Effect of Opening Size and Location on Reinforced Concrete Flat slabs with openings using SAFE 12.2.0

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Abstract— A reinforced concrete flat-plate floor system is widely used in various types of building structures including condominiums, parking garages, and office buildings. This floor system is advantageous in terms of simpler formwork, shorter construction period, reduced storey height, flexible room arrangement, more headroom, better air circulation, and better light penetration. In spite of the advantages, the system has its problems, one of which is the possibility of punching shear failure in the vicinity of the slab-column connections. Present aim of this study is to check the suitability of flat slabs with openings of different location & sizes. In this study FE analysis of flat slabs is proposed using SAFE 12.2.0 for two grid sizes of 5x5m and 7x7m respectively. Further the comparison has been done for the most suitable opening location w.r.t maximum deflection.

Key words: Finite element analysis, Flat slabs, SAFE 12.2.0, Maximum deflection, punching shear

I. Introduction

Reinforced concrete slabs supported on columns were initially developed in the United States of America and Europe in the beginning of the 20th century. Flat slabs can be constructed relatively rapidly because the absence of drop panels results in simpler formwork arrangements, enabling rapid floor construction. In addition, flat slab constructions do not restrict the positioning of horizontal services and partitions and help to minimize floor-to-floor heights. This provides advantages in terms of lower building height, with reduced facade and installation costs.

In general, in this type of system, 100 percent of the slab load has to be transmitted by the floor system in both directions (transverse and longitudinal) towards the columns. In such cases the entire floor system and the columns act integrally in a two- way frame action.

The design of flat slabs is mostly governed by serviceability conditions on the one side (with relatively large deflections in service) and by the ultimate limits state of punching shear (also called two-way shear) on the other side. These two criteria typically lead to the selection of the appropriate slab thickness.

The design of flat slab with opening is not clearly stated in IS 456. As a result of that the buildings which consist of flat slab must to be devoted to requirements of connecting to public utilities such as deflation pipes or gas pipes or others. These requirements require opening to be placed in the system. However, there remains the most critical forces moments and punching shear. Fig (1.1) shows the shape of cracks formed from these forces. The most critical force is the punching shear force because it’s sudden failure. These forces' effects increased when an opening is placed at a location at which cut the path of the load to column.

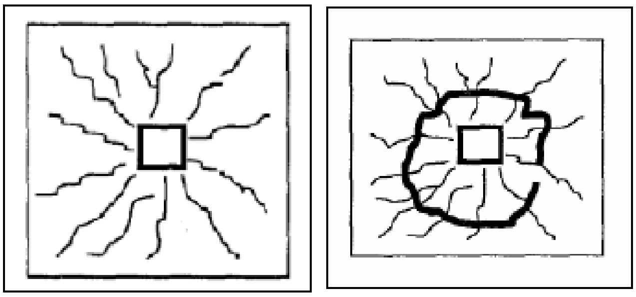

Fig. 1: Punching shear failure

A. Design Philosophy

There are three methods of analysis of flat slabs viz.

1) Direct Design Method (DDM)
2) Equivalent Frame Method (EFM)
3) Finite Element Method (FEM)

Out of this, first 2 methods are recommended by the I.S. code for determining the bending moments in the slab panel (approximate methods); either method is acceptable (provided the relevant conditions are satisfied).

B. Finite Element Method Using SAFE 12.2.0

The structures having irregular types of plans have limitations in analysis can be analyzed without any difficulties by the FEM. FEM is a powerful tool used in the analysis of flat slabs. Most finite element programs are based on elastic moment distribution and material that obey Hooke's Law. This works for steel plates but reinforced concrete is an elasto-plastic material and ones it cracks its behavior is non linear.

C. Advantageous Features of SAFE 12.2.0

SAFE is the ultimate tool for designing concrete floor and foundation systems. Generating pattern surface loads is easily done by SAFE with an automated option. Design strips can be generated by SAFE or drawn in a completely arbitrary manner by the user, with complete control provided for locating and sizing the calculated reinforcement. Finite element design without strips is also available and useful for slabs with complex geometries. Two types of cracked-section analysis are available, including:

1) Immediate cracked deflection
2) Long-term cracked deflection accounting for creep and shrinkage

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.

II. Research Significance

In the present study a 5x5m & 7x7m grid of G+7 storey flat slab having plan dimension 20mx20m & 28x28 m is analyzed using software SAFE 12.2.0. The main aim is to compare the impact of opening in variation with the span sizes. And also to check the location of opening and its effect on deflection, shear and moments.

In first alternative, flat slab without openings and without drop panels have been tried for both the panel sizes. In second alternative, Openings of different sizes with opening variation of 10%, 15% and 20% of panel size and location – parallel, diagonal & central are introduced within the various locations of flat slab to check the maximum shear concentrations, moments in middle & column strip & maximum deflection.

