Improving Punching Shear Behavior of Flat RC Slabs

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Abstract: This work presents a technique to improve punching shear behavior of flat RC slabs that develop cracking at regions between the slab and column due to error of design or construction. The work examines the improvement of the punching resistance due to repair of the slabs using glass fiber wrappings. The study consists of an experimental part and a theoretical part. The experimental work divides the test specimens into two groups (A & B). The first, Group (A) includes three specimens of reinforced concrete slabs having a compressive strength (35 N/mm2). This specimens rest on columns .The second group, Group (B) is similar; however, it has a compressive strength of (17 N/mm2). Tow reference specimens were loaded until failure and four specimens were loaded up to 80% and 50% of failure load. After being unloaded, these four specimens were repaired using glass wrapping then loaded to failure. The deflection, cracking, failure modes, strain in steel reinforcement and relationship between load deflection andload-strain were recorded and discussed. Results show that repair using GFRP enhanced the shear capacity of the tested specimens. Enhancement was more noticeable for 35 N/mm2 specimens. In the analytical study, the specimens were modeled using (ANSYS) computer program based on finite element analysis system. Fair agreement was found between the experimental and the theoretical results.

[Omar El-Nawawy, Ayman Hussein Hosny, Eiad H.Zahran and Hamada Ali Hamada Mohamed. **Improving Punching Shear Behavior of Flat RC Slabs.** *J Am Sci* 2015;11(7):122-129]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 15

Keywords: Glass Fiber Reinforced Polymers, Slab-Column connections, Punching Shear, Retrofit and Repairing.

1. Introduction:

Punching is a shear failure and one of the most critical phenomena for flat plat building system within the discontinuity region of the highly stressed slab at the column. An inclined crack forms around the column and finally the column with a punching cone separates from the slab as shown in figure (1).

Most researches showed the capability of increasing the resistance of punching shear for flat RC slabs by increasing the thickness of RC slab or by adding steel to the resistance of the shear However these techniques is required to be done during construction .This thesis present a technique to improve punching shear behavior of flat RC slabs which had cracks at connecting region between the slab and column due to error at designing or constructing and it can be repaired by using glass fiber.

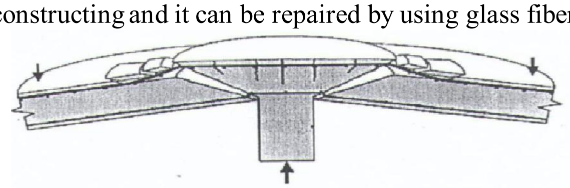


Figure (1): Punching Failure of Slab-Column Connection

This paper forms part of a wide research program conducted at the Reinforced Concrete Laboratory of the Department of Structural Engineering at Ain Shams University, investigating the improving punching shear behavior of flat RC slabs by using glass fiber.

Experimental Program

Details of the Test

The experimental work divides the test specimens into two groups (A & B). The first, Group (A) includes three specimens (S & S80 & S50) of reinforced concrete slabs dimensions (1250x1250) mm2 and thickness ts=120mm having a compressive strength (35 N/mm2). This specimens rest on columns dimensions (150 x 150) x 400. The second group, Group (B) (L& L80& L50) is similar; however, it has a compressive strength of (17 N/mm2). Tow reference specimens (S & L) were loaded until failure and four specimens (S80 & S50 & L80 & L50) were loaded up to 80% and 50% of failure load. After that, four Specimens (S80 & S50 & L80 & L50) of were repaired by using glass fibers then reloaded until failure.

2. Materials Properties and Concrete Casting

The flexural reinforcement for all slabs consisted of 15 ϕ 10 each direction, plus 8 ϕ 10 each direction as add reinforcement. The Stub column was casted monolithically at the slab center with a cross section of 150 mm × 150 mm and 400 mm height.The reinforcement of the stub column was 4 ϕ 16 and the stirrups were 8 ϕ 10 as shown in Fig (2).

