JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1131 - 1142
https://publishoa.com
ISSN: 1309-3452

CSI-SAFE Software Based Investigation of Effect on Deflection and Moment for Flat Slab with Different Opening Shapes and Positions

Jaicky Gurnani[1], Dr. Prabhakar Charpe[2]

[1]Student, Department of Civil Engineering,
Kalinga University, New Raipur, India,
jack.gurnani@gmail.com

[2]Professor/ Head, Department of Civil Engineering
Kalinga University, New Raipur, India,
prabhakar.charpe@gmail.com

ABSTRACT

The flat slab system has numerous benefits, and it is generally used in many several types of buildings, like shopping malls, hospitals, and offices. Buildings consisting of flat slabs must satisfy the requirements for connection to utilities, such as air conditioning or gas pipes lines. An opening in a structure causes an interruption in the natural load path. As a result, an imbalanced shear force and deflection will occur. When the opening is introduced, it will increase the effect of critical forces such as punching shears, deflections, and moments. This research carried out represents the numerical analysis and it was checked whether different shapes of openings and varying opening locations have an impact on the deflection and bending moment behaviour of flat slabs. The numerical analysis in this paper includes A and B Groups, and in addition, it is divided into three parts: without opening, square opening, and circular opening. Openings are placed parallel to a column's face. The size of openings considered in this study are 0.50 m x 0.50 m for a square opening, and 0.5642 m diameter for a circular opening. In order to conduct comprehensive parametric study, finite element analysis has been performed by using CSI-SAFE v16 based on IS 456:2000. The purpose of this investigation is to understand the behaviour of flat slabs with different opening shapes and with different opening positions from the column face. Based on the analysis, the study proposes various conclusions and recommendations.

Keywords: Flat slab, Openings in flat slab, Bending Moment, Deflection, CSI-SAFE, Square and Circular Opening.

I. INTRODUCTION

Flat slabs are reinforced concrete slabs that rest directly on concrete columns without any sup- port from beams. Flat slab construction has increasingly become popular and is being utilized more frequently. A flat slab is generally used in construction of large supermarkets, stores, under- ground garages, bridge decks, etc [1]. In high rise buildings with flexible three dimensional arrangements, flat slabs are used as a common and effective structural system where the flat slab is directly supported by the columns without any beams. Flat slabs are the best way to construct in situ concrete frame buildings [2-4]. A slab contains openings for architectural con- cerns including staircases, elevators, gas, electrical, and water connections, air conditioning, etc. Due to the opening, there is an interruption to the natural load path, which produces unbalanced shear forces and bending moments [5]. When designing a flat slab, punching shear capacity and deflection is the most important factor to consider. The punching shear failure may cause the entire structure to collapse as it is the major failure in flat slab [6-7]. Moment and punching shear capacity are highly affected by the opening size and location. The amount of steel required increases with increase in opening size [8]. There are several situations in which an opening creates the situation dangerous, but providing an opening at the face of the column is one of the most critical. Flat slabs with openings adjacent to columns have an impact on their punching shear capacity on a very large scale. Because flat plate slabs are weak against punching shear, openings at the face of columns on flat plate slabs may have consequences on the design constraints [9-11]. The punching shear of the flat slab is carefully examined when openings are made [12]. Punching shear failure is vital to observe carefully the effects of openings at the column face on punching shear and deflection behaviour in flat slab-column systems [13-14]. In this investigation of three dimensional nonlinear analysis of slab models, CSI-SAFE 16 software is used to understand the effect of deflection and moment on flat slabs behaviour with square and circular opening shapes, at different opening locations. A comparative analytical study is carried out between without opening, square shape opening and circular

JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1131 - 1142
https://publishoa.com
ISSN: 1309-3452
shape opening for Group A and Group B. Group A shows the specimen of a slab without a drop and without a column capital, and Group B shows the specimen of a slab with a drop and with a column capital.

The objectives of this research are

- To study the effect of different opening sizes on the behaviour of flat slabs.
- To study the effect of opening distance from the column face.
- To study the effect of square opening and circular opening on the behaviour of flat slabs.

II. METHODOLOGY

Numerical analysis of flat slab models is performed using the three-dimensional finite element program SAFE. All the cases are modeled and analyzed by using 0.10 x 0.10 m mesh size. The analytical modeling was divided into two groups to know the behavior of flat slabs with openings. Group A is the specimen of a flat slab without drop and without column capital. Group B is the specimen of a flat slab with drop and with column head and both Group A and B further subdivided into Part I, Part II, Part III of no opening, circular opening and square opening respectively. The location of the opening is at the face of the column i.e., from 0 m to 3.00 m with an interval of 0.20m. Finite element analysis of slabs is used to analyze results such as total deformation and moments. A relative analytical study is carried out between no opening, square opening and circular opening for Group A and Group B by SAFE software.

