Journal of Al-Azhar University Engineering Sector

Vol.16, No. 61, October, 2021,1024 -1041

# STRENGTHENING OF FLAT SLABS CONNECTION WITH EDGE COLUMNS AGAINST PUNCHING SHEAR USING NEAR SURFACE MOUNTED (NSM) CARBON FIBER REINFORCED POLYMER (CFRP) BARS

Ahmed Hasan[1,*], Mostafa Hamdy[2], Mostafa Ibrahim[3]
Department of Civil Engineering, Faculty of Engineering, Banha University, Egypt.

Corresponding Author E-mail: moustafa.ibrahim1687@gmail.com
**Received :6 March 2021 Accepted:6 September 2021**

## ABSTRACT

This paper discuses analytically and by experimentation the influence of near surface mounted (NSM) carbon fiber reinforcement polymer (CFRP) bars, which acted as an external strength, on the punching shear attitude of edge slab-column bonds. It was stated that many researchers used NSM as a new strengthening technique in different constructional elements. Nevertheless, the strengthening of edge slab-column connections that used NSM was the same and was also used for cardinal slab column connection by first author.

Seven Reinforced concrete (RC) square slabs with a bordered column were tested. The specimens were buttressed at the column -as an axis point - and at supportive line on the opposite side of the column. One control specimen was tested without strengthening, four specimens were strengthened using NSM-CFRP bar fitted into pre- dug pothole positioned around the column at the tension side of the slab, and two specimens were strengthened using external Bonded (EB) CFRP strips. The (EB) CFRP strips have the same tensile force of the CFRP bars. The place and area of strength to the strengthened materials were also tested differently.

The results of the investigation demonstrated that the use of NSM strengthening technique increased the punching shear capacity and ultimate stiffness appreciably compared to that of applying EB strengthening technique. There were ascending outcomes in the punching shear capacity and ultimate stiffness as 9%-15% and 4%-11% respectively. Furthermore, the cracks in the punching shear zone around the columns were remarkably lowered by the NSM- CFRP bars. The measured ultimate punching shear capacity for the tested specimens proved very rational accordance with the calculated punching loads. This capacity based mainly on a diagnostic specimen for edge slab-column connections strengthened by using FRP concerning its area of bars and place from face of column.

**STRENGTHENING OF FLAT SLABS CONNECTION WITH EDGE COLUMNS AGAINST PUNCHING SHEAR USING NEAR SURFACE MOUNTED (NSM) CARBON FIBER REINFORCED POLYMER (CFRP) BARS**

**KEYWORDS:** Edge slab column, strengthening, near surface mounted, carbon fiber reinforcement polymer (CFRP), external bonded.

## تدعيم الوصله بين البلاطات المسطحه والاعمده الطرفيه ضد القص الثاقب باستخدام قضبان من البوليمرات المسلحه بالالياف الكربونية داخل تجويفات سطحيه

احمد حسن [1]*، مصطفى حمدى[2] ، مصطفى ابراهيم[3]
قسم الهندسة المدنية, كلية الهندسة ببنها,جامعة بنها , مصر
*البريد الاليكتروني للباحث الرئيسى: Email: moustafa.ibrahim1687@gmail.com

**الملخص**

يناقش هذا البحث بشكل تحليلي وعن طريق التجارب المعملية تأثيرتدعيم الوصلة بين البلاطات المسطحة و الاعمدة الطرفية ضد القص الثاقب باستخدام قضبان من البوليمرات المسلحة بالالياف الكربونية داخل تجويفات سطحية خارجية كاسلوب تقوية جديد في العناصر الانشائية المختلفة علما بان اسلوب التقوية المقترح تم استخدامه بواسطة العديد من الباحثين و استخدم ايضا بواسطة الناشر الاول .

تم اختبار سبع بلاطات مربعة من الخرسانة المسلحة و بيها عمود طرفي تم تدعيم العينات حول العمود كنقطة محورية تم اختبار عينة واحده مرجعية بدون تقوية و تم تقوية اربع عينات باستخدام قضبان من البوليمرات المسلحة بالالياف الكربونية تم وضعها حول العمود في جانب الشد للبلاطه عن طريق تثبتها داخل تجويفات سطحية تم عملها مسبقا و تم تقوية عينتين بشكل مختلف عن طريق وضع شرايح من البوليمرات المسلحة بالالياف الكربونية و لها نفس قوة الشد لقضبان البوليمرات المسلحة بالالياف الكربونية .

