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Comparative analysis of the behavior of flat slab with drop panels and beam-slab system using response spectrum method

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ABSTRACT

The choice of floor system influences building height and seismic behavior. This study compares a beam-slab system (Model 1) and a flat slab with drop panels (Model 2) for a five-story reinforced concrete office building in Banda Aceh on site class SE and in seismic design category D. Response spectrum analysis was performed in ETABS V.22 in accordance with SNI 1726:2019, and the fundamental period, base shear, story drift, and slab deflection were compared. Model 1 had shorter fundamental periods than Model 2 in both directions, at 0.932 s versus 0.981 s in the x-direction and 0.951 s versus 0.980 s in the y-direction. Its base shear was also lower, at 1666 kN versus 1846.85 kN, consistent with its lower seismic weight. The maximum story drift of Model 1 was 17.39% lower in the x-direction, at 51.49 mm versus 62.33 mm, and 20.50% lower in the y-direction, at 49.52 mm versus 62.29 mm, indicating greater lateral stiffness. Conversely, the slab deflection of Model 1 was 10.58 mm, which is 36.7% higher than the 7.74 mm of Model 2, or equivalently 26.84% lower for Model 2. The flat slab with drop panels therefore performs better in slab deflection, whereas the beam-slab system performs better under lateral seismic loads. Because the two models differ in member sizes, these results apply only to the configurations analyzed.

Keywords: flat slab; drop panel; beam-slab system; response spectrum analysis; story drift

1 Introduction

The need for space in a building adds complexity and innovation in planning. In order for space needs to be met in accordance with the structure and architecture, planning is needed that can accommodate each area based on its function. The method to design these needs is to utilize the flat slab with drop panels for the floor. The flat slab with drop panels is a two-way floor slab system that does not utilize beams as a focus [1], [2].

In the absence of beams, a flat slab provides a larger clear height for the same floor-to-floor height [3]. This system will also facilitate the implementation of tasks in the field due to more practical formwork installation, easier casting, and simple reinforcement arrangement [4], [5]. With these advantages, the flat slab with drop panels will reduce costs in the implementation of the project. On the other hand, a slab system with conventional beams requires more complicated formwork planning due to the difference in the height of the slabs and beams. In addition, the arrangement of the reinforcement will be complex because it requires reinforcement of the beams on the slab using conventional beams. Even so, this system also has drawbacks such as the limitation of the slab range, where generally the range on the flat slab with drop panels is between 6-9 meters [6]. The shear strength of the flat slab with drop panels is also not as large as the shear strength of the slabs that use conventional beams [7]. In contrast, a slab system with a traditional beam can withstand a greater shear force and has a longer range.

With previous research on the flat slab with drop panels and the beam-slab system, this research will make a comparison of the behavior and serviceability performance of the building structure between these two types of systems, namely the flat slab with drop panels and the beam-slab system, using the response spectrum method in accordance with SNI 1726:2019. Comparative analysis of behavior will include aspects

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such as fundamental periods, base shear forces, story drift, as well as slab deflection. The author uses the ETABS V.22 software to then analyze the results obtained from the software.

2 Data and Methods

2.1 Methods

This study utilizes a literature review as a source of research data and conducts simulations using ETABS V22 software to analyze the structure through the response spectrum method in accordance with [7], [8], [9]. The research flow diagram can be seen in **Figure 1**.

