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Effect of Shear Wall Placement Variations on Seismic Response of Reinforced Concrete Dual-System Buildings

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Abstract

The seismic performance of reinforced concrete dual-system buildings is highly impacted by the shear wall position, particularly in seismic risk-prone and soft soil regions such as Jakarta, Indonesia. This study examines the influence of shear wall layout diversity on the elastic seismic response of a 15-story reinforced concrete dual-system building. Five structural models were developed in finite-element structural analysis software, consisting of one model without shear walls (N-SW) and four models with identical shear wall areas yet different layouts: diagonal corner (DC-SW), core (C-SW), four-corner (FC-SW), and mid-side (MS-SW). The seismic response was assessed using response spectrum analysis by comparing the fundamental period, modal mass participation ratio, lateral displacement, lateral stiffness, inter-story drift, and internal forces in columns and shear walls. All of the structural models containing shear walls satisfied the dual-system requirements, while the N-SW was not classified as a dual-system structure. All models likewise complied with the inter-story drift limits specified in SNI 1726:2019. Nevertheless, their seismic responses varied depending on the adopted shear wall layout. The core configuration generally exhibited the highest lateral stiffness, the shortest fundamental period, and the lowest lateral displacement. It also reduced the bending moment and shear force demands in the columns. These outcomes indicate that the location of shear walls governs the seismic force transfer and the overall behavior of reinforced concrete dual-system buildings.

Keywords: *Shear Wall Placement; Dual System; Reinforced Concrete Buildings; Seismic Response*

INTRODUCTION

Situated at Indo-Australian Plate, the Pacific Plate, and the Eurasian Plate junction, makes Indonesia as one of the countries in the world with a high level of seismic activity, making it highly exposed to earthquakes [1]. As the capital of Indonesia, Jakarta is the center of government, economy, and national business, with a high population density and rapidly growing mid-rise and high-rise building construction. The potential risk of losses due to earthquakes in Jakarta is enormous as it an populous city and and essential infrastructure.

Jakarta is exposed to seismic hazardz from both the Java subduction and several active crustal fault in western Java, including the Baribis Fault [2]. Recent seismological studies have identified the Baribis Fault, located south of Jakarta, as an active fault capable of generating significant future earthquakes, posing a considerable seismic hazard to the Jakarta metropolitan area [3,4,5]. Moreover, the soft soil conditions in most areas of

Jakarta will increase the seismic response of buildings if an earthquake occurs.

Soft soil is elastic and flexible. When propagating, the wave speed within the soil is low. Amplification also occurs, where the vibration energy is reflected and amplified. Moreover, resonance will develop when the vibration frequency matches the building's natural frequency causing the structure to sway more forcefully and for longer, thus increasing the risk of building damage.

One of the structural systems widely used in multi-storey buildings in Jakarta is a dual system that combines a moment-resisting frame system and shear walls. This system utilizes the ductility of the moment-resisting frame and the high stiffness of the shear walls to increase the structural capacity so that it is able to withstand cyclic loads due to earthquakes [6,7,8]. Shear walls have many forms, according to the distribution in the building, such as core walls, L-walls, planar walls, etc [9]. The placement of shear walls must be considered so as not to cause uneven stiffness distribution resulting in eccentricity between the center of mass and the center of stiffness of the building, thereby reducing torsional effects during seismic loading [10]. Optimal placement of shear walls can increase the efficiency of the structural system in resisting earthquake loads.

Several previous studies have investigated the influence of shear wall placing on the seismic response of reinforced concrete buildings using analytical and numerical approaches. Hosen et al. [11] stated that symmetrically arranged shear walls significantly improve the seismic performance of reinforced concrete buildings by lessen the lateral displacement, inter-story drift, and torsional effects compared with asymmetric configurations. Besides, recent research shows that both the location and the wall ratio play essential roles in controlling structural stiffness and seismic demand, indicating that poor wall placement may result in excessive drift and irregular lateral response even when the total wall area satisfies design requirements [12,13,14,15,16]. In particular, among various layout, centrally located core walls generally provides better structural performance by increasing lateral stiffness, reducing lateral displacement and inter-story drift, and improving torsional resistance through a more balanced stiffness distribution. It also provides more efficient load path and reduce torsional effects caused by stiffness irregularities. Thus, making core wall one of the most effective solutions for reinforced concrete buildings [17,18].

