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Analysis of Non-Linear Static Procedure Based on Fema 356 to Evaluate Structural Performance in the Alton Apartment Building

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ABSTRACT

Alton Apartment is a high-rise residential building. The city of Semarang, within a radius of 500 km, has a fault range with a strength of up to 8.3 magnitude. The purpose of this study is to calculate the performance level of the structure, find out the nonlinear static procedure conditions and whether the analysis results can be used, calculate the value of ductility R, check the boundaries between levels, check the influence of P-delta, adjust horizontal irregularities, and check the vertical irregularity conditions. This study uses the FEMA 356 method. New regulations are used in the analysis, such as peak acceleration maps and response spectra from PuSGeN in 2021, deaggregation maps of Indonesian earthquake hazards for planning and evaluation of earthquake-resistant infrastructure from the Director General of Cipta Karya in 2022, and earthquake resilience planning procedures for building and non-building structures from SNI 1726-2019. The result of the structure performance of the drift value is below 1% for the life safety (LS) performance level on the 250-year earthquake map, and the result of the drift value is below 2% for the collapse prevention (CP) performance level on the 100-year earthquake map. The results of the FEMA 356 condition one analysis show that the strength ratio (µstrength) value of less than µmax has been met for 250-year and 1000-year earthquake maps with a review of the x and y directions of the earthquake. The value of the R ductility in 250-year and 1000-year earthquakes is above seven according to the earthquake force holding system of special reinforced concrete sliding walls.

Introduction

Seeing the development of the city of Semarang, a destination for higher education and tourist attractions, the need for housing or housing is increasing (Lalo, 2023). The city of Upper Semarang, especially the Banyumanik and Tembalang sub-districts, is the center of the crowd as the place where many universities are located. Seeing the increasing population and decreasing land is a challenge to developing vertical housing. The Alton Apartment is located on Jalan Prof. Sudarto no.10 Pedalangan, Banyumanik District. The residence in the apartment has two basement floors, five podium floors, and 25 floors for each of the 3 towers. The total height of the building is 96.7 m from the basement floor (Suwandi, 2019).

With the condition of the building, which is a category of high-rise buildings, it is necessary to review the reliability of the structure from the earthquake side and the elements that hold the earthquake force. The city of Semarang, within a radius of 500 km, has several faults as follows (Masbudi, Purwanto, & Supriyadi, 2015). The first fault, the Pati fault, has a strike-slip mechanism with a value of 6.8 magnitude. The second fault, the Lasem fault, has a strike-slip mechanism with a value of 6.5 magnitude. Another earthquake source is the Java megathrust subduction, which has a reverse mechanism of 8.3 magnitude (Muttaqin & Afifuddin, 2020). The overall data collection is used to find out each potential source that can produce energy for soil movements heading to the city of Semarang. Data collection was recorded by the Meteorology, Climatology, and Geophysics Agency/BMKG, then the international institution National Earthquake Information Center, and the U.S. Geological Survey/NEIC-USGS. Earthquake data was collected from 1900 to 2013 with a minimum of 5 Mw and a maximum magnitude (Mmax) of 8.3 Mw (Partono, Irsyam, & Wardani, 2017).

At the time of planning, Alton Apartments used old regulations, including SNI 1726-2012 for earthquake resistance, SNI 1727-2013 for minimum load design, and SNI 1729-2015 for structural steel buildings. Seeing the high level of operational buildings and the need to adapt to earthquake resistance rules for buildings, damage mitigation is needed through pushover analysis or non-linear static analysis procedures. Pushover Analysis is a method of evaluating the structure contained in a new concept for earthquake engineering based on Performance Seismic Evaluation (PBSE) (Nabhilla & Hayu, 2020). This analysis method includes a specific static load with a lateral direction that is increased gradually until the collapse of the structural element is achieved due to the presence of plastic joints or reaching a specific displacement target (Andrio & Masagala, 2022).

Previous research related to the evaluation of building structure performance using pushover analysis, such as those conducted at RSGM UGM Prof. Soedomo Building, Faculty of Law, Sam Ratulangi University Manado, podium-type multi-story building structures, buildings with soft first stories, Postgraduate Building of the Faculty of Mathematics and Natural Sciences UGM, and the University of Indonesia Teaching Hospital Building, as well as the Graha Wiyata UNTAG Building Surabaya, the research has similar objectives and analysis methods. Namely to evaluate the performance of building structures against earthquake loads using pushover analysis. The results showed that the structure's performance was at a certain level of performance, such as Immediate Occupancy, which indicates the ability of the building to be reused after an earthquake without significant structural damage (Nabhilla & Hayu, 2020).

This study uses FEMA 356 rules with a non-linear static procedure method to assess the performance level of buildings, especially in meeting the drift value and strength ratio (μstrength) requirements. The formulation of the problem includes evaluation of performance point values, compliance with the requirements of the Non-Linear Static Procedure according to FEMA 356 rules, calculation of ductility values from pushover results, checking the boundaries between levels, calculation of P-delta stability, the need to adjust horizontal irregularities, and when the structure can be said to meet the requirements of vertical irregularities. The objectives of the study include understanding the performance level of the structure, verification of Non-Linear Static Procedure requirements, assessment of ductility, checking the difference of deviation at the center of mass, calculation of P-delta stability, adjustment of horizontal irregularities, and verification of vertical irregularities. The limitations of the problem include the building being studied, the type of structure, the source of earthquake data, the evaluation procedure, the earthquake resistance regulations used, and the performance evaluation method of the structure applied.

