A Critical Review of Flat Slabs under different parameters

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Abstract: *Flat slabs and other similar slabs are preferred in those structures having larger spans. Due to advancements in civilization emphasis has been put on the construction of newer and more advanced structures like buildings, shopping malls, airports, railway stations, etc. This led to the use of flat slabs for safety, stability, and better design. This works deals with the analysis of critically flat slabs regarding their design, stability, and uses. Cost–benefit analysis gives the economic viability of the use of flat slabs in comparison to other types of slabs. Different design methodologies have been adopted and critically reviewed and inferences are made for the selection of the particular method of designing the flat slab. Using various codes during design are also used for the purpose. The stability of flat slabs under different situations has been critically studied. In civil engineering uses different types of slabs are used in buildings, parking, etc. Using flat slab buildings has numerous benefits over standard RC frame buildings in terms of simpler formwork, space use, architectural flexibility as well as quicker construction times. The analysis demonstrates that flat slab structures are lighter than traditional slab structures. When compared to a standard slab, a flat slab structure is 15 percent less expensive. As per the study's results, flat slab structures outperform traditional slab structures in terms of cost-effectiveness for high-rise structures. Flat slab structures result in financial savings, aesthetic views, and greater artistic flexibility for the architect in contrast to typical slab structures. Structures of the flat slab are the highest selection for high-rise structures in comparison to traditional slab structures.*

Key Words: Flat slab, Load, Span, Panels, Concrete, Column Strip, Middle Strip etc.

Introduction: The term "flat slab" is used to describe both a reinforced concrete slab which is assisted only by concrete columns and a slab that is assisted directly with concrete columns without the requirement for beams. A panel is a piece of a slab that is bounded on all four sides by a column's center line. Panels can be split into middle and column strips. The flat slab is typically enlarged close to the supporting columns to offer enough shear strength and to decrease the amount of "negative reinforcement" in the support zones. (**Ghaleb**, 2015)[6] The word "flat slab" can also apply to a square slab with a one- or two-sided support system, known as "drop panels," with the shear stress of the slab being centered on the columns.

Without the need for beams, capitals, or drop panels, flat slabs are "solid concrete" slabs of uniform depth that carry weights to the columns (**Venugopal et al. 2016**)[20].

It is different from a conventional slab as the latter is supported on beams and columns. Also, a Flat slab has more thickness in comparison to a conventional slab. This type of slab offers a simpler structure, more architectural flexibility, clear space, quicker construction, and smaller building height.

Structures of flat slab buildings are substantially more flexible during seismic excitations as compared to conventional concrete slabs. The reinforced concrete flat slab is a much-admired idea in structural engineering because it meets architectural demands for better illumination, only needs straightforward formwork that could be removed more quickly (than other slabs), and ensures open vision while making the best use of the available space (**Sumit Pahwa et al., 2014**)[16].

The constructions designed to support vertical loads may lack the capacity to support lateral loads. The main loads are lateral ones because they are more variable and rise more quickly than vertical loads, which are believed to rise linearly with height. The "overturning moment" at the base of the structure is rather substantial and changes in relation to the square of the building's height under seismic loads and identical wind. The top-level experiences significantly greater lateral stresses than the bottom storey, which causes the building to exhibit cantilever behaviour. These lateral stresses cause the frame to tilt. Buildings that weren't built to withstand earthquake loads have failed on numerous occasions in several seismically active regions. The analysis of the impact of lateral loads is crucial in light of all these reactions. The present paper reveals the suitability of flat slabs under different parameters.

Research Gap: -

Many studies have discovered that when flat, grid, and traditional slabs were compared, for some standards, the flat slab has been observed to be acceptable, while at other times, the traditional slab proved to be appropriate for lateral stiffness.

In the current study, an attempt is made to determine the outcomes for the complete structure as well as merely the slab spans. The results are determined, as well as the impact on the columns and foundation when the slab is placed to a seismic load.

Forms of flat slab:

- Flat slab without drops panel and column head.
- Flat slab with drop panel and column head.
- Flat slab with drop panel.
- Flat slab with column head.

Some terminologies related to flat slab

(i) **Drop Panels**: The drop foil is a thicker piece of the flat slab surrounding the column to prevent shear at the intersection of the flat slab and column. It is a slab component. No other element of the structure is supported by it.