In this analysis, the material of M30 grade of concrete and Fe500 as the grade of steel are taken into consideration. For meshing of slab in SAFE, all the cases are modeled and analyzed by using the Automated slab mesh option. The 0.20 m thick flat slab is taken into consideration. The size of the column is taken as 0.50 × 0.50 m. The size of each slab panel is 6.00 × 6.00m. The square and circular opening of size 0.50 x 0.50 m and 0.56 m diameter is provided respectively. For Group A, no column capital nor drop panel is provided. But for Group B, a drop panel of size 2.00m x 2.00m x 0.30m and column capital of 1.33m x 1.33m x 0.50m is provided. Dead load of 5.00kN/m2, floor finish of 2.00kN/m2 and live load of 5.00kN/m2 is applied on the slab. The analysis of the flat slab is done using software SAFE2016 by finite element method.

TABLE I. DESIGN INPUT

Sr. No.	Parameters	Dimensions
1	Flat Slab Panel	6.00m X 6.00m
2	Column Size	0.50m X 0.50m
3	Flat Slab Thickness	0.20m
4	Floor to floor Height	4.00 m
5	Drop Panel	2.00m x 2.00m x 0.30m
6	Column Head	1.33m x 1.33m x 0.50m
7	Grade of Concrete	M30
8	Grade of Steel	Fe500
9	Live Load	5.50 kN/m2
10	Floor Finish	2.00 kN/m2
11	Square Opening	0.50m X 0.50m
12	Circular Opening	0.56 m

A. Nonlinear Analysis

In the nonlinear analysis of slab models, CSI-SAFE 16 is used. The long term cracked is considered for nonlinear analysis and the parameters required for creep coefficient and shrinkage strain are 2 and 0.0003 respectively. The computerized design is available for a modeling with opening or without opening in SAFE, we can easily obtain bending moment and deflection comparisons for the various cases.

B. Material Properties

In this research, compressive strength of concrete is 30 N/mm2 and grade of steel Fe500 is used.

JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1131 - 1142
https://publishoa.com
ISSN: 1309-3452

C. Boundry Condition

In this research, the interior panel of the flat slab is considered; hence, all the edges of the flat slab are continuous.

D. Mesh Size

The mesh of size 0.10m x 0.10m is adopted for this analysis.

E. Notation for the Specimen

Specimens are designated using the following notations.

S - D - C - NO	S + D + C - NO
S - D - C - SO@C	S + D + C - SO@C
S - D - C - SO@00	S + D + C - SO@00
S - D - C - SO@0.20	S + D + C - SO@0.20
S - D - C - CO@00	S + D + C - CO@00
S - D - C - CO @0.20	S + D + C - CO@0.20

Where,
"S - D – C" represents Slab with no Drop and no Column Head.
"S + D + C" represents Slab with Drop and with Column Head.
"NO" represents No Opening in slab.
"SO" represents Square Opening in slab.
"CO" represents Circular Opening in slab.
"@00" represents Placement of opening at the Column Face.
"@0.20" represents Placement of opening at 0.20m from the face of column.
"@C" represents Placement of opening at centre of flat slab.

Example: S - D - C - SO@00

Above example denotes the flat slab without drop and without column head with the square opening at the column face. (Gurnani, 2022)

III. RESEARCH FRAMEWORK AND MODELLING

The finite element method has been used for the modeling and analysis of reinforced concrete flat slab systems. The flat plates with highly irregular or unusual geometries are often analyzed with Finite Element Analysis. For the purpose of these models, the Static analysis type is utilized.

Table II shows the details of opening size, opening shape and location of opening in specimens. The specimens of Group A and Group B are shown in Table II. In addition, Group A and Group B are divided into three specimen groups: one consists of a control model without openings, and the other two represent models with circular and square openings at different locations where they are shown in Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6. The shape and location of the openings give us insight into the behavior of the flat slab.