Method

This study was conducted in Pedalangan, Banyumanik, focusing on the Alton Apartment, which has two basement floors, five podium floors, and 25 floors for three towers, totaling 96.7 m. The research is divided into several stages, from preparation, to data collection and analysis. Data collection consists of secondary data from direct surveys and literature studies. The data includes images, test reports, and maps of earthquake acceleration. The analysis process involves a pushover method using the ETABS V 18.1.1 program. The analysis steps include defining the mass source, gravity load, and pushover load. The analysis results are evaluated to determine the performance category of the structure, such as Immediate Occupancy, Life Safety, or Collapse Prevention. The analysis also considers aspects such as ductility, boundaries between levels, P-delta influence, and horizontal and vertical irregularities. All of these steps are important to ensure the structure's performance against earthquakes.

Research Flow Diagram

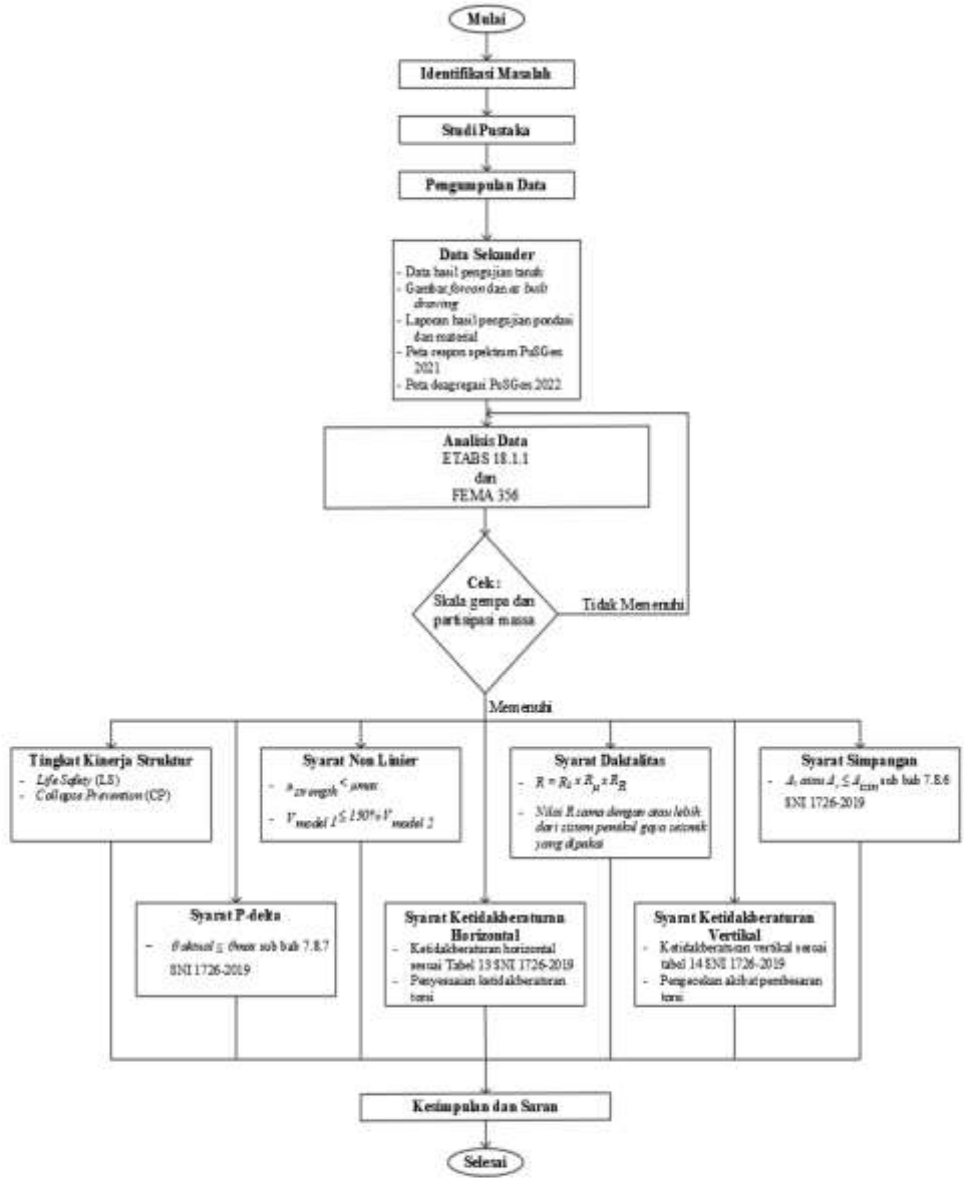

Figure 1. Research Flow Diagram

Results and Discussion

Earthquake Risk Categories and Priority Factors

Alton Semarang Apartment is an apartment function building, so the risk category based on Table 3 of SNI 1726-2019 is II. The Ie earthquake's priority factor is 1.0 according to Table 4 of SNI 1726-2019.

Categories Seismic Design and Seismic Force Bearing System

If a 1000-year reage earthquake map is used by the point of the research location, it is known that the SMS value = 0.792 and SM1 = 0.600. It can be known that the value of the seismic design category is according to Tables 8 and 9 of SNI 1726-2019. As a calculation of short periods, $0.5 \leq 0.792$ SMS are included in type D. For a period of 1 second, $0.20 \leq 0.600$ are included in type D.

