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Behaviour of Flat Slab a Study by Finite Element Analysis

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ABSTRACT: Flat slabs system of construction is one in which beams are absent. In this type of the slab, load from the slab is directly transferred to the columns and then to the foundation i.e. the slab is directly supported on columns. As there is no beam present, the thickness of slab near the support of the column is increased to support heavy loads. This increased thickness of the slab near the column is called as drops. The columns generally provided with enlarged heads called column heads or capitals are also used as an alternative. And sometimes due to more punching shear both drop as well as column capital is provided together. Due to ease of construction and its minimum depth, flat slabs have been widely used in the construction of buildings. A plain ceiling is formed due to the absence of beam, thereby giving a better architectural appearance. Plain ceiling diffuses light better, easier to construct and requires cheaper formwork.

Though many advantages, flat slab faces a major problem of punching shear. The brittleness of punching shear makes it the concern of structural engineer since it does not give any warning before failure. Hence in this research work, the behaviour of punching shear in the flat slab with drops, column capital, both drop & column capital together, grade of concrete and shear stud rails has been studied. Different models of the flat slab are analysed by Finite Element Analysis method using SAFE 2016. The punching shear behaviour has been studied and comparison among them has been done. However, the analysis of such a connection is rather complex and includes several challenges. Consequently, the punching strength depends on various parameters that have to be investigated individually.

Slab failure if predetermined can save the loss of lives, a proper analysis can help in proper designing which can enhance the performance of the structure.

KEYWORDS: Flat Slab, Punching Shear, Flat plate, Shear Strengthening.

I. INTRODUCTION

The flat slab is generally a type of two-way reinforced concrete slab in which the flooring slab is directly supported on columns without the agency of beam or girders. For span from 5 to 9m thin flat slabs are the preferred solution for the construction of in-situ concrete frame building, where a square or near square grid is used. Due to ease in construction and for the architectural view, flat slabs have been widely used in the construction of buildings. Though many advantages, flat slab faces a major problem of punching shear force acting at the slab-column junction. The punching shear force at the slab-column junction increases in this type of slab due to the transmission of vertical loads to the columns through the small thickness of slabs.

Punching failure forms up due to the transmission of vertical loads to the columns through the small thickness of slabs. Punching shear failure occurs with no warning signs due to the small deflection capacities and hidden cracks on the top side of the slab. A local punching shear failure in a single flat slab-column connection results in amplified shear forces on the neighbouring flat slab-column connections and may trigger the progressive punching shear failure of the neighbouring flat slab-column connections causing the total collapse of the complete structure. Accordingly, to prevent brittle and abrupt punching shear failure, some major precautions must be taken during the design process of the structure. The punching shear capacity of a flat slab-column connection may be improved by using a larger column dimension, a thicker slab, by providing more flexural reinforcement, using concrete with higher compressive strength or using additional shear reinforcement. However, in some cases, such techniques may not be the best option in relation

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to the economical and architectural concerns. In such situations, placing shear reinforcement in the intersection of the flat slab-column system is a good solution to the brittle punching shear failure problem[5,2]. Nonlinear finite element analyses of reinforced concrete slab-column connections under static and pseudo-dynamic loadings were conducted to investigate their failure modes in terms of ultimate load and cracking patterns[1]. Finite-element analyses (FEA) of reinforced concrete slab-column connections with shear reinforcement are presented and discussed. Ultimate loads and crack patterns are shown and compared to the experimental findings[2]. To date, a significant number of investigations have been conducted on strengthening existing slab to column connections for internal columns. The research investigates the effectiveness of strengthening flat slab to column corner connections by using carbon fibre reinforced polymer (CFRP) bolt[4]. A strengthening of flat slabs using steel bolts can also be done[11].

II. SPECIMEN DETAILS AND MATERIAL PROPERTIES

A flat slab model of having four bay in both the direction is considered which resembles with most of the commercial buildings. The slab is directly rested on column have the thickness of slab as 250mm. The size of the column is taken as 0.6m x 0.6m. The size of each slab-panel is 8m x 8m. The plan view of the model is given in Fig. 1. To ensure that punching shear takes place, no column capital nor drop panel is provided and nor any shear strengthening is done. The design of the Flat slab is done using CSI software SAFE2016 by Finite Element Method. Dead load of 6.25kN/m² and live load of 4kN/m² floor finish of 1.5kN/m² and partition of 2kN/m² is applied on slab and factor of safety of 1.5 is applied to the total load. Thus, the total factored load applied on the slab is 20.625kN/m². The clear cover of 15mm is provided at the bottom face as well as at top face of the slab. The grade of concrete used are M20, M25, M30 and grade of steel used is Fe415. Total 7 models are designed and analysed.

