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Evaluation of Seismic Potential Performance of Unej College Buildings in Lumajang Using the Pushover Method

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Abstract

The regulation on seismic safety design standards for building structures states that Indonesia is one of the countries with a high risk of earthquakes in most areas. To know the strength of structures during an earthquake, it is necessary to evaluate the performance of buildings using a nonlinear static analysis method (pushover). This analysis is used to assess the structural performance of buildings and to design them for seismic resistance in the event of an earthquake at the building's location. This indicates that structural components have been damaged and become less rigid, but are still strong enough to withstand collapse. Non-structural components still exist, but are no longer functional, but can be reused after repair. Strong column design concept when a beam weakness is met, this is indicated by the initial formation of plastic connections on the beam elements.

Keywords: Pushover Analysis; Earthquake Earth Building Structures.

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1. Backgrounds

The Regulation on Seismic Safety Design Standards for Building Structures states that Indonesia is one of the countries most commonly recognized as a high earthquake risk area [1]. Measuring structural damage during earthquakes has always been a difficult problem for seismic engineers [2]. Following traditional seismic design thinking, the structure is designed to withstand far less than expected seismic forces [3]. According to Wiryanto Dewobroto (2005), building safety depends not only on the degree of strength but also on the degree of deformation and energy measured from the performance of the structure [4]. Essentially, the enactment of such regulations is intended to protect the human psyche from strong seismic hazards by giving buildings integrity, strength, and resilience, and avoiding complete or partial collapse [5].

The latest trend in seismic building design today is performance-based design (PBD). The concept of performance-based planning combines resilience and service aspects. The design of seismic structures in seismic zones must meet two criteria. First, structures must have sufficient strength and stiffness to control damage and prevent structural damage in frequent mild to moderate earthquakes. Second, structures must be ductile enough to prevent collapse in rare, severe earthquakes [6]. An evolution of the PBD concept, performance-based seismic design can be used to design new buildings or reconstruct existing buildings with a realistic understanding of risks to safety (life) and usability (occupancy). Process, and property losses (economic losses) that may be caused by upcoming earthquakes [7]. Two basic requirements for seismic design are high stiffness at working loads and high ductility at severe overloads. This requirement is difficult to meet using the conventional frameworks above. In contrast, carelessly reinforced frames offer an economical frame system that meets both requirements [6].

To know the strength of structures against earthquakes, it is necessary to evaluate the performance of buildings using a nonlinear static analysis method (pushover)[8]. A pushover analysis is a non-linear static analysis in which the effects of a seismic plan on the building structure are considered as static loads captured at the center of gravity of each floor, increasing until the values exceed the gradually increasing loads. It first induces melting (plastic connection) within the structure [3], and then large post-elastic deformations occur upon the further increase in load until a plastic state is reached [9]. This analysis is used to evaluate the structure of a building based on its performance in the event of an earthquake occurring at the location where the building is installed and to implement seismic design[10]. Capability curves are produced by pushover analysis. A yield curve represents the relationship between shear force (V) and displacement (D) that occurs in a structure due to an earthquake. In the pushover process, the structure is pushed until it melts and then behaves non-linearly [11]. The purpose of the Pushover analysis is to estimate the maximum forces and deformations that occur and to obtain information about which parts are important to obtain and which parts require special treatment in terms of detail and stability. is [12].

This study is very useful for determining the level of susceptibility and performance of buildings to seismic loads [2], as well as the range of magnitudes of earthquakes that can cause building collapse, given that the building is subjected to lateral loads. important [13]. Equipment required to use the SAP2000 program. 1.BackgroundsThe Regulation on Seismic Safety Design Standards for Building Structures states that Indonesia is one of the countries most commonly recognized as a high earthquake risk area [1]. Measuring structural damage during earthquakes has always been a difficult problem for seismic engineers [2]. Following traditional seismic design thinking, the structure is designed to withstand far less than expected seismic forces [3]. According to Wiryanto Dewobroto (2005), building safety depends not only on the degree of strength but also on the degree of deformation and energy measured from the performance of the structure [4]. Essentially, the enactment of such regulations is intended to protect the human psyche from strong seismic hazards by giving buildings integrity, strength, and resilience, and avoiding complete or partial collapse. [5].

