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Research Article

Comparative Analysis of Flexural Strength and Reinforcement Weight of Flat Slab Floor System and Beam-Slab Floor System

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Abstract:

Analysis of reinforcement efficiency in concrete floor slab systems is a critical aspect of architectural and structural design, requiring significant time and precision. Advances in software have revolutionized this process by enabling accurate modeling, simulation, structural analysis, design, and optimization in a shorter timeframe. This study focuses on a comparative analysis of flexural strength and reinforcement weight between Flat Slab and Plate Beam floor systems. The research employs Safe v.21 software to model, simulate, and analyze these systems. The study uses varying non-fixed variables (such as frame specification and volume) while maintaining consistent fixed variables (material specifications, load cases, load combinations, and other structural parameters). The findings indicate distinct differences in performance metrics, including displacements, beam moments, shear forces, axial forces, and shell stress. The results demonstrate that the Flat Slab system offers greater reinforcement efficiency. The novelty of this research lies in the application of Safe v.21 software, which provides enhanced accuracy in evaluating the flexural strength and reinforcement characteristics of concrete floor slabs.

1. Introduction

A slab, also referred to as a thin plane element, is capable of withstanding transverse loads through bending moments distributed to its supporting planes. A floor slab, specifically, is a thin, horizontal structure constructed from reinforced concrete that resists loads acting perpendicular to its plane [1,2]. Plates or slabs are integral elements of reinforced concrete construction, serving as structural components for roofs and floors, where their implementation demands precise planning and significant resources due to the extensive workload involved [3]; their optimization, guided by architectural considerations and efficient material usage, is crucial in ensuring cost-effective solutions and maintaining the overall structural integrity against live, dead, and other load effects. The importance of ensuring structural integrity during emergencies, rather than solely focusing on minimizing construction costs [4] floor slab systems have evolved from traditional beam-and-slab configurations—comprising floor slabs, beams, and columns—to include flat slab systems, as recognized in SNI 2847:2013, where slabs are directly supported by columns without intermediate beams, offering advantages in construction efficiency and architectural flexibility [5]. A flat slab is a reinforced concrete floor system where the slab is directly supported by columns, with or without the inclusion of drop panels—thickened sections of the slab above the columns—to enhance shear strength and moment capacity [6]. The beam-plate floor system, while time-intensive due to its reliance on conventional reinforcement, concrete, and wooden formwork, offers notable advantages, including adaptability to specific design requirements, suitability for construction in confined spaces, and the ease of monitoring and controlling the construction process. Wijaksono et al (2018) Research has revealed that the use of beam plate floor systems takes longer but incurs lower costs compared to precast full slab and precast half slab methods in high-rise hotel construction projects in Surabaya. This finding underscores that beam plate concrete floor slabs remain a viable and frequently employed option in various building projects, particularly where cost efficiency is a priority. From a cost perspective, beam-slab systems can be more economical than alternative flooring options, such as flat slabs, particularly in projects with longer spans or heavier loads [8]. The waffle slab floor system offers several advantages, including high stiffness and reduced plate thickness [9], which can influence column layouts by allowing greater spacing between columns due to reduced beam deflection compared to traditional plate beam systems. Additionally, waffle slabs can be designed using joist beam construction for extended plate spans capable of supporting light live loads [10]. According to SNI 2847:2013, joist beam construction comprises a combination of regularly spaced monolithic ribs and overlying slabs, designed to span in either one direction or two orthogonal directions [11]. Paula and Leo [12] observed that the waffle slab system allows for greater column spacing and thinner plate thickness compared to the beam plate system, offering enhanced stiffness over conventional plate systems. Their study also highlighted that the waffle slab system uses less concrete and steel reinforcement than the beam plate system. Similarly, Latha & Pratibha [13] concluded that the grid plate system is more economical than the beam plate system, requiring a lower percentage of steel and concrete. Furthermore, the reduced self-weight and maximum structural displacements in grid plates contribute to decreased shear rates, albeit with a slight reduction in floor stiffness [14]. Flat slab systems, characterized by the addition of drop panels and column heads, offer enhanced structural rigidity and strength to resist applied forces [15,16].The adoption of flat slab systems in construction has increased due to their structural performance advantages and ease of construction. Key benefits include the elimination of beams, reduced floor height, and decreased structural loads. However, the absence of beams in the plate-column connection can limit shear resistance, leading to potential cracks and horizontal damage, which may result in plate failure. Despite these limitations, flat slab systems are suitable for buildings in low to medium seismic zones [17]. The selection of floor slab types is a critical aspect of multi-story building design, as each type presents distinct advantages and disadvantages. Key considerations in evaluating the efficiency of concrete floor slabs include material optimization, structural load reduction, safety and reliability, energy efficiency, innovation, and sustainability. A comparative analysis of reinforcement efficiency across various floor slab systems can offer valuable insights into resource optimization, enhanced structural safety, cost reduction, and environmentally sustainable building designs.

