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Structural Behavior of RC Slabs with Opening Strengthened with F.R.P

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Abstract - *In Reinforced Concrete (RC) structural upgrading, there are some instances where opening is needed to be punched through existing (RC) slabs to install new elevators staircases, elevators, escalators, windows and even electrical, heating or ventilation systems. But introducing opening in existing RC slabs can have a severely weaken slabs due to the cut of concrete and reinforcing steel. So, there are various approaches to strengthen RC slabs. These approaches may be requiring a significant usable floor, cumbersome and expensive. This article presents the exerted effort that are taken to understand the structural behavior of RC slabs with opening and the deterioration that happened due to the cut and how to strengthen it and also discussed different cases of opening in slabs.*

***Key Words*: RC Slabs, Openings, Fiber Reinforced Polymers FRP, Strengthening, Numerical analysis.**

1. INTRODUCTION

Reinforced concrete (RC) structures have to be adapted to comply with our living standards and/or legislation. Such modifications may include installing ventilation systems, electrical/heating ducts, staircases, escalators and elevators, all of which require to be cut into the RC slabs. These openings are essential to redesign the building for space efficiency and reuse for long-term conditions.

Openings are a source of weakness and can dependently reduce both the structures' stiffness and load-bearing capacity. The structural effect of the small openings is not considered in estimating the structural effect because the structure can redistribute the stress on it. On the other hand, large openings are done by a removal of concrete and reinforcing steel. This leads to lessening the ability of the structure to resist the stresses and it is needing to be strengthened.

So, a lot of ways are used to strength the slabs with opening. The traditional methods are one of them such as constructing concrete or steel columns beneath the opening or establishing load-bearing walls along these edges. But this method takes up a useful space and may not be convenient visually. On the other hand, Fiber Reinforced Polymers (FRP) has the ability to strength different structural elements without taking up a lot of space and this technique has been successfully tested to be used in strengthening of girders, slabs and beams in shear, flexure and also for some extents in torsion. The use of FRP to strengthen existing slabs and walls due to openings is becoming more popular, partly due to ease of installation and partly due to space and money saving, as well.

2. Opening RC Slabs According to Different Codes

The Egyptian code [1] put limitations and guidelines for making cut-outs in flat slab. It is possible to make cut-outs in the intersection between two middle strips, the maximum dimension of the opening is equal to 0.4 of the span, while for the intersection between a column strip and middle strip; openings in the intersection between column strip and middle strip can be cut with dimensions up to one-quarter of the span. Lastly for opening in the intersection area of two column strips the maximum dimension of the opening is equal to 0.1 of the span as shown in Fig. 1.

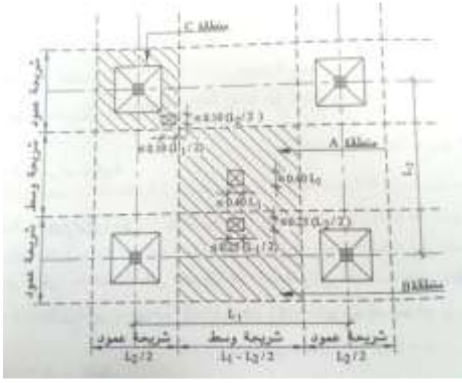

Fig -1: Suggested Opening area according to the Egyptian code [1]

The American Concrete Institute (ACI) Code [2] give limitations and guidelines for opening location and size. If the designer satisfies those requirements, the analysis could be waived. Modifications to an existing structure are not frequent but it is occurred according to user's requirements. New slab openings or cutouts in an existing concrete building are easily accommodated in the majority of instances. However, the analysis required, and the remedies are typically more involved than similar openings in a new slab. The purpose of these guidelines and limitations are to offer the structural engineer on selecting locations and sizes for openings in for both new and existing structures.

For opening in flat slabs, Fig. 2 illustrates the areas that are suggested where the openings can be made. Cause of the punching shear capacity of the floor around the column typically governs the design of flat plates, any openings in area 3 should be avoided as much as possible, but if there is a need to make an opening in this area for example installing a drainage pipe, the suggested opening size should not be larger than 30 cm, it should be noticed that openings in this area could reduce the critical section considered for resisting punching-shear as explained in ACI 318-02. The intersection between column and middle strips (area 2) is less critical than area # 3. So, the suggested openings having a width less than 15 percent of the span length can be made in this area.

While for opening in solid slabs, the situation is reversed for opening locations in solid slabs, openings in the intersection between two column strips (zone 3) can be cut with dimensions up to one-quarter of the span, while in the intersection between a column strip and middle strip (zone 2) openings are not allowable, for the intersection between two middle strips (zone 1) the maximum dimension of the opening is equal to one-eighth of the span. When removing entire panel of slab between beams, it is recommended to leave some overhang to allow development of reinforcing bars from adjacent spans. In this case the beams should be checked for torsion. The beams in this case may need to be strengthened.