Despite these studies provide valuable insights, most of them focus on mid-rise buildings or evaluate the seismic performance under general site conditions. Therefore, limited attention has been given to the influence of shear wall placement on the elastic seismic response of high-rise reinforced concrete dual-system buildings located on soft-soil sites, particularly under the Indonesian seismic design provision [19]. This limitation motivates the present study.

This study presents an analysis of the effect of varying shear wall configurations in high-rise reinforced concrete dual-system buildings adopting a case study in Jakarta, Indonesia, on soft soil sites. The novelty of this study lies in the comprehensive assessment of different shear wall positions by assessing natural period, lateral displacement, story stiffness, inter-story drift, and column along with shear wall internal forces with Indonesian Standard for Seismic Design of Buildings.

METHOD

The aim of this study is to examine the effect of different shear wall position on the seismic response of a typical reinforced concrete building subjected to gravity and seismic loads. A symmetrical 15-story reinforced concrete building was developed using finite-element structural analysis software pursuant to the provisions of SNI 1726:2019. Five buildings with identical structural properties were modeled, comprising one reference model without shear walls and four models with differing shear wall locations within the building plan while keeping the same total shear wall area.

Finite Element Model

The specifications and structural elements of the building are listed in Table 1. Model 1 (N-

SW) is the reference model without shear walls. Model 2 (DC-SW) adopts a Diagonal Corner Shear Wall configuration, Model 3 (C-SW) adopts a Core Shear Wall configuration, Model 4 (FC-SW) adopts a Four-Corner Shear Wall configuration, and Model 5 (MS-SW) adopts a Mid-Side Shear Wall configuration, with shear walls positioned at the midpoint of each side of the building perimeter.

Table 1. Building Specifications and Member Dimensions

Parameter	Specification
Number of stories	15 stories
Story height	4 m
Concrete compressive strength (f'c)	25 MPa
Steel yield strength (fy)	420 MPa
Beam dimensions	400 × 600 mm
Column dimensions	600 × 600 mm
Slab thickness	150 mm
Shear wall thickness	200 mm

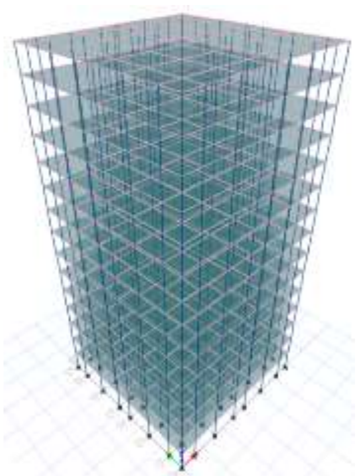

Figure 1. 3D model of (NSW)