A. Analysis of Flat Slabs without Openings

In this case of analysis, Flat slab is analyzed with variety of alternatives in terms of grid distances of 5m & 7m is considered to understand the nature of moments along the column strip and middle strip of flat slab and deflection along each panel locations within flat slab. An effort has been taken to study the effect of punching shear around columns at a distance of d/2 from column face.

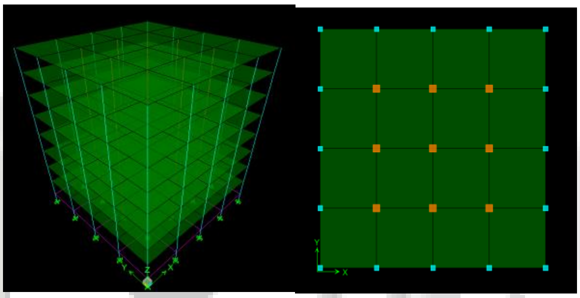

Fig. 2: Models for 5x5 m & 7x7m grid (plan & 3d view)

B. Analysis of Flat Slabs with Openings

The main aim of this work is to study the effect of opening in a flat slab and to find the ideal location of opening and most suitable size of square opening. Generally in almost all constructions, flat slab system includes openings. These may be of substantial size, as required by stair-ways and elevators shafts, or they may be of smaller dimensions, like those needed to accommodate heating, plumbing, and ventilating risers, floor and roof drains, and access hatches. To study the behavior of flat slab when opening is present different alternative have been adopted as mentioned in tabulated format. Various analysis trials have been performed and investigation has been done to study the nature of punching shear & maximum deflection in presence of the opening.

Fck	Fy	Superimposed DL	Live load	Load combinations
25 N/mm2	500 N/mm2	1.5 KN/m2	4 KN/m2	1.5(DL+SDL) +1.5 LL

Table 1: Loading parameters considered

Type Of Structural System	Slab(mm)	Column (mm)	Beam(mm)
5x5 m panel size G+7 storey	175	400x400 600 x 600	-
7x7 m panel size G+7 storey	200	600x600 750 x 750	-

Table 2: Geometrical Characteristics of the Analyzed Structural Systems

Model1	5x5 m panel (G+7 Storey building) without drop panels & opening	FS1
Model2	7x7 m panel (G+7 Storey building) without drop panels & opening	FS2
Model3	5x5 m panel (G+7 Storey building) with opening – 10% of panel dimension located parallel to column	FS3
Model4	5x5 m panel (G+7 Storey building) with opening – 15% of panel dimension located parallel to column	FS4
Model5	5x5 m panel (G+7 Storey building) with opening – 20% of panel dimension located parallel to column	FS5
Model6	7x7 m panel (G+7 Storey building) with opening – 10% of panel dimension located parallel to column	FS6
Model7	7x7 m panel (G+7 Storey building) with opening – 15% of panel dimension located parallel to column	FS7
Model8	7x7 m panel (G+7 Storey building) with opening – 20% of panel dimension located parallel to column	FS8
Model9	5x5 m panel (G+7 Storey building) with opening – 10% of panel dimension located diagonally to column	FS9
Model10	5x5 m panel (G+7 Storey building) with opening – 15% of panel dimension located diagonally to column	FS10
Model11	5x5 m panel (G+7 Storey building) with opening – 20% of panel dimension located diagonally to column	FS11
Model12	7x7 m panel (G+7 Storey building) with opening – 10% of panel dimension located diagonally to column	FS12
Model13	7x7 m panel (G+7 Storey building) with opening – 15% of panel dimension located diagonally to column	FS13
Model14	7x7 m panel (G+7 Storey building) with opening – 20% of panel dimension located diagonally to column	FS14
Model15	5x5 m panel (G+7 Storey building) with opening – 10% of panel dimension located Centrally	FS15
Model16	5x5 m panel (G+7 Storey building) with opening – 15% of panel dimension located Centrally	FS16
Model17	5x5 m panel (G+7 Storey building) with opening – 20% of panel dimension located Centrally	FS17
Model18	7x7 m panel (G+7 Storey building) with opening – 10% of panel dimension located Centrally	FS18
Model19	7x7 m panel (G+7 Storey building) with opening – 15% of panel dimension located Centrally	FS19
Model20	7x7 m panel (G+7 Storey building) with opening – 20% of panel dimension located Centrally	FS20

Table 3: Models designation

C. Maximum Deflection for Different Opening Locations (5x5 M Grid)

In the above TYPE 1, 10%, 15% & 20% opening size is considered as per the slab dimension (5x5 m). Therefore opening size of 500mm, 750mm & 1000mm is opted. The opening is located parallel, diagonally & centrally to the column as shown in fig. 3

