

# JURNAL KONSTRUKSI DAN INFRASTRUKTUR

## Teknik Sipil dan Perencanaan

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### A COMPARATIVE ANALYSIS OF EQUIVALENT STATIC AND TIME HISTORY DYNAMIC METHODS: LOW-RISE MALL BUILDING CASE STUDY

Kaira Jesusa Prasodjo<sup>1</sup>, Yosafat Aji Pranata<sup>2\*</sup>

<sup>1</sup>) Bachelor Program in Civil Engineering, Universitas Kristen Maranatha, Bandung, Indonesia.

<sup>2</sup>) Master Program in Civil Engineering, Universitas Kristen Maranatha, Bandung, Indonesia.

\*Corresponding Author's E-mail: [yosafat.ap@maranatha.ac.id](mailto:yosafat.ap@maranatha.ac.id)

No. HP Corresponding Author: 0816623703

#### ABSTRACT

Earthquake-resistant buildings are structures designed to safely withstand both of lateral and gravity loads. The purpose of this study is to analyze the behavior of the structural, which are stiffness and strength under lateral seismic loads using equivalent static analysis and time history dynamic analysis. The maximum displacement occurs at the 5th floor, reaching 27,34 mm (X-direction) and 29,99 mm (Y-direction). These results, from comparing both analysis methods, remain below the allowable limit of 70 mm per SNI 1726:2019. Strength evaluation, based on internal force demands indicates that beam and column capacities satisfy SNI 2847:2019 requirements. The flexural and shear capacities of beams and columns were verified using the design criteria  $M_u < \phi M_n$  and  $V_u < \phi V_n$ , confirming that the structural elements are able to resist the applied bending moments and shear forces safely. In general, the 5-storey mall building in Magelang City shows strength and stiffness behavior that meets the strength and stiffness requirements, using both equivalent static analysis and time history dynamic analysis.

**Keyword:** earthquake, static equivalent, stiffness, strength, time history.

#### 1. INTRODUCTION

Earthquake-resistant reinforced concrete buildings are structures that have criteria capable of withstanding forces resulting from earthquakes with controllable damage. The basic criteria that serve as a reference for earthquake-resistant buildings are structures with sufficient stiffness, uniform distribution of mass and building strength, and structures that could undergo transitions without significant loss of strength [1]. The design of building structures is carried out carefully and with attention to safety standards so that the building can respond well to earthquakes and protect its occupants [2]. Therefore, SNI 1726:2019 [3] is required, which is a guideline used in Indonesia containing regulations for the design of earthquake-resistant buildings. The guideline provides several methods that can predict the behavior of structures due to lateral loads. Analysis methods that can be used include the equivalent static analysis and time history dynamic analysis [4].

The object of this research is a building functioning as a five-storey shopping center located in Magelang City, Central Java Province, Indonesia. In seismic design, the assessment of lateral effect is primarily based on seismic hazard parameters in accordance with Indonesian earthquake code SNI 1726:2019 [3], which represent expected ground motion types, soil conditions, and characteristic of the response. These parameters consider factors like peak ground acceleration, spectral acceleration, and soil amplification. Magelang is located within Indonesia's seismically active zone [5] and has steep terrain, so earthquakes can trigger other disasters like landslides [6].

The purpose of this study is to analyze the behavior of the structural, which are stiffness and strength under lateral seismic loads using equivalent static analysis and time history dynamic analysis. Two static and dynamic methods known to produce differing response predictions, particularly in mid-rise buildings [7]. The scope of this research focuses on a building at coordinates - 7,476913, 110,219046, with structural modeling using finite element method performed in ETABS software [8] Walls are represented as a gravity loads applied as uniform loads on main beams, while the roof and stair structures are also modeled as a gravity loads and calculated using SAP2000 software [9]. The analysis focuses on drifts (stiffness behavior) and internal forces (strength behavior) in main beams and main columns under lateral forces (seismic loads).

Equivalent static analysis simplifies analyzing structural behavior to dynamic earthquake shaking by converting motion effects into steady lateral forces. In this method, seismic forces are distributed to each floor's center of mass based on weight and height. The building are modeled as a three dimensional structure [10]. This method focuses on the dominant first vibration mode and suits for low- to mid-rise, relatively stiff buildings, providing a practical and conservative seismic demand estimates [11]. This method is chosen with time history analysis because it provides a code-based and basic method. This can be directly compared to the detailed dynamic results from time history methods, making it easier to spot differences in predicted structural behavior.

