Design Considerations for Reinforced Concrete Flat Slab Floor System

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ABSTRACT
Flat slabs are highly versatile elements widely used in construction, providing minimum depth, fast construction and allowing flexible column grids. Common practice of design and construction is to support the slabs by beams and support the beams by columns. Here large Bending Moment & Shear Forces are developed close to the columns. These stresses brings about the cracks in concrete & may provoke the failure of slab, thus there is a need to provide a larger area at the top of column recognized as column head. The purpose of this paper is to present the use of flat plate/slab construction in India followed by a review of design methods for flat plate/slab structure designs based on Indian Standard 456:2000[1] and American Concrete Institute ACI-318[2]codes.

Keywords—flat slabs, flat plate floors, IS codes, post tensioned slabs

I. INTRODUCTION

A flat slab consists of a reinforced concrete slab that is directly supported by concrete columns. ***C.A.P. Turner*** constructed flat slabs in U.S.A. in 1906 mainly by conceptual ideas, which was the origin of this type of construction. Later in 1914, ***Nicholas*** proposed a method of analysis of flat slabs based on simple statics. This method is used even today for the design of flat slabs and flat plates and is known as the direct design method. Structural engineers commonly use the equivalent frame method with equivalent beams such as the one proposed by ***Jacob S. Grossman*** in practical engineering for the analysis of flat plate structures. They are generally employed for architectural reasons for large rooms such as auditoriums, vestibules, theatre halls, show rooms of shops where column free space is often the main requirement. Flat slabs are used mainly in office buildings due to reduced formwork cost, fast excavation, and easy installation. Many works and studies have been carried out on flat slabs and yet for Indian constructions the more refined works are needed by the researchers. Flat slabs are basically used for introducing more head rooms to the floors and to give better appearances for interiors. Major components of flat slab are capital/head, drop panel, columns strip and middle strips.

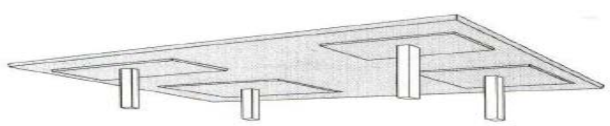


Fig.no.1 general view of flat slabs

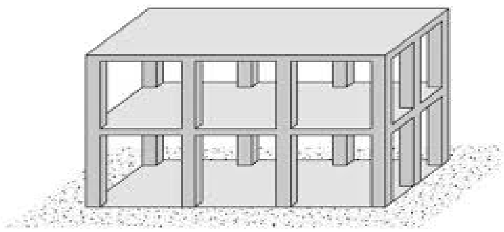


Fig 2: Typical flat slab floor

Architectural demands for **better illumination**, lesser fire resistance of sharp corners present in the form of beams & increase in the formwork cost, **optimum use of space** leads to the new concept in the field of structural engineering as Reinforced concrete flat slabs.

Fig 3: Aesthetic appearance of flat slab floor

II.LITERATURE REVIEW

Mostly among all available literature and experimental work is based on the analytical parts of flat slab floors .Seismic response of flat slab building has been a subject of discussion since many decades. A lot of research work has taken place in this field addressing all relevant issues pertaining to the modeling, analysis and construction of flat slab structures.

Park *et al*. (2008) found that Equivalent Frame method is not appropriate in accurately predicting the response of two-way slab systems under lateral loads. Currently design code, ACI 318-05[2.1] permit the EFM for the analysis of two-way slab system under gravity loads and lateral loads such as seismic loads.

Subramanian (2005) found that to increase the punching shear strength of flat slab, the shear reinforcement is found to provide economical solution. They not only enhance the shear capacity but also result in flexural failure of the slab and thus increasing the ductility of flat slab, which is very important in earthquake prone zone.

Meghally and Ghali (2005) have proposed the value of the unbalanced moment to be used in punching shear design.

Kim and Lee (2005) proposed an improved analytical method that can consider the stiffness degradation effects in the slab depending on the lateral drifts using super element for the efficient and accurate analysis of flat slab structure. The major observations and findings could be summarized as follows.

Structural analysis of the flat slab structure having irregular plan or slab with openings can be performed and stress distribution of floor slab can be easily represented by finite element method if the stiffness degradation could be considered properly

Corley and Jirsa (1970) first developed "Equivalent Frame Method (EFM)" for design of all types of slab system in 1970. This method had no limitation like direct design method. They compared the moment calculated by EFM with those measured in test slab and the moment shown the satisfactory agreement. They provided the list of constants for calculating stiffness, fixed end moments and carry over factor for beam element.

Dovich and Wight (2005) developed an effective slab width model to describe the lateral behavior of the reinforced concrete flat slab frame with in a two dimensional non linear frame analysis.

Hwang and Moehle (1993) carried out an experimental study on nine panel model having a slab supported without beams, drop panels, slab shear reinforcement. A part of the slab was designed for gravity and wind load in accordance with ACI 318-83.

III. DESIGN OF THE FLAT SLAB STRUCTURES

Classification of Flat Slab

a) Based on structural design

1. Conventional reinforced flat slabs and

2. Post tensioned flat slabs

b) Based on the components of slab

1. Slabs without drop and column head.

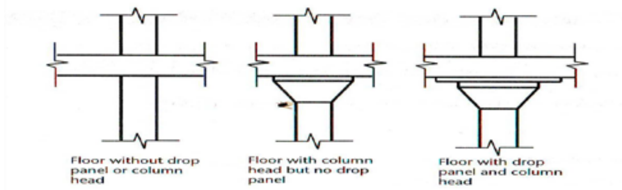
2. Slabs without drop and column with column head.

