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The Influence of Structure Height and Use of Shear Walls on the Behavior of Reinforced Concrete Building Structures

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Seismic Performance; Structural Stability; Dual System.

ABSTRACT

Bengkulu is one of the areas prone to earthquakes. The application of earthquake-resistant reinforced concrete buildings is essential to minimize lateral forces due to earthquakes. The reinforced concrete structural system commonly used to withstand these lateral forces is a dual system using shear walls. Shear walls are structural elements that enhanced rigidity and resist lateral loads caused by earthquakes. In addition, the structure's height will affect the load acting on the structure and the dimensions of the planned structural elements. This study aims to analyze the influence of structural height and the use of shear walls on the behavior of reinforced concrete building structures. The analysis in this study used spectrum response method analysis with the help of the ETABS application. The results show that the use of shear walls increases the structure’s stiffness at lower levels, and and as the height of the structure increases, the period of the structure, the primary shear force, the story drift, and P-delta effects also increase.

Introduction

Indonesia is a country with a high risk of earthquakes due to its location on the Eurasian, Indo-Australian, and Pacific plates. Bengkulu Province is one of the regions in Indonesia that is prone to earthquakes because it is located in a subduction zone that meets two tectonic plates, namely the Eurasian Plate and the Indo-Australian Plate. Based on data from the Meteorology, Climatology, and Geophysics Agency (BMKG), Bengkulu has a high intensity of earthquakes. Several large-scale earthquakes in Bengkulu caused extensive damage to buildings, causing fatalities in 2000 and 2007 with magnitudes of 7.3 and 7.9 (Baihaqi & Pujiastuti, 2023). The dangers and adverse effects of earthquakes highlight the necessity for infrastructure development in Bengkulu using earthquake-resistant building design methods to minimize damage and prevent significant losses, especially casualties (Effendi, Wesli, Chandra, & Akbar, 2017).

A shear wall is a commonly used lateral reinforcement system in reinforced concrete structures. Reinforced concrete shear walls are commonly used because of their lateral load-bearing capacity and their rigidity in resisting forces due to earthquakes

(Kheyroddin, Arabsarhangi, Shabani, & Kioumarsi, 2022). In designing building structures using a dual system, shear wall placement must be done appropriately to be used optimally. The placement of shear walls with symmetrical designs can produce smaller internal forces than asymmetrical shear wall designs; this is a consideration for the placement of symmetrical shear walls as a safe and stable building design for use (Saputro, Umam, & Rahmawati, 2020). In addition, shear walls will affect the rigidity of the structure. The greater the rigidity of the structure, the more the deviation that occurs in the structure will be reduced. The stiffness is influenced by the distance between the center of mass and the shear wall; the farther the distance, the greater the rigidity of the building structure (Andalas, 2016).

A dual system, namely a combination of a frame system bearing a special moment bearer and a shear wall, can be used to optimize the performance of building structures. Shear walls have been widely used in medium and high-rise buildings (Cando, Hube, Parra, & Arteta, 2020). Based on the description and considerations, this study aims to determine the structure's response due to the influence of the structure's height and the use of shear walls designed in the Bengkulu City area.

Method

The stages of research are made to make it easier to understand the stages to be carried out in this research. The research steps are succinctly depicted in the research flow chart shown in Figure 1.

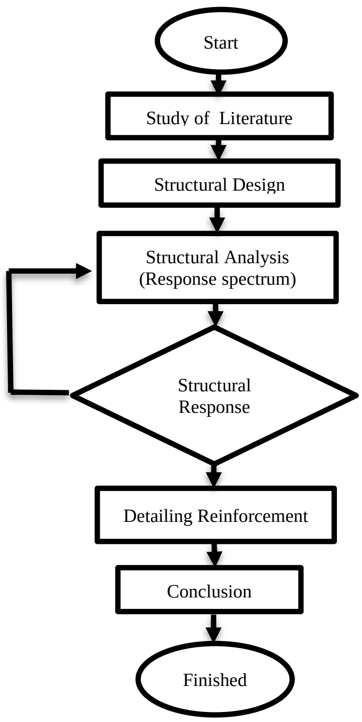


Figure 1 Research Flow Chart

Structure Design

This study involves structural design to determine the structural plan, the size of the structural elements, and the quality of the materials used. The provisions of SNI 2847:2019 carry out the determination by considering the working expenses (Liando, Dapas, & Wallah, 2020). The results will be modeled with the help of ETABS software (Lou et al., 2021). The structural plan image in this study can be seen in Figure 2.2, and the structure's height variation can be seen in Table 1 and Figure 2. This study uses three height variations.