Time history dynamic analysis is a structural method that uses recorded earthquake acceleration to show a building's detailed response [12]. The response is calculated step-by-step in small time intervals using numerical integration. This provides a realistic and accurate view of seismic effects compared to simpler methods [13]. This study compares structural responses from three earthquake ground motion records: El Centro 1940 with a magnitude of 6,9 in Imperial Valley, California, which caused major structural damage; New Zealand 2003 with a magnitude of 7,2, related to plate subduction zone; and Alaska 2011 with a magnitude of 7,2, which triggered tsunami warning due to high energy [14]. These records represent strong earthquakes with varied tectonic characteristics and response patterns, making them ideal for analyzing structural performance under varied dynamic loads. Their use supports the comparison between Equivalent Static Analysis, which converts seismic effects to code-based lateral forces, and Time History Analysis, which tracks detailed time-based responses, allowing differences in predicted structural behavior.

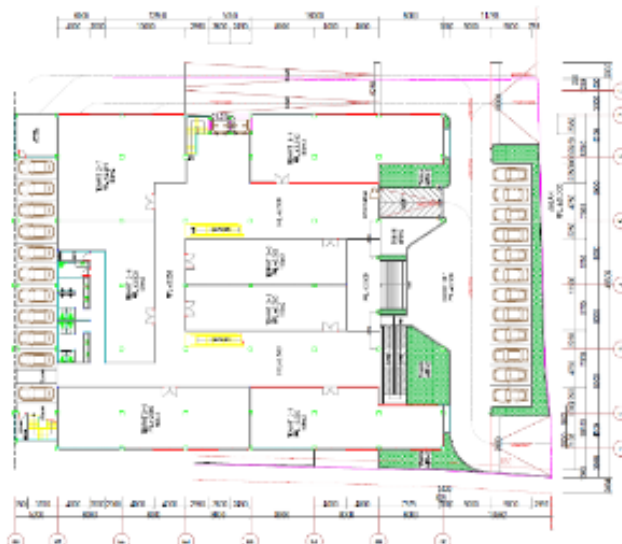
The 3D building was modeled using ETABS software [8] to compare the displacements occurring statically and dynamically based on actual earthquake records[15]. Through ETABS modeling [9] displacement values can be obtained and then compared with SNI 1726:2019 [3] to determine the allowable displacement requirements [16]. Load calculations can also be performed with the assistance of SAP2000 modeling [9] to obtain support reaction values [17].

## **2. RESEARCH METHOD**

The analysis method in this study uses numerical finite element analysis. Based on SNI 1726:2019 [3], the study applies equivalent static analysis and time history dynamic analysis to a five-storey mall building in Magelang City (Figure 1 to Figure 5). The main steps start with collecting structural and material data, then building a 3D structural model in ETABS [8].



**Figure 1.** Floor plan of the first-floor building [18]



**Figure 2.** Floor plan of the second-floor building [18]



**Figure 3.** Floor plan of the third-floor building [18]



Figure 4. Floor plan of the fourth-floor building [18]

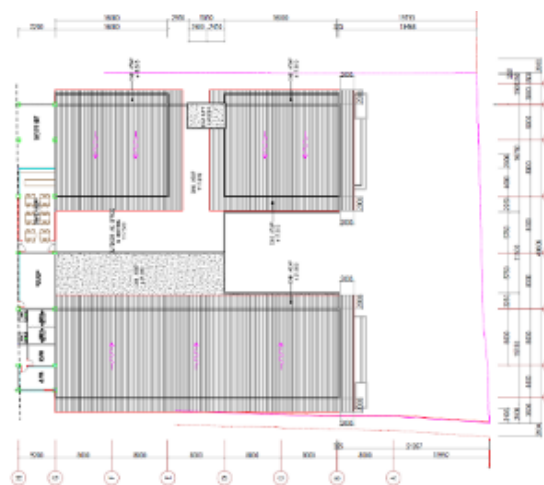


Figure 5. Floor plan of the fifth-floor building [18]

Roof and stair components are modeled separately in SAP2000 [9] for better accuracy. The structural responses obtained such as displacements and internal forces in beams and columns are then compared to assessing stiffness and strength performance under both analysis methods. The resulting structural responses, including displacements and internal forces in beams and columns, are then compared to evaluate stiffness and strength performance under both analysis methods.