This study focuses on a comparative analysis of the flexural strength and reinforcement weight between the Flat Slab and Plate Beam floor systems. By examining critical parameters such as flexural performance, displacement, moment, shear force, and axial force, the research aims to evaluate the efficiency and structural reliability of these systems under dead and live loads. The findings of this study will provide insights for structural engineers and architects in selecting the most suitable floor system for specific design and functional requirements.

2. Material and Methods

This study employs a qualitative research approach utilizing experimental and analytical methods through modeling and simulation techniques. Modeling involves designing and creating representations of real-world systems in specific formats, resulting in formulated depictions that capture the essence of these systems. Simulations, as replications of real or hypothetical contexts, enable the dynamic interaction of manipulated variables in a virtual environment, with implications for real-world application [18]. Leveraging advancements in information technology and computerization, digital simulations provide a platform for scenario testing and analysis [19]. This research specifically focuses on modeling reinforcement systems for concrete floor slabs, including Plate Beam, Waffle Slab, and Flat Slab systems, with simulations and efficiency analyses conducted using Safe v.21 software. The modeling process incorporates variable and fixed parameter configurations to assess the performance. Table 1 is the variable, frame specifications, and concrete volume of the beam-slab floor system. Table 2 is the variable, frame specifications, and concrete volume of the Flat Slab floor system. Table 3 shoes frame specifications, and concrete volume of the flat slab floor system.

Table 1. *The variable, frame specifications, and concrete volume of the beam-slab floor system*

VARIABLE	FRAME SPECIFICATION	VOLUME	UNIT
NON-FIXED VARCIABLE	FLOOR SLAB THICKNESS 12.0 CM	14.52	M3
NON-FIXED VARIABLE	BEAM DIMENSIONS 20X30 CM	6.8	M3
NON-FIXED VARIABLE	MAIN BEAM DIMENSIONS 30X50 CM	10.08	M3
FIXED VARIABLE	COLUMN DIMENSIONS 40X40 CM	5.76	M3
FIXED VARIABLE	COLUMN HEIGHT	4	M1
FIXED VARIABLE	GRID SPACING	6X6	M1

Table 2. *The variable, frame specifications, and concrete volume of the Flat Slab floor system*

Variable	Frame Specification	Volume	Unit
Non-Fixed Variable	Floor Slab Thickness 160 cm	24.14	m3
Non-Fixed Variable	Drop Panel Thickness 30 cm	3.42	m3
Fixed Variable	Column Dimensions 40x40 cm	5.76	m3
Fixed Variable	Column Height	4	m1
Fixed Variable	Grid Spacing	6x6	m1

Table 3. *Frame Specifications, and Concrete Volume of the Flat Slab Floor System*

Material Specification	Concrete Volume	Load Case	Load Combination
Concrete Grade K300	27.28 m3	Dead (D) = 1.3 Kn/m2 Live (L) = 2.4 Kn/m2	Comb1 = 1.2 D + 1.6 L

3. Results and Discussions

The Flat Slab system, modeled with a 6-meter column grid spacing and a slab thickness of 16 cm, exhibits distinct structural behavior due to its absence of beams. This higher displacement can be attributed to the lack of bracing elements, resulting in reduced stiffness compared to the Beam-Slab system.