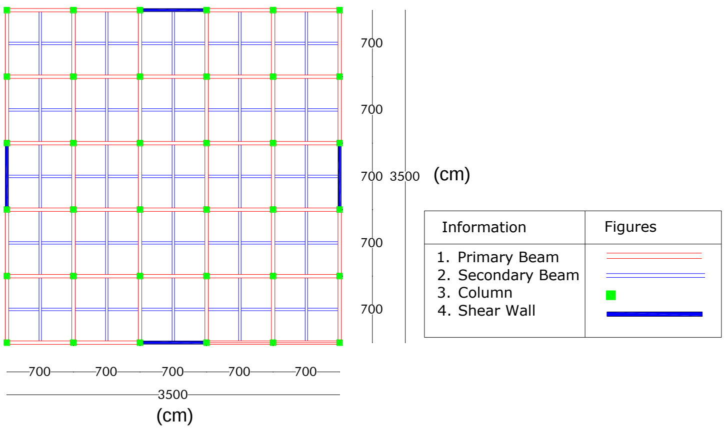
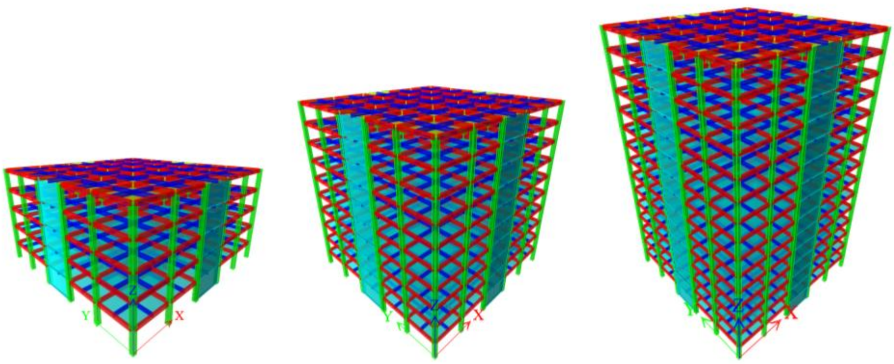


Figure 2 Structural Plan

Table 1
Height of Structure

Structure Data	Height	Unit
Height Between Story	3,8	m
Total Height of 5-Story Building Model	19	m
Total Height of 10- Story Building Model	38	m
Total Height of 15- Story Building Model	57	m



(a) (b) (c)

Figure 3
Variation in Structure Height (A) 5 Story, (B) 10 Story, (C) 15 Story

Structure Analysis

This study's structural analysis used spectrum response analysis (Seo, Hu, & Davaajamts, 2015). This analysis was done with the help of ETABS software (Lou et al., 2021). The structural analysis in this study uses the SNI 1727:2020 loading reference regarding minimum design loads and related criteria for buildings and other structures, as well as loading planning guidelines for houses and buildings in 1987 (Nurjaman, n.d.). In addition, the structural analysis refers to SNI 1726: 2019 concerning planning procedures for structural earthquake resistance of buildings and non-buildings.

Seismic Loads

The design seismic load uses a spectrum response that refers to SNI 1726:2019. This research was designed in the Bengkulu City area with hard soil conditions and a risk category IV structure. The results of the hard ground spectrum response are shown in Figure 4, with seismic design category D. Apart from the spectrum response, additional analysis data is required according to the requirements shown in Table 2.

