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Analysis of Deviation Behavior in the SMAN 2 Abiansemal Building with the SRPMK System and Flat Slab

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ABSTRACT

The development of educational infrastructure in seismically active regions demands structural systems that ensure both safety and functionality. This study evaluates the structural performance of the SMAN 2 Abiansemal building by comparing two structural systems: the conventional Special Moment Resisting Frame (SRPMK) and a flat slab system with drop panels. Finite element analysis using ETABS and dynamic response spectrum methods, as stipulated in SNI 1726:2019, was employed to assess inter-story drift and total displacement. The SRPMK system demonstrated stable behavior, with maximum drift values remaining below the permissible limit of 62.77 mm. In contrast, the flat slab system initially exceeded this threshold due to its lower lateral stiffness. A design revision increasing the column dimensions from 45×45 cm to 50×50 cm successfully reduced the drift values to compliant levels. Although the flat slab system requires dimensional adjustments, it offers architectural and construction benefits, making it a viable alternative for mid-rise educational buildings in seismic-prone areas. The study emphasizes the importance of dynamic drift analysis and early-stage design validation when adopting beamless slab configurations in earthquake-sensitive zones.

Keywords: flat slab; special moment resisting frame; inter-story drift; displacement

1 Introduction

The educational context in Indonesia has rapidly evolved over the past few decades, emphasizing the necessity for modernized school infrastructures that can accommodate contemporary pedagogies and facilitate effective teaching and learning processes. Recent assessments of school buildings, particularly those housing secondary education institutions, underscore the critical role that architectural design plays in promoting learning environments that are not only functional but also conducive to student engagement. In this vein, the design of school buildings like SMAN 2 Abiansemal in Bali needs to be addressed, focusing on structural integrity, especially in the face of seismic threats endemic to the region [1][2]. Thus, a comprehensive analysis that juxtaposes traditional building systems like the SRPMK system with more innovative designs such as flat slab systems can yield insights into optimizing educational infrastructure for both functionality and resilience.

In considering the structural systems used in educational buildings, the SRPMK (Sistem Rangka Pemikul Momen Khusus) or Special Moment Resisting Frame system has been standard in Indonesia. However, this system exhibits several limitations, particularly its capacity to resist lateral forces due to seismic activities. The rigidity and ductility requirements for effective seismic performance are often not adequately met by the SRPMK, creating vulnerabilities in the structural design and necessitating the exploration of alternative solutions that can offer improved performance [3][4]. Furthermore, the height and weight of structures designed with the SRPMK system can lead to increased seismic base shear, exacerbating their susceptibility to earthquake-induced damages [4][5]. These deficiencies prompt a critical evaluation of the existing systems to identify more efficient alternatives.

The emergence of the flat slab system stands as a pivotal innovation in structural engineering, particularly in the context of Indonesia's seismic landscape. This system eschews the conventional beam-slab configuration, relying solely on columns to support the flooring slabs. Not only does this result in higher usable floor space due to increased ceiling heights, but it also simplifies construction processes by reducing the amount of formwork and labor required [1][2]. Furthermore, the flat slab system's design allows for increased flexibility in accommodating utility installations, which is a significant advantage in complex building layouts common in educational facilities [1][6]. This structural concept has been successfully applied in several institutional buildings, including the G2 Building at Warmadewa University, where flat slab-drop panel configurations demonstrated satisfactory deflection control and compliance with height regulations as outlined in regional zoning codes [7]. The shift towards using flat slabs reflects a broader trend in structural engineering that aims to reconcile architectural requirements with robust structural performance, particularly in seismic-prone regions.

Considering the various merits of flat slabs, their advantages extend beyond mere aesthetics and construction efficiency. The reduced dead load associated with flat slabs, as opposed to traditional beam-slab systems, leads to lighter overall structures that perform better under seismic loading conditions [4][8]. This approach was also proven effective in the Sukawati Market Building project, where a flat slab with drop panel system maintained both structural integrity and vertical deflection within serviceability limits, while complying with strict regional height constraints [9]. The capacity for flat slabs to effectively manage excess lateral forces positions them as a superior alternative to conventional systems like SRPMK, especially as educational facilities increasingly require resilience against earthquakes. Furthermore, the compatibility of flat slabs with varying architectural designs enhances their appeal for school buildings, which must also cater to diverse functionality within limited spaces [10][11]. This versatility underscores a pivotal transition in building design philosophies, particularly in the context of education.

