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A Shear Wall Design Study in an 8-Story Building

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Abstract. Indonesia is highly vulnerable to seismic activity, making earthquake-resistant design a vital aspect of building construction. The Faculty of Engineering at Universitas Sriwijaya plans to construct an eight-story building (FE Tower) for academic and administrative purposes. This study investigates two key structural issues: (1) whether to use a standalone Special Moment Resisting Frame (SMRF) or a combined SMRF–Special Reinforced Concrete Shear Wall (SRCSW) system, and (2) how to determine the optimal shear wall positioning that maximizes structural performance while preserving interior layout. This study employs a simulation-based analysis of six structural models using STAAD PRO software. Key parameters analyzed include fundamental vibration period, mode shapes, soft story potential, torsional irregularities, and concrete design capacity. The results indicate that the FE Tower exhibits both horizontal and vertical irregularities, which require structural dilation and enhanced stiffness. The combined SMRF-SRCSW system with shear walls positioned along the outer walls and corners significantly improves structural performance. This study offers a practical framework for optimizing shear wall positioning in mid-rise buildings located in seismic zones. The findings contribute to more resilient design strategies while maintaining architectural functionality.

Keywords: shear wall, vibration period, mode shape, soft story, torsion

1. Introduction

Indonesia is known as an earthquake-prone region. There have been many major earthquakes in Indonesia such as the Aceh earthquake in 2004, the Yogyakarta earthquake in 2006, the Padang earthquake in 2009 and the Lombok and Palu earthquakes in 2018. Many buildings and infrastructure suffered damage, and the disasters took casualties due to the collapse of the building. With these conditions, buildings built in Indonesia must be resistant to earthquakes.

A building resistance system to earthquake can be done actively and passively (Mungase et al., 2024). The active resistance is based on the strength and rigidity of the structure such as structure frame, shear wall, floor diaphragm, joints and materials. The passive resistance, on the other hand, relies on mechanical or electronic equipment like base insulators and dampers to reduce earthquake dynamic vibrations towards structures.

The Faculty of Engineering (FE) at Universitas Sriwijaya plans to construct an eight-story building named FE Tower that will function as classrooms and office building (figure 1.1) to accommodate the academic and administration activities. The ground floor will be used for the parking lot, the 1st floor and the 7th floor will function as public facilities, the 2nd floor will be utilized as offices and faculty administration, the 3rd floor will serve as classrooms, and the 4th floor and the 6th floor will be used for administration rooms for departments and study programs. The layout and form of the building are designed based on the needs of space, site shape and aesthetics. 8-story buildings are already considered high-rise buildings, which means that lateral loads (earthquake loads and wind loads) will be dominant. In Indonesia, the building resistance system to lateral loads applied uses active resistance with reinforced concrete materials. There are two structural systems of reinforced concrete, namely the concrete frame and the combination of concrete frame and shear wall.

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The advantage of using shear walls lies in its very high rigidity (Arum et al., 2015) which is perfectly suitable in resisting the earthquake force. However, if the shear wall is positioned in an FE Tower without careful planning, it may cause excessive torsion (Satheesh et al., 2018) and damage the existing layout. Specifically, this study addresses two main problems: (1). Determining whether a conventional Special Moment Resisting Frame (SMRF) is sufficient or if a combination with Special Reinforced Concrete Shear Walls (SRCSW) is necessary; and (2). Identifying the most effective shear wall positioning that enhances structural performance without compromising internal space usage.

Figure 1.1. The block plan and FE Tower perspective (Romdhoni et al., 2024)

This study offers a novel simulation-based evaluation of six structural design models, focusing on shear wall positioning within an actual planned mid-rise building in a high-risk seismic zone. While previous studies have explored shear wall positioning in generalized building forms, this study applies those principles directly to a real-world project using current design codes and software tools. The study is significant for architects and engineers facing the dual challenge of optimizing earthquake resistance while maintaining functional building layouts.

The purpose of this study is to enhance the seismic performance of the FE Tower by evaluating alternative structural system configurations. The study specifically aims to: (1). Compare the performance of SMRF-only versus combined SMRF-SRCSW systems in terms of structural rigidity and deformation control, (2). Identify the optimal shear wall positioning that minimizes torsional irregularities and soft story effects, (3). Recommend a practical solution that aligns with current Indonesian seismic code (SNI 1726:2019) while maintaining architectural functionality.

