---|
| 1 | Foundation | -3550 | -3550 |
| 2 | Z2 | 0 | 0 |
| 3 | Z1 | 4000 | 4000 |
| 4 | LTL 1 | 3600 | 7600 |
| 5 | LTL 2 | 3600 | 11200 |
| 6 | LTL 3 | 3600 | 14800 |
| 7 | LTL 4 | 3600 | 18400 |
| 8 | LTL 5 | 3600 | 22000 |
| 9 | LTL 6 | 3600 | 25600 |
| 10 | LTL 7 | 3600 | 29200 |
| 11 | LTL 8 | 3600 | 32800 |
| 12 | LTL 9 | 3600 | 36400 |
| 13 | LTL 10 | 3600 | 40000 |
| 14 | Lt Roof | 3600 | 43600 |

Source: Field Data

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### 2. Building Structure Load Analysis

The load analysis aims to be input into the structure that has been made 3D modeling in the Robot Structural Analysis Pro program which is in accordance with building data which includes gravitational load analysis and earthquake load analysis.

**Calculation of Sedimentation on Structures**

**Table 4. Total Load**

| No | Floor | Dead Load | Living Burden | Total Weight |
|---|---|---|---|---|
| 1 | Basement 2 | 17498.94 kN | 9135.8 kN | 26634.74 kN |
| 2 | Basement 1 | 17498.94 kN | 9135.8 kN | 26634.74 kN |
| 3 | Floor 1 | 8976.73 kN | 14578.66 kN | 23555.39 kN |
| 4 | Floor 2 | 81813.24 kN | 17851.19 kN | 99664.43 kN |
| 5 | Floor 3 | 81813.24 kN | 17851.19 kN | 99664.43 kN |
| 6 | Floor 4 | 81813.24 kN | 17851.19 kN | 99664.43 kN |
| 7 | Floor 5 | 81813.24 kN | 17851.19 kN | 99664.43 kN |
| 8 | Floor 6 | 81813.24 kN | 17851.19 kN | 99664.43 kN |
| 9 | Floor 7 | 81813.24 kN | 17851.19 kN | 99664.43 kN |
| 10 | Floor 8 | 81813.24 kN | 17851.19 kN | 99664.43 kN |
| 11 | Floor 9 | 81813.24 kN | 17851.19 kN | 99664.43 kN |
| 12 | Floor 10 | 81813.24 kN | 17851.19 kN | 99664.43 kN |
| 13 | Roof flooring | 6590.51 kN | 10226.65 kN | 16817.16 kN |
| | | Total | | 990621.9 kN |

### 3. Earthquake Load Analysis

The earthquake load analysis in this study used equivalent static load (EQ) and spectrum response (RSP) analysis.

**Earthquake Data**

The earthquake load according to rsa.ciptakarya is located in the soft land archipelago.

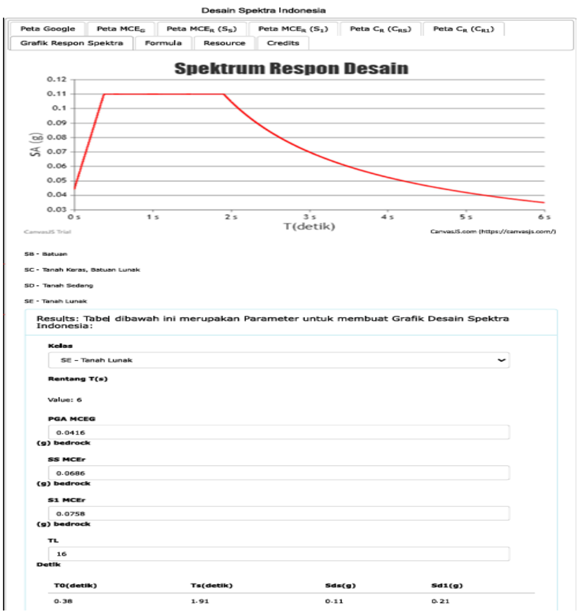


**Figure 4. Spectrum Response Graph for Kota Nusantara**

Source : https://rsa.ciptakarya.pu.go.id/2021/

ISSN: 2615-8019

**Statistical Earthquake Load Analysis**

The static earthquake load analysis in this study with the ASCE 7-16 seismic load pattern used the Robot Structural Analysis Professional program aid, so that only the gravitational load value and earthquake data were sufficiently inputted.