Table No. 1: Specimen details

Model	Detail Of Specimen	Drop Size	Head Size	Grade Of Concrete
I	Control Specimen	-----	-----	M20
II	With thickness 450mm	-----	-----	M20
III	With Drop Panel	2.66x2.66x0.45	-----	M20
IV	With Column Head	-----	1.2x1.2x0.6	M20
V	With Drop Panel & Column Head	2.66x2.66x0.45	1.2x1.2x0.6	M20
VI	With M25 Concrete	-----	-----	M25
VII	With M30 Concrete	-----	-----	M30

Table no. 1 contains the detail of the specimens used in this paper. Model I is the control specimen used as a reference of all Models. And other 6 models of varying thickness and grade of concrete are used. The size of the slab panel is kept constant for all models. Only the depth of the slab and grade of concrete is varied.

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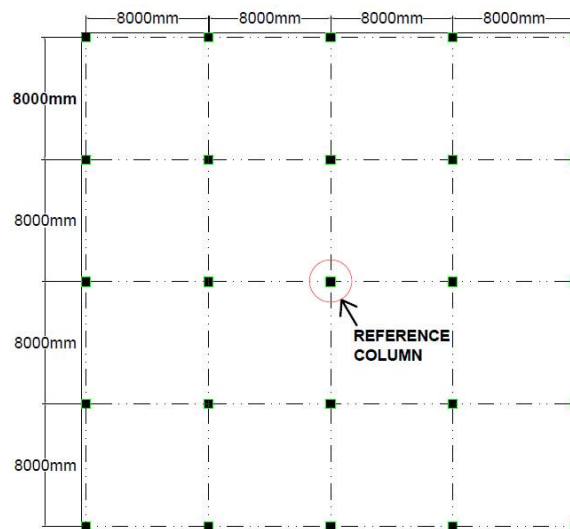


Fig. 1: Plan view of the model

The drop of 2.6x2.6m and depth of 450mm is provided in the 2nd model. The column head of dimension 1.2x1.2m and depth of 600mm is provided in the 3rd model. In the 4th model, both drop panel, as well as column head, provided together. In the 5th model, we use the M25 grade of concrete and as well as the depth of slab is also increased. And in the last model, we use the M30 grade of concrete. For overcoming the punching shear we use the FE415 models. All the model has been analysed in finite element analysis based software SAFE 2016.

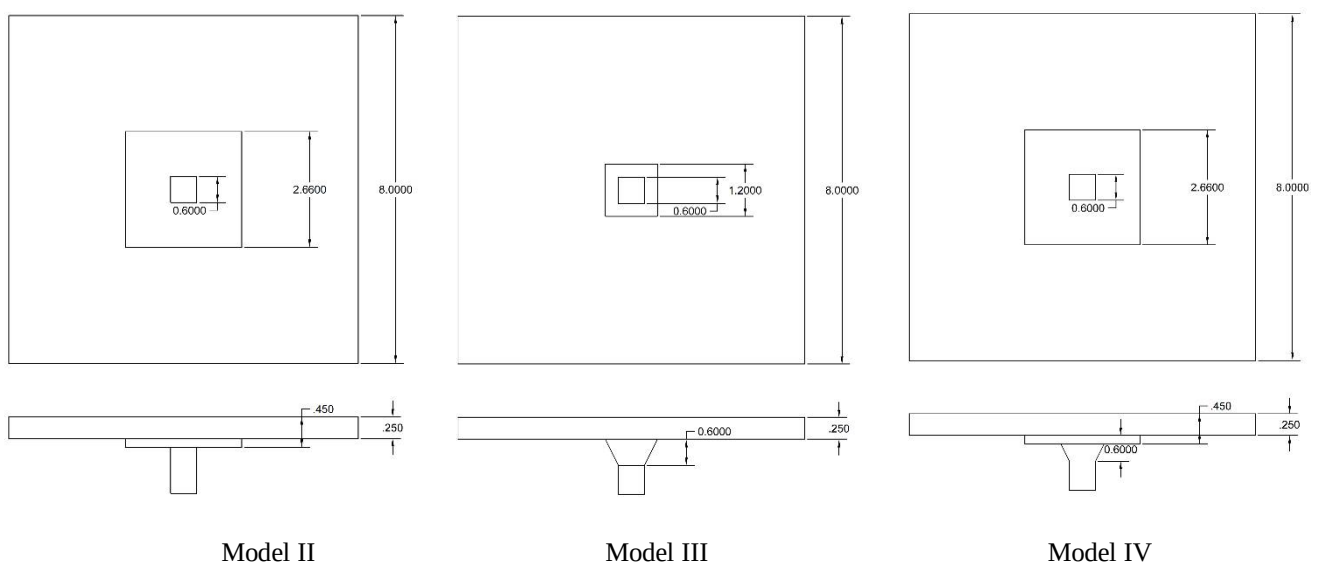


Fig. 2: Schematic Representation of Models

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III. NUMERICAL ANALYSIS

A three-dimensional finite element based program 'SAFE' is used for the numerical analysis of seven flat slab models, one of them as control specimen and other models with different arrangements. In this analysis, the material is defined as M20, M25, M30 for the grade of concrete and Fe415 as the grade of steel. All the seven case are modelled and analysed by using the 'Automatic slab mesh option' for the meshing of the slab. Minimum reinforcement ratio use for cracking is 0.12% as per IS 456. Since CSI SAFE is a designed based software the model/structure will not fail until the maximum percentage of steel reached the maximum permissible limit as per IS 456 i.e. 8%. Thus, in this software depending upon different arrangements the percentage of steel and the deflection is affected for all the seven case. Due to different arrangements the designed shear stress in the structure increases which results in the increment of punching shear ratio, where, punching ratio is,

$$\text{Punching Shear Ratio} = \frac{\text{Maximum Designed Shear Stress}}{\text{Shear Stress Capacity}}$$