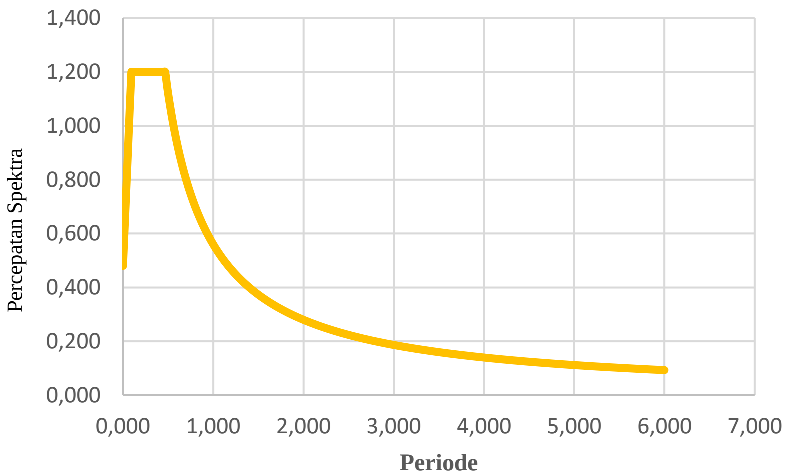


Figure 4
Spectrum Response Curve

Table 2
Seismic Parameters of Structural Analysis

Seismic Parameters	Symbol	Value
Importance Factor	I_e	1.5
Response Modification Coefficient	R	7
Overstrength factor	Ω0	2,5
Deflection Amplification Factor	Cd	5.5

In this research, the building was designed as a hospital building which was designed on the hard soil of Bengkulu City. In addition, the building in this study was designed using a dual system so that the response modification coefficient, system strength factor, and deflection enlargement factor were obtained as shown in Table 2.

Loading Combination

The structural design analysis in this study is designed to determine the effect of seismic or earthquake load. Therefore, combinations of loads on the influence by seismic loads must be considered. The most decisive influence of seismic load should be reviewed, but it does not need to be considered simultaneously with wind load. Based on SNI 1726:2019, the combination of loads used in this study are listed as follows:

1. 1,4 D
2. 1,2 D + 1,6 L
3. 1,440 D + 1,0 L + 0,390 Ex + 1,300 Ex
4. 1,440 D + 1,0 L + 0,390 Ex - 1,300 Ey
5. 1,440 D + 1,0 L - 0,390 Ex + 1,300 Ex
6. 1,440 D + 1,0 L - 0,390 Ex - 1,300 Ex
7. 1,440 D + 1,0 L + 1,300 Ex + 0,390 Ex
8. 1,440 D + 1,0 L + 1,300 Ex – 0,390 Ex
9. 1,440 D + 1,0 L - 1,300 Ex + 0,390 Ex
10. 1,440 D + 1,0 L - 1,300 Ex – 0,390 Ex
11. 0,660 D + 0,390 Ex + 1,300 Ex
12. 0,660 D + 0,390 Ex - 1,300 Ex
13. 0,660 D - 0,390 Ex + 1,300 Ex
14. 0,660 D - 0,390 Ex - 1,300 Ex
15. 0,660 D + 1,300 Ex + 0,390 Ex
16. 0,660 D + 1,300 Ex – 0,390 Ex
17. 0,660 D - 1,300 Ex + 0,390 Ex
18. 0,660 D - 1,300 Ex – 0,390 Ex

Checking and Results of Structural Analysis

This study will present the structural analysis results in the form of structural periods, elemental shear forces, intersections, P-delta influences, and reinforcement of structural elements. The Determination of structural response refers to SNI 1726:2019, while reinforcement refers to SNI 2847:2020.

Story Drift

The story drift is symbolized as Δ, and its value is determined by the provisions of Article 7.8.6 in SNI 1726:2019. The deviation of the center of mass at the-x level symbolizes as δ_x must be determined by Equation P.1. In addition, the story drift must not exceed the story drift limit, symbolized as Δ_a, which is 0,1 times the height between stories.

$$\delta_x = \frac{C_d \delta_{xe}}{I_e} \quad \text{(P.1)}$$

Effects of P-delta

The higher the structure and buildings with a more significant number of stories will experience the possibility of more significant P-delta influence (Rao, Janardhan, & Narasaiah, 2022). Thus, the P-delta needs to be checked. Based on article 7.8.7 SNI 1726:2019, P-delta effect on the shear rate and moment, the force and moment of the resulting structural elements, and the resulting story drift, need not be taken into account if the denoted stability coefficient θ as determined by equation P.2 is equal to or less than 0,10.

$$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d} \qquad \text{(P.2)}$$

Results and Discussion

Structure Period

The structure's height will affect the magnitude of the period of the structure. The higher the structure, the longer the period of the structure will be. This is because the period of the structure is affected by mass and stiffness (Pratama, Putri, & Santoso, 2021). The results of the structure periods for buildings of 5, 10, and 15-story are shown in Table 3.

