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Effect of Openings on Multi-Panel Flat Slab With CFRP Bars: A Numerical Analysis

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A B S T R A C T

Often designer needs require making openings in concrete slabs to provide extra service .Therefore it was necessary to study the size and the location of the opening in the slab and show the effect of it in the behavior of the slab. The aim of this study was to carry out nonlinear finite element analyses modeling of concrete slabs reinforced by CFRP bars and determine the effect of size openings on the structural behavior of the flat slabs in consideration, by using the ANSYS 19 program. All models were 3 by 3 panels of square flat slabs; each of them had dimensions 4000 x 4000 mm with a marginal beam and reinforced by carbon fiber polymer bars.
At first, the dimension of the opening is studied by taking 2000 x 2000mm, 1000 x 1000mm and 800 x 800mm in the field strip. The second case of study was the location of the opening in different position of the slab to choose the best location of it. The flat slab was analyzed without openings and with different size openings for comparison.
Finite element verification was made by comparing experimentally tested CFRP concrete slab with central opening with numerically solved specimen and showed good agreement. Results indicated that slabs with openings in the field strips possess better stiffness. The ultimate loads for slabs with central opening at the central panel decreased to around 14% of that without opening .In case of central opening at corner panel, the ultimate loads revealed higher reductions in ultimate load that reached 33% of that of the slab without opening.

1. Introduction

Flat slab is one of the most widely used structural systems nowadays due to its many features, the most important of which are capable to carry concentrated and distributed loads, requires less formwork and as reinforcement detailing as simple and easy to place and better quality control. In many cases, we need to make an opening inside the flat slab that reaches to eliminate a large area of it, in order to make elevators, stairs, or air conditioning….etc. Therefore, the need to determine the locations and sizes of the openings predetermined in the early stages of design accommodate them accordingly. However, the analysis required, and the remedies are typically more involved than similar openings in flat slabs. The utilization of fiber reinforced polymer bars for concrete structures and constructions exposed to

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corrosive environments (tanks and irrigation structures) have proven to provide high tensile strength and exceptional corrosion resistance, Due to the lower modulus of elasticity sections possess greater bending stiffness; hence deformations are largely reduced when cracked under loads [1–4] .

This study investigated the effect of openings in flat slab on the deflection, ultimate load and cracking load and compared it with flat slab without openings and also presented the crack of flat slab by use the most of one suitable finite element software ANSYS 19. Therefore it was necessary to study the size and location of openings in concrete slabs reinforced by fiber polymer. Dhipanaravind and Sivagamasundari [5] used the finite element to conduct numerical studies on the flexural behavior of concrete one-way slabs reinforced with hybrid (steel, FRP) bars. They found that the hybrid rods exhibited a linear elastic behavior up to failure with a modulus of elasticity lower than steel bars, and that the slab reinforced with hybrid FRP bars experiences greater deflection than the conventional slab.

Mohd et al. [6] investigated the effect of FRP bars in slabs by using experimental work with BFRP and steel bars. The results showed that all specimens failed due to punching shear, and that strengthened specimens, whether with steel links or BFRP reinforcement, increased the number of redial cracks, and that the yield strength of BFRP bar was significantly higher than that of steel bar..

According to the results of a theoretical study by Chee et al. [7] openings in square slabs with fixed ends had little effect on the ultimate load capacity up to a 0.3-times opening size; however, at a 0.5-times opening size, that ultimate load capacity skyrockets dramatically. Sajjad et al. [8] studied the deflection and cracks pattern by ABAQUS based finite element in beams strengthened by FRP bars, the numerical results showed that the developed model can be an effective tool to predict the performance of retrofitted beam under dynamic loading and the concrete beam reinforced with CFRP bars have higher quasi-static load capacity than that with GFRP bars.

