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Analysis Behaviour of Podium-Type Buildings with Special Moment Resisting Frame (SMRF) and Dual System Using the Spectrum Response Method

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ABSTRACT

The design of the building structure has undergone considerable changes so that it needs to be considered more for the calculation of earthquakes. Earthquakes are one of the biggest challenges in the design of modern building structures, because seismic forces can cause serious damage if not properly anticipated plus Indonesia's territory is on the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate. Podium-type buildings are buildings that have problems with the transition of stiffness because there is a relatively large difference in stiffness to relatively small stiffness. One way to anticipate stiffness problems in podium-type buildings is to consider the frame system used because it greatly affects the behavior of podium-type buildings. In this study, the behavior of podium-type buildings using a Special Moment Resisting Frame System is compared with a Dual System using *a Shear Wall*. The two models were analyzed to see the behavior consisting of basic shear force, interfloor deviation and p-delta influence. From the research obtained, it was concluded that the SMRF building has a basic shear force of 9794.71, 138.53% greater than the Dual System of 2361.96. The maximum inter-floor SMRF inter-floor deviation is 64.405 mm and passes through the permit deviation. For the dual system, the maximum deviation of 29.145 is 54.76% smaller than the SMRF and the influence of p-delta for SMRF and the dual system are still within the safe limit.

Keywords:
Podium type building, SMRF, dual system, base shear, inter story drift, P-delta

1. INTRODUCTION

The design of the building structure has undergone considerable changes. This development is influenced by various factors, including the increasingly complex need for space. If previously buildings generally had symmetrical and simple shapes, now many adopt more unique and asymmetrical shapes and concepts, such as podium-type buildings. However, this design change also requires more careful consideration of safety factors, especially in earthquake-prone areas.

Earthquakes are one of the biggest challenges in the design of modern building structures, as seismic forces can cause serious damage if not properly anticipated. Moreover, the territory of Indonesia is geographically located between two continents and two oceans. As is well known, the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate all pass through Indonesia. So that Indonesia is in the meeting area of four main tectonic plates, namely the Eurasian, Indo-Australian, Pacific, and Philippine plates, which are often called the Ring of Fire. [1]

Podium type building according to [2] Podium-type buildings in both one and two directions are included in irregular buildings, because The center of mass does not overlap vertically. The problem that will occur is in the area of transition of stiffness from large stiffness at the bottom to relatively less stiffness at the top. Podium structure type buildings according to have problems in the transition from relatively large stiffness to relatively low rigidity and according to have problems in the transition from relatively large stiffness to relatively low rigidity and stated that in podium type buildings there is a significant difference between floors that have different masses and stiffness in podium type buildings. [3] [4]

Shear walls are structural elements used in building construction to increase rigidity and stability against lateral loads such as wind and earthquakes. According to the use of shear walls in high-rise buildings, it can increase the rigidity of the structure and reduce deviations due to lateral forces such as earthquakes. [5] Because of some of the theories from the above research, this study was carried out to see how influential the podium-type structure building that uses the

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SMRF-S system is the one that uses the Dual System (Shear Wall)

2. METHOD

Data and Methods

2.1. General Data of the Building

The general data of the building used in the modeling consists of:

- Building Function : Office
- Stuructur type used : Reinforced Concrete
- Earthquake Zone : Zone 5 (Indonesian Earthquake Zones)
- Site Classification : Soft Soil (SE)Building Technical Data

2.2. Technical Data

The general data of the building used in the modeling consists of:

- Planning Building Area : 3600 m2
- Number of Floors : 15
- Height Between Floors : 4 m
- Total Building Height : 56 m

2.3. Podium Type Building Model

2.3.1. Model 1 (SMRF-S)

Model 1 is a podium-type structure building that uses a Special Moment Bearing Frame System which can be seen in figure 1.