2. Methods

2.1. Simulation Experiment

The study employed a simulation experiment to test the regularity of the building model so that it can meet the criteria for earthquake-resistant buildings.
This simulation experiment used STAAD PRO software. Model regularity checking was limited to the irregularities that frequently occur and have the most damaging impact; namely soft story and torsional irregularity (FEMA, 2020). In this study, the purpose of checking the fundamental vibration period (T) of each building model is to determine the rigidity of its geometry, the purpose of checking the mode shape is to determine the regularity of the building geometry, and the purpose of checking the structural system SMRF or the combined SMRF (Special Moment Resisting Frame) and SRCSW (Special Reinforced Concrete Shear Wall) to determine the structural strength of FE Tower.

Table 2.1. Structure properties of model 01-06 (Romdhoni et al., 2024)

Models	Beam dimension (cm)	Column dimension (cm)	Floor plate thickness (cm)	Shear wall thickness (cm)	Concrete grade (Kg / cm2)	Reinforcement grade (Kg / cm2)	Stirrup grade (Kg / cm2)
01	25x40, 25x50	80x80, 70x70	12	-	300	4200	4200
02	25x40, 25x50	80x80, 70x70	12	-	300	4200	4200
03-06	25x40, 25x50	80x80, 70x70	12	25	300	4200	4200

There are 6 models (figure 2.1), and they have structure properties in Table 2.1 as the software input. Model 01 is the full geometry of the FE Tower plan with SMRF structural system. In model 02, the north wing of the building is dilated from the main building and the structural system is still SMRF. Model 03-06 is the model of shear wall positioning plan with the combined structural system of SMRF and SRCSW.

The models were then analyzed using software to obtain fundamental vibration period, mode shape, soft story check, torsional irregularity check and concrete structure design analysis.

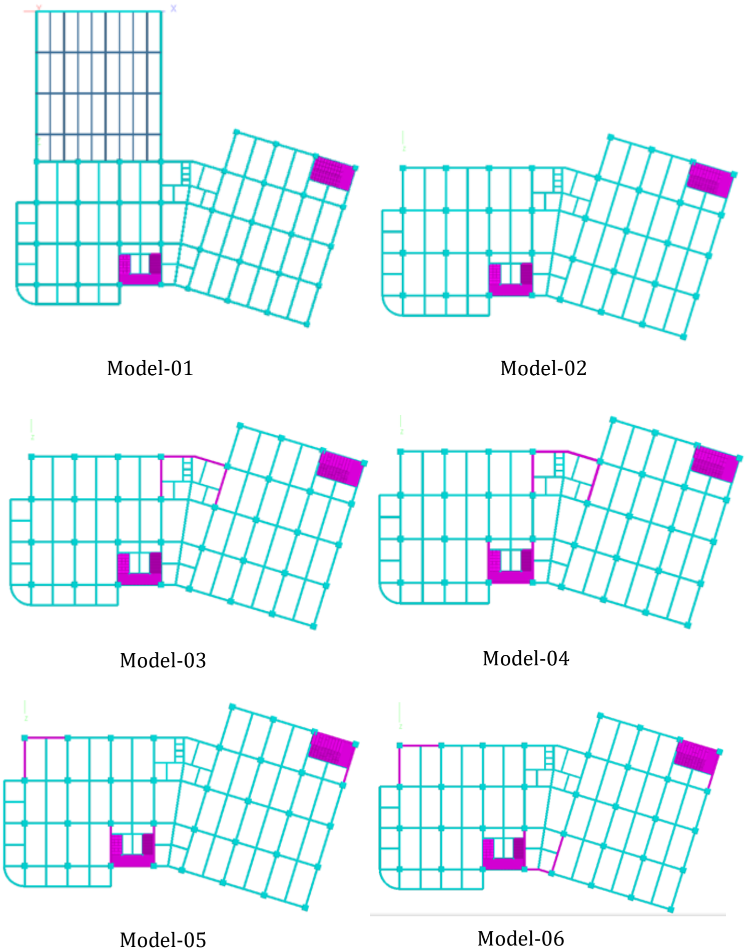


Figure 2.1. The simulation experiment model plan (Romdhoni et al., 2024)

2.2. Irregularities of Building Geometry

The irregular geometry of the building will affect the resistance of the building to earthquakes. When a large earthquake hits, buildings with irregular geometry tend to experience more severe damage than the ones with regular geometry (Harmankaya & Soyluk, 2012). To determine the geometrical irregularity of a building there are two evaluation criteria: horizontal geometric irregularities and vertical geometric irregularities (BSN, 2019). The horizontal geometric irregularities consist of: Torsional irregularity, Re-entrant Corner Irregularity, Diaphragm Discontinuity Irregularity, Out of Plane Offsets Irregularity, and Nonparallel Systems Irregularity; while the vertical geometric irregularities comprise of Stiffness (Soft Story) Irregularity, Weight (Mass) Irregularity, Vertical Geometric (setback) Irregularity, In-Plane Discontinuity Irregularity, and Strength (Weak Story) Irregularity.