The seismic force-bearing system is regulated in Table 12 of SNI 1726-2019, where it is determined based on the results of the selection of seismic design categories and the selection of frames to withstand seismic forces. In the structure of the Alton Apartment building, reinforced concrete walls are chosen as the seismic style carrying frame. Then, it is determined that particular reinforced concrete sliding walls can be allowed. The value of the specified factor is R = 7; Ω = 2,5, and Cd = 5.5.

Structural Modeling

The modeling is based on the results of the as-built drawings, which were issued by the contractor PT. PP (Persero) Tbk with the approval of PT's construction management. Maksi Engineering Solutions. Here is the application of modeling to ETABS and as-built drawings.

Figure 2 Basement Floor 1

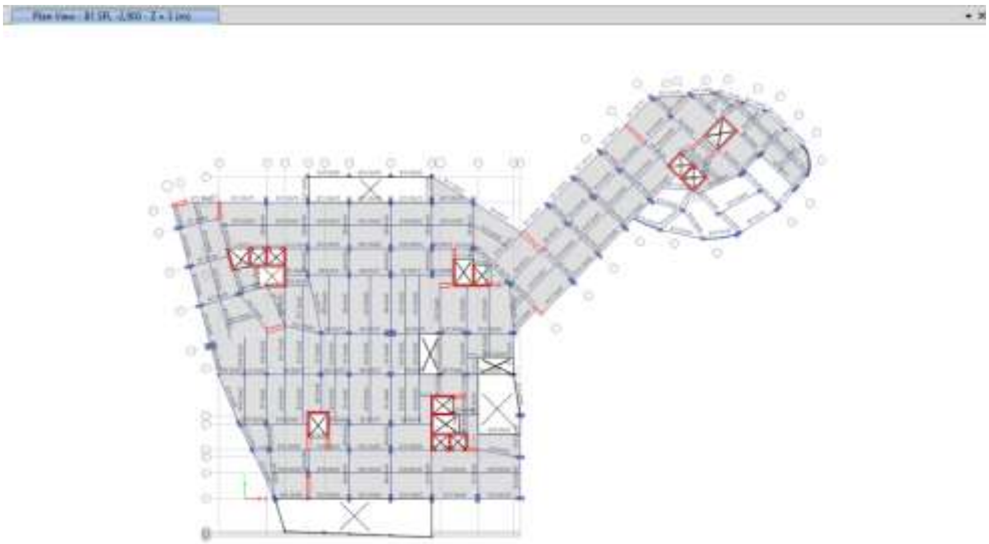

Figure 3 Basement Floor 1 on ETABS

Earthquake Response Spectrum Map

The map used is sourced from the results of a study by the National Center for Earthquake Studies on May 1, 2021, to retrofit and seismic evaluation of existing buildings. The types of maps used are 250-year and 1000-year periods. The following is the map used.

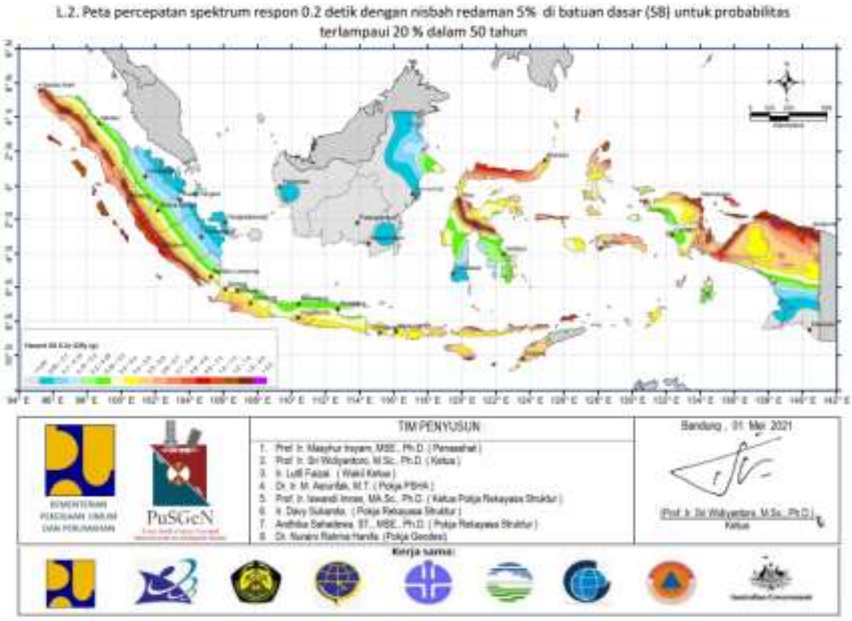

Figure 4
250-year repetition period with 0.2 second response spectral acceleration