Table 3
Structure Period

Symbol	Value			Unit
	5-Story	10-Story	15-Story	
T_x	0,47	1,13	1,94	second
T_y	0,47	1,13	1,94	second

The results show that the structure period of a15-story buildings is greater than that of 10- and 5-story buildings. According to Table 3.1, the period of a 10-story building increased by 140% compared to the period of a 5-story building structure and the period of a 15-story building structure increased by 71.68% compared to the period of a 10-story building structure. In addition, the periods of the structure in the x and y directions are equal. This happens because the analyzed building structure has a symmetrical structural plan.

Base Shear

The use of shear walls can cause the primary shear force to be greater due to the period of the small structure. However, shear walls can be more efficient to reduce the dimensions of the structural elements and reinforcement to be used. In addition, the dimensions of structural elements also affect the value of the shear force of the structure (Nursani & Noor, 2023). The results of the shear force fot 5, 10, and 15-story building structures are shown in Table 4.

Table 4
Base Shear

Base Shear	Value			Unit
	5-Story	10-Story	15-Story	
V_x	13821,79	14626,37	18203,39	kN
V_y	13821,79	14626,37	18203,39	kN

According to SNI 1726:2019, the shear force results of dynamic analysis using spectrum response must be at least 100% of the primary shear force of equivalent static analysis so that the seismic response coefficient and the effective weight of the structure influence the magnitude of this shear force. The results show that the shear force value in 15-story buildings is better than that of 10- and 5-story buildings.

Story Drift

Buildings with higher column and beam sizes show lower deviation and displacement values (Shoaei, Orimi, & Zahrai, 2018). However, the use of shear walls can reduce the size of structural elements and increase the rigidity of the structure, so the value of deviation and displacement of the structure can decrease compared to structures without shear walls. The results of deviations between levels in this study are presented in Tables 5 to 7 and Figures 5 and 6.

Table 5
Story Drift of 5-Story Building

Story	Displacement		Elastic Displacement		h	Story Drift		
	δx	δy	δex	δey		Δx	Δy	Δa
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
5	20,00	20,00	4,55	4,56	3800,00	16,70	16,70	38,00
4	15,45	15,45	5,02	5,02	3800,00	18,42	18,41	38,00
3	10,42	10,42	4,66	4,66	3800,00	17,08	17,08	38,00
2	5,76	5,76	3,78	3,78	3800,00	13,86	13,86	38,00
1	1,98	1,98	1,98	1,98	3800,00	7,27	7,27	38,00

Table 6
Story Drift of 10-Story Building

Story	Displacement		Elastic Displacement		h	Story Drift		
	δx	δy	δex	δey		Δx	Δy	Δa
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
10	49,49	49,49	5,38	5,38	3800,00	19,74	19,74	38,00
9	44,11	44,11	6,01	6,01	3800,00	22,04	22,04	38,00
8	38,10	38,10	6,24	6,24	3800,00	22,87	22,87	38,00
7	31,86	31,86	6,19	6,19	3800,00	22,68	22,68	38,00
6	25,67	25,67	5,97	5,97	3800,00	21,89	21,89	38,00
5	19,70	19,70	5,59	5,59	3800,00	20,51	20,51	38,00
4	14,11	14,11	5,03	5,03	3800,00	18,45	18,45	38,00
3	9,08	9,08	4,28	4,27	3800,00	15,68	15,67	38,00
2	4,80	4,80	3,25	3,25	3800,00	11,91	11,91	38,00
1	1,55	1,55	1,55	1,55	3800,00	5,69	5,69	38,00