Researchers have studied the effect of using FRP in bridges which indicates superior performance of slabs under dynamic loads, exhibiting a 26% to 111% increase in slab capacity, a 55% increase in flexural stiffness, and an increase in tensile strain when compared to steel reinforced slabs [9-17].

This study investigated the effect of openings when the varying areas and locations in the flat slab reinforced by CFRP bars. Also recorded the value of the deflection in three points and present the crack on flat slab. One of the most suitable finite element methods is ANSYS 19 because it is capable of analyzing the nonlinear behavior of a combination between 3D SOLID (concrete) and LINK elements (CFRP) bars in a structure based on the finite element procedure which can be utilized to describe the actual nonlinear behavior of flat slab with openings.

2. Finite element analysis

2.1 Element Types

To prepare the numerical model, elements in ANSYS library were used, which contains more than 150 different types of elements.

Solid elements were used in the definition of concrete in 3-D, 8- node and consists of z-nodes in ANSS 19 and it is called Solid 65, one of its most important features is its ability to calculate non-linear materials as it can consider crushing in three perpendicular directions, plastic deformation, and creep, as well as It is defined by eight nodes with three degrees of freedom in each node in the X, Y and Z directions as shown in Fig.1.

Link 180 was used in the modeling of carbon fiber polymer (CFRP) bars, and one of its most important features is that it has uniaxial pressure and tension and has three degrees of freedom at each node in the directions of the X, Y, and Z, in addition to being able to deform the plastic. Fig.2 shows the geometry of LINK180.

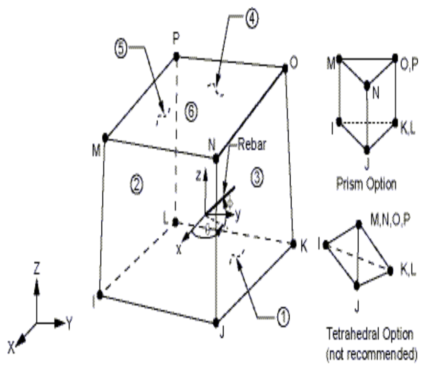


Fig. 1. Solid 65 3D-reinforced concrete solid element, ANSYS 19

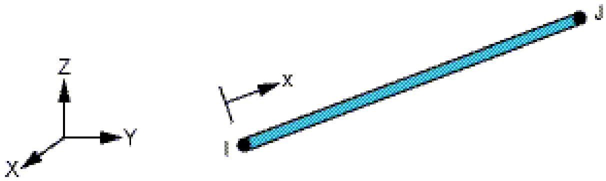


Fig.2. The geometry of LINK180

3. Modeling Verification

This experimental investigation, studies the effect of using CFRP bars as reinforcement for two way slab at dimension 1100 x 1100 mm with a square central opening 250 x 250 mm. Shown in Fig.3 and Fig.4 [18]

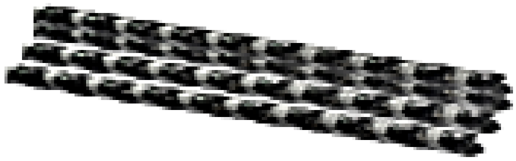
The slabs were tested under simply supported conditions and subject to four symmetrical concentrated loads as shown in Fig.5. The deflections were measured by using two (linear vertical displacement transducers) were placed at the tension face of the slab, one at mid side of the opening at under the force applied. The study would exhibit values of the ultimate loads, deflections, crack patterns, and failure modes.

Fig.3. Reinforcement in the wooden form

Fig.4. Finish of casting process at the concrete slab with central opening

Fig.5. Loading arrangement and test setup

The concrete used was normal concrete at 32.2 MPa compressive strengthen, which was the average of the concrete mix contained. The Reinforcement bars Ø 4 mm were used high tensile CFRP bars of 1600 MPa as shown in Fig.6.



. Fig. 6. Reinforcement bars

3.1 Material Properties

In order to model in ANSYS 19, the most be defined material properties as concrete and reinforcement bars.