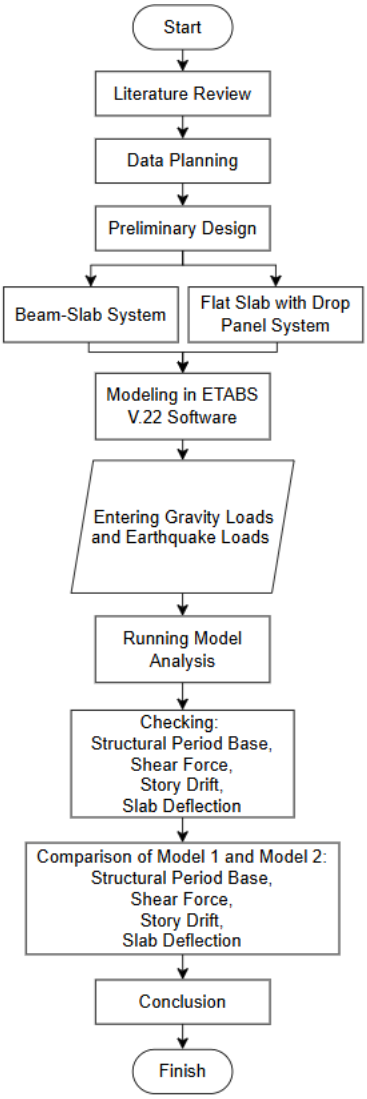


Figure 1. Research Flow Diagram

2.2 Drop Panel

Drop panel is the thickening of the slab around the column [2]. Drop panels are used to withstand the punching shear and negative moments on the slab in the area near the column [11], [12]. The dimensional requirement of the drop panel is that the drop panel must overhang under the slab at least 1/4 the thickness of the adjacent slab and must be extended in all directions from the centerline of the column, with a distance of not less than 1/6 of its span length [7].

2.3 Two-Way Slab

A two-way slab is a slab that is supported by a support on all four sides and also flexes in both directions that are perpendicular to each other [13]. The ratio between the long and short sides that are perpendicular to each other does not exceed 2 [1]. On a two-way slab, the reinforcement is carried out in both directions according to the moment that arises in each direction. The minimum thickness of the two-way slab is determined by **Table 1**.

Table 1. Minimum thickness of two-way slab slabs

αfm	Minimum h, mm		
$\alpha fm \leq 0.2$			(a)
$0.2 \leq \alpha fm \leq 2.0$	Largest of:	$\frac{\ln (0{,}8 + \frac{fy}{1400})}{36 + 5\beta(\alpha fm - 0{,}2)}$	(b)
		125	(c)
$\alpha fm > 2.0$	Largest of:	$\frac{\ln (0{,}8 + \frac{fy}{1400})}{36 + 9\beta}$	(d)

Where:

αfm : Average value of αf for all beams located along the slab edge.

ln : Effective longitudinal span measured at the interface between supports or beams (mm).

β : Ratio of the longer clear span to the shorter clear span in a two-way slab.

fy : Yield strength of the reinforcement (MPa).

2.4 Beam-Slab System

This slab system uses beams as a support. The load on the slab will be channeled to the beam and then channeled back to the column. Compared with flat slab systems, conventional slabs have several advantages, including:

a. The span of the slab is longer.
b. The existence of a beam as a horizontal element that can withstand greater lateral forces.
c. Some of the disadvantages of using conventional slabs with beams:
d. The height between the floors is reduced due to the presence of beams under the slab.
e. Installation of formwork is more complicated due to the different heights of the slabs and beams.
f. Greater casting volume due to the presence of beams.

2.5 Flat Slab with Drop Panels

A slab with a drop panel (flat slab) is a two-way slab that does not use a beam in which the load of the slab will be directly received by the column [13], [14]. In the flat slab system, a drop panel or column capital may be used to withstand the shear force. With the thickening of the slabs in the column area or the enlargement of the column head, the flat slab with

drop panels will be able to withstand greater loads [1].

The minimum thickness of the flat slab with drop panels is regulated based on [7]. The determination of slab thickness is seen from the use of drop panels and the presence or absence of edge beams. The minimum thickness for slabs with and without drop panels is given in **Table 2**.

Table 2. Minimum Slab Thickness on Flat Slab with Drop Panel

fy (MPa)	No drop panel			With drop panel		
	Panel exterior		Panel Interior	Panel exterior		Panel Interior
	No edge beams	With edge beams		No edge beams	With edge beams	
280	ln/33	ln/36	ln/36	ln/36	ln/40	ln/40
420	ln/30	ln/33	ln/33	ln/33	ln/36	ln/36
520	ln/28	ln/31	ln/31	ln/31	ln/34	ln/34

There are several advantages in the use of the panel flat slab with drop panels such as ease in assembling formwork, easier assembly of slab reinforcement, larger net height of the room so that the height of the building can be reduced [4], [5]. In addition, in the panel-drop system there are several disadvantages such as low earthquake force resisting strength due to not using beams and the presence of punching shear force that occurs on the floor slab due to shear forces and unbalanced moments[15], [16], [17] .