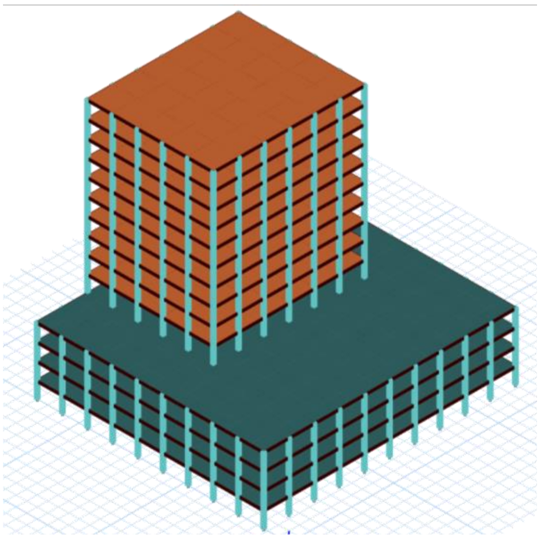


Figure 1: Building Modeliing SMRF-S

2.3.2. Model 2 (Dual System)

Model 2 is a podium-type structure building that uses a Dual System with the addition of a Shearwal on the side of the building's tower.

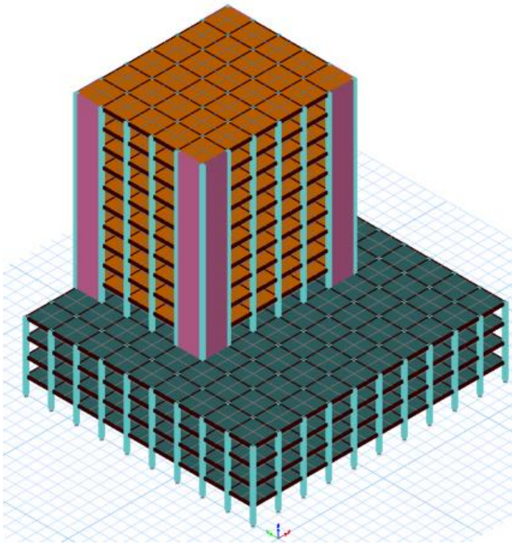


Figure 2: Building Modelling Dual System

2.4. Preliminary Design Structure

Building structure design must be full of precision according to Building structure planning is an important process in ensuring the strength and stability of the building, which involves load analysis, material selection, and the design of structural elements such as columns, beams, and foundations. According to his book entitled Concrete Structure 1 says that beams are structural elements that function to withstand working forces, be it compressive or tensile forces. Beams are usually used in the construction of banguna. to distribute the load from other elements, and in the book it is also mentioned about the floor plate, the horizontal structural element that receives the load from the floor and distributes it to the beam or column. In his journal, he also stated about Columns which are vertical elements in the structure that function to transmit loads from the top to the foundation. The use of shear wall on building structures can improve the shear strength and overall stability of the building against lateral loads such as earthquakes and according to [6] [7] [5] [8]

Based on the theory above, the calculation of the initial dimensions of the planned structure is very important so that the dimensions of columns, beams, plates and shear walls can be seen in Table 1.

Table 1. Preliminary Design Structure

Structural Components	Dimension (mm)
Column (K1)	800 mm x 800 mm
Main Beam (B1)	600 mm x 350 mm
Secondary Beam (B2)	400 mm x 250 mm
Floor Slabs	120 mm
Shear Wall	600 mm

2.5. Structural Loading

According to the loading of the structure on the irregular building, it is necessary to consider the earthquake load, wind load, and live load to ensure the stability and safety of the structure. In his book [9] [10] Structural loading must consider the combination of dead load, live load, and earthquake load in accordance with applicable standards to ensure the safety and stability of the structure.