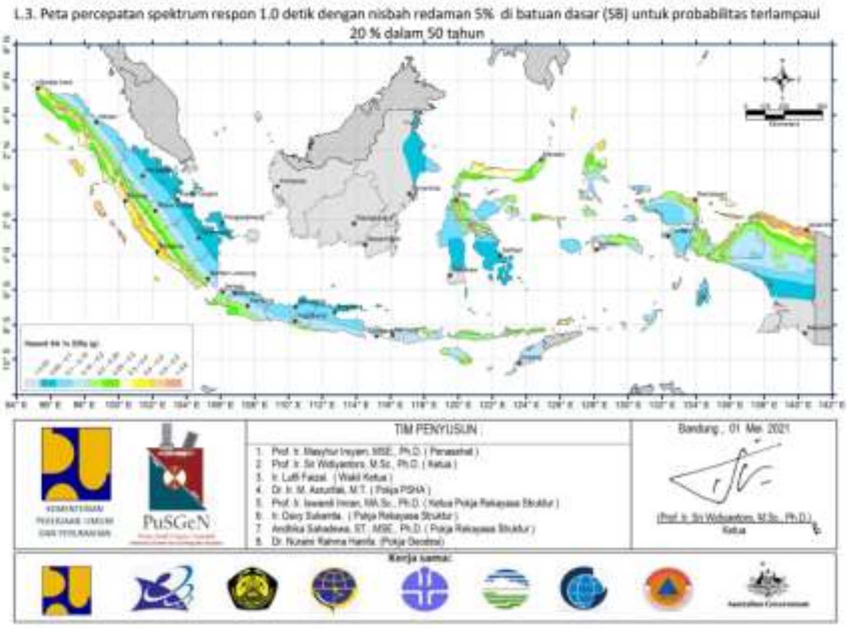

Figure 5 250-year reage period with 1.0-second response spectral acceleration

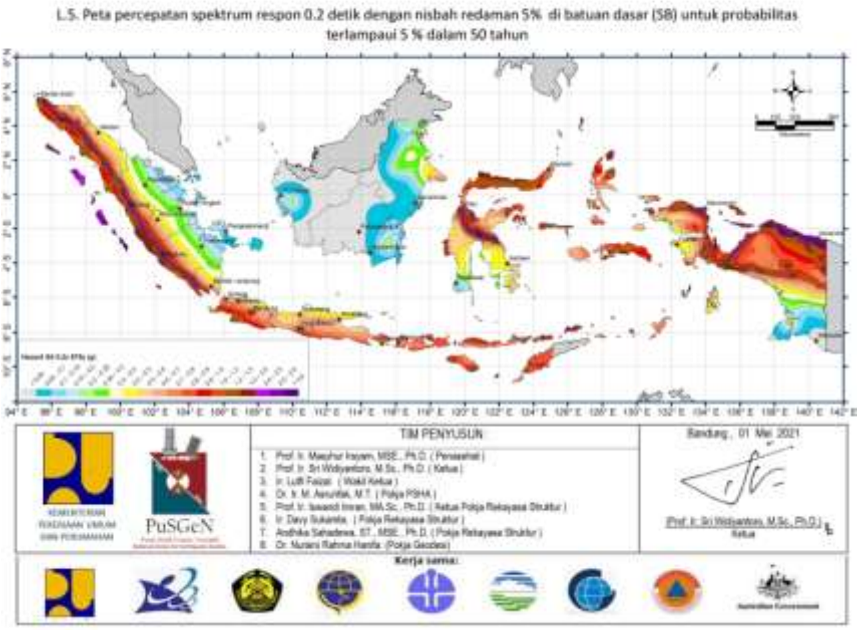

Figure 6
1000-year re-period with 0.2-second response spectral acceleration

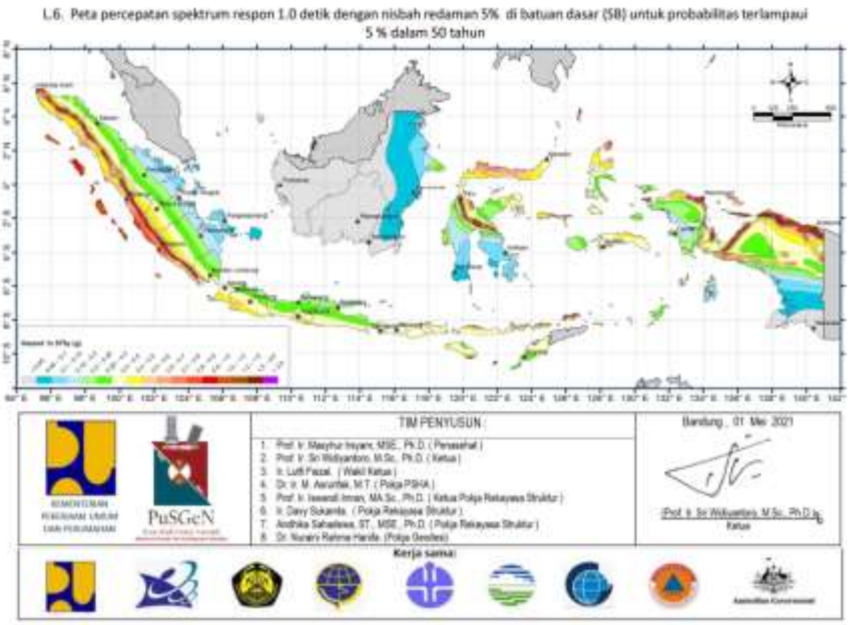

Figure 7
1000-year re-period with 1.0-second response spectral acceleration

Entering Earthquake Data

On the earthquake map, 2 data were obtained: the Short-Period Acceleration Spectrum of 0.2 seconds (Ss) and the Period Acceleration Spectrum of 1.0 seconds (S1). Then, the site coefficients Fa and Fv are looked for; the soil site class also determines this at the project site (Dalo, Handono, & Wallah, 2019). The Alton Semarang Apartment Project is determined by the medium soil site (SD) class. For the sake of the 250-year and

1000-year earthquake recurrence periods, the 2/3 multiplier is not used. The following are the results of the earthquake data input.