Table 1. Description of the 5-story mall building

Building Specifications	Descriptions
Structural system	Special moment resisting reinforced concrete frame
Building function	Shopping center
Building height	21,06 m
First floor	2,50 m
Second floor	6,08 m
Third floor	4,48 m
Fourth floor	4,50 m
Fifth floor	3,50 m
Compressive strength ( $f_c'$ )	30 MPa
Modulus of elasticity (E)	25.742,96 MPa
Yield stress of BJ 40 ( $f_y$ )	400 MPa

Source: Result Analysis, 2025.

**Table 2.** Design spectral data for the location of the five-story mall building in Magelang City

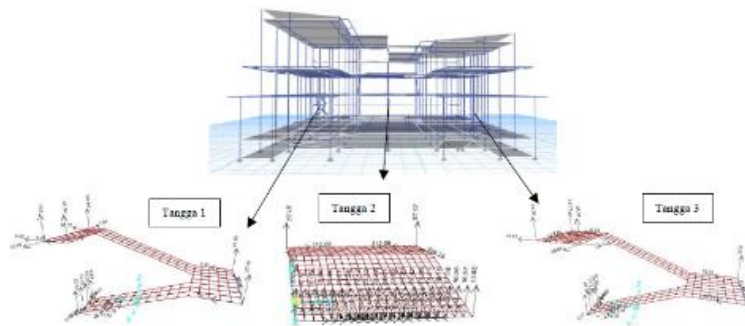
Description	Details
Coordinates	-7,476, 110,219
Soil type	Medium soil
Short period spectral response acceleration parameter ( $S_S$ )	0,7610 g
Spectral response acceleration parameter at a 1 second period ( $S_1$ )	0,3450 g
Short period spectral response acceleration parameter ( $S_{DS}$ )	0,6066 g
Spectral response acceleration parameter at a 1 second period ( $S_{D1}$ )	0,4507 g
Seismic design category	D
Peak ground acceleration (PGA)	0,3390 g

Source: PuSGen, 2021.

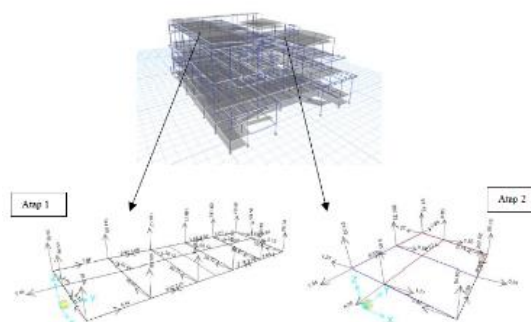
The structural model includes columns, beams, slabs, and walls, with walls represented as uniform loads. Applied loads consist of gravity loads (dead and live loads based on room functions, as shown in the floor plans in Figures 1–5) and earthquake acceleration loads obtained from local soil data for Magelang City as well as design ground motions from the NGA Subduction Ground Motion Portal, including records from El Centro, New Zealand, and Alaska for comparison [14]. The structure used in this mall building is a reinforced concrete frame. The specifications and descriptions of the building studied in this research are fully presented in Table 1 and Table 2.

### 3. RESULT AND DISCUSSION

The modeling of stairs and roofs include creating geometry and applying dead and live loads according to SNI 1727:2020 [19] using SAP2000 [9]. The resulting support reactions are then applied as concentrated loads on the stair and roof beam models in ETABS [8].



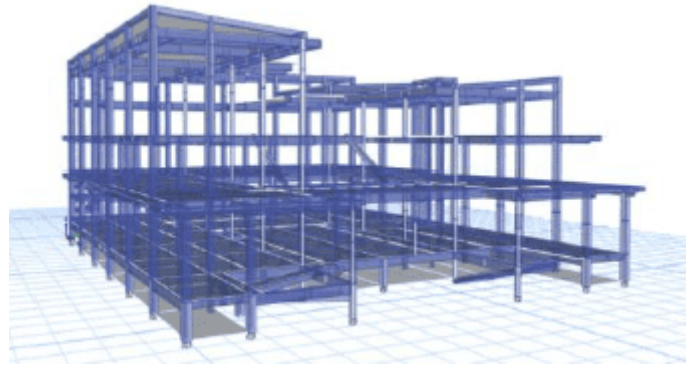
**Figure 6.** Modeling of stairs using SAP2000 [20]



**Figure 7.** Modeling of roofs using SAP2000 [20]

Support reactions are the forces at the support points caused by the building's loads. The supports distribute these forces to the lower parts of the structure, creating reactions that balance them [20]. In this mall building, there are three staircase models, their locations shown in Figure 6. Figure 7 illustrates the modeling results for two different roof models.