3.1. Modelling

Modeling of the Beam-Slab Floor System

Modeling of the beam-slab floor system with a column grid spacing of 6 meters, featuring the placement of 30x50 cm main beams along the outer edges and 20x30 cm secondary beams within the interior as dividing beams. In the X direction, the 20x30 cm beams are spaced 3 meters apart, and in the Y direction, the spacing is also 3 meters. The concrete slab has a thickness of 12 cm (Figure 1)

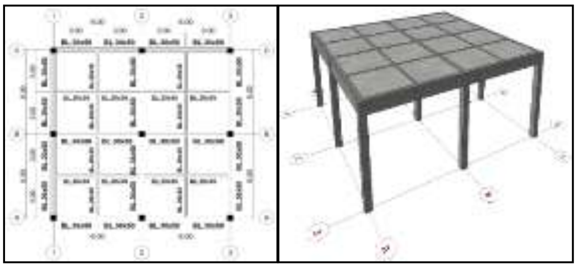

Figure 1. *Modeling of the Beam-Slab Floor System*

Modeling of Flat Slab Floor System

Modeling of the concrete flat slab floor system with a column grid spacing of 6 meters and a slab thickness of 16 cm (Figure 2).

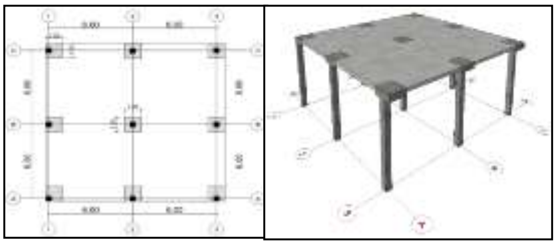

Figure 2. *Modeling of the Flat Slab Floor System*

3.2. Simulation

Simulation of the Beam-Slab Floor System

In the conventional concrete slab floor system, displacement Uz occurs due to dead and live loads, causing the floor slab to experience deformation and shape changes in the direction of gravity, with a magnitude of -6.674 mm. This displacement is uniformly distributed across the slab floor area (Figure 3). The loads acting on the 30x50 beams, 20x35 beams, and the floor slab result in a moment of 53.46 kN at the column support (Figure 4).

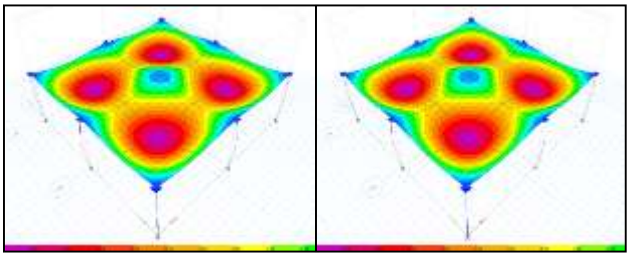

Figure 3. *Displacements on Beam-Slab System*

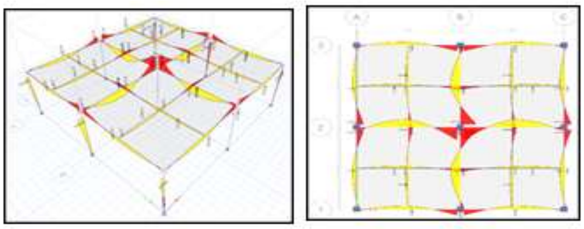

Figure 4. *Column Moment in the Beam-Slab System*

As a result of the loads acting on the 30x50 beams, 20x35 beams, and the floor slab, a shear force occurs at the column support amounting to 15.27 kN (Figure 5). The loading applied on the slab and beams results in the highest axial force occurring in the central

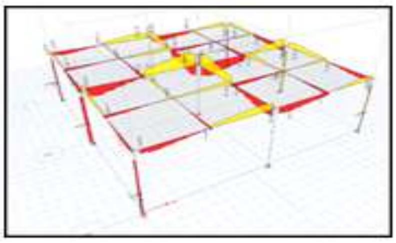

Figure 5. *Shear Force in the Beam-Slab System*

column, with a magnitude of -548.52 kN (Figure 6). Reinforcement based on the loads acting on the floor slab is automatically designed by the Safe software. For the 30x50 beams and 20x35 beams, a total reinforcement of 2084.54 kg is required, while the floor slab requires 2330.64 kg of reinforcement. The total reinforcement weight needed is 4415.18 kg (Figure 7).

