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A Critical Analysis of the Structural Performance of Flat Slab without Drop-Thin Plate System

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***Abstract*: A thin plate, also known as a flat slab, is a reinforced concrete slab that typically lacks beams and girders, instead transferring loads directly to supporting concrete columns. These structures are widely used in industrial, commercial, and institutional settings. However, they are susceptible to shear failure, particularly in the case of flat slabs with no slab drop. The major drawback of this type of slab is punching shear failure, which can occur due to the slab's low thickness and inability to support heavy loads. Despite these limitations, flat slab without drop has gained popularity in recent years due to its many advantages. This review paper provides an overview of this structural system, including its design considerations, benefits, and applications. Additionally, the paper highlights past and ongoing research in the field and discusses the potential for future developments in this technology.**

***Keywords*: Punching shear, thin plates, without drop.**

1. Introduction

A plate refers to a flat and thin structural element with a thickness that is small compared to its lateral dimensions. The plate's support can be anything, including simply supported, fixed or cantilever, and the loads on the plates are usually perpendicular to the surface, resulting in moments and shear. Plates are often flat and can develop moments, twisting moments, and shear forces. In thin plates, the straight line normal to the middle plane remains normal even after deformation. Plate structures have aesthetic appeal compared to conventional structures and are widely used for structures that do not require beams. A flat slab without drop is a type of reinforced concrete slab system that has gained popularity in high-rise buildings. This system is different from traditional flat slab systems that have drops or capitals at the columns. The flat slab without drop system does not have any such features, making it simpler, more economical, and faster to construct. Due to its numerous benefits, flat slab without drop is widely used in commercial, residential, and institutional buildings.

Advantages: The flat slab without drop system offers several advantages over traditional flat slab systems. It is easier to construct, requires less formwork, and is faster to build. The absence of drops or capitals also results in more floor-to-ceiling height, providing a more spacious interior. Flat slab without drop is also more flexible in terms of architectural design since there are no constraints imposed by the drop caps.

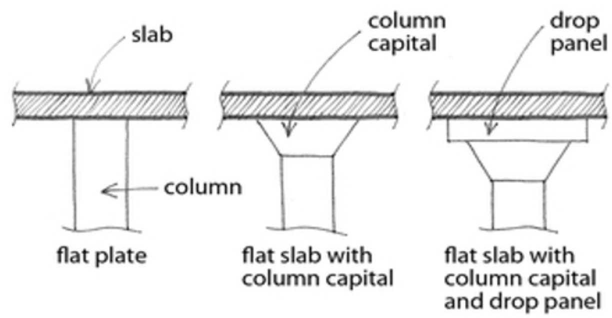

Fig. 1. Flat Slab and Column Cap

2. Literature Review

Kaulkhere R.V, G. N. Shete (2017): Flat slab buildings offer several advantages over RC frame buildings, including greater architectural flexibility, more efficient use of space, and simpler formwork under earthquake loads. For this study, G+8 storey building models with flat slab structures are being examined. To enhance the building's performance, it is crucial to analyze its seismic behavior.

M. Vinod Kumar Reddy, Vaishali G. Ghorpade; Vol. 3 Issue 10, October (2014): The displacement of a structure varies based on the type of slab system and masonry infill used. In particular, flat slab structures with drops exhibit greater deflection than both conventional and flat slab structures with drop frames. Additionally, the base shear of conventional framed structures exceeds that of flat slab structures with and without drop frames. Specifically, conventional framed structures have 7% greater base shear than flat slab structures with drop frames, and 16% greater base shear than flat slab structures without drop frames. Furthermore, structures with shear walls demonstrate lower base shear than those with struts and bracing.

David Z. Yankelevsky, Yuri S. Karinski, Alex Brodsky, Vladimir R. Feldgun,12 August (2021): The falling slab incurs severe damage and shear cracks, with severe bending damage

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occurring across the entire area. The impacted slab experiences major damage that extends beyond the area of direct impact. Damage occurs throughout the entire impacted zone, with relatively limited slab displacement. Column damage is also observed above and below the connection with the slab. The connection damage sensitivity, in terms of displacement magnitude, is moderately more significant for smaller DP sizes than for moderate size increases beyond the optimal point, which results in considerably greater damage. The intermediate DP depth (56 mm) is superior for lower DP sizes and somewhat beyond the optimal DP size. Increasing the DP size beyond half of the span size leads to complete failure of the impacted slab connection and subsequent downward motion. Unlike in static loading, where a larger DP size may be acceptable and does not adversely affect slab resistance, increasing the DP width has a positive effect until an optimal resistance is reached, after which resistance decreases considerably with DP size increase. Failure occurs at larger DP sizes. Additionally, damage is observed in the column domain above and below its connection with the slab.