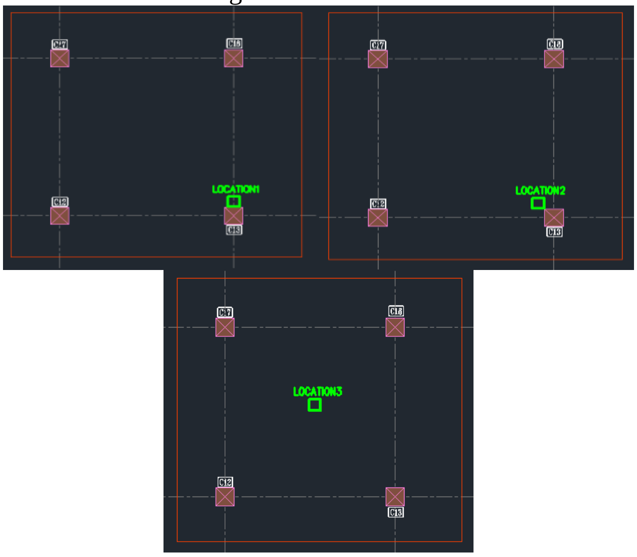

Fig. 3: Plan view of opening location for case 1, case 2 & case 3

Cases	Models	Opening size	Grid size	Position of openings	Deflection mm
Case 1	FS1	-	5000x5000 mm	-	4.269
	FS3	500mm	5000x5000 mm	Parallel to column	4.582
	FS9	500mm	5000x5000 mm	Diagonal to column	4.297
	FS15	500mm	5000x5000 mm	centrally	4.267

Table 4: maximum deflection for case 1

Cases	Models	Opening size	Grid size	Position of openings	Deflection mm
Case 2	FS1	-	5000x5000 mm	-	4.269
	FS4	750mm	5000x5000 mm	Parallel to column	4.312
	FS10	750mm	5000x5000 mm	Diagonal to column	4.322
	FS16	750mm	5000x5000 mm	centrally	4.263

Table 5: maximum deflection for case 2

Cases	Models	Opening size	Grid size	Position of openings	Deflection mm
Case 3	FS1	-	5000x5000 mm	-	4.269
	FS5	1000mm	5000x5000 mm	Parallel to column	4.302
	FS11	1000mm	5000x5000 mm	Diagonal to column	4.311
	FS17	1000mm	5000x5000 mm	centrally	4.271

Table 6: maximum deflection for case 3

Cases	Models	Opening size	Grid size	Position of openings	Deflection mm
Case 4	FS2	-	7000x7000 mm	-	12.15
	FS6	700mm	7000x7000 mm	Parallel to column	12.158
	FS12	700mm	7000x7000 mm	Diagonal to column	12.106
	FS18	700mm	7000x7000 mm	centrally	12.16

Table 7: maximum deflection for case 4

Cases	Models	Opening size	Grid size	Position of openings	Deflection mm
Case 5	FS2	-	7000x7000 mm	-	12.15
	FS7	1050mm	7000x7000 mm	Parallel to column	13.17
	FS13	1050mm	7000x7000 mm	Diagonal to column	13.017
	FS19	1050mm	7000x7000 mm	centrally	13.204

Table 8: maximum deflection for case 6

Cases	Models	Opening size	Grid size	Position of openings	Deflection mm
Case 6	FS2	-	7000x7000 mm	-	12.15
	FS8	1400mm	7000x7000 mm	Parallel to column	13.011
	FS14	1400mm	7000x7000 mm	Diagonal to column	13.207
	FS20	1400mm	7000x7000 mm	centrally	13.405

