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AN Experimental Study on Strengthening of R.C Flat Slab Edge Column Connections Subjected to Punching Shear Due to Eccentric Loads Using FRP

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Abstract:

During the last few years, the need to flat slab systems has rapidly increased. The slab column connections behavior plays decisive role because of the sudden expected brittle failure as the slab may be punched by column, so improving the behavior of these connections is essential. Flat slab column connections can benefit from being strengthened by fiber reinforced polymers (FRP) as a structural application in punching shear [1]. The effect of using carbon fiber (CFRP) and glass fiber (GFRP) was investigated experimentally, also steel reinforcement bars were utilized as strengthening element for comparison. Results of tested fifteen half-scale flat slab-edge column connections reinforced concrete specimens under eccentric loads were obtained. The investigated parameters were the eccentricity value, the type of strengthening material and the number of rows of strengthening elements. Five groups were created from the fifteen tested specimens, every one contained three specimens. The first group consisted of three non-strengthening specimens, with variable eccentricity values (0, e & 2e), these specimens were considered as control ones. Each

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of the other four groups consisted of three specimens, which were strengthened by CFRP, GFRP and steel bars. All the specimens of the second and fourth groups were strengthened by one row of strengthening elements. All the specimens of the third and fifth groups were strengthened by two rows of strengthening elements. The second and third groups were loaded with the eccentricity value (e) while the fourth and fifth groups were loaded with the eccentricity value (2e). According to the test results, punching shear resistance increased up to 82 %. Also, the ductility factor results revealed improvement of up to 50%. Ultimate loads were predicted according to ACI 440, and the calculated values shown good agreement with the experimental ones.

Keywords: Punching shear, edge column-flat slab connections, FRP and strengthening.

1. Introduction

Residential buildings, shopping centers, hospitals, hotels, and garages all use flat slabs as structural system [2]. It is architecturally appealing, the uniform surface of the slab's bottom facilitates formwork and allows for reduced building heights [3], and however, a major problem called -punching shear failure - related to flat slab statical system, punching shear failure is a tendency for a failure mode at a slab-column connection. The opportunity of this failure occurrence increases as increasing the shearing effects around the columns due to the geometric asymmetry, as in the case of slab-exterior column connections [4]. This undesirable kind of failure occurs without any warning and may cause a sudden collapse of the slab connection. Therefore, appropriate techniques to improve the shear resistance of punching should be considered. Increasing the slab thickness around the column by applying a column head or a drop panel and/or adding special shear reinforcement are the two major solutions to secure the slab-column connection during design phase [5]. In case of already existing flat slab, several strengthening techniques can be used to strengthen the column-slab connection. Recently, Fiber Reinforced Polymers (FRP) are gaining wide acceptance in construction applications. In concrete elements exposed to harsh environmental conditions, FRP is an attractive alternative to steel reinforcement due to its high tensile strength and resistance to abrasion and chemical attacks [6]. Khaled Soudki [7] studied the impact on the punching shear of externally attached CFRP strips, its obtained that the strengthened slabs gained an increasing on punching capacity up to 29%. Nasr Z. Hassan [8] investigated the effect of system of shear bands all over the column as a shear reinforcement which enhanced the load capacity up to 55%. Khaled F. El-Kashif [2] Experimental research was done on strengthening slab-column connections using CFRP-fans, it showed that punching shear capacity had improved up to 21%. Haider K. Ammash [9] indicated that applying steel stiffeners was efficient in repair the cracked flat slabs against punching shear, with increases in strength and deformation capacity of around 74.2% and 66.4%, respectively. Hikmatullah Akhundzada [10] was found that strengthening by using CFRP laminates that are externally bonded can improve ultimate punching load by up to 25% while lowering maximum deflection up to 50%. M.A.L. Silva [11] observed that using CFRP plates fastened to the specimen tension side with steel end anchors resulted an improvement in punching shear more than 46%. M.R. Esfahani [12] used sheets from CFRP placed on the slab's tension face in two perpendicular orientations; test study revealed that the CFRP sheet achieved punching shear resistance up to 58%.

2. Experimental Investigation

FRP external stirrups and steel links were used in an experimental study to investigate the behavior and ultimate strength of strengthened slab-edge column connections. Centric load was applied with varied eccentricity values to obtain the flexural stresses effect with the punching shear stress on slab- column connections. Half-scale models of a conventional prototypes flat slab were used as test specimens.

Dimensions of slab were estimated to include the region of negative moments surrounding the column and within the contra flexure line.

2.1. Tested specimen's details

Fifteen half-scale specimens were prepared. The dimensions and reinforcement of all specimens were identical as shown in Figs. 1&2. The dimensions of specimen were 900 mm × 900 mm in plane and 130 mm thickness. The cross section of the column was 150 × 150mm with 300 mm height from the slab lower face and 50 mm from the upper slab face. The column had a leg cantilever of 150 mm projected length with 150 × 150mm cross section as shown in Fig. 1, which provides a free distance for load eccentricity. The column was casted monolithically with the slab. The specimens were made to have a clear span of 750 mm while point support are placed on the opposite side of the slab and at the cantilever of the column with a clear span of 750 mm. Specimens were made with sufficient flexural reinforcement whenever flexural failure wouldn't occur before punching-shear failure done. Therefore, the effectiveness of the shear-strengthening systems can be assessed up to the maximum punching load. High-tensile steel of 12 &16 mm diameters were used for the bottom and top reinforcement bars. The top reinforcement was 9 Φ 12 mm in the transverse direction and (8 Φ 12 mm & 3 Φ 16) in the longitudinal direction, while the bottom reinforcement was 12 Φ 12 mm in the longitudinal direction and 6 Φ 12 mm in the transverse direction, as shown in Fig. 2. The vertical reinforcement of the column was 6 Φ 16 high tensile steel bars and mild steel stirrups of 8 mm diameter at 100 mm spacing. Table 1 shows all samples classified into five groups according to the study variables.

2.2. Preparation of tested specimens

A form work was made from pine wood for all the fifteen specimens partitioned to the required dimensions using 5 cm thickness foam. Also, polyethylene linoleum was used in form work before reinforcement installation as shown in Fig. 2. After the installation of steel reinforcement, commercial ready mix concrete was used for pouring the specimens as shown in Fig. 4. Mechanical vibrator was used to compact the fresh concrete then its surface had finished. After that, the specimens were cured for seven days before the implementation of strengthening processes. The fifteen specimens were divided into five groups, every group consisted of three specimens, group no. one includes the non-strengthening specimens or the control specimens. The six specimens of groups no. 2 & 4 were drilled to penetrate the full depth of the slab making a 10mm holes diameter in one rows, while the six specimens of groups no. 3&5 were drilled similarly but in two rows. The holes were arranged at the positions of the vertical legs of the steel links or the FRP strengthening stirrups. CFRP, GFRP stirrups and steel links were used, as shown in Fig. 5, as the strengthening system in this study. The FRP intertwined stirrups were prepared manually. The cross section area of FRP was equal to the cross section area of the used steel links of 8 mm diameter. The CFRP wraps were saturated by epoxy as a resin (sikadur-330) and the GFRP ones were saturated by polyester. The stirrups were created by stitching the intertwined strands through holes throughout the thickness of slab as shown in Fig. 6. To ensure full contact between concrete and FRP stirrups, epoxy resin and polyester was filled -after one day- into the concrete holes around the stirrups. The steel links were made of 8 mm diameter steel bars, which fixed at lower and upper ends by steel nuts supported on steel plates of 40 mm width and 5 mm thickness.

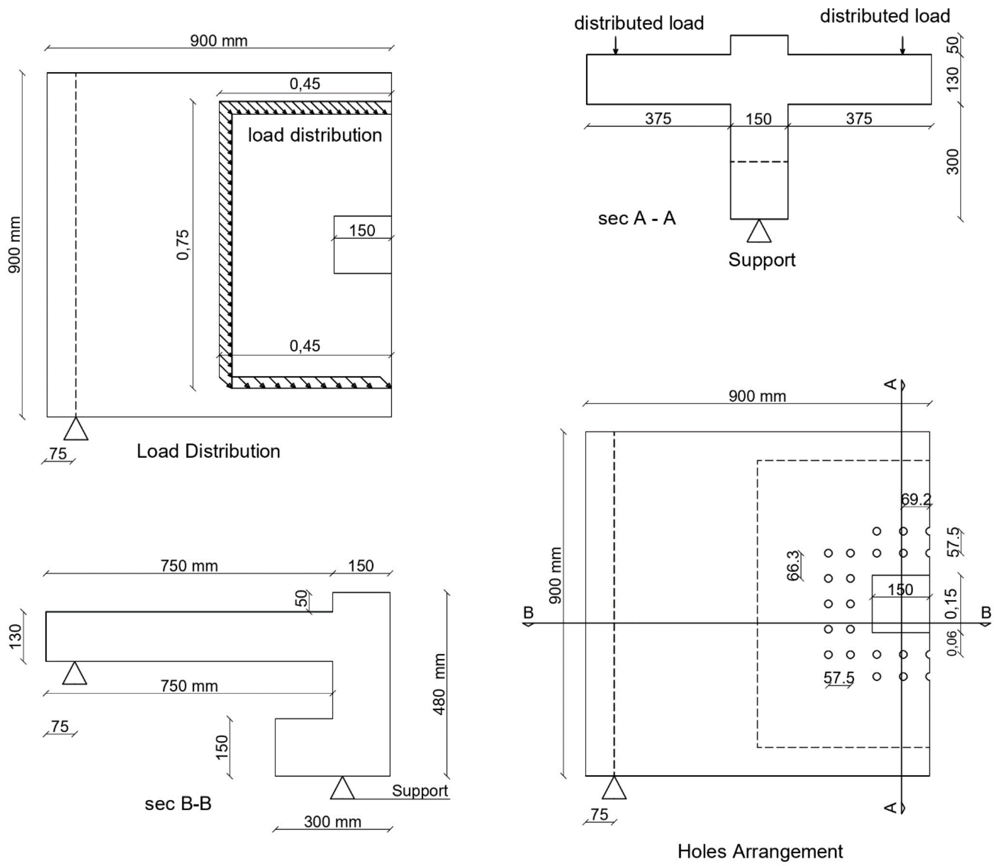

Fig. 1 The specimens' supports and dimensions.