The building structure modeled in the ETABS software [8] consists of columns, beams, and slabs as shown in Figure 8. These structural components support the non-structural components to form a unified whole [21]. The loading includes dead loads, live loads, rainwater loads, and earthquake loads [22]. Rainwater loads are applied to areas without a roof, while earthquake loads comprise static loads in the X and Y directions, as well as seismic data from El Centro, New Zealand, and Alaska.



**Figure 8.** Structural modeling diagram of a building using ETABS [23]

In the application of time history dynamic analysis, a scale factor is used to adjust the earthquake data to comply with the building seismic design standards. According to SNI 1726:2019 [3], the peak ground acceleration in Magelang City must be adjusted according to the site classification, which is medium soil. To calculate earthquake scaling, the original peak ground acceleration data is required, which can be obtained from the SeismoSignal software [24]. The earthquake scaling calculation results are presented in Table 3.

$$PGA_M = F_{PGA} \times PGA \quad (1)$$

Where:

$PGA_M$  = peak ground acceleration according to site class (g)

$F_{PGA}$  = site coefficient for PGA

$PGA$  = mapped peak ground acceleration (g).

(Source: BSN, 2019a)

**Table 3.** Earthquake record accelerogram scale

Earthquake Record	Inherent Peak Ground Acceleration (g)	$PGA_M(\text{scaled})$ (g)	Earthquake Scale (g)
El Centro,1940	0,28080	0,0534	0,1902
New Zealand, 2003	0,00947	0,0534	5,6389
Alaska, 2011	0,01967	0,0534	2,7148

Source: Result Analysis, 2025.

**Table 4.** Displacement results in the X direction

Floor	Equivalent Static (mm)	El Centro Earthquake (mm)	New Zealand Earthquake (mm)	Alaska Earthquake (mm)
Fifth floor	23,28	24,60	26,03	27,34
Fourth floor	15,39	15,67	18,20	17,82
Third floor	11,08	11,40	13,57	12,31
Second floor	0,92	0,92	1,10	1,00

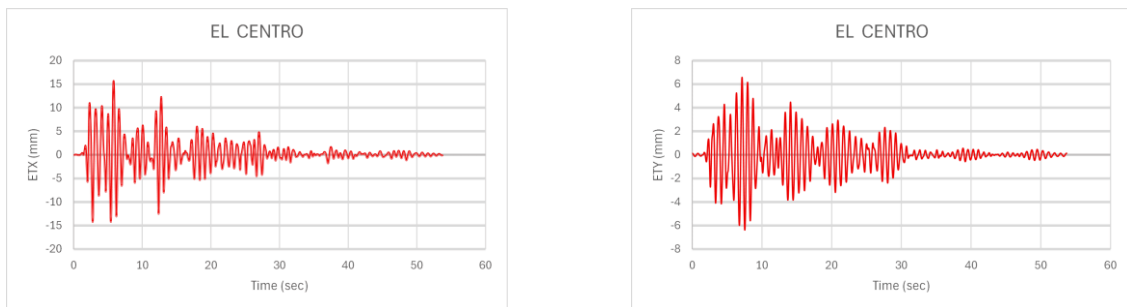
Source: Result Analysis, 2025.