2.3. Positioning of Shear Walls

Shear walls serve multiple functions, including resisting shear forces (BSN, 2019), mitigating torsion caused by the eccentricity of the mass center and the rigidity center (Batu et al., 2016), enhancing rigidity and reducing deformation (Kewalramani & Syed, 2018), and reducing soft story effects (Ujwal et al., 2024).

The efficiency and optimization of shear walls depend on their positioning. If they are not properly positioned, it will increase the existing eccentricity (Banerjee & Srivastava, 2020). Regarding shear walls positioning, some experts suggest the trial and error method (Banerjee & Srivastava, 2020; Kewalramani & Syed, 2018; Powale & Pathak, 2019). Furthermore, the study of Andalas et. al. (Andalas & Riakara Husni, 2016) argues that the most optimal position of shear walls is at the outer wall because they can increase the inertia rigidity of the building.

2.4. Modal Analysis

Period (T) is the period of fundamental vibration of a building, and it is used to measure the building's structure rigidity (Budiono & Supriatna, 2011). If the building has a period (T) < Tmax, the structure is considered rigid while if it has a period (T) > Tmax, the structure is considered flexible. Tmax is the maximum period of vibration allowed to occur in a building.

Mode shapes (Ux, Uy and Rz) are the deformation of the structure when they vibrate at their natural frequency. Mode shapes can be used as an initial indication in assessing the degree of building irregularities. A building, with mode 1=translation of the X or Y axis direction, mode 2=translation of the Y or X axis direction and mode 3=rotation of the Z axis direction, is indicated to have relatively regular geometry (Chopra, 2001; Kartiko et al., 2021; Murty et al., 2012; Putri et al., 2021). Modes 1, 2 and 3 have values between 0-1, so If the value approaches 1, it means translational or rotational dominance and vice versa.

2.5. Structural system of SMRF and SRCSW

In Indonesia, SMRF and SRCSW are the most commonly used structures. According to SNI 1726: 2019 (BSN, 2019), the SMRF structural system has factors R=8, Ωo=3 and Cd=5.5. On the other hand, the combined structural system of SMRF and SRCSW has factors R=7, Ωo=2.5 and Cd=5.5 and must meet the criteria of SMRF where it must able to resist at least 25% of seismic forces while the remaining 75% is resisted by SRCSW.

3. Discussion

3.1. Fundamental Vibration Period (T)

Table 3.1. Fundamental Vibration Period (T) of Models 01-06
(Romdhoni et al., 2024)

Models	Ta	Tmax	T (seconds)	
	(seconds)	(seconds)	X	Y
Model-01	1.304	1.825	2.099	2.009
Model-02	1.304	1.825	2.208	2.179
Model-03	0.783	1.097	1.441	1.153
Model-04	0.783	1.097	0.800	0.877
Model-05	0.783	1.097	0.902	0.855
Model-06	0.783	1.097	0.980	0.874

Ta and Tmax are the minimum and maximum limits of the fundamental vibration period based on SNI code 1726:2019 (BSN, 2019) while T is the fundamental vibration period of the model obtained from software analysis results. The analysis of fundamental vibration periods (T) shows that Model 01 and Model 02 exceed the maximum allowable vibration period (Tmax), indicating insufficient stiffness (table 3.1). These models use SMRF-only systems and are therefore too flexible for a mid-rise building in a seismic zone. In contrast, Models 04 to 06 which implement combined SMRF and SRCSW systems demonstrate improved rigidity with T values below Tmax. This confirms that the addition of shear walls substantially enhances the lateral stiffness of the structure.

3.2. Mode Shape

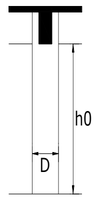
The mode shape results further support this finding. Model 01, Model 05, and Model 06 display dominant translational modes (Modes 1 and 2), with limited rotational dominance in Mode 3 (table 3.2). This suggests that these models possess relatively regular geometries and favorable dynamic behavior. Models 02 to 04, however, show irregular responses, with higher rotational components particularly in Model 04 indicating geometric irregularities and poor dynamic performance.