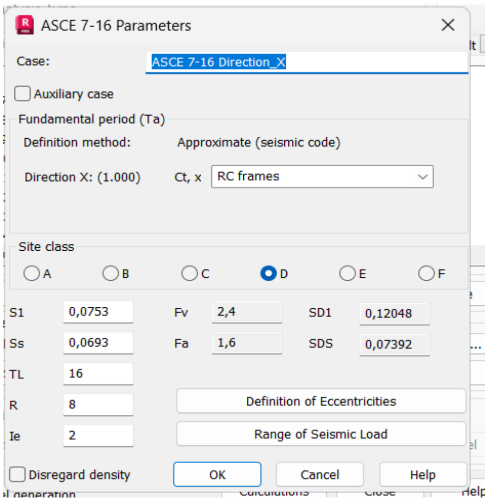


**Figure 5. ASCE 7-16 X direction static load pattern**
Source: Robot Structural Analysis Pro

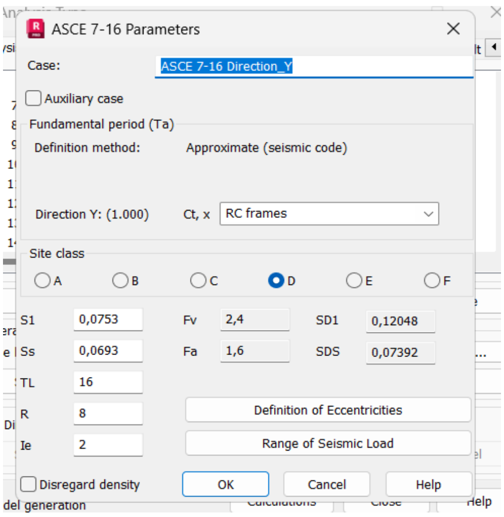


**Figure 6. ASCE 7-16 Y-direction static load pattern**
Source: Robot Structural Pro

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**Table 4. Static gempak analysis**

| Story | UX (kn) | UY (kn) |
|---|---|---|
| Basement 1 | 242,55 | 242,55 |
| Basement 2 | 51366,80 | 566,80 |
| 1st Floor | 60,56 | 1360,56 |
| 2nd Floor | 1886,25 | 1886,25 |
| 3rd Floor | 2614,16 | 2614,16 |
| 4th Floor | 3421,15 | 3421,15 |
| 5th Floor | 4294,65 | 4294,65 |
| 6th Floor | 5231,44 | 5231,44 |
| 7th Floor | 6228,26 | 6228,26 |
| 8th Floor | 7274,95 | 7274,95 |
| 9th Floor | 8386,70 | 8386,70 |
| 10th Floor | 9543,26 | 9543,26 |
| Roof Flooring | 2654,64 | 2654,64 |

**Pushover Method**

The stages of Pushover analysis using the Robot Structural Analysis Pro program are as follows:

a. Enter the load type and its contributing factors

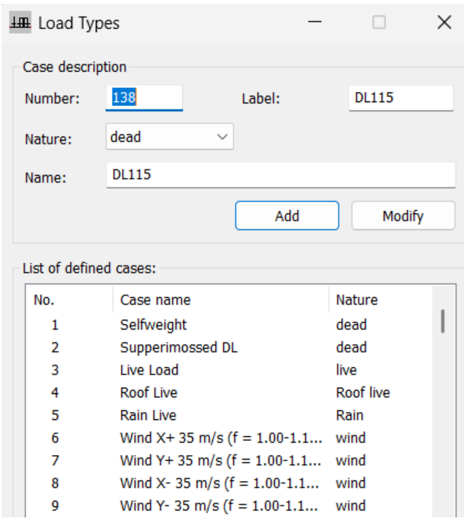


**Figure 7. Load Type**

Source : Analysis on Structural Robots

b. Determining identity Nonlinear static analysis, i.e. data entry

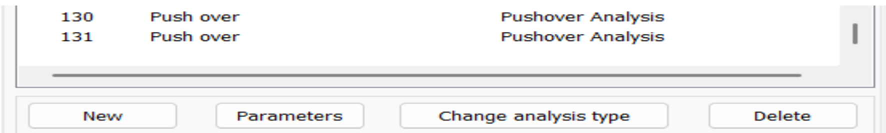


**Figure 8, Identity of the Pushover**

Source : Analysis on Structural Robots

ISSN: 2615-8019

c. Results Running

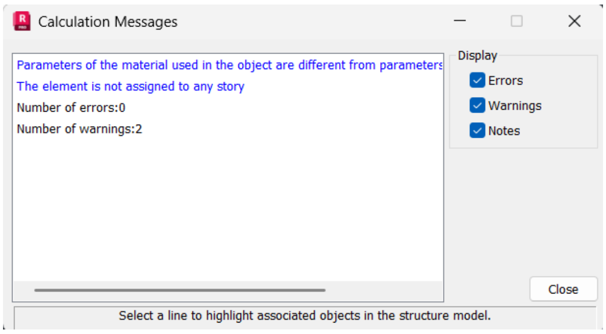


**Figure 9. Running Results**

Source : Analysis on Structural Robots

**4. Pushover Analysis Results**

From the results of the analysis, the capacity curve was obtained which is the relationship between the displacement of the reference point on the roof (D) and the basic shear force (V).

**Table 6. X-direction curve pushover data**

| Step | Reaction Sum (kN) | Displacement (mm) |
|---|---|---|
| 0 | 0,0 | 0,0 |
| 1 | 3079,20 | 0,04 |
| 2 | 6158,41 | 0,08 |
| 3 | 9237,61 | 0,12 |
| 4 | 12316,81 | 0,16 |
| 5 | 15396,02 | 0,20 |
| 6 | 18475,22 | 0,24 |

Source : Analysis on Structural Robots

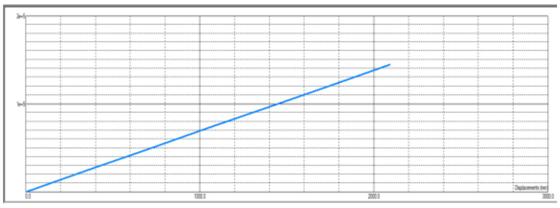

**Figure 10. Pushover Reaction Sum -FEMA 356-PUSH X**

Source : Analysis on Structural Robots

Based on the results of the static non-linear analysis presented in Table 4.6, the structural Pushover Capacity Curve shows a monotonically increasing relationship between the total base shear force (Reaction Sum) and the roof lateral displacement in the X direction. At the end of the pushover analysis listed (Step 6), the structure had achieved a total shear force of 18475.22 kN with a roof deviation (total displacement) of 0.24 mm. The value of this roof displacement of 0.24 mm is important data that will be used as input to calculate the target displacement of the δt structure. The curves formed from this data will then be converted into a Spectral Capacity Curve (ADRS format) to be integrated with the Planned Earthquake Demand Spectrum, which will ultimately determine the actual performance point and seismic performance level of the building.

**Table 7. Data Pushover curve Y direction**

| Step | Reaction Sum (kN) | Displacement (mm) |
|---|---|---|
| 0 | 0,0 | 0,0 |
| 1 | 3524,79 | 0,04 |
| 2 | 7049,58 | 0,08 |
| 3 | 10574,36 | 0,12 |
| 4 | 14099,15 | 0,16 |
| 5 | 17623,94 | 0,20 |
| 6 | 21148,73 | 0,24 |

Source: Analisis Pada Robot Structural

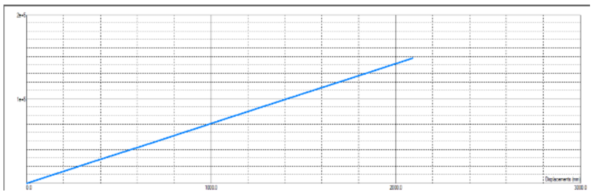

**Figure 11. Pushover Reaction Sum-FEMA 356-PUSH Y**
Source: Analisis Pada Robot Structural

Based on the results of the static non-linear analysis presented in Table 4.7, the Pushover Capacity Curve of the structure shows a monotonically increasing relationship between the total base shear force (Reaction Sum) and the lateral displacement of the roof (Displacement) in the Y direction. At the end of the stated pushover analysis (Step 6), the structure had achieved a total shear force of 21148.73 kN with a roof deviation (total displacement) of 0.24 mm. This roof displacement value (0.24 mm) is important data that will be used as input to calculate the target displacement of the δt structure. The curves formed from this data will then be converted into a Spectral Capacity Curve (ADRS format) to be integrated with the Planned Earthquake Demand Spectrum, which will ultimately determine the actual performance point and seismic performance level of the building.

**Performance Point of Structure (Performance Point)**

Performance point or building displacement target is the intersection between the curve of the capacity spectrum and the demand spectrum in ADRS format, which shows how the strength of the structure in meeting a given load is.

