A COMPREHENSIVE REVIEW OF FINITE ELEMENT MODELLING APPROACHES FOR DROP PANEL SLAB ANALYSIS

R.H. Mohankar[1] , Nitesh Thikare[2], Pranali Wandhare[3], Ruchita Fanibhare[4], Shrujal Chaudhari[5], Shreyash Borkar[6], Sumedh Khobragade[7]

[1], Assistant Professor, Department of Civil Engineering, Priyadarshini Bhagwati College of Engineering, Nagpur Maharashtra India, ORCID ID: 0009-0002-3330-9314

[2], Assistant Professor, Department of Civil Engineering, Priyadarshini Bhagwati College of Engineering, Nagpur Maharashtra India,

[3,4,5,6,7] Students, Department of Civil Engineering, Priyadarshini Bhagwati College of Engineering, Nagpur Maharashtra, India

Abstract:

The Finite element method is used to analysis the structural elements, which are essential components in structure to be analyzed for various loading to evaluate their behavior in different condition for different loads. The drop panel slab is provided to increase the floor height. The purpose behind evaluating the drop panel slab is to increase shear resistance, reduce deflection and to optimize materials used in it.

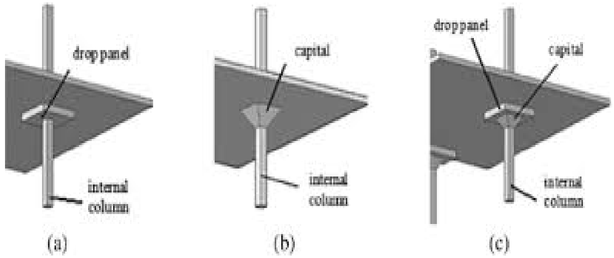
The aim of this study is to find the response of various analysis of flat slab with drop panel using tabs software program. The design of flat slab is carried out as per IS code 456:2000. The flat slab system of construction is the one in which the slab is directly resting on the column and load from the slab is directly transferred to the columns and then to the foundation. The analysis and design are carried out by equivalent frame method with staggered columns and without staggered columns as mentioned in the IS code 456:2000. We get information that flat slab with drop is developing construction in India even in the seismic prone areas for better stability and life span of the building. Compared to the conventional concrete, flat slab has a very good story drift, and it lies within the permissible limit. Hence the design construction will be safe. Flat slab with drops is used to avoid the beams by this we can say that it is economical way of construction. The initial cost of the flat slab is high, and results shows that the ductility of building and stiffness of the building is within the codal provision.

Keywords:

Flat slab, drop panel, equivalent frame method, staggered column, story drift, ductility, stiffness, beamless slab system, structural analysis.

Introduction:

Reinforced concrete slabs, also called beamless slabs, directly supported by columns. The part of the floor is defined by the centerline of the column on each of the four sides is called the panel. The slab is usually thickened near the support column to provide sufficient shear strength and negotiate the amount of negative reinforcement in the support area. The thickened part that is the protruding part under the floor is called the drop. The flat slab system is a beam system that uses traditional construction methods. The direct support in the column is eliminated, and the load on the slab is straightly transmitted to the column and foundation. Drops or columns are usually marked with column headings or capital letters. The lattice floor system is composed of beams equally spaced in the vertical direction and integrated with the floor slab. They are usually used for aesthetics reasons of large rooms, such as auditoriums, corridors, theaters, boutique lounges, where column-free space is usually the main requirement



The finite element method (FEM) is a widely used numerical technique for analyzing structural elements under various loading conditions to predict their behavior. In structural engineering, accurate analysis is essential for ensuring safety, serviceability, and cost-effectiveness. One of the structural systems gaining popularity in modern construction is the flat slab with drop panels.

Drop panels are thickened portions of a slab provided around columns. Their primary purpose is to increase shear resistance, reduce deflection, and optimize material usage. Additionally, in some cases, they allow for an increased floor height by eliminating the need for beams.

In this study, the behavior of flat slabs with drop panels is analyzed using ETABS software. The design is carried out in accordance with the Indian Standard IS 456:2000. The flat slab system is characterized by the direct transfer of loads from the slab to the supporting columns and then to the foundation. The analysis and design are performed using the equivalent frame method as per IS 456:2000, considering both staggered and non-staggered column arrangements.

Flat slabs with drop panels are increasingly being adopted in India, even in seismic-prone areas, due to their structural stability, improved ductility, and longer service life. Compared to conventional reinforced concrete slabs with beams, flat slabs generally exhibit favorable story drift values within permissible limits. Although the initial cost of construction is higher, the absence of beams can make the system economical in terms of architectural flexibility, reduced formwork, and faster construction.

This study aims to evaluate the structural performance of flat slabs with drop panels in terms of shear resistance, deflection control, ductility, and stiffness, ensuring compliance with codal provisions. The results can guide engineers and designers in optimizing the use of flat slab systems in multi-story buildings for enhanced safety and economy

Literature review:

1) Sumit Sharma et.al., (2018): In this study author expressed, flat slabs are often used, cheiflyin public buildings. Due to several advantages of flat slab systems over traditional panel systems, flat panels are often used in construction. A slab is best realized as a slab without beams, which directly rests on the support due to the bending moment and shear stress generated near the column. The intention of this article is to introduce the advantages and disadvantages of flat slabs in construction. The found that flat slab systems are commonly used in public buildings due to their advantages over conventional beam–slab systems. These advantages include elimination of beams, faster construction, reduced formwork, ease in installation of services, improved aesthetics, and architectural flexibility. However, the study also notes disadvantages such as increased vulnerability to punching shear near column support and the requirement for precise structural detailing. Flat slab systems provide significant functional and architectural benefits in building construction. Their adoption can improve construction speed and flexibility, but their structural performance depends on proper analysis and detailing about the shear and serviceability concerns.

2) M. Jeelani et.al., (2018): The advent of flat panels provides features such as increased rigidity, increased loadbearing capacity, safety, and at the same time economy. In this article, seismic analysis was carried out to verify that commercial buildings with slabs are suitable for different areas without any failure. We analyze and design G-2 and G+7 commercial buildings with flat panels in the ETABS programThe seismic analysis conducted using ETABS on G+2 and G+7 commercial buildings with flat slab systems showed that such structures possess adequate rigidity, enhanced load-bearing capacity, and economic benefits. The analysis confirmed that flat slab systems can safely withstand seismic forces within permissible limits for different seismic zones without experiencing structural failure. Flat slab systems are suitable for commercial buildings in various seismic regions when properly designed. They offer a combination of structural safety, economy, and performance under seismic loading, making them a viable alternative to conventional slab–beam systems for multi-storey construction.