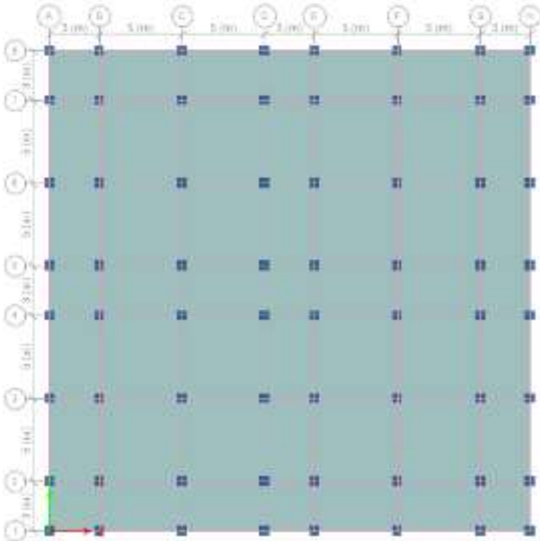

Figure 2. Model 1 (N-SW) Plan

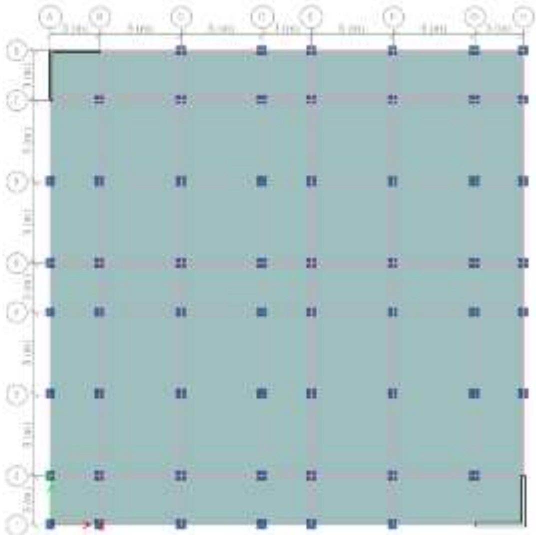

Figure 3. Model 2 (DC-SW) Plan

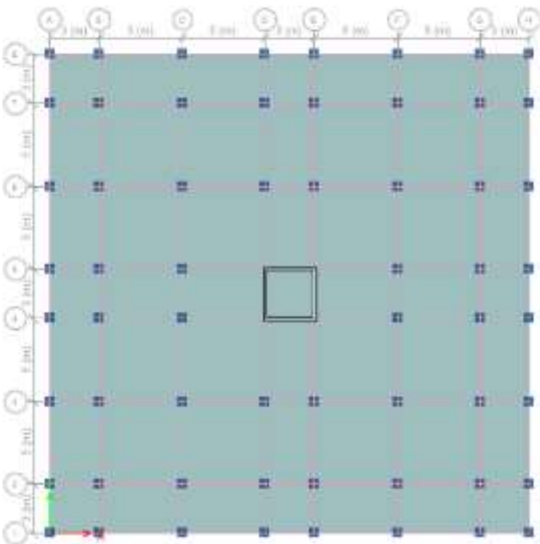

Figure 4. Model 3 (C-SW) Plan

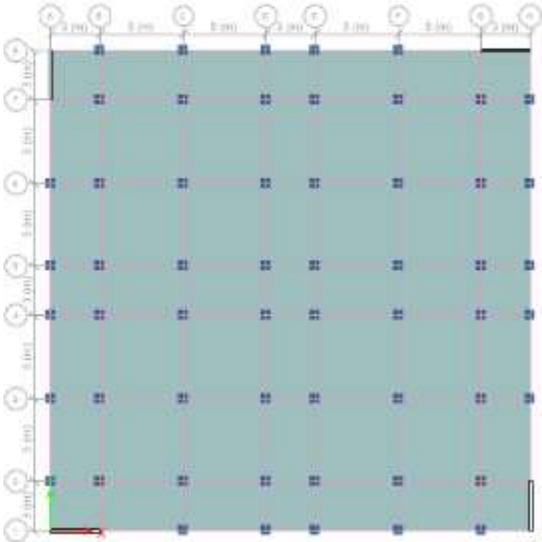

Figure 5. Model 4 (FC-SW) Plan

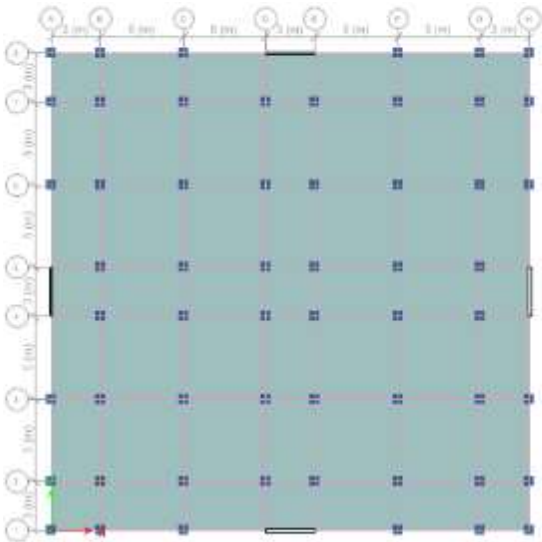

Figure 6. Model 5 (MS-SW) Plan

The support was assumed to be fixed. Piers were defined for the shear walls so that they act as a single element in resisting lateral loads. In this study, the scaling requirement for the base shear force resulting from the response spectrum analysis to the base shear force using the equivalent static method was not applied to minimize the influence of the scaling factor on the structure's seismic response comparison.