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2. Methods

From the results of pushover analysis will be obtained capacity curve that shows the relationship between the basic shear force to the transition, which shows a change in the behavior of the structure from linear to non-linear,[14] in the form of a decrease in stiffness [15] This is indicated by a decrease in the slope of the curve due to the formation of plastic connections between beams and columns [11]. Shear load analysis is performed separately for each weak and strong axis direction of the building[1]. According to Lumantarna (2007), the capacity curve obtained from pushover analysis describes the strength of the structure, the magnitude of which is highly dependent on the moment-deformation capability of each component of the structure [4]. The easiest way to construct is to gradually push the structure and record the relationship between the base shear force (base shear) and the displacement of the roof due to lateral loads exerted on the structure with a certain loading pattern. The relationship is then mapped into a curve called the structural capacity curve. This method is simple but the resulting information is very useful because it can describe the inelastic response of the building. This analysis is not the best way to get answers to analysis and design problems, but it is relatively simple to get a nonlinear response structure. (Fig 1) [16].

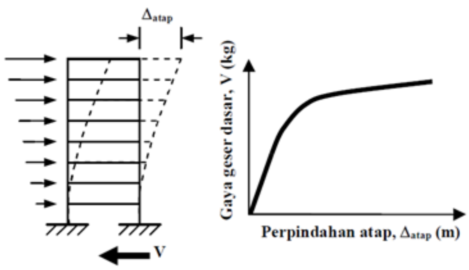

Figure 1: The Curves of Capacity (Source: Applied Technology.

Council, Report ATC-40)

2.1 Structure Performance Fema 356 Method

Based on FEMA 356, the performance of building structures during an earthquake is divided into several categories and can be seen in Figure 2.1 the level of performance in FEMA is broadly the same as the level of performance in ATC-40. nonlinear responses are related to axial /bending and shear behavior. Recently, a large number of experimental studies have shown that bending and shearing of aspect ratio walls are occurring almost simultaneously, even this interaction has been observed in lean reinforced concrete walls with an aspect ratio greater than 2.0 [17]. Numerical analysis has been developed to simulate the seismic behavior of paired wall systems by many researchers [17]. provides direct numerical calculation of maximum global displacement in structures. The solution is done by modifying the elastic response of the SDOF (single degree of freedom) system equivalent to the coefficient factors C0, C1, C2, and C3 so that the maximum global displacement (elastic and inelastic) is obtained, called the displacement target (αt). The parameters are taken from the idealization of the capacity curve of the structure or the bilinear curve of the structure. The capacity curve usually has two possible behaviors, positive and negative slopes. [12].

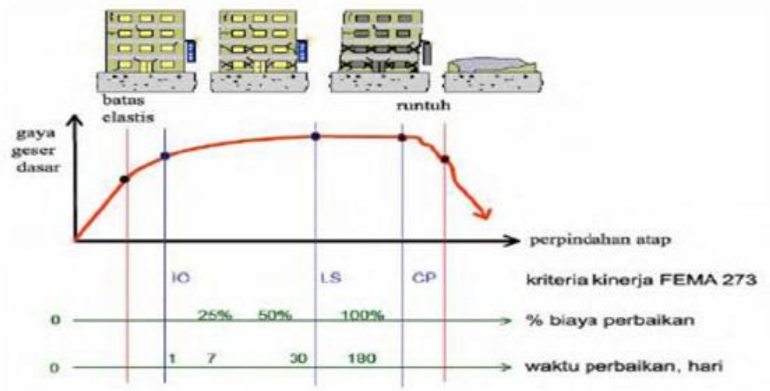

Figure 2: The capacity curve.

2.2 Structure Performance Fema 440 Method

FEMA 440 method is a development method of the FEMA 356 displacement coefficient method or can also be called the improved displacement coefficient method. In outline, the basic calculation method in FEMA 440 is the same as FEMA 356, namely with the final result of determining the displacement target value (δt). Its improvement or modification is given to determine the parameters C1 and C2.

2.3. Displacement Coefficient Based On Fema 356 And Fema 440 Method

1. Strongly withstands axial moment. For column elements, use standard PMMs with a relative spacing of 0.05 and 0.95. The default selection of column elements In PMM, there is a relationship between axial forces and moments.
2. Determination of the type of loading.
3. Thrust load analysis

The thrust load can be given based on two directions, namely x-direction, and y-direction. The result of the addition of thrust load is a structural capacity curve that shows the relationship of the basic shear force to its displacement. This curve shows the change in the behavior of the structure from linear to non-linear structure.