اظهرت نتائج الدراسة ان استخدام تقنية التقوية بقضبان من البوليمرات المسلحة بالالياف الكربونية داخل تجويفات سطحية زادت من قدرت مقاومة القص الثاقب و الصلابة النهائية بشكل ملحوظ مقارنتا باستخدام تقنية التقوية باستخدام شرايح من البوليمرات المسلحة بالالياف الكربونية يتم لصقها علي سطح العينة و ذلك بنسبة (9-15%) و (4-11%) علي التوالي علاوة علي ذلك تم تخفيض الشروخ في منطقة القص الثاقب حول العمود بشكل ملحوظ جدا و ذلك باستخدام تقنية التقوية بقضبان من البوليمرات المسلحة بالالياف الكربونية كما ان نتائج القص الثاقب للعينات المختبرة كانت مناسبة جدا مع نتائج القص الثاقب للمعادلات الحسابية و ذلك لعينات ذات العمود الطرفي المدعمة باستخدام بقضبان من البوليمرات المسلحة بالالياف الكربونية وذلك طبقا لمساحة القضبان و مكانها من وش العمود .

**الكلمات المفتاحية :** عمود البلاطة الطرفي , القص الثاقب , التدعيم , تجويفات سطحية , البوليمرات المسلحة بالالياف الكربونية , اللصق الخارج .

# 1. INTRODUCTION

Plane slabs have been widely applied in many construction projects. Structural system without the obsolete fallen beams resulted in a rise of floor height, easy working and swift buildings. Following this method, the most crucial part was indicated in the punching shear failure of slab- column connections. The nature of punching shear collapse was fragile and always found within small deviations. However, the slab punching strength could become limited due to many reasons like design construction mistakes, alteration of building exploitation, or any new service for establishment which required launching in the slab and corrosion of fortification. These conditions explained the necessity to the occurrence of strengthening edge slab- column connections.

During the ex- decade, research tackled and accomplished on fiber reinforcement polymers (FRP) and its usage as a strengthening material in order to enhance the act of slab-column connections' existence. FRP could help in two different ways; external support [1-6] and internal one [7-10]. The CFRP external strengthening system consisted of one or more FRP sheet - layers attaching to the strain edge of the slab by epoxy resin glue. By retarding the shear cracks configuration, this reinforcement approach increased the flexibility and led to high punching shear strength. The ordinary failure for applying the external strengthening technique was the hasty decrypting of CFRP. Decrypting could be delayed developing the structural attitude of strengthened connection via supplying a final berth to the external connected FRP [11]. Post-installation of CFRP shear bolts, as shear strengthening, in penetrated holes were stuffed with suitable epoxy cement. They were dropped into an internal strengthened method for edge slab-columns attaching. The corrupted slab could be damaged by the punched holes with an aim to insert shear reinforcement into the conflict punching shear area of the slab which was near the column. That approach for strengthening was not virtually the suitable solution in many conditions.

NSM technique is very modern and very useful in strengthening reinforced concrete elements. In the case of using NSM technique grooves are made in the concrete cover of the element to be strengthened, then the grooves are partially filled with a highly adhesive material such as sikadur-330, CFRP bars are installed inside the grooves, then the grooves are filled with adhesive and then the surface is leveled.

Comparing the (NSM) technique with the external bonded (EB) technique, several advantages appeared. The problems of debonding in EB technique were less than those in NSM technique which led to an advanced quality in the structural attitude of strengthened elements. Furthermore, both concrete cover and the cement glue material shielded the reinforcing bars from temperature, hooliganism, and ruin. Different research investigated the reconstruction and strengthening of RC beams and slabs in a more flexible mode via NSM technique and by using FRP bars [12-16]. Other researchers discussed the shear reaction of RC beams strengthened by the NSM technique using FRP bars in the form of external stapes [17-20]. Strengthening by making NSM FRP bars use the eccentric slab-column connection which was investigated previously by first author This research achieved the desired goal in evaluating the NSM technique in strengthening the connection between flat concrete slabs and edge columns against punching shear, where specimens were prepared and tested, results were extracted and analyzed, and a comparison was made between the results of experimental tests and mathematical equations, where the results of the comparisons were highly acceptable.