Kelas Situs

Kelas situs tanah proyek ini adalah tanah sedang (SD).

Kelas Situs		=	SD		

Percepatan Spektral Desain

			1000	250	2500
Spektral Percepatan Periode Pendek	S_s	=	0,6000	0,3000	0,8948
Spektral Percepatan Periode 1 Detik	S_1	=	0,3000	0,1500	0,3812
Koefisien Situs	F_a	=	1,3200	1,5600	1,1421
Koefisien Situs	F_v	=	2,0000	2,3000	1,9188
Percepatan Desain Periode Pendek	S_{DS} / S_{MS}	=	$F_a * S_s$		$2/3 * F_a * S_s$
		=	0,7920	0,4680	0,6813
Percepatan Desain Periode 1 Detik	S_{D1} / S_{M1}	=	$F_v * S_1$		$2/3 * F_v * S_1$
		=	0,6000	0,3450	0,4876
	T_0	=	$0.2 * S_{D1} / S_{DS}$		$0.2 * S_{D1} / S_{DS}$
		=	0,1515	0,1474	0,1431
	T_s	=	S_{D1} / S_{DS}		S_{D1} / S_{DS}
		=	0,7576	0,7372	0,7157

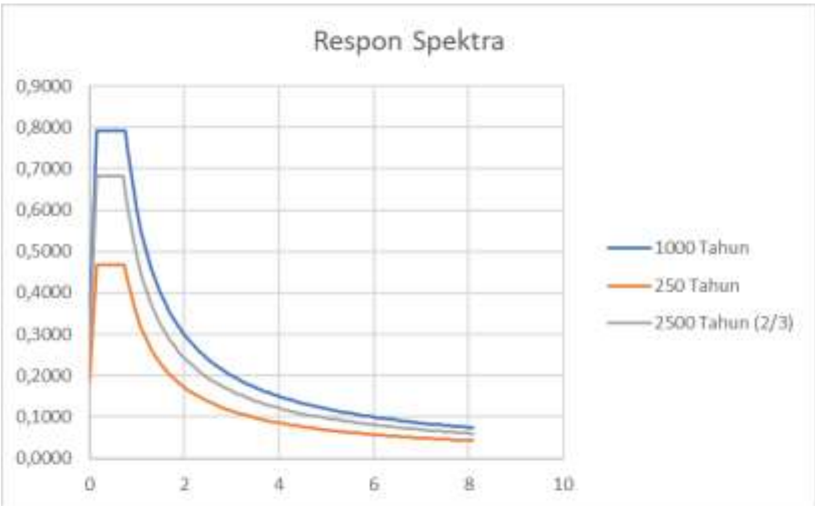

Figure 8
Comparison of 250-year, 1000-year, and 2500-year re-period Spectral Responses

Entering the Block Repeating Area

The beam repetition area and effective height (d') need to be entered according to the results of the implementation and installation drawings. These results are needed to consider the moment yields and test a block's level of vitality. The following are the results of the block repetition input.

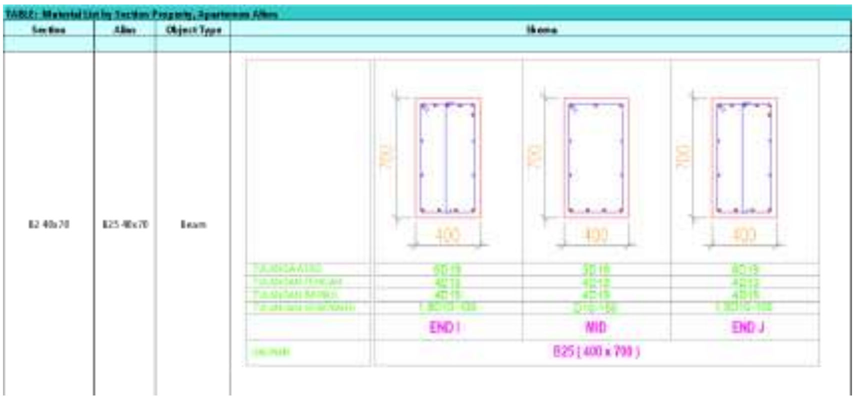

Figure 9 Repeating of B25 40x70 Beam

Figure 10 Input ETABS Repeatability Area and effective height of B25 Beam 40x70

Enter the Column Repetition Area

The repetition input is intended to check the size, diameter, number of repetitions, and quality of the repetitions. The following are the results of the input on ETABS.

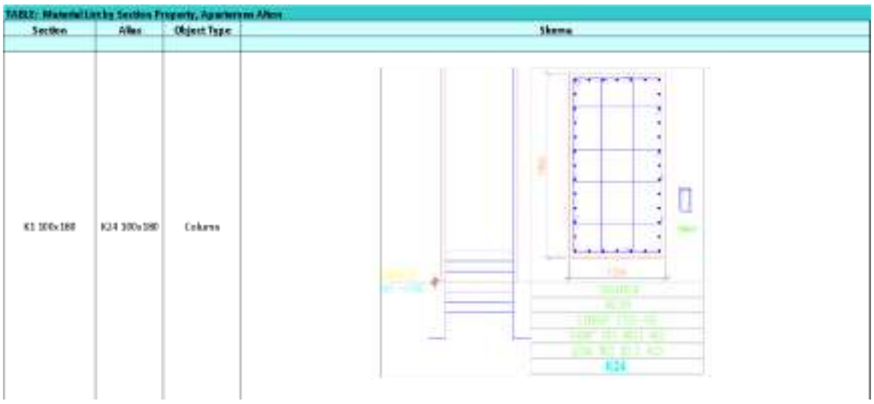

Figure 11 K24 column repetition ETABS input 100x180

Entering the Shearwall Repeating Area

The sliding wall's repetition is divided into a special boundary element area and a body area. The following is the sliding wall's repetition on ETABS.