Table 7
Story Drift of 15-Story Building

Story	Displacement		Elastic Displacement		h	Story Drift		
	δx	δy	δex	δey		Δx	Δy	Δa
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
15	86,17	86,17	6,34	6,34	3800,00	23,24	23,24	38,00
14	79,83	79,83	6,76	6,76	3800,00	24,77	24,77	38,00
13	73,07	73,07	7,00	7,00	3800,00	25,65	25,66	38,00
12	66,08	66,08	7,06	7,06	3800,00	25,90	25,90	38,00
11	59,01	59,01	7,03	7,03	3800,00	25,78	25,78	38,00
10	51,98	51,98	6,94	6,94	3800,00	25,45	25,45	38,00
9	45,04	45,04	6,81	6,81	3800,00	24,96	24,96	38,00
8	38,24	38,24	6,62	6,62	3800,00	24,27	24,27	38,00
7	31,62	31,62	6,37	6,37	3800,00	23,34	23,34	38,00
6	25,25	25,25	6,02	6,02	3800,00	22,07	22,07	38,00
5	19,23	19,23	5,56	5,56	3800,00	20,39	20,38	38,00
4	13,67	13,67	4,97	4,97	3800,00	18,21	18,21	38,00
3	8,70	8,71	4,20	4,19	3800,00	15,39	15,38	38,00
2	4,51	4,51	3,11	3,11	3800,00	11,39	11,40	38,00
1	1,40	1,40	1,40	1,40	3800,00	5,13	5,15	38,00

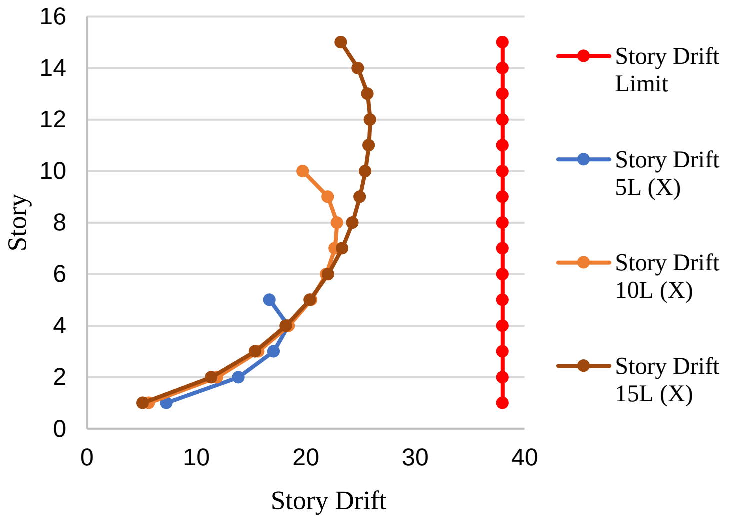


Figure 5
Graph of Story Drift (X)

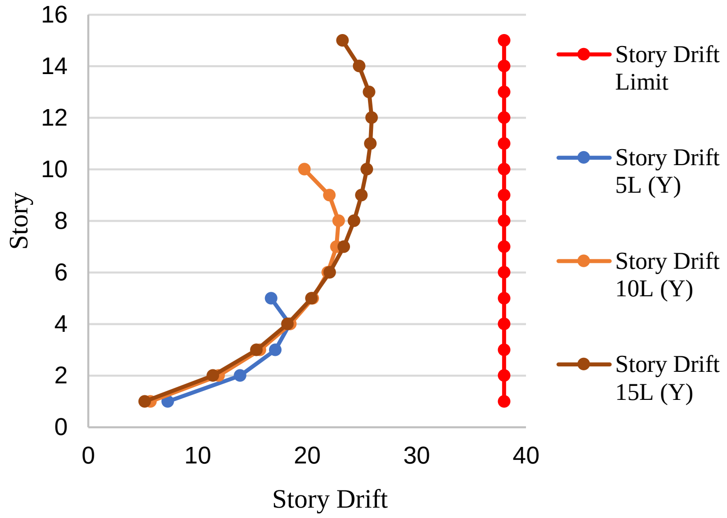


Figure 6
Graph of Story Drift (Y)

Based on the graph depicting the story drift in the x and y direction levels, it is evident that the higher the structure, the greater the story drift that occur. This shows that building structures with a lower height using shear walls have greater rigidity than taller structures. In addition, the designs of 5, 10, and 15-story structures all meet the requirements of SNI provisions that the story drift must not exceed the value of the story drift limit by 0.01h as stipulated in Article 7.12.1.1 of SNI 1726:2019.