TABLE II. MODEL SPECIFICATION DETAILS

Group	**Case**	**Opening Shape**	**Opening Size**	**Opening Location**
Group A	Part I	No Opening	-	-
	Part II	Circular Opening	(0.5642 m ϕ)	At face of column from 0 m to 3 m with interval of 0.2m.
	Part III	Square Opening	(0.5 x 0.5 m)	
Group	Part I	No Opening	-	-

JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1131 - 1142
https://publishoa.com
ISSN: 1309-3452

B	Part II	Circular Opening	(0.5642 m ϕ)	At face of column from 0 m to 3 m with interval of 0.2m.
	Part III	Square Opening	(0.5 x 0.5 m)	

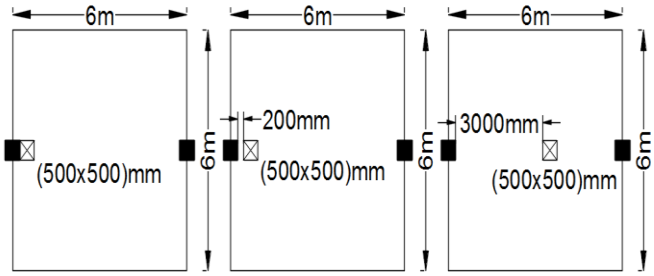


Fig. 1. Flat slab without drop and without column capital with square opening at different positions.

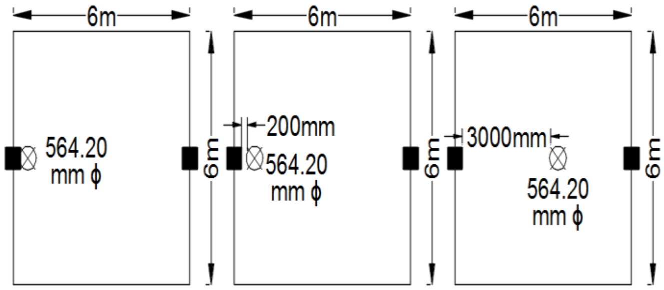


Fig. 2. Flat slab without drop and without column capital with circular opening at different positions.

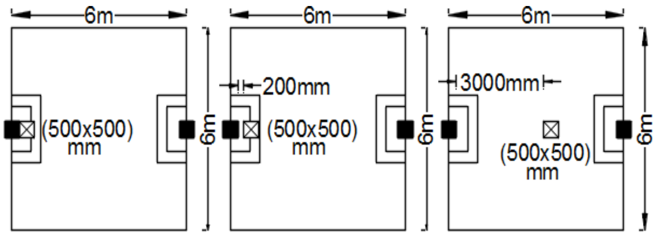


Fig. 3. Flat slab with drop and column capital with square opening at different positions.

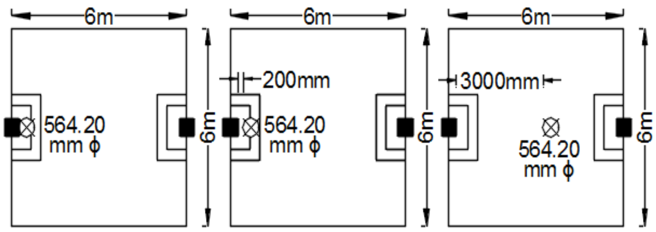


Fig. 4. Flat slab with drop and column capital with circular opening at different positions.

JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1131 - 1142
https://publishoa.com
ISSN: 1309-3452

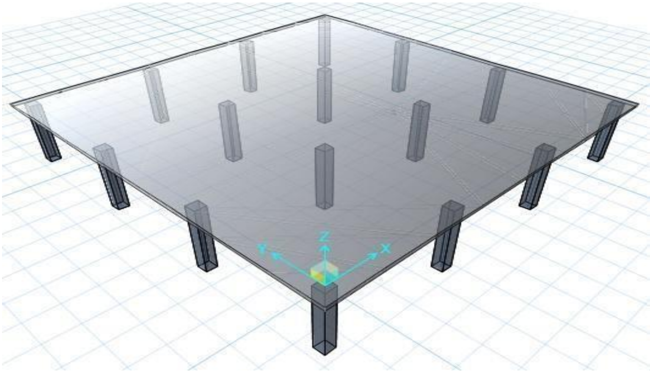


Fig. 5. Isometric view of flat slab without drop and without column head for Group A

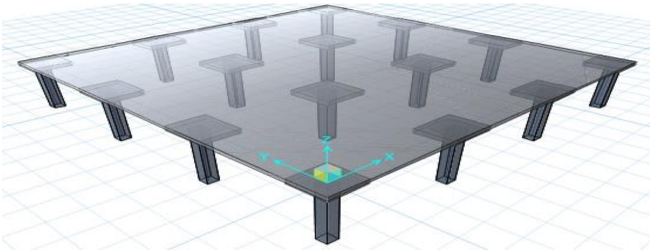


Fig. 6. Isometric view of flat slab with drop panel and with column head for Group B

IV. ANALYTICAL RESULTS AND OBSERVATIONS

In this research the flat slab was analyzed by using SAFE software with the drop and with the column head, as well as without drop and without column head. The results obtained are represented in the graphical form from Fig. No. 7 to Fig. No. 17.

