Effects of Opening & Strengthening on Structural Behavior of Slabs-A Review

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ABSTRACT

The structural behavior of reinforced concrete flat plate is different as compared with beam supported slabs as flat plate is directly supported on columns. Sometimes the modification of the structure demands for the structural changes such as the removal of the portion of the slab, i.e. the opening in the existing slab or in the newly constructed work. The opening is required for the electrical and plumbing services, also required for the installation of lifts, escalators. The openings in slabs reduce the slabs load carrying capacity; shear capacity, stiffness, and ability to control deflection. The various strengthening techniques were introduced by researchers to restore the capacity of these mentioned parameters. The present study aims to review the effect of opening and various strengthening measures to restore the structural behavior of reinforced concrete slabs.

1. INTRODUCTION

The various reinforced concrete roofing systems are available as per the requirement which includes economy, aesthetics and other parameters. It includes reinforced concrete one way; beam supported two way and flat slabs .Apart from all the relevant considerations of importance structural stability plays a crucial role in the structural design of these elements. One of the conventional roofing adopted systems is the inclusion of beams between columns to support the slab which provides the required structural stability.

2. Punching Shear in Flat Plate Slab

Sunil kumar M. S and B. S. Suresh Chandra [1] stated the details for the purposes of design, two-way slab systems are divided into column and middle strips in two perpendicular directions. The column strip width on each side of the column centre-line is equal to 1/4 of the length of the shorter span in the two perpendicular directions. The middle strip is bounded by two column strips. ACI 318-052 permits openings of any size in any new slab system, provided you perform an analysis that demonstrates both strength and serviceability requirements are satisfied. As an alternative to detailed analysis for slabs with openings, ACI 318-05 gives the following guidelines for opening size in different locations for flat slabs. The guidelines for openings in flat slabs generally follow the recommendations for flat plates, but the chances of accommodating larger openings in Area near the columns are increased due to the lower shear stresses in the region of the drop panels. The percentage decreases in strength of slabs with openings are compared with slab without opening [1].

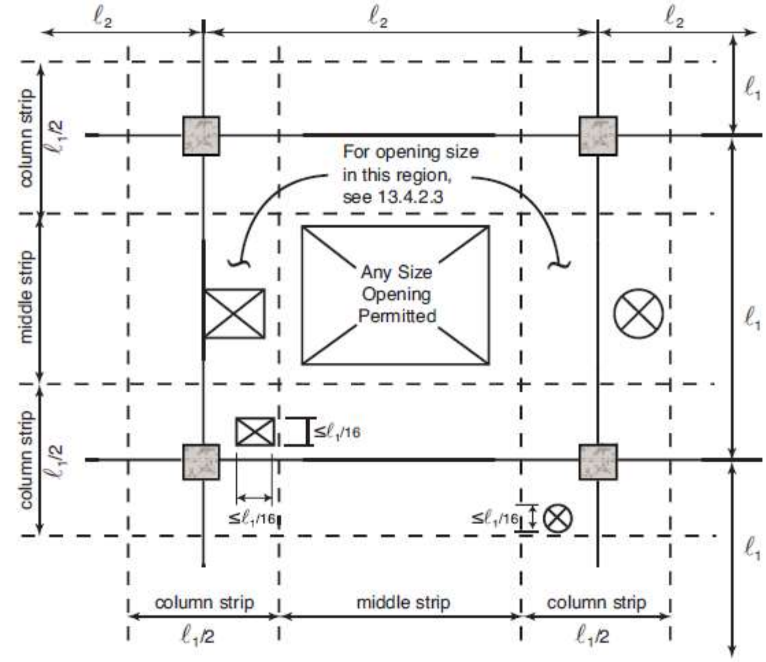

Figure 1 Suggested opening sizes and locations in flat plates with l2≥l1. [1]

Taehun Ha *et.al*, [2] ,the flat-plate slabs generally have low flexural stiffness compared with the conventional concrete slab-beam system and are susceptible to brittle punching shear failure. The punching shear capacity of flat-plate slabs can be dramatically reduced by the existence of openings. However, if the openings are near columns, the amount of concrete required to resist punching shear is reduced, and the layout of longitudinal reinforcing bars in the slab is interrupted, leading to reduced punching shear capacity. To avoid this problem, the openings may be intentionally moved away from the columns, or the slab may be thickened in the vicinity of columns. Nonetheless, there are situations where reduction of punching shear strength due to the openings is unavoidable. Thus, it is important to accurately estimate the punching shear strength of flat-plate slabs with openings. This paper experimentally evaluates the effects of openings on the punching shear strength of flat plates by considering the layout and number of openings as test variables. The failure characteristics of each specimen were examined, and the effects of the test variables on the shear strengths of the test specimens were investigated. The measured punching shear strengths of the test specimens were compared with the predictions of the ACI 318-11, CEB-FIP model code 1990/Eurocode 2 and fib model code 2010. The CEB-FIP model code 1990 and LoA II of fib model code 2010 can predict the punching shear strengths almost equal to the test results, while the predictions by ACI 318-11 and LoA I of fib model code 2010 are more conservative than those by the model code 1990 and LoA II.