2.6 Dynamic Analysis (Response Spectrum)

Dynamic analysis for earthquake-resistant structure planning is carried out on buildings that are very tall or have multiple levels, are irregular, and buildings that require high precision. The strength of a building's structure is something that cannot be ignored to avoid building collapse due to earthquakes [3]. The response spectrum can be seen as an improvement compared to linear static analysis. One of the main differences between the linear static method and the response spectrum is the effect of gravity and its spread along with the height of the structure being analyzed. In the response spectrum, a response with many degrees of freedom is displayed as a modal response [18].

Response spectrum is a linear analysis method for solving dynamic equations caused by earthquakes [19]. The characteristics of the earthquake and the dynamic properties of the building will affect the response spectrum [20]. The magnitude of the base shear force and story drift can be generated from the linear analysis of the dynamic response spectrum [21].

2.7 Structure Vibration Period

Period is the time to reach a single vibration. While resonance is a state at the frequency of the structure that is equal to the frequency due to external loads. Fundamental periods need to be obtained to avoid resonance in the structure. The distribution of stiffness and mass of the structure will affect the fundamental vibration period [22]. Based on [9] the fundamental period of the approach (Ta) must be determined from the following equations:

$$Ta = Ct \times hn^{x} \quad (1)$$

Information:
hn : height of the structure
Ct : structure type approach parameters

2.8 Base Shear

The base shear force is the lateral force that appears at the basic level [20]. The determination of the base shear force in each lateral direction is generally based on elastic response spectrum analysis [23]. The presence of shear forces on structural elements can produce bending moments . The base shear force is determined based on [9] using the formula:

$$V = Cs \times W \quad (2)$$

Where:
Cs : the specified seismic response coefficient.
W : effective seismic weight.
To get the value of Cs using the equation:

$$Cs = \frac{S_{DS}}{\left(\frac{R}{Ie}\right)} \quad (3)$$

Where:

SDS :design spectral response acceleration parameters within a period range short.
R : the response modification coefficient.
Ie : seismic importance factor.

The value does not need to exceed the max Cs, namely:

For $T \leq TL$

$$Cs = \frac{S_{D1}}{T \times \left(\frac{R}{Ie}\right)} \quad (4)$$

For $T > TL$

$$Csmax = \frac{S_{D1} \times TL}{T^2 \times \left(\frac{R}{Ie}\right)} \quad (5)$$

Cs must be no less than:

$$Csmin = 0{,}044 \times S_{DS} \times Ie \geq 0{,}01 \quad (6)$$

If $S_1 \geq 0.6g$, then Cs should be no less than:

$$Csmin = \frac{0{,}5 \times S_1}{\left(\frac{R}{Ie}\right)} \quad (7)$$

2.9 Story Drift

The displacement is described by the total overall lateral displacement at the top of the structure and the displacement between floors which is defined as the relative lateral displacement that occurs between two adjacent building stories [24]. Based on [9], in determining the story drift between the design floors (δ) must be calculated as the difference in story drift at the center of mass above and below at the level under review [25]. The story drift of the center of mass at the x-level (δx) in mm is determined using the formula:

$$\delta x = \frac{Cd \times \delta xe}{Ie} \quad (8)$$

Information:
Cd : Deflection amplification factor
δxe : Elastic displacement at level x
Ie : Seismic importance factor

2.10 Deflection

In addition to safety through design capabilities, deflection control is a key element to ensure comfort, stability and structural integrity [5], [17]. Deflection occurs due to the presence of vertical loads acting on the elements resulting in a change in shape in the vertical direction [26]. The deflection in structural elements is affected by the stiffness of the elements, the magnitude of the force, and the dimensions or thickness of the elements [26]. Permit limits are needed on deflection to avoid a decline in the ability to serve the structure.

2.11 Seismic Input

The structure analyzed in this study is a five-story reinforced concrete office building located in Banda Aceh, with a plan size of 18 m × 24 m, a story height of 3.5 m, and a total height of 17.5 m. The structural elements were modeled using concrete with a compressive strength ($f'c$) of 35 MPa and reinforcing steel with a yield strength (fy) of 450 MPa. Both the beam-slab system (Model 1) and the flat slab with drop panels (Model 2) share these building data. The seismic loads were defined in accordance with SNI 1726:2019, and the design parameters used in the response spectrum analysis are summarized in **Table 3**.