(**Mehrain and Graf W P M 1992**)[7] A pillar is on both sides of the column top or, more accurately, a higher upright with a bit across the column at its maximum point on which other structures could rest. It also adds to the base region, which acts as a base for other structures (**Apostolska R P et al. 2008**)[2]

(ii) **Column Capital**: The post or "post throne" that is given at the top of a column is primarily designed to raise the slab's topics so that punching shears may be supported. The top of the post is often flared so that the column's geometry and the plot geometry there are connected. The law-making limits the section of the desired post that is structurally acceptable to that portion that falls inside the huge pyramid with noon of 90 and may be considered within the confines of the post and post throne's shape (**Dhangar A L et al 2008**)[4].

Recommendations of the Indian Code for Proportioning Flat Slab:

1) Flat slab Thickness: - The span-to-effective-depth ratio must typically regulate the thickness of the flat slabs.

2) Drops: - The drops, if any, must have a rectangular plan and a length in every direction that is at least one-third length of the panel. For external panels having dropped at right angles to the "non-continuous edge" and assessed from the columns' center line, the width of the drop should be half that of interior panels.

3) Column heads: - When column heads are offered, the column head's section that fits totally inside the limits of the column and the column head and has a vertex angle of 90 degrees must be taken into consideration for design.

Retrofitting could be carried out by

- The installation of beams on the floor
- Column jacketing
- Beam additions and column jacketing

Although column jacketing is an excellent cost-effective method, it only performs effectively in areas with limited seismic insufficiency.

Design Steps:

1. Calculation of thickness/depth of the slab

2. Size of drop
3. Loading Calculation
4. Total design moment calculation
5. Calculation of stiffness and α_c
6. Two–way shear check
7. Reinforcement along shorter and longer direction
8. Detailing

The design of a flat slab based on the given dimension is carried out according to IS 456:2000.

Some design constants have been recommended by IS 456:2000

"f_{ck} = 20 MPa, F_y = 415 MPa, $P_{t\,max}$ = 0.95"

1. Calculation of thickness/depth of slab: $Thickness = \dfrac{\text{Span}}{\text{26 x Modification factor}}$ + cover

2. Size of drop: It should not be less than one-third of the Span (whether longer or shorter)

3. Load:

Total Load = Self weight (dead load) + Finishing load + Live load + Partition Load (if present)

Self-weight = Length x Width X total Thickness x unit weight of concrete

Live load: as per IS 456:2000

Partition Load: Assumed as per IS 456:2000.

The design load is 1.5 times the total load.

4. Calculation of Moment: The absolute moment (Sum of negative and positive bending moment) (M_0) in every direction can be computed as:

$$M_0 = \frac{Wl_n}{8}$$

W indicates design load for a certain area l_2 ln

l_n – a clear span between faces of columns, capitals, and no less than 0.65 l1.

l_1 – span length in direction of M_0

l_2 – span transverse length to l_1

The design moment M0 must be spread in an interior span in the following ways:

Positive and Negative design moments: 0.35 and 0.65

The negative design moment of the exterior can be calculated as:

$$\frac{0.65}{1+\frac{1}{\alpha_c}}$$

Where α_c indicates the ratio of the flexural stiffness of the slab's "exterior columns" to the slab at a joint taken inside direction moments are being calculated and is denoted by

$$\alpha_c = \frac{\sum K_c}{K_s}$$

Check for shear:

Nominal shear stress $\tau_v = \frac{V}{b_0 d}$

Here V indicates a shear force resulting from design load,

b_0 denotes the critical section's periphery and

d signifies effective depth.

Reinforcement:

$$M_u = 0.87 f_y A_{st} d \left[1 - \frac{A_{st}}{bd} x \frac{f_y}{f_{ck}}\right]$$

A_{st} – an area of steel,

d – effective depth

f_{ck} – Characteristic compressive strength of concrete

f_y – Characteristic strength of steel

b – Width of column strip

The above calculations are summarised and detailings are tabulated.

In the summary, the grade of concrete, steel, the thickness of the slab, moment, the quantity of concrete, steel (%), area of reinforcement, etc. is mentioned.

Behavior and Performance of Flat Slabs under different conditions:

(a) Load – Multi – Storey Building under Seismic conditions

(b) Span

(c) Cost

Load: The following conclusions could be taken from the investigations conducted thus far by various researchers.

1) The lack of lateral stiffness in a flat slab building results in a worse seismic response than in a conventional building.