Ahmed Aziz Abdulhussein [3] ,the six square reinforced concrete flat plates with dimensions of (1500×1500×100) mm were tested under a concentrated load applied on a column located at the center of the slabs. One of these slabs was the control specimen, whereas, in the others, steel angles (steel collars) were used, fixed at the connection region between the slab and the column to investigate the effect of the presence of these collars on punching shear strength.

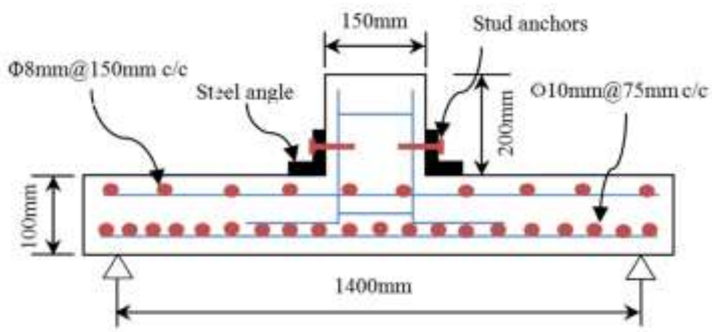

Fig. 2. Details of the tested specimens [3]

The results of the experimental study show that the punching shear resistance increased by 41 to 77% when steel collars were used. The experimental results were in good agreement with the numerical analysis acquired with the ABAQUS software [3].

3. Strengthening techniques for slab

Hazem M.F. Elbakry & Said M. Allam [4] , presented experimental and analytical study on the punching strengthening of reinforced concrete two-way slabs using external steel plates. One control slab was tested without strengthening; however, four tested slabs were strengthened using four configurations of square steel plates provided with steel anchor shear studs. The strengthened four slabs showed improved stiffness and punching shear capacity. The magnitude of improvement depended on the plate dimensions and the studs diameter and arrangement.

Figure 3 Steel plate with shear studs (S-5) [4]

Dina Hassan *et.al*.[5] , carried out test on Seven RC two way solid slabs with dimensions 1650×1650×80 mm and having central openings under four point static vertical loading. The slabs either had existing openings or openings were introduced under partial loading, after welding the steel reinforcement bars, to be cut to a steel frame provided on the perimeter of the opening. The experimental results show that by welding the steel bars to be cut to a steel frame surrounding the opening, before removing the concrete and cutting the bars, can ensure the same ultimate load like slabs with existing openings. However, the deflections of slabs with introduced openings are higher than those with existing openings.

Ali M. Al-hafiz,*et.al* [6] introduces a new technique to strengthen opening by using steel plates and steel connectors. The effect of thickness of slabs with an opening and thickness of steel plates which were used to strengthen openings on flexural strength of reinforced concrete one-way slabs were investigated and compared with other slabs without opening.

Fig. 4-Details of mold. Fig. 4-b: steel plate used for strengthening [6]

Test results showed that, The ultimate loads for slabs with unstrengthen opening less than the ultimate loads for slabs without opening by (23 to 27) %, and when steel plates were used to strengthen openings, the ultimate loads for slabs strengthen with steel plates of 2, 4 and 6mm thickness decrease by about (3.5 to 23) % of the ultimate loads for slabs without opening.

Mohammad Adil Dar, *et.al*.,[7] casted ten panels of size 1m*1m each were for the present study. One of the slab panels is treated as modal panel (control panel) with no opening, with which all the comparisons are to be made. The other nine panels were classified into three groups. The test results of the ten slab models are presented and discussed on the basis of comparison of load-deflections relationships. Comparisons made between the slab panels are made systematically. The study concluded that the deflection increases at the positions which are close to the openings, and decreases in the positions which are far from openings and continue in decreasing gradually. With 4% decrease in modal area the load carrying capacity reduces by about 16%, with 9% decrease in modal area the load carrying capacity reduces by 28% and with 16% decrease in modal area the load carrying capacity reduces by 32 %. Slabs having central openings fail under flexure, Slabs having corner openings fail under shear before flexure and Slabs having edge openings fail almost together in both flexure and shear.