3.1.1 Concrete

In verified ANSYS R.C model, concrete properties are defined as stated in the following Table1.

Table1. Material parameters of concrete

Description	Value
Modulus of elasticity E_c	24311 N/mm^2
Poisson's ratio(PRXY)	0.2
Open crack shear transfer coefficient	0.26
Closed crack shear transfer coefficient	0.9
Uniaxial Cracking Strength (ft) = 0.1 fcu	3.2 N/mm^2
Uniaxial Crushing Strength (fc) = fcu	32N/mm^2

3.1.2 Reinforcement Bars

The parameters used to identify the properties of reinforcement bars the verified ANSYS concrete slabs, the specimens were using CFRP bars ,the reinforcement element was assumed to be a bilinear isotropic elastic-perfectly material and identical in tension and compression as shown in Table 2.

Table2. Material parameters of concrete

Description	Value
Modulus of elasticity E_c	121212 N/mm^2
Poisson's ratio(PRXY)	0.3

3.1.3 Meshing

A sweep command was used to mesh all volumes, all meshes are rectangular. The element type number, material number and Real constants set number were set for each mesh. The crushing hardness factor (CSTIF) for concrete is 0.02. LINK180 had two main real constants; Cross-sectional area and added mass. Both tension and compression capacities were selected. Real constants at bars with diameter 4 mm was cross-sectional area of 12.56 mm^2.

The maximum meshing dimension for model is 20x 20 mm.

3.1.4 Loads and Boundary Conditions

According to experimental work, the modeling analysis was hinged supported on four edges. The load was applied as a vertical displacement in Y direction instead of forcing load to get a good representation of the curves after the peak point.

3.1.5 Results and Discussion

The analytical results for the numerical analysis were presented and compared with experimental values. Fig.7 shows the Load-deflection of the numerical analysis and the experimental work. Fig.8 shows the slab cracks pattern of the numerical analysis and the experimental work. As well as Table 3 show a comparison between the numerical analysis and the experimental work slab.

Table3. Comparison between the verification model and the experimental tested slab

Slab	Experimental work	Numerical analysis
Ultimate load (kN)	85.52	83.62
Deflection (mm)	16.4	18

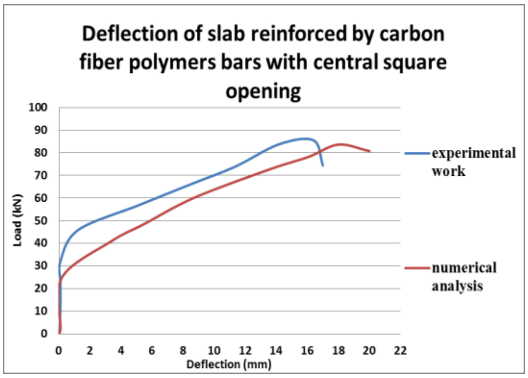


Fig. 7. Load-deflection of the numerical analysis and the experimental tested slab

(a) (b)

Fig. 8. Comparison of crack pattern between experimental work and numerical analysis
(a) experimental work. (b)numerical analysis

4. Modeling Parametric Study

The research consists of six square slabs of dimensions 12000mm and 150mm thickness; with marginal beams were dimension at depth 500mm and width 250 mm. One flat slab without opening, three flat slabs with square opening at dimension 1000 x 1000 mm in different locations and two slabs with square opening at dimension of the opening is 2000 x 2000mm and 800 x 800mm in the field strip shown in Fig .9, Fig.10 and Table 4.

