The Effect of Punching Shear in Flat Slab Due to Staggered Column

Onkar G. Sarda[1], Dr. S. R. Parekar[2]
[1, 2] Department of Civil Engineering
[1, 2] A.I.S.S.M.S. College of Engineering, Pune

Abstract- *"Flat Slab" is better understood as the slab without beams resting directly on supports like columns. The 'drop panel' is formed by the local thickening of the slab around the supporting column. Drop panels or simply drops are provided mainly for the purpose of reducing shear stress around the column supports and increases the stiffness of the floor system under vertical loads, which increases the economical span range. This also reduces the steel requirements for the negative moments at the column supports. The flaring of the column at top is generally provided such that the plan geometry at the column head is similar to that of the column. In modern multi-storey complexes, staggered column is required due to various parking requirements, floor wise variation in building plan or due to architectural views. The present work is mainly focus on the effect of staggered column in flat slab on punching shear capacity. In this work, Various parameters which affects the punching shear strength are taken into consideration.*

Keywords- Analysis of Flat Slab, SAFE software, Staggered Column, Punching Shear Ratio.

I. INTRODUCTION

Reinforced Concrete slabs with long spans extended over several bays and only supported by columns, without beams are called as flat slab. Flat slab buildings are very easy to construct and also efficient. It can accommodate more number of stories within the same height of RC building with beams. Such type of structure contains large bending moment and vertical forces in the region of slab-column junction. Flat slab gives a very proficient structure which minimizes material usages and reduces the economic span range when compared to reinforced concrete. The structural performance of flat slab structure can improve significantly by post tensioning. It is generally used in office buildings, warehouses, public building, and hospitals. Flat plates are stiffened near column using drop panels or column heads. Flat slab system is more suitable than flat plate system. The flat slab system is generally used for higher load and larger span. Also, it enhances its capacity in resisting shear and hogging moments near the support. The slab thickness varies from 125 mm to 300 mm for spans ranging from 4 m to 9 m. The flat slab system is the one with the highest dead load per unit area in all floor system. In such cases the entire floor system and the columns act integrally in a two- way frame action. 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. Recently, with the development of modern flat-plate floor system for high-rise residential buildings, the use of irregular column layout are preferred now a days. The currently existing methods of flat plate design are applicable to rectangular grid column layout. Guidelines are not provided for design of flat slab in IS codes. The ACI Building Code contains two design procedures that are applicable to the reinforced slab systems. The first method is called the Direct Design Method (DDM). The use of this method is limited and restricted only for fairly regular floor layouts. When the spans and loads are irregular, the Equivalent Frame Method (EFM) is used. Though this method covers a wider range of slab definitions compared to the DDM, the use of it is limited to floor with regular column layouts. Currently, a probable technique for designers for irregularity of column layout is made by finite element analysis. However, the problems are not merely in the analysis aspects, there are other aspects also, such as the flexural design method, the flexural reinforcement layout, the flexural reinforcing details etc.

1. Direct Design Method

Direct Design Method (DDM) for slab systems with or without beams loaded only by gravity loads. In each direction, there must be three or more spans. Long span is less than twice the short span and panels should be rectangular. Center to center distance between the supports in each direction should be less than one third of the longer span. From general column line, the corner column cannot have offset more than 10% of span in each direction. All loads shall be due to gravity only and uniformly distributed over an entire span. The live load should be less than 3 times the dead load in each direction.

2. Equivalent frame method (EFM)

Equivalent frame method may be used in those cases where, slab layout not fulfils the restrictions stated formerly and are irregular, loading applied to the structure is horizontal, nature of the loading signifies the partial loading patterns, the ratio of live load to dead load is high.