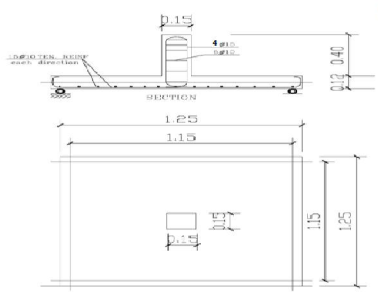


Figure (2): Detail of Reinforcement of Slabs

Table (1): Concrete Mix Constituents (35N/mm2)

Constituents	Contents (kg/m^3)	Proportions
Cement	325	1.00
Sand	600	1.85
Crushed stone grade (1)	600	1.85
Crushed stone grade (2)	600	1.85
Water	170	0.45

Table (2): Concrete Mix Constituents (17N/mm2)

Constituents	Contents (kg/m^3)	Proportions
Cement	275	1.00
Sand	650	2.36
Crushed stone grade (1)	550	2.00
Crushed stone grade (2)	550	2.00
Water	150	0.55

Wooden forms were used. They were coated with oil film before concreting the reinforcement was then placed in their position in the forms. Special supporting bars are placed to hold the reinforcement at the proper position and were removed soon after the concrete was poured. Concreting took place immediately after mixing. A mechanical vibrator was used in placing the concrete around the reinforcing bars together with the hand tamping and rodding to ensure full compaction.

Slabs were left in forms for 24 hours after which the sides of the forms were stripped away. The specimens were sprinkled with water for the next week. Then they were left in the ordinary atmosphere of the laboratory for 28 days before testing.

Figure (3): Details of Specimens Casting Forms

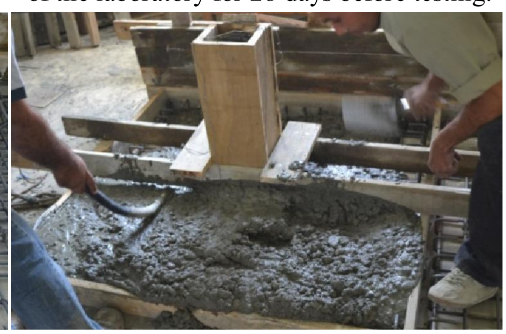


Figure (4): pouring concrete in slabs

Instrumentation

The deflection of the slab was measured with a linear voltage differential transducer (LVDT). Special arrangement was designed for each dial gauge to fix it in the desired position at the bottom face of the slab (tension side) to ensure proper readings and verticality. The LVDTs positions of the control specimen as shown in Fig (5)

To record specimens concrete vertical deflections, vertical LVDTs were used below slab-column specimens at two different locations measured from centerline of the slab as shown in Fig (6).

Fig (5): Locations of vertical LVDT'S

Fig (6): Locations of vertical LVDT'S

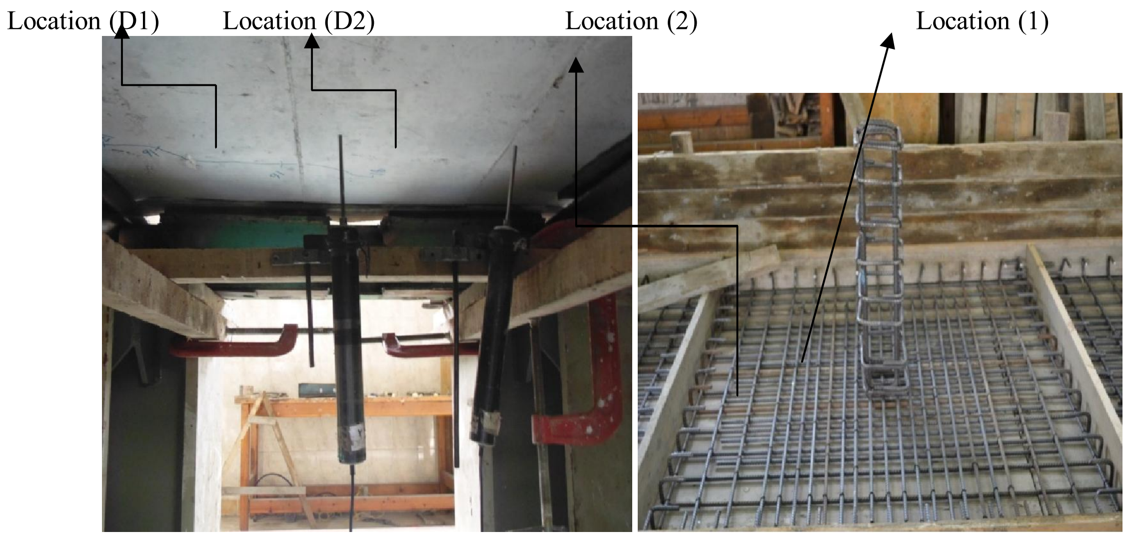


Fig (7): location of deflection Fig (8): Steel Strain Gauges Positions

The deflection was measured at two locations as shown in Fig (7)

1-At the center of the Specimen (D1)

2- At distance of 30 cm from the center of the specimen (D2).