Loads
Gravity loads were calculated based on SNI 1727-2020 [20]. Gravity loads applied to the floor slab included an additional dead load of 1.50 kN/m2 and a live load of 1.92 kN/m2. Seismic loads were calculated based on SNI 1726-2019 using the linear response spectrum method for Jakarta City with a soft soil (SE) site class.

RESULTS AND DISCUSSION

Because the building has a symmetrical configuration, the analysis results in the X and Y directions do not show significant differences. Therefore, the discussion in this study will focus on the X direction.

Dual System Requirements
All models containing shear walls satisfy the dual structural system requirement, whereby the moment-resisting frame resists at least 25% of the design seismic force. The distribution of seismic force to the shear walls amounts to 57.76%, 61.51%, 49.07%, and 49.85% for DC-SW, C-SW, FC-SW, and MS-SW, respectively. Among the four configurations, the core wall system exhibited the highest share of seismic force resistance.

Fundamental period and Cumulative Modal Load Participation Ratio
Table 2 compare the fundamental period and modal load participation ratio among all models. The C-SW configuration shows the shortest fundamental period of 2.534 s, indicating the highest lateral stiffness. Locating the shear walls around the building core brings an efficient load-resisting mechanism and improves the structure's global stiffness. On the other hand, the N-SW model has the longest period of 2.769 s, reflecting the lowest lateral stiffness because of no shear walls installed. The PSW, FC-SW, and MS-SW configurations bring about intermediate periods, show that their stiffness enhancement is less pronounced than that of the core wall configuration.

The cumulative modal mass participation ratios range from 94.62% to 95.65% for all models, satisfying the minimum 90% requirement specified by the seismic design code. This shows that the modal analysis includes a sufficient number of vibration modes to reliably capture the dynamic behavior of the structures.

Table 2. Fundamental period and Modal Load Participation Ratio

Model	Fundamental Period, *T* (s)	Modal Load Participation Ratio (%)
N-SW	2.769	95.65
DC-SW	2.671	95.34
C-SW	2.534	94.62
FC-SW	2.707	94.64
MS-SW	2.670	94.67

Diaphgram Center Of mass Displacement

Figure 7 and Table 3 compare the diaphragm center of mass displacement along the building height for all structural models under seismic load in X direction.

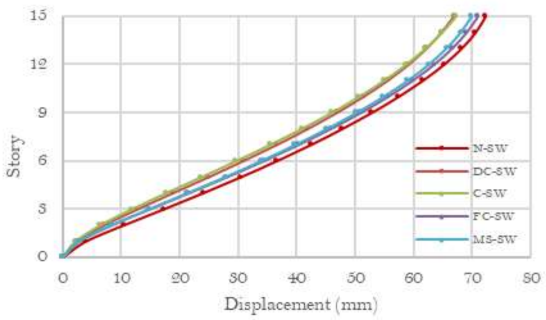

Figure 7. Displacement due to Seismic Load vs Story

Table 3. Diaphgram Center of Mass Displacement

Flr.	N-SW	DC-SW	C-SW	FC-SW	MS-SW
	mm	mm	mm	mm	mm
15	72.28	66.88	67.30	70.95	69.90
14	70.55	64.76	64.86	68.98	67.99
13	68.16	62.20	62.02	66.50	65.55
12	65.13	59.12	58.71	63.42	62.52
11	61.51	55.52	54.92	59.75	58.92
10	57.38	51.42	50.66	55.56	54.79
9	52.78	46.86	45.96	50.88	50.18
8	47.76	41.88	40.85	45.76	45.14
7	42.35	36.52	35.39	40.22	39.69
6	36.56	30.84	29.63	34.31	33.86
5	30.42	24.90	23.67	28.05	27.69
4	23.96	18.82	17.64	21.51	21.25
3	17.24	12.76	11.76	14.83	14.67
2	10.40	7.06	6.39	8.34	8.26
1	3.91	2.34	2.13	2.77	2.75
0	0	0	0	0	0

