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Redistribution of Punching Shear in Flat Slab with Opening

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ABSTRACT: The type of slab in which the flooring slab is directly supported on columns without the agency of beam or girders is known as flat slab. These flat slabs may have openings for various reasons such as stairways or elevators, electricity, water, the transition of gas and duct for air-conditioning systems, etc. Due to the opening, the discontinuity occurs in load distribution, which results in unbalanced bending moment and shear force, the punching shear strength also gets considerably affected. Effects of these openings on the punching shear behaviour of flat slab-column systems must be examined carefully since this punching shear failure is a sudden failure and this may lead to the failure of whole structure. The punching shear failure must be examined and the design must stay on the conservative side for safety purpose. In order to provide the required safety, the flat slab-column systems with openings must be fitted with the suitable method at the time of construction itself to avoid failure.

The objective of this study is twofold - the size of the opening and secondly, the location of the opening in a flat slab. In this paper, 9 different models/specimens have been studied in which 8 models have an opening of size 1.2m x 1.2m and 2m x 2m at 0.6m and 1.6m from the column. Openings are placed parallel to the face of the column and diagonal to the face of the column. And 1 model is the control specimen without opening. All these models are analysed by Finite Element Analysis-based software SAFE 2016.

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

I. INTRODUCTION

The flat slab is 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 of construction and minimum depth, flat slabs have been widely used in the construction of buildings[1]. Though construction of this type of slab has a lot of benefits, it also has disadvantages. The major disadvantage is, the 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[2-5].

These flat slabs may have openings for various reasons such as stairways or elevators, electricity, water, the transition of gas and duct for air-conditioning systems, etc. Due to the opening, the discontinuity occurs in load distribution. Which further results in unbalanced bending moment and shear force, the punching shear strength also gets considerably affected[6,7]. Since flat plate slab is already vulnerable to punching shear, opening in such slab may cause great effect on the design parameters of the flat slab. So effects of these openings on the punching shear behaviour of flat slab-column systems must be examined carefully due to the vulnerability of such systems to brittle and abrupt punching shear failure[8-10]. The punching shear failure must be examined and the design must stay on the conservative side for safety purpose. Effects of these openings on the punching shear behaviour of flat slab-column systems must be examined carefully[11,12].

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II. SPECIMEN DETAILS AND MATERIAL PROPERTIES

A flat slab model of having four bay in both the direction is considered which represents typical arrangement in commercial buildings. The slab is directly rested upon column have the thickness of slab as 250mm. The size of column is taken as 0.8m x 0.8m. 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 panned is provided and neither any shear strengthening is done. The design of the Flat slab was done using CSI software SAFE2016 by Finite Element Method. Dead load of 6.25kN/m^2 and live load of 3.5kN/m^2 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 14.625kN/m^2 . 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 is M20 and grade of steel used is Fe415. Total 9 models are designed, out of which 8 models have an opening of different sizes at the different location and 1 model is the control specimen without opening. Also, for the ease of understanding the concept better, the imaginary strips are plotted known as column strip and middle strip is used. Column strip is $0.25L_x$ on both side of column centre line where L_x is the length of span in the X direction. And middle strip means the strip bounded on each of its opposite sides by column strip. Similarly, the strip in Y directions is plotted.

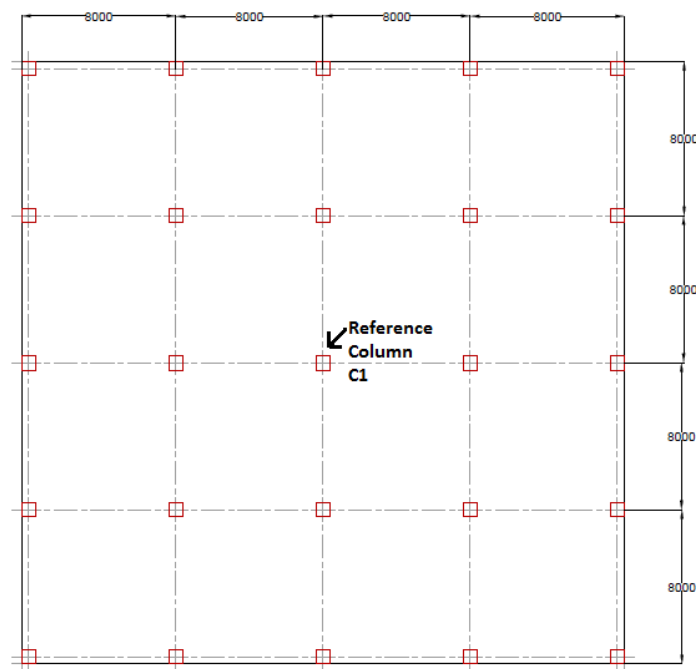


Fig. 1: Plan view of the model

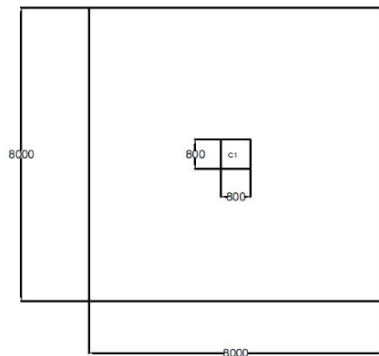
The square opening of size 1.2m x 1.2m and 2m x 2m is provided at the various location near reference column C1. Fig. 2 shows the diagrammatic representation of the size and location of the opening in specimens.