The steel strain was measured at two locations for test slab are shown in Fig (8).

Test Setup and Loading Scheme

Two days before testing, Slabs were painted with a white lime solution to facilitate cracks detection. The slab specimens were mounted in a horizontal position in the loading frame and the load was applied to the stub-column in a vertical direction fig (9).The load was applied using an hydraulic jack of 100 ton or 200 ton capacity provided with and electrical transducer attached with a digital screen for the load reading. Load was applied on successive increments. Slab deflection, steel strain of shear reinforcement elements and cracking condition were recorded after each load increment and up till slab failure.

Fig (9): Test setup

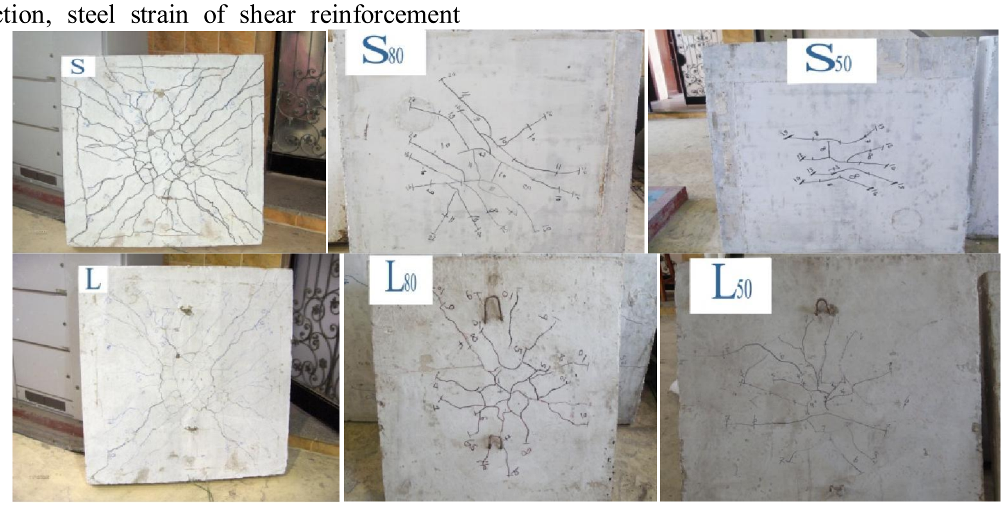


Fig (10): Crack pattern of the slabs.

3. Experimental Results And Discussion

Test Observations

During loading, flexural cracks appeared first under of the column and then shear cracks appeared on the shear span at higher load in most of the tested slabs as shown in fig (10). The cracks widths of the diagonal (shear) cracks increased with the increase in loading until it reached the load of failure while for the flexure cracks. In this section, the cracking patterns and the cracking behavior of the tested slabs during loading is discussed and compared. Final failure took place when the column was pushed into the slab locally around the connection area.In this part cracking and ultimate loads in the first group (A) is discussed. From results of failure load of the specimens (S & S80 &S50) it can be observed the failure load in the slab reference (S) was (300 KN) but specimens which had been repaired by glass fibers (S80) its failure load after it was repaired by glass fiber was (340 KN) and (S50) was failure load after repairing by glass fiber was (370 KN) and the second group (B) is discussed. From results of failure load of the specimens (L & L80 & L50) it can be observed the failure load in the slab reference (L) was (130 KN) but specimens which had been repaired by glass fibers (L80) its failure load after it was repaired by glass fiber was (100 KN) and (L50) was failure load after repairing by glass fiber was (130 KN) as shown in fig (11).

