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Original Research Article

Seismic performance evaluation of flat slab structures with varying thickness and drop panels

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Flat slab structures; Drop panel; Punching shear; ETABS; Response spectrum.

ABSTRACT

This paper evaluates the dynamic behavior of flat slab structures under seismic loading through a comparative analytical study. six structural models (M1 to M6) were created using ETABS software for a G+4 reinforced concrete building with an identical plan of 30 m × 20 m with different slabs (150 mm, 200 mm, and 250 mm) and drop panels (2000 mm x 2000 mm) with and without drop panels. The modal analysis and response spectrum analysis were governed by IS 1893 (Part 1): 2016 for seismic zone IV, medium soil conditions, M30 concrete, and Fe500 steel. The results indicate that the addition of drop panels and slabs increases lateral stiffness, essentially significantly reducing the fundamental time period from 1.038 s (Model M1) to 0.776 s (Model M6). Maximum storey displacement reduced from 11.048 mm to 8.133 mm, and story drift was safely below the limit stipulated by the IS codes, decreasing from 0.001 to 0.00076. Base shear increased according to stiffness, increasing from 635.67 kN to 1192.73 kN, indicating more resistance to lateral force. Punching shear analysis indicated that only the models with 250 mm slabs (M5 and M6) passed all safety checks, while models with thinner slabs, even those with drops, experienced localized failures. The results are consistent with other studies (e.g., Thakkar et al., 2017; Gowda & Tata, 2016) on the benefits structural drop panels and sufficient slab thickness offer when designing a flat slab in seismic conditions. This study emphasizes the need for combining overall seismic design and local punching shear design to achieve safe and resilient structural behaviour.

1. Introduction

Over the past few decades, flat slabs have been increasingly utilized in reinforced concrete (RC) construction due to their architectural versatility, offering clean spans, ease of formwork, and additional height save in typical floor to floor height. Unlike conventional beam-slab systems, in a flat-slab system, loads transfer directly from the slab to the columns with no beams intervening, and are typically used for commercial buildings, parking structures, and most often high-rise buildings. Thus, slab systems can optimize floor space with no beams, but come with their own structural complexities, including seismic performance and punching shear under vertical loads. Under earthquake loading, flat slab structures experience more lateral displacement compared to regular framed systems. Furthermore, ductility under extreme load conditions is reduced, and shears can be concentrated at slab-column junctions leading to failure in those regions. In areas with substantial seismic loading, such as design practice and agency levels with respect to post- seismic performance, these vulnerabilities are amplified considering how high lateral forces are compared to gravity loads. Some researchers have previously indicated that, overall, flat slabs are likely to have a longer fundamental time period, lower lateral stiffness, and therefore draw in higher displacements and also experience higher inter-storey drift ratios under the same earthquake loads than conventional framed systems [1-3]. For these reasons structural lower performance issues (with respect to traditional systems, at least) have led to the incorporation of other structural elements such as drop panels. Drop panels are approximately localized thickened areas of the slab surrounding the columns that provide increased shear strength and stiffness at the slab-column junction. Furthermore, increasing the thickness of the slab provides increased global stiffness and limits lateral deformation, in addition to the punching shear performance. Significant research has been conducted on the dynamic response of flat slab systems in the context of earthquake-resistant design. Flat slabs have large lateral displacements and longer fundamental time periods, and they are more flexible than frame structures because of the absence of beams. Also, flat slabs are more prone to punching shear failure, especially under seismic forces. Evaluations have included multiple measures to improve the seismic performance of flat slabs, including the use of drop panels, the use of shear heads, or increasing the thickness of flat slabs. Apostolska et al. [4] did a comparative study of structures with different systems, and their results showed pure flat slabs exhibited higher flexibility and less lateral resistance than conventional reinforced concrete frames. They also found that if the slab thickness increased and critical local zones had strengthening, it would improve their seismic performance. El-Shaer [5] compared flat slabs, ribbed rigid slabs, and paneled beam slabs in a 30-story building using ETABS. The study acknowledged that flat slabs were technically an efficient architectural solution; however, flat slabs provided excessive inter-story drift and brittle failures under seismic forces. Navyashree and Sahana [6] analyzed G+3, G+8, and G+12 RC buildings and reported that flat slab systems exhibited 28–57% higher lateral displacements and drift than conventional beam-slab frames. They emphasized the need for shear walls or drop panels in flat slab designs for buildings in high seismic zones.