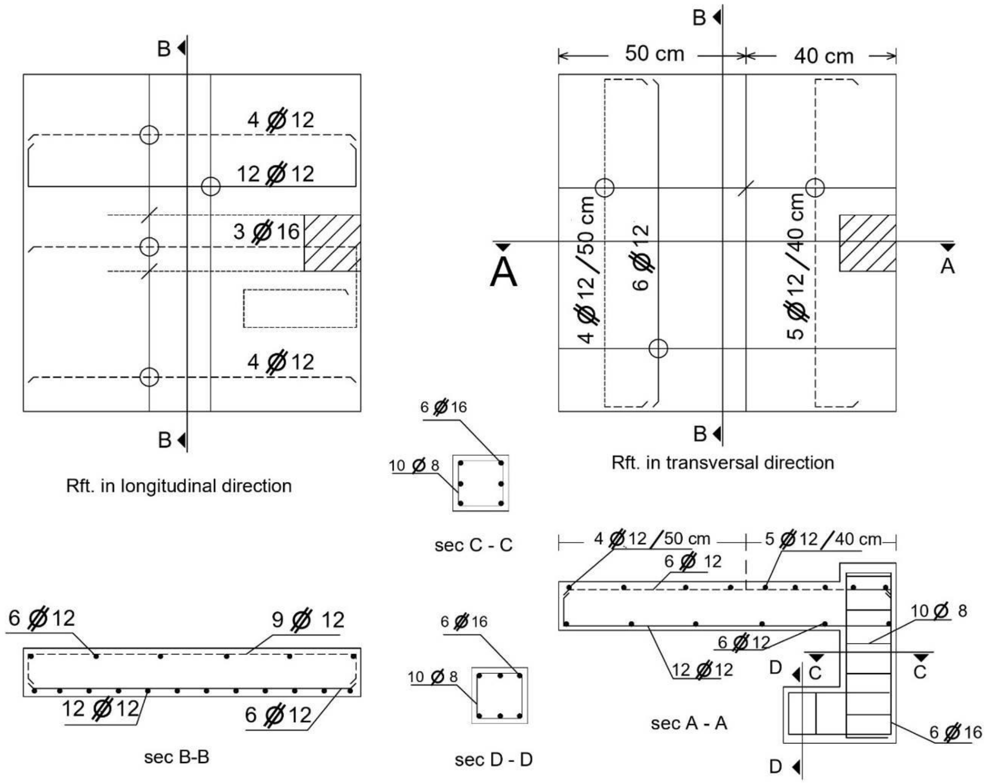

Fig. 2 The specimen's reinforcement.

Fig. 3 Preparation form work and reinforcement.

Fig. 4 Concrete casting-in-situ.

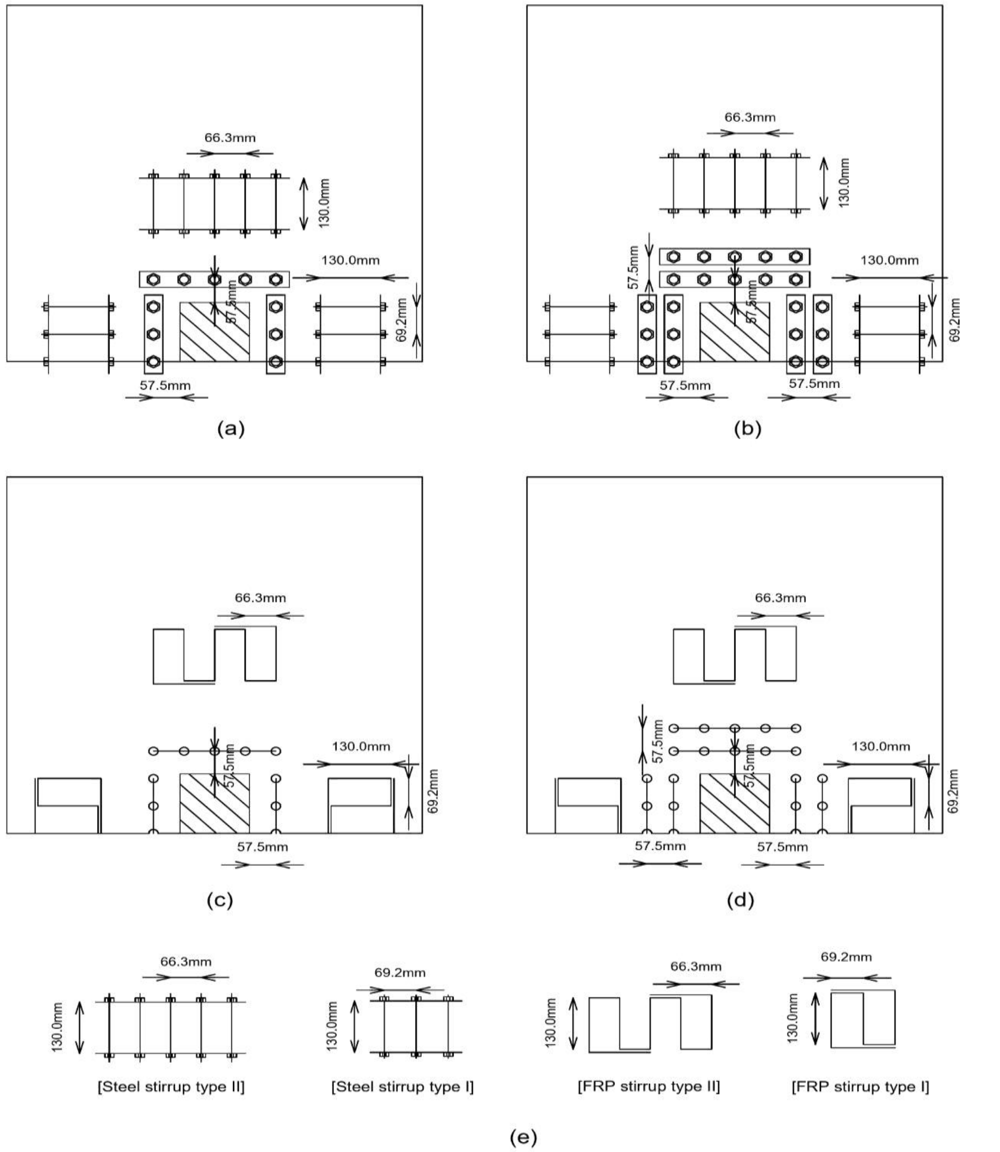

Fig. 5 Strengthening systems details; steel links using one row (a), two rows of steel (b), Using one row of FRP stirrups (c), Using two rows of FRP stirrups (d) stirrups types details (e).

Fig. 6 Manufacturing of strengthening stirrups systems.

Table 1. Details of experimental tested specimens.

Group	Specimen code	Specimen case	Rows number	Eccentricity value (mm)	Strengthening material
No. 1	C	control	----------	0	----------
	C-1e	control	----------	50	----------
	C-2e	control	----------	100	----------
No. 2	SC1-1e	Strengthened	1	50	CFRP stirrups
	SG1-1e	Strengthened	1	50	GFRP stirrups
	SS1-1e	Strengthened	1	50	Steel Links
No. 3	SC2-1e	Strengthened	2	50	CFRP stirrups
	SG2-1e	Strengthened	2	50	GFRP stirrups
	SS2-1e	Strengthened	2	50	Steel Links
No. 4	SC1-2e	Strengthened	1	100	CFRP stirrups
	SG1-2e	Strengthened	1	100	GFRP stirrups
	SS1-2e	Strengthened	1	100	Steel Links
No. 5	SC2-2e	Strengthened	2	100	CFRP stirrups

SG2-2e	Strengthened	2	100	GFRP stirrups
SS2-2e	Strengthened	2	100	Steel Links

3. Materials properties

3.1. Concrete

A ready mixed concrete was used to pour all specimens together by the same mix, design mix is shown in Table 2, a super plasticizer was used to enhance workability of the fresh concrete mix. Fresh concrete had a 10 cm slump. Average compressive strength was 262 kg/cm^2 from three standard cubes.