A. *Deflection*

For the specimen with a circular opening of size 0.56m, (S - D - C - CO@3) and (S + D + C -CO@3) has the maximum deflection while comparing it with without opening and square opening, which is due to the opening shape. For flat slabs, nonlinear behavior was observed in fig. 7 and fig. 9. Since the center of the slabs is away from the supports, it experiences greater deflection. From the results, it is clear that the rigidity of a flat slab is heavily influenced by the concrete section. The presence of openings reduces the rigidity of slab. This will result in an increase in deflection of the flat slab.

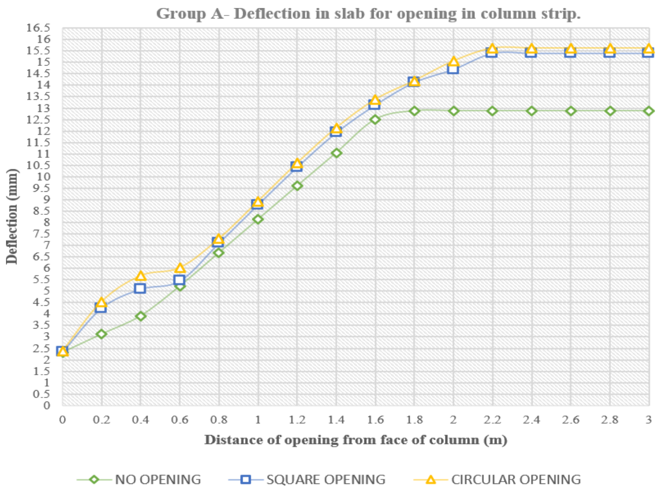


Fig. 7. Deflection in slab with respect to opening distance

Figure 7 shows the maximum deflection at the center of span for square and circular opening as compared to no opening condition.

JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1131 - 1142
https://publishoa.com
ISSN: 1309-3452

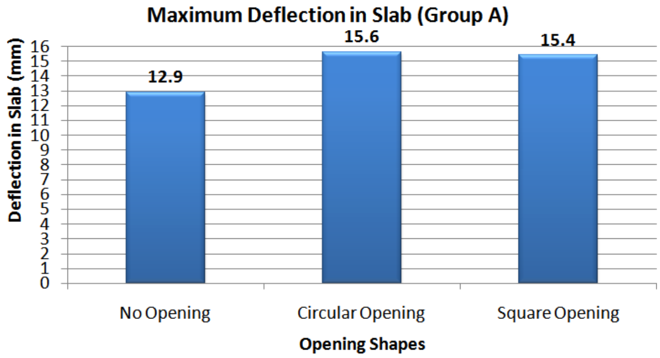


Fig. 8. Maximum Deflection in flat Slab for Group A

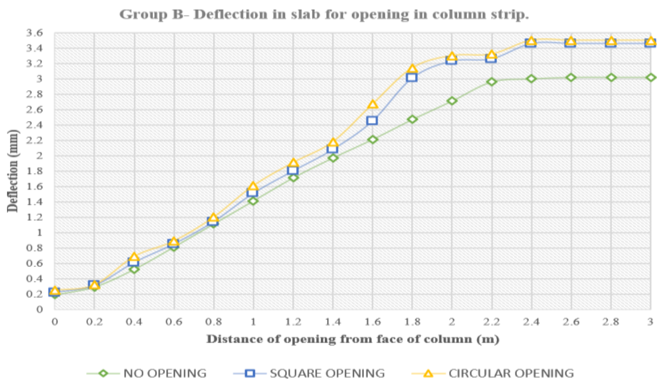


Fig. 9. Deflection in flat slab with respect to opening distance

Fig. 9 shows the maximum deflection at the center of span for square and circular opening as compared to no opening condition.