3) Kolapur Akshita et.al., (2018): Flat slab systems are widely used in professional buildings and residential buildings, hospitals, schools and hotels. They can be formed and constructed quickly and easily. The negotiation of beams can reduce the height of floors, thereby saving the cost of vertical envelopes, partitions, mechanical installation, pipes and many other structural elements, especially for buildings and mid-to-high-rise buildings. Provides the flexibility of partition placement and allows easy switching and maintenance. SAP is evolving into a structural analysis program. SAP 2000 is the most advanced and easy-to-use version of the SAP software suite. It is the first SAP version to be fully merged with Microsoft Windows. It has a well-built graphical user interface and is second to none in terms of ease of use and performance. SAP 2000 is object-based, which means that models are created using elements that represent physical reality. A beam with multiple frame members is created as a single body because it exists in the real world, and the grid required to connect to other members is processed internally by the program The emphasizes that flat slab systems are extensively applied in commercial, residential, healthcare, educational, and hospitality buildings due to their quick and easy construction. Eliminating beams reduces overall floor height, resulting in savings in vertical envelope costs, partitions, mechanical installations, and other structural elements—particularly in mid- and high-rise buildings. Flat slabs also allow flexible partition placement and ease of maintenance. Structural modeling and analysis carried out using SAP2000 demonstrated the program's capability to accurately represent physical structural behavior through its object-based modeling approach and user-friendly interface. Flat slab systems offer substantial advantages in construction efficiency, cost reduction, and architectural flexibility, making them ideal for various building types, especially mid- to high-rise structures. The use of advanced structural analysis tools like SAP2000 ensures accurate modeling, efficient design, and reliable performance evaluation, thereby supporting the safe and economical application of flat slab systems in modern construction.

4) Lalit Balhar et.al., (2019): Use STAAD.PRO V8i software for analysis. The seismic characteristics of traditional reinforced concrete frame buildings and slab buildings mean that additional measures need to be taken to guide the origination and design of these structures in earthquake areas and improve the construction efficiency of traditional reinforced concrete buildings. Flat plate under seismic load. The purpose of this research is to study the ways of multistorey buildings with traditional RC slab buildings and slabs, and to study the behavior of such buildings under the influence of earthquake forces. The current research includes information

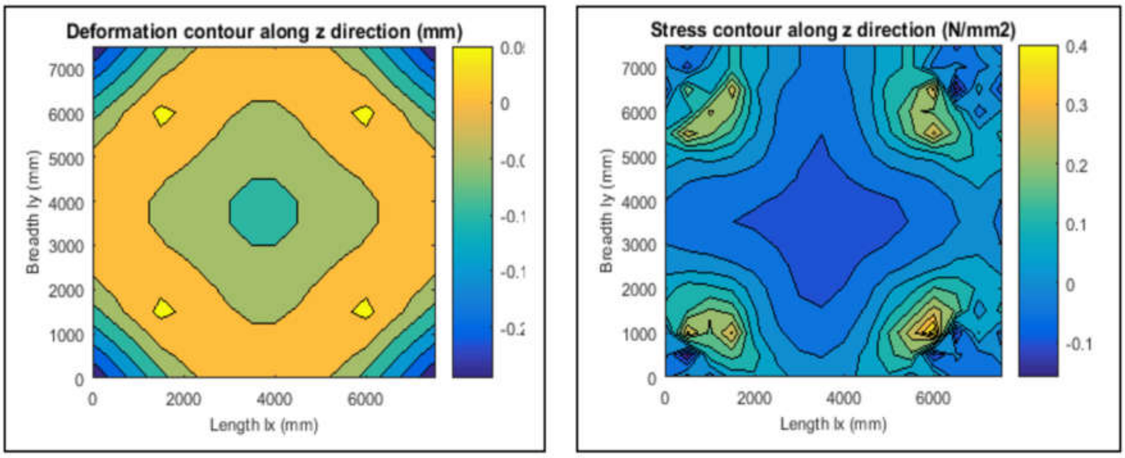
Conventional RC slab buildings demonstrated better seismic performance compared to flat slab buildings in terms of reduced structural damage after earthquakes. Punching shear was identified as the most critical failure mode in flat slab structures under seismic loads. Providing column heads significantly improves punching shear resistance and strengthens the column–slab connection Flat slab buildings with shear walls performed better than those without shear walls, as shear walls increase structural rigidity and reduce lateral displacement. It is concluded that the seismic response of conventional building is better than flat slab terms of structural damage after earthquake Punching shear is major critical failure takes place in flat slab structure. To avoid punching shear failure column head can provide which gives strength to column. Flat Slab Building with shear wall performs best over conventional slab without shear wall. Structure becomes more rigid because of shear walls which will result in cracking. Dampers can provide at exterior corner of the building which will dissipate earthquake energy thus damps motion of building. Structural damage after earthquake. Punching shear is major critical failure that takes place in flat slab structure. To avoid punching shear failure column head can provide which gives strength to column. Flat Slab Building with shear wall performs best over conventional slab without shear wall. Structure becomes more rigid because of shear walls which will result in cracking. Dampers can provide at exterior corner of the building which will dissipate earthquake energy thus damps motion of build It is concluded that the seismic response of conventional building is better than flat slab in terms of structural damage after earthquake. Punching shear is major critical failure that takes place in flat slab structure. To avoid punching shear failure column head can provide which gives strength to column. Flat Slab Building with shear wall performs best over conventional slab without shear wall. Structure becomes more rigid because of shear walls which will result in cracking. Dampers can provide at exterior corner of the building which will dissipate earthquake energy thus damps motion of building.

Analysis of both flat slab and conventional slab were carried out for different load cases and their combination such as Dead load, Live load, Wind load and Earthquake load. Many authors have done Non-linear that is Time History analysis and Pushover analysis and also compared results for Static and Dynamic analysis. After applying all load and their combination static and dynamic analysis were carried out. Dynamic analysis of structure gives more appropriate results compared to static analysis. At upper story allowable maximum displacement vary between H/50 and H\2000 where is total height of structure. Results were represented in tables and in graph to compare effectiveness. It is concluded that the seismic response of conventional building is better than flat slab in terms of structural damage after earthquake. Punching shear is major critical failure in a keys place in flat slab structure. To avoid punching shear failure column head can provide which gives strength to column. Flat Slab Building with shear wall performs best over conventional slab without shear wall. Structure becomes more rigid because of shear walls which will result in cracking. Dampers can be provided at exterior corner of the building which will dissipate

earthquake energy thus damps motion of building

5) Saurabh Agrahari, Pradeep Kumar Ramancharla (2017) During an earthquake, many building with flat slab have been performing poorly. This was mainly due to inadequate resistance for punching shear under the earthquake loading. Many codes that were available for the design ware studied for the analysis of flat slabs under gravity loading. Some provisions exist for punching shear resistance however, they were inadequate. To understand the behavior of building with flat slab subjected lateral loads, a numerical study was performed. A three-dimensional finite element method was used to perform the analysis. This case study states that a flat slab along with the columns was modelled. Nonlinear constituted equations were used to model material, i.e., concrete. Parametric study was performed for understanding the nonlinear behavior of flat slab subjected to lateral loads. Design of slab was done in such a way that it considers both types of stress behavior. Special attention was given to the slab and column sub assemblage as the complete change in stress behavior of slab is at the column location.