Suyash Garg, Vinay Agrawal, Ravindra Nagar Volume-5, Issue-10 (2016): This research study examines the impact of three methods for strengthening a flat slab building model in response to static and dynamic loading when columns are removed in various sequences on the first floor. The model includes corner, edge, and interior columns, and the response of the building is analyzed for different column removal sequences. A 3-story model is constructed to verify the modeling process, and numerical results are compared to experimental data to ensure accuracy. The proposed 3D model is capable of accurately estimating the overall dynamic behavior of the flat slab building. Using this model, the study conducts static and dynamic progressive collapse analyses on eight 4-story flat slab buildings with different strengthening methods, considering various column removal scenarios.

S. Unnikrishna Pillai, Wayne Kirk, and Leonard Scavuzzo Journal Proceedings, Volume: 79, Issue: 1: Four subassemblies consisting of reinforced concrete slab and columns were tested under high intensity shear and moment transfer at the column-slab connection. The first subassembly did not have any shear reinforcement in the slab, the second and third subassemblies had different configurations of shear reinforcement, and the fourth subassembly had the same shear reinforcement configuration as the second one but with unanchored shear reinforcement on the compression side of the slab. The study assessed the effectiveness of shear reinforcement in increasing shear strength and preventing punching failure, and in improving the connections' ductility. The findings indicate that shear reinforcement in the slab at the connections prevents punching failure and generally doubles the ductility of the connections. Effective anchorage for shear reinforcement can be achieved without tying the stirrups around flexural steel on the compression side of the slab, even for subassemblies subjected to gravity loading only.

David S. Hatcher; Mete A. Sozen, and Chester P. Siess: This study presents an analysis of the behavior of a flat plate, which is the first of the five test structures that were built and tested to investigate multiple panel reinforced concrete floor slabs. The moments measured in the critical sections of the test structure were compared with the ACI design moments, revealing that the total extent of flexural reinforcement provided by the design method in the entire structure was adequate but the specified distribution was inefficient. The collapse of the structure occurred due to punching through one of the interior columns. The flexural strength of the slab was higher than the load that could be transferred from the slab to the interior columns.

Gravity and Lateral Load-Carrying Capacities of Reinforced Concrete Flat Plate Systems, July 2014 ACI Structural Journal 111(4):753-764: The specimen having 50% more top slab bars at the column strips showed approximately 25% higher gravity load-carrying capacity. The strength of a connection at punching failure was dependent upon the quantity of slab top reinforcement.

Philipp Schmidta, Dominik Kueresb, Josef Heggera, Elsevier- Engineering Structures-28 October (2019): The findings of the study on flat slabs with closed stirrups as shear reinforcement propose a design methodology that utilizes a suspension strut-and-tie model with varying concrete contribution based on the amount of shear reinforcement. This implies that the design criteria should consider reducing the concrete contribution as the shear reinforcement ratio increases, with a lower limit of approximately 50% compared to the punching strength without shear reinforcement (for closed stirrups). Additionally, the study suggests that the steel contribution is not dependent on the shear reinforcement ratio. Based on the examined range of parameters, it is suggested that more advanced design approaches, particularly for low and moderate levels of shear reinforcement, can be developed.

Ala Torabiana, Davood Mostofinejada, António: The current research aims to study the behavior of thin reinforced concrete (RC) slabs under concentrated loads as well as to investigate the application of Critical Shear Crack Theory (CSCT) to such slabs. For this purpose, four square 100-mm-thick slabs were cast and subjected to concentrated punching monotonic loading. The experimental parameters were the flexural reinforcement ratio, 0.38% and 1.00%, and the presence or absence of shear headed stud reinforcement.

Characterization of the Punching Shear Capacity of Thin Ultra-High Performance Concrete Slabs - D.K. Harris, Roberts-Wollmann, Carin L.: Ultra-high-performance concrete (UHPC) is a relatively new type of concrete that exhibits mechanical properties that Ultra-high-performance concrete (UHPC) is a relatively new type of concrete that exhibits mechanical properties that are far superior to those of conventional concrete and in some cases rival those of steel. The main characteristics that distinguish UHPC from conventional reinforced concrete are its very high compressive strength (20 to 33 ksi), the addition of steel fibers which enables tension to be carried across open cracks without conventional reinforcing steel, and a very high resistance to corrosion and degradation.