Similarly, Gowda and Tata [2] compared flat slabs with and without drop panels across all seismic zones and found that models with drop panels demonstrated significantly better performance in terms of displacement and drift control. Thakkar et al. [1] performed a study on G+5, G+8, and G+11 structures using flat slabs with and without drops and conventional slabs. They concluded that while increasing storey height results in higher displacement, conventional slabs offer superior seismic behaviour. In contrast, Manzoor and Kumar [7] focused on parametric analysis of vibration control in flat slabs, noting that slab thickness and damping play a crucial role in improving stability under dynamic loading. More recent work by Pranjal and Chayan Gupta [8] analyzed five flat slab configurations, including drop panels, column heads, and area beams, using pushover and response spectrum methods. They found that combinations of drop panels and additional reinforcement substantially improved base shear capacity and delayed the formation of plastic hinges. Keles et al. [9] compared different slab types and found that flat slabs exhibited the longest natural periods, indicating lower stiffness, and required additional detailing for seismic zones. Punching shear—a localized failure mode critical in flat slabs—has also been widely studied. Borkar et al. [10] analyzed five slab systems, concluding that drop panels and column heads effectively reduced torsion and shear-related failures. Lamperti Tornaghi et al. [3], through full-scale testing, showed that flat slab systems integrated with shear walls exhibited near- elastic response under pseudo-dynamic loading. Their findings support the inclusion of secondary elements like shear walls or structural deepening to improve seismic resilience.

2. Materials and methods

To evaluate the seismic performance of flat slab structures with varying slab thicknesses and drop panel configurations, a parametric analytical study was conducted using ETABS software. The methodology involved structural modelling, load definition, seismic analysis, and evaluation of key performance indicators such as fundamental time period, base shear, story displacement, story drift, and punching shear.

2.1 Building configuration

A symmetric G+4 storeyed reinforced concrete (RC) commercial building was modelled with a rectangular plan dimension of 30 m × 20 m. The floor height was maintained at 3 m for all stories. The structural system was a flat slab type without beams, designed in accordance with IS 456:2000 and analyzed under seismic conditions as per IS 1893 (Part 1): 2016 [11, 12].

Figure 1: Building plan.

2.2 Modelling variations

Table 1: Model variations

Model	Slab Thickness (mm)	Drop Panel (2000mm× 2000 mm)
M1	150 mm	No
M2	150 mm	Yes
M3	200 mm	No
M4	200 mm	Yes
M5	250 mm	No
M6	250 mm	Yes

All models used M30 grade concrete and Fe500 steel. The columns were designed as 400 mm × 400 mm square sections. Slabs were modelled using shell elements with appropriate stiffness and diaphragm action.

Load Assumptions

- The following loads were applied:
- Dead Load (DL): Self-weight of structural elements Live Load (LL): 3.0 kN/m²
- Floor Finish Load: 1.5 kN/m² Seismic Zone: Zone IV
- Soil Type: Medium Importance Factor (I): 1.0
- Response Reduction Factor (R): 5.0 (SMRF) Damping Ratio: 5%

Seismic Analysis

Both Modal Analysis and Response Spectrum Analysis (RSA) were performed: Modal Analysis was used to determine the natural time periods and mode shapes. Response Spectrum Analysis was carried out using the design spectrum provided in IS 1893 (Part 1): 2016 for Zone IV and medium soil type. The fundamental time period, base shear, story displacement, and drift ratios were extracted and compared across all models.

Punching Shear Check

Each model was subjected to punching shear verification at the column-slab connections using ETABS's in-built design module. The check was performed as per the guidelines of IS 456:2000. Critical slab-column joints were selected to assess whether the slab thickness and drop panel configuration provided sufficient shear resistance against punching failure.

3. Results and discussion

The seismic performance of all six models (M1 to M6) was evaluated using key response parameters, including fundamental time period, base shear, storey displacement, storey drift, and punching shear. The impact of varying slab thickness and the presence of drop panels was systematically analyzed.

Fundamental Time period

The fundamental time period of the structure decreased as the slab thickness increased and when drop panels were provided. Model M1 (150 mm slab without drop panel) recorded the highest time period of 1.038 s, indicating lower stiffness. In contrast, Model M6 (250 mm slab with drop panel) showed the lowest time period of 0.776 s, demonstrating enhanced lateral stiffness.

Fundamental Time Period vs. Slab Thickness with and Without Drop Panel.