## 2. EXPERIMENTAL PROGRAM

### 2.1 Specimens and Text Matrix

Seven RC edge slab-column connections, which were exposed to punching loading, were formulated and tested carefully according to an experimental program. The basic purpose of the experiment was to explore the of RC edge slab-column connection's behavior which was strengthened at the tension side of the slab via applying NSM technique. One of the un-strengthened specimens was planning to act as a control specimen. Four specimens were reinforced by a 10 mm diameter CFRP bar using NSM with different area of strength and positions. CFRP strips were used in strengthening the remaining two specimens connected externally to the slab from the tension side. This connection happened with two various strengthening areas similar to that used on NSM strengthened specimens for faces of comparison purposes. Moreover, and for comparison, CFRP strip's width was selected specially to give tension force for strips to be equal to that of CFRP bars. The full elaboration of strengthening systems and categorization for the examined specimens were shown in Table1. The first letter of the specimen terminology (S) referred to slab. As for the second letter, it pointed to the strengthening method, where (S) was for CFRP strip and (B) for CFRP bar which plus adding number (2) in case of doubling the area of strengthening. But for the last number, it referred to the distance of central part of the CFRP strip or NSM- CFRP bar to the face of column. Hence, (0.5) for distance equaled half the depth of the slab and (1.0) for distance equaled the total depth of the slab Fig.1 conveyed the schemes of strengthening used in this study discussion.Fig.2 discussed that all specimens had the identical dimensions and steel reinforcement information, as proved. Seven specimens of flat reinforced concrete slabs with dimensions 900x900 mm and thickness 130 mm were prepared and they were reinforced using high-strength steel reinforcement with a diameter of 12 mm, where the bottom and the top meshes were 11Ø12 and 9Ø12 respectively. The edge column was made with dimensions of 150x150 mm, and an extension of the column was made 150 mm above the flat concrete slab and 50 mm below it, then the column was reinforced with high-resistance steel 12 mm diameter, 4Ø12 was used, and stirrups were made using mild steel 8 mm diameter every 100 mm. Groves were made in the concrete cover of the specimens of flat concrete slabs using pieces of wood installed under the flat concrete slabs, where the width of the grooves was 25 mm and the depth of 25 mm, then concrete was poured into the wooden slot that had been prepared in advance, then the treatment and strengthened by using NSM-CFRP bars and EB-CFRP strips was done for the flat concrete slabs, tested and extracted the results .

**Table 1. Test matrix**

| Specimen code | Strengthening technique | Strengthening Area | Location from column* |
|---|---|---|---|
| Control | | | |
| S-B-0.5 | NSM-CFRP bar | Single Area | d**/2 |
| S-B-1 | | Single Area | d |
| S-2B-0.5 | | Double Area | d/2 |
| S-2B-0.5-1 | | Double Area | d/2&d |
| S-S-0.5 | EB-CFRP strips | Single Area | d/2 |
| S-2S-0.5 | | Double Area | d/2 |

*Distance between center line of CFRP bar or CFRP strip to the column face; **Slab depth*