3. Objective of the Work

In modern multi-storey complexes staggered column is required due to various parking requirement, floor wise variation in building plan or due to architectural views. The main objectives of the present study are as follows:

i. To develop the software model of whole building with staggered column in flat slab.
ii. To analyze the effect of various parameters on punching shear of flat slab (with & without drop, with & without column head) using software.
iii. Compare software results with specification as per ACI code.
iv. To study the effect of staggered column with variable span on punching shear capacity of flat slab.
v. To suggest guidelines for increasing punching shear capacity of flat slab.
vi. To investigate effect of punching shear on flat slab with staggered column.

II. LITERATURE REVIEW

S. S. Patil, R. Sigi (2014): presented the use of flat plate/slab construction in India. In this paper, comparison is made for design of flat slab by IS 456 and ACI 318 code. Design of flat slab involves three steps as framing systems, engineering analysis and reinforced design and detailing. This paper focus on the limitations of IS 456:2000 for design of flat slab such as minimum thickness of slab, drop thickness, minimum column diameter etc. whereas ACI 318 given imperial formulae. DDM have limitations for design of flat slab such as it should have minimum three continuous spans, span length should not be less than 1/3rd of long span in slab panel, it should not have staggered column, etc. This paper gives information and advantages of post tensioned flat slab such as PT slab is crack free, due to lack of cracking leads to smaller deflection than conventional R.C.C slabs, also leads to smaller deflection of slab. This paper concluded that there is an increase in cost by 15%-20% rather than decrease in post tensioned slab as claimed by PT design & build contractor, also there is no decrease in thickness of PT slab practically.

K.N. Mate and P.S. Patil (2015): presented a complete detailed procedure of analysis and design of flat slab structure as per IS 456:2000. This paper follows guidelines given by IS code such as guidelines for selection of drop, panel width, slab thickness, width of column and middle strips and also gives the reinforced details as per IS 456:2000 table no.16. This paper also shows that if nominal shear stress τ_v) < permissible shear stress (τ_c) then shear reinforcement is not required. If $\tau_c < \tau_v < 1.5 \tau_c$ then shear reinforcement shall be provided. If shear stress exceeds 1.5τ_c flat slab shall be redesigned. Flat slab gives the advantages over beam slab structure.

Harshal Deshpande et al. (2014): presented the use of flat slab construction in India. In this paper, they have also taken review of design methods for flat plate/slab structure designs based on Indian Standard 456:2000 and American Concrete Institute ACI-318 codes. This paper gives main factors to be considered for adopting flat slab with concrete column system as spacing of columns, long term deflection of flat plate and punching shear checks at column areas. This paper shows that the design of punching shear force as per IS 456:200 is 32% conservative compared to ACI-318. Indian code underestimates the concrete two-way shear. This paper concludes that design of RC flat slab is preferable up to span of 10 meters and design of flat slab utilizing Indian codes, has many shortcomings.

R.S.More and V.S.Sawant (2015): given the guidelines for analysis of flat slab. Flat slab structures contain large bending moment and vertical forces occur in a zone of supports. In flat slab system 100% slab load has to be transmitted towards the column. In this paper, some evidence of flat slab failure was presented. The failure of flat slab occurred due to smaller column designed for carrying gravity loads and also, stairway and elevators were placed in building asymmetrically. Major problem in this paper is that the slab column connection does not possess the rigidity as that in beam column connections. Shear concentration around column is very high due to the possibility of the column punching through the slab and deflection tends to very large value due to lesser depth of the slab. In this paper, Finite element method (FEM) described for flat slab. For this method, proper choice of finite elements, degree of discretization is required for overall economy.

Uwe Albrecht (2002): studied the punching shear design and detailing of shear reinforcement for different European and American design codes. They have shown that the thickness of slab, the amount or distribution of shear reinforcement may vary by using different codes. In this paper, the punching shear capacity of concrete, the punching shear resistance with shear reinforcement and the relevant detailing provisions were compared between four European, two American codes and the CEB-FIP Model Code. The provision of all these codes compared by analysing flat slab with typical dimensions and reinforcement ratios. The possibilities and limitations of each code and the consequences in practice will be demonstrated, with the help of the flat slab of an office building as an example. This paper revealed considerable differences among seven different codes with respect to the punching shear capacity, distribution of shear reinforcement and integrity reinforcement in reinforced concrete flat slabs. In all codes punching shear capacity calculations were based on a critical perimeter, which was located between 0.5d and 2d from the face of the column. The location of the critical perimeter was decisive for the increase of the punching shear capacity with an enlarged column. Except in the North American codes, the punching shear capacity depends on the flexural reinforcement ratio. However, the effect of the flexural reinforcement was quite different in each code.