**Table 5.** Displacement results in the Y direction

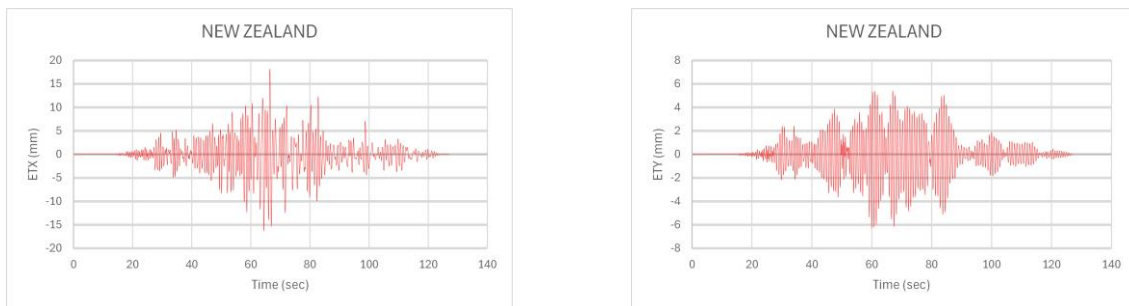
Floor	Equivalent Static (mm)	El Centro Earthquake (mm)	New Zealand Earthquake (mm)	Alaska Earthquake (mm)
Fifth floor	28,09	29,99	28,54	28,39
Fourth floor	18,54	19,70	19,94	19,78
Third floor	10,85	11,77	12,12	11,92
Second floor	1,66	1,84	1,90	1,85

Source: Result Analysis, 2025.

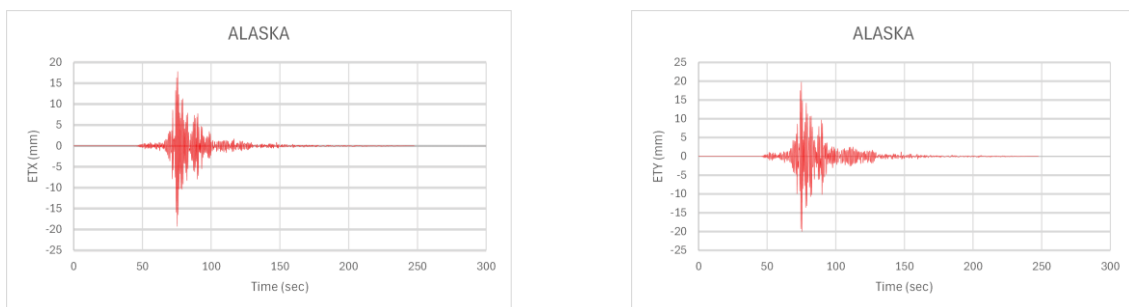
Displacement is a term describing the change in an object's position due to applied forces. Tables 4 and 5 present a comparison of displacement results obtained using the equivalent static analysis method and time history dynamic analysis (data was taken at the largest displacement during the lateral loading time history). Figures 9 to 11, on the other hand, show the time history dynamic earthquake graphs.



**Figure 9.** Graph of El Centro earthquake displacement in the X direction (left) and Y direction (right) [28]



**Figure 10.** Graph of New Zealand earthquake displacement in the X direction (left) and Y direction (right) [28]



**Figure 11.** Graph of Alaska earthquake displacement in the X direction (left) and Y direction (right) [24]

Column is a vertical structural element that resists loads from beams. Internal forces generated by applied loads were obtained through ETABS modeling [8] for the columns examined in this study, as shown in Figure 12. These internal force results were then evaluated using SPColumn software [25] to determine the building's safety level [26]. Table 6 presents result for a 500 × 500 mm column on the fourth floor, selected as a representative column experiencing high internal force demand. The ultimate moment is lower than the moment capacity, indicating the column has sufficient strength to resist the applied loads.

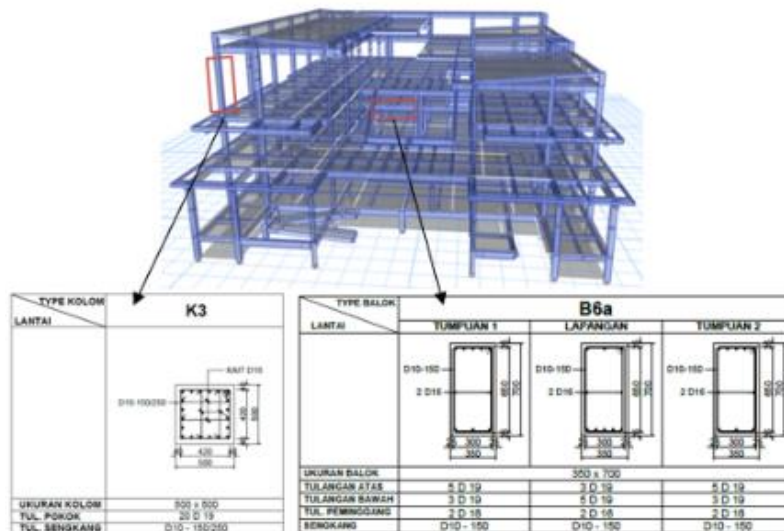


Figure 12. The beam and column investigated [20]