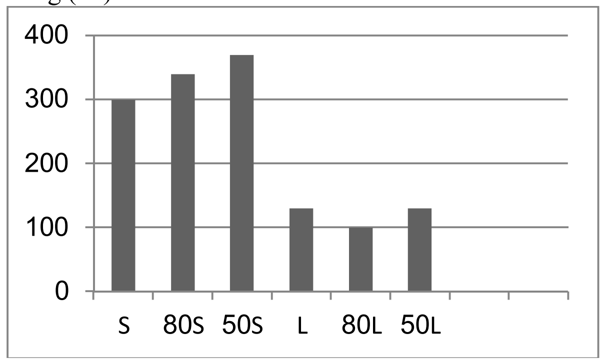


Fig (11): Ultimate load in Specimens.

Table (3): Experimental results for specimens at all specimens.

Notations	Concrete Compressive strength (N/mm2)	Type of Repair	Ultimate Load (KN)	Specimen after repair/Ref
S	35	Reference	300	1
S80	35	GFRP	340	1.13
S50	35	GFRP	370	1.23
L	17	Reference	130	1
L80	17	GFRP	100	0.77
L50	17	GFRP	130	1

Deflection

The deflection was measured at two locations for test slab as previously shown in fig (7) during loading and up to failure, and the relation between the load and the deflection was drown as shown in fig(12) and fig (13).

Generally, deflection curves starts more or less straight linear until the cracking load was attained, then, a non linearity is observed because the load increases as a result of cracks propagation.

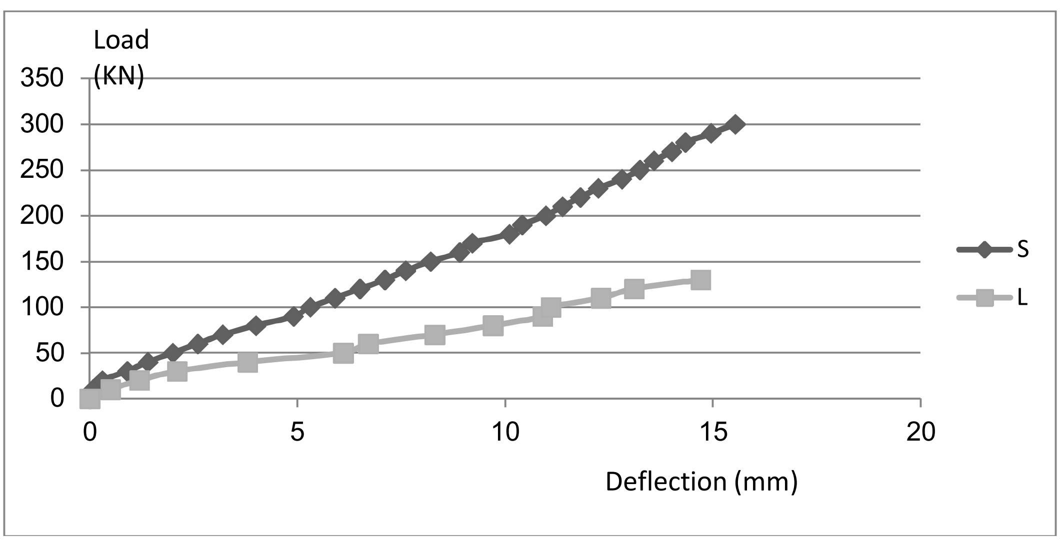


Fig (12): Deflection values at different stages of loading for slabs S, L at location (D1).

