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ALTERNATIVE SHEAR WALL DESIGN ON POLINEMA AC BUILDING STRUCTURE: Story Drift Perspective Due to Earthquake

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ABSTRACT

Shear walls in high-rise buildings enhance resistance against lateral loads. This study compares the performance of four different shear wall configurations in an eight-stories building designed with a dual structural system using the Response Spectrum method, including structural period, shear force, story drift, and cost. Four shear wall configurations are planned: (1) Existing Condition with Core Wall shear walls on the right and left sides (SW0); (2) Frame Wall in an L shape around the lift and stairs (SW1); (3) Two L shapes around the lift and stairs and two I shapes on the facade (SW2); and (4) I shapes around the lift, stairs, and facade (SW3). Simulations were conducted using ETABS, considering dead loads, live loads, and earthquake loads. Cost estimate for shear walls of each alternative. Based on Structural Performance analysis Shear wall alternatives 2 (SW2) performs best compared to others models. Based on the Cost Comparison SW0 is the cheapest among other configurations, however, from the structural performance perspective, SW2 & SW3 perform much better than those in SW0.

Keywords : Shear Wall, Dual System, Structural Performance, Cost Estimate

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1. INTRODUCTION

Shear walls in high-rise buildings serve to enhance the resistance of tall buildings against lateral loads. The research (Pratama, 2021) compares the performance of an existing 8-stories building designed as a special moment-resisting frame (SMRF) structure with the same building redesigned as a dual structural system (wall-frame structure) comparing 3 configurations of shear wall. The comparison includes: Period Structure, shear force, and Story drift [1].

The Accounting and Business Administration Lecture Building of Politeknik Negeri Malang is selected as the research object. This research aims to compare the structural performance of an 8-stories building utilizing a dual structural system. Unlike previous studies that compared existing conditions using Special Moment Resisting Frame (SMRF) systems, this research examines existing conditions that already employ a dual system and compares them with alternatives of shear wall configurations. The comparison focuses on the structural performance of different variations in shear wall placement configurations compared to the existing layout. Three new configurations of shear wall placements are further proposed and analyzed. Simulations are conducted utilizing ETABS software, considering dead loads, live loads, and seismic loads. Before comparing the structural performance, all configurations must satisfy the dual system requirements. Furthermore, the structural performance metrics such as structural period, shear force, and story drift are evaluated extensively, as well as cost comparison for each configuration is also provided. In conclusion, a shear wall design with the most optimal performance based on the research findings will be recommended.

Literature Review

This study will use the response spectrum method based on SNI 1726:2019 [2]. The research includes five controls used to evaluate a building to be categorized as an earthquake-resistant building, namely dual structural system requirement, structural period, shear force, and story drift. After that Cost estimate was also reviewed.

A. Dual System

Based on SNI 1726:2019 [2] Article 7.2.5.1 states that for dual structural systems, moment-resisting frames must be capable of resisting at least 25% of the seismic design forces. The total seismic force resistance should be provided by a combination of moment-resisting frames and shear walls or bracing frames, with proportional distribution based on their stiffness. In essence, for dual systems, the frames should be able to withstand at least 25% of their seismic forces.

B. Structural Period

The structural period of structure inherent characteristic of the structure, influenced by the mass and stiffness of the building [3]. The fundamental period of the structure (T), in the direction under review should be obtained using the structural properties and deformation characteristics of the bearing elements in the tested analyses [2]. Every configuration of the structure should have a unique structural period.

C. Shear Force

The impact of an earthquake on building structures is usually modeled by the occurrence of shear forces acting at the base of the building, which is referred to as the shear force [4]. In the response spectrum method, the static equivalent shear force value must be equal to the dynamic shear force that occurs in the response spectrum method. Shear force value can calculate with equation (V = Cs.Wt)

D. Story Drift

Seismic forces greatly affect the structure; when the structure encounters large seismic forces, it may result in large horizontal drift, which can cause structural failure. Therefore, necessary attempts are required to address this issue [5]. Drift can be used to measure the safety level of a building structure in withstanding seismic forces. In this study, the story drift limit can be determined using the equation $\frac{0.01\,hx}{\rho}$, with the value of ρ is 1,3. The story drift occurring at each story can be calculated using the equation $\frac{\delta_x . Cd}{Ie}$.