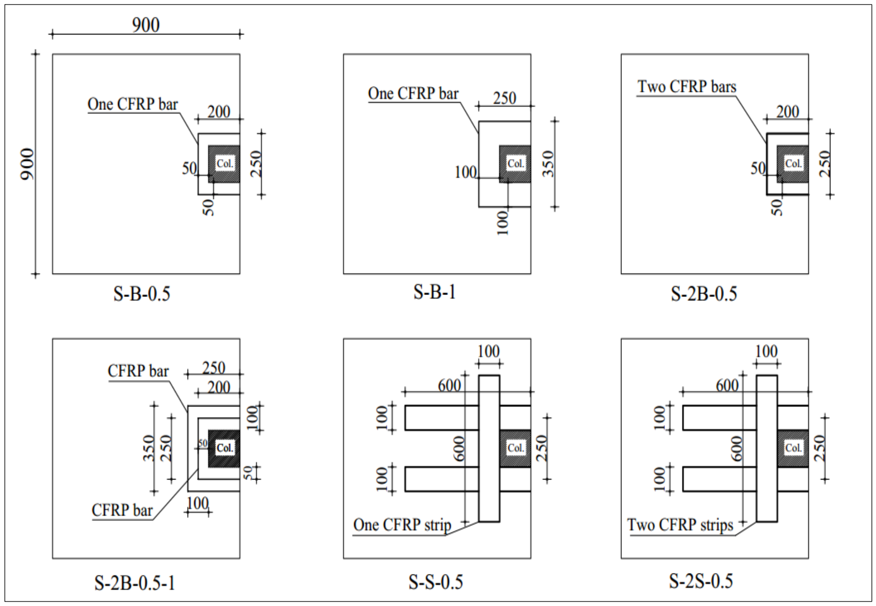


**Fig.1: Strengthening schemes (All dimensions in mm)**

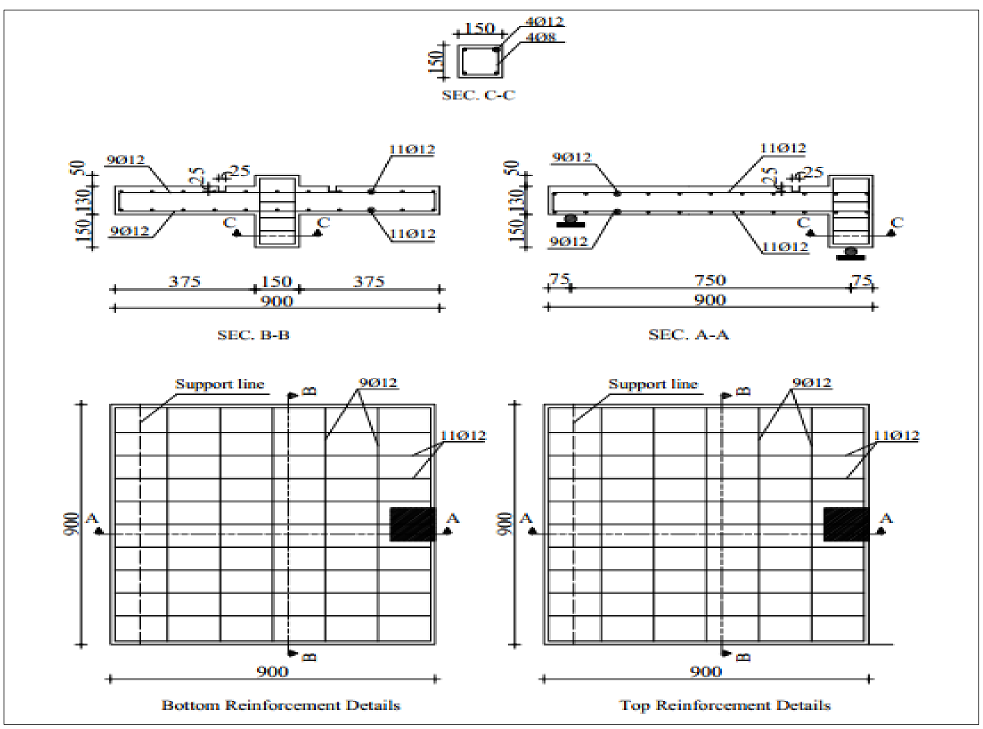


**Fig.2: Dimensions and reinforcement details for specimens**

## 2.2 Material Properties

### 2.2.1 Concrete

Concrete was used consisting of a mixture of ordinary Portland cement, natural sand and dolomite fracture, where the target pressure strength (fcu) after 28 days was 35 MPa. The actual pressure strength (fcu) was obtained from the results of testing standard cubes, which were prepared from concrete Made for casting flat concrete slab specimens, processed and tested after 28 days.

### 2.2.2 CFRP bars

CFRP rods were manufactured in the Materials Laboratory of the Benha Faculty of Engineering, Benha University, and were typically produced with the appropriate diameter and dimensions for the study variables as shown in Figure 3. Where the CFRP rods were manufactured from carbon fiber reinforced with polyester resin, a specimen of CFRP rods was tested to obtain the characteristics mechanical as shown in Table 2.

### 2.2.3 CFRP strips

Slides of carbon fiber reinforced polymers CFRP were used produced by Sika under the name of wrap-230, and the use of adhesives produced by Sika also under the name of sikadur-330. Table 2 shows the mechanical properties of CFRP strips obtained from Sika.

**Table 2. Dimensions and characteristic properties of CFRP**

| a) CFRP bars | | b) CFRP strips | |
|---|---|---|---|
| **Property** | | **Property** | |
| Diameter of bars (mm) | 10 | Fabric design thickness (mm) | 0.128 |
| Area of bars ($mm^2$) | 78.5 | Fabric width (mm) | 100 |
| Area of fibers ($mm^2$) | 29.3 | Tensile strength (MPa) | 4300 |
| Fiber ratio by area | 37% | Elasticity modulus (MPa) | 234000 |
| Tensile strength (MPa) | 1420 | Strain at failure | 1.84% |
| Elasticity modulus (MPa) | 216000 | | |
| Strain at failure | $6600x10^{-6}$ | | |

## 2.3 Strengthening Procedures

### 2.3.1 NSM strengthening technique

The ruts at the strung side of the slabs were mannered by the help of some wooden fragments during the molding of concrete, as mentioned before. Hence and by finishing the process of specimens hardening as well as moduli, all the grooves were disappeared in the wood bits and many substances were released. Subsequently, halfway of the groove was stuffed with the epoxy Sikador-330. Here, CFRP bar was positioned bit by bit constraining the epoxy to cover the area till the edges between the bar and groove. A double level of epoxy was added to occupy the groove and the remnant epoxy was dismissed and to coat with epoxy to the surface.

Fig.4 showed gradually the steps to strengthen the specimens by applying the NSM technique.

**Fig. 3. CFRP bars used in this study**


**Fig.4: Strengthening procedures using NSM technique**

### 2.3.2 EB strengthening technique

The concrete slab was reinforced from outside by The CFRP strips. They were limited to 600 mm long and 100 mm wide and were put around the column perpendicular direction, as displayed in Fig.5.An angle shredder with a wire brush were helping to roughen the concrete surface, at which the CFRP strips would be set. The plane area was cleared out from any slack substances by using the vacuum cleaner. Next, both of the CFRP strips surfaces and the marked places, found on the concrete surface, were filled with the epoxy adhesive (Sikadur-330). The strips were squeezed to the surface of concrete using a very tiny roller. Any extra amount of epoxy which was compressed from the slides had to be removed.