Table 6. Results of internal forces in the column

Earthquake Records	$P_u$	$M_{ux}$	$M_{uy}$	$\phi M_{nx}$	$\phi M_{ny}$	$\frac{\phi M_n}{M_u}$	Description
	kN	kNm	kNm	kNm	kNm		
Equivalent static	-65,93	191,31	222,90	252,94	294,71	1,3220	Safe
El Centro	-17,76	255,03	230,60	287,00	259,51	1,1250	Safe
New Zealand	16,79	254,71	225,09	289,24	255,61	1,1360	Safe
Alaska	28,06	287,21	249,01	291,54	252,76	1,0150	Safe

Source: Result Analysis, 2025.

Beam is a horizontal structural element that transfers loads from the upper structure to the columns [27]. Tables 7 and 8 show internal force results for a 350 mm × 700 mm beam on the 3rd floor as shown in Figure 12, selected as a representative primary beam subjected to significant bending and shear. Reinforced concrete beam design must satisfy  $M_u < \phi M_n$  and  $V_u < \phi V_n$  to ensure structural safety.

Table 7. Results of internal moments in the beam

Earthquake Records	$M_u$	$\phi M_n$	$\frac{\phi M_n}{M_u}$	Description
	kNm	kNm		
Equivalent static	397,31	514,24	1,2943	Safe
El Centro	430,63	514,24	1,1942	Safe
New Zealand	393,95	514,24	1,3053	Safe
Alaska	369,75	514,24	1,3908	Safe

Source: Result Analysis, 2025.

**Table 8.** Results of shear forces in the beam

Earthquake Records	$V_u$	$\phi V_n$	$\frac{\phi V_n}{V_u}$	Description
	kN	kN		
Equivalent static	218,31	233,79	1,0709	Safe
El Centro	208,46	233,79	1,1215	Safe
New Zealand	217,53	233,79	1,0748	Safe
Alaska	210,88	233,79	1,1087	Safe

From the displacement results, the maximum response occurred at the 5th floor, with the largest displacement in the X direction caused by the Alaska record and the largest displacement in the Y direction caused by the El Centro record due to dominant dynamic effects. Time history analysis produced slightly higher displacements, which were 27,34 mm in the X direction and 29,99 mm in the Y direction, compared with equivalent static analysis, which gave 23,28 mm in the X direction and 28,09 mm in the Y direction. However, all values remain well below the allowable limit of 70 mm, which equals 0,02 multiplied by 3500 mm (the height of the 5th floor), as specified in SNI 1726:2019 [3], indicating that the building maintains sufficient stiffness and can be considered structurally safe against the evaluated seismic demands.

Evaluation of internal forces shows that, in both analysis methods, the maximum factored load effects in columns and beams remain below their nominal capacities, indicating sufficient structural strength. In the time history analysis, variations in frequency, duration, and acceleration affect internal force responses. The Alaska record caused the largest column moment with a ratio of 1,015. El Centro produced the largest beam moment with a ratio of 1,1942. The highest beam shear capacity of 1,0709 occurred under equivalent static loads. Overall, these capacity ratios show that columns and beams meet SNI 2847:2019 [28] strength requirements. This confirms the building is structurally safe under the tested seismic loads.

#### 4. CONCLUSION

The research results indicate that the structural stiffness under the design earthquake load, represented by the displacement, showed a maximum value of 27,34 mm in the X-direction and 29,99 mm in the Y-direction. Both occurred on the 5th floor. The displacement results in both directions are lower than the allowable limit of 70 mm, meaning the structure satisfies the stiffness requirements according to SNI 1726:2019 regulations. The strength of the structure is determined by the internal forces acting on it. The capacity analysis results of the beam and column elements in resisting these internal forces indicate that the capacity still meets the safety requirements according to the strength provisions of SNI 2847:2019. In general, the 5-story mall building located in Magelang City demonstrates strength and stiffness behavior that complies with the strength and stiffness requirements, using two lateral load models analyzed by equivalent static and time history dynamic methods. This research has a limitation; the time history dynamic analysis assumes linear elastic behavior for the element model. Therefore, future research could consider using structural modeling and analysis that accounts for the nonlinear behavior of building structural elements.

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