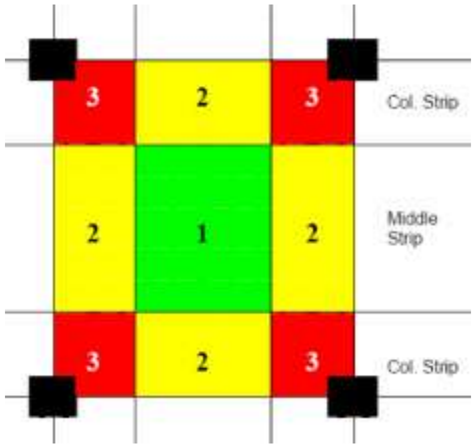

Fig -2: Suggested Opening area according to ACI [2]

For the Swedish code he Swedish code (BBK 04) [3] depends on the type of the load in determination the opening size of the slab, for the slab that is subjected to a uniformly distributed load, the allowable opening with a length of maximally 1/3 of the shortest slab span is defined as small, otherwise it is defined as a large opening. For some cases it is a must to make an opening in the slab more than where is stated in the different civil codes so there is a need to investigate the behavior of opening in slabs with different areas and locations.

3. Literature Review

Numerous efforts and tests have been exerted to examine the behavior of the structural members that are strengthened by using FRP , these tests showed that how strengthening slabs by FRP is convenient and effective , FRP has the ability to improve the strength and the stiffness of the member and it also have the ability to increase shear strength .

3.1 Experimental Examination of RC Slabs with Opening

Hamdy et al. [4] analyzed five one way RC slabs with the dimensions of 2000 mm long X 1000 mm width X 100 mm thickness and with a cantilever 700 mm long experimentally and numerically. All the slabs were reinforced with 10 steel reinforcement bars of 10 diameter, the description of their tested slabs was shown table 1.

Table -1: Description of tested slabs [4]

Group	Slab No.	Opening aspect ratio	Opening size (mm)	Use of CFRP sheets
Reference	S0	None	None	None
1	S1	1:1	200 X 200	None
	S2	2:1	200 X 400	None
2	S3	1:1	200 X 200	Around opening at tension surface
	S4	2:1	200 X 400	Around opening at tension surface

They concluded that the ultimate load capacity of slabs (S3) and (S4) increased by 10.7% and 9.7% comparing to slabs (S1) and (S2) respectively and also the deflection of slabs (S3) and (S4) decreased by 23% and 17% comparing to slabs (S1) and (S2) respectively, as it is shown in Chart.1

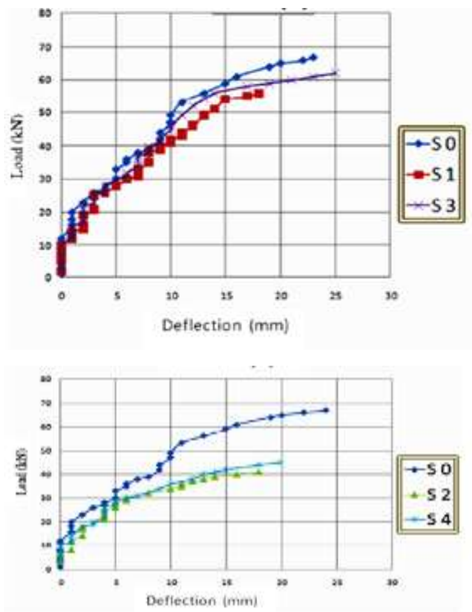

Chart -1: Load-Deflection curves for tested slabs [4]

Muhammed [5] tested eight self-compacting RC slabs to analyse the effect of using steel fibre and CFRP sheets. Results showed that using of CFRP sheets is more effective than using steel fibre, the load capacity for small openings increased by 26.67% and 46.67% for steel fibre and CFRP respectively, while the load capacity for large opening increased by 9.83% and 55.7% for steel fibre and CFRP, respectively.

Casadei et al. [6] presented experimental works on one-way slabs with openings strengthened with CFRP laminates, the test results showed that the use of CFRP laminates in slab strengthening was effective and there was an approximate increasing in load capacity by 30% and shear failure was found to be the controlling mechanism when the openings were placed in the negative moment region of one-way slabs.