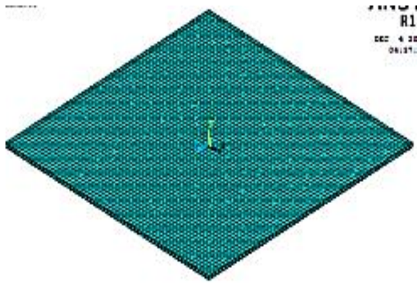


Fig. 9. 3D Model of flat slab without openings

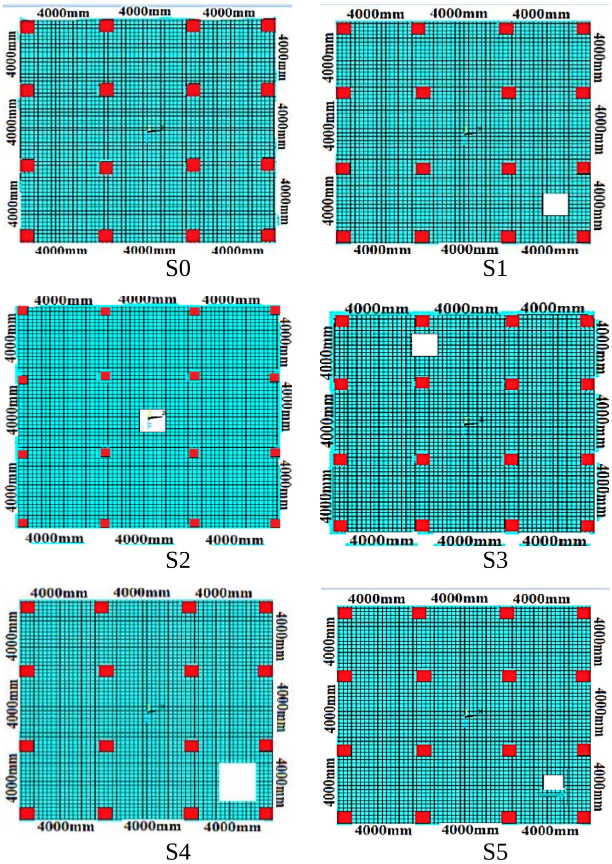


Fig.10 .Location of the openings(all columns (300 x 300mm)

Table4. Location of openings at specimens of parametric study

Specimen No.	Location of openings	Dimension of opening (mm)
S0	Without openings	-
S1	With opening in corner panel of slab (field strip)	1000 x 1000
S2	With opening in centre of slab (field strip)	1000 x 1000
S3	With opening in column-field strip	1000 x 1000
S4	With opening in corner panel of slab (field strip)	2000 x 2000
S5	With opening in corner panel of slab (field strip)	800 x 800

4.1 Material Properties

In order to model in ANSYS 19, the most be defined material properties as concrete and reinforcement bars.

4.1.1 Concrete and CFRP Reinforcement Bars

The concrete and reinforcement bars properties were mentioned in Table.1 and Table.2 respectively.

4.1.2 Meshing

All models meshes are rectangular. The crushing hardness factor (CSTIF) for concrete is 0.02. LINK180 had two main real constants; Cross-sectional area and added mass. Both tension and compression capacities were selected. Real constants at the modeling for bar with 12 mm diameter with cross-sectional area of 113mm^2 and real constant at the marginal beams were upper and lower reinforcement bars 12 mm with cross-sectional area of 113 mm^2.The maximum meshing dimension for models at parametric study was 100x 100 mm.

4.1.3 Loads and Boundary Conditions

Columns were modeled with multiple hinges simulating total fixation to reduce model size and analysis time, and marginal beams were modeled with hinges at four edges in the modeling. The load was applied as distributed load at area surface of slab.

4.1.4 Results and Discussion

The results of the parametric study of the numerical analysis are evaluated and discussed in this section. The models were used to calculate the deflection at directly next to the opening of the different openings and exhibit crack patterns of slab with openings in comparison with slab without opening.