Top surface deformation contour and stress concentration contour in z-direction are shown in



figures. The shows the considered model is safe against gravity as reaction at the column base is equal to weight of the structure.

The study demonstrates that flat slab behavior varies under gravity and lateral loading. Under gravity load, positive stresses concentrate at column locations, while negative stresses dominate elsewhere Lateral loading induces both positive and negative stresses around columns, with nonlinear analysis (Model 3) capturing material nonlinearity more accurately. Slab design should account for both stress types, with special attention to the slab–column connection, where stress behavior changes significantly

6) Ola Enochsson, Peter Dufvenberg (2001): described those simple structures of flat slab floors used for the FE-analysis. Anchor or joint lengths and required top or anchor reinforcement in corners was not considered in reinforcement design the traditionally designed methods, the strip method and the yield line theory, distributed moments with the same size in a certain area, whereas FEM-Design calculates moments according to the theory of elasticity at each node. This means that FEM-Design's design moments or the required reinforcement have been to be chosen at certain points and redistributed by a design method. Finally, the FE based method was recommended as a design method of flat slab floors, because it gives a faster and more adequate determination of distribution distances and quantities both at bending- and final design in addition, the calculated moment distribution and displacement field in FEM-Design generally shows very good agreement with the Abacus analyses. Using finite element analysis via FEM-Design, the study evaluated slab behavior with different mesh densities, element types, and modeling of column stiffness. It found that support moments (near columns) are significantly affected by mesh resolution and stiffness modeling, while field moments are relatively insensitive to these modeling choice Finite element methods can effectively inform practical reinforcement design for concrete slabs, if moment distributions are interpreted and redistributed thoughtfully into reinforcement zones rather than taken directly as nodal forces.

7) Seema Rajabhau Ghogare, Dr. Ashok Kasnale, Kadlag Viswajeet (2020): analyzed that the implementation and verification of a procedure of finite element method to design reinforced concrete flat slab systems based on the result of non-linear finite element analysis. And also, to determine what causes in slab when they put the opening in the slab due to various reasons. This paper stated that the most suitable shape of opening in the flat slab was of circular shape and the most preferable location was away from the corner supports. Existence of openings in flat slabs of small thickness affects their behavior more than those of big thickness.

A non-linear finite element analysis (FEM) procedure was implemented and verified for the design of reinforced concrete flat slab systems. Introduction of openings in slabs significantly altered stress distribution, deflection patterns, and cracking behavior. Circular openings were found to be the most suitable shape in terms of minimizing stress concentration. The preferred location for openings was away from column supports, particularly avoiding corners where shear and moment demands are high. Slabs with smaller thickness experienced greater adverse effects from openings compared to thicker slabs.

Non-linear FEM provides a reliable means to assess the structural behavior of flat slabs with openings. The shape and location of openings are critical design factors; circular openings placed away from corner supports minimize structural weakening. Thickness plays a major role—thinner slabs are more sensitive to openings and require greater reinforcement or design precautions.

8) James B. Deaton (2005): Presented that the development of a procedure in GT STRUDL to design reinforced concrete flat plate systems based on the results of finite element analysis. On test section, they used an existed floodwall for verification of analytical models. A flat plate design procedure based on the element force approach, the DESIGN SLAB command was implemented in GT STRUDL. The DESIGN SLAB command provides the user the ability to specify a cross section designed simply by a start and end node, an element in the plane of the cut, and several optional design parameters. The procedure then determines all nodes and elements along the cut, computes the resultant forces and moments acting on the cut, and designs according to ACI 318 and any input parameters, such as bar size and spacing, specified by the user.

The implementation of the finite element–based flat plate design procedure within GT STRUDL, using the DESIGN SLAB command, was validated through multiple design examples. These examples included both single-panel and multi-panel flat plate systems, incorporating variations in support conditions, column spacing, and geometric regularity. The SLAB command in GT STRUDL provides a practical and accurate method for designing reinforced concrete flat plates directly from finite element analysis results. Or regular slab configurations, the method yields result consistent with experimental data and traditional analytical techniques, validating its reliability for standard applications. The method offers greater flexibility for irregular geometries and non-uniform loading conditions, situations in which conventional methods become less accurate or inapplicable. Cut orientation has a significant impact on the accuracy of the design. Non-orthogonal cuts relative to the principal bending axes can lead to under-reinforced sections due to unaccounted torsional effects.

9) Sherif A. G. (1996): Sherif A.G submitted the report on the behavior of flat slabs which they investigated. Three aspects are studied: the analysis, the deflections and the shear strength of flat slabs. To achieve this, a new test set-up was used to test the 5 m multi span full slabs. The test set-up facilitates the testing of a part of a slab centered about an edge column and the adjacent interior column. By providing edge restraint around the periphery of this area the behavior of the full slab can be simulated. Boundary frames provide these edge restraints. The first slab was tested three times and repaired after the first two failures. Shear failures happened at the interior and edge column connections with and without shear studs. In addition, four isolated edge column slab connections are tested to failure. The test variables are the distribution of the flexural reinforcement and the load eccentricity. Tests from the literature are used to study the different parameters affecting the punching shear strength of slab-column connections. The results are compared with the provisions of the ACI, BS, CSA and CEB-FIP Codes and new shear strength equations reflecting these parameters are proposed. For interior slab-column connections subjected to shear and moment transfer, a correction factor for y v (portion of unbalanced moment resisted by shear stresses according to the American and Canadian Codes) was proposed.