4. Performance evaluation.

In evaluating the performance 2 methods are based on ATC-40 and FEMA 356, namely:

a. Capacity spectrum method, which refers to the ATC-40. Building performance based on the capacity spectrum method, ATC-40 regulates by looking at the deformation limit. Drift value is used as an indicator of structural performance, using the equation:

$$\text{maximum total drift} = \frac{D_t}{H} \quad (1)$$

Drift limits for different performance level categories are based on Table 1.

Table 1: Performance Level.

	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 V_i/P_i
Maximum inelastic drift	0,005	0,005-0,015	*No limit*	*No limit*

(sumber: ATC-40)

In the displacement coefficient method, modification is made to the linear elastic response of the SDOF system equivalent to the coefficient factor, so that the maximum global displacement is obtained, called the displacement target, δT.= (2)

$$\delta_t = C_0\, C_1\, C_2\, C_3\, S_a \left(\frac{T_e}{2\pi}\right)^2 g \qquad (2)$$

For the value of the factors in Equation 2, the value refers to FEMA 356. In the displacement coefficient method improved by FEMA 440, the formulation used in determining the value of the displacement target is the same as FEMA rule 356, but some coefficients are modified and improved including in the calculation of factors C1 and C2 as follows:

$$C_1 = 1 + \frac{R-1}{aT_{e^2}}$$
$$C_2 = 1 + \frac{1}{8}\left(\frac{R-1}{T}\right)^2$$

2.4 Calculation Procedure

The calculation procedure with pushover analysis based on ATC 40 (1997) is as follows :

1. Created an analytical model of the structure to be analyzed in 2 dimensions or 3 dimensions,
2. Determined a performance criterion (performance), such as the deviation permit limit on the roof floor at a certain joint point
3. The structure is loaded with the force of gravity according to the planned load
4. The structure is then also loaded with equivalent static earthquake loads that are added gradually. Loading pattern is determined according to applicable regulations
5. Specified control points to monitor the displacement, especially in response top of the structure.
6. Furthermore, the structure is pushed (push) with a loading pattern, which has been determined in advance in stages (incremental) until it reaches the limit of the deviation permit or reaches the planned collapse
7. The relationship between base shear vs displacement controlled displacement. This curve is called the capacity curve, from here can be seen the events for different performance criteria [4].

3. Results And Discussion

Structural System Planning

Planning Data

The Data used include :

a.Number of floors: 4 floors, and roof

b.Building height: 20 m

c.Height Of Each Floor

1.1st Floor - 4: 4 m

2. Roof: 4m

d.Concrete Grade: 20.75 MPa

e.Quality Of Reinforcing Steel

1. Flexural reinforcement: 400 MPa (BJTD D10)

2. Shear reinforcement: 240 MPa (BJTP 8)

f.Building Location: Lumajang, East Java

g.Soil specifications: SD (medium soil)

Loading Data For Each Floor

Loading Data based on existing data obtained from the project and SNI 1727:2019

a.1st Floor-Mezzanine

Additional Dead Load / Super Dead Load

Cement mortar: 42 kg/m2

Mechanical & Electrical: 40 kg/ m2

Tile floor covering: 24 kg/ m2

Ceiling covering: 4 kg/ m2

Others: 10kg/ m2

Total: 120 kg/ m2

Live Load :

Classroom space: 192 kg/ m2

Corridor : 479 kg/ m2

b.Roof

Cement mortar: 50 kg/m2

Total: 50 kg / m2

Live Load :

Roof: 96 kg/ m2

Seismic data

Seismic load analysis is planned using the spectral response method. The data used is from the RSA Cipta Karya website.

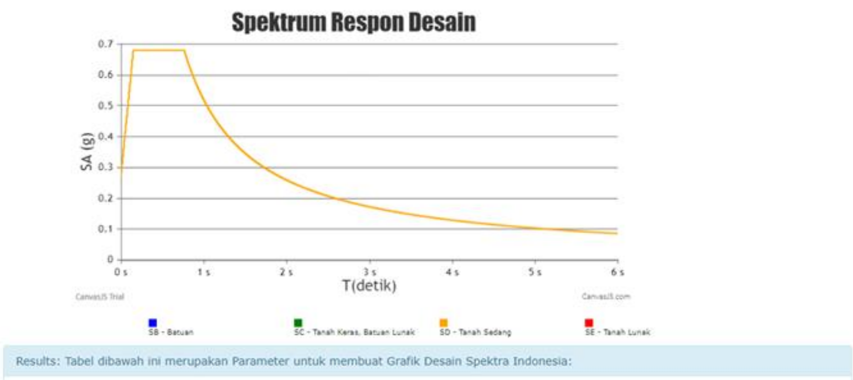

Figure 3: Spectrum Respons.