Table 3. Seismic Design Parameters

Parameter	Symbol	Value
Risk category	-	II
Seismic importance factor	I_e	1.0
Site class	-	SE
Peak ground acceleration	PGA	0.59 g
Spectral acceleration, short period (bedrock)	*Ss*	1.47 g
Spectral acceleration, 1 s (bedrock)	S_1	0.58 g
Design spectral acceleration, short period	*SDS*	0.79 g
Design spectral acceleration, 1 s	*SD1*	0.79 g
Transition periods	*T0, Ts, TL*	0.20 s, 1.00 s, 20 s
Seismic design category	SDC	D
Response modification factor	R	8
Overstrength factor	Ω_0	3
Deflection amplification factor	Cd	5.5

Source: Indonesian Design Spectra (RSA 2021) of the Ministry of Public Works and Housing.

3 Results and Discussion

3.1 Structural Modeling

The dimensions of the structural elements used in the two models are given in **Table 4**. Model 1 and Model 2 were modeled in ETABS V.22 software, and the 3D models are shown in **Figure 2** and **Figure 3** respectively.

Table 4. Structural Element Dimensions (mm)

Element	Model 1	Model 2
Column	600 x 600	900 x 900
Beam	300 x 600	-
Floor slab thickness	150	170
Drop panel projection below slab	-	160

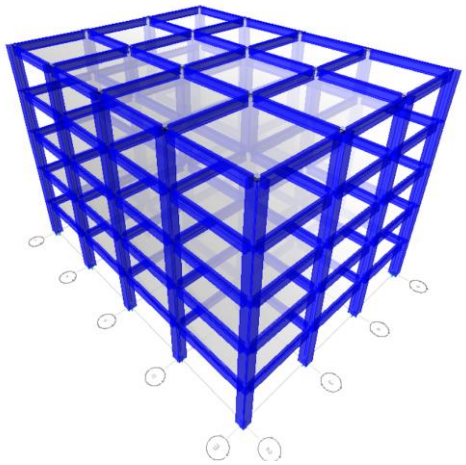


Figure 2. 3D modeling model 1

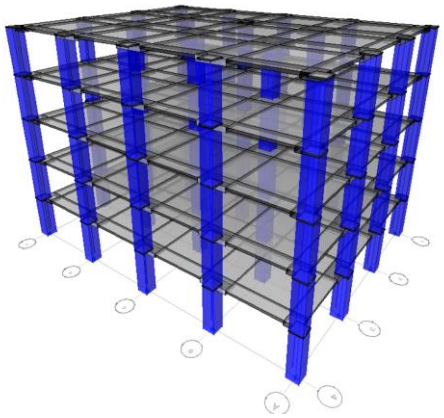


Figure 3. 3D modeling of model 2

3.2 Structure Period

A comparison of the structure vibration period taken from the results of the analysis on both model 1 and model 2 is shown in **Figure 4**.

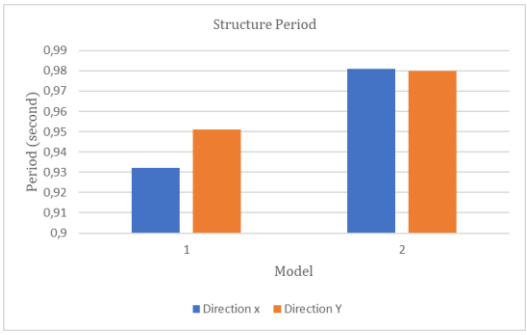


Figure 4. Comparison of X-Directional and Y-Directional Structure Periods

From the results of the analysis, the period in model 1 for the x direction is 0.932 seconds with the y direction period is 0.951 seconds. Meanwhile, in model 2, the period obtained from the results of the analysis x directions was 0.981 seconds with the y direction is 0,980 seconds. The value also supported [27].

3.3 Base Shear

The comparison of the base shear forces of the building taken from the results of dynamic analysis on both model 1 and model 2 is shown in the following **Figure 5**.