4.1.4.1 Effect of Opening Location

Three points were chosen at the same locations for all slabs to check deflection and cracking loads, chosen point numbers are illustrated at Fig. 11

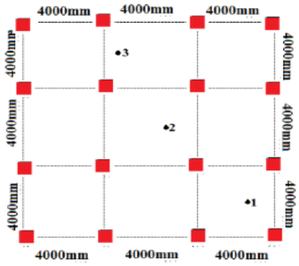


Fig. 11.Location at all point of all slabs

The load versus deflection curve for each opening is compared with the slab without an opening for the three separate opening cases. The values of the crack load, the ultimate load and deflection of all case (with and without openings) are considered for comparison. The load deflection relationship of the slab at point 1 showed a non–linear behavior in Fig.12, it can be divided in two stages non-cracked and cracked. The first stage represents the behavior before cracking of concrete to reach the peak; the second stage follows the cracking till the ultimate load at failure is reached. Descending branch after the ultimate load is reached at Fig.13

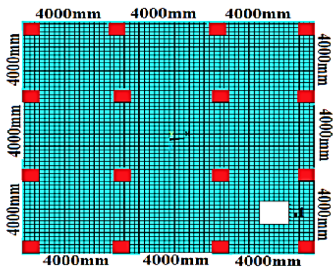


Fig. 12.Location at deflection at point 1

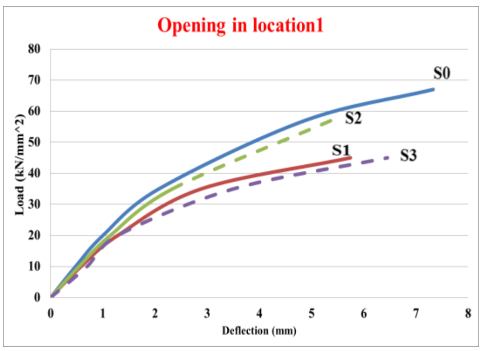


Fig. 13. Load-deflection curves for concrete slabs at point 1

Fig. 14 shows as load deflection curves of concrete slabs at point 2 shown in Fig.15. The slab with opening in center slab is better performance than all slabs with opening, that this maximum ultimate loads value and deflection value.

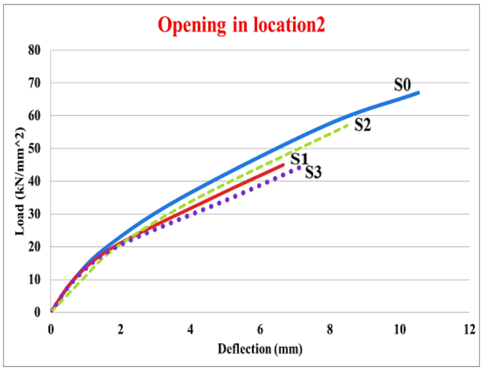


Fig 14. Load-deflection curves for concrete slabs at point 2

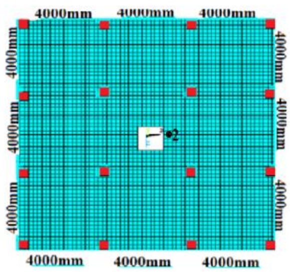


Fig. 15. Location at deflection of point 2

Finally, Fig.16 shows as load deflection curves of concrete slabs at point 3 shown in Fig.17. The performance in slab with opening at column feild strip is less than all slabs with opening.

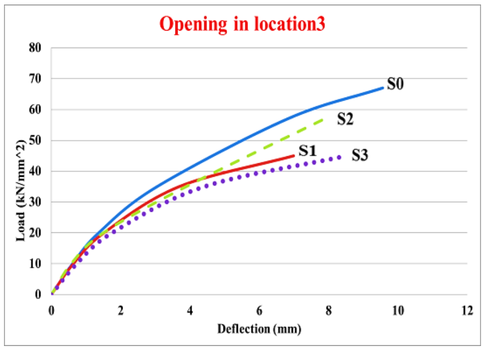


Fig. 16. Load-deflection curves for concrete slabs of point

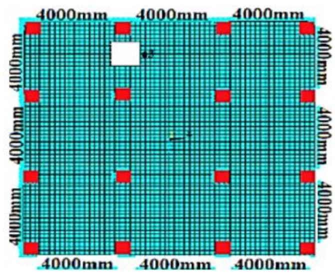
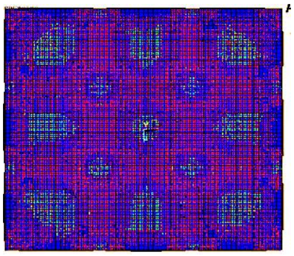