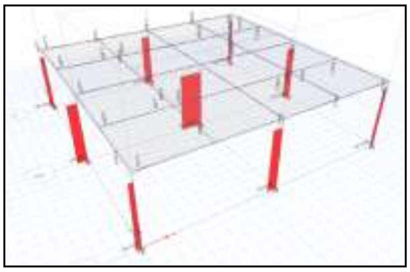

Figure 6. *Axial Force on the Central Column*

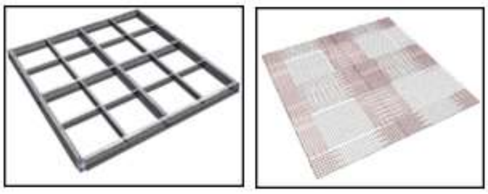

Figure 7. *Reinforcement Requirements for the Beam-Slab System*

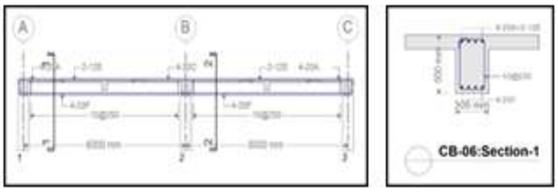

Figure 8. *Cross-Section of the 30x50 Beam*

The Beam-Slab floor system, modeled with a grid spacing of 6 meters and beams (30x50 cm as main beams and 20x30 cm as secondary beams) spaced 3 meters apart, provides notable structural benefits. The inclusion of beams enhances the system's rigidity, which is reflected in the low displacement of -6.674 mm under applied dead and live loads. This minimal displacement is due to the bracing effect of the beams, which effectively distribute loads and reduce deformation (Figure 3). Moments and shear forces at the column supports are also relatively low, with a moment of 53.46 kN (Figure 4) and a shear force of 15.27 kN (Figure 5). This indicates the system's capacity to handle loads efficiently by transferring them through the beams to the supports. However, the axial force on the central column is higher, measured at -548.52 kN (Figure 6). This is expected, as the axial load includes the combined weight of the beams, slab, and applied loads. Reinforcement requirements for the Beam-Slab system amount to 4415.18 kg, comprising 2084.54 kg for the beams and 2330.64 kg for the slab (Figure 7). This reflects the need for additional materials to support the rigidity and load distribution benefits of the system.

Simulation of the Flat Slab Floor System

In the concrete flat slab floor system, displacement Uz occurs due to vertical loads, causing the floor slab to experience deformation and shape changes in the direction of gravity, with a magnitude of -12.69 mm. This displacement is uniformly distributed across the slab floor area (Figure 9). The application of dead and live loads on the Flat Slab induces a positive bending moment of 92.49 kN at the column support and a negative bending moment of -92.48 kN (Figure 10.)