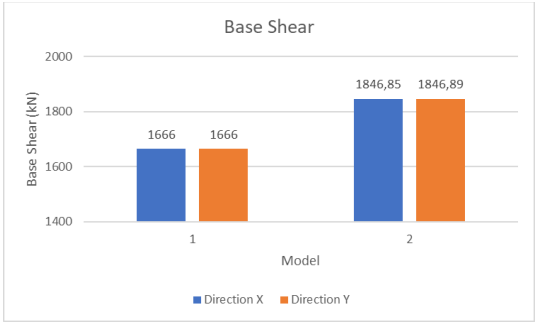


Figure 5. Base Shear Force of X-Direction and Y-Direction Buildings

The base shear value was obtained through response spectrum analysis, where the value of the dynamic base shear force for the x direction model was 1666 kN and for the y direction was 1666 kN, these results were obtained from the scaled dynamic base shear values. As for the 2nd model, the base shear force in the x direction is 1846,85 kN and for the y direction is 1846.89 kN. The value also supported [27], [28].

Because the fundamental periods of both models are shorter than Ts = 1.00 s (Table 3), both lie on the constant-acceleration plateau and share the same seismic response coefficient, Cs = SDS/R = 0.79/8 ≈ 0.099. The difference in base shear therefore reflects the difference in effective seismic weight, about 10.9% higher for Model 2.

3.4 Story Drift

Comparison of the story drift between floors between model 1 (beam-slab) and model 2 (flat slab with drop panels) due to dynamic earthquake load taken from the story drift value at the center of mass. A comparison of the story drift values between the beam-slab system and the flat slab with drop panels in the x-direction can be seen in **Figure 6**.

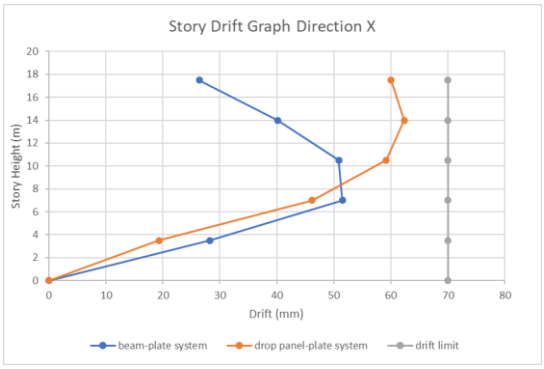


Figure 6. Comparison of Story Drift Between X-Directions Floors

A comparison of the story drift values between the beam-slab system and the flat slab with drop panels in the x-direction can be seen in **Figure 7**.

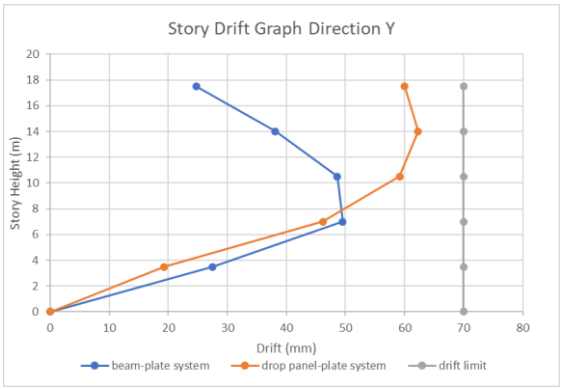


Figure 7. Comparison of Intersections Between Floors in the Y-Direction

From **Figure 6** and **Figure 7** the maximum story drift value on the beam-slab system (Model 1) for the x direction is 51.49 mm and for the y direction is 49.52 mm. Meanwhile, in the flat slab with drop panels (Model 2), the maximum story drift value for the x direction is 62.33 mm and for the y direction is 62.29 mm, consistent with the trend in [28]. The story drift value on both structural systems is below the predefined permissible story drift value, which is 70 mm.

3.5 Deflection of Slabs

The deflection ratio obtained from the two models uses the deflection value on one of the slabs with the maximum moment value. A comparison of the deflection of the floor slabs in the two models can be seen in **Figure 8**.