2.5.1. Dead Load

The loading of the structure on the building must refer to SNI 1727: 2020 concerning the design of loading on the building structure as a reference in the calculation of the dead load of the structure. According to research conducted by dead load is the total weight of all fixed components of a building, including additional elements, machinery, and fixed equipment that are an integral part of a building consisting of columns, beams, plates, floors, and modeled walls. The dead load on the building structure is determined by the specific gravity of the building material. Therefore, in this study, concrete material with a specific gravity of 24 kN/m was used [11] and steel quality 75.8 kN/m^3

2.5.2. Additional Load (SIDL)

1. 1st Floor

ME Installation : 0.19 kN/m^2		= 0.19 kN/m^2
Cement Plaster : 0,72 kN/m^2		= 0.72 kN/m^2
Ceramic : 0,77 kN/m^2		= 0.77 kN/m^2
	Total	= 1.68 kN/m^2

2. 2nd Floor – Rooftop

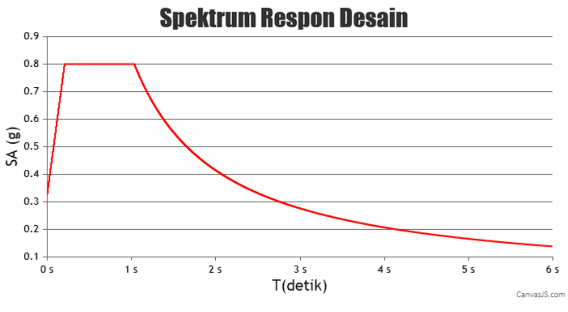
ME Installation : 0.19 kN/m^2		= 0.19 kN/m^2
Gypsum : 0,008 kN/m^2		=0,008kN/m^2
Ceramic : 0,77 kN/m^2		= 0.77 kN/m^2
	Total	=0,968kN/m^2

2.5.3. Burden of Life

The load for the living load of the structure is one of the additional loads that must be taken into account on the structure. The magnitude of the burden of life on the structure varies and is not constant due to human activities that are not always the same. According to Living Load is all loads that occur due to the occupancy or use of a building, including loads on the floor that come from movable items and/or loads due to rainwater on the roof and according to Living Load is a load caused by users and occupants of buildings or other structures, such as wind, rain, and others. In this study, all models used the office live load, which was 4.79 kN/m [12] [13]

2.5.4. Earthquake Load

Earthquake load is the dominant lateral load on the stability of the structure, where the magnitude of vibration that occurs in the structure is caused by the movement of the ground by the earthquake. In this study, the design spectrum response is sourced from the Indonesian Spectra design site which is in accordance with the location of the building. So that the following data was obtained: [14]



- Site Class : Soft Soil
- To : 0,21 s
- Ts : 1.04 s
- Ss : 1,5 g
- S1 : 0,6157 g

Based on the above data, earthquake load planning was carried out for these 3 models based on SNI 2847: 2019 so that Earthquake Loading was obtained, namely:

- Ago : 0,8 g
- Fv : 2
- SMS : Fa x Ss = 1,2
- SM1 : Fv x S1 = 1,2768
- SDS : 2/3 〖x S〗_MS = 0,8 g
- SD1 : 2/3 〖x S〗_M1 = 0,8512 g
- Seismic Style Bearer System for MACCK
  Response modification coefficient (R)= 8
  Strong factor over system (Ω0) = 3
  Deflection magnification factor (Cd)= 5,5
  Reduction Factor for Earthquake Load Calculation:
  I/R x 9,81=I/R x 9,81 = 1,22625
- Seismic Force Bearing System Axle System (Shearwall)
  Response modification coefficient (R)= 7
  Strong factor over system (Ω0) = 2,5
  Deflection magnification factor (Cd)= 5.5
  Reduction Factor for Earthquake Load Calculation:
  I/R x 9,81=I/R x 9,81 = 1.4014

2.6. Spectral Analysis Response by ETABS-V18 Software

In planning earthquake-resistant structures, spectral response analysis is a commonly used method. This method serves to predict the response of the structure to earthquake loads. The trick is to use the response spectrum, which is a graphical representation that shows the relationship between the vibration period and the maximum response magnitude of the structure. The spectrum of this response itself depends on the characteristics of the earthquake and the structural dynamic properties. According to Spectral response analysis has become the dominant method in seismic engineering design, allowing engineers to estimate the dynamic response of structures to earthquakes with an adequate degree of accuracy. The ETABS V18 software is highly recommended for spectral response analysis due to its capable ability to perform high-accuracy structural dynamics analysis. In addition, ETABS V18 is also efficient in modeling and calculations. This software is used to analyze the behavior of the structure to obtain the value of the basic shear force, the deviation between the levels, and the influence of the P-delta. [15]