Table 2. The concrete design mix.

Average compressive strength	Cement content Kg/m^3	Coarse aggregate kg/m^3	Siliceous Sand Kg/m^3	Water Liter/m^3	Super plasticizer Kg/m^3
262	350	1240	680	175	4

3.2. Aggregate

Coarse aggregate used in this investigation was crushed dolomite of maximum aggregate size 20 mm, while fine aggregate was natural siliceous sand was used as fine aggregates in the concrete mix.

3.3. Plasticizer

A concrete super plasticizer admixture, commercially called Addicrete BVF was used as a super plasticizer without concrete retarding effect. It is produced and supplied by Chemicals for Modern Building International (CMB). Addicrete BVF conforms to ES 1899, EN 934-2, and ASTM C 494 type F (thereafter type A).

3.4. FRP

Sika Wrap Hex-230C is the high tensile strength carbon fibers used with epoxy -Sikadur-330- to make the CFRP stirrups. While sika wrap Hex-430G used to manufacture the GFRP stirrups were, which is produced by sika company, and polyester was the used polymer. Mechanical properties are given - by producer- in Table 3.

Table 3. Mechanical properties of FRP.

Property	(GFRP)	(CFRP)
Thickness	0.17 mm	0.14 mm
Tensile strength	22500 kg/cm^2	35000 kg/cm^2
Modulus of elasticity	700000 kg/cm^2	2300000 kg/cm^2
Strain at failure	3.10%	1.5%

Table 4. Coarse and fine aggregate properties.

Property	(Fine aggregate)	(Coarse aggregate)
Specific weight	2.73	2.7
Volume weight kg/m^3	1620	1670
Percent of water absorption	0.43	1.2

3.5. Steel

12 & 16 mm diameters bars of high tensile-steel were used to reinforce the tested specimens. 8 mm diameter of mild-steel (24/36) bars are used to for the strengthening steel links.

Table 5. Properties of Steel Reinforcement.

Nominal diameter mm	Grade	Area cm^2	weight Kg/m	Yielding strength Kg/cm^2	Ultimate strength Kg/cm^2
Φ8	24/35	0.50	0.395	2675	4800
Φ12	36/52	1.13	0.888	3860	5697
Φ16	36/52	2.01	1.578	3790	5487

4. Test Procedure

All the specimens were tested, in the Reinforced Concrete Laboratory, at Benha Faculty of Engineering. A 100-ton capacity rigid frame provided with hydraulic jack of 100-ton maximum capacity was used in loading process for the testing. A vertical concentrated load was acted by the hydraulic jack which was distributed to a uniform line load by rigid steel frame directly rested on the upper face of the specimen's slab as seen in Fig. 7. As mentioned earlier, the specimens were supported on the other side of the column on steel beam worked as line-support and at a 100-ton capacity load cell installed under the column leg cantilever worked as a hinged support. Force on the column which causing the punching shear on the slab was recorded momentarily by the load cell. The deflection was recording at five detected points with each load increment till the failure using five of a linear-variable-differential-transformers LVDT shown in Fig. 8. Load at the first crack generation, load at ultimate state and Vertical deflection were recorded. Cracks Propagation was marked at each increment of load up to failure. The test set-up is illustrated in Fig. 9.

Fig. 7. The used distributed rigid steel beams.

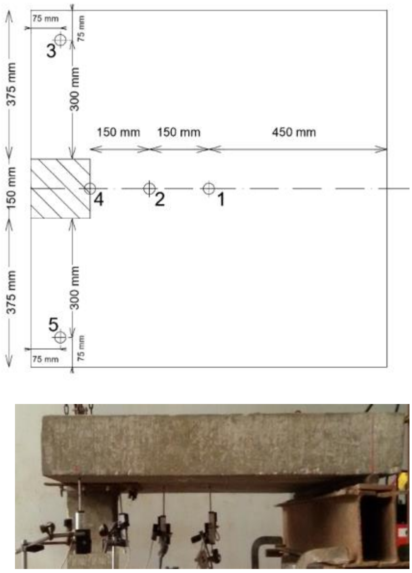

Fig. 8. LVDT locations at lower face.

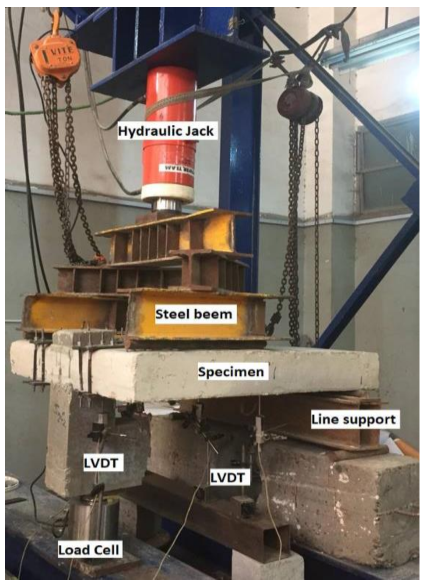

Fig. 9. Test set up.

5. Results and Discussion

Cracking and ultimate load were recorded, load deflection relationship curves were drafted for each tested specimens and the propagation of the cracks was noted and recorded. A comparison between the experimental results of the all tested specimens were done to illustrate the investigated parameters effects in this study.

5.1. Relationships between load and deflection

As shown in Fig. 8, the tested specimen's vertical deflections were measured at the mentioned five locations. Deflection was briefly recorded for each load increase up to failure. The relationships between the deflection at the center of the specimen -point (1)- with the column' load measured by the load cell for each specimen was plotted. Load-deflection relationships comparisons for all specimens were done to obtain the studied parameters effects. The studied strengthening strategies used in this research significantly improve the ductility and strength of the tested specimens, subjected to shear punching. As shown in Figs. (10 to 25), at the same loading level, it can be seen that:

1- Compared to the control specimens, strengthened specimens using CFRP, GFRP, or steel links had reduced deflection values.
2- Using two rows of strengthening stirrups recorded lower deflection values compared to the use of one row that with both, CFRP, GFRP and steel links.
3- Loaded under eccentricity value (2e) recorded higher deflection values compared to (1e) eccentricity loaded value.

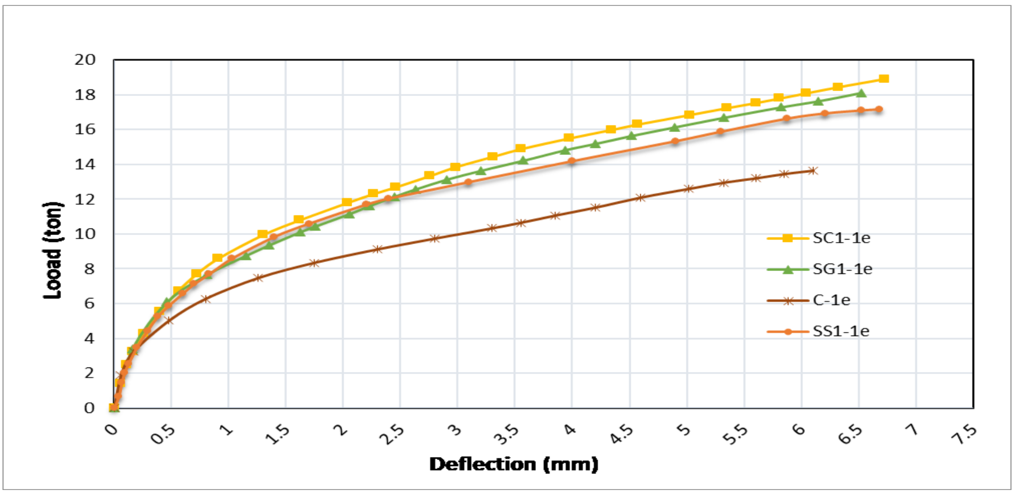

Fig. 10. Effect of using different strengthening materials (CFRP, GFRP& Steel links) in case of specimens strengthened by one row and loaded under eccentricity value (1e).

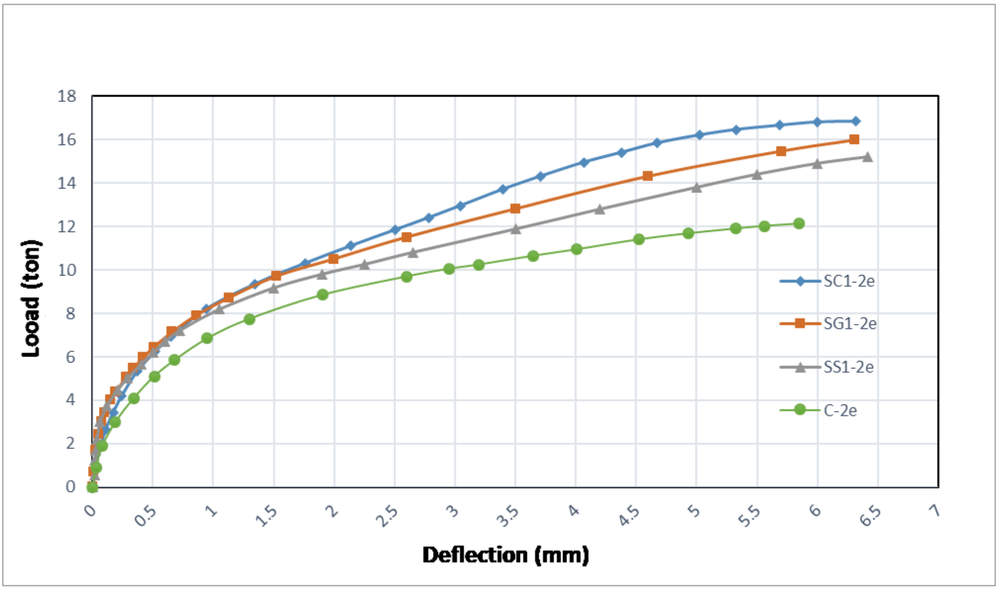

Fig. 11. Effect of using different strengthening materials (CFRP, GFRP& Steel links) in case of specimens strengthened by one row and loaded under eccentricity value (2e).

