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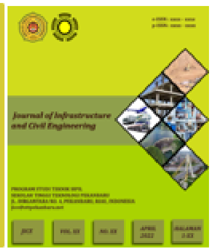

Comparative Seismic Performance of Flat Slab-Drop Panel and Conventional Slab Systems for Hospital Buildings

Putu Didik Sulistiana[1*], I Putu Pranayoga Aditya[2], I Gusti Agung Putu Eryani[3]

[1]*Department of Professional Engineer Program, Faculty of Engineering and Planning, Warmadewa University, Bali, 80239*
[2,3]*Department of Civil Engineering, Faculty of Engineering and Planning, Warmadewa University, Bali, 80239*

*[*didik.sulistiana@warmadewa.ac.id](mailto:didik.sulistiana@warmadewa.ac.id)*

Abstract

Hospitals are classified as essential facilities and therefore require adequate seismic performance to maintain structural safety during earthquake events. This study compares the seismic performance of a conventional slab system and a flat slab-drop panel (FSDP) system in a four-story reinforced concrete hospital building using the Response Spectrum Analysis (RSA) method. Two three-dimensional structural models were developed in ETABS v21.2 with identical geometry, material properties, loading conditions, and boundary conditions. The only variable considered was the floor system configuration. Structural responses, including structural weight, fundamental period, inter-story drift, slab deflection, base shear, and column reinforcement demand, were evaluated in accordance with SNI 1726:2019 and SNI 2847:2019. The results indicate that the FSDP system increased the total structural weight by 6.54%, the fundamental period by 30.2% and 18.2% in the X- and Y-directions, respectively, and the base shear by 42.29% and 26.85%. In addition, the FSDP system produced larger inter-story drift, slab deflection, and column design demand than the conventional slab system. Nevertheless, all evaluated structural responses satisfied the design requirements specified in the applicable Indonesian standards. Overall, the conventional slab system was found to be more structurally efficient, exhibiting lower inter-story drift, slab deflection, base shear, and column reinforcement demand than the FSDP system, while both structural systems satisfied the seismic design requirements specified in SNI 1726:2019 and SNI 2847:2019. The FSDP system, however, offers greater architectural flexibility and construction efficiency.

Keywords: *Conventional slab, flat slab-drop panel, hospital building, response spectrum analysis, seismic performance*

1. Introduction

The increasing demand for multi-storey buildings has encouraged the development of structural systems that are not only efficient in construction but also capable of maintaining adequate structural performance under seismic loading. Among these, flat slab systems have gained considerable attention because they eliminate beams, provide greater architectural flexibility, reduce storey height, simplify formwork, and accelerate construction compared with conventional beam-supported slab systems [1], [2]. These advantages have led to the widespread application of flat slab systems in office buildings, residential buildings, hotels,

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shopping centres, and hospitals, where flexible interior layouts and shorter construction durations are highly desirable [1], [3].

Hospital buildings are classified as essential facilities because they are expected to remain operational immediately after an earthquake. Consequently, structural systems adopted for hospital buildings must satisfy not only strength requirements but also serviceability and seismic performance criteria to ensure the continuity of medical services during and after seismic events [3], [4]. Unlike ordinary buildings, excessive structural deformation may interrupt hospital functionality, damage medical equipment, and compromise life safety. Therefore, selecting an appropriate floor system becomes one of the critical considerations in seismic structural design.

Conventional reinforced concrete slab systems have long been recognized for providing relatively high lateral stiffness through the interaction between beams, slabs, and columns. Conversely, flat slab-drop panel systems transfer gravity loads directly to columns without intermediate beams, resulting in different structural behaviour under lateral loading. Although drop panels significantly improve punching shear resistance and local slab-column performance, numerous studies indicate that their contribution to the overall lateral stiffness of the structure remains limited when additional lateral force-resisting elements are absent [2], [5], [6], [7]. Consequently, flat slab structures generally exhibit longer fundamental periods, larger inter-storey drifts, greater roof displacements, and higher seismic vulnerability than conventional slab systems [6], [8].