Table 3.2. Mode Shape Ux, Uy and Uz, Model 01-06
(Romdhoni et al., 2024)

Models	Mode 1		Mode 2		Mode 3	
	Ux (%)	Uy (%)	Ux (%)	Uy (%)	Ux (%)	Uy (%)
Model-01	59.63	0.26	0.79	66.33	8.27	1.55
Model-02	6.47	46.22	68.68	5.11	0.09	23.65
Model-03	26.58	1.8	3.49	63.24	38.45	1.55
Model-04	18.52	0.68	0.03	64.44	50.5	0.53
Model-05	62.79	1.72	1.88	63.69	2.43	0.13
Model-06	57.84	4.11	5.24	59.95	4	1.64

3.3. Soft Story Check

Table 3.3. Column Slenderness Criteria
(Seki & Islam, 2015 and Okada Et Al., 2005)

Lateral element type	**Requirements**	
Columns	Net column height/column dimension; h0/D	Definition of h0/D
a). Slender	6°h0/D	
b). Normal	2<h0 / D<6	
c). Short	h0 / D2	

One potential occurrence of a soft story is the existence of different column heights (Pesaralanka et al., 2023; Ulutas, 2024). This problem can be seen in the FE Tower plan. Soft story effects were detected in Model 01 due to uneven column heights and floor layouts. After introducing structural dilatation in Models 02 to 06, this issue was mitigated (table 3.4). The column dimensions adopted in these models satisfy the slenderness criteria by Seki (Seki & Islam, 2015) and Okada (Okada Et Al., 2005), ensuring better load transfer and minimizing the risk of soft story formation under seismic loading.

Table 3.4. Checking Soft Story Model 01-06
(Romdhoni et al., 2024)

Floor	Model01	Model02	Model03	Model04	Model05	Model06
elev. 3 meters	OK	OK	OK	OK	OK	OK
elev. 7 meters	Soft	-	-	-	-	-
elev. 9 meters	OK	OK	OK	OK	OK	OK
elev. 13 meters	OK	OK	OK	OK	OK	OK
elev. 17 meters	OK	OK	OK	OK	OK	OK
elev. 21 meters	OK	OK	OK	OK	OK	OK
elev. 25 meters	OK	OK	OK	OK	OK	OK
elev. 29 meters	OK	OK	OK	OK	OK	OK
elev. 33 meters	OK	OK	OK	OK	OK	OK
elev. 37 meters	OK	OK	OK	OK	OK	OK

3.4. Torsional Irregularity Check

Table 3.5. Checking Torsional Irregularity Model 01-06
(Romdhoni et al., 2024)

Floor	Model01	Model02	Model03	Model04	Model05	Model06
elev. 3 meters	OK	OK	Extreme	Extreme	Failed	OK
elev. 7 meters	Extreme	-	-	-	-	-
elev. 9 meters	Failed	OK	Extreme	Extreme	OK	OK
elev. 13 meters	OK	OK	Extreme	Failed	OK	OK
elev. 17 meters	OK	OK	Extreme	Failed	OK	OK
elev. 21 meters	OK	OK	Extreme	Failed	OK	OK
elev. 25 meters	OK	OK	Extreme	Failed	OK	OK
elev. 29 meters	OK	OK	Extreme	Failed	OK	OK
elev. 33 meters	OK	OK	Extreme	Failed	OK	OK
elev. 37 meters	Extreme	Extreme	Extreme	Extreme	Failed	Failed

As shown in Table 3.5, torsional irregularities are particularly critical in irregular buildings. Model 01 displayed excessive torsion at the 7 m and 37 m elevations. While Model 02 improved performance through dilatation, some torsional issues remained. Models 03 and 04, which introduced shear walls in less optimal positions, showed significant torsion and even failed in some floors. Models 05 and 06, where shear walls were optimally placed along the outer walls and corners, demonstrated the best overall performance, with Model 06 being the most balanced.

3.5. Structure System

From a systems design perspective, the SMRF-only configuration is inadequate for the seismic demands of the FE Tower. The structural simulation and design checks confirm that even with dilatation, SMRF alone results in design failures under combined loading: gravity and lateral loads. A combined SMRF-SRCSW configuration, particularly as seen in Model 06, is required to ensure sufficient lateral stiffness, regular dynamic response, and minimal structural damage during seismic events.

This study highlights that shear wall positioning is not only critical for stiffness but also plays a significant role in controlling irregularities and enhancing overall structural integrity. The use of an outer-corner configuration achieves a balance between performance and architectural constraints, making it the most practical solution for FE Tower.

4. Conclusion

This study assessed the effectiveness of different structural configurations and shear wall positioning is in enhancing the seismic performance of an eight-story mid-rise building in Indonesia.

Key conclusions include:

- The FE Tower exhibits vertical and horizontal irregularities that can be addressed through structural dilation and the use of a combined SMRF–SRCSW system.
- A SMRF-only system is insufficient for resisting seismic loads, as demonstrated by both vibration period and design failure analyses.
- The optimal shear wall configuration involves positioning the walls along the outer perimeter and at the corners of the building (Model 06). This setup significantly improves rigidity, minimizes torsional effects, and avoids interference with the building layout.
- The study confirms that analytical modeling and simulation are essential for validating structural performance, especially in high-risk seismic zones.

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