International Journal of Innovative Research in Science, Engineering and Technology

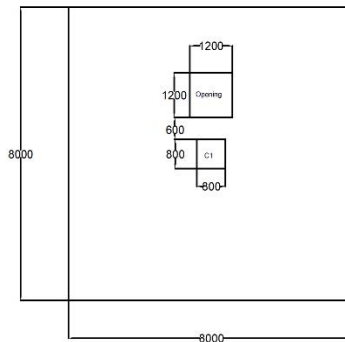
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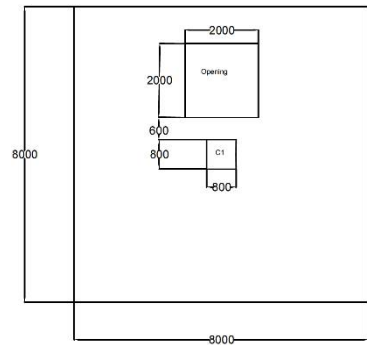
Vol. 7, Issue 3, March 2018



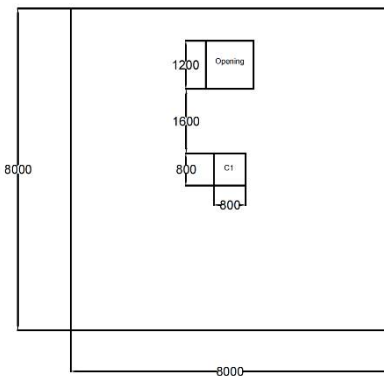
Case I



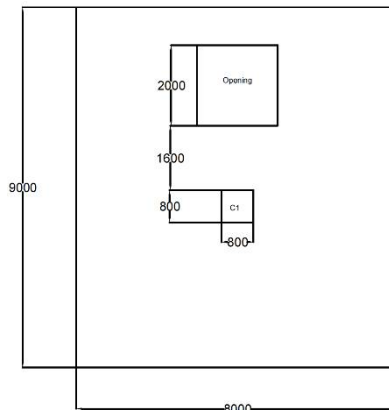
Case II



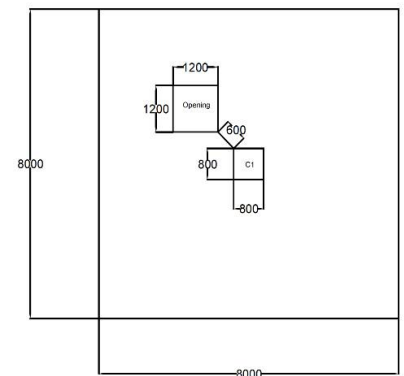
Case III



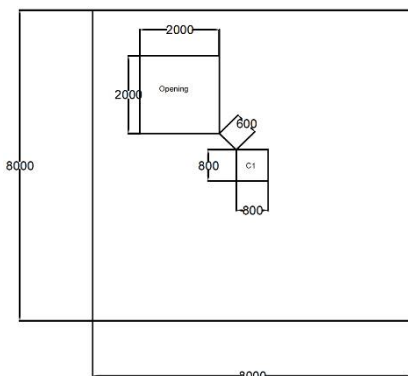
Case IV



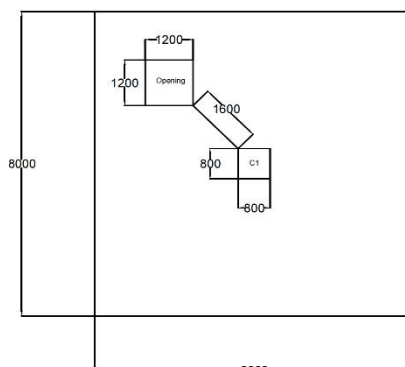
Case V



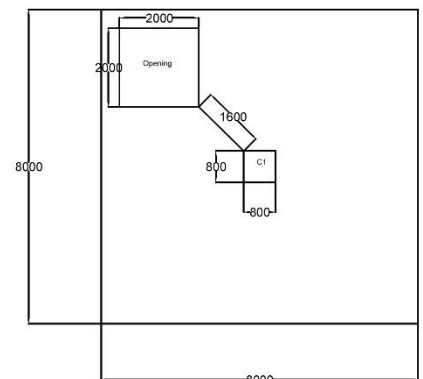
Case VI



Case VII



Case VIII



Case IX

Fig. 2: Opening layout scheme of models. (Dimensions in mm)

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 7, Issue 3, March 2018

Table no. 1 shows details of specimen, specimen 1 show the control model without opening and other eight models have opening of different size at different location as per denoted in Fig. 2. The different size and location of opening help to understand the behaviour of discontinuous flat slab.