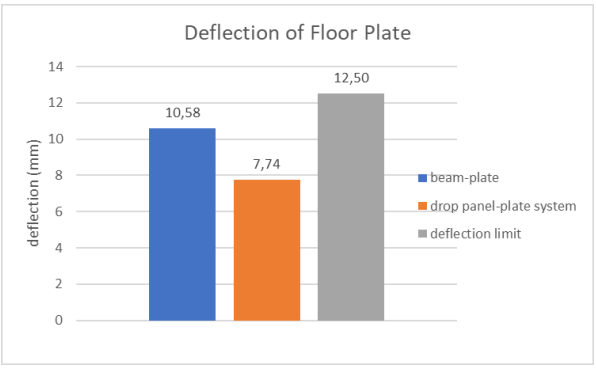


Figure 8. Comparison of Floor Slab Deflection Values (mm)

From **Figure 8**, the instantaneous deflection value of the floor slab on model 1 is 10.58 mm, while the instantaneous deflection value of the floor slab on model 2 is 7.74 mm. The deflection value on both models is lower than the maximum deflection allowed for the slab. The value also supported [26].

Meanwhile, in the calculation on the software, the deflection value in model 1 is 10.729 mm, which is shown in **Figure 9**.

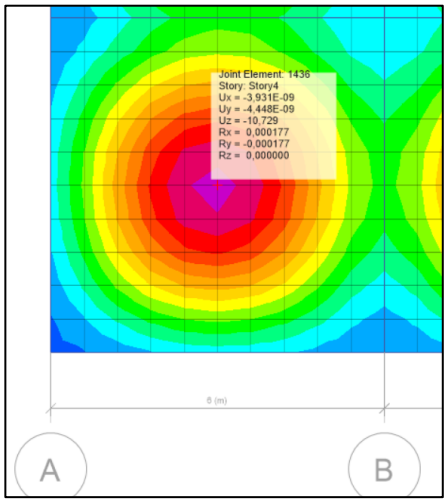


Figure 9. Floor Slab Deflection Value Model 1 ETABS V.22 Analysis Results

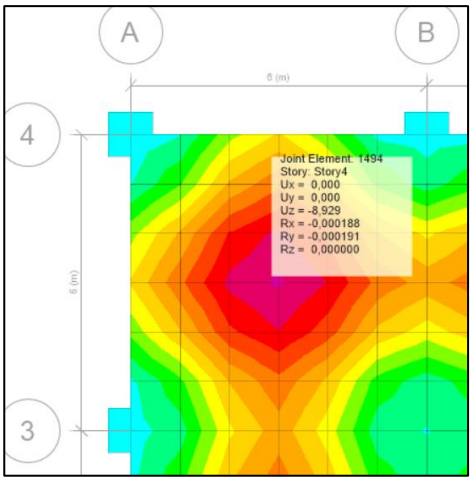


Figure 10. Floor Slab Deflection Value Model 2 ETABS V.22 Analysis Results

In Model 2, the deflection value produced by the ETABS V.22 software is 8.929 mm, as shown in **Figure 10**. These ETABS contour values differ from those in **Figure 8**, but Model 2 shows the lower deflection in both cases.

4 Conclusion

Based on the analysis that has been carried out, a comparison is made between the beam-slab system (model 1) and the flat slab with drop panels (model 2). From the analysis of the two structural systems, conclusions were obtained, including:

1. The fundamental periods of Model 1 (beam-slab) are 0.932 s in the x-direction and 0.951 s in the y-direction, and those of Model 2 (flat slab with drop panels) are 0.981 s and 0.980 s. Model 1 is therefore stiffer in both directions.
2. The base shear of Model 1 is 1666 kN in both directions, and that of Model 2 is 1846.85 kN in the x-direction and 1846.89 kN in the y-direction. Because both periods are shorter than Ts = 1.00 s, both models share the same seismic response coefficient, so the 10.9% higher base shear of Model 2 reflects its higher effective seismic weight, which is consistent with its larger columns, thicker slab, and drop panels.
3. The maximum story drift of Model 1 is 17.39% lower in the x-direction (51.49 versus 62.33 mm) and 20.50% lower in the y-direction (49.52 versus 62.29 mm), so Model 1 is more effective in limiting lateral displacement. Both models are below the drift limit plotted in **Figure 6** and **Figure 7**.
4. The slab deflection of Model 2 is 7.74 mm, which is 26.84% lower than the 10.58 mm of Model 1. Both are below the limit of 12.5 mm plotted in **Figure 8**, so Model 2 is more favorable for slab serviceability.

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