Effects of P-Delta

The P-delta effects needs to be considered in the analysis of the session structure of SNI 1726:2019 requirements—results of P-delta effects on this study, as shown in Figures 7 and 8.

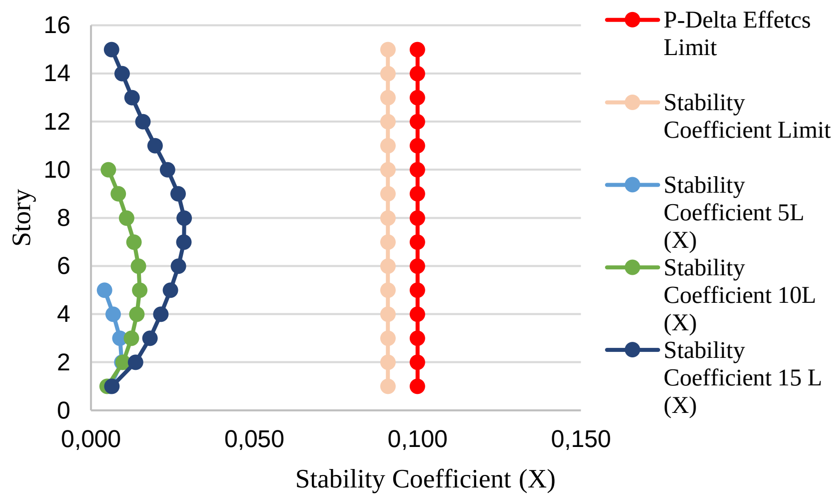


Figure 7
Graph of P-Delta Effects (X)

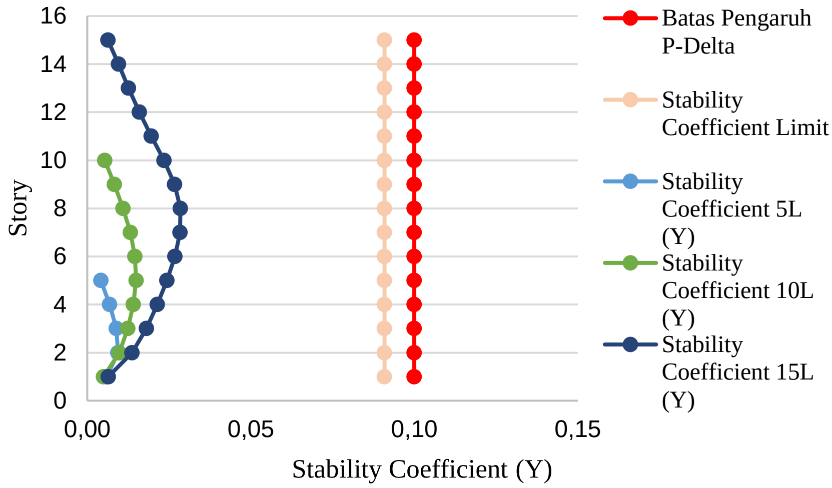


Figure 8
Graph of P-Delta Effects (Y)

The design of 5, 10, and 15-story buildings can be seen from the values on the Table and Graph of P-delta effects that meets the requirements of Article 7.8.7 SNI 1726:2019. Based on the data above, it can be seen that the limit value of P-Delta influence is less than the limit value of structural stability. Moreover, the value of the structural stability coefficient in 5, 10, and 15-story buildings has a value that does not meet the requirements of the P-Delta influence limit and structural stability. Therefore, in the analysis to obtain the value of forces in structural elements and deviations between levels, there is no need to consider the influence of P-Delta.

Reinforcement results

The results of the recapitulation of the reinforcement of structural element, as shown in Tables 8 to 12, are obtained from the calculation of structural elements based on the force output in the maximum structural element using ETABS and calculated according to the requirements for concrete reinforcement as specified in SNI 2847:2019 concerning structural concrete requirements for buildings.