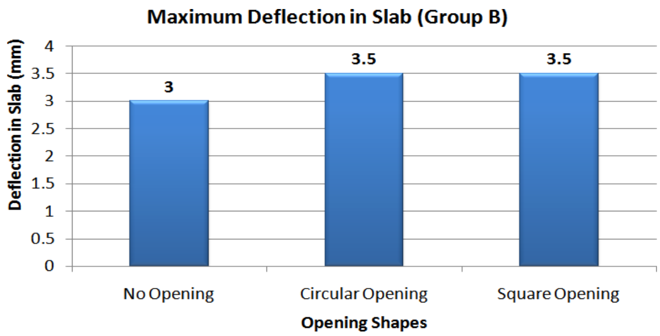


Fig. 10. Maximum Deflection in flat Slab for Group B

Fig. 8 and fig. 10 refers, When the opening size is increased at the same load level, it is obvious that the deflection is increased because there is a lack of concrete, which reduces the slab stiffness.

This study has determined that, for all models, an increase in deflection with increased opening size is seen at various floor levels.

A reduction in the stiffness of the resisting section results in a greater deflection.

TABLE III. PERCENTAGE INCREASE OF DEFLECTION IN SLAB

Sr. No.	**Opening Shape**	**Increase in % of deflection in slab than no opening**	**Increase in % of deflection in slab than no opening**

		Group A	*Group B*
1	Circular Opening	20.93%	16.70%
2	Square Opening	19.40%	16.70%

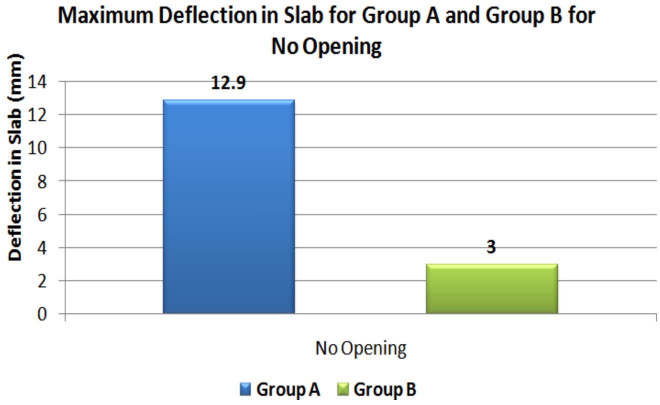


Fig. 11. Maximum Deflection in flat Slab for Group A and Group B for without Opening

Fig. 11 refers, Flat slab with drop panel of L/3 decreases the deflection by 76.70% than Flat slab without drop panel for no opening condition.

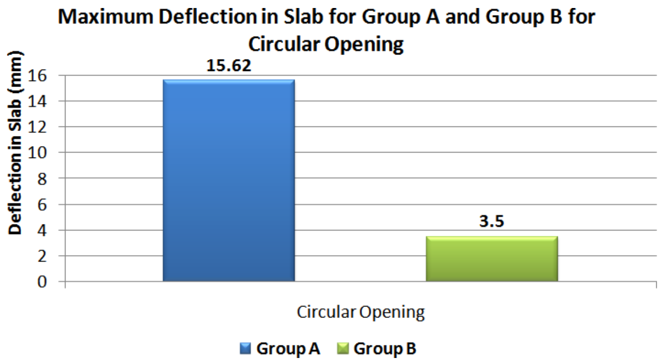
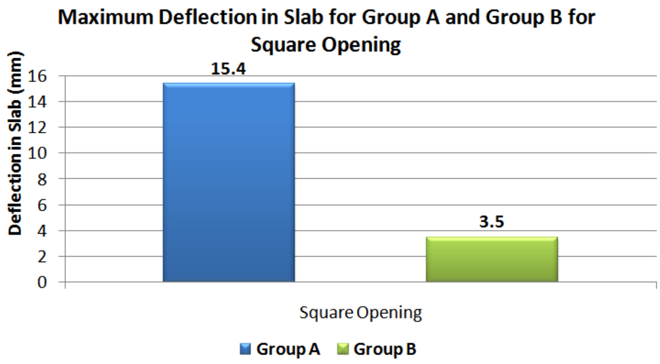


Fig. 12. Maximum Deflection in flat Slab for Group A and Group B for Circular Opening

Figure 12 refers, Flat slab with the drop panel of L/3 size decreases the deflection by 77.60% than Flat slab without drop panel for circular opening condition.



JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1131 - 1142
https://publishoa.com
ISSN: 1309-3452

Fig. 13. Maximum Deflection in flat Slab for Group A and Group B for Square Opening

Fig. 13 refers, Flat slab with drop panel of L/3 size decreases the deflection by 77.30% than flat slab without drop panel for square opening condition.

Table 4 represents percentage decrease in deflection in slab for Group A.