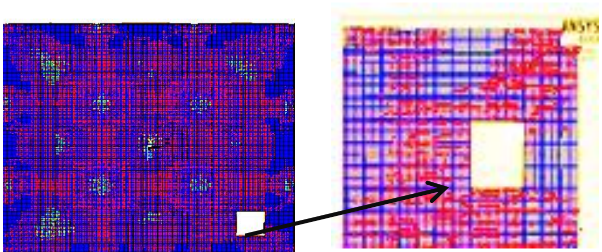
Fig. 17. Location at deflection of point3

Fig.18 shows the crack pattern of analytical tested slabs of slabs with opening and without opening and shows cracking around openings.

Shows all the cracking distributed around corner of openings and increase around opening at column field strip. The cracks are regular and horizontal around the opening in the center of the slab.

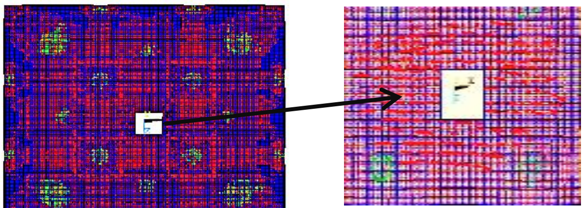


(a) S0



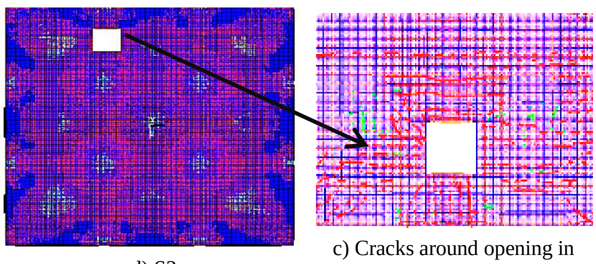
(b) S1

(c) Cracks around opening in S1



(d) S2

(e) Cracks around opening in S2



d) S3

c) Cracks around opening in S3

Fig. 18. Crack pattern for Concrete Slabs

The polymer fiber reinforced panels were tested with or without openings under the influence of a uniformly distributed load until reaching the failure loads and recording the values of the first crack load, ultimate load and deflection for all panels as shown in Table 5.

Table5. The crack load (Pcr), ultimate load (Pu) and deflection at models

Chosen point	Slabs	Load at chosen point (kN) Pu	Load at chosen point (kN) Pcr	Deflection at chosen point (mm) At Pu	Deflection at chosen point (mm) At Pcr	Increase at failure loads (%)
Point (1)	S0	67.5	35	7.3	2.7	0
	S1	45	30	5.4	2.2	33
	S2	58	30	5.3	2.1	14
	S3	45	32	5.5	2.2	33
Point (2)	S0	67.5	15	7.3	1.7	0
	S1	45	20	5.4	2	33
	S2	58	11	5.3	1.9	14
	S3	45	20	5.5	2	33
Point (3)	S0	67.5	35	7.3	1.4	0
	S1	45	20	5.4	1.7	33
	S2	58	18	5.3	1.5	14
	S3	45	21	5.5	1.7	33

4.1.4.2 Effect of opening dimension

The effect of changing the dimensions of openings in flat slab reinforced by CFRP bars is shown during the analysis of the load –deflection curves in Fig. 19. It has been measured the deflection near opening. In Table 6 shows as details of opening in field strip.