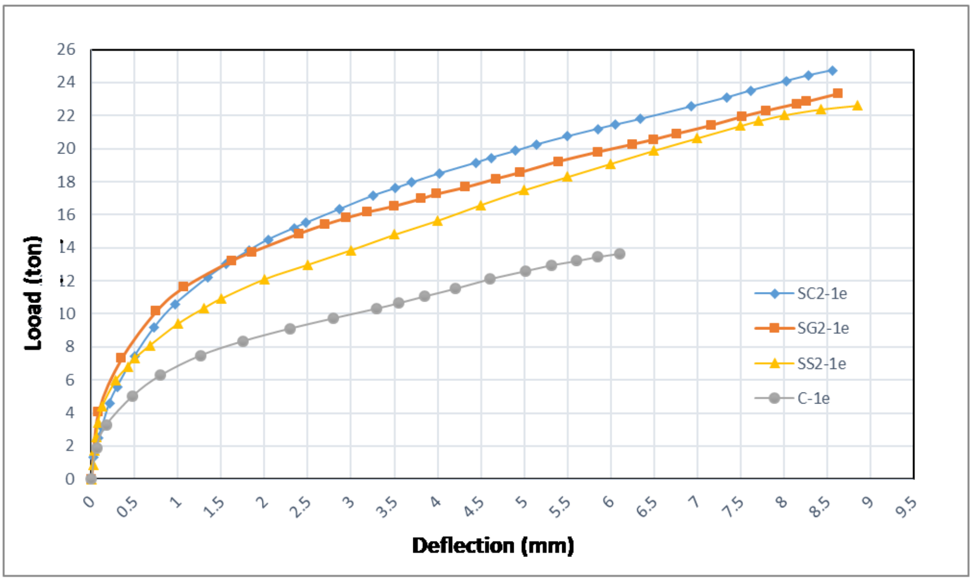

Fig. 12. Effect of using different strengthening materials (CFRP, GFRP& Steel links) in case of specimens strengthened by two rows and loaded under eccentricity value (1e).

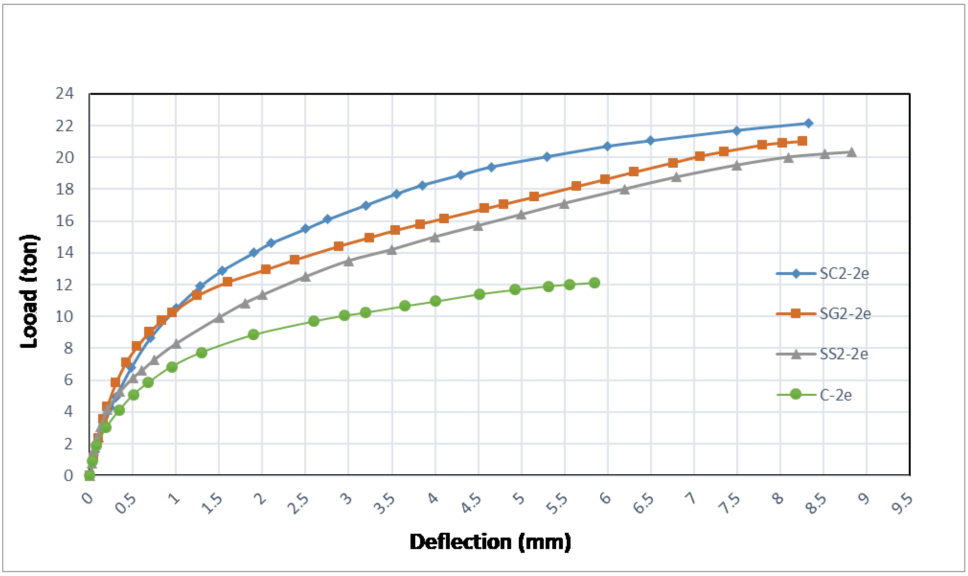

Fig. 13. Effect of using different strengthening materials (CFRP, GFRP& Steel links) in case of specimens strengthened by two rows and loaded under eccentricity value (2e).

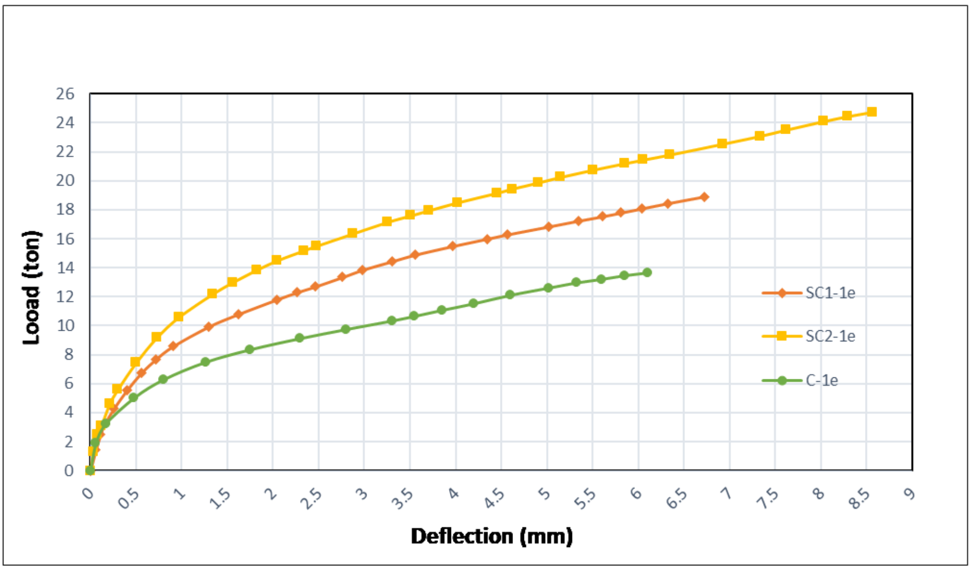

Fig. 14. Effect of rows number of (CFRP) strengthening stirrups with eccentricity value (1e).

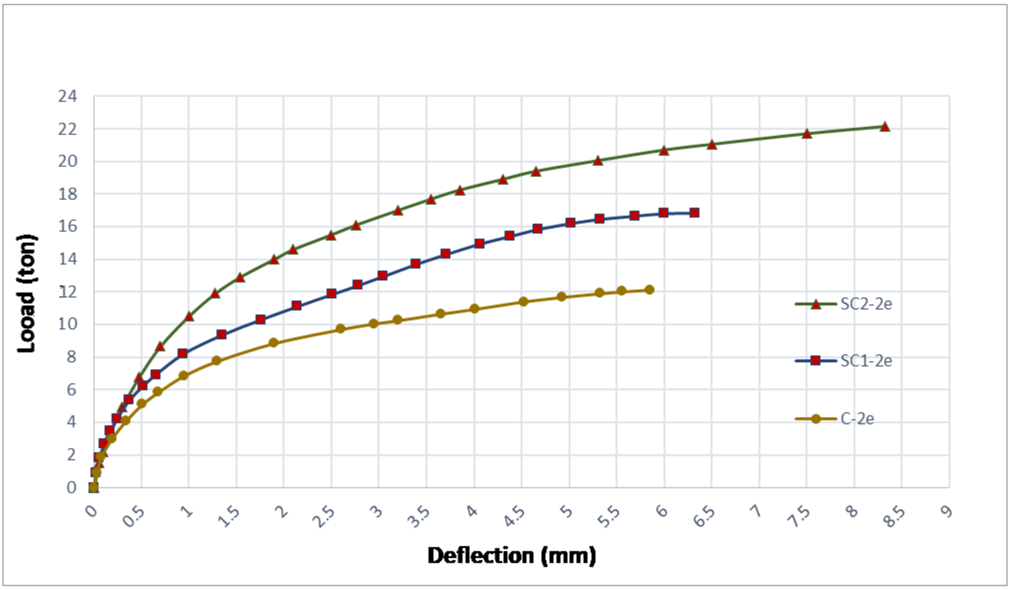

Fig. 15. Effect of rows number of (CFRP) strengthening stirrups with eccentricity value (2e).