2.7. Basic Sliding Syles

Base shear or base shear force is the total horizontal force acting on the base of the structure due to earthquake loads. Basic shear force is one of the important parameters in seismic analysis used to determine the strength of the structure against lateral loads. The calculation and determination of the seismic base shear force (V) in the given direction is determined based on the equation [16]:

$$V = Cs \times W$$

Information:

Cs = Seismic response coefficient

W = Effective Seismic Weight

The basic shear force should be controlled according to the dynamic basic shear force of the response spectrum should be equal to 100% of the equivalent static shear force. If the combined response to the basic shear force resulting from the analysis of variance (Vt) is less than 100% of the shear force (V) calculated using the equivalent static method, then the force must be multiplied by V/Vt, where V is the equivalent static ground shear force, and Vt is the basic shear force obtained from the result of the analysis of the combination of variances. There fore the basic shear force must meet the Vdynamics ≥ 100% static V (Vs). [17]

2.8. Inter-Floor Junction

The deviation between floors is the difference in deflection that occurs at the center of mass above and below the level under review [18] . The deviation between floors due to earthquake load was analyzed using spectral response methods and time history. The results of this analysis are important for evaluating the performance of the structure and ensuring the deviation meets planning standards. The deviation is calculated based on the equation:

$$\delta_x = \frac{C_d\, \delta_{xe}}{I_e}$$

Information:
C_d = lateral deviation magnification factor
δ_{xe} = Deviation at the x-level required in this article, which is determined by elastic analysis
I_e = Determined earthquake priority factor

The deviation between the levels must be controlled so that the deviation between the design levels (Δ) must not exceed the deviation between the inter level permit (Δ_a) which can be seen in the Table 2.

Table 2. Inter-Story Drift

Structure	Categories Risk		
	I or II	III	IV
Structures other than brick sliding wall structures, 4 levels or less with interior walls, partitions, ceilings and exterior wall systems that have been designed to accommodate inter-level deviations.	0.002HSX	0.020HSX	0.015HSX
Brick cantilever sliding wall structure.	0.010HSX	0.010HSX	0.010HSX
Other brick sliding wall structures.	0.007HSX	0.007HSX	0.007HSX
All other structures.	0.020HSX	0.015HSX	0.010HSX

2.9. P-Delta Effects

According to SNI 1726-2019, the influence of P-delta on moment and level shear, moment of structural elements, as well as the generated force and deviation between levels does not need to be considered if the stability coefficient (θ) is equal to or less than 0.10. The influence of p-delta on the structure accordingly affects the stability and capacity of the column, especially in the structure with a flat slab-drop panel system. Thickening at the end of the column (drop panel) can increase the axial and lateral forces acting on the column, so it needs to be considered in the planning of the structure of a multi-storey building The equation to determine this can be calculated using the following formula:

$$\theta = \frac{P_x \Delta Ie}{V_x h_{sx} C_d}$$

Information:
Px = Total vertical design load at and above x-level (kN)
Δ = Deviation between design levels as defined in 0, occurs simultaneously with (mm)V_x
Ie = Determined earthquake priority factor
Vx = Seismic shear force acting between degrees x and x-1 (kN)
hsx = Height of level below level x, (mm)
Cd = Deflection magnification factor

According to the P-Delta effect on the structure can be controlled by ensuring that the value of the stability coefficient (θ) does not exceed the specified maximum limit, which is 0.09. If the θ value exceeds that limit, the influence of the P-Delta should be taken into account in the structural analysis to ensure the stability and safety of the building. Therefore. The influence of p-delta should be controlled with stability coefficient (θ) so that the influence of p-delta must not exceed the max determined based on the equation : θ

$$\theta_{max} = \frac{0,5}{\beta * C_d}$$

Information:

β = The ratio of shear requirement to shear capacity for the level between the level and x-1.

