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Structural Performance and Cost Optimization of Flat Slab, Two-Way Slab, and Beam–Slab Systems for Multi-Storey Commercial Buildings Based on STAAD. Pro Analysis

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ABSTRACT: The selection of slab systems plays a critical role in determining the structural performance, economy, and constructability of multi-storey commercial buildings. This study presents a comparative analysis of three reinforced concrete slab systems—beam–slab, two-way slab, and flat slab—using STAAD.Pro under identical geometric configurations, material properties, and loading conditions in accordance with Indian Standards. A representative commercial building model is analyzed under gravity, wind, and seismic loads to evaluate key response parameters such as bending moments, shear forces, deflections, storey drift, and vibration characteristics. Design outputs are further used to quantify concrete and reinforcement requirements, enabling an economic comparison of the slab systems. The results indicate that the beam–slab system provides superior stiffness and serviceability, the two-way slab offers balanced performance and economy, and the flat slab ensures architectural flexibility and faster construction but with higher deflections and punching shear demand. The findings provide practical insights for designers in selecting efficient and economical slab systems for commercial buildings.

KEYWORDS: Flat slab, Two-way slab, Beam–slab, STAAD.Pro, Seismic analysis, Cost optimization, Multi-storey buildings.

I. INTRODUCTION

The rapid growth of urban infrastructure has increased the demand for multi-storey commercial buildings that are structurally safe, economically viable, and architecturally efficient. Among various structural components, slab systems significantly influence the global behavior, load transfer mechanism, material consumption, and construction speed of reinforced concrete buildings. Traditionally, the beam–slab system has been widely adopted due to its predictable structural behavior and high stiffness. However, with advancements in construction technology and architectural requirements, alternative slab systems such as two-way slabs and flat slabs have gained popularity.

The beam–slab system transfers loads from slabs to beams and subsequently to columns and foundations, providing effective control of deflections and lateral displacements. Two-way slabs distribute loads in two orthogonal directions, reducing stress concentration and improving load sharing. Flat slabs, characterized by the absence of beams, offer enhanced architectural flexibility and faster construction but may exhibit higher deflections and punching shear vulnerability, particularly under lateral loads.

Despite extensive applications, the selection of an appropriate slab system often depends on qualitative judgment rather than systematic evaluation under uniform design conditions. Therefore, a comparative assessment based on structural performance and economic parameters is essential. Modern structural analysis software such as STAAD.Pro enables accurate modeling and simulation of complex structural systems under realistic loading conditions, including seismic and wind effects.

This study aims to compare the structural behavior and cost efficiency of beam–slab, two-way slab, and flat slab systems for a multi-storey commercial building. By analyzing key response parameters and material consumption, the research provides a rational basis for selecting optimal slab systems in commercial building design. The outcomes of

this study are expected to assist structural engineers in making informed design decisions that balance safety, economy, and functionality.

II. LITERATURE REVIEW

Several researchers have investigated the structural behavior and economic performance of different slab systems in reinforced concrete buildings. Studies on beam–slab systems highlight their superior stiffness and reliable load transfer mechanisms, making them suitable for seismic-prone regions. Investigations on two-way slab systems report improved load distribution and reduced bending moments compared to one-way slab systems, with moderate material consumption.

Research on flat slab systems emphasizes their architectural advantages and construction efficiency but also identifies critical issues related to punching shear and lateral stiffness. Comparative studies using finite element-based software tools have demonstrated that flat slabs generally exhibit higher deflections and storey drift compared to conventional systems. Economic analyses conducted by various authors indicate that flat slabs and two-way slabs may offer cost benefits for moderate spans, whereas beam–slab systems are more economical for larger spans and heavy loading conditions.

Recent works employing structural analysis software such as ETABS, SAFE, and STAAD.Pro have provided quantitative comparisons of slab systems under seismic and wind loads. However, many studies focus either on structural performance or cost analysis separately. Therefore, an integrated evaluation of structural behavior and economic aspects under uniform design conditions remains necessary. This study addresses this gap by combining structural analysis and material-based cost assessment for three commonly used slab systems in multi-storey commercial buildings.