δ_x = Elastic displacement
Cd = Lateral deviation magnification factor
Ie = Seismic importance factor

E. Cost Estimate

Cost Estimate is the determination of potential construction costs of any given project. Many items (such as materials, labor, equipment, insurance, overhead, estimated profit, and others) affect and contribute to the cost of a building project. Each item must be analyzed, quantified, and priced [6]. This study will analyze the cost of each shear wall alternative with the equation (volume x Unit Price).

2. METHOD

The following explanation elaborates stages that are conducted in this research:

A. Loading Calculation

The structural loading refers to SNI 1727-2020 [7], with the following details:

Dead Load

The dead load on the structure consists of the structure's self-weight and Superimposed Dead Load (SDL). Self-weight will automatically be calculated by ETABS with the density of concrete being 23.6 kN/m³. The additional dead loads on the floor slabs of levels 1-8 consist of 30mm lightweight concrete, 19mm ceramic or quarry tile, acoustical fiberboard, suspended steel channel system, 50mm sand, and MEP amounting to 2.31 kN/m². Calculation details are shown in the table 1 below:

Table 1. Coefficient of Superimposed Dead Load (SDL)

No.	Components in Building	units	Load (kN/m2)
1	Lightweight Concrete, per mm	30	0.45
2	Ceramic or quarry tile (19 mm)		0.77
3	Acoustical fiberboard		0.05
4	Suspended steel channel system		0.1
5	Sand per mm	50	0.75
6	MEP		0.19
		Total	2.31

Source: SNI 1727:2020

Live Load

The building is intended to function as a facility for lectures, with a planned load of 1.92 kN/m², and the live load on the roof is 0.96 kN/m².

Seismic Load

The calculation of seismic loads refers to SNI 1726-2019 regarding the calculation of seismic loads on buildings and non-building structures. The seismic loads are planned in the form of spectral response using the data in Table 2. The spectral response curve is shown in Figure 1.

Table 2. Seismic Load Planning Data

Function	: Lecture Building
Location	: Malang City
Site Class	: SD
S_{DS}	: 0.627g
S_{D1}	: 0.277g
KDS	: D

Source: Analysis Result

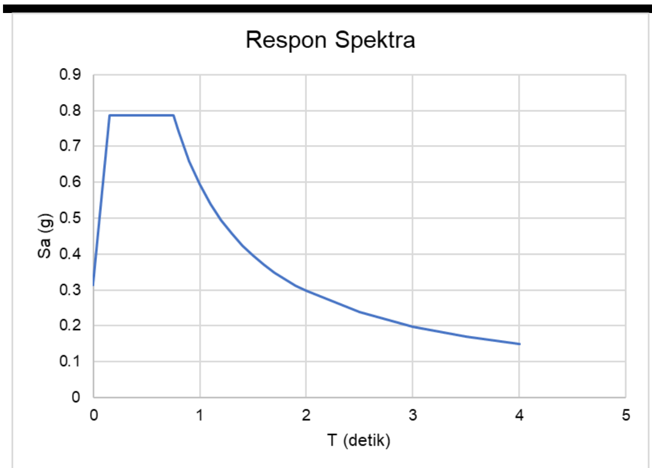

Figure 1. Response Spectral Curve
Source: Analysis Result

B. Structure Modeling

The modeling of the building structure is done by inputting the structural elements with dimensions, configurations, and material properties according to the design data. The structure is planned using concrete with a strength of 30 MPa for the frame, 35 MPa for the shear walls, and deformed reinforcement using fy = 420, and plain reinforcement using fy = 240.

Slab

The types of slabs are differentiated based on their usage with details shown in Table 3.

Table 3. Slab Dimension

Code	Dimension (cm)
P_1	12
P_2	15

Source: Analysis Report

For the slab, there are two types P1, and P2, where P2 are placed at the meeting room on the 2nd floor, and the remaining placement of the slab using P1.

Beam

The dimensions of the beams are shown in Table 4.

Table 4. Beam Dimension

Code	Dimension (cm)
B_{1A}	80/120
B_1	35/70
B_2	30/60
B_{2A}	30/60
B_3	30/40
B_4	25/50
B_5	25/40
B_6	40/80
B_7	15/30
B_8	20/40

Source: Analysis Result

Beam B1A is especially placed at the meeting room on the 2nd floor, for other types of beam placed at every story in models.