3. Slabs with drop and column head.

IS 456:2000 codal Recommendations for Proportioning Flat Slab

1) Thickness of flat slab: - The thickness of flat slab shall be generally controlled by considerations of span to effective depth ratio.

2) Drops: - The drops when provided shall be rectangular in plan, and have a length in each direction not less than one third of the panel length in each direction. For exterior panels, with drops at right angles to the non continuous edge



and measured from centre line of the columns shall be equal to one half the width of drop for interior panels.

Fig.3 connections of flat slab floor and column

Column heads: - When column heads are provided, that portion of column head which lies within the largest circular cone or pyramid that has vertex, angle of 90 and can be included entirely within the outlines of the column and the column head, shall be considered for design purposes.

The following is a discussion of the process of designing flat plate/slabs to meet Indian codes. Limitations in the Indian codes IS 456:2000 are overcome by utilizing ACI-318. for Maintaining the Integrity of the Specifications

General Considerations for use of Flat slab Floor System

The following are the main factors to be considered before adopting the use of the concrete flat plate with steel/concrete column system

1. Spacing of columns

2. Long term deflection of the flat plate

3. Punching shear checks at column areas.

Steps involved in the design of flat slab structures

1) Framing system
2) Engineering analysis

3) Reinforcement design and detailing

Framing system

Initial framing system formulation provides a detailed geometric description of the column spacing and overhang. Architect provides this part of the design; the engineer should emphasis on the following:

• Three continuous spans in each direction or have an overhang least one-forth times adjacent span length in case of only two continuous spans and

- Typical panel must be rectangular and
- The spans must be similar in length i.e. adjacent span in each direction must not differ in length by one-third

Engineering Analysis

Flat plate/slab may be analyzed and designed by any method as long as they satisfy the strength, stiffness and stability requirements of the IS 456:2000 or ACI-318 codes. A typical flat plate/slab can be analyzed by **direct design method** or **equivalent frame method** as prescribed by the code. However, if the flat plate/slab is a typical one with unusual geometry, with irregular column spacing, or with big opening then the designer can use finite element method model analysis using various soft ware. The design of flat slabs irrespective of the methodology used must first assume a minimum slab and drop thickness and a minimum column dimension to ensure adequate stiffness of the system to control deflection. The IS 456:2000 code is not clear on these minimum conditions. However ACI specifies empirical formulae to arrive at these minimums. Critical reactions for the load combinations are used for the design of the supporting columns and foundations.

Seismic Design of Flat Plate/Slab

Seismic design lateral force is based on the provisions of Indian Standard IS 1893 (Criteria for Earthquake Resistant Design of Structure), however of IS1893 is not clear about it. Hence a designer, in addition may use, other codes like UBC-2000 (Uniform Building Code) to design an effective floor system. As per these codes a common practice is to determine lateral force by considering either of static or a dynamic procedure. In this paper seismic design is not discussed.

REINFORCEMENT DESIGN AND DETAILING

Reinforcement design is one of the critical parts of flat plate/slab design; maximum forces from the analysis shall be used in the design of the reinforcement. Reinforcement required for flexure by using minimum slab thickness per table 1 typically will not require compression reinforcement. The tension steel area required and detailing for appropriate strips can be as per IS 456:2000 or ACI-318, both being similar. However design for punching shear force (including additional shear due to unbalanced moment) per IS 456:2000 is 32% conservative compared to ACI-318, because Indian code underestimates the concrete two-way shear strength by 32% compared to ACI. Design of Flat slab by Direct Design Method has some restrictions that (a) It should have minimum three spans in each direction.(b) It must not have staggered column orientation Hence many a times Equivalent Frame Method is adopted.

All the Negative & Positive moments are distributed in the column strips & Middle strips respectively using equivalent codes. IS 456-2000 gives Distribution of moments across panels for Exterior and interior Slab .whereas ACI 318 also gives distribution table for moments. According to design considerations these codal provisions must be used.

IV. POST-TENSIONED FLAT PLATE/SLAB

Post-tensioned flat plat/slabs are a common variation of the conventional plate structure where most of the reinforcement is replaced by post-tensioned strands of very high strength HYSD steel. The structural advantage of post tensioning over conventional RCC is that the slab is nearly crack- free at full service load. Pictorially it can be shown as in the figure 4.

Fig.4 post tensioned flat slab

This leads to a smaller deflection compared to conventional RCC because of the higher rigidity of the un-cracked section. Hence reduction in thickness of the slab compared to conventional RCC is the rationale for using post-tensioning system for spans over 10m and above. Further the lack of cracking leads to a watertight structure. Flat plat/slab design and build contractors in India claim a nearly 15to 20%cost reduction. But many practical considerations have shown that theoretical cost reduction is not possible practically resulting in high cost of post tensioned flat slab constructions.

V. CONCLUSIONS

Flat plate/slab construction is a developing technology in India Flat slabs has many advantages over conventional slabs and hence it can be a very good option for modern constructions demanding structural stability and state of art aesthetic aspects and prospects. Flat plate/slab can be designed and built either by conventional R.c. or post-tensioning. However, due to issues mentioned above with post- tensioning construction in India and its higher cost, conventional R.c design should be the preferred choice for spans up to 10 meters. Design of conventional R.c. flat plate/slab in India, utilizing Indian codes, has many shortcomings, which have to be addressed and revised soon.

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