2) The placement of shear walls within a building has an impact on the “seismic response” of that structure. Since shear walls offer greater lateral “load resistance”, it is crucial to understand how flat slab buildings with shear walls behave and where they should be placed in the building.

From various studies and research, it has been concluded that storey displacement, as well as bending moment, are greater for a structure with a flat slab than for a standard two-way slab.

We need to know the different loads that are applied to the column to calculate the total load on the column, beam, and slab. The Column, Slab, and Beam configurations are typically found in frame-style structures.

The load is transmitted via the frame structure from “slab” to “beam” to “column” till it finally reaches the building's foundation. The following elements' loads must be determined for the building's load calculation:

Load on Column, Beam & Slab

- Walls load per running meter
- Number of floorsxColumn Self Weight
- Self-Weight Beams per running meter
- Slab’s total load(Live load + Dead load + Self–weight)

In addition to the aforementioned loads, the columns are also exposed to “bending moments”, which must be taken into account in the final design.

The volume of Concrete = length x width x thickness

Weight of Concrete = Volume x density

Steel Weight (1%) in Concrete

Total Column Weight = Weight of concrete+steel

The columns’ self-weight is estimated to be between 10 and 15 kN/floor when performing calculations for column design.

2. Beam Load Calculation

We suppose that every beam’s meter has measurements of (x and y mm) excluding “slab thickness”.

Suppose beam each (1 m) meter has a measurement of x and y mm excluding the slab.

Concrete Volume = x x y x 1 = xy m^3

Weight of Concrete = xy x ρ_c (ρ_c is the density of concrete)

Steel Weight (2 percent) in Concrete

Total Weight of Column = Weight of steel + concrete

As a result, the self-weight per running meter will be approximately 3.5 kN.

3. Wall Load Calculation

We are aware that bricks range in density from 1500-2000 kg/cubic meter.

For a brick wall that is six inches thick and three meters high with a one-meter length,

The running/load meter is assumed to be equivalent to 0.150x1x3x2000=900 kg, or 9 kN/meter.

The weight/cubic meter ranges from 550-700kg for aerated concrete as well as autoclaved concrete blocks, such as Siporex or Aerocon.

4. Slab Load Calculation

Each square meter of the slab's self–weight should be determined by its length x width x density of concrete. Now, if the finishing load is set at 1kN per meter and the overlaid live load is set at 2kN per meter.

5. Safety Factor

As Per IS 456:2000, the factor of safety is 1.5.

One of the crucial components of every construction structure is a column. The building's column size is determined by the weight that the superstructure will impose on each column.

The column size is raised for buildings under extreme weight situations. When developing any architectural construction, the size of the columns is a crucial consideration.

Variations in column sizes are employed in building design,

9" x 9"; 9" x 12"; 12" x 12"; 15" x 18"; 18" x 18"; and 20" x 24"

More sizes could be employed following the structural load.

We needed the following information to calculate the column size:

(a) Concrete Grade (b) Steel Grade and (c) Factored Load on Column

(Note: The column's minimum size must not be below 9′′x9′′(230x230 mm).

To determine the column's size for the building, perform the following column design calculations.

"$Pu = 0.4\ f_{ck}\ A_c + 0.67\ f_y\ A_{sc}$ (Clause Number: 39.3 Page Number: 71 IS 456:2000)

f_{ck} = Characteristics compressive strength of concrete

A_c = Area of Concrete

f_y = Characteristics Tensile strength of concrete

A_{sc} = Area of Steel Reinforcement

Pu = Axial Load on Column

$A_c = A_g - A_{sc}$

$A_{sc} = 0.01\ A_g$

$A_c = 0.99\ A_g$

Here A_g = Column's Gross Area

Consider 1 percent of Steel in Column,

$A_c = A_{g} - A_{sc}$"

How do you determine a beam's slab load?

The slab typically measures 125 mm thick. As a result, the slab's thickness and the concrete's per-square-meter load, which is anticipated to be roughly 3 kN, would be the formula for the self-weight of the slab's every square meter. The overall slab load will be in the range of 6-7 kN/square meter when the finishing load and superimposed live load are taken into account.

Load Calculation of Building (As per IS 456:2000)

The dead, living, wind, as well as snow loads, are added together to form the building load when a building is located in a snowfall area. Long-lasting static forces are referred to as dead loads. They can be compressed or in strain. The majority of live loads are varying or shifting loads. These loads might be very dynamic and may consider parameters such as fluid slosh dynamics, vibration, momentum, impact, and so on.