Koh et al. [7] experimented five slabs with dimension 1100 mm length X 300 mm width X 75 mm with a rectangular opening of dimension 300 mm length X 150 mm width. All slabs were reinforced with 8 steel reinforced bars of diameter 10 mm, the slab details are presented in Fig.3, whereas S1 is a control slab. Where S3 were reinforced by additional rectangular bars surrounding the opening, S4 were provided by additional diagonal bars at the opening corners and S5 were enhanced with both additional rectangular bars surrounding the opening and additional diagonal bars at the opening corners. Test results revealed that, additional rectangular bars surrounding the opening is the most effective detailing as S5 gained the highest flexural strength. S5 reached 16.2%, 7.4% and 12.3% higher flexural strength compared to S2, S3 and S4 respectively. As it is shown in Chart 2.

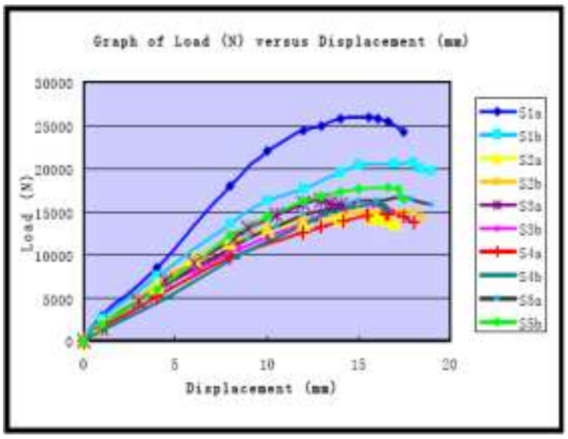

Chart -2: Load-Deflection curve of tested slabs [7]

Elgabbas et al. [8] experimented different methods of strengthening at slabs with prestressed concrete. They tried to find the best strengthening technique throughout various strip thickness and width. The results showed that there is an increase in load capacity between 15% and 80% and there is no significant change in the maximum displacement value.

3.2 Numerical Investigation of RC Slabs with Opening

Hossam [9] used Finite Element Analysis (FEA) by sing ANSYS 5.4 program with a nonlinear concrete method of a complex support conditions to foretell the ultimate loads of different kinds of slabs. He chose the support condition as the parameter of the study. The results showed that the deflection of the slabs with opening that fixed on all four sides was about 5.6% of that simply supported on the all four sides. Also; the deflection of slabs that are fixed at two opposite sides and fixed-free at the other two sides was about 9.6 of that simply supported at two opposite sides. The value of normal stresses distributions were greatly affected by opening in slabs especially at the opening zone.

Ahmed et al. [10] carried out a numerical simulation by using ANSYS to the design coefficients for the column and the field strips of the internal panel of a waffle slab and to study the response of waffle slabs with and without openings and. He also studied the effect of openings and stiffening ribs on the design coefficients. The linear modeling results were used to study the coefficient of moments before cracking, while the nonlinear models were used to calculate the coefficient of moment at ultimate loads. Finite element models were used to study the effect of slab thickness, location on the coefficient of moments, opening size and column size. The results showed that the value of the moment coefficients obtained from the linear analysis was higher than the values of the moment coefficients of that obtained from the nonlinear analyses. Also by increasing the solid portion size, it was found that the negative moment coefficient of the column and field strips increased for column strips and field strips, whereas the positive moment coefficient of the column and field strips decreased for column strips and field strips.

Sheetal and Itti [11] used (FEA) of RC slab models to study the displacement and stresses variations, in slab with different boundary conditions. Non-Linear static analysis was executed by using ANSYS 10 Software and a rectangular RC slabs with tensile reinforcement was analyzed. Comparing the slabs with different boundary conditions both with and without opening, the slab simply supported on all the edges shows highest displacement and slab fixed all the edges shows least displacement. The slab having fixed support on all the edges with and without opening shows highest stresses, whereas slab simply supported on all edges shows least stresses among all other slabs.

Anjaly and Preetha [12] used (FEA) to examine the structural behavior of waffle slabs with and without openings and the effect of openings sizes and locations on the ultimate loads. The results showed that the size of openings in the region bounded by two column strips should not be exceeded to 10% of the column strip width while in the region bounded by a column strip and a middle strip, size limit is 20% of the column strip width. But for the region bounded by two middle strips, no such limitation has been found in opening size leading to a conclusion that in this region, opening size can be even up to 40% of the width of column strip. It was concluded from the results that special measures have to be taken to improve the performance of waffle slabs having large openings in the regions bounded by two column strips and that bounded by a column strip and middle strip.

4. CONCLUSIONS

The following conclusions from the previous literature review can be drawn, as:

- Investigating numerically the structural behavior of RC slabs un-strengthened with openings.
- Investigating numerically the structural behavior of RC slabs strengthened with FRP
- Studying different parameters that are affected on the behavior of both un-strengthened and strengthened slabs with FRP.

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