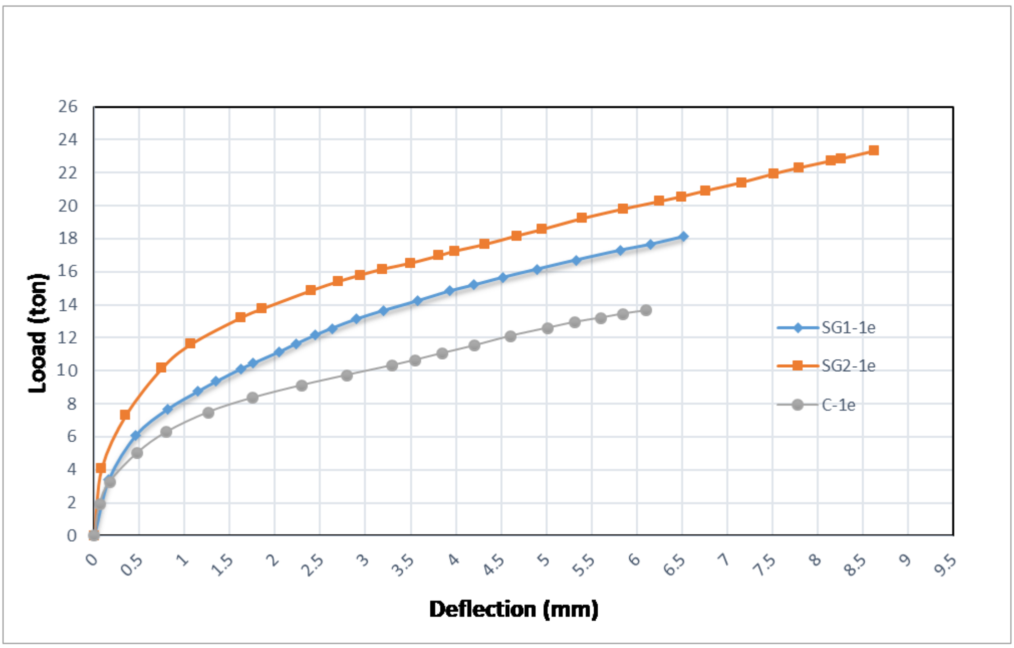

Fig. 16. Effect of rows number of (GFRP) strengthening stirrups with eccentricity value (1e).

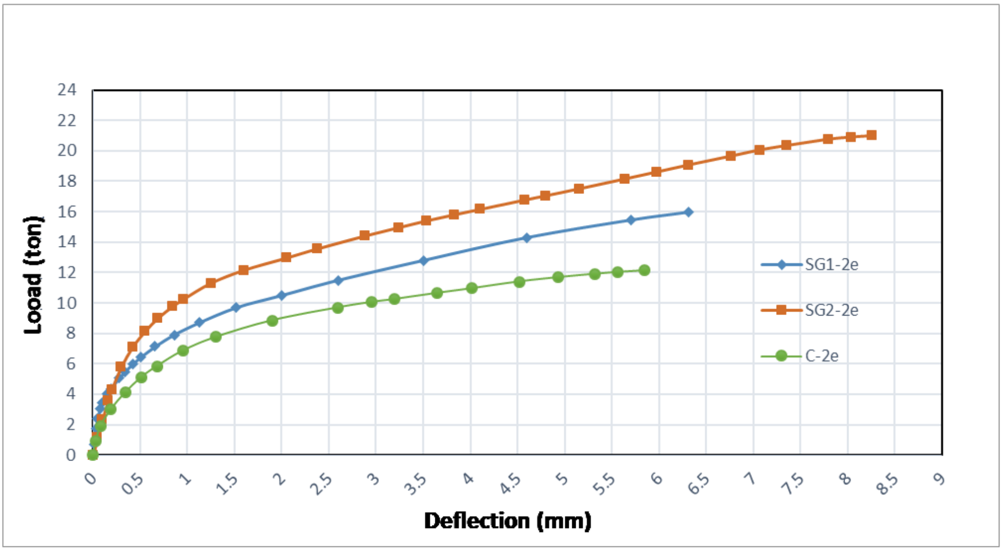

Fig. 17. Effect of rows number of (GFRP) strengthening stirrups with eccentricity value (2e).

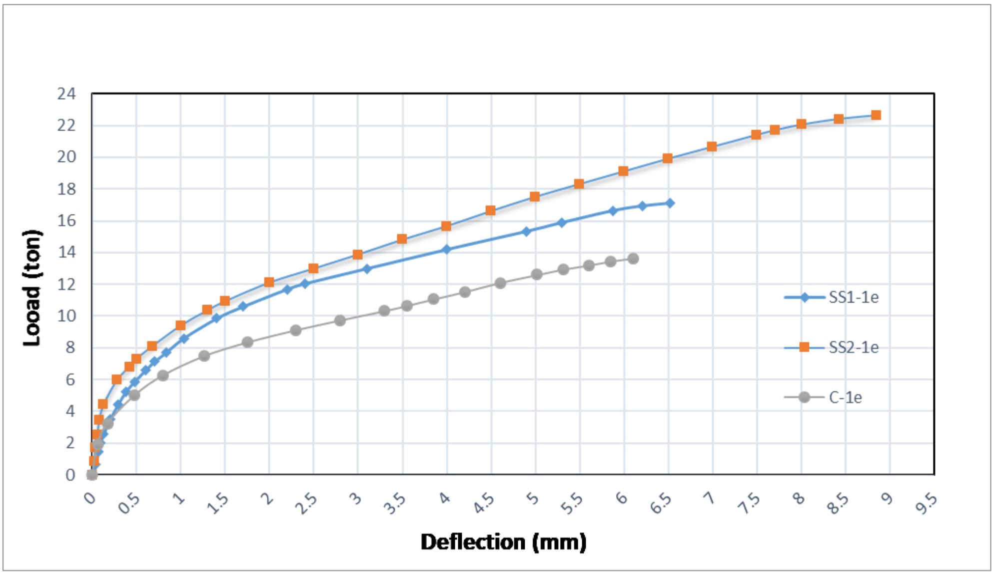

Fig. 18. Effect of rows number of strengthening steel links with eccentricity value (1e).

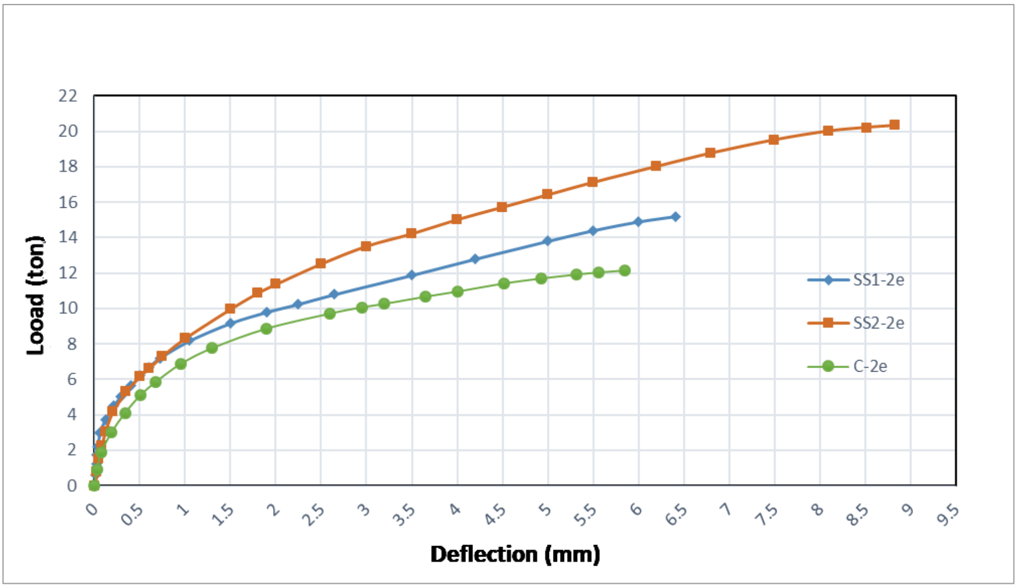

Fig. 19. Effect of rows number of strengthening steel links with eccentricity value (2e).

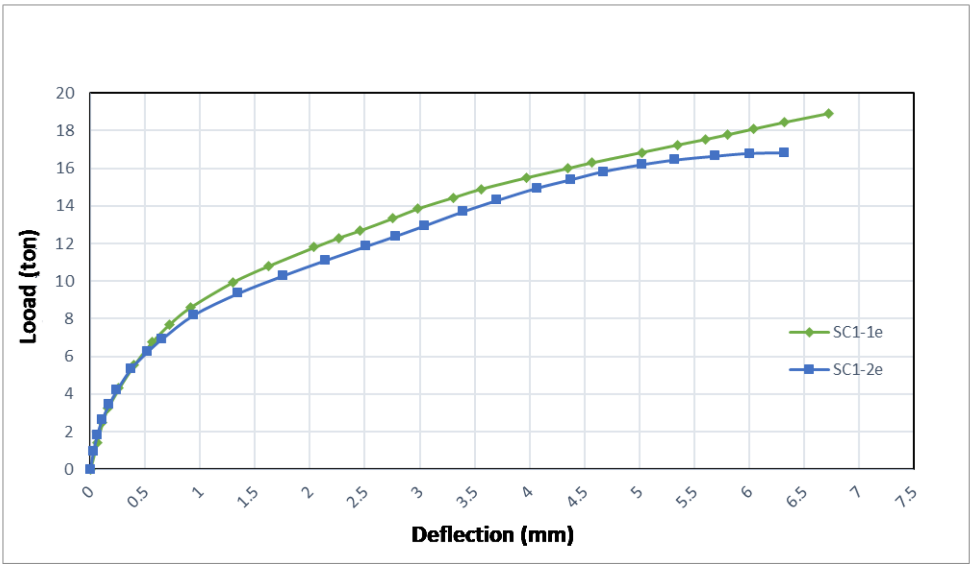

Fig. 20. Effect of load eccentricity value (e) variation with one row of (CFRP) strengthening stirrups.