Recent studies have demonstrated that the seismic performance of flat slab structures can be substantially improved through the incorporation of structural strengthening components such as shear walls, edge beams, bracing systems, and enhanced reinforcement detailing. These additional structural elements increase lateral stiffness, improve base shear resistance, delay plastic hinge formation, enhance energy dissipation capacity, and reduce punching shear failure under earthquake loading [5], [9]. Several researchers further reported that integrated flat slab systems incorporating shear walls are capable of satisfying seismic performance objectives comparable to conventional structural systems while preserving the architectural advantages of beamless construction [5], [10], [11].

Despite the extensive research conducted on flat slab systems, several important research gaps remain. First, most previous investigations primarily focus on generic office or residential buildings, whereas studies involving hospital buildings are still relatively limited [4], [12], [13]. Second, existing investigations generally evaluate only selected seismic parameters such as displacement, story drift, or punching shear behaviour, without providing a comprehensive comparison of structural responses including structural weight, natural period, inter-storey drift, serviceability behaviour, and base shear within the same structural model [6], [8], [14]. Third, most published studies employ idealized numerical models or nonlinear analyses, while comparative evaluations based on practical design models following current seismic design provisions remain relatively scarce [4], [9], [15].

Therefore, this study presents a comparative evaluation of the seismic response of flat slab-drop panel and conventional slab systems in a reinforced concrete hospital building using ETABS. The comparison considers structural weight, fundamental vibration period, inter-storey drift, deflection, base shear, and column reinforcement demand to evaluate the influence of floor systems on overall seismic performance. The findings are expected to provide practical guidance for structural engineers in selecting efficient floor systems for essential buildings located in seismic regions while contributing to the ongoing development of earthquake-resistant structural design.

2. Methodology

2.1 Structural System and Floor System Configuration

The structural system adopted in this study is the Special Moment Resisting Frame (SMRF) in accordance with SNI 2847:2019 [16]. Since hospital buildings are classified as Risk Category IV according to SNI 1726:2019 [17], both structural models were initially developed with identical geometry, member dimensions, material properties, loading conditions, and boundary conditions. The floor system configuration was defined as the primary analytical variable. Any differences in the final column dimensions presented in the results represent the structural design outcomes obtained after analysis, reflecting the different force demands induced by each floor system rather than differences in the initial analytical models.

Two floor systems were investigated, namely the conventional slab system and the flat slab-drop panel (FSDP) system. The conventional slab transfers gravity loads through beams to columns, whereas the FSDP system transfers loads directly from the slab to the columns without interior beams. Although this configuration improves architectural flexibility and construction efficiency, it generally provides lower lateral stiffness than the conventional slab system.

To improve the slab-column connection against punching shear, the FSDP model was designed with drop panels in accordance with SNI 2847:2019 [16]. The minimum dimensions of the drop panel satisfy the following requirements:

$$h_{dp} \geq \frac{1}{4} h_s \quad (1)$$

$$l_{dp,x} \geq \frac{1}{6} L_x \quad (2)$$

$$l_{dp,y} \geq \frac{1}{6} L_y \quad (3)$$

where h_{dp} is the drop panel thickness, h_s is the slab thickness, and L_x and L_y are the span lengths in the X and Y directions, respectively. All drop panel dimensions adopted in the numerical model satisfy the minimum requirements specified in SNI 2847:2019 [16].

2.2 Structural Loading

The structural models were subjected to gravity and seismic loads in accordance with the applicable Indonesian design standards. Gravity loads consisted of dead loads and live loads following the provisions of SNI 1727:2020 [18], while seismic loads were determined based on SNI 1726:2019 [17], using the Response Spectrum Analysis (RSA) method. The response spectrum was generated according to the seismic hazard parameters corresponding to the location of Bhayangkara Hospital, Denpasar.