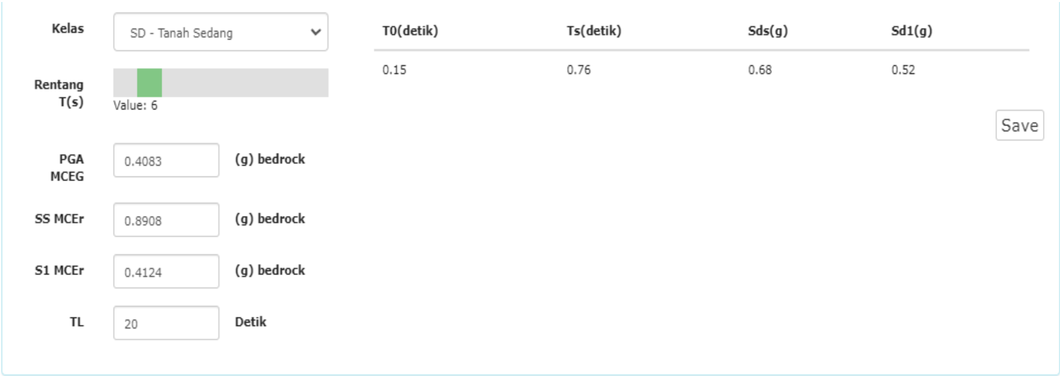

Figure 4: Seismic Response Spectrum Design Plan (Source: RSA Ciptakarya).

Structure Modeling

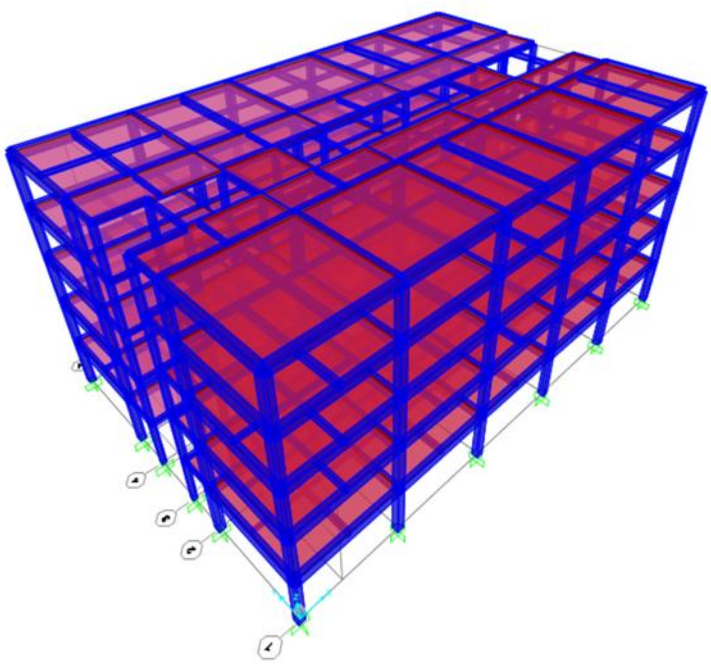

Figure 5: Modeling of the existing structure of the shear wall.

Validation

Validation was performed to properly compare the mass of the manual global structure with that of the SAP2000 modeling software.

A margin of error of 10% has been placed on the validation values to ensure that the deviations that occur are not too large.

Based on the calculation of the SAP2000 program, the results obtained are in Table 2 *Base reactions* of an existing structure

Table 2: *Base reactions* of an existing structure.