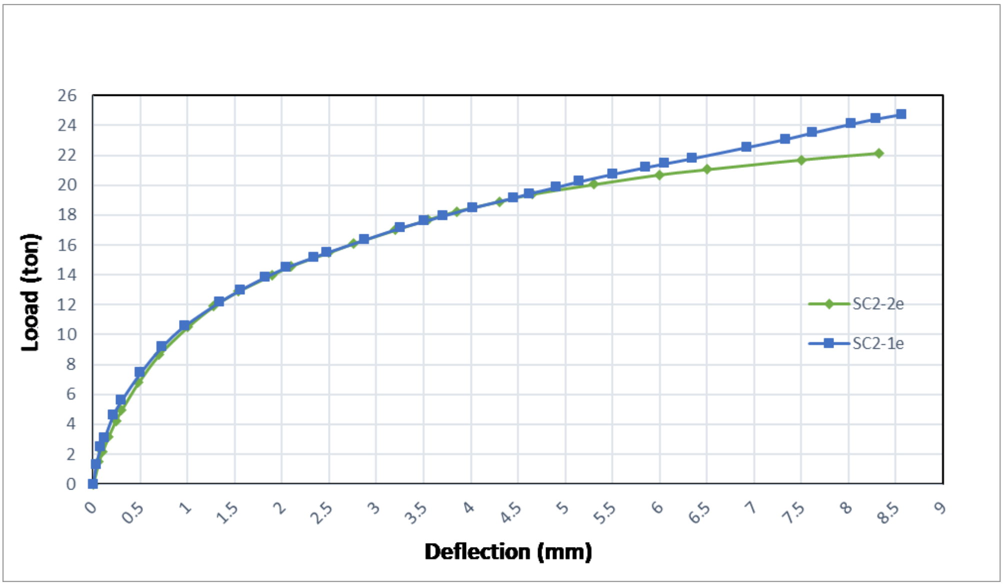

Fig. 21 Effect of load eccentricity value (e) variation with two rows of (CFRP) strengthening stirrups.

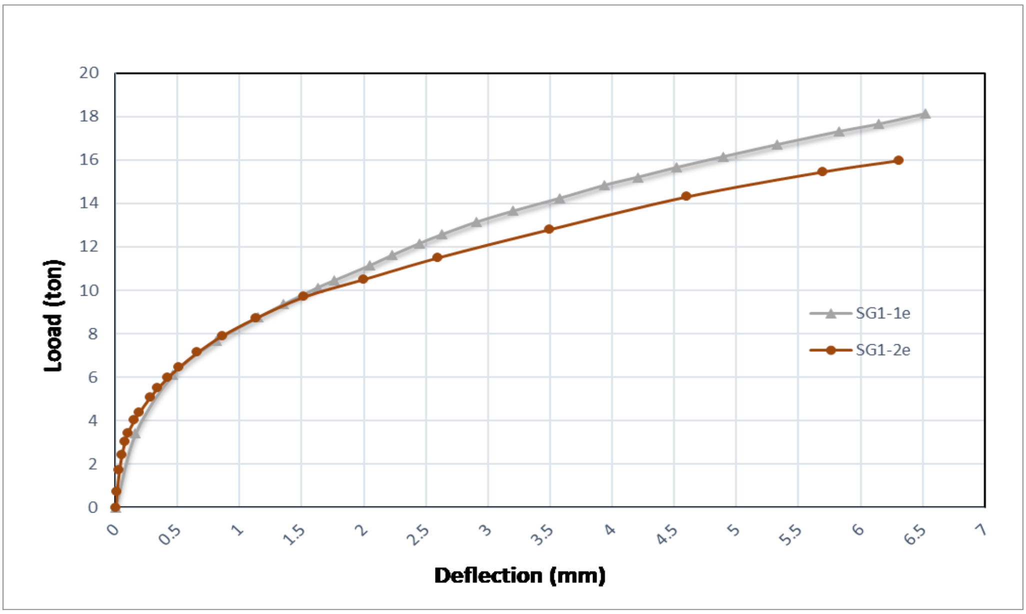

Fig. 22. Effect of load eccentricity value (e) variation with one row of (GFRP) strengthening stirrups.

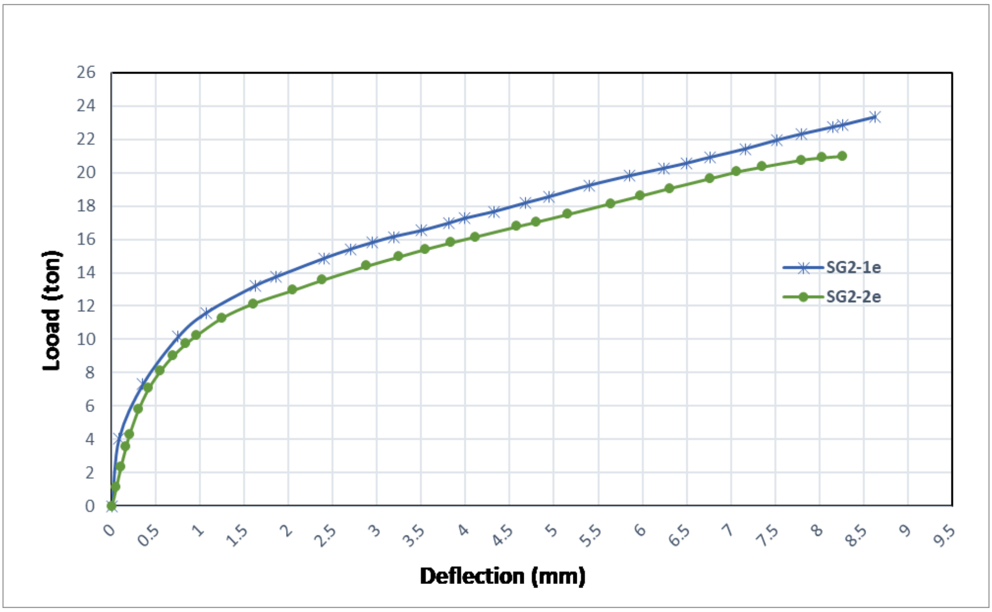

Fig. 23. Effect of load eccentricity value (e) variation with two rows of (GFRP) strengthening stirrups.

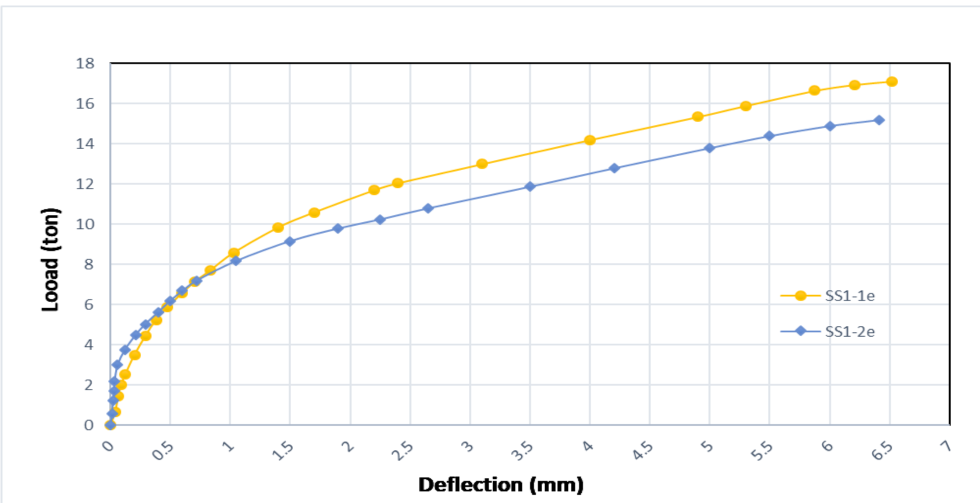

Fig. 24. Effect of load eccentricity value (e) variation with one row of strengthening steel links.