TABLE IV. PERCENTAGE DECREASE IN DEFLECTION IN SLAB

Sr. No.	Opening Shape	% Decrease in deflection in Group B than Group A
1	No Opening	76.70%
2	Circular Opening	77.60%
3	Square Opening	77.30%

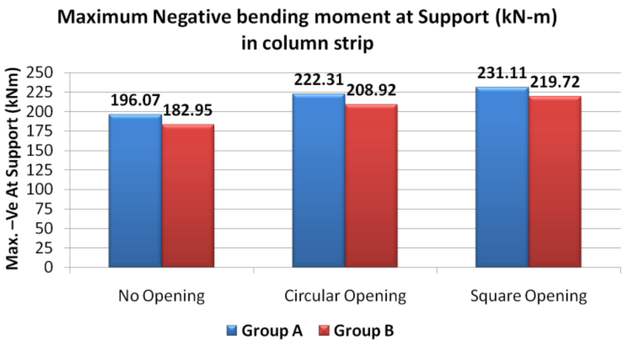


Fig. 14. Maximum Negative bending moment at Support in column strip (kN-m)

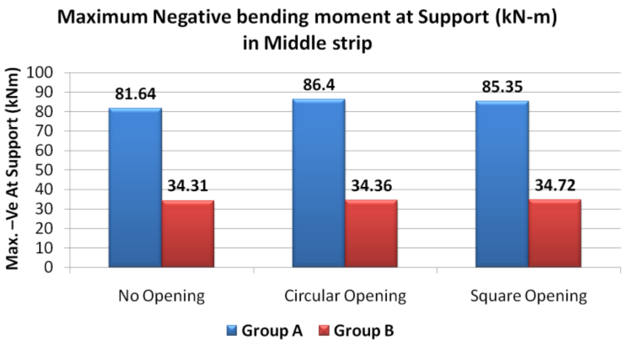


Fig. 15. Maximum Negative bending moment at Support in Middle strip (kN-m)

B. *Bending Moment*

Fig. 14 and fig. 15 refers, For Group A, the opening at the face of column increases the negative bending moment at support in column strip by 13.40% for circular opening than no opening, 17.90% for square opening than no opening and 3.95% for square opening than circular opening. For Group B, the opening at the face of column increases the negative bending moment at support in column strip by 14.20% for circular opening than no opening, 20% for square opening than no opening, and 5.17% for square opening than circular opening.

TABLE V. PERCENTAGE DECREASE IN NEGATIVE BENDING MOMENT IN COLUMN STRIP

Sr. No.	Opening Shape	% Decrease in Negative bending moment in Group B than Group A
1	No Opening	6.70%
2	Circular Opening	6.00%
3	Square Opening	5.00%

JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1131 - 1142
https://publishoa.com
ISSN: 1309-3452

Table 5 represents percentage decrease in negative bending moment in column strip for Group A. For Group A, the opening at the column face increases the negative bending moment at support in the middle strip by 5.83% for circular opening than no opening, 4.54% for square opening than no opening and 1.22% decreases for square opening than circular opening.

For Group B, the opening at the column face increases the negative bending moment at support in the middle strip by 0.15% for circular opening than no opening, 1.19% for square opening than no opening and 1% for square opening than circular opening.

TABLE VI. PERCENTAGE DECREASE IN NEGATIVE BENDING MOMENT IN MIDDLE STRIP

Sr. No.	Opening Shape	% Decrease in negative bending moment in Group B than Group A
1	No Opening	57.97%
2	Circular Opening	60.23%
3	Square Opening	59.32%

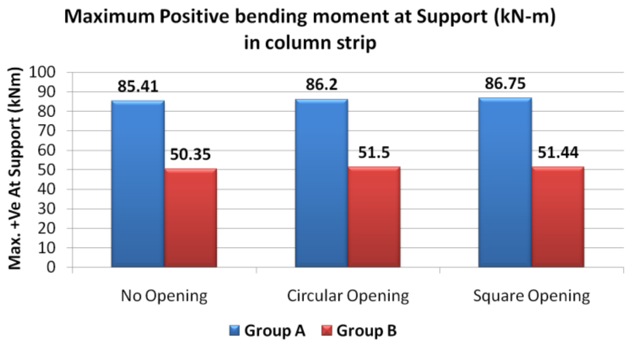


Fig. 16. Maximum Positive bending moment at Support in column strip (kN-m)

Fig. 16 refers, For Group A, the opening at the column face increases the positive bending moment at support in column strip by 0.69% for circular opening than no opening, 1.57% for square opening than no opening, and 0.64% for square opening than circular opening.