Table 8
The Results of The Reinforcement Design of Primary Beam Elements

Primary Beam Reinforcement	5-Story (60/30)	10-Story (65/35)	15-Story (65/35)
	Value	Value	Value
Longitudinal Upper Focus	5D19	6D19	6D19
Longitudinal Central Focus	2D10	4D13	4D16
Longitudinal Bottom Focus	3D19	4D19	4D19
Longitudinal Upper Field	3D19	4D19	4D19
Longitudinal Midfield	2D10	4D13	4D16
Lower Field Longitudinal	3D19	4D19	4D19
Focus dash	2D10-100	2D10-80	2D10-100
Field dash	2D10-170	2D10-220	2D10-220

Table 9
The Results of The Reinforcement Design of Secondary Beam Elements

Secondary Beam Reinforcement	5-Story (50/30)	10-Story (50/30)	15-Story (50/30)
	Value	Value	Value
Longitudinal Upper Focus	3D19	3D19	4D19
Longitudinal Central Focus	2D10	2D10	2D13
Longitudinal Bottom Focus	2D19	2D19	2D19
Longitudinal Upper Field	2D19	2D19	2D19
Longitudinal Midfield	2D10	2D10	2D13
Lower Field Longitudinal	2D19	2D19	2D19
Focus dash	2D10-100	2D10-100	2D10-100
Field dash	2D10-150	2D10-150	2D10-150

Table 10
The Results of The Reinforcement Design of Column Elements

Column Reinforcement	5-Story (65/65)	10-Story (90/90)	15-Story (115/115)
	Value	Value	Value
Longitudinal	20D22	28D22	32D25
Focus dash	4D13-90	6D13-110	6D13-100
Field dash	2D13-130	2D13-130	2D13-130

Table 11
The Results of The Reinforcement Design of Plate Elements

Plate Reinforcement	5-Story (13 cm)	10-Story (13cm)	15-Story (13cm)
	Value	Value	Value
Bottom Midspan Reinforcement, axis 1 (X)	D10-200	D10-200	D10-200
Top Support Reinforcement, axis 1 (X)	D10-200	D10-200	D10-200
Bottom Midspan Reinforcement, axis 2 (Y	D10-200	D10-200	D10-200
Top Support Reinforcement, axis 2 (Y)	D10-200	D10-200	D10-200
Minimum reinforcement	D10-200	D10-200	D10-200

Table 12
The Results of The Reinforcement Design of Shear Wall Elements

Shear Wall Rebar	5-Story (30 cm) Value	10-Story (35cm) Value	15-Story (35cm) Value
Longitudinal Boundary Element	20D25	28D25	32D25
Transverse (Wide Aligned)	5 D13-100	5 D13-100	6 D13-100
Transverse (Long Parallel)	5 D13-100	5 D13-100	6 D13-100
Longitudinal Shear Wall	2 D22-75	2 D22-100	2 D25-75
Transverse	2 D19-250	2 D19-250	2 D19-220
Confinement EBK	2 D13-100	2 D13-120	2 D13-80

Based on this recapitulation, it is shown that there is an increase in the number of reinforcements 5, 10, and 15-story buildings. Results showed that the 15-story building had more reinforcement on columns and shear walls. The recapitulation of reinforcement shows that the higher the structure and the weight of the structural mass, the more significant internal forces on structural elements will be. In addition, the cross-section of structural elements, especially columns, will be more significant in order to withstand the load that occurs. This is also supported by the column function, which transfer the load from all structural elements to the foundation of the structure. This is reinforced by the internal forces that occur in the columns and shear walls getting more prominent as the height of the designed building structure increases. Beam reinforcement in 10 and 15-story buildings is greater compared to 5-story buildings. This is due to the internal forces that occurs more significantly as the height of the building structure is designed.

Conclusion

The results of this analysis show an increase in the structural period of a 10-story building by 140% compared to the period of a 5-story building structure and an increase of 71.68% in the period of a 15-story building structure compared to the period of a 10-story building structure. Structures with lower heights exhibit greater structural rigidity than taller structures. However, taller structures show an upward trend in structural response, including the structural period, elemental shear forces, story drift and the influence of P-delta, and an increase in the dimensions of the required structural elements and reinforcement. This is due to the increase in structural mass and load that occurs in taller buildings and the stiffer strength of structures in shorter structures.

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