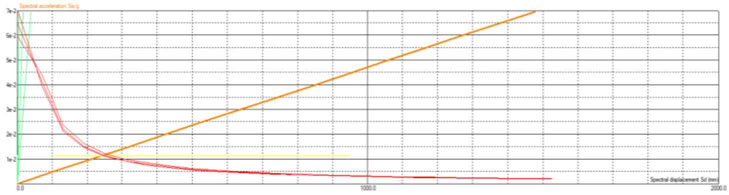

**Figure 12. Performance point arah X**
Source: Analisis Pada Robot Structural

**Table 8. Performance point value in the direction of X**

| Parameter | X Direction |
|---|---|
| Performance Point (V;D) | 15843,35 ; 179,29 |
| Performance Point (SA; Sd) | 0,24 ; 164,08 |
| Performance Point (Teff; Beff) | 1,65 ; 0,05 |

Source : Analysis on Structural Robots

Based on Table 4.8, performance point values for the X direction are obtained which consist of three main parameters, namely the relationship between the basic shear force to displacement (V–D), the relationship of spectral acceleration to spectral displacement (Sa–Sd), and the relationship between effective period and effective attenuation (Teff–Beff).

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The performance point value (V–D) of 15,843.35 kN with a displacement of 179.29 mm indicates the ability of the structure to withstand maximum lateral force until it reaches the performance limit condition. The magnitude of the basic shear force value indicates that the structure still has a fairly high lateral load absorption capacity before significant melting occurs in the main elements, especially in the earthquake load-bearing frame system.

In the performance point parameter (Sa–Sd), a spectral acceleration value of 0.24 g with a spectral displacement of 164.08 mm was obtained. These results show that the structure reaches a balance point between capacity and seismic demands (capacity–demand balance) at the deformation level that is included in the category of Life Safety Performance Level in accordance with FEMA criteria 356 (2000) and ATC-40 (1996). Thus, it can be concluded that the structure of the building is still able to maintain its global stability without experiencing collapse in critical elements.

Meanwhile, the performance point value (Teff–Beff) of 1.65 seconds for effective period and 0.05 for effective damping indicates an increase in natural periods due to the influence of nonlinearity on the structural system. A damping value of 5% indicates that the structure's ability to dissipate energy is still within acceptable limits for elastoplastic conditions.

Overall, the results of the X-direction analysis show that the building structure has good seismic behavior to the planned earthquake load. The performance points obtained confirm that the plastic deformation that occurs is still within tolerable limits, so that the performance of the structure can be categorized at the Life Safety level based on the Performance-Based Seismic Design approach.

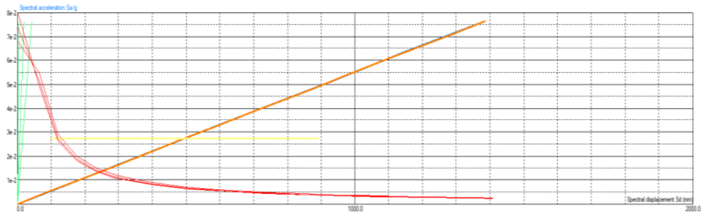

**Figure 13 : Performance point in the direction of Y**

Source : Analysis on Structural Robots

**Table 9. Performance point value in the direction of Y**

| Parameter | Direction Y |
|---|---|
| Performance Point (V;D) | 15479,03 ; 200,51 |
| Performance Point (SA; Sd) | 0,22 ; 178,00 |
| Performance Point (Teff; Beff) | 1,79 ; 0,05 |

Source : Analysis on Structural Robots

Based on Table 4.9, the performance point value for the Y direction is obtained which also consists of three main parameters, namely the relationship between the base shear force to displacement (V–D), the spectral acceleration relationship to spectral displacement (Sa–Sd), and the relationship between effective period and effective damping (Teff–Beff).

The performance point value (V–D) of 15,479.03 kN with a displacement of 200.51 mm indicates the ability of the structure to withstand the maximum lateral force in the Y direction until it reaches the performance limit condition. Compared to the X direction, the value of the basic shear force is slightly lower, while the displacement that occurs is larger. This indicates that the rigidity of the structure in the Y direction is relatively small, but the structure is still able to withstand lateral loads with adequate capacity without experiencing global failure.