2.10. Flowchart

A research flowchart is a visual representation that describes the steps to be followed in a study, from problem identification to data analysis. This diagram helps researchers and readers understand the research process in a systematic and structured way. The stages of research that will be carried out are as seen in figure

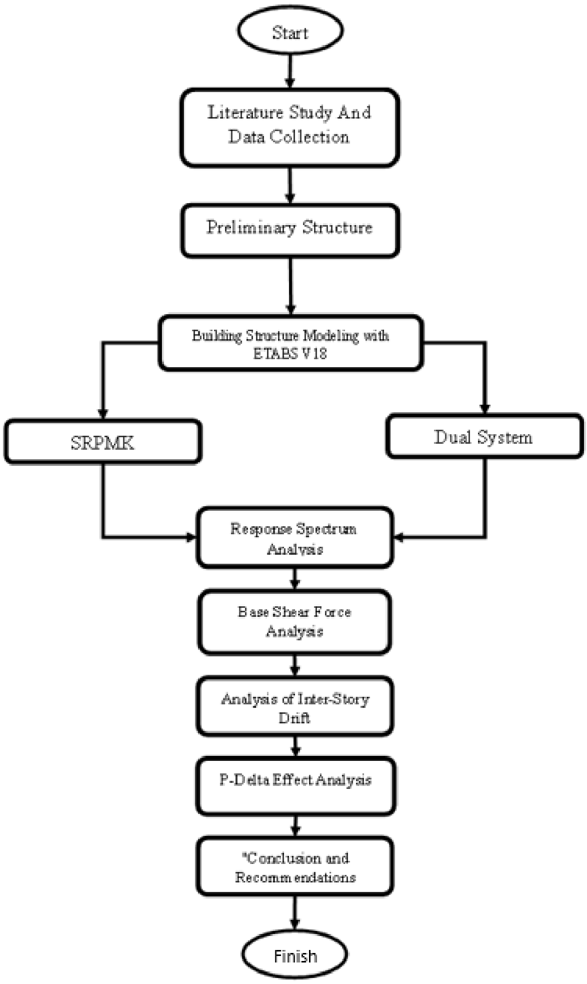


Figure 3: Flow Chart Diagram Research

3. RESULT AND DISCUSSION

3.1 Structural Vibration Period Analysis

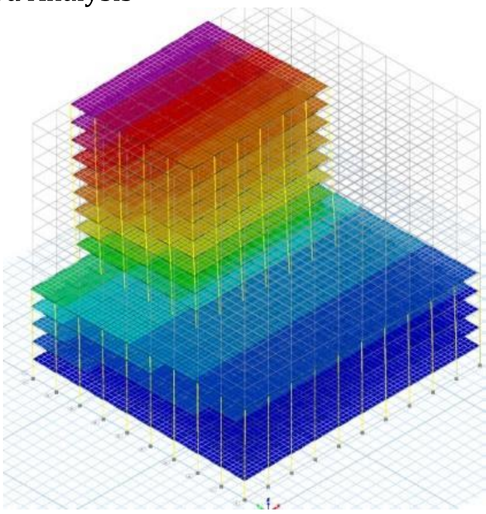


Figure 4: Mode 1 Structure Vibration Period (SMRF-S)

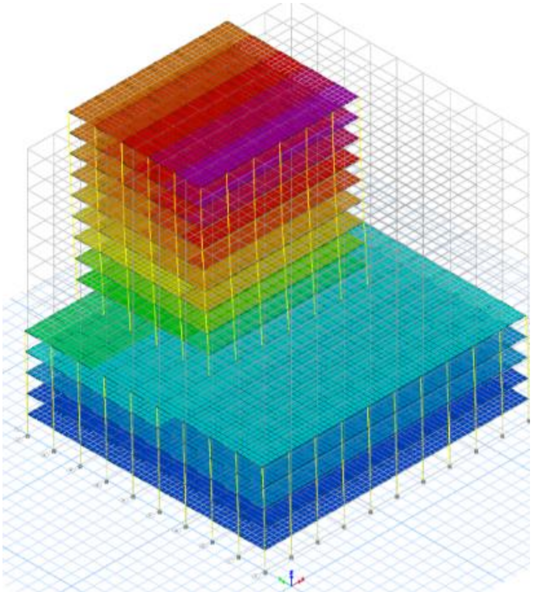


Figure 5: Mode 2 Structure Vibration Period (SMRF-S)