The large openings in dimension 2000 x 2000 mm shown that brittle failure, the ultimate load were 45 kN/mm^2 and deflection at 2.48 mm and the cracking load were 39.8 kN/mm^2.The effect of small opining at dimension 800 x 800 mm, ultimate load at were 47 kN/mm^2 and deflection at 3.2 mm and the cracking load were 35 kN/mm^2. Shown that the measured deflection at directly next to opening, for larger openings the area loaded is reduced and the point for measuring deflection is near to the support and this may leads to smaller values of deflection.

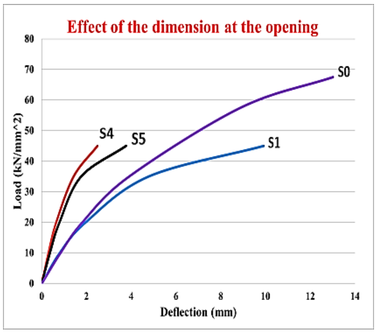
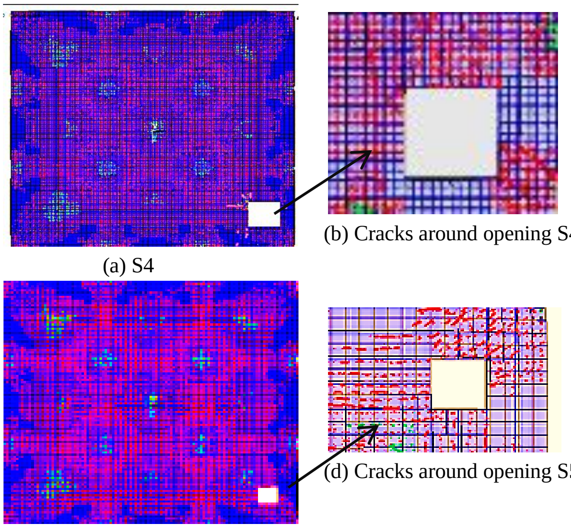


Fig. 19. Load-deflection curves for concrete slabs.

Table6. Details of opening, crack load, ultimate load and deflection of all slabs model

Slabs	Dimension of openings	Crack load at slabs (kN/m^2)	Ultimate load at slabs (kN/m^2)	Deflection at ultimate load (mm)
S1	1000 x 1000	25	45	9.
S4	2000 x 2000	39	45	2.48
S5	800 x 800	35	47	3.2

Fig. 20 shows the crack pattern for two slabs with opening in field strip at dimension of opening in S4 were 2000 x 2000 mm and dimension of opening in S5 were 800 x 800 mm.



(a) S4 (b) Cracks around opening S4

(c) S5 (d) Cracks around opening S5

Fig. 20. Crack pattern for Concrete Slabs

5. Conclusion

This paper is intended to investigate the impact of the presence of location and size of opening in flat slabs reinforced by CFRP bars. Using six flat slabs, observations of the experimental, the numerical analysis and verification models, the following were concluded:

1. The presence of the openings in the RC flat slabs reduces the load carrying capacity and reduces their stiffness also increasing the opening dimensions lead to reduction of the slabs efficiency compared to the slab without openings.
2. When increasing the opening dimensions impairs the bearing capacity of slab and reduces its efficiency.
3. It is recommended not to make any openings in the slabs especially in the corner panel of slab.
4. The location of the opening in the center showed higher stiffness than all slabs with an opening reinforced by CFRP bars. The ultimate load of the slab with central opening was 14% of that of the slab without opening.

References

[1] A. F. Ashour, "Flexural and shear capacities of concrete beams reinforced with GFRP bars", Construction and Building Materials Vol. 20, No.10, pp.1005-1015, 2006.

[2] I. F. Kara, and A. F. Ashour, "Flexure design methodology for concrete beams reinforced with fibre-reinforced polymers". Compos Struct, Vol. 94, No.5, pp.1616-1625, 2012.