Figure 12
Shearwall SW23 Retraction

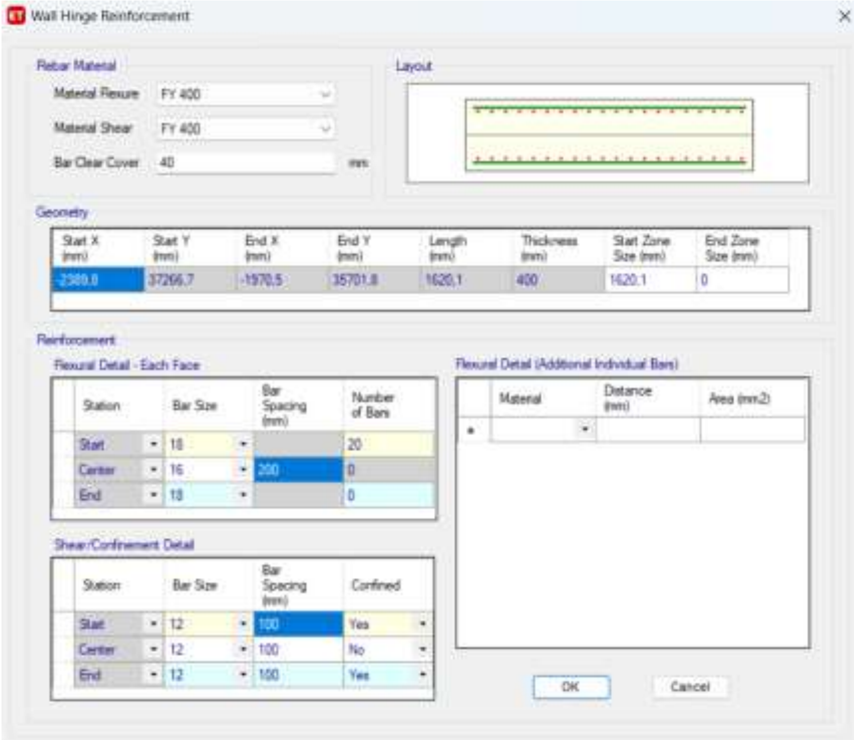

Figure 13 SW23 Shearwall Repeating ETABS Input

Mass Source Analysis and Gravitational Load Cases

In the non-linear analysis, the live load is calculated at 25% without reducing by ASCE rule 7 but not less than the actual live load.

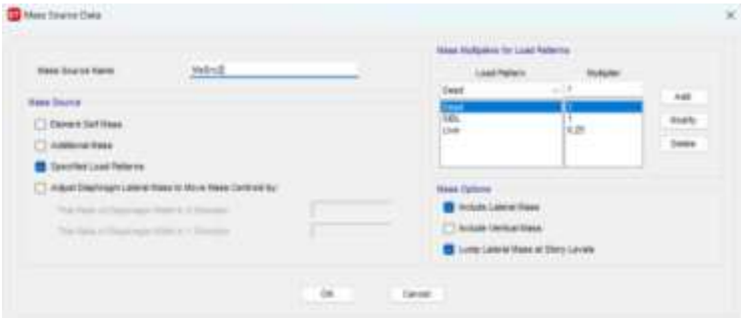

Figure 14 Mass Source

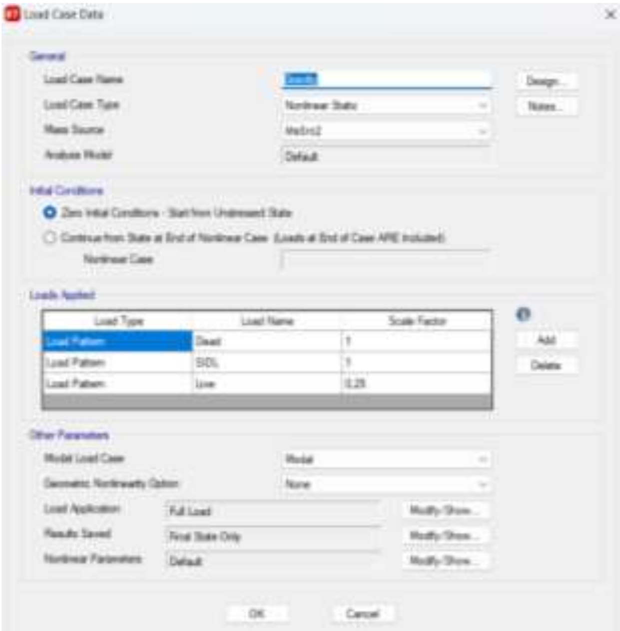

Figure 15 Gravitational Load Case

Pushover Load Case Analysis

The performance target in the Alton Apartment project is determined, namely Life Safety, with a drift of 1% according to the function of the structural concrete wall. To control the magnitude of displacement, the formula 150% x drift performance target x building height is used. This is by FEMA 356 Table C1-3 rules.