Both structural models were assigned identical loading conditions and load combinations to ensure that the comparison was influenced solely by the difference in floor system configuration. The seismic analysis was performed independently in the X- and Y-directions, and the structural responses obtained from ETABS were used to evaluate the seismic performance of each floor system.

2.3 Structural Performance Evaluation

The seismic performance of both structural models was evaluated based on several structural response parameters obtained from the ETABS analysis. The evaluated parameters included the inter-story drift, maximum slab deflection, fundamental period, structural weight, base shear, and column reinforcement demand. These parameters were selected to represent the overall structural behavior under seismic loading.

The inter-story drift was calculated according to SNI 1726:2019 using the amplified elastic displacement as expressed in Eq. (4).

$$\delta = \frac{C_d \delta_e}{I_e} \quad (4)$$

where δ is the design inter-story drift, C_d is the deflection amplification factor, δ_e is the elastic displacement obtained from the response spectrum analysis, and I_e is the importance factor.

The calculated inter-story drift was then compared with the allowable drift limit specified in SNI 1726:2019 [17] to verify the serviceability performance of each structural model.

In addition, the slab deflection was evaluated according to the serviceability requirements of SNI 2847:2019 [16]. The maximum deflection obtained from ETABS was compared with the allowable deflection limit, as expressed in Eq. (5).

$$\Delta_{allow} = \frac{L}{480} \quad (5)$$

where L is the effective span length of the slab.

2.4 Case Study and Structural Modelling

The case study was conducted on the Bhayangkara Hospital Building, located on Jl. Trijata No. 32, Denpasar, Bali, Indonesia. The building consists of four stories with a total structural height of 16.95 m, comprising a first-floor height of 3.50 m, second- and third-floor heights of 3.70 m, and a fourth-floor height of 3.00 m. As a hospital building, the structure is classified as an essential facility (Risk Category IV) and therefore requires a higher level of seismic performance than ordinary buildings.

A three-dimensional finite element model was developed using ETABS v21.2 to evaluate the seismic response of the two floor systems. Two structural models were established with identical geometry, material properties, loading conditions, and boundary conditions. The only variable considered in this study was the floor system configuration, namely the conventional slab system and the flat slab-drop panel (FSDP) system. This modelling approach ensures that any differences in structural response are solely attributed to the floor system.

The material properties adopted in both structural models are summarized in Table 1, while the case study location and three-dimensional structural model are presented in Figure 1 and Figure 2, respectively.

Table 1. Structural Properties of the Building Model

Category	Parameter	Value
Structural Material	Foundation	Reinforced Concrete
	Columns	Reinforced Concrete
	Beams	Reinforced Concrete
	Floor Slab	Reinforced Concrete
	Roof Structure	Steel Wide Flange (WF)
Concrete Properties	Compressive Strength, (f'_c) (Slab, Beam, Foundation)	25 MPa
	Compressive Strength, (f'_c) (Columns)	30 MPa
	Modulus of Elasticity, (E_c) (25 MPa Concrete)	23,500 MPa
	Modulus of Elasticity, (E_c) (30 MPa Concrete)	25,742.96 MPa
Reinforcement Steel	Plain Reinforcing Bar (BJTP 280)	(f_y = 280) MPa
	Deformed Reinforcing Bar (BJTS 420)	(f_y = 420) MPa