**a) Roughening of Concrete Surface** **b) Strengthening with CFRP Strips**

**Fig.5: Strengthening procedures using EB technique**

## 2.1 Test-up and Instrumentation

The loading system consisted of hydraulic jack with maximum capacity 1000 KN , and reaction frame with 1000 KN maximum capacity, connected to an electrical pump which supplies with oil pressure. Vertical concentrated load was used for testing the specimens which was distributed to uniform line load acting on the upper surface of slab, as shown in Fig.6-7. used a rigid steel system for distributing the load from concentrated to uniform line load, as shown in Fig. 8. As already mentioned, the specimens were supported as a point support at the column and at the column opposite side supported as a line support. For recording the punching shear force a load cell with 1000 KN max. Capacity was installed between the column and its support. Vertical deflections were recorded at first cracking load and ultimate failure load. For recording the deflection at five detected points, 5 linear variable differential transformers (LVDT) were used, as shown in Fig.9. Propagation of cracks was marked after each load increment up to failure. Fig.10 illustrates the test set- up. The tests were conducted in the reinforced concrete laboratory Faculty of Engineering, Benha.

**Fig.6: The line load distribution.**

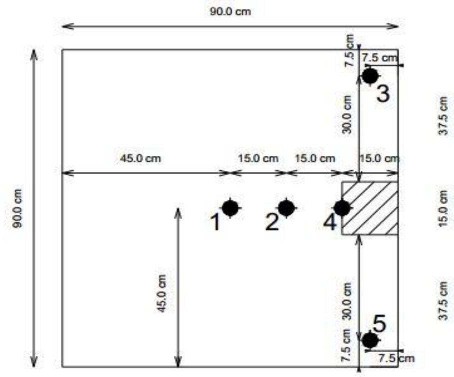


**Fig.7: Details and dimensions of line load.**

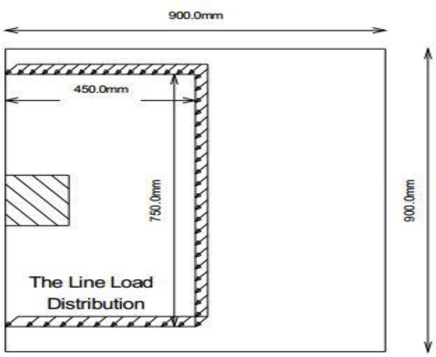


**Fig.8: The rigid system**

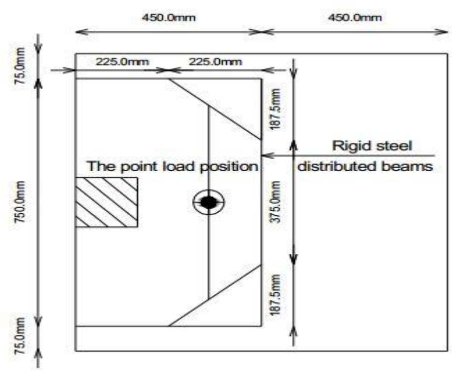


**Fig.9: LVDT locations at bottom side**

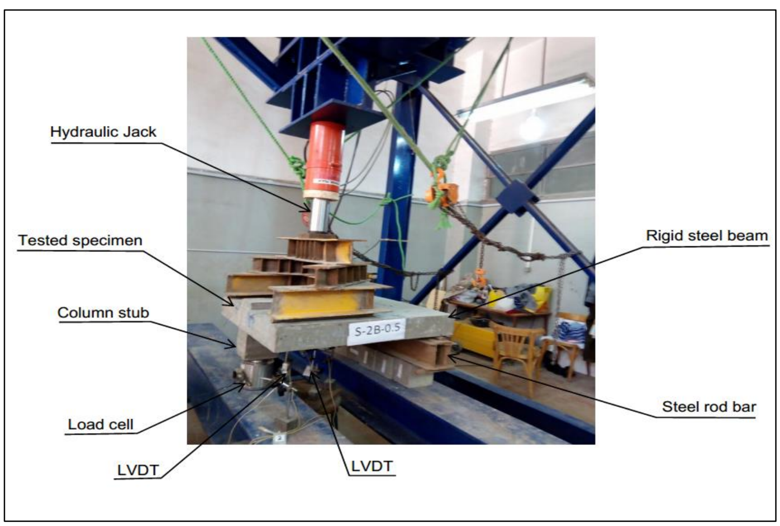


**Fig.10. Set-up of Test**

# 3. EXPERIMENTAL RESULTS AND DISCUSSION

The results of this study were summarized in Table 3, where all the results were monitored and recorded through experimental tests and the different results were compared according to the study variables that were previously identified. The load deflection curves were drawn and the cracks resulting from the loading were monitored and their effect on the punching shear capacity was evaluated compared to the control specimen.

## 3.1 Load-deflection Relationships

The central vertical deflections were measured for all concrete flat slabs at point No.1 as shown in Fig.9, and the vertical deflections were recorded against the increase in the load for all tested specimens. It was observed that the load deflection curve increased until it reached its maximum value and then suddenly started to decrease due to the collapse of the punching shear. The load deflection relations were compared for all tested concrete flat slab specimens according to the previously proposed study variables as shown in Fig.11-13. It was observed that the specimens that were strengthened using NSM-CFRP technique and the specimens that were strengthened using the EB-CFRP technique increased strength, hardness and punching shear resistance compared to the control specimen. It was also observed that the specimens that were reinforced had an increased failure load by 66% - 81% compared to the control specimen.