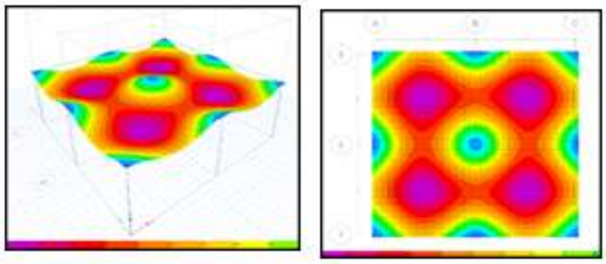

Figure 9. *Displacements on the Flat Slab*

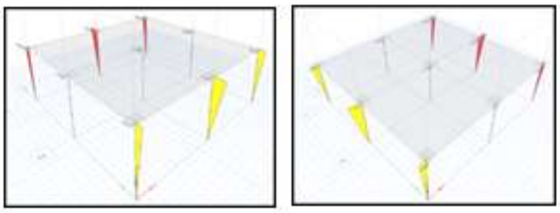

Figure 10. *Moments on the Flat Slab*

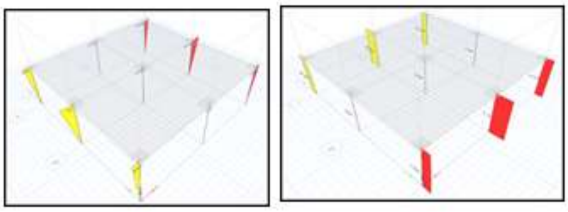

Figure 11*. Shear Forces on the Flat Slab*

Figure 8 is cross-section of the 30x50 beam. The system experiences greater displacement under vertical loads, with a displacement of -12.69 mm uniformly distributed across the slab (Figure 9). The moments and shear forces at the column supports are also higher, with a positive moment of 92.49 kN and a negative moment of -92.48 kN (Figure 10), as well as shear forces of -23.17 kN and 23.12 kN in the X and Y directions, respectively (Figure 11). These higher values highlight the increased stresses at the supports due to the absence of beams to distribute the loads. However, the axial force at the column is lower at -466.16 kN (Figure 12), as the system primarily bears the slab's self-weight and applied loads without the additional load from beams. Reinforcement requirements for the Flat Slab system are lower than those of the Beam-Slab system, totaling 4064.90 kg, which includes reinforcement for the slab and drop panels (Figure 13). This indicates a material efficiency advantage, though it comes at the cost of reduced rigidity and higher moments and shear forces.

The loads acting on the flat slab result in a shear force of -23.17 kN in the X direction and 23.12 kN in the Y direction (Figure 11).

The loading applied on the slab results in an axial force on the column of the concrete Flat Slab floor system amounting to -466.16 kN (Figure 12). The reinforcement required for the flat slab and drop panel, based on the loads acting on the floor slab, is