OutputCase	CaseType	GlobalFX	GlobalFY	GlobalFZ
Text	Text	Kgf	Kgf	Kgf
COMB1	Combination	7,399E-11	-4,987E-10	4710341,96
COMB2	Combination	1,052E-10	-1,819E-10	5828770,36
COMB3	Combination	1,046E-10	-1,8E-10	5807794,36
COMB4	Combination	9,226E-11	-2,843E-10	5269743,16
COMB4	Combination	6,685E-11	-4,403E-10	4177519,16
COMB5	Combination	6,685E-11	-4,403E-10	4177519,16
COMB5	Combination	6,685E-11	-4,403E-10	4177519,16

Source: Data output SAP2000, 2022

From the table is taken the largest value of 5828770.36 Kg

From manual calculations obtained the results of 5805161.6 Kg

Validation = (Pu Software-Pu Manual)/(Pu Software) x 100%

= (5828770,36 - 5805161,6)/5828770,36 x 100%

= 0,405 %

Validation control: 0.405% < 10 % (OK!) Then the structure modeling 99.595% resembles the existing structure. Structure Performance Check , Mass Participation

Capacity spectrum method, which refers to the ATC-40. Building performance based on the capacity spectrum method, ATC-40 regulates by looking at the deformation limit. Drift value is used as an indicator of structural performance, using the equation:

Table 3: Modal Participating Mass Ratio.

OutputCase	StepType	StepNum	Period	SumUX	SumUY	SumUZ
Text	Text	Unitless	Sec	Unitless	Unitless	Unitless
MODAL	Mode	1	1,987357	0,00000137	0,93969	8,342E-10
MODAL	Mode	2	1,872077	0,9464	0,93969	2,948E-09
MODAL	Mode	3	1,783078	0,94659	0,94108	3,549E-09
MODAL	Mode	4	0,574287	0,94659	0,98774	1,808E-08
MODAL	Mode	5	0,542688	0,98943	0,98774	4,951E-08
MODAL	Mode	6	0,514974	0,98945	0,98781	5,806E-08
MODAL	Mode	7	0,300093	0,98945	0,99679	6,374E-08
MODAL	Mode	8	0,288486	0,99727	0,99679	8,492E-08
MODAL	Mode	9	0,271002	0,99727	0,9968	8,807E-08
MODAL	Mode	10	0,196577	0,99727	0,9993	1,141E-07
MODAL	Mode	11	0,194339	0,99729	0,9993	1,148E-07
MODAL	Mode	12	0,192929	0,99937	0,9993	3,578E-07

Based on the table, mass participation is more than 90% in the 2nd mode. So that it has met the criteria for mass participation of more than 90%.

Structure Vibrating Period				
Acceleration design period 1 second	SD1	=	0,519	g
Coefficient for the limit period	Cu	=	1,4	
	Ct	=	0,0488	
	x	=	0,9	
Building Height (Seismik)	h	=	20 m	
Fundamental period approaches Ta		=	Ct * hx	
		=	0,6907	detik
Maximum Period	Tmax	=	Cu * Ta	
		=	0,967	detik
Analysis Result Period of X Direction	Tc,X	=	1,987	detik
Analysis Result Period of Y Direction	Tc,Y	=	1,872	detik
Period of Wear X Direction	TX	=	0,967	detik
Period of Wear Y Direction	TY	=	0,967	detik

Seismic Base Shear Force

Earthquake Acceleration Data

Acceleration of short-period design, SDS= 0,679 g

Acceleration design period 1 second, SD1 = 0,519 g

The value of the seismic response coefficient, Cs, is taken as the largest of the upper and lower boundary conditions

1. Seismic Response Coefficient

$$C_s = \frac{S_{DS}}{(\frac{R}{I_e})}$$

Example of calculation of seismic response coefficient of existing structures :

$$S_{DS} = 0{,}679g; R = 8;\ I_e = 1{,}5$$

$$C_s = \frac{S_{DS}}{(\frac{R}{I_e})} = \frac{0{,}679}{(\frac{8}{1{,}5})} = 0{,}127$$

2. Upper Limit

An example of calculating the seismic response coefficient for the upper limit of the existing structure of X direction :

$$S_{D1} = 0{,}519; T_x = 0{,}967; R = 8;\ I_e = 1{,}5 C_{s\,max} = \frac{S_{D1}}{T \cdot (\frac{R}{I_e})}$$

$$C_{s\,max\,x} = \frac{S_{D1}}{T_x \cdot (\frac{R}{I_e})} = \frac{0{,}519}{0{,}967 \cdot (\frac{8}{1{,}5})} = 0{,}1006$$

3. Lower Limit

$$C_{s\,min} = 0{,}044 S_{DS} I_e$$

Example of calculation of the coefficient of seismic response for the lower boundary of the existing structure of the shear wall :

$$S_{DS} = 0{,}679;\ I_e = 1{,}5$$

$$C_{s\,min} = 0{,}044 S_{DS} I_e = 0{,}044 \cdot 0{,}679 \cdot 1{,}5 = 0{,}0448$$

4. Wear Seismic Response Coefficient

$$C_{s\,pakai} = \text{nilai maksimum dari } C_s, C_{s\,max}, C_{s\,min}$$

Table 4: Comparison of seismic response coefficients of existing structures.