Dead Loads

Dead loads must be computed using unit weights that are determined while taking the materials required for construction into account. As an alternative, the dead loads might be examined using the material unit weights from IS 875. (Part 1). The plain concrete's unit weights and reinforced concrete built with crushed natural stone aggregate or sand and gravel may be used as estimates until more precise calculations are necessary.

24 and 25 kN/m^3 respectively.

Imposed, Wind & Snow Loads:

These loads must be following IS 87S (Part 2), IS 87S (Part 3), and IS 875 (Part 4) respectively.

Earthquake Forces

The IS 1893 standard must be followed in calculating the earthquake forces.

Span: The slab's thickness varied between 70, 80, 90, and 100mm. As thickness increased, deflection for a corner, as well as penultimate column failure, decreased. Additionally, it has been shown that for the same weight, the deflection in the corner column failure scenario was lower than that in the penultimate column failure condition.

Numerous investigations revealed that the deflection for a corner as well as penultimate column failure cases increased as slab length increased. Additionally, it has been noted that for the same weight, the deflection in the "corner column failure" scenario is lower than that in the "penultimate column failure" situation (**K, Senthil et al 2018**)[11].

Cost: A function that should be reduced is the materials cost (steel and concrete reinforcement) and the formwork. The slab's overall cost could be presented as follows:

"$C = C_c \times (Q_c) + C_S \times (W_S) + C_f \times (A_f)$"

Here,

C_c denotes the concrete cost/unit volume

Q_c indicates the concrete volume

C_S signifies the steel cost/unit of mass

W_S denotes the steel's weight

C_f represents the formwork cost/unit area

A_f signifies the form's surface area

C indicates the total cost function

The following cost function may be used to demonstrate the impact of the unit costs of the steel and concrete:

$$\frac{C}{C_S} = \frac{C_C}{C_S} \text{ x } Q_C + W_S + \frac{C_f}{C_S} \text{ x } A_f$$

It is concluded from the relation that the rising of the ratio $\frac{C}{C_S}$ leads to reducing the entire slab cost, with the reduction in the material cost ratio having little impact on the slab's effective depth.

The cost function may be constructed in the following manner to analyze the impact of formwork cost on the ideal solution:

$C = C_C \times Q_C + C_S \times W_S$

the optimum ratio of the slab's total cost, including formwork costs, to the slab's total cost, excluding formwork costs.

Conclusions:

Buildings with flat slabs have several benefits over those with slab-beam-columns, including lower floor heights, quicker construction times, architectural functionality, and cost-effectiveness. But while beams are not needed in flat slab buildings because columns support the slab directly, shear walls are necessary to stiffen the structure against lateral stresses. Among the most often utilized lateral "load-resisting" systems in "high-rise buildings" is the shear wall system. These walls are extremely strong and rigid in the plane. To determine what changes will take place if the height of both flat slab buildings and typical RC Frame buildings increases, it is required to examine the buildings' seismic behavior for a range of heights.

- Sway increases as the number of levels rises
- The highest sway occurs at the terrace level for both types of buildings.
- When compared to a traditional R.C.C. structure, storey drift (also known as Sway) is substantially more common in flat slab buildings. This leads to the development of more moments. Therefore, the extra moment brought on by drift should be considered while designing the columns of such buildings.
- Compared to flat slab buildings, typical R.C. framed buildings have a higher base shear.
- Base shear in a flat slab rises steadily for the first three stories, after which it rises relatively slowly. And in a traditional R.C. frame, it rises to 6 levels before gradually falling.

Bending moment and shear force are comparably greater in traditional slab buildings, but the axial force on the column caused by all load combinations is almost the same in buildings.

The flat slab has a greater shear force as well as bending moment when evaluated to the grid slab and 2-way slab.

Therefore, flat slab constructions improve from an aesthetic point of view and provide the architect with a great degree of formwork flexibility, air pipes, open space for water, ease of casting concrete, ease of placing flexural reinforcement, etc. The lowering of the building height of multi-storey constructions by preserving one storey height etc. between the slab and a potential furred ceiling.

This results in the Flat slab being more cost-effective as compared to traditional and Grid slabs. These structures are the greatest choice for high-rise buildings compared to Grid Slab and traditional slab structures.

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