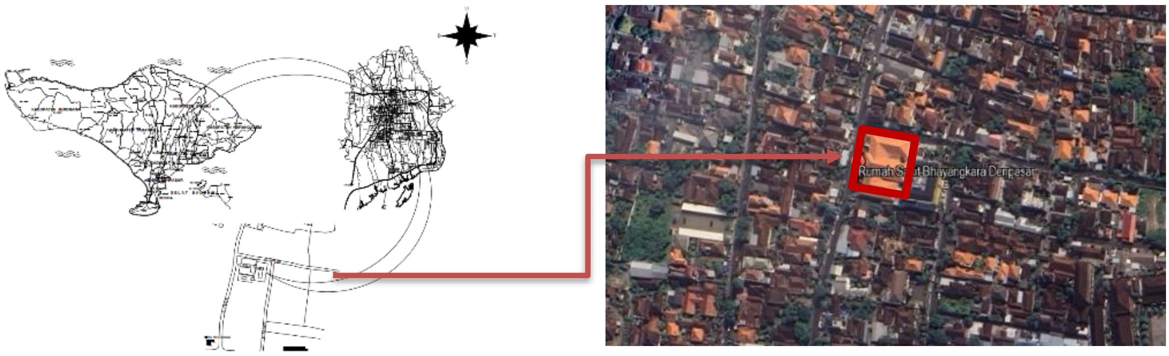


Figure 1. Location of Bhayangkara Hospital, Denpasar

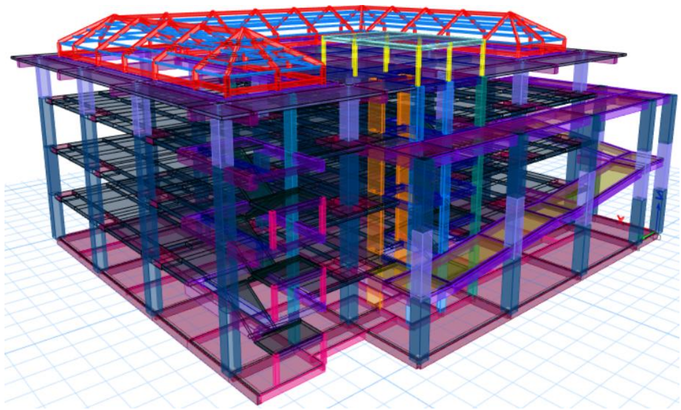


Figure 2. Three-dimensional structural models developed in ETABS

2.5 Research Workflow

The research methodology adopted in this study is summarized in the workflow presented in Figure 3. The study began with collecting the structural design data of the Bhayangkara Hospital Building, followed by the development of two three-dimensional structural models in ETABS, namely the conventional slab system and the flat slab-drop panel (FSDP) system. Both models were assigned identical material properties, loading conditions, and design parameters. Subsequently, gravity and seismic loads were applied using the Response Spectrum Analysis (RSA) method in accordance with SNI 1726:2019 [17]. The structural responses obtained from both models, including structural weight, fundamental period, inter-story drift, slab deflection, base shear, and column reinforcement demand, were then compared to evaluate the influence of the floor system on the overall seismic performance of the building.