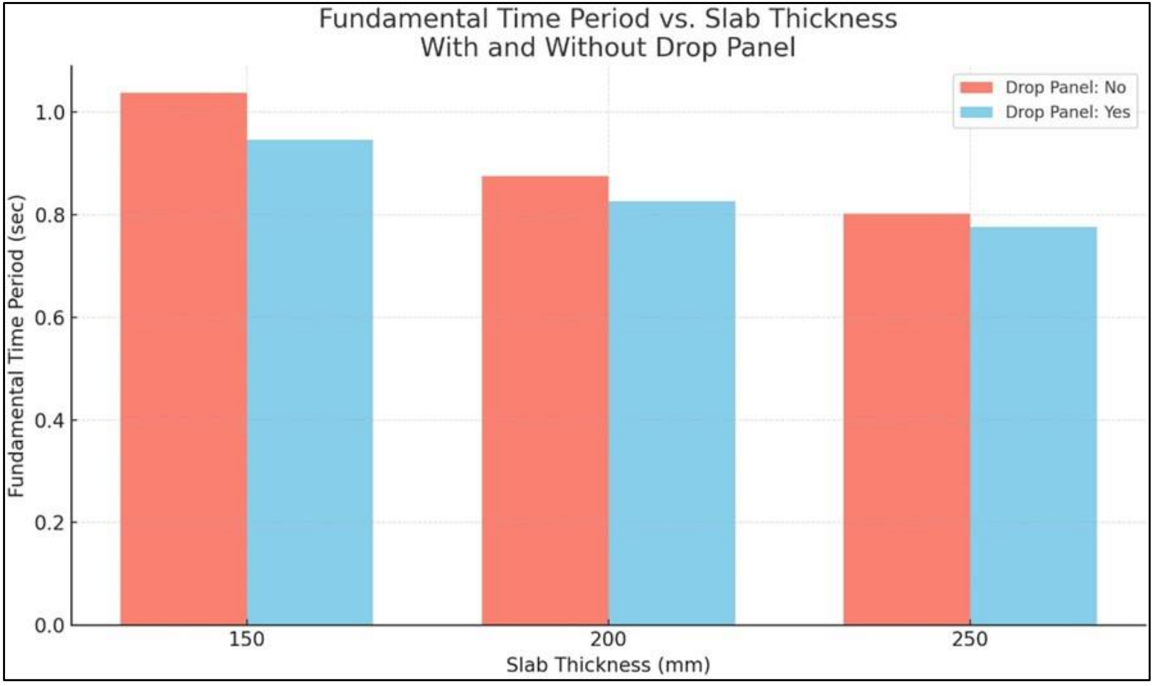

Figure 2: Variation of fundamental time period across models.

Base Share

Base shear was observed to increase with increased slab thickness and drop panel inclusion due to the stiffer nature of the structural system. The base shear for M1 was 635.67 kN, which progressively increased to 1192.73 kN in M6. This increase signifies that the system's lateral force-resisting capacity improved as stiffness increased.

Base Shear Comparison

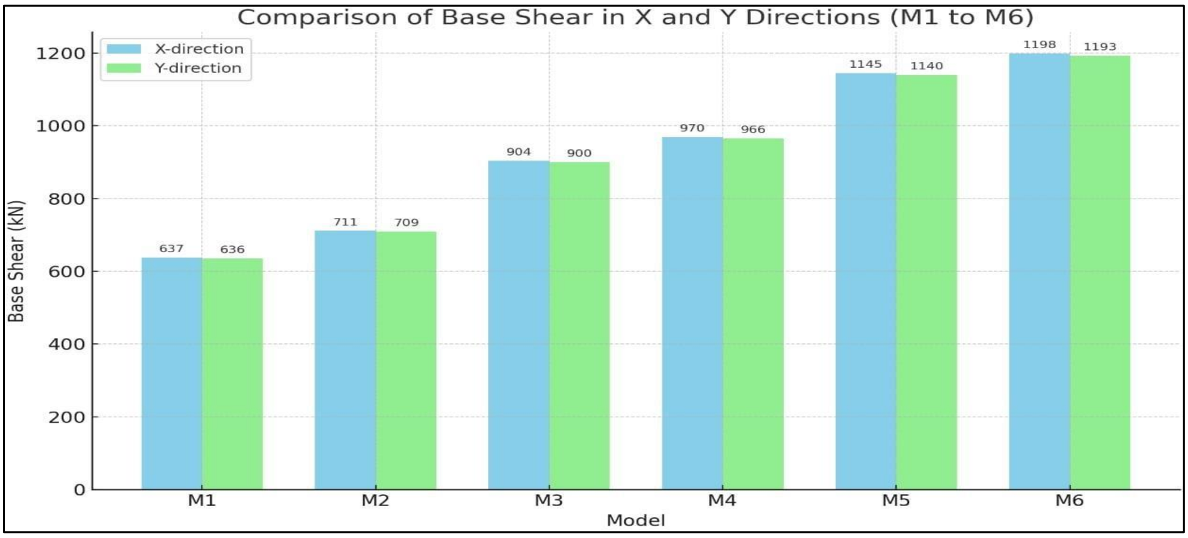

Figure 3: Base shear comparison for all models.