In the performance point parameter (Sa–Sd), a spectral acceleration value of 0.22 g with a spectral displacement of 178.00 mm was obtained. This value shows that the structure achieves a balance between capacity and demand balance at the level of deformation that is included in the category of Life Safety Performance Level in accordance with FEMA criteria 356 (2000) and ATC-40 (1996). This condition indicates that the structure is still able to maintain overall stability and does not suffer damage that could lead to significant loss of structural function.

Meanwhile, a performance point value (Teff–Beff) of 1.79 seconds for the effective period and 0.05 for the effective damping indicated an increase in the natural period of the structure compared to the linear conditions due to the influence of nonlinear behavior. A damping value of 5% indicates that the energy dissipation ability of the structure is still within acceptable limits, and the structural system is still behaving stably under elastoplastic conditions.

Overall, the results of the Y-direction analysis show that the building structure has good seismic performance against the planned earthquake load. Despite a slight increase in deformation compared to the X-direction, the structure still shows adequate ability to absorb earthquake energy and maintain global stability. Therefore, the performance of the structure for the Y direction can also be categorized at the Life Safety level based on the Performance-Based Seismic Design approach.

1. Displacement Limit according to SNI 1726-2002 Found = 2% H = 0,02 × 43600 = 872 mm > D = 200,51 then performance displacement Good building
2. Building performance according to ATC-40 Tabel 2.
   Maksimal Drift X = $\frac{Dt}{H} = \frac{179,29}{43600}$ = 0,004
   So that the level of building performance is Immediate Occupancy
   Maksimal Drift Y = $\frac{Dt}{H} = \frac{200,51}{43600}$ = 0,004
   So that the level of building performance is Immediate Occupancy

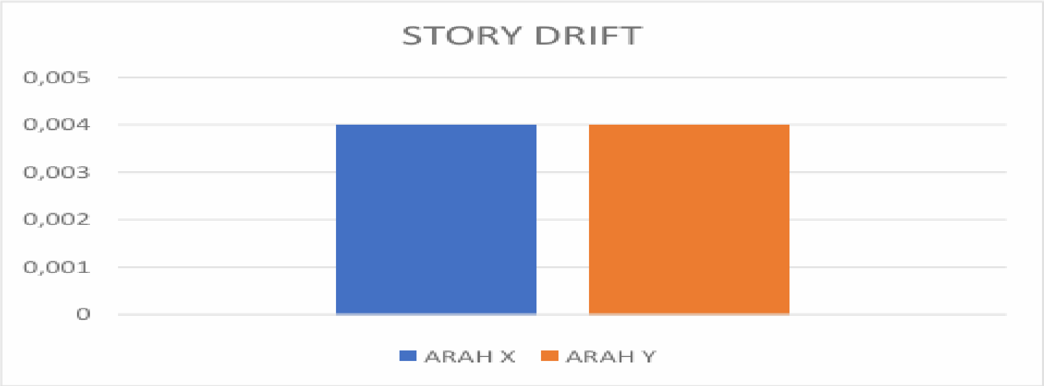


**Figure 14. Story Drift**
Source: Analisis Pada Robot Structural

## CONCLUSION

Based on the results of the analysis that has been carried out, the distribution of plastic joints in the structure of apartment buildings is more dominant in beam elements than columns, so that it has met the principle of strong column–weak beam. This suggests that the collapse mechanism that occurred is still within the expected pattern. The performance point value of the structure in the X direction was obtained with a displacement of 179.29 mm and a base shear of 15,843.35 kN, while in the Y direction a displacement of 200.51 mm and a base shear of 15,479.03 kN. In addition, the structural performance level based on the maximum total drift value of 0.004 in both directions is included in the Immediate Occupancy category according to the ATC-40 method, which indicates that the building is still in a safe condition when it is exposed to an earthquake with minimal risk of structural failure.

ISSN: 2615-8019

## REFERENCES


[1] Arifin, Z. S. (2016). Analisa struktur gedung POP Hotel terhadap beban gempa dengan metode pushover analysis. Jurnal Rekayasa Sipil dan Desain, 427–440.

[2] ATC-40. (1996). Seismic evaluation and retrofit of concrete buildings. Applied Technology Council.

[3] Badan Pusat Statistik. (2024). Statistik konstruksi Indonesia 2024: Pertumbuhan pembangunan gedung tinggi. Badan Pusat Statistik Republik Indonesia.

[4] Bagas, H. (2006). Evaluasi kinerja gedung beton bertulang tahan gempa dengan pushover analysis. Jurnal Teknik Sipil, 41–52.