Column

There are several types of columns in the building model. The details of the column dimensions are shown in Table 5.

Table 5. Column Dimension

Code	Dimension (cm)
K_1	80/80
K_2	100/100
K_3	40/40
K_4	30/30
K_5	20/20

Source: Analysis Report

Column K2 is especially placed on the 1st, and 2nd floor, for other types of column placed at every story in models.

Shear Wall

The dimensions of the existing shear wall thickness are shown in Table 6. The new shear walls are designed based on the requirements of SNI 2847-2019 [8], Article 11.3.1.1, with new shear wall thicknesses of 200 and 250 mm.

Table 6. Shear Wall Dimension

Code	Dimension (cm)
SW_{EKS}	20
$SW_{1\ NEW}$	20
$SW_{2\ NEW}$	25

Source: Analysis Result

C. Shear Wall Configuration

Based on the explanation, the configuration of the shear walls must consider several requirements, such as the following:

a. Usually located in the core area of lifts/stairs.
b. Often placed along the transverse direction of the building, either as exterior facades or interior walls.
c. Placing L-shaped shear walls symmetrically on two axes at each corner of the building can provide optimal structural performance.
d. The placement of shear walls in the structure needs to consider the eccentricity between the center of mass and the center of stiffness of the structure.

At this research, The configuration of shear wall placements is further analyzed in 4 (four) different forms, such as the following: (1) Existing Condition where the shear walls are located on the right and left sides of the building in the form of a Core Wall (SW0); (2) Frame Walls located on the left and right sides in an L shape placed near the elevator and stairs (SW1); (3) Two L shapes located near the elevator and stairs, and two I shapes as the building facade (SW2); and (4) I shape located near the elevator, stairs, and facade (SW3). The configuration of shear wall placements is shown in Figure 2 to Figure 5.

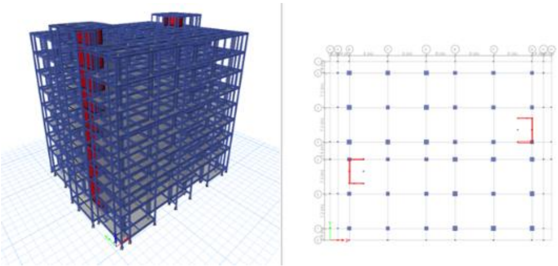

Figure 2. Existing Model (SW0)
Source: ETABS Model of Existing Structure

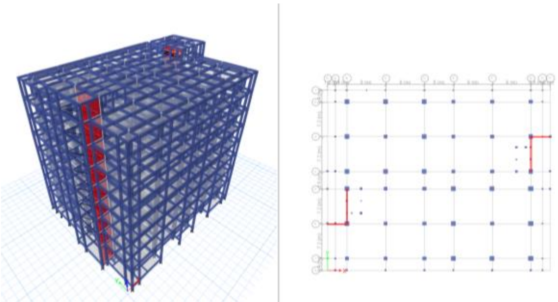

Figure 3. Alternative Design 1 (SW1)
Source: ETABS Model of New Structure

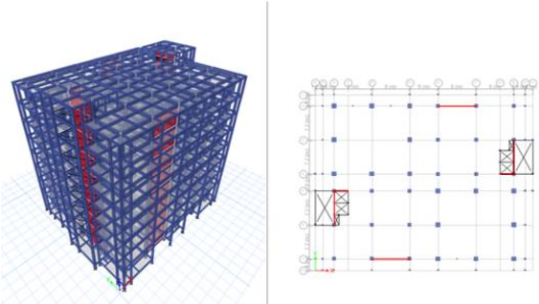

Figure 4. Alternative Design 2 (SW2)
Source: ETABS Model of New Structure

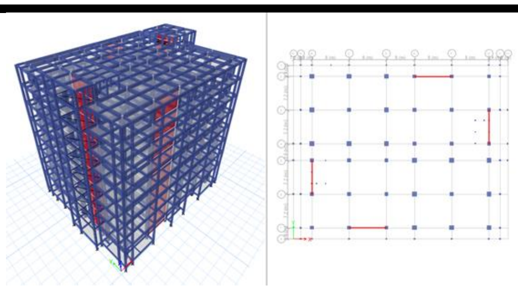

Figure 5. Alternative Design 3 (SW3)
Source: ETABS Model of New Structure

D. Research Flow Chart

The research process can be carried out in several stages, as shown in the flow chart in Figure 6 below:

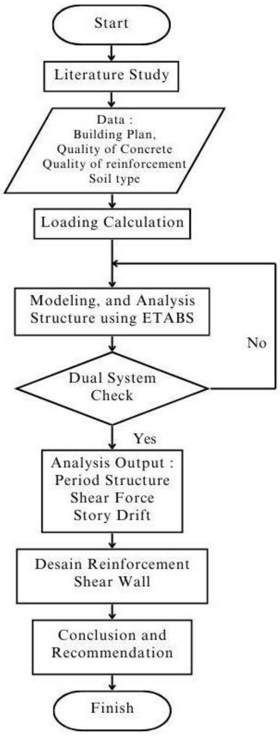

Figure 6. Research Flowchart
Source: Analysis Result

3. RESULT AND DISCUSSION

Below, the results of this research will be explained:

A. Dual System

Since the dual structural systems, moment-resisting frames must be capable of resisting at least 25% of the seismic design forces, the analysis was conducted with the result as presented in table 7.

Table 7. Dual System Requirement

Model	System	Seismic X-dir	Seismic Y-dir

SW0	SW	42.84%	51.18%
	Frame	57.16%	48.82%
SW1	SW	41.12%	59.15%
	Frame	58.88%	40.85%
SW2	SW	70.87%	74.39%
	Frame	29.13%	25.61%
SW3	SW	73.82%	73.18%
	Frame	26.18%	26.82%

Source: Analysis Result

B. Structural Period

For multi-storey buildings, the structural vibration period must not exceed the value of the coefficient (C_u) and the approximate natural period (T_a). According to SNI 1726-2019 [2], Article 7.8.6.2, the maximum vibration period (T_{max}) serves as a limit to prevent P-delta effects, excessive inter-storey drift, serviceability issues for occupants, and to avoid potential structural or non-structural damage. The result as presented in table 8, and table 9.

Table 8. Structural Period X-dir

Model	T_a (sec)	T_{max} (sec)	T_c (sec)	Sig (%)
SW_0	0.8606	1.205	2.198	-
SW_1	0.8606	1.205	2.206	0.36
SW_2	0.8606	1.205	1.498	-31.85
SW_3	0.8606	1.205	1.531	-30.35

Source: Analysis Result

Table 9. Structural Period Y-dir

Model	T_a (sec)	T_{max} (sec)	T_c (sec)	Sig (%)
SW_0	0.8606	1.205	2.206	-
SW_1	0.8606	1.205	1.391	-36.94
SW_2	0.8606	1.205	1.381	-37.40
SW_3	0.8606	1.205	1.482	-32.82

Source: Analysis Result

The analysis results indicate that the natural vibration period (T_c) of the new model can reduce the period values compared to the old model, except for the SW1 X-dir, which shows an increase of 34.573%. However, all Tc values exceed (T_{max}).

C. Shear Force

Based on SNI 1726:2019, the equivalent lateral force procedure in determining seismic base shear uses the formula $V= C_S.W$, with C_S Value is 0.1252, and W value get from Analysis in ETABS for every model. The result of Shear force value as presented in table 10, and table 11.

Table 10. Shear force Analysis Manual and Dynamic

Model		SW0	SW1	SW2	SW3
Static	X (kN)		17950.02	17964.96	18186.80
	Y (kN)		17950.02	17964.96	18186.80
Dinamic	X (kN)		17950.02	17964.96	18186.80
	Y (kN)		17950.02	17964.96	18186.80

Source: Analysis Result

Table 11. Comparation of Shear force

Model	X -dir (kN) Sig. (%)	Y-dir (kN) Sig. (%)
SW0	17950.016 -	17950.016 -
SW1	17964.9612 0.083%	17964.9612 0.083%
SW2	18186.79615 1.319%	18186.79615 1.319%
SW3	18039.8351 0.500%	18039.8351 0.500%

Source: Analysis Result

From above analysis, Shear force in 3 (three) new analysis models have increased compared to the existing model in the x and y directions.

Story Drift

Figure 7, and figure 8, It shows that the story drift of shear walls in SW2 model can reduce story drift value larger than other models.