III. MODELING AND ANALYSIS OF FLAT SLAB

Modeling of building is made by using ETABS software. Analysis and design of building is carried out by using SAFE software. This was divided in four phases namely pre-processing, analysis of modelled building, post processing, design and detailing of building.

Pre-processing Modelling of building involved model in flat slab configuration by defining material properties of model, defining of section properties and assigning of it to the model at specific locations i.e column, slab etc. Apply static load cases and load combination and then assign the load to slab. Then, after providing support to column, analysis will be carried out.

As per our requirement we choose specific analysis case to perform analysis. The building is analyzed for different parameters like flat slab with drop, without drop, with column head and drop. To find the permissible limit up to which column can be staggered, different models are prepared. After modelling of building, floors are exported to SAFE one by one. Design strips are generated on floors then analysis is carried out. After analysis performed as per required analysis case, without any warning and errors, the software displays deformed shape, various result such as shear force, bending moment etc.

1. Procedure for calculation of Punching Shear Ratio in Flat Slab

Decide depth of slab:

For span of l_n, minimum thickness of slab without drop and for interior panel is given by table no.9.5 of ACI code as $l_n/36$

Minimum depth of flat slab should not be less than 125mm.

Calculations of load: calculation of self-weight of slab = 25 x D in KN/m^2

where, D is thickness of slab in m

Floor finish load= thickness of floor finish x 24 KN/m^2

Live load considered for the design purpose.

Total design load = Addition of above floor finish load, self-weight of slab and live load in KN/m^2

Calculations of width of column strip and middle strip:

Width of column strip = 0.25 x l_1 or 0.25 x l_2, whichever is less.

Where, l_1 and l_2 are spacing in longitudinal and transverse direction respectively.

Width of middle strip = total spacing of slab – (2 x width of column strip).

Calculations of total factored static moment (M_0):

$$M_0 = \frac{W \times L_n}{8}$$

Where,

M_0 is total moment,

W is design load on the area l_2 x L_n

L_n is clear span from face to face of columns, capitals, brackets.

L_1 is the length of span in the direction of moment

L_2 is length of span transvers to the L_1.

Moment distribution is given by clause no. 13.6.3.3 in negative and positive moment in column and middle strip.

Check for shear:

Critical section is at d/2 from the face of column.

Critical section is = width of column + d/2 + d/2

Nominal shear stress $\tau_v = \frac{V}{bd}$

According to clause no 11.11.2.1 shear strength of concrete (Vc) shall be smallest of:

$$V_c = \left(1 + \frac{2}{\beta_c}\right)\frac{\sqrt{f_{ck}}}{6}$$

$$V_c = \left(\frac{\alpha_s X d}{u}\right)\frac{\sqrt{f_{ck}}}{12}$$

$$V_c = \frac{\sqrt{f_{ck}}}{3}$$

Where,

βc – ratio of longest column dimension to the shorter column dimension.

αs - 40 for interior column, 30 for edge column, 20 for corner column.