III. MATERIAL AND METHODS

3.1 Building Description

A representative multi-storey commercial building is considered for analysis. The building geometry, storey height, and structural layout are kept identical for all slab systems to ensure a fair comparison.

Table 1: Building Parameters

Parameter	Value
Number of storeys	10
Storey height	3.5 m
Structural system	RC moment-resisting frame
Concrete grade	M30
Steel grade	Fe500
Seismic zone	III
Soil type	Medium

3.2 Slab System Configurations

Three slab systems are modeled:

1. Beam–slab system

Beam–slab systems, commonly referred to as conventional slab–beam systems, form a foundational framework in reinforced concrete (RCC) construction for multi-storey buildings. These systems comprise horizontal slabs supported by an interconnected grid of beams, which in turn channel loads to vertical columns and foundations. This configuration ensures efficient load distribution, making it a staple in commercial, residential, and industrial structures worldwide. The beams act as primary load-bearing elements, while slabs provide the flooring surface, often designed as one-way or two-way spanning members depending on the aspect ratio and support conditions. Governed by standards like IS 456 in India, these systems integrate M30 concrete and Fe500 steel for optimal strength and ductility, particularly in seismic zones such as Zone III.

2. Two-way slab system

A two-way slab system is a structural element in which loads are distributed in both orthogonal directions and the slab is supported along all four edges. This system is particularly efficient for square or nearly square panels, where the aspect ratio of spans (l_y/l_x) is less than 2. Compared to one-way slabs, two-way slabs provide improved structural performance and material efficiency due to their bidirectional load-carrying mechanism.

3. Flat slab system with drop panels

A flat slab system is a beamless structural configuration in which the slab is directly supported by columns, often enhanced with drop panels to improve stiffness and load capacity. This system is widely adopted in modern buildings due to its architectural flexibility and efficient use of space.

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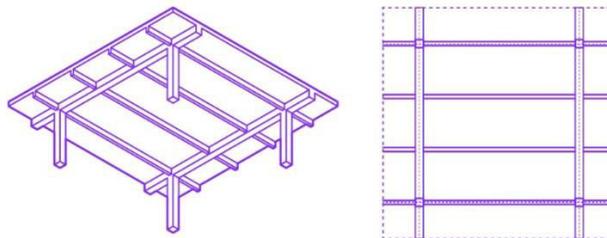


Figure 1: Structural Modeling of Slab Systems (schematic representation)

3.3 Loading Conditions

Loads are calculated as per IS 875 and IS 1893 codes, including:

- Dead load
- Live load
- Wind load
- Seismic load

Table 2: Loading Details

Load Type	Value
Floor finish	1.0 kN/m ²
Live load	3.0 kN/m ²
Wind speed	As per IS 875 (Part 3)
Seismic parameters	As per IS 1893

3.4 Structural Modeling and Analysis

The building models are developed in STAAD.Pro with identical geometry and boundary conditions. Static and dynamic analyses are performed to obtain response parameters such as bending moments, shear forces, deflections, storey drift, and natural frequencies.



Figure 2: Analysis Workflow in STAAD. Pro

3.5 Economic Evaluation

Concrete volume and reinforcement quantities are extracted from design outputs. The total cost is estimated based on material consumption.

Table 3: Material Quantification Methodology

Parameter	Description
Concrete volume	Extracted from STAAD.Pro
Steel quantity	Design output
Cost estimation	Unit rates applied

IV. RESULTS AND DISCUSSION

4.1 Structural Response Comparison

The analysis results reveal significant differences in structural behavior among the slab systems.