[3] H. A. Rasheed, R. Nayal, and H. Melhem, "Response prediction of concrete beams reinforced with FRP bars", Composite Structures, Vol. 65, No.2, pp.193-204, 2004.

[4] S. D. Sivagamasundari, "Flexural Behaviour of Concrete Oneway Slabs Reinforced with Hybrid FRP Bars", International Journal of Applied Engineering Research, Vol. 13, No. 7, pp. 4807-4815, 2018.

[5] M. T. Khan, M. Raja, M. S. Ansari, A. M. Ansari, K. R. Saud, U. H. Momin, and S. Ibrahim, "Experimental Investigation of Punching Shear on FRP Strengthened Slab", Journal Impact Factor, Vol. 3, No.191, 2018.

[6] C. K. Ng, T. J. Edward, and D. K. T. Lee, "Theoretical evaluation on effects of opening on ultimate load-carrying capacity of square slabs", Electronic Journal of Structural Engineering, Vol. 8, pp. 12-19, 2008 .

[7] S. Roudsari, S. Hamoush, S. Soleimani, T. Abu-Lebdeh, and M. HaghighiFar, "Analytical study of reinforced concrete beams strengthened by FRP bars subjected to impact loading conditions", arXiv preprint arXiv:1806.06929, 2018.

[8] Y. Toutanji, "Deflection and crack-width prediction of concrete beams reinforced with glass FRP rods", Constr. Build. Mater. Vol, 17, pp. 69–74, 2003.

[9] M. T. Junaid, A. Elbana, S. Altoubat, and Z. Al-Sadoon, " Experimental study on the effect of matrix on the flexural behaviour of beams reinforced with Glass Fiber Reinforced Polymer (GFRP) bars", Composite Structures, Vol.222, No.110930, 2019.

[10] M. N. Habeeb, and A. F. Ashour, "Flexural behaviour of continuous GFRP reinforced concrete beams, Journal of composites for construction", Vol.12, No.2, pp.115-124, 2008.

[11] H. A. Abdalla, "Evaluation of deflection in concrete members reinforced with fibre reinforced polymer (FRP) bars", Composite structures, Vol.56, No.1, pp.63-71, 2002.

[12] M. A. Adam, M. Said, A. A. Mahmoud, and A. S. Shanour, "Analytical and experimental flexural behavior of concrete beams reinforced with glass fiber reinforced polymers bars", Construction and Building Materials, Vol.84, pp.354-366, 2015.

[13] R. A. Hawileh, and M. Z. Naser, "Thermal-stress analysis of RC beams reinforced with GFRP bars". Composites Part B: Engineering, Vol.43, No.5, pp.2135-2142, 2012.

[14] Q. S. Khan, M. N. Sheikh and M. N. Hadi, "Tension and compression testing of fibre reinforced polymer (FRP) bars", 2015.

[15] Piotr,"Two -way concrete slabs with openings" Master of Science Programe, lulea university of technology , Depatment of Civil and environmental Engineering, ISSN:1402-1617,

[16] M. Mohammadi, and F. Nikfar, "Strength and stiffness of masonry-infilled frames with central openings based on experimental results", Journal of Structural Engineering, Vol.139, No.6, pp.974-984, 2013.

[17] M. Mahlis, A. E. Shoeib, S. Abd Elnaby, and A. Sherif, "The Effect of Cutting Openings on the Behavior of Two-way Solid Loaded Slabs", Elsevier, Vol. 16, pp. 137-149, 2018.

[18] H. E. Abd-EL-Mottaleb, L. A. Aboul-Nour, M. Y. Zaghlal, and R. E. EL-Daly, "Effect of Openings on Concrete Slabs Reinforced by Fiber Polymer Bars", Design Engineering, ISSN: 0011-9342, Issue: 8, pp. 4217-4231, 2021.