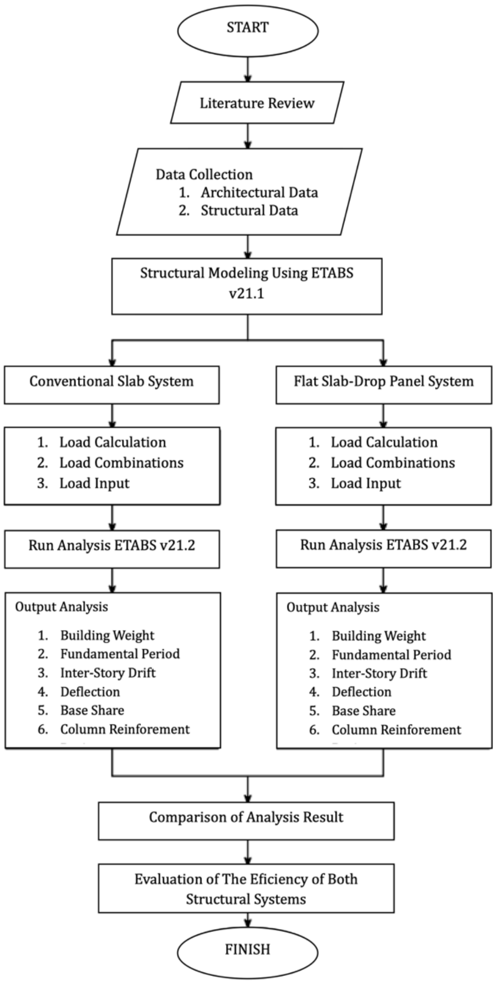


Figure 3. research Flowchart

3. Results and Discussion

3.1 Structural Weight Distribution

The structural weight distribution of the conventional slab and flat slab-drop panel (FSDP) systems is presented in Table 2. The results indicate that the FSDP system generally exhibits a greater structural weight than the conventional slab system at the roof and upper stories. This increase is primarily attributed to the additional concrete volume introduced by the drop panels surrounding the slab-column connections. Consequently, the total structural weight of the FSDP model reached 42,935.90 kN, which is 6.54% higher than that of the conventional slab system (40,301.30 kN).

Interestingly, the first floor shows a lower structural weight in the FSDP model than in the conventional slab system. This difference is mainly associated with the elimination of interior beams, which reduces the structural self-weight and partially offsets the additional concrete volume contributed by the drop panels. Nevertheless, the cumulative weight of the upper floors remains dominant, resulting in a higher overall structural weight for the FSDP system.

Structural weight is one of the primary factors influencing seismic response because it directly contributes to the seismic mass of the building. An increase in structural mass generally leads to larger inertia forces during earthquake excitation, which may subsequently affect the fundamental period, base shear, and internal force demand of structural members. Therefore, although the FSDP system provides architectural and construction advantages, the increase in structural weight should be considered in the overall evaluation of its seismic performance.

The findings are consistent with previous studies reporting that the incorporation of drop panels increases the dead load of flat slab systems due to the additional concrete surrounding slab-column connections, while simultaneously improving punching shear resistance [1]. Therefore, the effect of increased structural weight should be evaluated together with other seismic response parameters rather than being considered independently.

Table 2. Comparison of Structural Weight Distribution

Story	Conventional Slab (kN)	Flat Slab-Drop Panel (kN)	Difference (%)
Roof	5,124.08	6,020.16	+17.49
Level 4	8,692.64	9,522.16	+9.54
Level 3	9,285.66	10,232.53	+10.19
Level 2	9,241.59	10,221.19	+10.60
Level 1	7,957.28	6,939.85	−12.79
Total	**40,301.30**	**42,935.90**	**+6.54**

3.2 Fundamental Period

The comparison of the fundamental periods for the conventional slab and flat slab-drop panel (FSDP) systems is presented in Figure 4. The fundamental period was obtained from the first vibration mode for the X-direction and the second vibration mode for the Y-direction.

As shown in Figure 4, the conventional slab system exhibits a fundamental period of 0.789 s in the X-direction and 0.746 s in the Y-direction. In comparison, the FSDP system has longer fundamental periods of 1.027 s and 0.882 s in the X- and Y-directions, respectively. These results indicate that the FSDP system increases the fundamental period by approximately 30.2% in the X-direction and 18.2% in the Y-direction compared with the conventional slab system.

The increase in the fundamental period is mainly attributed to the lower lateral stiffness of the FSDP system. Unlike the conventional slab system, which transfers loads through beams and columns, the FSDP system eliminates interior beams, thereby reducing the overall flexural stiffness of the structural frame. Consequently, the structure becomes more flexible and requires a longer vibration period under seismic excitation.

These findings are consistent with previous studies reporting that flat slab systems generally exhibit lower lateral stiffness and longer vibration periods than conventional beam-supported slab systems. Although a longer fundamental period may reduce the seismic response under certain spectral conditions, it is also commonly associated with increased lateral displacement and inter-story drift. Therefore, the effect of the increased fundamental period should be evaluated together with other seismic performance parameters rather than independently.