H.M. Afefy & Tarek Mohamed Fawzy,[8] investigate the structural flexural performance of strengthened one-way reinforced concrete slab included cut-out, six slabs including cut-out adjacent to the central patch load in addition to one slab without cut-out as a reference slab were tested up to failure under incremental monotonic loading. The six slabs including cut-outs contained one control un-strengthened slab along with five strengthened slab. These slabs were strengthened using either Near Surface Mounted (NSM) steel bars or Externally Bonded Carbon Fiber Reinforced Polymer (EB-CFRP) at the tension side, while four out of them were strengthened by either NSM-steel bars (one slab) or an overlay of Engineered Cementitious Composites (ECC) material (three slabs) at the compression side. It can be concluded that end anchors for the EB-CFRP sheets along with the surface preparation before installing the ECC overlay are very important parameters in order to guarantee the optimum utilization for both the EB-CFRP sheets and the ECC overlay material.

N.Girish, N. Lingeshwaran [9] , aims to study the performance of reinforced concrete flat slabs equipped with different punching shear reinforcement parameters. Three flat slab specimens were cast where two specimens contain punching shear reinforcement in the form of shear stirrups and structural shearbands. The test specimens have length and width of 1000mm and thickness of 185mm for the slabs. The slabs are connected to a column at the center with length and breadth of 300mm and a depth of 700mm. The test specimens were supported by steel plates with length and breadth of 150mm and a thickness of 25mm at the four corners of the slab. The test specimens are loaded on the column face at the top. The deflection, strain and crack pattern were observed and recorded.

U. Ebead and H. Marzouk [10], This paper introduces a strengthening technique of two-way slabsusing steel plates and steel bolts. The effectiveness of two configurations of steel plates and four different arrangements of steel bolts were evaluated. The strengthened slabs showed an increase in stiffness and energy absorption. In addition, the ductility was slightly improved. The load-carryingcapacity of the strengthened slabs was increased by 56.55, 57.76,and 64.56% over that of the control specimen with slabs that had eight, 12, and 16 bolts, respectively. The control specimen's mode of failure is classified as a ductile punching shear failure, where the failure mode is neither pure bending (flexural) failure nor pure punching shear failure.

S.C. Floruț, *et.al*, **[11]** deals only with the experimental behavior and numerical modeling of such slabs, this representing the initial part of a larger study which aims to evaluate the shear capacity of such deficient slabs resulted from faulty design or execution and to identify viable and efficient strengthening solutions. The usually applicable solutions can be identified in the below Figure 6,7 , This research aimed to study the behavior of slab-column connections in RC flat slabs subjected to punching shear. The performances in terms of maximum load carrying capacity and stiffness degradation were discussed. At the same time, based on the testing procedure, the progression of cracks, damage and failure modes were highlighted [11].

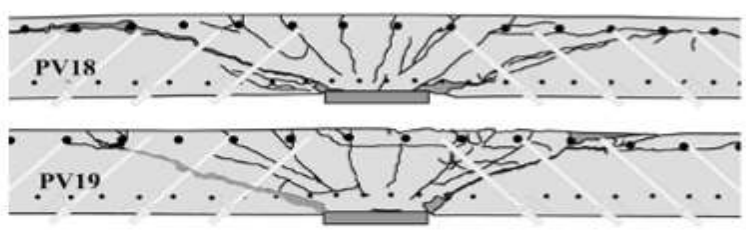

Figure 5. Failure of a RC flat slab under punching shear failure (Fernandez Ruiz, 2011) [11]

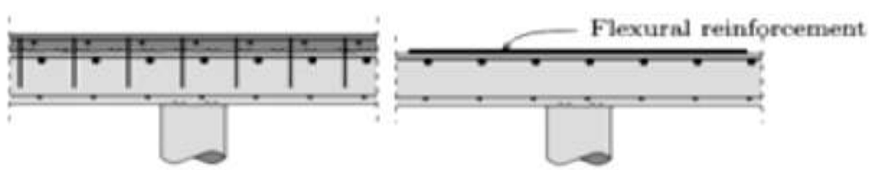

Figure 6. Usual applicable solutions for strengthening of deficient flat slabs against punching (Fernandez Ruiz, 2011) [11]

Figure 7. Usual applicable solutions for strengthening of deficient flat slabs against punching (Fernandez Ruiz, 2011) [11]

Conclusion:

The following conclusion can be drawn

i. The structural behavior introduces punching shear in reinforced concrete flat plate as the main concern.

ii. The shear reinforcement enhances the resistance against shear. The opening in the critical section or near the column should be properly strengthened

iii. Opening or cut out in slabs reduces the punching shear capacity; slabs load carrying capacity, stiffness, and ability to control deflection.

iv. The strengthening techniques improve the structural behavior of the slab.

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