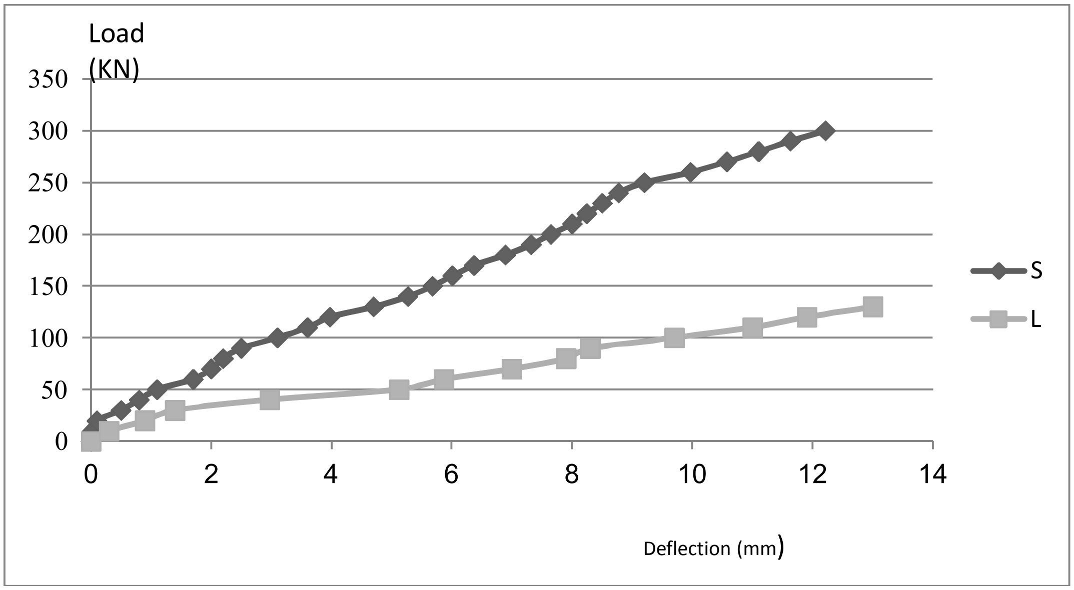


Fig (13): Deflection values at different stages of loading for slabs S, L at location (D2).

Table (4): Experimental results maximum deflection for specimens at specimens Reference.

Notations	Concrete Compressive strength (N/mm2)	Maximum deflection at center (D1)(mm)	Maximum deflection at distance of 30cm from the center (D2) (mm)
S	35	15.33	12.21
L	17	21.33	21

Strain Steel Reinforcement Characteristics

The strain was measured at two locations for test slab as previously shown in fig (8) and the relation between the load and the steel strain was drown as shown in fig(14) and fig (15)

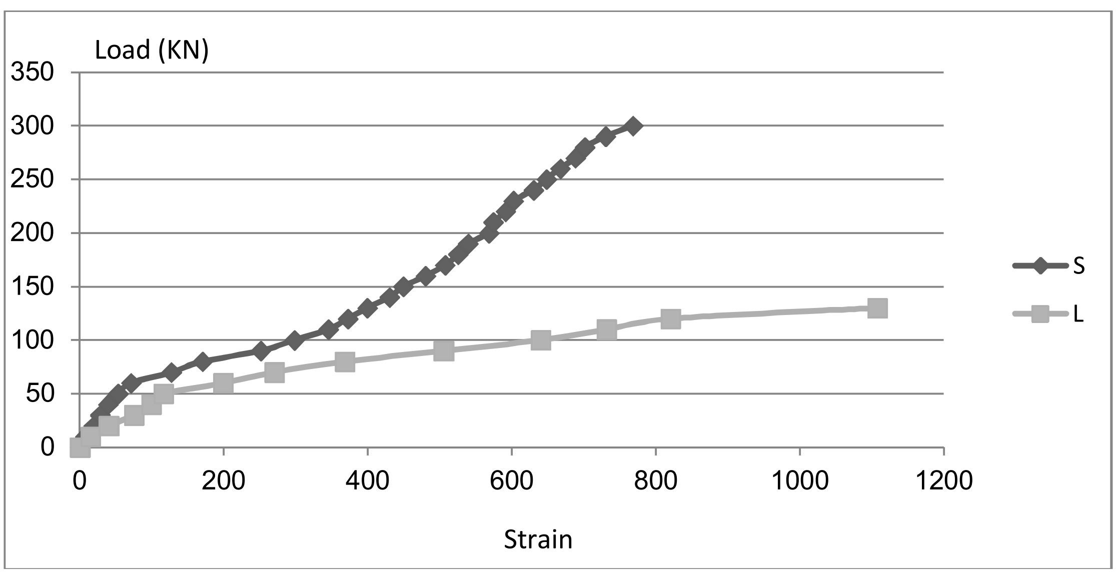


Fig (14): Load-Strain Steel Reinforcement Relationship in location (1) for Slab S and L.