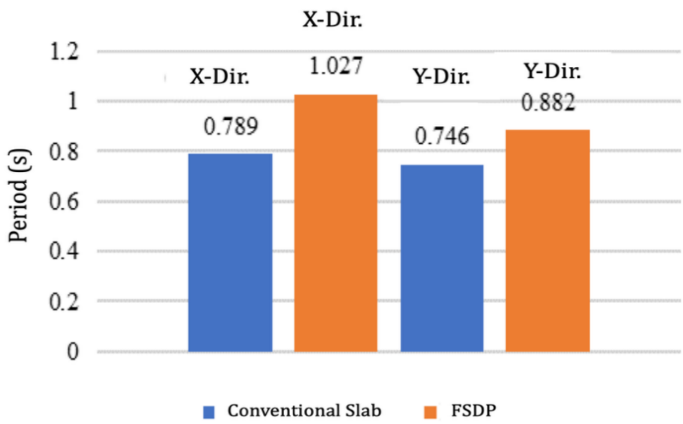


Figure 4. Comparison of the fundamental periods

3.3 Lateral Deformation Performance

3.3.1 Inter-story Drift

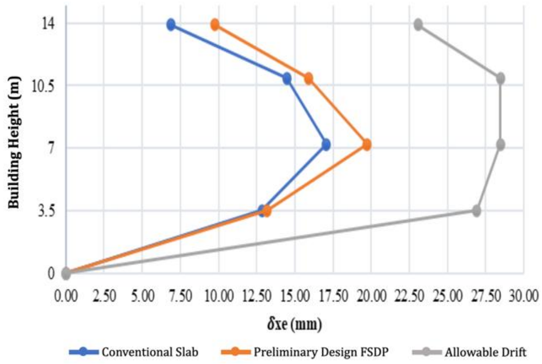
The inter-story drift responses of the conventional slab and flat slab-drop panel (FSDP) systems are presented in Tables 3 and 4, while the comparison of the drift distribution is illustrated in Figure 5.

Table 3. Inter-story drift results of the conventional slab system

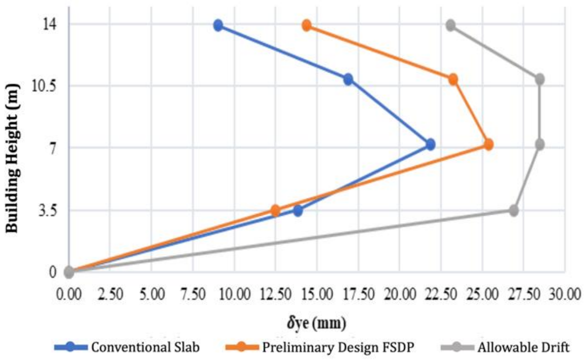
Story	h_{sx} (mm)	δ_x (mm)	δ_y (mm)	Inter-Story Drift (Δ_x) (mm)	Inter-Story Drift (Δ_y) (mm)	Allowable Drift (Δ_i) (mm)	Check $\Delta_i > \Delta_x$ & Δ_y
Roof	3000	13.988	16.826	6.89	9.05	23.08	**OK**
Story 4	3700	12.110	14.359	14.48	16.91	28.46	**OK**
Story 3	3700	8.161	9.747	17.07	21.89	28.46	**OK**
Story 2	3500	3.506	3.777	12.86	13.85	26.92	**OK**
Story 1	0	0	0	0	0	26.92	**OK**

Table 4. Inter-story drift results of the flat slab-drop panel (FSDP) system

Story	h_{sx} (mm)	δ_x (mm)	δ_y (mm)	Inter-Story Drift (Δ_x) (mm)	Inter-Story Drift (Δ_y) (mm)	Allowable Drift (Δ_i) (mm)	Check $\Delta_i > \Delta_x$ & Δ_y
Roof	3000	15.975	20.589	9.78	14.36	23.08	**OK**
Story 4	3700	13.309	16.673	15.88	23.24	28.46	**OK**
Story 3	3700	8.978	10.335	19.73	25.41	28.46	**OK**
Story 2	3500	3.596	3.405	13.19	12.49	26.92	**OK**
Story 1	0	0	0	0	0	26.92	**OK**



a. X-Direction



b. Y-Direction

Figure 5. Comparison of inter-story drift

The results indicate that the FSDP system generally produces larger inter-story drift than the conventional slab system in both the X- and Y-directions. The maximum drift in the conventional slab system is 17.07 mm and 21.89 mm, whereas the FSDP system reaches 19.73 mm and 25.41 mm, respectively. This increase is attributed to the lower lateral stiffness of the FSDP system resulting from the elimination of interior beams.