The multi-span full slab tests showed punching shear failures at both interior and edge column connections, occurring with and without shear studs. The addition of shear studs increased shear capacity but did not prevent failure under high loads. The distribution of flexural reinforcement and load eccentricity had a significant influence on shear strength and failure mode. Tests on isolated edge column–slab connections confirmed that reinforcement detailing, and moment transfer mechanisms strongly affected connection capacity. Comparisons with ACI, BS, CSA, and CEB-FIP provisions revealed that some existing code equations overestimated shear strength, particularly for connections with significant moment transfer

Punching shear strength of flat slabs is highly sensitive to reinforcement distribution, load eccentricity, and presence of shear reinforcement. Existing code provisions can be non-conservative for cases involving significant moment transfer, particularly at edge column connections. The proposed new shear strength equations and eve corrections methods provide more reliable predictions and should be considered for design refinement. The truss-model–based method for edge connections more accurately reflects observed behavior than current code approaches.

10) Hemalatha K.R, Ashwini B.T, Chethan V.R. (2021): Analyzed the flat slab with drop panel using etabs software. The design of flat slab was carried out as per IS 456:2000. The flat slab system of construction was the one in which the slab was directly rested on the column and load from the slab was directly transferred to the columns and then to the foundation. The analysis and design are carried out by equivalent frame method with staggered columns and without staggered columns as mentioned in the IS code 456:2000. We get result that flat slab with drop was developing construction in India even in the seismic prone areas for better stability and life span of the building. This case study was able to come with the conclusion that flat Slab with drop construction is developing construction in India and can be implemented for Apartment buildings even in the seismic prone areas for better stability and life span of the building. Compared to conventional concrete, flat slab has a very good story drifts and it lies within the permissible limit and hence the design and construction will be safe.

The ETABS analysis and design of flat slabs with drop panels, conducted as per IS 456:2000 using the Equivalent Frame Method, demonstrated that the system effectively transfers loads directly from slab to columns and then to the foundation without intermediate beams. Both configurations—with staggered columns and without staggered columns—were evaluated. The analysis showed that flat slabs with drop panels exhibited better structural performance in terms of story drift control, with drift values well within the permissible limits specified by the code. The presence of drop panels enhanced stiffness and improved load distribution to columns, resulting in better seismic performance compared to conventional RC frame systems Flat slab with drop panels provides improved structural stability and service life for buildings, even in seismic-prone areas. The system offers superior drift performance compared to conventional RC slabs, ensuring compliance with IS 456:2000 safety limits. The inclusion of drop panels increases stiffness, reduces deflection, and enhances seismic resistance. This construction method is practical and suitable for apartment buildings in India, offering advantages in terms of safety, durability, and architectural flexibility

11) Chee Khoon Ng, Et.al. (2008): A study on simply supported and fixed end; square slabs with opening at the ultimate limit state using the yield line method was carried out and the results are presented herein. For simply supported slabs, the analytical study on the ultimate load capacity of the slab shows that the ultimate total load decreases with the size of the opening and for fixed-end slabs, the results show that the opening has insignificant effect on the ultimate area load capacity for a small opening size of up to 0.3 times the slab dimension. The analytical investigation on simply supported and fixed-end square reinforced concrete slabs with central openings using the yielding line method yielded the following key findings: Simply Supported Slabs The ultimate total load capacity decreases progressively as the size of the opening increases. When the total load is expressed as ultimate area load (load per unit area of the slab), the trend reverses, showing an apparent increase with opening size. This indicates that while the total capacity of the slab reduces due to material removal, the load distribution relative to the remaining slab area changes favorably. Fixed-End Slabs For small openings up to 0.3 times the slab dimension, both the ultimate area load and ultimate total load remain largely unaffected by the presence of the opening. For large openings greater than 0.5 times the slab dimension, both ultimate area load and ultimate total load increase significantly. This unexpected increase is attributed to changes in failure mechanisms and redistribution of yield lines due to the large void. Design Tools All analytical results were presented in nomograph form, enabling straightforward estimation of ultimate load capacities for various opening sizes and support conditions. The study demonstrates that the presence of openings in reinforced concrete slabs significantly influences their ultimate load capacity, with the effect dependent on both the support condition and relative opening size. For simply supported slabs, increasing the opening size reduces total load capacity, but relative area load may appear to increase. For fixed-end slabs, small openings have negligible impact, while very large openings may unexpectedly increase ultimate load capacity due to altered yield line patterns. The developed nomographs provide a practical tool for engineers in designing slabs with openings at the ultimate limit state, offering quick estimates without resorting to complex calculate

12) Liana L. J. Borges, Et.al. (2013): This paper deals with Punching shear tests were conducted on 13 reinforced concrete flat plates with and without openings or/and shear reinforcement. The openings (one or two) were adjacent to the shorter sides of rectangular supports and had widths equal to those of the supports. The methods of calculating punching shear strengths given in ACI 318-11 and MC90/EC2 are reviewed along with some proposed formulations, and their predictions are compared with the test results. Punching shear tests were carried out on 13 reinforced concrete flat plates, both with and without openings and shear reinforcement. The main findings are Effect of Openings, whether single or double, were positioned adjacent to the shorter sides of the rectangular supports and had widths equal to those of the supports. For the relatively small openings considered, their influence on punching shear strength was limited, provided proper reinforcement detailing was maintained. Influence of Plate Depth Test results confirmed that plate depth plays a significant role in the unit shear resistance from concrete, with deeper plates showing higher shear resistance. Opening Geometry and Control Perimeters Using straight projections of openings onto the control perimeter gave satisfactory predictions of their influence, providing a simpler alternative to radial projections. Eccentricity in the arrangement of openings affected the punching shear capacity and should be considered in design calculations. Shear Reinforcement Effects The presence of shear reinforcement significantly improved punching shear capacity. Continuous bars placed adjacent to openings were effective in replacing the removed reinforcement area, providing adequate flexural capacity. Code Predictions vs. Test Results ACI 318-11 and MC90/EC2 predictions were generally conservative but did not always fully capture the beneficial effects of shear reinforcement near openings. The study suggests that the shear stress limit in ACI 318-11 could be increased when assessing strength at the outer control perimeter in zones with shear reinforcement. The study shows that for reinforced concrete flat plates with relatively small openings adjacent to supports, proper detailing—particularly the provision of continuous reinforcement bars alongside the openings—can effectively maintain flexural performance. Punching shear capacity is influenced by plate depth, opening eccentricity, and the presence of shear reinforcement. Straight projection methods for incorporating openings into control perimeter calculations are both practical and sufficiently accurate. Current design codes (ACI 318-11 and MC90/EC2) are generally conservative, but refinements such as increasing allowable shear stress at the outer control perimeter in zones with shear reinforcement could lead to more efficient designs.