Indonesia faces unique seismic challenges due to its geographical positioning along the Pacific Ring of Fire. The archipelago is highly susceptible to earthquakes, necessitating stringent building codes and advanced structural designs to enhance safety and structural integrity [12]. Recent seismic assessments highlight that inadequate designs can lead to catastrophic failures during seismic events that jeopardize not only infrastructure but also human safety [3][4]. Thus, it is imperative to adopt innovative structural solutions, such as flat slabs, to mitigate seismic risks effectively. Existing research has underscored the importance of integrating advanced structural designs with a deep understanding of local seismic behavior to enhance the overall resilience of Indonesian buildings, particularly schools where learning continuity is crucial [8].

This study aims to investigate the structural drift behavior under seismic loading of the SRPMK and flat slab systems as applied to the SMAN 2 Abiansemal building. The focus will be on a comparative analysis of horizontal displacement and drift behavior under earthquake loading, utilizing data and modeling techniques that characterize the unique challenges posed by the Indonesian seismic landscape [4][13]. By examining these two systems, the study aspires to illuminate not only the performance efficacy of flat slab designs in educational infrastructures but also provide a foundational basis for future architectural innovations within Indonesia's evolving educational context.

2 Data and Methods

2.1 Case Study Overview

The methodology followed in this study is outlined in Figure 1, depicting a sequential framework starting from data collection to final comparison and recommendation.

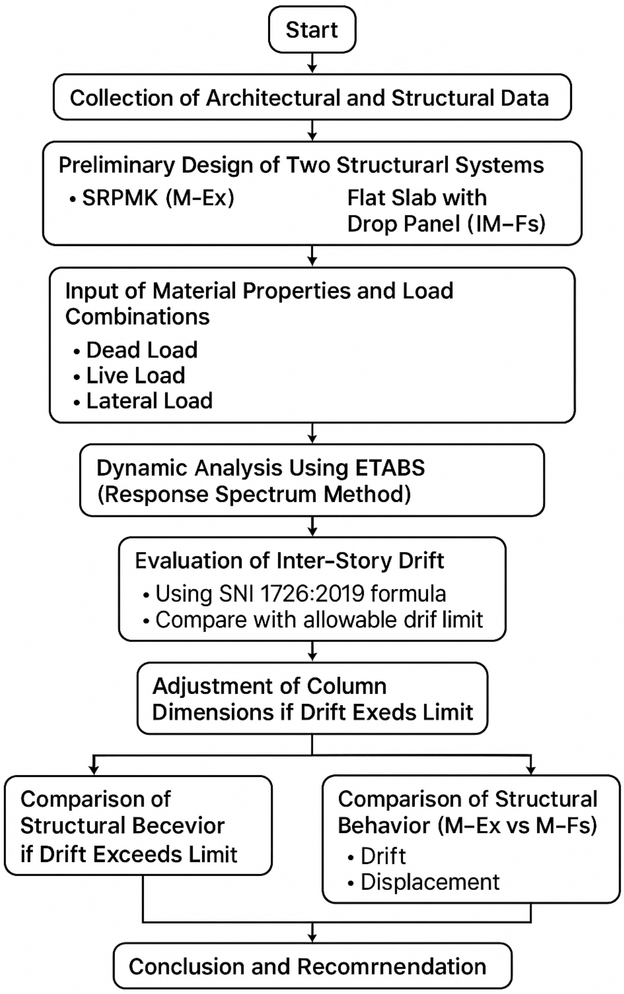


Figure 1. Research flowchart of structural performance analysis for SRPMK and flat slab systems

The object of this study is the SMAN 2 Abiansemal building located in Badung, Bali, Indonesia. This four-story reinforced concrete educational building includes one basement level. Given its function as a public educational facility, the building is classified as Risk Category II under SNI 1726:2019. The structure is situated in Seismic Zone D, as Bali lies within an active tectonic boundary zone. This makes structural resilience against lateral loads especially earthquakes a priority in the design. This study focuses on comparing two alternative structural systems applied to the same architectural configuration:

- M-Ex: Special Moment Resisting Frame (SRPMK), the existing configuration.
- M-Fs: Flat Slab with Drop Panel system, a proposed alternative.

2.2 Structural Modeling and Assumptions

Following the determination of the research framework and structural systems under study, the next step involves detailed structural modeling. This modeling encompasses two primary systems—SRPMK and flat slab with drop panel—based on the architectural configuration and actual dimensions of the SMAN 2 Abiansemal building. Each model is developed using technical assumptions aligned with the relevant Indonesian codes, covering slab thickness, column dimensions, and material strengths.

To ensure clarity and fairness in comparison, both models are constructed identically in terms of building geometry, load inputs, and boundary conditions, so that any performance differences are attributed solely to the structural system employed. The specific assumptions and dimensional configurations for each model are elaborated in the following subsections.