Despite the increase in drift, all calculated values remain below the allowable drift limits specified in SNI 1726:2019 [17], indicating that both structural systems satisfy the serviceability requirements under the design earthquake.

The larger inter-story drift observed in the FSDP system is consistent with the increase in the fundamental period discussed in Section 3.2. A longer vibration period reflects a more flexible structural system, which consequently experiences greater lateral deformation under seismic excitation.

3.3.2 Slab Deflection

The comparison of slab deflection is presented in Table 5. The results show that the FSDP system exhibits larger slab deflections than the conventional slab system for both investigated span lengths. For the 8.5 m span, the maximum slab deflection increases from 13.513 mm to 15.715 mm, while for the 8.0 m span it increases from 12.701 mm to 14.975 mm. The increase is mainly associated with the absence of interior beams, which reduces the flexural stiffness of the floor system.

Nevertheless, all calculated slab deflections remain lower than the allowable deflection limit of L/480, indicating that both floor systems satisfy the serviceability requirements specified in SNI 2847:2019.

The deflection trend agrees well with the inter-story drift results, confirming that the reduction in structural stiffness associated with the FSDP system leads to greater structural deformation under loading.

Table 5. Comparison of slab deflection results

Structural System	L (Column Spacing)	Allowable Deflection (L/480)	Maximum Deflection	Design Check
	(mm)	(mm)	(mm)	
Conventional Slab	8500	17.71	13.513	OK
	8000	16.67	12.701	OK
Flat Slab-Drop Panel	8500	17.71	15.715	OK
	8000	16.67	14.975	OK

3.4 Base Shear

The comparison of the base shear obtained from the Response Spectrum Analysis (RSA) is presented in Figure 6. Base shear represents the total lateral seismic force acting at the base of the structure and is one of the primary parameters used to evaluate the seismic demand imposed on a structural system.

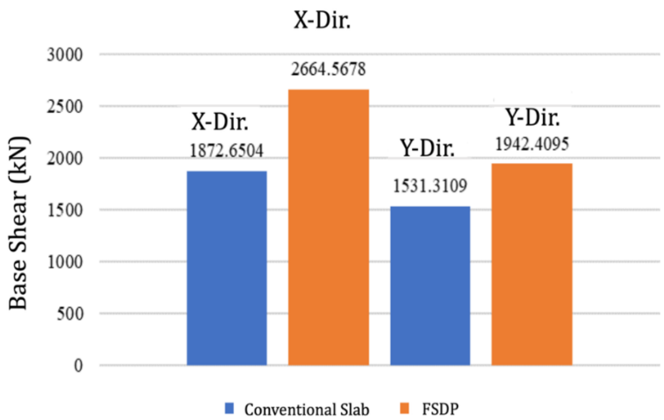


Figure 6. Comparison of base shear in the X- and Y-directions

As shown in Figure 6, the conventional slab system developed a base shear of 1,872.65 kN and 1,531.31 kN in the X- and Y-directions, respectively. In contrast, the flat slab-drop panel

(FSDP) system produced higher base shear values of 2,664.57 kN in the X-direction and 1,942.41 kN in the Y-direction. Compared with the conventional slab system, the base shear of the FSDP system increased by approximately 42.29% in the X-direction and 26.85% in the Y-direction.