13) Ashraf Mohamed Mahmoud (2015): This paper used Ansys 10 finite element software for modeling and load was calculated by Newton-Raphson method. Punching shear reinforcement increases with the deformation capacity and strength. FEM element Solid 65 was used for concrete and beam 188 for stud element. Several important parameters are incorporated in the analysis, namely the column size, the slab thickness and the punching shear reinforcement system to study their effects on the flat slab behavior. Reduction was observed 40% in the proposed load–rotation values, leading to somewhat non-agreeing values. An increase in the proposed strength capacity values of 22% compared to the experimentally available data was concluded, leading to a good agreement between them. Punching shear reinforcement (studs, stirrups) increased slab capacity and ductility, delaying cracking. Larger column size and greater slab thickness improved punching shear resistance. Central point loading was most critical; distributed/off-center loads reduced shear stress. Openings near columns reduced capacity, but effects were mitigated by adequate reinforcement results correlated well with experimental data, accurately predicting punching shear failure behavior.

The study confirms that the proposed FEM model in ANSYS can reliably simulate the nonlinear punching shear behavior of flat slabs, accurately predicting load capacity and crack development. Punching shear reinforcement systems, particularly studs and stirrups, substantially enhance slab performance by increasing ultimate strength and ductility. Larger column sizes and increased slab thickness also improve resistance, while openings and eccentric loading can reduce capacity unless mitigated by proper reinforcement detailing. The validated FEM model offers a powerful tool for parametric studies, enabling the optimization of slab design for improved punching shear performance.

14) Zienkiewicz, Yau kai Chung (1964): In this work, they extended the general finite element method of flat plates and presented the formulation for boundary conditions typical to these systems. The linear elastic isotropic analysis was extended to orthotropic slab systems with variable thickness, and the ease with which a slab can be analytically coupled to frame members, or an elastic foundation was presented. The simplicity of formulation and of dealing with boundary conditions allows hitherto difficult problems of slabs with variable thickness and of orthotropic slabs to be dealt with. The slab can be included in the analysis of a more complex structure involving other types of members (such as beams, columns, etc.) without difficulty. Developed a finite element formulation for flat plate analysis with boundary conditions tailored to such systems. Extended the linear elastic isotropic slab analysis to handle orthotropic slabs and slabs with variable thickness. Demonstrated the ability to analytically couple slabs with frame members and elastic foundations. Showed that the method can easily incorporate slabs into the analysis of more complex structural systems. The study provided a simple yet powerful finite element approach for analyzing flat plates, including orthotropic and variable-thickness slabs. Its flexibility in handling boundary conditions and compatibility with other structural elements (beams, columns, foundations) makes it well-suited for practical engineering applications. This method enables the solution of previously difficult slab problems and facilitates integrated analysis of complex structures.

15) Chee Khoon Ng et.al (2008): Carried out, a study on simply supported and fixed-end, square slabs with opening at ultimate limit state using the yield line method. A study on the effect of opening on the load carrying capacity of simply supported and fixed-end slabs was presented. After their analysis they came to a conclusion that, since most of the slabs have small opening of size up to 0.3 times the slab dimension, a simply supported slab would have a reduction in ultimate area load of up to 11% and a reduction of ultimate total load of up to 19% and a fixed-end slab would experience less significant reduction in both ultimate area load and ultimate total load capacities of 4% and 7%, respectively. They also presented charts in normalized load capacity and opening size which could be used as guidelines for predicting the load capacity of simply- supported and fixed-end slabs with openings. Simply supported slabs: Ultimate total load decreases with increasing opening size, but ultimate area load shows the opposite trend.

Fixed-end slabs:

For openings ≤ 0.3 slab dimensions, both ultimate total and area loads are largely unaffected.

For openings ≥ 0.5 slab dimension, both ultimate total and area loads increase significantly due to altered yield-line patterns.

All results are presented in nomograph form for quick design reference.

The yield line method analysis shows that the effect of openings on ultimate load capacity depends strongly on support conditions and relative opening size. Small openings have little influence, while large openings can unexpectedly increase load capacity for fixed-end slabs. The provided nomographs offer practical guidelines for designing reinforced concrete slabs with openings at the ultimate limit state.

16) Koh Heng Boon.et.al (2009): Carried out an experimental work to determine the structural performance of one-way reinforced concrete slabs with rectangular opening. Five types of RC slab which consist of two panels for each type were tested by four points bending test. These include one control slab without opening and other four with rectangular opening at the center. Based on the experiment result it was found that the reduction of 15% area due to the rectangular opening located at the center of RC slabs reduces 36.6% of flexural strength. The crack pattern obtained for slab with opening and without additional reinforcement around was found to be same as that of slabs with opening and additional reinforcement of either rectangular bars or diagonal bars around opening. The provision of additional reinforcements surrounding the opening increases the flexural capacity of the RC slab. Also, the cracking pattern found in the opening slab shows a high concentration stress occurred at the corner of the opening when vertical load applied. Flexural strength reduction: A central rectangular opening reduced slab area by 15% resulted in a 36.6% reduction in flexural strength. Crack patterns: Slabs with and without additional reinforcement around the opening exhibited similar crack patterns, with stress concentration at the corners of the opening under vertical loading. Effect of additional reinforcement: Providing reinforcement around the opening (rectangular or diagonal bars) improved the flexural capacity compared to slabs without such reinforcement. Stress concentration: The highest stress concentration occurred at the opening corners. Central openings in one-way RC slabs significantly reduce flexural strength, with the degree of reduction being disproportionate to the removed area. Additional reinforcement around openings enhances flexural capacity but does not significantly alter crack patterns. Stress concentration at opening corners is a critical factor in slab performance and should be considered in design detailing.