Based on the stages of the analysis of the Structural Vibration period in model 3 (Eccentric), the following results were obtained:

Table 3: Results of Model 1 Structural Vibration Period Analysis

Period Structure	T(s)
Ta (Ct hnx)	2,443
Tmax (Cu x Ta)	3,367
TKomputer Mode 1	2,671
TKomputer Mode 2	2,591
T Period of Use X	2,433
T Y Wear Period	2,433

3.1.1. Periodic Results of Model 2 Structural Vibration (Dual System)

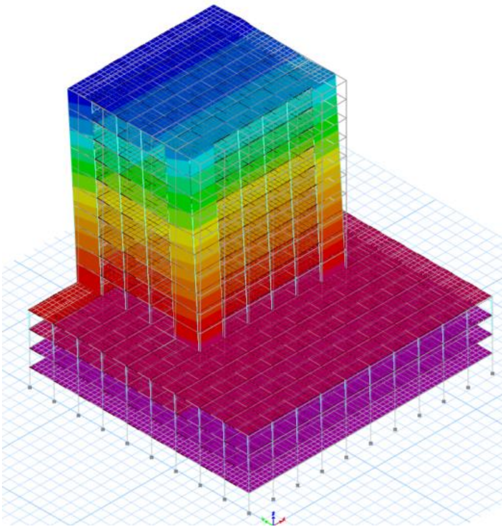


Figure 6: Vibration Period Structure Mode 1 (Dual System)

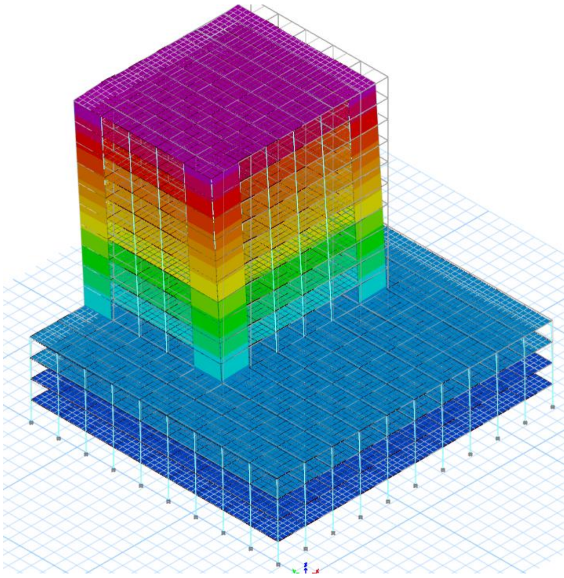


Figure 7: Vibration Period Structure Mode 2 (Dual System

Based on the stages of the analysis of the Structural Vibration period in model 2 (Eccentric), the following results were obtained:

Table 4: Results of Model 1 Structural Vibration Period Analysis

Period Structure	T(s)
Ta (Ct hnx)	0,9990
Tmax (Cu x Ta)	1,399
TKomputer Mode 1	1,346
TKomputer Mode 2	1,342
T Period of Use X	1,346
T Y Wear Period	1,342

3.2 Basic Sliding Styles

3.2.1. Basic Shear Force Analysis Model 1 (SMRF)

The following is the basic seismic shear force that occurs in buildings obtained by structural modeling using ETABS V21 presented in Table 5.

Table 5: Model 1 Basic Shear Force Analysis Results

V	X- Direction (kN)	Y- Direction (kN)	Check
Static Equivalent	9794,71	9794,71	Not Ok
Spectral Response	7055,68	7613,19	Not Ok

Based on Table 5, it is found that the value of the planned earthquake force (Vt) is less or not the same as the seismic shear force (V) so that the value of the basic seismic shear force of the spectral response can be multiplied by the factor scale using the calculation of V/Vt, the final result of the analyzed shear force can be seen in Table 6.