The N-SW experiences the largest displacement, with a peak value of 72.28 mm, indicating the lowest lateral stiffness as no shear walls are installed. Conversely, all shear wall models show reduced lateral displacements, confirming that the presence of shear walls enhance the global stiffness of the structure. Although the differences among the shear wall models are relatively small, the C-SW model consistently produces the lowest lateral displacement over most story levels. An exception occurs at the roof level, where the DC-SW model exhibits a slightly smaller displacement of 66.88 mm than the C-SW model of 67.30 mm. At the top floor, C-SW representing a reduction of approximately 6.9% compared to the N-SW model. Overall, the C-SW configuration demonstrates better displacement performance, while the MS-SW, FC-SW, and DC-SW models also produce lower displacements than the N-SW model to varying degrees. These findings are generally consistent with the study by Fares [21], which reported that core wall configurations exhibit superior overall seismic performance by providing lower displacement and higher lateral stiffness than other shear wall layouts.

Lateral Stiffness

Figure 8 and Table 4 present a comparison of the lateral stiffness along the building for all models. The lateral stiffness decreases with increasing elevation, reflecting the reduction in cumulative structural restraint toward the upper stories. The N-SW gives the lowest stiffness throughout the building height, while on the other hand, the C-SW model achieving the greatest values over most story levels, except at the floor 14 and 15 where the MS-SW model exhibits slightly higher stiffness than the C-SW model. For example, on the first floor, the lateral stiffness escalates from 8.44×10^5 kN/m in the N-SW model to 1.57×10^6 kN/m in the C-SW model, indicating an improvement of approximately 86%. The MS-SW, DC-SW, and FC-SW models also provide better stiffness than the frame alone, eventhough to a lesser extent. It shows that not only the presence of shear walls but also their location contribute to enhancing the overall lateral stiffness of the structure. This outcome aligned with Simon et al. [22], who stated that shear walls around the building core are more effective to control the lateral deflection and inter-story drift than other shear wall arrangements because of their more efficient distribution of lateral stiffness throughout the structure.

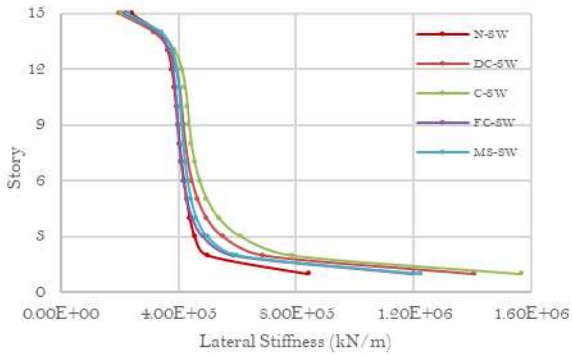

Figure 8. Lateral Stiffness due to Seismic Load vs Story

Table 4. Lateral Stiffness Values

Flr.	N-SW kN/m	DC-SW kN/m	C-SW kN/m	FC-SW kN/m	MS-SW kN/m
15	2.42E+05	2.00E+05	2.09E+05	2.21E+05	2.29E+05
14	3.35E+05	3.18E+05	3.33E+05	3.32E+05	3.43E+05
13	3.66E+05	3.69E+05	3.88E+05	3.70E+05	3.81E+05
12	3.80E+05	3.92E+05	4.12E+05	3.84E+05	3.96E+05
11	3.88E+05	4.03E+05	4.24E+05	3.91E+05	4.03E+05
10	3.94E+05	4.10E+05	4.31E+05	3.96E+05	4.08E+05
9	4.00E+05	4.16E+05	4.37E+05	3.99E+05	4.13E+05
8	4.05E+05	4.22E+05	4.44E+05	4.04E+05	4.17E+05
7	4.12E+05	4.32E+05	4.55E+05	4.10E+05	4.24E+05
6	4.20E+05	4.45E+05	4.72E+05	4.19E+05	4.33E+05
5	4.30E+05	4.65E+05	4.97E+05	4.30E+05	4.44E+05
4	4.41E+05	4.95E+05	5.39E+05	4.49E+05	4.63E+05
3	4.57E+05	5.52E+05	6.15E+05	4.86E+05	5.00E+05
2	5.02E+05	6.89E+05	7.87E+05	5.87E+05	6.03E+05
1	8.44E+05	1.41E+06	1.57E+06	1.20E+06	1.23E+06