[5] Bowles, J. (1993). Analisa daya dukung tanah dan penurunan pondasi. Forum Profesional Teknik Sipil, 89–95.

[6] Dipohusodo, I. (1999). Struktur beton bertulang. Jakarta.

[7] FEMA 356. (2000). Prestandard and commentary for the seismic rehabilitation of buildings. Federal Emergency Management Agency.

[8] Hariono. (2008). Teknik struktur bangunan. Direktorat Pembinaan Sekolah Kejuruan.

[9] Isneini, M. (2009). Kerusakan dan perkuatan struktur beton bertulang. Jurnal Teknik Sipil.

[10] Krisnamurti, K. K. (2013). Pengaruh variasi bentuk penampang kolom terhadap perilaku elemen struktur akibat beban gempa. Rekayasa Sipil, 13–27.

[11] Kusuma, V. (2018). Metode pelaksanaan struktur pelat lantai pada proyek pembangunan gedung. Politeknik Negeri Manado.

[12] Limbongan, S. S. (2016). Analisis struktur beton bertulang kolom pipih pada gedung bertingkat. Jurnal Sipil Statik.

[13] Masril, S. M. (2013). Analisis perilaku struktur atas gedung asrama pusdiklat IPDN Baso Bukittinggi. Rang Journal, 2(1).

[14] Mulyono. (2013). Penerapan manajemen mutu pada proses pembangunan struktur beton gedung di Surakarta. Jurnal Teknik Sipil dan Arsitektur, 13–17.

[15] Nawy. (1998). Peninjauan struktur kolom gedung sekolah. PhD Thesis Undip.

[16] Nugroho, F. (2016). Penerapan analisis pushover untuk menentukan kinerja struktur pada bangunan eksisting gedung beton bertulang. Jurnal Momentum, 18(2).

[17] Nugroho, F. (2017). Pengaruh dinding geser terhadap perencanaan kolom dan balok bangunan gedung beton bertulang. Jurnal Momentum, 19(1).

[18] Nurjannah, S. A., & Megantara, Y. (2011). Pemodelan struktur bangunan gedung bertingkat beton bertulang rangka terbuka simetris di daerah rawan gempa dengan metoda analisis pushover.

[19] Oktopianto, Y., & Andayani, R. (2013). Evaluasi kinerja struktur beton bertulang dengan pushover analysis. Prosiding PESAT, 5.

[20] Pangemanan, S., & Mantiri, H. G. (2017). Analisis pushover perilaku seismik struktur bangunan bertingkat: Studi kasus bangunan ruko. Simposium II UNIID, 2(1), 365–373.

[21] Prabowo, A., & Lase, Y. (2016). Tinjauan nilai faktor modifikasi respon (R) dan faktor kuat lebih ($\Omega_0$) pada struktur gabungan rangka baja dan rangka beton bertulang dengan analisis pushover. Jurnal Teknik Sipil ITB, 23(1), 75–88.

[22] Sianturi, N. (2017). Tinjauan penggunaan balok pracetak pada pembangunan gedung. Jurnal Rancang Sipil, 6–11.

[23] Sintyawati, L. W. (2018). Evaluasi kinerja struktur bangunan bertingkat di Jakarta menggunakan analisis pushover. Jurnal Rekayasa Sipil, 14(1), 45–56.

[24] SNI. (1989). Nilai slump untuk berbagai pekerjaan beton.

[25] SNI. (1990). Perbandingan kuat tekan beton pada berbagai umur.

[26] SNI. (2002). Satuan dan benda uji beton.

[27] Sudarmoko, J. N. (2005). Diagram perancangan kolom beton bertulang. Jurnal Teknik Sipil UGM, 12–20.

[28] Sulendra, I. K. (2005). Kerusakan akibat gempa dan metode perbaikan elemen struktur pasca gempa. Jurnal SMA Tek, 3(1), 12–20.

[29] Sultan, M. A. (2017). Evaluasi struktur beton bertulang tahan gempa dengan analisa pushover. Jurnal Sipil Sains, 6–11.

[30] Tjokrodimuljo. (2009). Analisis pengaruh temperatur terhadap kuat tekan beton. Jurnal Teknik Sipil ITB, 63–70.

[31] Wiratmoko, B. A. (2019). Perencanaan pondasi tiang pancang gedung ketahanan pangan Nganjuk. Jurnal Manajemen Teknologi dan Teknik Sipil, 106–120.