A. Structural Systems Modeled

- SRPMK (M-Ex) uses beams and columns rigidly connected, typically with deeper sections and higher stiffness in lateral directions.
- Flat Slab with Drop Panel (M-Fs) removes beams and transfers loads directly through slabs thickened at column intersections.

B. Geometry and Dimensions

To clarify the physical characteristics of both structural configurations, Table 1 summarizes the main geometric dimensions applied in the modeling of SRPMK (M-Ex) and flat slab (M-Fs) systems. These values reflect realistic assumptions based on standard construction practices and code-compliant structural planning.

To further illustrate the differences between the two structural systems under evaluation, Figure 3 presents a visual comparison of the three-dimensional models created using ETABS software. Both models share identical architectural geometry and load assumptions, with the key variation lying in the use of beams (M-Ex) versus drop-panel-enhanced flat slabs (M-Fs).

Table 1. Summary of structural geometry and dimensional parameters for M-Ex and M-Fs models

Element	SRPMK (M-Ex)	Flat Slab (M-Fs)
Slab Thickness	120 mm	200 mm
Drop Panel Thickness	-	250 mm
Drop Panel Area	-	2.0 m x 2.0 m
Initial Column Size	45 cm x 45 cm	50 cm × 50 cm
Story Height	3.00 m	3.00 m
Bay Span (X/Y)	8.0 m / 7.0 m	8.0 m / 7.0 m

C. Material Properties

The material properties used in the simulation reflect common values for reinforced concrete design in Indonesia. The compressive strength of concrete was set at $f'c = 30$ MPa, in accordance with moderate-strength concrete widely applied in educational building construction. For reinforcement, high-yield deformed bars with yield strength $fy = 420$ MPa were adopted to represent standard grade steel that offers a balance between ductility and strength.

These material inputs were consistently applied across both structural systems to ensure that the comparison focuses purely on the effects of geometric and system differences, rather than on variations in material behavior.

D. Loading and Design Standards

All structural load combinations are configured in accordance with:

- SNI 1727:2020 [14] – Minimum design loads
- SNI 2847:2019 [15] – Concrete structural requirements
- SNI 1726:2019 [16] – Seismic analysis methodology

The seismic parameters used in the response spectrum analysis were derived from the national seismic hazard map. These values were applied to configure the dynamic input in ETABS and reflect the seismic environment of the site in Bali. A summary of the relevant spectral response design parameters is presented in Table 2.

Table 2. Spectrum response design parameters [16]

Spectrum Response Design Parameters		
Risk category		II
Priority factors	Ie	1
Soil site class		Medium Soil (SD)
Acceleration of spectral response, MCE	Ss	0,9654
	Si	0,3939
Acceleration of spectral response	Sds	0,7169
	Sdi	0,5005
long period	Tl	12
Seismic design category		D
Earthquake force resisting structural system	Special Moment Resisting Framing System	
Ductility reduction factor	R = 8; Ω0 = 3; Cd = 5,5	

2.3 Deviation Between Levels

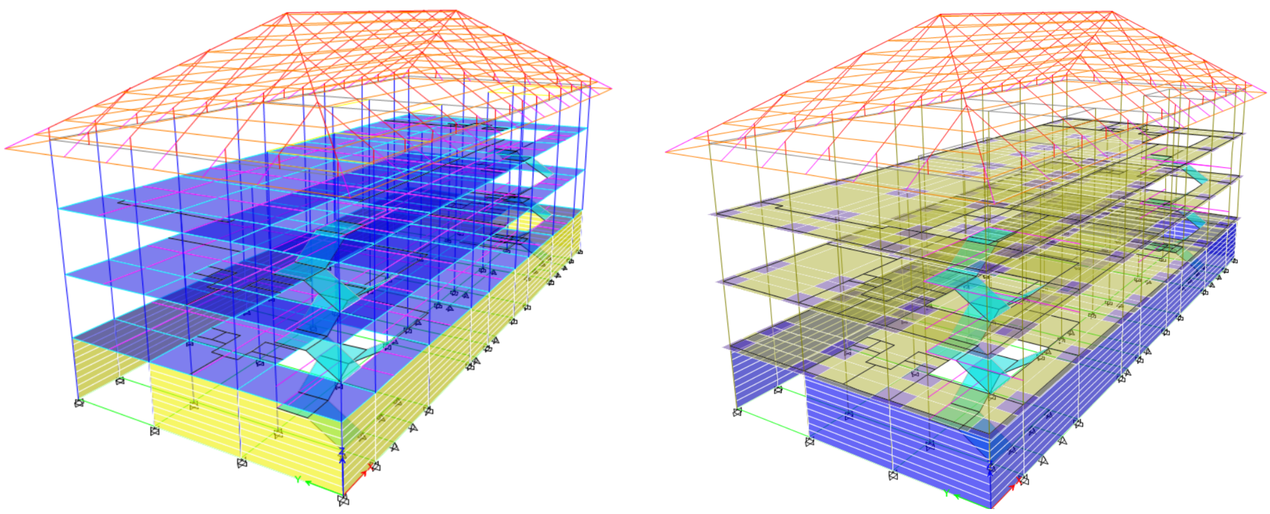
Deviations between levels in a structure need to have limits in order to prevent the building structure from experiencing excessive horizontal deformation so that the structure can avoid collapse due to earthquake loads. The deviation between floors is calculated based on the provisions of SNI 1726:2019 Article 7.8.6. [16] In determining the design floor drift (Δ), it must be calculated as the difference in deflection at the center of mass at the top and bottom levels reviewed by the following equation:

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

Where Cd is the magnification factor of the lateral displacement, δxe is the deviation at the x-th level determined by elastic analysis, and Ie is the priority factor of the earthquake. After calculating from the deviation value that occurs, then calculate from the boundary condition of the deviation value itself. The limit of the allowable deviation or permit deviation is calculated based on the equation in table 20 of SNI 1726:2019 [16]. The deviation value between levels must not exceed the value of the deviation limit conditions. The equation of the permit deviation limit is as follows:

$$\Delta_{\mathrm{i}} = \frac{0{,}020.h_{sx}}{\rho} \quad (2)$$

The selection of the formula for this deviation limit must be adjusted to the risk category of the building, as stated in Table 20 of SNI 1726:2019 [16]. SMAN 2 Abiansemal Building is a building with risk category II because it is an office building. The value of hsx in the equation above is the height between floors, and ρ is the redundancy factor.



(a) (b)

Figure 2. ETABS model comparison between (a) Existing SRPMK structure (M-Ex) and (b) Redesigned flat slab structure (M-Fs)

3 Results and Discussion

3.1 Inter-Story Drift Performance

Inter-story drift represents the relative horizontal displacement between two successive floors under seismic loading. It is one of the most important structural performance criteria in seismic design because it directly influences the safety of both structural and non-structural components. Excessive drift can cause cracking in beams, columns, and walls, and severely damage interior partitions, ceilings, or facades.

Drift analysis was conducted based on dynamic response spectrum results from ETABS, referring to the limitations outlined in SNI 1726:2019, where the allowable inter-story drift for Risk Category II buildings is 62.77 mm. The drift results for the SRPMK structure (M-Ex) are presented in Table 3. Recapitulation Drift Displacement Eksisting Structure (M-Ex), showing that the highest drift values occur at the second floor with Δx = 30.59 mm and Δy = 40.48 mm. All values remain below the prescribed limit, confirming that the moment frame system provides sufficient lateral stiffness.

The flat slab structure with 45×45 cm columns (M-Fs) produced higher drift values, as shown in Table 4. Recapitulation Drift Displacement Flat Slab Structure (M-Fs). The most critical drift was recorded at the second floor, with Δy = 63.38 mm, which exceeds the allowable limit. This condition signals insufficient lateral stiffness due to the absence of beams, which normally help resist shear deformation.

Tabel 3. Recapitulation drift displacement eksisting structure (M-Ex)

Floor	hsx (mm)	Driff (Δx) (mm)	Driff (Δy) (mm)	Driff Terms (Δi) (mm)
4th floor	4080	21,66	30,23	62,77
3rd floor	4080	20,16	27,85	62,77
2nd Floor	4080	30,59	40,48	62,77
1st floor	4080	27,53	33,92	62,77
Basement	4080	0,00	0,00	0,00

Tabel 4. Recapitulation drift displacement flat slab structure (M-Fs)

Floor	hsx (mm)	Driff (Δx) (mm)	Driff (Δy) (mm)	Driff Terms (Δi) (mm)
4th floor	4080	31,004	38,643	62,77
3rd floor	4080	35,624	41,993	62,77
2nd Floor	4080	49,918	63,382	62,77
1st floor	4080	36,784	42,389	62,77
Basement	4080	0,00	0,00	0,00

To correct this, the column size in the M-Fs model was increased to 50×50 cm. The recalculated drift, detailed in Table 5. Recapitulation Drift Displacement Flat Slab Structure (M-Fs) column 50 × 50 cm, shows substantial improvement. The revised model achieved maximum drift values of Δx = 47.99 mm and Δy = 56.37 mm, both within the acceptable limit.