Therefore,

$$\text{Punching shear ratio} = \frac{\text{maximum design shear strength}}{\text{concrete shear strength capacity}}$$

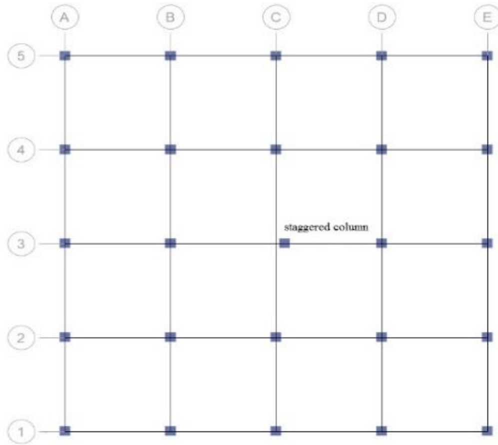

Figure 1. Plan showing the staggered column

IV. RESULT AND DISCUSSION

The result obtained from analysis of 5 stories RCC building having flat slab with staggered column by using static analysis method for different parameters such as flat slab without drop, flat slab with drop, flat slab with column head and flat slab with drop and column head are as follows.

1. Flat slab with staggered column without drop.

Punching shear capacity ratio is the ratio of maximum design shear strength to the concrete shear strength capacity. The area affected by punching shear is around the periphery of column at a distance of d/2 from the face of column. According to ACI 318 code the permissible limit for punching shear capacity ratio is 1. If the ratio exceeds 1, shear reinforcement is required at that area.

Table 1. Floor wise deflection of flat slab with staggered column without drop

Story level	Deflection (mm)
Floor 1	2.85
Floor 2	10.26
Floor 3	18.37
Floor 4	25.81
Floor 5	55.3

Table 2. Floor wise punching shear capacity ratio of flat slab with staggered column without drop.

Story level	Punching shear capacity ratio
Floor 1	0.8649
Floor 2	**1.61**
Floor 3	**2.27**
Floor 4	**3.37**
Floor 5	**3.09**

2. Flat slab with staggered column with drop:

Table 3. Floor wise deflection of flat slab with staggered column with drop

Story level	Deflection (mm)
Floor 1	1.991
Floor 2	6.84
Floor 3	12.566
Floor 4	18.15
Floor 5	**42.38**

Table 4. Floor wise punching shear capacity ratio of flat slab with staggered column with drop.

Story level	Punching shear capacity ratio
Floor 1	0.6079
Floor 2	0.9417
Floor 3	1.3483
Floor 4	2.0075
Floor 5	1.6702

3. Flat slab with staggered column with column head:

Table 5. Floor wise punching shear capacity ratio of flat slab with staggered column with column capital

Story level	Punching shear capacity ratio
Floor 1	0.2542
Floor 2	0.4114
Floor 3	0.5327
Floor 4	0.8347
Floor 5	0.6904

4. Flat slab with staggered column with column head and drop:

Table 6. Floor wise punching shear capacity ratio of flat slab with staggered column with drop and with column capital

Story level	Punching shear capacity ratio
Floor 1	0.1895
Floor 2	0.2679
Floor 3	0.3429
Floor 4	0.4938
Floor 5	0.4242

5. Effect of staggered column on punching shear capacity ratio of flat slab

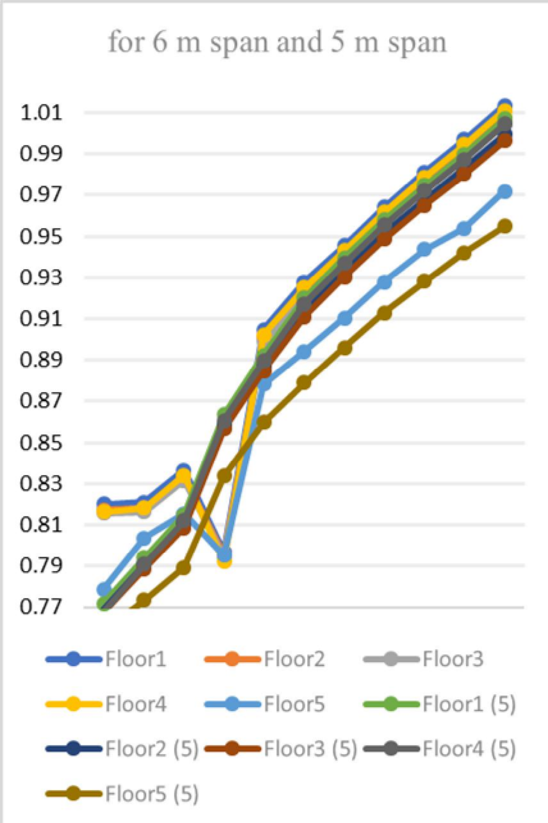

Figure 2. Punching shear ratio for span to depth ratio 30 and ratio of span to size of square column 12.