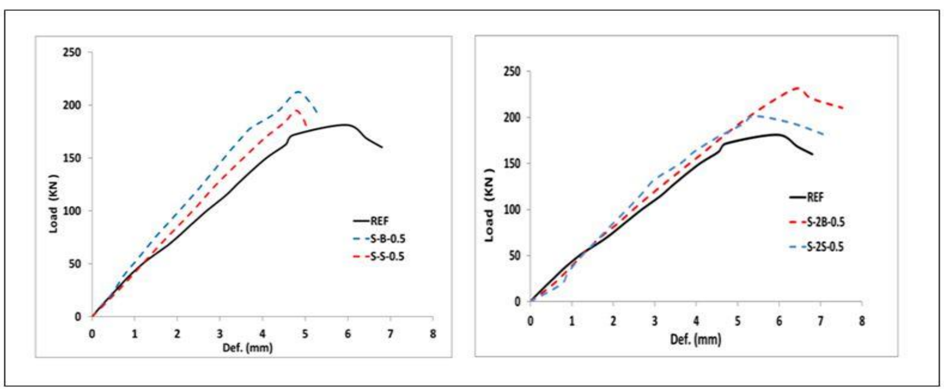


**Fig.11: comparison of Load deflection based on the strengthening techniques**

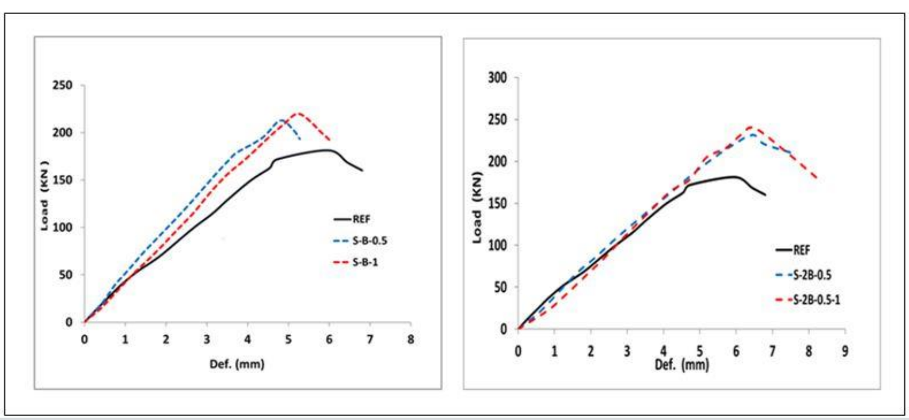


**Fig.12. comparison of Load deflection based on the strengthening locations**

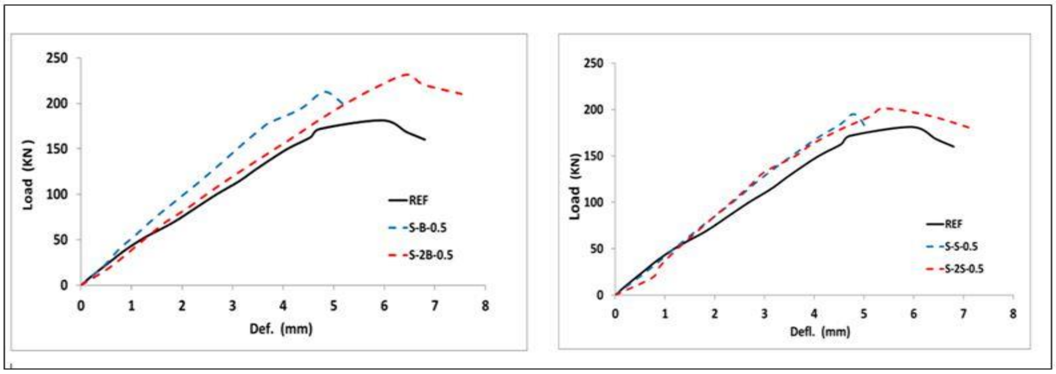


**Fig.13: comparison of Load deflection based on the strengthening are**

## 3.2 Load Carrying Capacity

As shown in table 3, a detailed comparison was fulfilled between the cracking load ($P_{cr}$), the ultimate load (Pu), and the gain in the Pu for the strengthened specimens and those for the control specimens. An observation was taken as the $P_{cr}$ for the external reinforced specimens by CFRP strips was almost improved on the contrary with those for the control specimen. Moreover, the $P_{cr}$ was notably affected via the strengthening process by using NSM-CFRP bar. To calculate the difference, the $P_{cr}$ raised with the control specimen by 59-62% and 64-71% for single area and double area bars accordingly. The ultimate load capacity for all strengthened specimens increased clearly, and the obtained Pu was 8- 32%. The growth in the Pu value for the specimens strengthened with NSM-CFRP bar over the control specimen was 17-32%. Whereas it was just 8-11% for specimens strengthened with EB-CFRP strips. Hence, the reached result was that applying the NSM technique for strengthening slabs causes to enhance the punching shear capacity of slab-column connections more than applying the EB technique.