Tabel 5. Recapitulation driff displacement flat slab structure (M-Fs) with column 50 x 50 cm

Floor	hsx (mm)	Driff (Δx) (mm)	Driff (Δy) (mm)	Driff Terms (Δi) (mm)
4th floor	4080	32,104	41,091	62,77
3rd floor	4080	36,124	44,902	62,77
2nd Floor	4080	47,999	56,370	62,77
1st floor	4080	32,670	36,531	62,77
Basement	4080	0,00	0,00	0,00

This analysis emphasizes that while flat slab systems may initially underperform in drift control, appropriate dimensional reinforcement can effectively restore code compliance. It also reinforces the importance of drift evaluation as an early design checkpoint for structural adequacy in seismic zones.

3.2 Displacement Behavior

Total displacement reflects the absolute lateral movement of each story from its original vertical position due to lateral forces. While not regulated as strictly as inter-story drift, displacement affects architectural detailing, façade durability, and structural stability especially at the roof level where cumulative movement is highest.

The displacement results for the SRPMK (M-Ex) system are shown in Table 6. Displacement Eksisting Structure (M-Ex). The values gradually increase from the ground to the roof, with the highest displacement being 18.17 mm in X and 24.09 mm in Y. These values reflect the global deformation profile of a structure with well-distributed stiffness.

In contrast, the flat slab structure with initial columns (M-Fs) exhibits significantly higher displacements, as detailed in Table 7. Displacement Flat Slab Structure (M-Fs). Roof-level displacements reach 27.88 mm in X and 33.89 mm in Y, suggesting higher flexibility and greater lateral sway.

Tabel 6. Displacement Eksisting Structure (M-Eks)

Floor	δx (mm)	δy (mm)
4th floor	18,172	24,089
3rd floor	14,234	18,592
2nd Floor	10,568	13,528
1st floor	5,006	6,168
Basement	0,000	0,000

Tabel 7. Displacement Flat Slab Structure (M-Fs)

Floor	δx (mm)	δy (mm)
4th floor	27,878	33,892
3rd floor	22,241	26,866
2nd Floor	15,764	19,231
1st floor	6,688	7,707
Basement	0,000	0,000

Following the same strategy used in drift improvement, a column size revision to 50×50 cm was applied. The results, presented in Table 8. Displacement Flat Slab Structure (M-Fs) column 50 × 50 cm, indicate that displacements at roof level were reduced to 27.07 mm in X and 32.52 mm in Y. While still greater than those of M-Ex, they are safely below serviceability thresholds and pose no significant threat to performance. The displacement comparison confirms that flat slab systems require not only drift control but also displacement management to ensure safety and occupant comfort during and after seismic events.

Tabel 8. Displacement Flat Slab Structure (M-Fs)

Floor	δx (mm)	δy (mm)
4th floor	27,072	32,526
3rd floor	21,235	25,055
2nd Floor	14,667	16,891
1st floor	5,940	6,642
Basement	0,000	0,000

4 Conclusion

This study investigated the structural performance of the SMAN 2 Abiansemal building by comparing two structural systems: the existing Special Moment Resisting Frame (SRPMK) system and an alternative flat slab system with drop panels. Using response spectrum analysis in ETABS and referring to SNI 1726:2019, the evaluation focused on inter-story drift and total lateral displacement under seismic loading.

The findings show that the SRPMK system demonstrated superior performance in controlling both inter-story drift and total displacement. All values remained well below the allowable drift limit of 62.77 mm, reflecting the system's inherent lateral stiffness due to the integration of beams and rigid joints.

In contrast, the flat slab system initially exceeded the drift limit, particularly at the second floor, where the Y-direction drift reached 63.38 mm. This excessive drift highlighted a deficiency in lateral stiffness caused by the beamless configuration of the system. To rectify this, a design modification was implemented by increasing the column size from 45×45 cm to 50×50 cm. The revised flat slab model successfully brought all drift values within acceptable limits, with a maximum of 56.37 mm in the Y direction.

Although the flat slab system required adjustments to meet seismic code requirements, it offers advantages in terms of architectural flexibility, construction efficiency, and floor height optimization. These findings support the conclusion that flat slab systems can serve as a viable alternative to SRPMK in mid-rise educational buildings located in seismic zones—provided that structural modifications, particularly in vertical element sizing, are made accordingly.

Ultimately, the study underscores the importance of integrating detailed structural analysis and design adaptation in early planning stages, especially when using flexible structural systems in earthquake-prone areas. The results also demonstrate the effectiveness of response spectrum-based drift assessment as a practical tool for ensuring seismic compliance in building design.

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