The shear stress capacity of the concrete is 1.118 N/mm^2 for M20 and 1.25 N/mm^2 for M25 and 1.3693 N/mm^2 for M30. The shear stress capacity depends upon the grade of concrete and the shear reinforcement provided. And the design shear stress i.e. nothing but punching shear depends on the grade of concrete, depth of concrete at that location and shear reinforcement. Since the punching shear changed by using different arrangements in this paper, the shear stress capacity is only due to concrete.

For, Punching Shear ratio ≤ 1 (Implies the Structure/Model is safe)

Punching Shear ratio > 1 (Implies the Structure/Model fails in punching)

Depending upon above relation the following studies has been done.

IV. EFFECT ON PUNCHING SHEAR

Depending upon the load applied, the punching force varies abruptly. Punching shear occurs when the design/maximum shear stress at a point is more than shear stress capacity at the same point. Generally, the punching shear occurs due to localized forces. Since punching shear is a type of brittle failure the failure in the structure is sudden so it is more important to design the structure within permissible shear stress capacity.

Table No. 2: Results Comparison

Model	Detail Of Specimen	Punching Shear Ratio	% Reduction In Punching Shear Ratio w.r.t Model I	% Reduction in deflection w.r.t Model I	% Top AST Changes w.r.t Model I	% Bottom AST changes w.r.t Model I
I	Control Specimen	1.56	0	0	0	0
II	With thickness 450mm	0.88	43.58	75.53	-25.96	-34.87
III	With Drop Panel	0.67	57.05	55.74	-19.95	-29.89
IV	With Column Head	0.86	44.87	0.85	+23.05	-2.09
V	With Drop Panel & Column Head	0.4	74.35	55.74	-19.75	-29.89
VI	With M25 Concrete	1.39	10.89	10.54	+1.48	-1.39
VII	With M30 Concrete	1.27	18.58	16.63	+2.05	-2.185

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Total 7 models have been analysed by finite element analysis using CSI software SAFE 2016 for the loading condition as per IS 875. It is observed that for this loading condition the punching shear capacity is very low since only flat slab plate of thickness 250mm is provided. In order to increase punching shear capacity so that structure should be safe, the depth of slab needed to be increased. The depth of slab required is 450mm in order to be safe in punching. Though the structure is safe in punching, the economy of the structure is highly affected. From above observation, we have noticed that the depth of 450mm of the slab is required at a slab-column junction only for increasing punching shear capacity. Hence in model III & IV, the punching shear ratio was calculated by providing drop panel & column head respectively. And the result obtained was positive i.e. punching shear capacity is considerably increased.

So in model V both drop panel, as well as column head, are provided together. And thus it shows the drastic change in punching behaviour of flat slab i.e. the punching shear is reduced to 74%. Which is the most effective & economical in this case. Thus model V should be used in critical cases. Further, the effect of the grade of concrete is also studied using M25 and M30 grade of concrete then the result shows the punching shear capacity of structure increase with respect to grade of concrete but the increase in the punching shear capacity is in the small amount. So this shows that the effect of drop panel with column head gives the much better results compared to other models.

From the result it was observed that for the specimen with both drop panel and column head together, the punching shear reduced drastically also it was observed the required percentage of steel was also reduced by 19.75%.

VI. CONCLUSIONS

This paper represents a numerical analysis of flat slab with different models. Without providing any shear reinforcement the results were obtained for all the seven cases so that the effect of depth on concrete & grade of concrete in the flat slab can be studied and compared among themselves. Based on the numerical results and discussions, the following conclusions are drawn,

- i. The punching shear capacity of flat slab depends on the depth of flat slab at the slab-column junction.
- ii. The grade of concrete also affects the punching shear but in the small amount.
- iii. The depth of slab is inversely proportional to the deflection in slab i.e. as the depth of slab increases the deflection decreases.
- iv. The area of steel in the flat slab is inversely proportional to the depth of slab i.e. with an increase in the depth of slab, the area of steel required decreases.
- v. The design punching shear is low in which both column drop and column head are provided together.
- vi. It was observed that by increasing the depth of slab near slab column junction i.e. in punching area the punching capacity can be increased so there is no need to provide more depth throughout the section. Hence for optimisation purpose the more depth of slab is provided at punching area only.

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