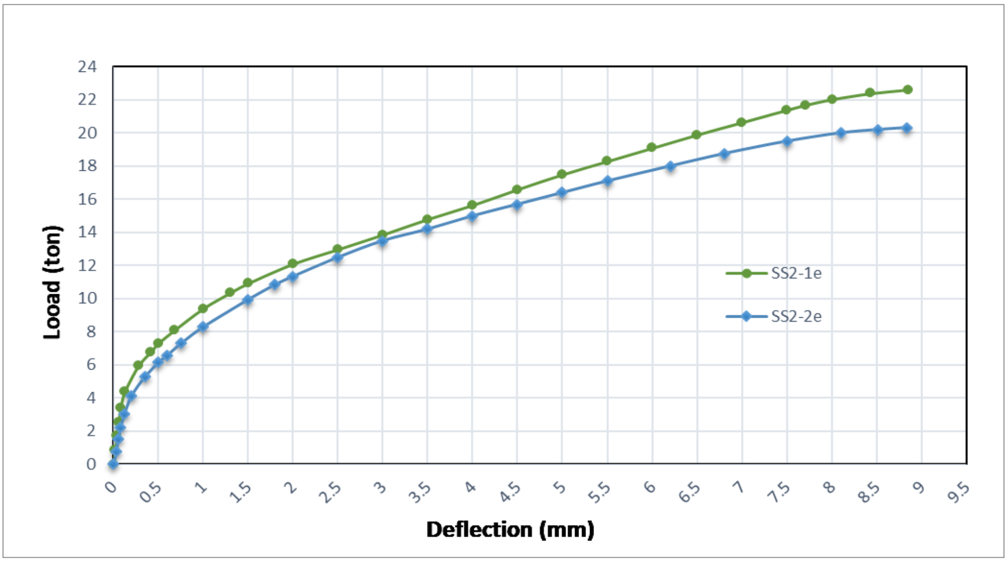

Fig. 25. Effect of load eccentricity value (e) variation with two rows of strengthening steel links.

5.2. Ultimate-punching shear resistance.

The main results of the tested specimens, included ultimate load, are presented in Table 6. The CFRP stirrups system was the most effective system, where the highest values for the ultimate load were obtained. Strengthening system using one row of stirrups loaded under eccentricity value (1e) achieved an increasing in ultimate load reached to 139%, 133% and 126% for specimens SC1-1e, SG1-1e and SS1-1e, respectively, of that recorded for control specimen C-1e. Also, in case of loaded under eccentricity value (2e), specimens SC1-2e, SG1-2e and SS1-2e achieved 139%, 132% and 125%, respectively, of that recorded for control specimen C-2e. Strengthening system using two rows of stirrups loaded under eccentricity value (1e) achieved also, an increasing in ultimate load reached to 181%, 171% and 166% for specimens SC2-1e, SG2-1e and SS2-1e, respectively, of that recorded by the control one C-1e, and in case of loaded under eccentricity value (2e), SC2-2e, SG2-2e and SS2-2e gave 183%, 173% and 168%, respectively, of that recorded by the control one C-2e. The effect of strengthening systems for different eccentricity values can be seen in Figs. 26, 27, 28 & 29.

Table. 6. The main tested specimen's results.

Group	Specimen code	Ultimate Load (ton)	Ultimate def. (mm)	U. L. Exp. / U. L. control	Frist crack Load (ton)	Frist crack def. (mm)	Ductility Factor (UL. def. Spec. / UL. def. Control)
No. 1	C	15.8	6.29	1.00	8.05	1.42	1
	C-1e	13.64	6.1	1.00	7.48	1.26	1
	C-2e	12.13	5.85	1.00	7.75	1.30	1
No. 2	SC1-1e	18.92	6.72	1.39	8.60	0.91	1.10
	SG1-1e	18.12	6.52	1.33	8.75	1.15	1.07
	SS1-1e	17.18	6.68	1.26	8.60	1.03	1.10
No. 3	SC2-1e	24.75	8.56	1.81	10.60	0.97	1.40
	SG2-1e	23.3	8.63	1.71	10.15	0.75	1.41
	SS2-1e	22.63	8.85	1.66	9.40	1.00	1.45
No. 4	SC1-2e	16.83	6.32	1.39	8.20	0.94	1.08
	SG1-2e	15.97	6.31	1.32	8.72	1.13	1.08
	SS1-2e	15.2	6.41	1.25	8.18	1.05	1.10
No. 5	SC2-2e	22.15	8.33	1.83	10.50	1.03	1.42
	SG2-2e	20.98	8.26	1.73	10.25	0.96	1.41
	SS2-2e	20.32	8.83	1.68	8.30	1.00	1.51

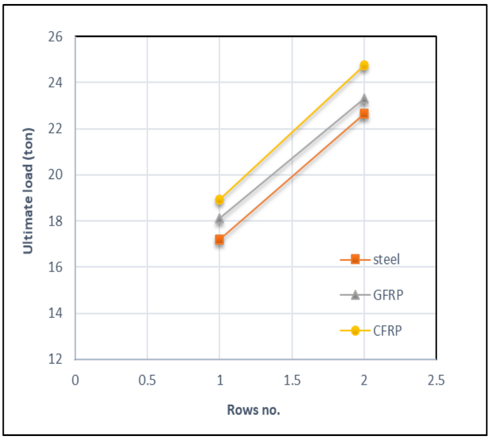

Fig. 26. Number of rows effect with 1e.

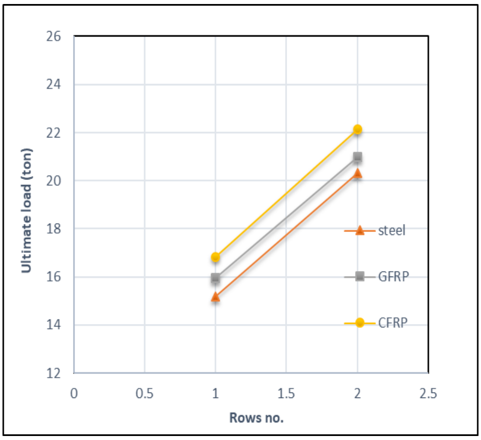

Fig. 27. Number of rows effect with 2e.

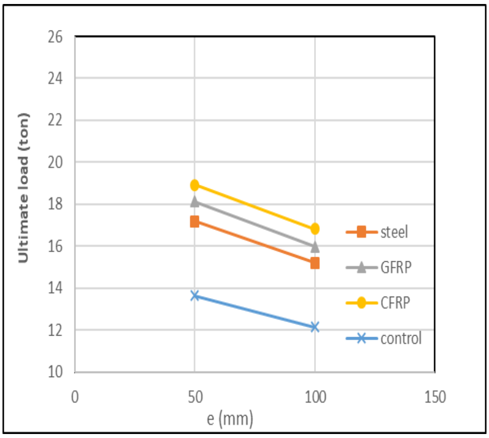

Fig. 28. The (e) value effect with one row.

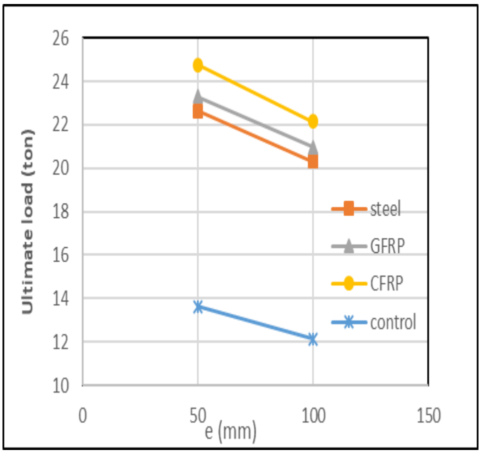

Fig. 29. The (e) value effect with two rows.

5.3. Ductility

The ratio between the tested specimen's deflection at ultimate load to the control specimen's deflection at ultimate load was used to calculate the ductility factor of the tested specimens, I. Gamal, [13], as shown in Table 6. The ductility factor increased up to 51% when the proposed strengthening systems (CFRP, GFRP stirrups and steel links) were applied. The results revealed that using two rows of stirrups was more effective than one row, where, the third and the fifth groups gave a ductility factors from 1.40 to 1.51 respectively, while the second and fourth groups gave ductility factors from 1.07 to 1.10 respectively.

5.4. Behavior of cracking and the mode of failure.

All of the tested specimens were failed due to punching shear. The load value associated with the onset of cracking is shown in Table 6. The first cracking load increased as a result of strengthening systems from 105% for strengthening system using one row up to 141% for strengthening system using two rows. Cracks appeared close to the edges of the columns on the slab compression side. With increasing the applied load, more and wider cracks appeared, and additional cracks start to form and spread radially in the direction of the edge of slab borders. For all the tested specimens, the slab was finally penetrated by the column, and the top perimeter crack formed a semi-rectangular shape at the tension face of the slab. All the fifteen tested slabs gave the same punching shear failure shape –the cone shape-, as the failure surfaces started from the outermost stirrups row with an inclined direction as shown in Figs (30 to 44).

Fig. 30. Cracking pattern for specimen (C).

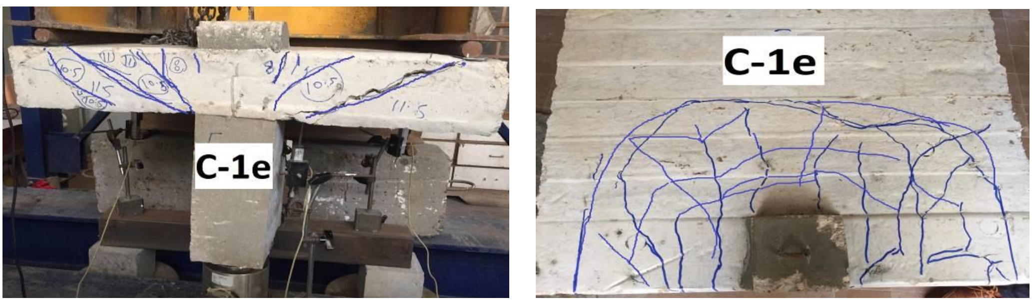

Fig.31. Pattern of cracking for specimen (C-1e).