Table No. 1: Model Specification Details

Case	Direction	Distance	Opening Size
I	Control Specimen	-	No opening
II	Parallel to Column Face	0.6m	1.2m x 1.2m
III	Parallel to Column Face	0.6m	2m x 2m
IV	Parallel to Column Face	1.6m	1.2m x 1.2m
V	Parallel to Column Face	1.6m	2m x 2m
VI	Diagonal to Column Face	0.6m	1.2m x 1.2m
VII	Diagonal to Column Face	0.6m	2m x 2m
VIII	Diagonal to Column Face	1.6m	1.2m x 1.2m
IX	Diagonal to Column Face	1.6m	2m x 2m

III. NUMERICAL ANALYSIS

A three-dimensional finite element program 'SAFE' is used for the numerical analysis of nine flat slab models, one of them as control specimen (without opening) and remaining eight model with the opening of varying size and location of the opening. In this analysis, the material is defined as M20 for the grade of concrete and Fe415 as the grade of steel. All the nine 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 size and location of opening the percentage of steel is affected and the deflection is constant for all the nine case. Due to opening 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 1.118N/mm^2 . The shear stress capacity depends upon the grade of concrete and the shear reinforcement provided. Since no shear strengthening is done 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)

IV. EFFECT OF OPENING IN FLAT SLAB

The path from which the loading is transferred from slab to column is known as 'load-path'. Providing an opening in flat slab discontinues the natural load path of the structure due to which the load carrying capacity of the structure decreases. Or in other words, it can be said that to regain its original load carrying capacity additional strengthening of the structure is required to be done. Table no. 2 shows the result obtained from CSI SAFE software. In control specimen (i.e. Case I) the designed shear stress is less the shear stress capacity of concrete near column C1, thus

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Vol. 7, Issue 3, March 2018

the control specimen is safe. For all other cases, an opening of the different size and at the different location is provided, which resulted into the increase of designed shear stresses near column C1. It is also noted that there is an insignificant change in the punching shear capacity of all other columns. From the results, it can be noted that the punching shear capacity is directly proportional to the distance of opening from the column. As the distance between the opening and the column face decreases, the punching shear capacity also decreases.

Table No. 2: Punching Shear Capacity of the specimens.

Case	Punching Shear Ratio at column C1	The percentage decrease in Punching shear capacity with respect to Case I	Percentage increase in reinforcement with respect to Case I	
			At Top Face	At Bottom Face
I	0.9181	-	-	-
II	1.1294	23.02%	11.58%	18.57%
III	1.3512	47.17%	16.16%	57%
IV	1.0203	11.13%	1.2%	62.22%
V	1.0638	15.87%	0.32%	71.42%
VI	1.2917	40.69%	45.66%	23.07%
VII	1.1607	26.42%	41.55%	30.7%
VIII	1.1316	23.25%	22.22%	38.46%
IX	1.1634	26.72%	20.55%	46.15%

From the result it is also noted that, the location of opening plays an important role in defining the requirement of steel in the structure. For the opening situated in the column strip, the requirement of reinforcement at top increases considerably (1), whereas for the opening situated in the middle strip, the requirement of reinforcement at bottom increases considerably(2). Also, it is noted that irrespective of the size and location of opening there is always increase in reinforcement at the bottom face. This is due to the flexural behaviour of the slab(3).

So, the total increment in reinforcement for opening in column strip is a combination of: (1) + (3)

and the total increment in reinforcement for opening in middle strip is a combination of: (2) + (3)

Thus, for all the opening in column strip, there is an increment of reinforcement in the top as well as in bottom. Whereas for the opening in middle, there is an increment of reinforcement at bottom face only and negligible increment of reinforcement at top face.

V. CONCLUSIONS

This paper represents a numerical analysis of flat slab with the opening. Without providing any shear reinforcement the results are obtained for all the nine cases so that the effect of size and location of the opening in the flat slab can be studied and compared among themselves. Based on the numerical results and discussions, the following conclusions are obtained,

- The punching shear capacity of the flat slab without opening is higher than the flat slab with the opening.
- For the opening is provided in the column strip, the requirement of steel at top face increases considerably.
- And for the opening is provided in the middle strip, the requirement of steel at bottom face increases considerably.
- The punching shear capacity is lowest in case II. The opening of size 2m x 2m is at 0.6m from the face of the column, thus opening lies in column strip as well as middle strip and so the strength of slab is significantly reduced.

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Vol. 7, Issue 3, March 2018

- v. For the location of the opening in middle strip, there is an insignificant change in the percentage of steel at top face.
- vi. But, for the location of opening in middle strip as well as in column strip, there is always a significant increase in the percentage of steel at bottom face due to the flexural behaviour of the slab.
- vii. Except for column C1, there are negligible changes in punching shear capacity of all other the column, since all the opening are located near column C1.
- viii. Form the results, it is also concluded that, there is a necessity to provide shear strengthening in the form of shear reinforcement or stud rail or by column head or column drop or combination of these; otherwise the structure will fail in punching shear irrespective of increase in reinforcement at top and bottom face of the slab.

The results presented here will give an impetus to structural engineers to understand and use of flat slab in an optimized way.

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