Storey Displacement

Maximum lateral displacement at the roof level reduced significantly with increasing slab thickness. Model M1 exhibited the highest displacement of 11.048 mm, whereas Model M6 recorded the lowest at 8.133 mm, showing a 26.37% reduction. This proves the effectiveness of increasing slab depth and adding drop panels in minimizing seismic deflections.

Table 2: Stores displacement at roof level.

Model	Max Story Displacement in X-dir. (mm)	Max Story Displacement in Y-dir. (mm)
M1	11.009	11.048
M2	10.011	10.047
M3	9.181	9.224
M4	8.591	8.639
M5	8.267	8.31
M6	8.100	8.133

Storey Drift

All models remained within the permissible drift limit of 0.004 as per IS 1893:2016. However, flatter configurations showed comparatively higher drift values. Model M1 had a maximum inter-storey drift of 0.001, while M6 recorded the lowest at 0.00076. This reduction reflects enhanced inter-storey stiffness and lateral load performance due to geometric modification.

Punching Shear

Punching shear checks indicated that models with 150 mm slab thickness (M1 and M2) failed the punching shear safety requirement, even with drop panels in M2. Conversely, Models M5 and M6 (250 mm thick slabs) passed all punching shear criteria, with adequate safety margins. This emphasizes the importance of both slab depth and localized thickening in resisting concentrated shear stresses.

Table 3: Punching shear check summary.

Model	Slab Thickness	Drop Panel	Punching Shear Result
M1	150 mm	No	Fail
M2	150 mm	Yes	Fail
M3	200 mm	No	Fail
M4	200 mm	Yes	Marginal Fail
M5	250 mm	No	Safe
M6	250 mm	Yes	Most Safe

Overall Observation

- Increasing slab thickness from 150 mm to 250 mm resulted in 25.3% reduction in displacement and 87.6% increase in base shear.
- Drop panels contributed to an average 10–15% improvement in stiffness-based parameters.
- Model M6 (250 mm slab + drop panel) consistently outperformed others across all parameters.
- These results are consistent with previous findings by Thakkar et al. [1], Gowda and Tata [2], and Borkar et al. [10], who emphasized the role of drop panels and slab thickness in improving both seismic performance and

punching shear resistance.

4. Conclusions

This study presented a detailed investigation into the seismic performance of reinforced concrete flat slab structures using six analytical models with varying slab thicknesses and drop panel configurations. The dynamic response of each model was evaluated through modal and response spectrum analysis as per IS 1893 (Part 1): 2016 guidelines.

The key findings can be summarized as follows:

1. Fundamental time period reduced significantly with increased slab thickness and inclusion of drop panels, indicating improved lateral stiffness. The time period dropped from 1.038 s in Model M1 to 0.776 s in Model M6.
2. Base shear increased proportionally with stiffness, rising from 635.67 kN in the most flexible model (M1) to 1192.73 kN in the stiffest (M6), demonstrating improved lateral load-resisting capacity.
3. Maximum storey displacement decreased by over 26% between the least and most efficient configurations, reflecting the effectiveness of geometric enhancements in controlling seismic deformations. All models satisfied IS 1893:2016 story drift limitations, with M6 showing the lowest drift of 0.00076.
4. Punching shear checks revealed that 150 mm thick slabs, even with drop panels, failed to meet safety criteria. Only the 250 mm thick slab models (M5 and M6) passed all punching shear verifications, confirming the critical role of slab depth in local safety performance.

Among all the configurations, Model M6 (250 mm slab with drop panels) demonstrated the best seismic performance, offering optimal structural stability, code compliance, and resistance to local failure modes. These results emphasize the necessity of integrating both global dynamic performance and local punching shear resistance in the design of flat slab systems in seismic zones.

Authors' contributions

All authors contributed equally to the conception, design, experimental work, data analysis, interpretation of results, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

Conflicts of interest

The author declares no conflict of interest.

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Data availability

No new data were created.

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