Structure	Existing
(1)	0,1273
(2)	0,1006
	0,1006
(3)	0,0448
(4)	0,1006
	0,1006

Source: Researcher’s data analysis, 2022

Effective Seismic Weight

Taken from the value of the building's weight

W = 2888849,32 kg = 28329,94 kN

Seismic Base Shear Force

V = CsW

Table 5: Comparison of earthquake dynamic basic shear forces of existing structures.

Structure	Existing
Vx	2850,65 kN
Vy	2850,65 kN

Table 6: Comparison of basic static shear forces of SAP2000 earthquake existing structures.

Structure	Existing
Vx SAP	2768,40 kN
Vy SAP	2768,40 kN

Based on Table 5 and Table 6, values of basic dynamic shear force (less than 10%) of nearby earthquakes were obtained by calculation or analysis using SAP2000. Thus, the seismic dynamic shear force already represents or replaces the static shear force value, and the base seismic dynamic shear force value can be included in the calculation.

Style Scaling

1. Initial Scale Factors

$$SF = \frac{g \cdot I_e}{R}$$

Example of calculation of the initial scale factor of the existing structure of the shear wall :

$$g = 9{,}81\ {}^{m}/_{s^2}\,;I_e = 1{,}5;\ R = 8$$

$$SF = \frac{g \cdot I_e}{R} = \frac{9{,}81 \cdot 1{,}5}{8} = 1{,}839\ {}^{m}/_{s^2}$$

2. Basic shear force structure analysis SAP2000

Based on SNI 1726: 2019 article 7.9.1.4.1, due to the variety shear force (Vt) being less than 100% of the shear force (V), The Force must be multiplied by V/Vt.

3. Earthquake-style scaling

$$f_x = \frac{V_x}{V_{tx}}$$

$$f_y = \frac{V_y}{V_{ty}}$$

Example of earthquake force scaling calculation of existing wall structure x direction :

$$V_x = 2850{,}65\ kN;\ V_{tx} = 1619{,}799\ kN$$

$$f_x = \frac{V_x}{V_{tx}} = \frac{2850{,}65}{1619{,}799} = 1{,}76$$

4. New scale factor

$$SF_{x\,baru} = f_x \cdot SF$$

$$SF_{y\,baru} = f_y \cdot SF$$

Example of calculation of the new scale factor of the existing structure of the X-direction wall :

$$f_x = 1{,}76;\ SF_x = 1{,}839\ {}^{m}/_{s^2}$$

$$SF_{x\,baru} = f_x \cdot SF = 1{,}76\ \cdot\ 1{,}839\ {}^{m}/_{s^2} = 3{,}236\,{}^{m}/_{s^2}$$

Table 4. 1: Style scaling.

Structure	Existing
(1)	1,839 m/s2
(2)	1619,799 kN
	1516,663 kN
(3)	1,76
	1,88
(4)	3,236 m/s2
	3,456 m/s2

Source: Researcher's Analysis, 2022

Thus it obtained the basic shear force analysis of the new structure close to the static equivalent.

Table 7: Basic shear force comparison.

Structure	Existing
Vtx	2850,28 kN
Vty	2850,28 kN
Vstatik x	2850,65 kN
Vstatik y	2850,65 kN

Source: Researcher's Analysis, 2022

4. Conclusion

Seismic loads should always be considered when designing the structure of a high-rise building so that components do not immediately collapse in an earthquake and potentially cause a large number of fatalities.The evaluation result is based on the target value of the largest structural change. Structural performance levels are on the line between Life Safety (SF) and Collapse Prevention (CP). This indicates that structural components are damaged and less rigid, but still strong enough to withstand collapse. Non-structural components are still present, non-functional, but can be reused after repair. Strong Column Design Concept When a beam weakness is met, this is indicated by the initial formation of plastic connections on the beam elements.

5. Suggestion

a. It is a need for a better understanding of how SAP 2000 programs work, the underlying theory of analysis, and the accuracy with which parameters are provided, to obtain more accurate analytical results.
b. perform 3D auxiliary Program is excellent for analyzing buildings by pushover method

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