17) Hosam A. Daham (2010): Carried out finite element analysis by using ANSYS 5.4 program with a nonlinear concrete model satisfying complex support condition to predict the ultimate load for different types of RC slabs. The effects of openings for different types of boundary conditions were studied. Effect of supports status on the deflection of the slabs with and without opening was studied and the results shows that the opening in slabs supported on four edges have little effects on slabs. Results obtained from the analysis carried out for different boundary conditions shows that the deflection for slabs with opening fixed on all four sides was about 5.6% of that of slab simply supported at all four sides. Also, the deflection of slab with opening fixed at two opposite side and fixed free at other two opposite side was about 9.6% of that of slab simply supported at two opposite sides and simply supported free at other two opposite sides. The values distributions of normal stresses were also greatly affected by opening in slabs, especially at opening region. The finite element analysis using ANSYS 5.4 with a nonlinear concrete model revealed the following:

Effect of Openings and Support Conditions: Openings in RC slabs supported on all four edges caused minimal change in slab behavior. For slabs with openings and fixed supports on all four edges, the deflection was about 5.6% of that of a similar slab simply supported on all four sides.
For slabs with openings and fixed supports on two opposite sides and free-fixed on the other two sides, the deflection was about 9.6% of that of a slab simply supported on two opposite sides and simply supported-free on the other two sides.
Stress Distribution: Openings significantly altered the normal stress distribution, especially in regions near the openings, indicating localized stress concentrations.
The support condition of RC slabs plays a critical role in mitigating the effects of openings on slab performance. Fixed edge support greatly enhances stiffness, reducing deflections even in slabs with openings. Openings cause substantial local stress concentration, which must be considered in design to avoid potential cracking or failure near the opening. Proper selection of support conditions can effectively control deflections and maintain structural integrity in slabs with openings.
18) Ahmed Ibrahim et.al. (2011): Used numerical simulations using ANSYS to study the response of waffle slabs with and without openings and the design coefficients for the column and the field strips of the internal panel of a waffle slab. He also studied the effect of openings and stiffening ribs on the design coefficients. The linear modeling results were used to study the moment coefficients before cracking, whereas the nonlinear models were used to calculate the moment coefficients at ultimate loads. Finite element models were used to study the effect of column size, slab thickness, solid portion size, and opening size and location on the moment coefficients. By comparing the results, it was found that the linear analyses gave higher values for the moment coefficients than the ones obtained from the nonlinear analyses and the ACI code coefficients. Also, by increasing the solid portion size, it was found that the negative moment coefficient of the column and field strips increased for column strips and field strips, whereas the positive moment coefficient of the column and field strips decreased for column strips and field strips. The ANSYS finite element analysis of waffle slabs, with and without openings, showed that: Linear elastic models predicted higher moment coefficients than both nonlinear models and ACI code provisions. Nonlinear analysis at ultimate loads produced more realistic and generally lower moment coefficient values. Increasing the solid portion size increased the negative moment coefficients for both column and field strips, while the positive moment coefficients decreased. Linear analysis tends to overestimate moment coefficients; nonlinear modeling is essential for accurate ultimate load predictions. Increasing the solid portion in waffle slabs enhances negative moment resistance but reduces positive moment capacity, influencing design balance. Opening and stiffening ribs have a substantial effect on moment distribution and must be carefully accounted for in design.
19) Dina M. Ors(2024): The aim of this research is to present correction factors for the punching shear formulas of ACI-318 and EC2 design codes to adopt the punching capacity of post tensioned ultra-high-performance concrete (PT-UHPC) flat slabs. To achieve that goal, the results of previously tested PT-UHPC flat slabs were used to validate the developed finite element method (FEM) model in terms of punching shear capacity. Then,

a parametric study was conducted using the validated FEM to generate two databases, each database included concrete compressive strength, strands layout, shear reinforcement capacity and the aspect ratio of the column besides the correction factor (the ratio between the FEM punching capacity and the design code punching capacity). The first considered design code in the first database was ACI-318 and in the second database was EC2. Finally, there different “Machine Learning” (ML) techniques manly “Genetic programming” (GP), “Artificial Neural Network” (ANN) and “Evolutionary Polynomial Regression” (EPR) were applied on the two generated databases to predict the correction factors as functions of the considered parameters. The results of the study indicated that all the developed (ML) models showed almost the same level of accuracy in terms of the punching ultimate load (about 96%) and the ACI-318 correction factor depends mainly on the concrete compressive strength and aspect ratio of the column, while the EC2 correction factor depends mainly on the concrete compressive strength and the shear reinforcement capacity.

20) Sheetal Gawas and Dr. S.V. Itti (2013): Presented finite element analysis of RCC slab models to study variation of displacement and stresses, in slab with different boundary conditions. Non-Linear static analysis was carried out using ANSYS 10 Software and a rectangular RC slab with tensile reinforcement was analyzed. Comparing the slabs with different boundary conditions both with and without opening, the slab simply supported on all the edges shows highest displacement and slab fixed all the edges shows least displacement. The slab having fixed support on all the edges with and without opening shows highest stresses, whereas slab simply supported on all edges shows least stresses among all other slabs. The nonlinear static finite element analysis of rectangular RCC slabs with varying boundary conditions showed that: Deflection behavior: Slabs simply supported on all edges exhibited the highest displacements. Slabs fixed on all edges exhibited the lowest displacements. Stress behavior: Slabs fixed on all edges, both with and without openings, showed the highest stresses. Slabs simply supported on all edges showed the lowest stresses. Effect of openings: Openings influenced both displacement and stress magnitudes, but the support condition had a more dominant effect on structural performance. Boundary conditions significantly affect displacement and stress distribution in RCC slabs. Slabs with fixed edge support offer greater stiffness, reducing displacement but leading to higher stress concentrations. Slabs with simply supported edges are more flexible, resulting in larger displacements but lower overall stress levels. The presence of openings modifies slab performance, but support conditions remain the primary factor controlling displacement and stress behavior.

21) Prof. Dr.Nazar K. Oukaili, and Thaar Saud Salman, (2014): Conducted an experimental test on six half-scale reinforced concrete flat plates connections with an opening in the vicinity of the column. The tests were designed to study the effect of openings on the punching shear behavior of the slab-column connections. From the results it was found that all the specimens have failed in punching shear mode. The capacity of the flat plate was greatly affected by size of the opening. The ultimate strength of the flat plate with the larger opening decreased by 29.25% with respect to the ultimate strength of solid specimen. For the specimen with a smaller opening, the decrease in capacity was 12.42%. For the specimen with opening at distance h (70mm) from the front face of the column, the shear capacity decreased by 13.47% from control one. For specimen with the opening next to the column, the decrease in capacity was 19.65%. The opening located at the front of the column decreases the shear capacity of the flat plate more than the same size opening located at the corner of the column. The opening location adjacent to the front column face decreased the shear capacity by 19.65% from control one, while that adjacent to the column corner decreased the capacity by 11.43%. The presence of openings in flat plates decreases the stiffness depending on the size and locations of these openings. The experimental testing of six half-scale RC flat plate–column connections with openings near the column revealed that:

Failure Mode: All specimens failed in punching shear.

Effect of Opening Size:

Large opening → 29.25% reduction in ultimate capacity compared to the solid specimen.

Small opening → 12.42% reduction in ultimate capacity.

Effect of Opening Location:

Opening at distance h (70 mm) from front face of column → 13.47% reduction in capacity.

Opening adjacent to column front face → 19.65% reduction.