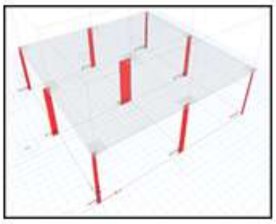

***Figure 12**. Axial Force on the Column of the Flat Slab*

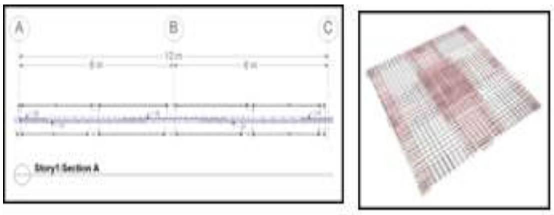

***Figure 13.** Reinforcement of the Flat Slab System*

automatically designed by Safe software. The total reinforcement needed amounts to 4064.90 kg (Figure 13). Flat slabs, characterized by their direct support on columns without the use of beams, offer several advantages, including reduced construction time, increased architectural flexibility, and lower overall material usage [20,21]. However, they also present challenges, particularly concerning their susceptibility to punching shear failure, which can lead to catastrophic structural failures if not adequately addressed [22]. Flat slab systems are known for their architectural flexibility and ease of construction. They allow for greater heights in floor spaces due to the absence of beams, which can also simplify the installation of utilities and reduce formwork complexity [21], [23]. This design can lead to a reduction in overall material use and construction time, which is beneficial from both economic and environmental perspectives [16], [24]. In terms of flexural strength, studies have shown that flat slabs can achieve comparable or superior performance to beam-slab systems when designed appropriately. For instance, the incorporation of drop panels or shear heads can significantly enhance the punching shear resistance and overall load-carrying capacity of flat slabs [25]. On the other hand, beam-slab systems typically provide better distribution of loads and can be more resilient to progressive collapse due to the presence of beams that can redistribute loads in the event of a failure [22]. Additionally, beam-slab systems often require more reinforcement, which can increase the overall weight of the structure and impact construction costs [26]. When comparing reinforcement weight, flat slabs generally require less steel reinforcement than beam-slab systems due to their design efficiency and the ability to utilize higher concrete strengths [16,21]. However, the specific reinforcement requirements can vary significantly based on the design loads, span lengths, and the presence of additional features like drop panels [27]. The presence of beams allows for a more effective transfer of loads, which can mitigate the risks associated with sudden failures in the slab [22]. However, this system typically requires more reinforcement, resulting in increased material weight and potentially higher construction costs [20]. According to Tran & Tan [28] The Beam-Slab floor system demonstrates significant structural advantages, particularly in load distribution and rigidity resulting in minimal displacement under applied loads, reflecting its efficiency in maintaining structural integrity. The system achieves a low displacement of -6.674 mm under dead and live loads, primarily due to the bracing effect of the beams that enhance overall rigidity. Additionally, the system effectively distributes loads, as indicated by the relatively low moments (53.46 kN) and shear forces (15.27 kN) observed at column supports, showcasing its capability for efficient load management [29]. However, the central column experiences a higher axial force of -548.52 kN, which reflects the combined weight of the beams, slab, and applied loads, a typical characteristic of beam-slab systems [30]. The total reinforcement requirement for the system amounts to 4415.18 kg, with specific allocations for beams and slabs, underscoring the need for robust materials to maintain structural reliability [31]. While the Beam-Slab system offers enhanced structural rigidity and effective load distribution, it also involves higher material costs and increased design complexity, necessitating careful planning and consideration during construction. Comparing to another study, Zaman & Al-Zaidee [32] stated that in terms of flexural strength, flat slabs can achieve approximately 60% greater strength compared to beam-slab systems, especially when designed with drop panels to enhance resistance to punching shear. The flexural reinforcement ratio plays a critical role

Table 4. *Comparative analysis of reinforcement for concrete slab systems*

No.	Floor Slab System	Displacements Uz (mm)	Moment at Column Support (kN)	Shear Force at Column Support (kN)	Axial Force (kN)
1.	Beam-Slab System	-6,674 mm	53.46	15.27	-548.52
2.	Flat Slab Systm	-12.69 mm	92.49	23.12	-466.16

in punching shear strength, with tension reinforcement being more effective than compression in improving structural performance [33]. Regarding reinforcement weight, flat slabs demonstrate cost-saving potential, with the reinforced cement concrete (RCC) flat slab system reducing construction costs by approximately 6.07% compared to beam-slab systems, primarily due to lower formwork requirements [34]. Beam-slab systems, by contrast, typically require more reinforcement owing to the inclusion of beams, which increases both weight and material costs [34]. However, despite their strength and cost advantages, flat slabs face challenges in shear resistance, particularly at column connections, necessitating meticulous design and detailing to ensure structural safety [35,36].

3.3. Efficiency analysis

The comparative analysis of reinforcement for concrete slab systems—beam-slab systems and flat slab systems—based on indicators such as displacement, moment, shear force, and axial force demonstrates that the Beam-Slab System performs better than the Flat Slab System in most aspects. However, for the axial force indicator, the Flat Slab System shows a lighter load. The beam-slab system experiences minimal displacement due to the presence of 20x30 beams that act as bracing elements. The moments and shear forces at the column supports are also relatively low due to the beams that bind the columns and other beams together. However, the axial force is significantly higher because it carries dead and live loads as well as the weight of the beams and slab. On the other hand, the flat slab system experiences greater displacement due to the absence of beams as bracing elements. The moments and shear forces at the column supports are also high. However, the axial force is relatively lower because it only bears dead and live loads as well as the slab's self-weight.

4. Conclusions

The findings of this study have significant implications for the development of architectural knowledge, particularly for structural planners who leverage advancements in software to simplify the analysis of reinforcement efficiency for various concrete slab systems. The use of software in structural planning is essential for saving time, labor, and ensuring precise analysis from various models and simulations. Further research is encouraged to explore economic analyses related to material requirements and the costs associated with reinforcement work. Table 4 is comparative analysis of reinforcement for concrete slab systems.Optimization techniques can be employed to identify combinations of parameters that achieve maximum efficiency, while considering environmental aspects such as the use of eco-friendly materials, regional conditions, and sustainable construction techniques. Moreover, real-world implementation is necessary to test and verify the modeling and simulation results from this study.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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