The increase in base shear is primarily attributed to the higher structural mass of the FSDP system resulting from the additional concrete provided by the drop panels, as discussed in Section 3.1. Although the FSDP system exhibits a longer fundamental period than the conventional slab system (Section 3.2), the increase in structural mass has a more significant influence on the seismic force generated under the adopted response spectrum. Consequently, the FSDP system experiences greater seismic force demands than the conventional slab system.

Nevertheless, the increased base shear remains within the design capacity of both structural models, as they were designed using the Special Moment Resisting Frame (SMRF) system in accordance with SNI 2847:2019 and analyzed following the seismic provisions of SNI 1726:2019. These findings indicate that the floor system configuration influences not only the dynamic characteristics and deformation response of the structure but also the magnitude of seismic forces transferred to the structural members. Therefore, the selection of an appropriate floor system should consider both architectural efficiency and seismic performance to achieve an optimal structural design.

3.5 Column Reinforcement Demand

The comparison of the column design results for the conventional slab and flat slab–drop panel (FSDP) systems is summarized in Table 6. The column capacity was verified using SPColumn based on the internal forces obtained from the ETABS analysis. Both structural systems require the same amount of longitudinal reinforcement, consisting of 24D22 bars. However, the FSDP system requires a larger column cross-section of 700 × 700 mm, whereas the conventional slab system satisfies the design requirements with a 600 × 600 mm column. In addition, the transverse reinforcement spacing in the plastic hinge region is reduced from 100 mm to 80 mm in the FSDP system, indicating a higher confinement demand under seismic loading.

The increase in column dimensions and the closer transverse reinforcement spacing are primarily associated with the greater seismic force demand developed in the FSDP system. As discussed in the previous sections, the FSDP model exhibits higher structural weight, a longer fundamental period, larger inter-story drift, and greater base shear than the conventional slab system. These factors collectively increase the axial force and bending moment acting on the columns, thereby requiring greater column capacity to satisfy the strength and ductility requirements of the Special Moment Resisting Frame (SMRF).

Overall, although the FSDP system offers architectural advantages by eliminating interior beams, its application results in higher demands on the primary structural members. Consequently, larger column dimensions and more closely spaced transverse reinforcement are required to maintain adequate seismic performance.

Table 6. Comparison of Column Design Results

Design Parameter	Conventional Slab	Flat Slab–Drop Panel
Concrete strength	25 MPa	25 MPa
Column size	600 × 600 mm	700 × 700 mm
Longitudinal reinforcement	24D22	24D22
Plastic hinge transverse reinforcement	D10 @100 mm	D10 @80 mm
Outside plastic hinge	D10 @150 mm	D10 @150 mm
Confinement demand	Lower	Higher

4. Conclusion

This study compared the seismic performance of conventional slab and flat slab-drop panel (FSDP) systems in a four-story reinforced concrete hospital building using the Response Spectrum Analysis method. The comparison demonstrated that the floor system significantly influences the structural response under seismic loading.

The FSDP system exhibited a higher structural weight, longer fundamental period, larger inter-story drift, greater slab deflection, higher base shear, and increased column design demand compared with the conventional slab system. These responses were primarily attributed to the reduced lateral stiffness resulting from the elimination of interior beams, despite the presence of drop panels to improve punching shear resistance.

Although the FSDP system produced greater seismic demands, all evaluated structural responses satisfied the serviceability and strength requirements specified in SNI 1726:2019 and SNI 2847:2019. Therefore, both floor systems are structurally feasible for application in hospital buildings.

Based on the elastic design-level response obtained from Response Spectrum Analysis, the conventional slab system was found to be more structurally efficient, exhibiting lower inter-story drift, slab deflection, base shear, and column reinforcement demand than the FSDP system. However, both structural systems satisfied the design requirements specified in SNI 1726:2019 and SNI 2847:2019. The present study is limited to linear elastic analysis and does not evaluate nonlinear behavior, plastic hinge formation, ductility capacity, or collapse mechanisms under severe seismic loading.

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