Opening adjacent to column corner → 11.43% reduction.

Openings at the front of the column caused greater capacity loss than those at column corners.

Stiffness: Openings reduced stiffness, with severity depending on opening size and location.

Punching shear behavior of slab–column connections is significantly influenced by the size and location of openings near the column. Larger openings cause substantial reductions in shear capacity, while even smaller openings lead to noticeable strength losses. Openings adjacent to the front face of the column are more detrimental to capacity than those at column corners. The presence of openings reduces stiffness, making the slab more flexible and vulnerable underload. Design of flat plate–column connections should minimize opening size and place openings as far as possible from critical shear zones to preserve capacity.

Anjaly Somasekhar and Preetha Prabhakaran (2015): Examined the structural behavior of waffle slabs (ribbed flat slabs) with and without openings and the effect of openings sizes and locations on the ultimate loads. These items were studied using finite element software by analyzing nonlinear finite element models of an internal panel of waffle slab under uniform loading. Results obtained from numerical study showed that opening dimensions and its locations have a significant effect in the structural behavior of waffle slab. The size of openings in the region bounded by two column strips should be limited to 10% of the column strip width while in the region bounded by a column strip and a middle strip, size limit is 20% of the column strip width. But for the region bounded by two middle strips, no such limitation has been found in opening size leading to a conclusion that in this region, opening size can be even up to 40% of the width of column strip. It was concluded from the results that special measures have to be taken to improve the performance of waffle slabs having large openings in the regions bounded by two column strips and that bounded by a column strip and middle strip.

The nonlinear finite element analysis of waffle slabs with and without openings under uniform loading indicated that: Opening size and location significantly influence ultimate load capacity. In the region between two column strips, allowable opening size should not exceed 10% of the column strip width. In the region between a column strip and a middle strip, allowable opening size should not exceed 20% of the column strip width. In the region between two middle strips, openings can be as large as 40% of the column strip width without critical loss of capacity. Larger openings in critical load transfer regions led to notable strength reductions, whereas openings in less critical zones had minimal effect. Both opening size and location are decisive factors in the structural performance of waffle slabs. Critical zones near column strips should have strictly limited opening sizes to maintain strength. Openings in less stressed zones can be larger without significantly affecting performance. Large openings in critical regions require strengthening measures to ensure safety and serviceability. Strategic planning of opening placement can effectively control strength loss and maintain structural integrity.

22) Anandrao Jadhav (2023): In today's construction activity the use of flat slab is quite common which enhances the weight reduction, speed up construction, and economical. Similarly, from the beginning conventional slab has got place in providing features like more stiffness, higher load carrying capacity, safe and economical also. Here large Bending Moment & Shear Forces are developed close to the columns. To prevent progressive collapse of flat slab-column connections, it is necessary to provide a secondary load carrying mechanism after punching shear failure. In this research, some suggestions for establishing an alternative mechanism in flat slab connections after punching failure are proposed. In the present study, RCC building is analyzed, IS 456-2000 is used for the manual calculation of flat slab and the models are developed using SAFE 2016 with M30 grade concrete for beams, M30 grade concrete for columns and Fe 500 Mpa grade of steel for reinforcement are taken as material properties. The study aims to provide a better and easy understanding of flat slab analysis

The study on flat slab analysis, using IS 456:2000 for manual calculations and SAFE 2016 software modeling, revealed that: Flat slabs offer significant advantages in weight reduction, construction speed, and economy compared to conventional slabs. Conventional slabs still provide greater stiffness and higher load-carrying capacity, but flat slabs are more efficient for rapid construction. High bending moments and shear forces occur near slab–column connections, making them critical zones for potential punching shear failure. The analysis confirmed the need for a secondary load-carrying mechanism to enhance post-punching shear performance and prevent progressive collapse. Material specifications (M30 concrete, Fe 500 steel) provided adequate capacity for typical design loads but still require detailing attention near columns.

Flat slabs are structurally efficient and economical but punching shear near columns remains a critical design consideration. Incorporating a secondary load-carrying mechanism after punching failure is essential to improve structural safety and prevent progressive collapse. While flat slabs are advantageous for faster and lighter construction, careful detailing of reinforcement near columns is necessary to sustain post-failure integrity. The combined use of manual calculations (IS 456:2000) and software analysis (SAFE 2016) provides a more comprehensive understanding of slab performance. The research highlights that designing both strength and redundancy is key to safe flat slab applications in modern construction.

23) Dr. Grzegorz Golewski (2019): The use of flat slab systems is a common structural solution for residential and commercial buildings as they are a cost-effective structural solution that simplifies and speeds up the construction phase. However, the flat slab systems have complex behavior, particularly in the slab–column connection zones, because of punching shear. Therefore, to prevent brittle flat slab collapse because of punching shear, there are some conditions which must be met in regulations such as Eurocode 2, American Concrete Institute's Code, and Türkiye Building Earthquake Code—2018. Flat slab collapses because of punching shear can be caused by deficiencies in the design phase as well as deficiencies in the construction phase. The purpose of this study is to investigate the causes of flat slab collapses due to punching shear, focusing on whether these failures arise from design or construction deficiencies. The study highlights the importance of adhering to regulations to prevent brittle flat slab collapses. A case study of an actual building collapse due to punching shear was conducted. Theoretical punching shear strength was calculated based on the Türkiye Building Earthquake Code—2018. A finite element model of the collapsed part of the building was created, and collapse mechanism simulations were performed. It was examined whether the punching collapse mechanism was caused by deficiencies in the design or the construction phase. The findings revealed the critical role of proper design phases and construction practices in ensuring structural integrity Finite element analysis and theoretical calculations confirmed that the collapse was due to punching shear failure at the slab–column connections. The failure was linked to both design deficiencies (insufficient shear capacity) and construction flaws (poor workmanship and reinforcement placement), highlighting the need for strict compliance with relevant codes and quality control in practice. Proper design in accordance with structural codes and rigorous quality control during construction are essential to prevent brittle punching shear failures in flat slabs. Both design-phase errors and construction deficiencies can critically compromise slab–column connections, making strict adherence to Eurocode 2, ACI Code, and Türkiye Building Earthquake Code—2018 vital for structural safety.