Table 6: Model 1 Basic Shear Force Analysis Results

V	X-Direction (kN)	Y-Direction (kN)	Check
Static Equivalent	9794,71	9794,71	OK
Spectral Response	9794,71	9794,71	OK

3.2.2. Basic Shear Force Analysis Model 1 (SMRF)

Table 7: Model 2 Basic Shear Force Analysis Results

V	X-Direction (kN)	Y-Direction (kN)	Check
Static Equivalent	23361,96	23431,60	OK
Spectral Response	13193,66	13081,88	OK

Based on Table 7, it is found that the value of the planned earthquake force (Vt) is smaller or not the same as the seismic shear force (V) so that the value of the basic seismic shear force of the spectral response can be multiplied by the factor scale using the calculation of V/Vt, the final result of the analyzed shear force can be seen in Table 8.

Table 8: Model 2 Basic Shear Force Analyst Results

V	X-Direction (kN)	Y-Direction (kN)	Cheque
Static Equivalent	23361,96	23431,60	OK
Spectral Response	23361,96	23431,60	OK

3.3 Inter-story Drift

3.3.1. Interstory Drift Model 1 (SMRF-S)

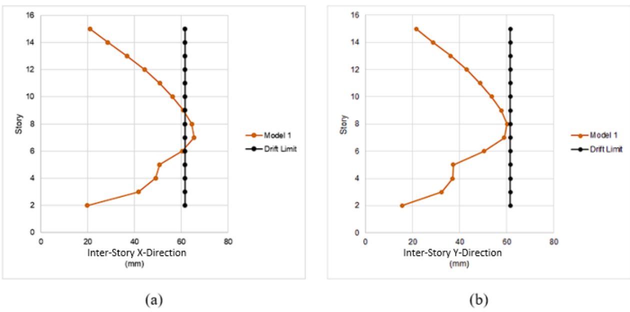
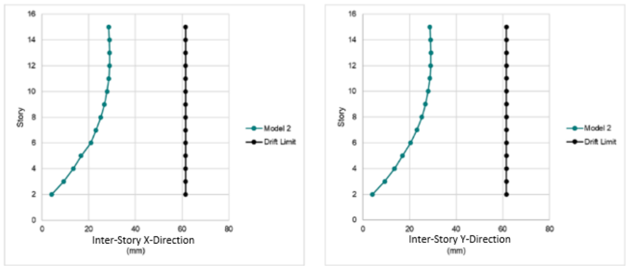


Figure 8: Interstory Drift Model 1: (a) X-Direction; (b) Y- Direction

Based on the results of the analysis of the calculation of the deviation between floors in model 1, it is shown in the graph Figure 8(a) for the x direction. In model 1, it was found that the deviation in the direction of x exceeded the deviation limit because the largest deviation of 64.405 mm between the permission levels so that it could be declared unsafe. For the Y direction, it was found that the deviation in the direction of Y still met, which was 60, 088 mm and did not exceed the permission limit of the deviation between levels.

3.3.2.Interstory Drift Analysis Model 2 (Dual System)

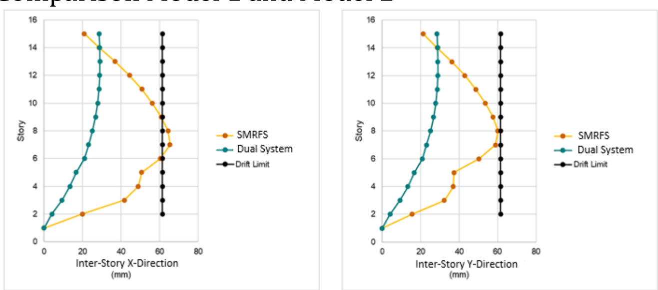


(a) (b)

Figure 9: Interstory Drift Model 2 (a) X-Direction ; (b) Y-Direction

Based on the results of the analysis of the calculation of the deviation between floors in model 2 which uses a dual system, it is shown in Figure 10 for the x direction and Figure 11 for the y direction and it is found that the inter-level deviation in model 2 in the x direction and the y direction has a deviation of 28.911 mm for the x direction and 29.145 for the y direction and is stated not to cross the deviation limit so that it can be categorized as safe.