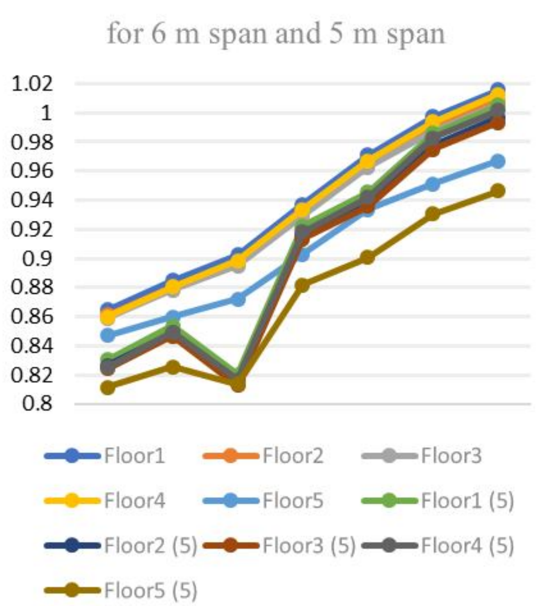

Figure 3. Punching shear ratio for span to depth ratio 30 and ratio of span to size of square column 13.33.

6. Effect of change in thickness of flat slab on punching shear ratio:

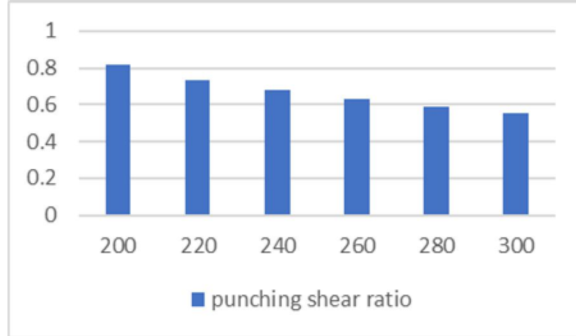

Figure 4. Effect of change in thickness in flat slab on punching shear ratio.

V. CONCLUSIONS

Analysis of 5 stories RCC building having flat slab with staggered column is carried out by static analysis method. Punching shear capacity for flat slab with staggered column and with drop is increased by 39.65 % and deflection is decreased by 30.86 % as compared to flat slab with staggered column and without drop. According to ACI code the permissible limit for punching shear capacity ratio is 1. In the given case study, third, fourth and fifth floor of flat slab with staggered column without drop is failed in punching shear. According to ACI code the permissible limit for deflection is l/240 = 6000/240 = 25 mm. The fifth floor of flat slabs with staggered column in all parameters failed in deflection criteria. For case of 6 m span and 200 mm thickness of flat slab with column size of 500 mm x 500 mm and also for case of 5 m span and 165 mm thickness of slab with column of size 415 mm x 415 mm, column can be staggered up to 900 mm from its original position. Beyond this limit flat slab will fail in punching shear. Also, when we reduce size of column to 450 mm x 450 mm and 375 mm x 375 mm for the 6 m span and 5 m span respectively, column can be staggered up to 500 mm from its original position. When aspect ratio is changed, corner column is more susceptible to punching shear. Thickness of flat slab affects the punching shear ratio. Increase in thickness of flat slab also increases the punching shear capacity of flat slab and vice versa.

REFERENCES

[1] ACI committee 318 (2002). Building code requirement for structural concrete (ACI 318).

[2] Indian Standards IS 456-2000, Plain and reinforced concrete code of practice.