Table 6: maximum deflection for case 3

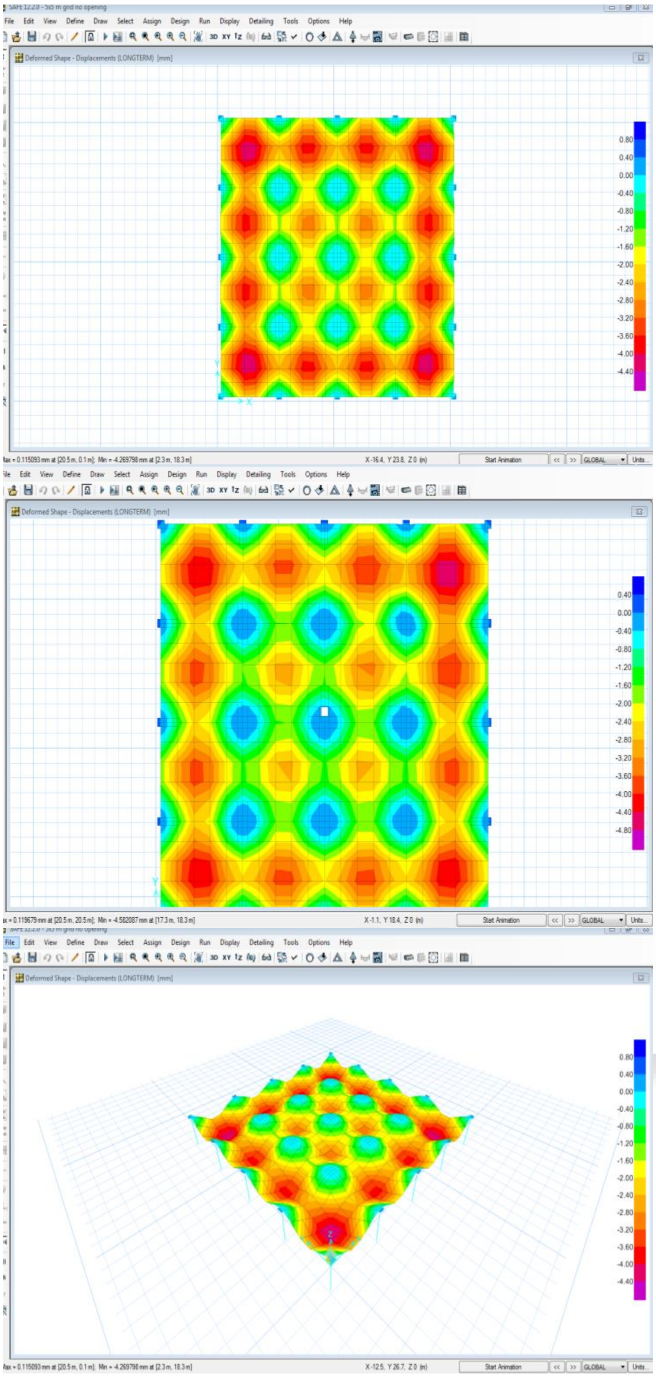

Fig. 4: Maximum deflection contours in SAFE 12.2.0

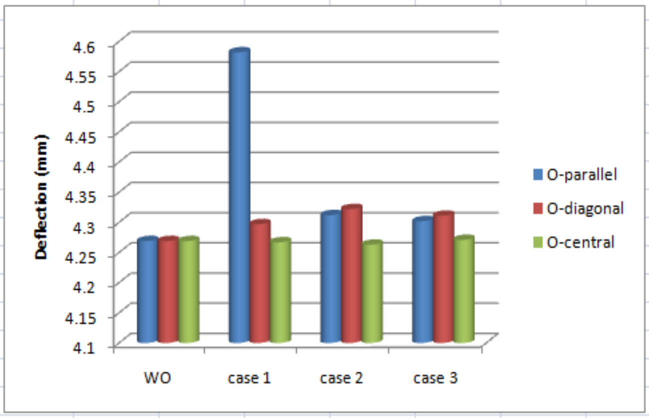

Fig 5: Maximum deflection for case 1, case 2 & case 3

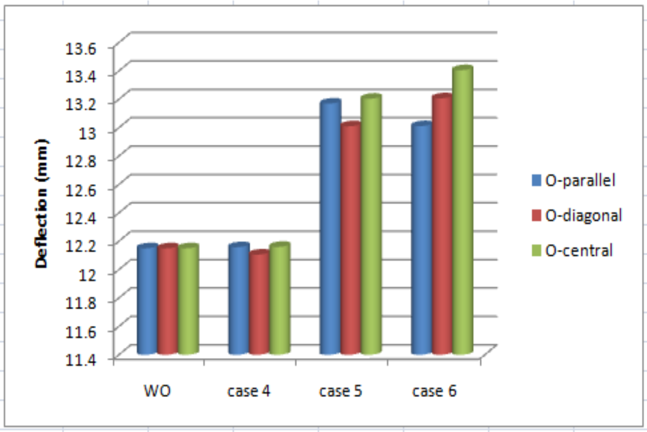

Fig 6: Maximum deflection for case 4, case 5 & case 6

III. CONCLUSIONS

Following observation has been drawn from Table and graphs presented above.

1) The maximum deflection decreases as the size of opening goes on increasing. However for the same size of grid and for different location of square opening, the openings located parallel & central to the column is having more impact on the deflection value.
2) There is no major variation observed by changing the size of opening from 10% to 15 % and 20 % in both the models.
3) If the grids distance changes by 25-30%, then the deflection variation of 60-65% is observed when compared between 5x5 m & 7x7 m grid.

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