Story Drift

Interstory drift must be controlled and is an essential requirement in seismic design to ensure both structural safety and serviceability. Excessive interstory drift may lead to structural instability, damage to structural components, and failure of nonstructural elements. The design interstory drift, Δ, is calculated as:

$$\Delta = \frac{C_d \times \delta_{xe}}{I_e} \quad (1)$$

Where δ_{xe} is the elastic displacement obtained from the seismic analysis, C_d is the deflection amplification factor corresponding to the selected seismic force-resisting system, and I_e is the importance factor of the structure.

To ensure acceptable structural performance, the calculated interstory drift must not exceed the allowable drift limit specified in SNI 1726:2019. For most reinforced concrete buildings, the allowable interstory drift is limited to 2% of the story height.

Table 5. Interstory Drift

Flr.	N-SW mm	DC-SW mm	C-SW mm	FC-SW mm	MS-SW mm
15	9.55	11.62	13.40	10.81	10.52
14	13.12	14.09	15.64	13.66	13.38
13	16.68	16.93	18.17	16.97	16.66
12	19.89	19.82	20.85	20.15	19.82
11	22.74	22.55	23.45	23.07	22.71
10	25.28	25.08	25.87	25.73	25.34
9	27.60	27.39	28.09	28.17	27.75
8	29.77	29.45	30.04	30.44	29.99
7	31.83	31.25	31.67	32.54	32.07
6	33.76	32.66	32.80	34.44	33.92
5	35.53	33.48	33.17	35.96	35.43
4	36.98	33.31	32.33	36.70	36.17
3	37.64	31.36	29.50	35.72	35.25
2	35.65	25.93	23.47	30.64	30.31
1	21.52	12.88	11.70	15.23	15.14

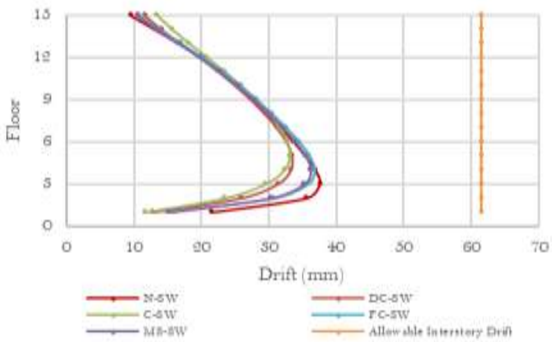

Figure 9. Story Drift vs Story

The story drift responses of all models under the design earthquake are presented in Figure 9 and Table 5. All models exhibit a similar drift profile, where it gradually increasing from the upper stories, reaching its peak in the mid-height region (approximately Floors 4–6), and then decreasing toward the ground floor. This trend represents the typical lateral deformation pattern of a mid-rise reinforced concrete building subjected to seismic loading. Although the inclusion of shear walls modifies the drift distribution, the differences among the five configurations remain relatively small at each story. The effect of shear wall positioning is more noticeable in the lower stories, where the DC-SW and C-SW exhibit smaller drift than the remaining models. In comparison, the N-SW model shows relatively greater drift in these stories, reflecting the lower lateral stiffness associated with the absence of shear walls. Even so, no single shear wall configuration achieves the lowest drift throughout the entire height of the building, indicating that the contribution of shear wall location changes from one story to another. Regardless of these differences, the drift of every model remains considerably lower than the allowable limit specified by the seismic design provisions indicating that all structural configurations satisfy the code requirements for drift control under the design seismic loading.

Column Internal Forces

Table 6 shows the comparison of column internal forces.