Fig. 32. Pattern of cracking for specimen (C-2e).

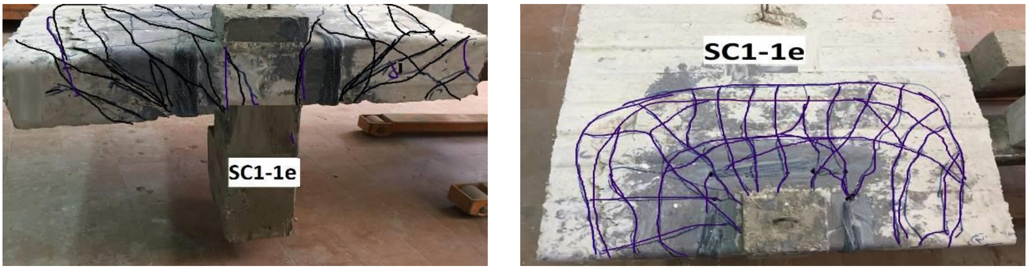

Fig. 33. Pattern of cracking for specimen (SC1-1e).

Fig. 34. Pattern of cracking for specimen (SC1-2e).

Fig. 35. Pattern of cracking for specimen (SC2-1e).

Fig. 36. Pattern of cracking for specimen (SC2-2e).

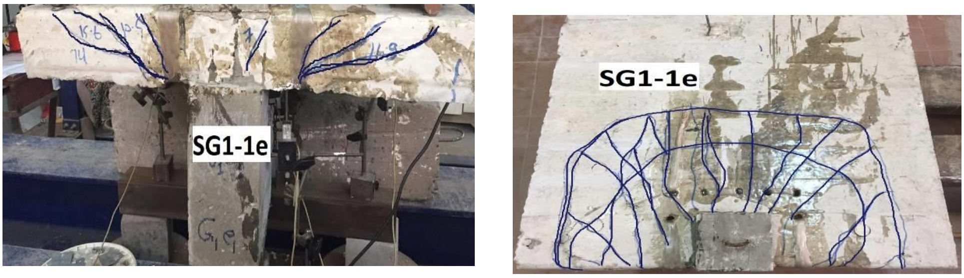

Fig.37. Pattern of cracking for specimen (SG1-1e).

Fig. 38. Pattern of cracking for specimen (SG1-2e).

Fig.39. Pattern of cracking for specimen (SG2-1e).

Fig. 40. Pattern of cracking for specimen (SG2-2e).

Fig. 41. Pattern of cracking for specimen (SS1-1e).

Fig. 42. Pattern of cracking for specimen (SS2-1e).

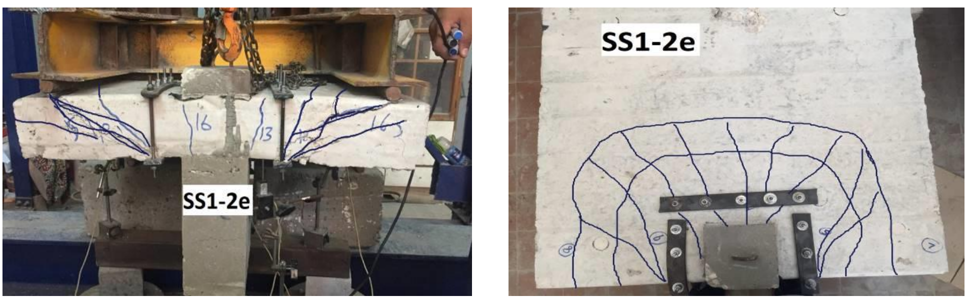

Fig. 43. Pattern of cracking for specimen (SS1-2e).

Fig. 44. Pattern of cracking for specimen (SS2-2e).

6. Analytical Model

All the tested specimens were failed due to exhaustion of concrete under punching shear stress at the critical section, which was positioned d/2 away from the outermost row of strengthening element. The values of predicted punching shear strength for concrete (vc) may be determined using the following equation, which is based on ACI 440, to calculate the ultimate test load [15];

$$vc = 0.33\,\left(1 - \frac{\alpha - 1}{6}\right)\sqrt{f_{C'}} \qquad \text{(MPa)} \qquad (1)$$

Where; α: ratio of the distance between the column face and critical section to the effective depth of the slab $4 \geq \alpha \geq 1$;

fc': concrete compressive-strength (based on cylinder specimen)

The nominal punching-shear strength for the strengthened specimens using steel links can be expressed by the following:

$$v_n = (v_c + v_s) \qquad (2)$$

Where; v_c : resisted shear by concrete;

v_s : resisted shear by the steel links;

$$V_s = (A_v \times f_{yv} \times d)/s \qquad (3)$$

Where; A_v : the vertical legs area forming the punching shear strengthening element using one row;

f_{yv} : the steel yield stress used for strengthening;

S : rows spacing;

The following equation may be used to determine the punching shear force that concrete alone resists at each critical section;

$$V_c = (v_c \times b \times d) \qquad (4)$$

Where; v_c : indicated by equation (5.6);

b : the critical section perimeter (at a d/2 from the punching shear strengthening outermost row);

The nominal punching-shear strength for the strengthened specimens using FRP stirrups can be expressed by the following:

$$v_n = (v_c + \psi \times v_f) \qquad \leq Vmax. \qquad (5)$$

$$Vmax = 0.60 \times \sqrt{fc'}$$

where $V_{f:}$ is the resisted shear by FRP stirrups;

ψ = 0.95 (for completely wrapped),

ψ = 0.85 (for 3-sides "U-wraps"),

Where; V_f : is the resisted shear by FRP reinforcement;

The provided shear strength by FRP (V_f) may be determined by calculating the resulting force from the effective stress for fiber tensile (f_{fe}) depending on its effective strain (ϵ_{fe}).

$v_f = (A_{fv} \times f_{fe} \times d_f)/s_f$ (6)

$A_{fv} = n_s \times n_v \times t_f \times w_f$ (7)

$f_{fe} = \epsilon_{fe} \times E_f$ (8)

Where; ϵ_{fe} = 0.004 (for completely wrapping around the all 4 sides) [16];

s_f : spacing between fiber rows;

t_f : fiber thickness;

w_f : width of the fiber strip;

n_v : number of side row links;

n_s : number of vertical legs in one side of row;

A_{fv} : area of fiber in one row;

d_f : depth of fiber stirrups;

β: depends on the eccentricity of the force causing punching shear and can be assumed equal to 1, 1.10 and 1.20 for $e/t = 0$, $e/t < 0.5$ and $e/t > 0.5$ respectively. The values of β were suggested in consideration of the experimental results of this investigation. [18].

For the tested specimens, the ultimate punching shear load was predicted using the abovementioned equations. Comparing the predicted values of the ultimate load (Vu, cal.) with the experimental results (Vu, exp.) is shown in Table 7.

Table 7. Comparison of experimental and predicted results.

Group	Specimen code	$V_{u, exp.}$	$V_{u, cal.}$	$\frac{V_{u, exp.}}{V_{u, cal.}}$
No. 1	C	15.8	14.28	1.11
	C-1e	13.64	12.98	1.05
	C-2e	12.13	11.90	1.02
No. 2	SC1-1e	18.92	17.08	1.11
	SG1-1e	18.12	17.08	1.06
	SS1-1e	17.18	17.08	1.01
No. 3	SC2-1e	24.75	21.34	1.16
	SG2-1e	23.3	21.34	1.09
	SS2-1e	22.63	21.34	1.06
No. 4	SC1-2e	16.83	15.66	1.07
	SG1-2e	15.97	15.66	1.02
	SS1-2e	15.2	15.66	0.97
No. 5	SC2-2e	22.15	19.56	1.13
	SG2-2e	20.98	19.56	1.07
	SS2-2e	20.32	19.56	1.04

7. Conclusions

1- Even if shear-reinforced, flat slab-column connections have a significant weakness, namely sensitivity to punching-shear failure.

2- The strengthening technique worked well and considerably enhanced these connections' punching shear behavior.

3- For all of the strengthening systems utilized in this study, flexural rigidity had been enhanced, the initial cracking load increased by 5% to 41% for strengthened specimens, and punching shear capacity also increased by 25% to 82% for strengthened specimens.

4- All specimens failed due to punching shear forming a semi-rectangular shape.

5- The CFRP stirrups system was the most effective strengthening technique, where the highest rigidity enhancement and the highest punching shear strength were obtained.

6- The proposed strengthening techniques improved the ductility factor of the tested specimens by 7% to 51%. Also, these strengthening systems gave an increasing in the distance between the column face and the critical punched shear section.

7- The ACI 440-based prediction of ultimate shear strength could be made using equations that had a good level of agreement with all the tested slabs.

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