The behavior of flat plates subjected to various horizontal and vertical loads – A. Tugrull Tankt: Two large scale test structures, consisting of a 21 ft. x 21 ft. and 4 in. thick plate supported on nine columns spaced at 10 ft. centers, were designed, instrumented, and tested. The general flexural behavior of the test structure, under various load combinations, the local behavior of various types of slab-column connections, with reference to the punching shear strength problem.

Behavior of Slab-Column Connections of Existing Thin-Plate Structures - Ying Tian, James O. Jirsa, Oguzhan Bayrak, Widianto, and Jaime F. Argudo: As the reinforcement ratio increased, connection punching capacity and lateral stiffness increased significantly. The damage to slab concrete near the column under cyclic load up to 1.25% drift did not reduce the connection gravity load-carrying capacity. The damage caused by cyclic lateral loading, however, significantly reduced the connection stiffness.

Structural Performance of Reinforced Concrete Flat Plate Buildings Subjected to Fire - Sara J. George & Ying Tian: Nonlinear finite element simulation using calibrated concrete thermal and mechanical properties is carried out on a flat plate building. The analysis indicates that, because the thermal-induced slab rotational deformation is restrained by columns, the slab top reinforcement near the columns yields quickly at around 4 min of heating. Consequently, the heated slab experiences severe bending moment redistribution that changes positive bending moment at the mid-span due to the initial gravity loading into negative moment. However, very little change in bending moment is seen between 30 and 90 min of heating. Due to the restrained thermal expansion, membrane forces in the slab become compressive at all sections after only a short period of thermal loading.

Influence of Column Rectangularity on the Behavior of Flat Plate Structures - Neil M. Hawkins, H.B. Fallsen, and R.C. Hinojosa: Tests were carried out on nine concentrically loaded reinforced concrete slabs supported on centrally located rectangular columns. A procedure is proposed for taking account of the column shape in calculations of the shearing capacity of the slab.

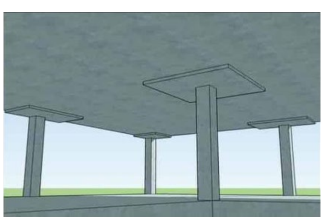

Fig. 2. Slab with drop

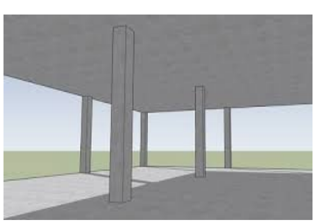

Fig. 3. Slab without drop

3. Observations from Literature

1) As per the above review paper it's been observed that thickness of the building having flat slab with shear wall changes with the storey height.
2) Indian code use for design flat slab suggests more reinforcement and stiffness as compared to European code.
3) Flat slab provides more flexibility to the building as compared to conventional slab.
4) We can design flat slab by post tensioning and as well as by conventional reinforced concrete, but we prefer reinforce concrete more as cost of post tensioning is higher.
5) In case of industrial structures constructed in a square and rectangular layout the displacement is more is case of flat slab as compared to waffle system and displacement is increases with the increases in the height of the building.
6) Punching shear failure was postponed by the installation of headed studs.
7) Critical Shear Crack Theory failure criteria are validated for thin slabs.
8) High strength and high-performance concrete should be used to prevent failures.
9) In addition to steel reinforcement adding fibers will strengthen the concrete and prevents crack reaching the steel bars.
10) Thin plates can withstand basic gravity loads, failure is caused due to lateral loads.
11) Column rectangularity, position, spacing and orientation plays an important role in thin plate structures.
12) Column – slab joints should be reinforced heavily to avoid punching failure.

4. Conclusion

Thin plate structures are becoming increasingly popular in industrial, institutional, and commercial structures. One such structure, the flat slab without drop, offers numerous benefits over traditional flat slab systems, including easy construction, increased floor-to-ceiling height, and design flexibility. Although this system has some limitations, proper design and detailing can address them. Ongoing research in this area is expected to improve the understanding and application of flat slab without drop in real-world projects. However, punching shear failure is a major concern for these structures, which can cause significant damage. To prevent such failures, additional columns can be added, but this may create architectural imbalance. Increasing the grade of concrete for the slab can help to some extent, but strengthening the column and slab junction is the recommended solution. This can be achieved by providing additional reinforcement in the column-slab joint, such as more bars of larger diameter rod, or by using shear studs to reduce the risk of failure.

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