Table 6. Column Internal Forces

	P (kN)	M (kNm)	V (kN)
N-SW	728.19	179.61	67.17
DC-SW	658.10	121.43	60.32
C-SW	657.62	112.96	55.90
FC-SW	806.05	130.94	63.37
MS-SW	689.49	128.57	62.97

For the N-SW model, which only contains a moment-resisting frame, the largest bending moment at 179.61 kNm is obtained, suggesting that columns are the main lateral load-resisting members. After the installation of shear walls, the bending moment of the columns decreases significantly, with a reduction of about 27-37%, indicating that some portion of the lateral load is transferred from the frame to the shear walls. The C-SW model has the smallest column bending moment at 112.96 kNm among all the configurations, followed closely by the DC-SW model at 121.43 kNm, indicating a more effective redistribution of seismic forces.

A similar trend is observed in the axial and shear forces. The DC-SW and C-SW models produce the smallest axial forces at 658.10 kN and 657.62 kN, respectively-and lower shear forces than the N-SW model, whereas the FC-SW configuration results in the highest axial force at 806.05 kN. Overall, these results imply that a good shear wall arrangement can effectively reduce the force demand on structural columns, through improving the overall seismic performance of the frame system.

Shear Wall Internal Forces

The internal forces developed in the shear walls, shown in Table 7, vary considerably depending on their placement within the building, indicating that each configuration follows a different lateral load transfer mechanism. Among the four shear wall models, the DC-SW arrangement carries the largest axial force at 1201.94 kN together with high bending moments of about 7899.47 kNm in both local axes. This behavior suggests that the diagonally located shear walls contribute substantially to resisting overturning moments while sharing the seismic forces with the surrounding frame. Unlike the DC-SW model, the C-SW configuration does not generate any compelling axial force or bending moment. It is mostly shear-controlled, as evidenced by the highest V_2 value at 2132.68 kN and is able to withstand a moderate torsional moment at 656.30 kNm. The FC-SW model displays a different behavior where a relatively high axial force at 1007.29 kN is associated with a huge torsional moment at 4977.98 kNm. Thus, the corner position of shear walls increases the structure's capacity to resist torsional impact resulting from lateral loading. Contrary to the MS-SW configuration, it produces moderate values for all internal force components with no force component dominating the response. This distribution offers a more balanced interaction between the frame and the shear walls. These observations indicate that the relocation of the shear walls modifies not only the magnitude of the internal forces but also the participation of the walls in resisting seismic actions, obtaining different structural responses for each configuration.

Table 7. Shear Wall Internal Forces

Internal Forces	N-SW	DC-SW	C-SW	FC-SW	MS-SW
P (kN)	-	1201.94	0.00	1007.29	982.10
V2 (kN)	-	946.13	2132.68	831.46	859.78
V3 (kN)	-	946.13	0.00	39.97	35.22

M2 (kNm)	-	7899.47	0.00	14.27	71.54
M3 (kNm)	-	7899.47	20275.61	81.15	4972.06
T (kNm)	-	13.24	656.30	4977.98	13.93

CONCLUSION

This study focused on the effect of shear wall arrangement on the seismic response in the elastic range of a 15-story reinforced concrete dual system building located on a soft-soil site in Jakarta. The comparison of the five structural models indicates that the location of the shear walls has a significant effect on the global structural response, even with the same total wall area. The introduction of shear walls enhanced the lateral stiffness, reduced the fundamental period, decreased the lateral displacement, and transferred the seismic forces from the moment-resisting frame to the shear walls. Among the investigated configurations, the core shear wall arrangement gave the best overall performance by yielding the highest lateral stiffness, the shortest natural period, the lowest lateral displacement, and the smallest internal force demand in the columns while meeting all the dual system and inter-story drift requirements of SNI 1726:2019. Although the remaining configurations also enhanced the structural response compared with the frame-only model, their effectiveness depended on the adopted load-transfer mechanism and the resulting internal force distribution. These findings highlight that the seismic performance of reinforced concrete dual-system buildings is governed not only by the presence of shear walls but also by their placement within the structural plan. Future studies are recommended to observe the impact of shear wall layout under nonlinear seismic analysis and to evaluate its performance for buildings with plan irregularities, varying heights, and different site conditions.

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