3.3.3. Interstory Drift Comparison Model 1 and Model 2



(a) (b)

Figure 10: Interstory Drift Model 1 and Model 2: (a) X- Direction; (b) Y- Direction

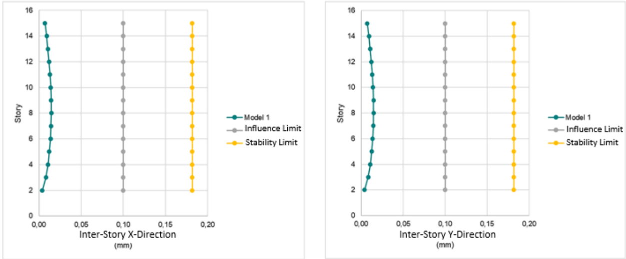
Based on the comparison graph, it can be concluded that the inter story drift X-direction using SMRF passing the drift limit but for duel system is save. Otherwise inter story drift Y-Direction is good and didn't pass the drift limet for SMRF and Dual System.

3.4 P-Delta Influence

3.4.1. P-Delta Analysis Model 1

Based on the results of the analysis of the influence of p-delta in model 1, it can be concluded that model 1 using SMRF has a maximum p-delta influence of 0.072 in the x direction and 0.0652 for the y direction and meets the requirements by not exceeding the limit or limit of the influence of p-delta. However, there is a difference in values in the X-direction and the Y-direction. The value of the influence of p-delta in the x direction is greater than in the y direction.

3.4.2. P-Delta Analysis Model 2

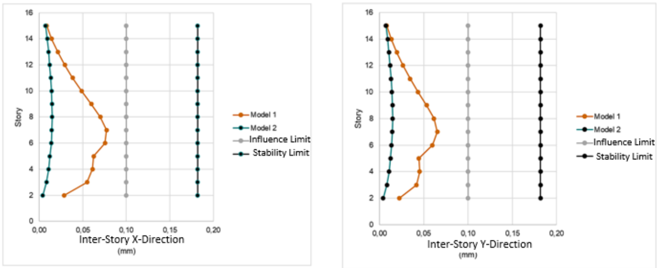


(a) (b)

Figure 11: Graph of Inter-Level Deviations Model 1 and Model 2: (a) X- Direction; (b) Y- Direction

Based on the results of the analysis of the influence of p-delta in model 2, it can be concluded that model 2 using the Dual System has a maximum p-delta influence of 0.0147 for the x direction and 00148 for the y direction and meets the conditions by not exceeding the limit or limit of the influence of the p-delta.

3.5 Comparison of P-Delta Model 1 and 2



(a) (b)

Figure 12: P-Delta Influence Junction Graph Model 1: (a) X-Direction; (b) Y- Direction

Based on the graph, it can be stated that all models meet the p-delta condition because they do not exceed the influence limit of 0.1 so that they can be categorized as safe for each model. However, there is a large difference in the influence of p-delta between model 1 SMRF is greater than model 2 Dual System.

4. CONCLUSION

1. The basic Shear Force value of Model 1 is 9794.71 kN and for model 2 is 23361.96 kN so that it can be concluded that the difference of model 2 is 138.53% from the value of Model 1.
2. The maximum value of the inter-level deviation in model 1 is 64.405 mm and exceeds the permit deviation limit. In model 2 the maximum is 29.145 mm so it can be concluded that the difference between model 2 and model 2 is 54.76% from the value of model 1
3. The influence of P-delta for the 2 models met the conditions by crossing the limit of influence of p-delta. However, it can be seen that the greatest p-delta influence value is found in SMRF buildings.

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