[3] S.S.Patil, Rupali Sigi, “Flat slab construction in India”, International Journal of Engineering and Innovative Technology (IJEIT) Volume 3, Issue 10, April 2014, pp.

138-141.

[4] Gasparini, D.A: Contributions of C. A. P. Turner to Developement of Reinforeced Concrete Flat Slabs 1905. - 1909., Journal of Structural Engineering, 128 (2002) 10, pp. 1243–1252.

[5] Harshal Deshpande, Radhika Joshi and Prashant Bangar, Design Consideration for Reinforced Concrete Flat Slab Floor System, International Journal of Scientific and Engineering Research, Vol.5, Issue 12 (2014), pp. 59-62.

[6] K.N. Mate and P. S. Patil, Study of Flat Slab, International Journal of Science and Research, Vol.4 Issue 6, June 2015, pp. 1106-1110.

[7] S.S.Patil, Rupali Sigi (2014), “Analysis and Design of flat slab using various codes”, International Journal of Engineering and Innovative Technology (IJEIT) Volume 3, Issue 10.

[8] R.S. More and V. S. Sawant, Analysis of Flat Slab, International Journal of Science and Research, Vol.4 Issue 7, July 2015, pp. 98-101.

[9] Uwe Albrecht, Design of flat slab for punching- European and North American practices, journal of cement and concrete composites, vol 24 (2002), pp. 531-538.

[10] Micael M. G. Inacio, Andre F. O. Almeida, Duarte M.V. Faria, Valter J.G. Lucio and Antonio Pinho Romos, Punching of high strength concrete flat slabs without shear reinforcement, Journal of engineering structure, 103 (2015), pp. 275-284.

[11] A. Pinho Romos, Valter J.G. Lucio and Paul E. Regan, Punching of flat slab with in- plane forces, Journal of engineering structure, 33 (2011), pp. 894-902.

[12] Robert Koppitz, Albin Kenel and Thomas Keller, punching shear of RC flat slabs – Review of analytical models for new and strengthening of existing slabs, Journal of engineering structure, 52 (2013), pp. 123-130.

[13] J. Sagaseta, L. Tassinari, M. Fernández Ruiz and A. Muttoni, punching of flat slabs supported on rectangular columns, Journal of engineering structure, 77 (2014), pp. 17-33.

[14] Jurgen Einpaul, Miguel Fernandez Ruiz and Aurelio Muttoni, Influence of moment redistribution and compressive membrane action on punching strength of flat slabs, Journal of engineering structure, 86 (2015), pp. 43-57.

[15] Ahmed Ibrahim, Salah E.E. El-Metwally, Hamed H. Asker, Mohamed A. El Zareef, Effect of mid thickness rebar mesh on the behavior and punching shear strength of interior slab-column connection, housing and building national research Center, 12 (2016), pp. 272-283.

[16] Iyad Alkroosh and Hayder Ammash, Soft computing for modeling punching shear of reinforced concrete flat slab, Aim Shams Engineering Journal, 6 (2015), pp. 439-448.

[17] Robert Koppitz, Albin Kenel and Thomas Keller, effect of load history on punching shear resistance of flat slab, Journal of engineering structure, 90 (2015), pp. 130-142.

[18] Dominik Kueres, Carsten Siburg, Martin Herbrand, Martin Classen and Josef Hegger, uniform design method for punching shear in flat slab and column bases, Journal of engineering structure, 136 (2017), pp. 149-164.

[19] Dr. H. J. SHAH, Reinforced concrete Vol. II, Charotar Publishing house Pvt. Ltd, Gujarat, India.

[20] Dr. B. C. Punmia, Ashok Jain and Arun Jain, Reinforced concrete structures, Tenth Edition, Laxmi Publications Pvt. Ltd., New Delhi.

[21] M. L. Gambhir, Design of Reinforced Concrete Structures, PHI Learning Private Limited, New Delhi, 110001.

[22] P. C. Varghese, Advanced Reinforced Concrete Design, Second Edition, PHI Learning Private Limited, New Delhi, 110001.