Beam Hinge Analysis

The beam hinge was determined based on the distance between the plastic joints, which is 0.05 from the left edge and 0.95 from the right edge. Then, the degree of freedom is determined using the M3 value. The repetition distribution in this study is considered conforming because, in past work practice, reinforcing the beam structure was very concerning. Beam hinge parameters are based on ASCE 41-17 rules with table 10-7.

Column Hinge Analysis

For hinge columns based on ASCE rules 41-17 with tables 10-8 and 10-9. The degree of freedom in the column is determined using P-M2-M3. The repetition of the columns is considered adequate based on the drawings as-built drawings. The axial force P is determined based on the case of gravity and gravity plus lateral load in the form of pushover load in the x and y directions.

Hinge Shearwall Analysis

This is in contrast to columns and beams, which apply sliding walls using hinge properties in the form of fiber. The following are the results of the sliding wall shell hinge assignment on ETABS.

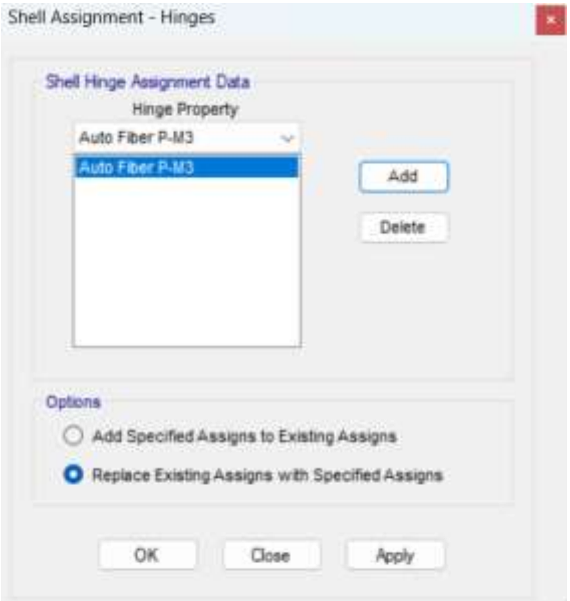

Figure 15
Shell Assignment Hinges for Sliding Walls

Performance Point Analysis

The following are the results of analyzing the performance level of buildings for pushover in the x and y directions on the 250-year and 1000-year earthquake maps. It is known that the height of the building is 96100 mm, with two basements and 30 floors that function as apartment occupancy (Nugroho, 2015). If you look at Table 2.1 ASCE 41-17 regulations, the risk category is II. On the 250-year earthquake map, the specified performance requirement is life safety (LS) if you look at Table 2.1 ASCE 41-17 with a 1% drift according to Table C1-3 FEMA 356. Meanwhile, in the 1000-year earthquake map, the specified performance requirement is collapse prevention (CP) if you look at Table 1 ASCE 41-17 with a drift of 2% according to Table C1-3 FEMA 356. The results of the breakdown are described in the form of a table.

Table 1
X-Directional Pushover Performance Point Value

	Earthquake Map	
Direction X	250	1000
Displacement (D)	327,09	483,09
Drift (D/H)	0,34%	0,50%
Performance	LS	CP
Drift limits	1%	2%
Conclusion	Meet	Meet

Table 2
Y Direction Pushover Performance Point Value

	Earthquake Map	
Direction Y	250	1000

Displacement (D)	408,67	697,22
Drift (D/H)	0,43%	0,73%
Performance	LS	CP
Drift limits	1%	2%
Conclusion	Meet	Meet

The results above show that the Alton Apartment building still meets the life safety and collapse prevention performance level.

Analisis Syarat 1 Non Linear Static Procedure

The purpose of this check is to determine whether the Non-Linear Static Procedure (NSP) analysis results can be used if the strength ratio (µstrength) is less than µmax.

Analisis Syarat 2 Non Linear Static Procedure

Checking this condition is to compare story forces of the first model structure with capital participating mass ratios of 90% and not more significant than the second model in analysis of one variety only and by taking into account 130% x Vstory forces model 2. The primary purpose of checking one variety for the second modeling is not significant for the higher mode of the first modeling (Kurniati, 2019).

Structural Ductility Calculation

The greatest is the calculation of ductility to see the level of the structure's ability to experience post-elastic deviation when it reaches the condition on the verge of collapse. The ductility value was achieved based on calculating the R-value from the pushover analysis with the formula µstrength, µmax, and RR factor. The result of the ductility value R must be achieved according to the seismic force-bearing system.

Calculation of Inter-Tier Limits

The diaphragm in the Alton Apartment research is divided into two types: diaphragm 1 (D1) and diaphragm 2 (D2). The diaphragm 1 (D1) division includes basement floors 1 to the rooftop floor with podium area, towers 1 and 2. The division of diaphragm 2 (D2) covers the 8th floor to the rooftop floor with a tower area of 3. An example of calculation is taken for the 1st floor with diaphragm 1 (D1).