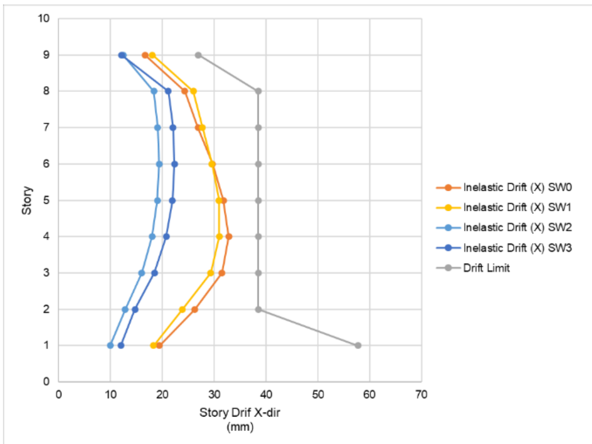

Figure 7. Graph Comparison of Story Drift X-dir
Source: Analysis Result

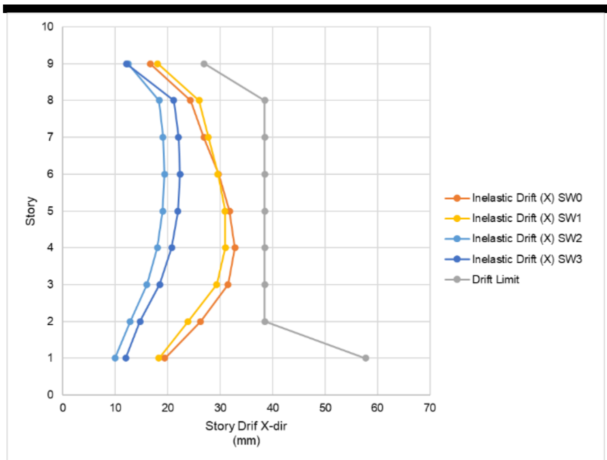

Figure 8. Graph Comparison of Story Drift Y-dir
Source: Analysis Result

D. Cost Estimate

At table 12, It indicates the estimated cost calculation for shear wall construction with a unit price of Rp. 7,779,212.83/m^3

Table 12. Cost Estimate of Shear Wall

Model	Volume	Total (Rp)	
SW0	200.124	Rp	1,556,807,188.99
SW1	205.632	Rp	1,599,655,093.28
SW2	298.368	Rp	2,321,068,174.56
SW3	254.304	Rp	1,978,284,940.28

Source: Analysis Result

The unit price of the work is based on the Unit Price of Construction Work (HSPK) for Reinforced Concrete Wall Construction in Malang City. These calculation results can serve as an alternative for readers, allowing them to compare the effectiveness of other analyses conducted at this price point.

4. Conclusion

Based on the analysis and discussion above, a few information can be concluded as follows:

1. Based on the comparison of Structural performance, SW2 exhibits the best performance out of all the other models. The following explanations are the result of analysis:
   a. Structural Period for the SW1 model, the structural period in the x-axis increased by 0.36%, while the y-axis reduced by 36.94%. Structural period for the SW2 model, the structural period in the x-axis reduced by 31.85%, while the y-axis reduced by 37.40%. Structural period for the SW3 model, the structural period in the x-axis reduced by 30.35%, while the y-axis reduced by 32.82%.
   b. Story Drift for the SW1 model, inter-story drift values for floors 1 to 6 were reduced, but the drift values for floors 7 to the top increased in the x-axis direction. In the y-axis direction, inter-story drift was reduced on each floor. Story drift for the SW2 model, inter-story drift was reduced on each floor for both the x and y axes. Story drift for the SW3 model, inter-story drift was reduced on each floor for the x-axis. In the y-axis direction, drift from floors 1 to 6 was reduced, but from floor 6 to the top, drift values increased.
   c. Shear Force for the SW1 model, shear force increased by 0.083% compared to SW0 for both axes. Share force for the SW2 model, shear force increased by 1.319% compared to SW0 for both axes. Story drift for the SW3 model, shear force increased by 0.5% compared to SW0 for both axes.
2. Based on the cost comparison analysis, SW0 requires the lowest cost, however, from the structural performance perspective SW2 & SW3 perfom much better than those in SW0.

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