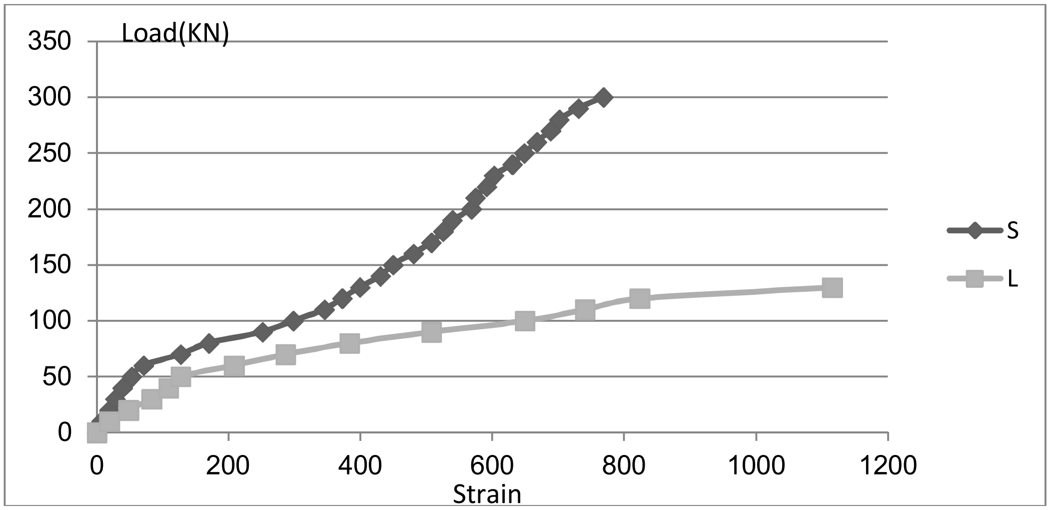


Fig (15): Load-Strain Steel Reinforcement Relationship in location (2) for Slab S and L.

Modelling Using Ansys

Introduction

This paper introduces the finite element modeling (FEM) and the FEM by ANSYS in particular. In the next section the required general background to the finite element modeling is presented. Then an introduction to the use of ANSYS in FEM modeling is given. The main phases in modeling by ANSYS are reviewed; these are the preprocessing phase, the solution phase and the post processing phase. Afterwards a complete review of the element types -that will be used in this work- out of the ANSYS element-library is given. These elements are the SOLID65, and link180 element. The model presented in this work is completely explained by the end of this paper; this includes the geometry of the model the used data, the loading conditions and the boundary conditions.

Finite Element Modelling

Concrete Element

To be able to account for the failure modes of concrete cracking in tension and crushing in compression, a special brittle finite element material model should be used. This material model could be accessed only with the three dimensional solid element (SOLID65) which was used to model concrete.

The element SOLID65 is defined by 8 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. A 2x2x2 lattice of integration points is used with Gaussian integration procedure. This means that for each element there are eight integration points. The geometry, node locations, and the coordinate system for this element as shown in fig (16). The element material is assumed to be isotropic and the most important aspect of this element is the treatment of nonlinear material properties where concrete is capable of directional cracking and crushing besides incorporating plastic and creep behavior.