Δ_a = 0,02 h
ρ = 1,3
$\Delta_{max} = \Delta_a / \rho$
Δ_{max} = 0,015 h
Cd = 5,5
Ie = 1,0
Δ_{izin} floor 1 = $\Delta_{max} \; x \; h$
Δ_{izin} floor 1 = 0,015 x 2900 mm $_{1} - \delta_{1\ lanai\ basement})$ * $Cd / Ie\Delta x$ floor 1 = (1,33 – 0,41) * 5,5 / 1,0Δx floor 1 = 5,02 mmΔy floor 1 = $(\delta_{2\ \text{lantai}\ 1} - \delta_{1\ lantai\ basement})$ * / Ie0$_{zi}$ r$\theta x\ lantai \frac{P_x\ \Delta\ I_e}{V_x\ h_{sx}\ C_d} \theta x\ la \frac{764118{,}8687\ x\ 5{,}022\ x\ 1{,}0}{11607{,}3717\ x\ 2900\ x\ 5{,}5} \theta x\ lantai\ 1 = 0{,}0207 \theta y\ lantai\ 1 = \frac{P_y\ \Delta\ I_e}{V_y\ h_{sx}\ C_d} \quad \theta y\ lantai\ 1 = \frac{764118{,}8687\ x\ 4{,}884\ x\ 1{,}0}{11499{,}2955\ x\ 2900\ x\ 5{,}5} \quad \theta y\ lantai\ 1 = 0{,}0203 \theta_{max}\ \frac{0{,}5}{\beta C_d} \leq 0{,}25 \theta_{max} = \frac{0{,}5}{1\ x\ 5{,}5} \leq 0{,}25 \theta_{max} = 0{,}0909 \theta x\ atau\ \theta y\ lantai\ 1 \leq \theta_{max}$ $0{,}207 at 0209 emenuhi$

Horizontal Irregularity Calculation

In this calculation, horizontal irregularities are calculated based on several types, namely torque irregularities, excessive torque irregularities, inner angle irregularities, diaphragm discontinuity irregularities, irregularities due to perpendicular shifts to the plane, and nonparallel system irregularities.

Conclusion

Based on the results of the analysis carried out, it can be concluded that this building can withstand the earthquake force that occurs well. The requirements for Non-Linear static procedure analysis have been met, indicating that the building has adequate strength. In addition, the ductility of buildings against earthquakes has also been fulfilled and safe. All deviation values and calculations of P-delta values show that the building remains stable and safe against the effects of earthquakes. Although horizontal irregularity adjustment is necessary, the building is safe from vertical collapse failure in the event of an earthquake. Suggestions for the next research include the addition of Linear Dynamic Procedure (LDP) analysis, review of displacement points, maintenance of the shape and function of existing spaces, and checks by earthquake maps and the latest building evaluation rules.

Bibliography

Andrio, Nur, & Masagala, Algazt Aryad. (2022). *Evaluasi Kinerja Struktur Bangunan Menggunakan Pushover Analysis Berdasarkan Fema 356 Dan Atc-40 (Studi Kasus: Gedung Hotel Asialink) Evaluation Of Building Structure Performance Using Pushover Analysis Based On Fema 356 And Atc-40 (Case Study: Asialink Hotel Building)*. University Technology Yogyakarta.

Dalo, Yohanes Debrito, Handono, Banu Dwi, & Wallah, Steenie E. (2019). Studi Assessment Kerentanan Gedung Fakultas Hukum Universitas Samratulangi Manado Menggunakan Metode Pushover Analysis. *JURNAL SIPIL STATIK*, *7*(9).

Kurniati, Dwi. (2019). Kajian Analisis Pushover Untuk Performance Based Design Pada Awana Condotel Yogyakarta. *Jurnal Rekayasa Sipil (e-Journal)*, *6*(1), 85–93.

Lalo, Finsensius. (2023). *Analisis Nonlinear Struktur Bangunan Beton Bertulang Pada Gedung Bertingkat*. Universitas Atma Jaya Yogyakarta.

Masbudi, Masbudi, Purwanto, Edy, & Supriyadi, Agus. (2015). Evaluasi Kinerja Struktur Gedung Dengan Analisis Pusover (Studi Kasus: Gedung Bedah Sentral Terpadu

Rumah Sakit Bethesda Yogyakarta). *Matriks Teknik Sipil*, *3*(4).

Muttaqin, Muttaqin, & Afifuddin, Mochammad. (2020). Evaluasi Kinerja Struktur Bangunan Gedung Serba Guna Kabupaten Pidie Jaya Akibat Gempa Dengan Menggunakan Analisis Pushover. *Journal of The Civil Engineering Student*, *2*(3), 274–280.

Nabhilla, Rinda Fitri, & Hayu, Gati Annisa. (2020). Analisis Perilaku Struktur Perkantoran Tahan Gempa Menggunakan Metode Pushover Analysis. *Siklus: Jurnal Teknik Sipil*, *6*(2), 141–154. https://doi.org/10.31849/siklus.v6i2.4889

Nugroho, Fajar. (2015). Evaluasi Kinerja Bangunan Rencana Gedung Hotel ANS dengan Dilatasi (Model B2) di Daerah Rawan Gempa. *Jurnal Momentum ISSN: 1693-752X*, *17*(2).

Partono, Windu, Irsyam, Masyhur, & Wardani, Sri Prabandiyani Retno. (2017). Development of site class and site coefficient maps of Semarang, Indonesia using field shear wave velocity data. *MATEC Web of Conferences*, *101*, 5010. https://doi.org/10.1051/matecconf/201710105010

Suwandi, Hilda Pradita. (2019). Analisis Gempa Non-Linear Static Pushover dengan Metode ATC-40 untuk Evaluasi Kinerja Struktur Bangunan Gedung. *Media Komunikasi Dunia Ilmu Sipil (MoDuluS)*, *1*(1), 35–45.