For Group B, the opening at the column face increases the positive bending moment at support in column strip by 2.28% for circular opening than no opening, 2.16% for square opening than no opening, and 0.12% decrease for square opening than circular opening.

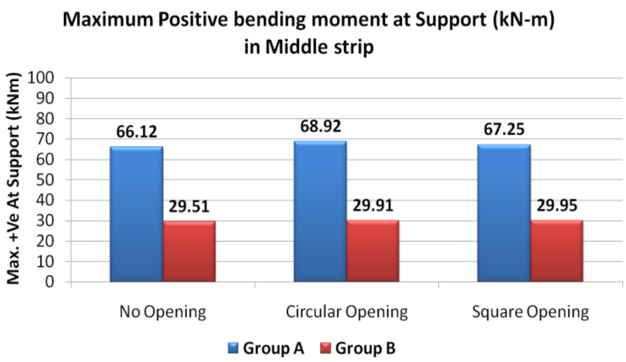


Fig. 17. Maximum Positive bending moment at Support in Middle strip (kN-m)

Fig. 17 refers, For Group A, the opening at the column face increases the positive bending moment at support in the middle strip by 4.23% for circular opening than no opening, 1.71% for square opening than no opening, and 0.64% for square opening than circular opening.

JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1131 - 1142
https://publishoa.com
ISSN: 1309-3452

Table 6 represents percentage decrease in positive bending moment in column strip for Group A.

TABLE VII. PERCENTAGE DECREASE IN POSITIVE BENDING MOMENT IN COLUMN STRIP

Sr. No.	Opening Shape	% Decrease in positive bending moment in Group B than Group A
1	No Opening	41.05%
2	Circular Opening	40.26%
3	Square Opening	40.70%

For Group B, the opening at the column face increases the positive bending moment at support in the middle strip by 1.36% for circular opening than no opening, 1.49% for square opening than no opening, and 0.13% for square opening than circular opening.

TABLE VIII. PERCENTAGE DECREASE IN POSITIVE BENDING MOMENT IN MIDDLE STRIP

Sr. No.	Opening Shape	% Decrease in positive bending moment in Group B than Group A
1	No Opening	55.37%
2	Circular Opening	56.60%
3	Square Opening	55.46%

Where, W = Design load on a total area = $L_2 X L_n$;

L_n = Clear span from face to face of columns, but not less than 0.65xL.

The opening size and shape have a noticeable effect on negative moments in column strips and a negligible effect on all other moments.

Table 9 and 10 shows the factor for Maximum Bending Moment in column strip and middle strip for Group A and Group B Respectively. Increases in opening size result in greater changes in slab moments.

TABLE IX. FACTORS FOR MAXIMUM BENDING MOMENT IN MIDDLE STRIP AND COLUMN STRIP FOR GROUP A.

Sr. No.	Opening Condition	Strip	Max.–ve at Support	Max.+ve at Support
1	No Opening	Column Strip	W x Ln/16.70	W x Ln/38.30
2		Middle Strip	W x Ln/40	W x Ln/49.50
3	Square Opening	Column Strip	W x Ln/14.20	W x Ln/37.70
4		Middle Strip	W x Ln/38.30	W x Ln/48.60
5	Circular Opening	Column Strip	W x Ln/14.70	W x Ln/37.90
6		Middle Strip	W x Ln/37.80	W x Ln/47.40

TABLE X. FACTORS FOR MAXIMUM BENDING MOMENT IN MIDDLE STRIP AND COLUMN STRIP FOR GROUP B

Sr. No.	Opening Condition	Strip	Max.–ve at Support	Max.+ve at Support
1	No Opening	Column Strip	W x Ln/17.90	W x Ln/64.90
2		Middle Strip	W x Ln/95.20	W x Ln/110.70

3	Square Opening	Column Strip	W x Ln/14.90	W x Ln/63.50
4		Middle Strip	W x Ln/94.10	W x Ln/109.10
5	Circular Opening	Column Strip	W x Ln/15.60	W x Ln/63.50
6		Middle Strip	W x Ln/95.10	W x Ln/109.20

A flat slab with square openings causes a significant effect on slab moments as compared to no opening and circular opening.