Table 4: Comparison of Structural Parameters

Parameter	Beam-Slab	Two-Way Slab	Flat Slab
Max deflection (mm)	10	12	15
Max bending moment (kNm)	320	280	340
Max shear (kN)	85	78	95
Max storey drift (mm)	18	22	28
Natural frequency (Hz)	3.6	3.2	2.8

The beam–slab system exhibits the highest stiffness and lowest deflections, indicating superior serviceability performance. The two-way slab system shows balanced behavior with moderate deflections and bending moments. The flat slab system demonstrates higher flexibility and increased storey drift due to the absence of beams, making punching shear a critical design consideration.

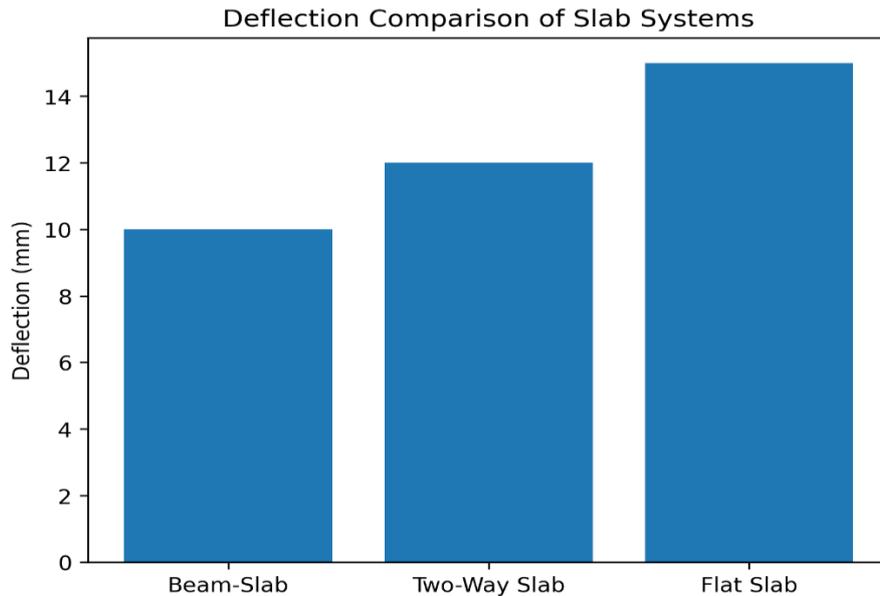


Figure 3: Deflection Comparison of Slab Systems

4.2 Material Consumption and Cost Analysis

Material quantities extracted from design results highlight the economic implications of each slab system.

Table 5: Material Consumption Comparison

Parameter	Beam–Slab	Two-Way Slab	Flat Slab
Concrete volume (m ³)	High	Medium	Low
Steel quantity (t)	High	Medium	Medium
Relative cost	High	Medium	Low

The beam–slab system requires higher concrete and steel quantities, leading to increased cost but improved structural performance. The two-way slab system offers an optimal balance between performance and economy. The flat slab system provides cost savings and faster construction but demands careful design against punching shear and excessive deflection.

4.3 Overall Performance Assessment

Table 6: Qualitative Performance Evaluation

Criterion	Beam–Slab	Two-Way Slab	Flat Slab
Stiffness	High	Medium	Low
Deflection control	Excellent	Good	Moderate
Construction speed	Moderate	Moderate	Fast
Architectural flexibility	Low	Medium	High
Seismic suitability	High	Medium	Low

The results confirm that structural efficiency is strongly influenced by stiffness characteristics and load transfer mechanisms. Therefore, the choice of slab system should be based on both structural and economic considerations.

V. CONCLUSION

This study demonstrates that the beam–slab system provides superior stiffness and seismic performance but at higher cost, while the two-way slab system offers balanced structural behavior and economy. The flat slab system ensures architectural flexibility and faster construction but exhibits higher deflections and punching shear demand. An integrated evaluation of structural performance and cost is essential for selecting optimal slab systems in commercial buildings. The findings provide practical guidance for engineers in achieving safe, economical, and efficient structural designs.

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