As for the strengthening procedures, it was observed that the steps for duplicating the strengthening area led to a little rise in Pu, on the opposite to those arrangements of the single area. It happened whether it was for specimens strengthened approaching even EB or NSM technique. The high ratio in Pu for specimens of single area arrangement was 5.9- 2.6% less than that of double area strengthening one.

Coming to the various site comparison of CFRP bar from the facial side of the column, Pu of S-B-1 was higher than Pu of S-B-0.5.

Concerning the specimens with perpendicular strengthening structures, the S-B-1 specimen with bar at a distance d from the column face was bigger with 3.3% in Pu than the S-B-0.5 specimen with bar at a distance d/2. Fig.15 $_{described}$ an elaborated difference between $P_{cr}$ and Pu for all the examined specimens.

## 3.3 Ductility

All reinforced concrete flat slabs were tested to failure due to punching shear, specimens strengthened using NSM-CFRP bars and specimens strengthened using EB-NSM strips technique. The use of these techniques in reinforcing significantly increased the load of the first crack by holding the first crack of the specimen. The control where the first crack was monitored for all tested samples, then the load corresponding to the first crack was recorded and the cracks shape and spread around the column were monitored until the specimen collapsed due to the punching shear. The edges of the slab are in the tension side of the slab in the three directions, and Tab.3.shows the values of the load corresponding to the first crack for all tested specimens.

**Table 3. Summary of experimental results**

| Specimen Code | $f_{cu}$ (Mpa) | 1st Cracking | | Ultimate | | $\Delta_{uc}^{*}$ | $\frac{P_u}{P_{u,c}^{**}}$ | $\frac{\Delta_{uc}}{\Delta_{uc,c}^{***}}$ | Un-cracked Stiffens ($K_i$) | Ultimate Stiffness ($k_U$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Load ($P_{cr}$) (kN) | Cracking $\Delta_{cr}$ (mm) | Load ($P_u$) (kN) | Cracking $\Delta_u$ (mm) | | | | $\frac{P_{cr}}{\Delta_{cr}}$ (kN/mm) | $\frac{(P_u - P_{cr})}{(\Delta_u - \Delta_{cr})}$ (kN/mm) |
| Control | 33.7 | 50 | 1.5 | 181.2 | 5.98 | 5.98 | 1 | 1 | 33.33 | 29.2 |
| S-B-0.5 | 33.4 | 79.5 | 1.7 | 212.5 | 4.79 | 3.9 | 1.17 | 0.66 | 46.8 | 43.1 |
| S-B-1 | 34.1 | 81 | 1.9 | 219.5 | 5.27 | 4.2 | 1.21 | 0.71 | 42.63 | 41.1 |
| S-2B-0.5 | 34.8 | 82.1 | 2.1 | 231.6 | 6.27 | 4.7 | 1.28 | 0.79 | 39.6 | 35.9 |
| S-2B-0.5-1 | 35.1 | 85.3 | 2.3 | 239.9 | 6.49 | 4.8 | 1.32 | 0.81 | 37.1 | 36.9 |
| S-S-0.5 | 33.8 | 85 | 1.95 | 194.9 | 4.79 | 4.4 | 1.08 | 0.74 | 43.6 | 38.7 |
| S-2S-0.5 | 34.9 | 87.5 | 2.1 | 201.2 | 5.39 | 4.7 | 1.11 | 0.79 | 41.7 | 34.6 |

* Deflection of tested specimens at Pu of control specimen; ** Pu of control specimen; ****Deflection of control specimen corresponding to its Pu*

## 3.4 Stiffness

The ultimate stiffness (ku) and the un-cracked stiffness (ki) for the specimens which were experimented had been measured by deflection proportion at ultimate and cracking loads, as demonstrated in Table 3. It appeared that (ki) was highly increased for all strengthened specimens with a rage of 11%-40% comparing to that of the control specimen. Meanwhile, results also proved that (Ku) was greatly influenced by the strengthening technique. (ku) was raised strongly for the reinforced specimens through NSM-CFRP bar by 23%-43% and was little high for specimens with EB- CFRP strips by 18%-31% concerning the control specimens.

With regard to the impact of strengthening area, the double area strengthening led to the occurrence of larger stiffness compared to the single area. Besides, both of (Ki) and (Ku) for the specimens with double area strengthening had achieved a rising point by 15%-18% and 11%-23%, respectively on the contrary to the specimens with single area. These outcomes achieved that (Ku) was less enhanced by strengthening area than (Ki). However, the place factor of the CFRP bar from the face of column always lowered (Ki) more than (Ku). By testing the specimens and putting the CFRP bar at distance d from face of column, (Ki) and (Ku) were rising gradually by 7%-10% and 3%-5% respectively more than that with CFRP bar which positioned at distance (d/2).