V. COMCLUSIONS AND RECOMENDATIONS

- The deflection increases when the opening dimension is increased, so the ultimate load capacity is decreased.
- Based on the results, it is concluded that the openings that are situated away from the column's face appeared to be more effective than openings that were located at the face of the column.
- An opening reduces slab rigidity, resulting in increased deflection of the slab.
- Increasing the opening size results in increased deflection because the slab stiffness decreases due to a lack of concrete
- The circular opening at the face of column has the maximum deflection than no opening and square opening, which is due to the decrease in stiffness in a flat slab.
- Flat slab with drop panel of L/3 decreases the deflection by 76.70%, 77.60%, 77.30% than Flat slab without drop panel for no opening condition, circular opening, square opening respectively.
- Introduction of a drop pane of L/3 size decreases the negative bending moment at support in the column strip by 6.7%, 6%, 5% than Flat slab without drop panel for no opening, circular opening, square opening res.
- Introduction of a drop pane of L/3 size decreases the negative bending moment at support in the middle strip by 58%, 60%, 59% than Flat slab without drop panel for no opening, circular opening, square opening res.
- Flat slab with drop panel of L/3 size decreases the positive bending moment at support in column strip value by 41%,40%, 41% than Flat slab without drop panel for no opening, circular opening, square opening res.
- Flat slab with drop panel of L/3 size decreases the positive bending moment at support in middle strip value by 55%, 57%, 55% than Flat slab without drop panel for no opening, circular opening, square opening res.

ACKNOWLEDGMENT

I would like to express my deep gratitude to my guide Dr. P. S. Charpe for their valuable guidance and encouragement. I would also like to sincerely thank all the faculty members of the civil engineering department and my colleagues for helping me throughout this project.

REFERENCES

[1] Abdulrahman, B. Q., Wu, Z., and Cunningham, L. S. 2017. Experimental and numerical investigation into strengthening flat slabs at corner columns with externally bonded cfrp. Construction and Building Materials 139, 132–147.

[2] Al-Saawani, M. A., El-Sayed, A. K., and Al-Negheimish, A. I. 2015. Effect of basic design parameters on ic debonding of cfrp-strengthened shallow rc beams. Journal of Reinforced Plastics and Composites 34, 18, 1526–1539.

[3] Anil, O. ¨ , Kina, T., and Salmani, V. 2014. Effect of opening size and location on punching shear behaviour of two-way rc slabs. Magazine of concrete research 66, 18, 955–966.

[4] Durucan, C. and Anil, O. ¨ 2015. Effect of opening size and location on the punching shear behavior of interior slab–column connections strengthened with cfrp strips. Engineering Structures 105, 22–36.

[5] Faria, D. M., Einpaul, J., Ramos, A. M., Ruiz, M. F., and Muttoni, A. 2014. On the efficiency of flat slabs strengthening against punching using externally bonded fibre reinforced polymers. Construction and Building Materials 73, 366–377.

[6] Florut¸, S.-C., Sas, G., Popescu, C., and Stoian, V. 2014. Tests on reinforced concrete slabs with cut-out openings strengthened with fibre-reinforced polymers. Composites Part B: Engineering 66, 484–493.

JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1131 - 1142
https://publishoa.com
ISSN: 1309-3452

[7] Gardner, N. and Shao, X.-y. 1996. Punching shear of continuous flat reinforced concrete slabs. Structural Journal 93, 2, 219–228.

[8] Guandalini, S., Burdet, O., and Muttoni, A. 2009. Punching tests of slabs with low reinforcement ratios. ACI Structural Journal 106, ARTICLE, 87–95.

[9] Gurnani, J. 2022. Investigation of behavior of flat slab with openings adjacent to column of different shapes using csi-safe. ECS Transactions 107, 1, 377.

[10] Jendele, L. and Cervenka, J. 2006a. Finite element modelling of reinforcement with bond. Computers & structures 84, 28, 1780–1791.

[11] Jendele, L. and Cervenka, J. 2006b. Finite element modelling of reinforcement with bond. Computers & structures 84, 28, 1780–1791.

[12] Li, R., Cho, Y. S., and Zhang, S. 2007. Punching shear behavior of concrete flat plate slab reinforced with carbon fiber reinforced polymer rods. Composites Part B: Engineering 38, 5- 6, 712–719.

[13] Torabian, A., Isufi, B., Mostofinejad, D., and Ramos, A. P. 2019. Behavior of thin lightly reinforced flat slabs under concentric loading. Engineering Structures 196, 109327.

[14] Yuan, Q., Shi, C., De Schutter, G., Audenaert, K., and Deng, D. 2009. Chloride binding of cement-based materials subjected to external chloride environment–a review. Construction and building materials 23, 1, 1–13.