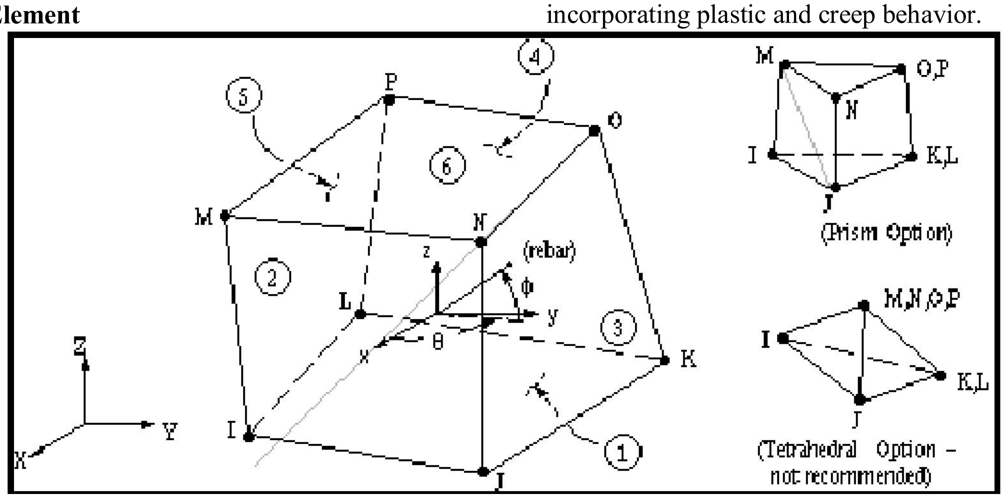
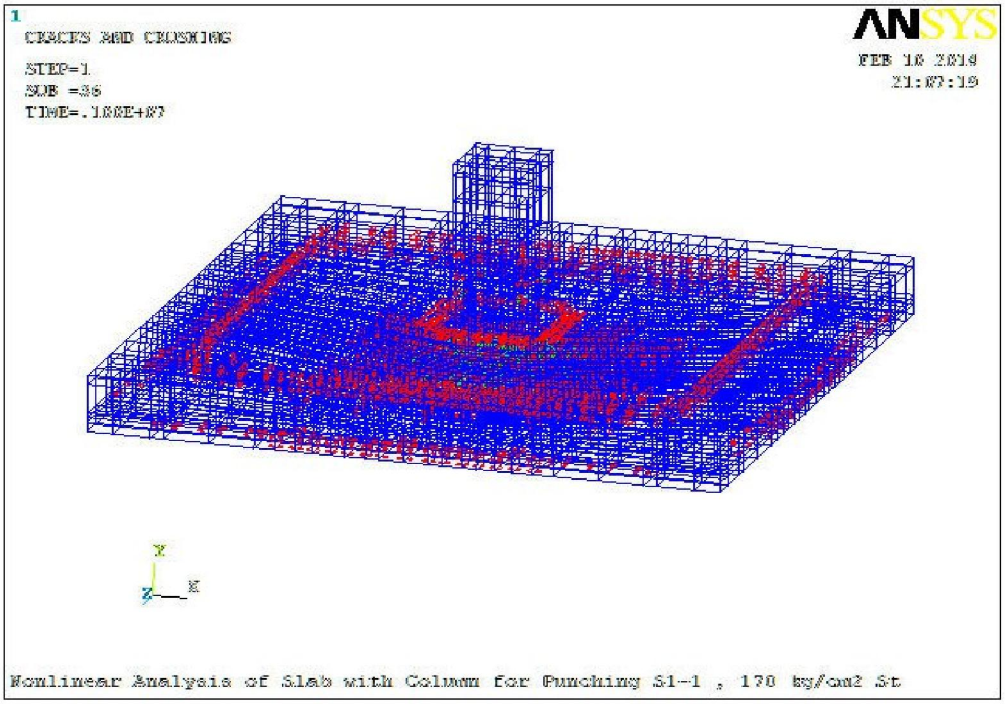


Fig (16): Solid65- 3-D Reinforced Concrete Soil Element (ANSYS Ver.14, 2012)

Reinforcement Element

A link180 element was used to model the steel reinforcement. Two nodes are required for this element. Each node has three degrees of freedom, translations in the node in x, y and z directions.