24) Dr. David Arditi (2023): Structural members with low-flexural stiffness, such as slabs, are more susceptible to impulsive loadings induced by falling machines/tools during construction and installation, and from rolling boulders/rocks triggered by wind/earthquake, especially in mountainous areas. The impact resistance of reinforced concrete (RC) slabs supported on two opposite edges (often called the one-way slab) and on all four edges (i.e., two-way slab) has been adequately studied experimentally as well as computationally and is available in the literature. However, the slabs supported on three edges have not been studied under low-velocity impact for their impact response. For this purpose, a computational study is performed through finite elements by implementing ABAQUS software on the validated model, resulting in the slab, which is supported on (i) three edges and (ii) two opposite edges, to be subjected to low-velocity impact, induced by dropping a 105 kg non-deformable steel mass from a height of 2500 mm onto the slab centroid. Furthermore, the role of the material strength of the concrete of the slab is investigated via replacing the ultra-high-performance concrete (UHPC) for standard or normal-strength concrete (NSC). The impact load is modeled by considering the explicit module of the software. Failure mechanism, stress/strain contour, displacement distribution, and crack pattern of the slabs are compared and discussed. Finite element simulations in ABAQUS revealed that slabs supported on three edges exhibited different impact responses compared to slabs supported on two opposite edges under low-velocity impact from a 105 kg steel mass dropped from 2500 mm. Ultra-high-performance concrete (UHPC) slabs showed significantly reduced displacement, delayed crack initiation, and improved energy absorption compared to normal-strength concrete (NSC) slabs. The support configuration strongly influenced stress distribution, crack patterns, and overall damage extent, with three-edge support providing improved impact resistance over two-edge support. The study demonstrated that both support conditions and concrete strength critically affect the low-velocity impact resistance of RC slabs. Using UHPC in slabs greatly enhances impact performance, while three-edge support improves structural resilience compared to two-edge support. These findings suggest that adopting stronger materials and optimized support conditions can significantly improve slab safety against accidental or environmental impact loads.

25) Suzana Ereizv (2022): At the time of designing structures up to date, the density and magnitude of the load have increased, and the requirements for regulation have also become more stringent. To ensure the essential requirements, especially the mechanical resistance and stability, the numerical modelling of the structure is carried out according to the current regulations. Due to various assumptions, idealization, discretization, and parameterizations that are introduced numerical modelling, obtained numerical model may not always reflect the actual behavior. It is known that these structures have a hidden resistance that can be determined by combining experimental investigations (static or/and dynamic tests) and finite element model updating methods to minimize the differences between the actual and predicted structural behavior. This paper provides a review of the FEMU process and methods used and summarizes the FEMU approach to help future engineers to select the appropriate method for solving some discussed issues. First, the main important terms for understanding FEMU are introduced. The whole process of model updating is described step by step: selection of updating parameters (design variables), definition of the model updating problem, its solution using different FEMU methods. An overview of the following methods is given: sensitivity-based, maximum likelihood, non-probabilistic, probabilistic, response surface and regularization methods. Each of the method is presented with the corresponding mathematical background, implementation steps, and examples of studies from the literature.

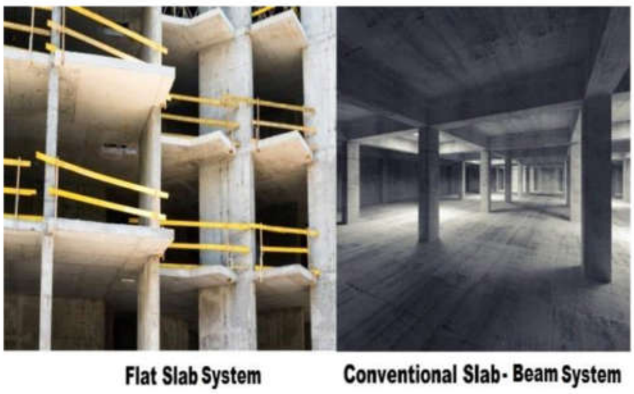


Fig: Shows the flat slab system and conventional slab-beam system

3.1 Methodology:

The systematic approach used to analyze, design, and optimize structures to ensure they are safe, stable, and efficient. Here's an overview of the core methodology typically followed in structural engineering projects:

Fig: Storey Shear up to 8 storeys

4.1. Result & Discussion:

1. General The current project work is to comparative study of conventional Building and Flat Slab Building as per flow of project mentioned in the previous chapter. Conventional slab and Flat slab are designed governed by various parameters calculated using tables. The result value of various parameters has been solved using finite element package. Maximum and minimum values are obtained for each case
2. Flow of Project

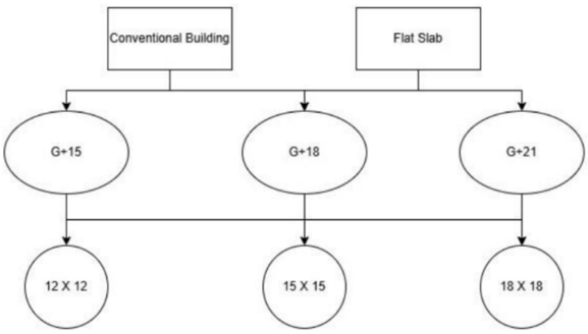


Fig. Flow of Research Work

3. As shown in figure number 1 there are two types of building. Conventional building and Flat slab, as we see there are three types of stories in building, g + 15, g + 18 and G+ 21. In further these buildings are again discretized in three types of size criteria which are 12 X 12, 15 X 15 and 18 X 18.

5.1 Conclusion:

1. The four-side supported slab can increase the stiffness of the slabs and enhance concrete ductility and integrity of domain of slab-column connections.
2. Flat Slab with drop construction is developing construction in India and can be implemented for Apartment buildings even in the seismic prone areas for better stability and life span of the building
3. Compared to conventional concrete, flat slab has a very good storey drifts and it lies within the permissible limit and hence the design and construction will be safe.
4. Maximum displacement is seen at higher stories and to improvise the strength and stability of the building we can increase the supporting drop panel thickness, or the overall slab thickness can be increased.
5. The equivalent static method analyzed can get more accurate results in Etabs when compared to manual calculations as it is a big procedure to carry out.
6. Flat Slab with drops is used avoiding the beams in this apartment building system by this we can conclude that its economical way of construction and only the initial cost will be high.

6.1 Acknowledgements:

This project helped me understand that flat slab construction, particularly with drop panels, is gaining prominence in India—even in seismic-prone regions—due to its superior stability and structural performance. Compared to conventional RCC framed systems, flat slabs offer improved story drift behavior within permissible limits, making them a safe and efficient option. Although the initial cost may be high, the elimination of beams contributes to construction economy, and the system exhibits sufficient ductility and stiffness as per codal provisions.

I extend my heartfelt thanks to my guide, faculty members, and peers for their continuous encouragement and valuable feedback, which greatly contributed to the successful completion of this project.

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