Results Of Ansys

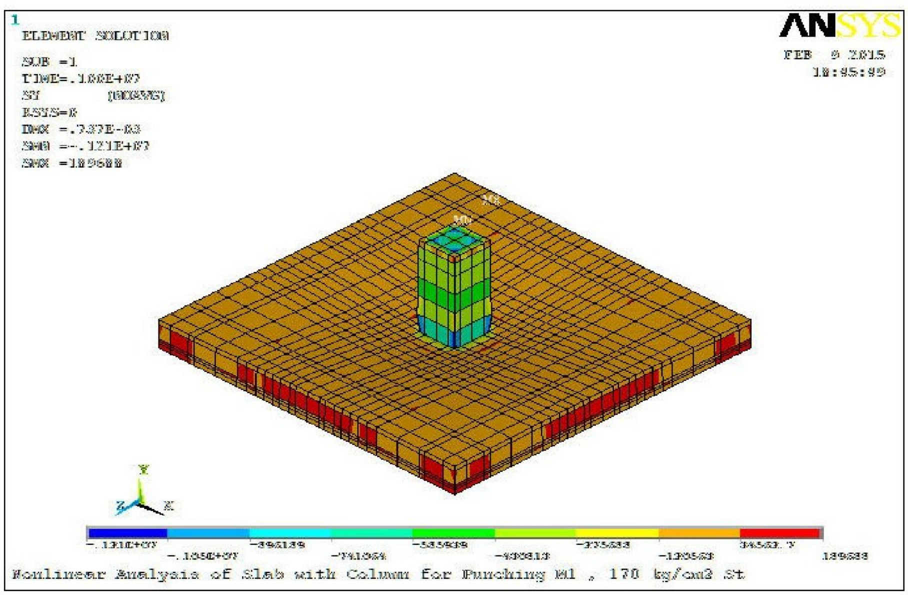


Fig (17): Finite Element Model

Comparison between Ansys and Experimental Results

Table (5): Comparison between ANSYS and Experimental Results

Notations	Compressive strength (N/mm2)	Experimental		Numerical		Exp / Num	
		Ultimate Load (KN)	Ultimate deflection at center (mm)	Ultimate Load (KN)	Ultimate deflection at center (mm)	Load	Deflection
S	35	300	15.35	330	14.17	0.90	1.083
L	17	130	14.7	110	15.54	1.181	0.946

Conclusions

1. When the slab-column connection is subjected to heavy vertical loading, cracks will occur inside the slab in the vicinity of the column. These cracks then propagate through the slab thickness at an angle of 20 to 45 degree to the bottom of the slab. This can lead to punching shear failure of the slab along the cracks.
2. Repairing of slab-column connection using GFRP wraps is quick and simple to implement.
3. For slabs with concrete compressive strength (35 N/mm2) repairing of slab-column connection which has been loaded 80% from ultimate load of reference using the technique by GFRP delayed the failure of specimens by about 13.33% and repairing the slab-column connection which has been loaded 50% from ultimate load of reference using the technique by GFRP delayed the failure of specimens by about 23.33%.
4. For slabs with concrete compressive strength (17 N/mm2) repairing the slab-column connection which have been loaded 80% from ultimate load of reference using the technique by GFRP then it was reloaded up to 77% from failure load of reference (using glass fiber didn't give high results) and repairing the slab-column connection which has been loaded 50% from ultimate load of reference using the technique by GFRP then it was reloaded up to same failure load of Reference.
5. Using GFRP in repairing specimens of concrete compressive strength (35 N/mm2) give high results but using GFRP in repairing specimens of concrete compressive strength (17 N/mm2) didn't give high results.
6. In the analytical study, the specimens were modeled using (ANSYS) computer program based on finite element analysis system. Fair agreement was found between the experimental and the theoretical results.

References

1. Cheng-Chen and Chung-Yan," Punching Shear Strength of Reinforced Concrete Slabs Strengthened with Glass Fiber-Reinforced Polymer Laminates ", ACI Structural Journal, Vol.102, No.4, 2005, p.535-542.
2. Ehab El-Salakawy, Khaled Soudki; Maria Anna Polak, "Punching Shear Behavior of Flat Slabs strengthened with Fiber Reinforced polymer Laminates ", Journal of Composites for Construction, Vol. 8, No.5, 2004, p.348-392.
3. Larralde, J, "Compressive Strength of Small Concrete Specimens Confined with Fiberglass Laminates," Cement, Concrete, and Aggregates, V. 19, No. l, 1997 pp. 17-21.
4. Lee, J.-H.; Yoon, Y.-S.; Cook, W.D.; and Mitchell, D., "Improving Punching Shear Behavior of Glass Fiber-Reinforced Polymer Reinforced Slabs," ACI Structural Journal, V. 106, No. 4, 2009,pp.427-434.
5. Mohamed Osman Serry, "Use of FRP for enhancing the Punching Shear Strength of Flat Slabs ," Thesis presented to Faculty of Engineering, Zagazig University, Banha Branch, Shoubra, Egypt, in 2004, in Partial fulfillment of the requirements for the degree of Doctor of Philosophy in Structural Engineering.
6. Said Aly Mohamed Taher," Strengthening of R.C. Slab-Column Connection to resist Punching Shear," Thesis presented to Faculty of Engineering, Cairo University, Giza, Egypt, in 1998, in Partial fulfillment of the requirements for the degree of Doctor of Philosophy in Structural Engineering.

6/1/2015