## 3.5 Crack Propagation and Failure Characteristics

Fig.14. shows the failure in the lower face of reinforced concrete flat slabs for all tested specimens. Some flexible cracks were observed around the column, and these cracks spread towards the edges of the reinforced concrete flat slabs. As the load increased, the number of cracks increased and widened until the collapse occurred suddenly due to the punching shear, where it is concluded from the failure of the maximum capacity of the punching shear, and then a severe decrease in the load occurs. Where the failure was clear as a result of the column penetrating the slab due to the punching shear around the column in the direction of tension of the slab.

For specimens of reinforced concrete flat slabs that were reinforced using NSM-CFRP bars technique, at a distance (d/2) from the column, bending cracks appeared away from the reinforced area. The specimen that was reinforced with the same previous technique and at a distance (d) from the face of column The bending cracks were concentrated near the shaft and did not spread in the area being strengthened.

For specimens of reinforced concrete flat slabs that were reinforced using EB-CFRP strips technique, no one was able to see the cracks under the strengthened slab due to the presence of CFRP strips, but it was noted that the higher the load, the separation of CFRP strips occurred until a complete separation occurred between the slab and CFRP strips Then the failure of the specimen occurred suddenly and the load began to decrease gradually.


**Fig.14: The tested specimens crack patterns at failure load (bottom faces)**

## 4. CALCULATED PUNCHING SHEAR CAPACITY

The study showed the expected results of piercing shear and comparing the arithmetic equations with the experimental results as shown in Table 4 and Fig.15. From the comparison it can be concluded that the specimens that were reinforced using the NSM-CFRP technique give an arithmetic mean ratio of 1.14 and a coefficient of variation of 0.048. It was concluded that the specimens that It was reinforced using EB-CFRP technology, giving an arithmetic mean ratio of 1.27 and a coefficient of variance of 0.028, where the experimental results are very close to the results of the arithmetic equations.

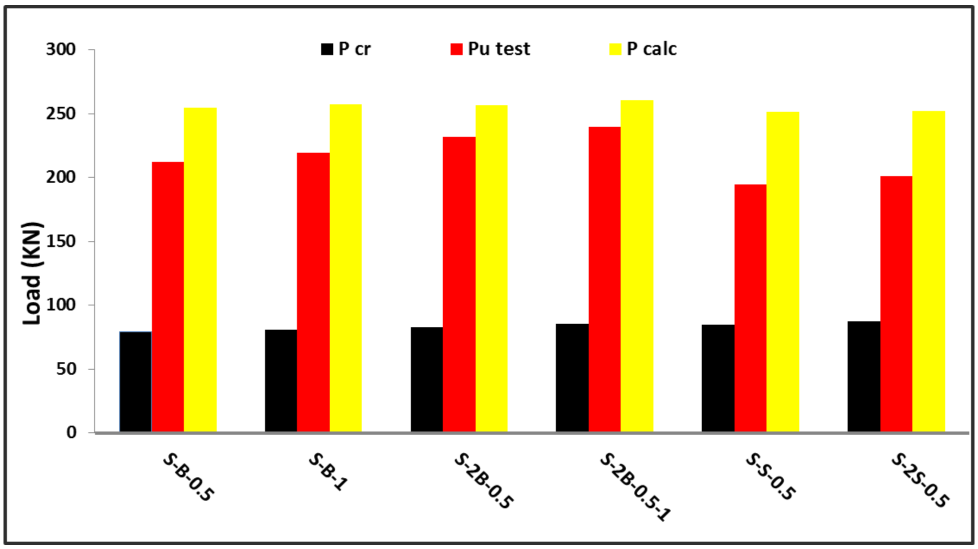


**Fig. 15. Comparison between cracking load, experimental ultimate load and calculated ultimate load for the strengthened specimens**

**Table 4: Experimental and predicted results comparison**

| **Specimen Code** | $P_{u,exp}$ **(kN)** | $P_{u,calc}$ **(kN)** | $\frac{P_{u,calc}}{P_{u,exp}}$ |
|---|---|---|---|
| S-B-0.5 | 212.3 | 254.7 | 1.19 |
| S-B-1 | 219.5 | 257.4 | 1.17 |
| S-2B-0.5 | 231.6 | 256.7 | 1.11 |
| S-2B-0.5-1 | 239.9 | 260.6 | 1.09 |
| Mean | | | 1.14 |
| Standard deviation | | | 0.048 |
| S-S-0.5 | 194.9 | 251.5 | 1.29 |
| S-2S-0.5 | 201.3 | 252.2 | 1.25 |
| Mean | | | 1.27 |
| Standard deviation | | | 0.028 |

## 5. SUMMARY AND CONCLUSION

Seven specimens of flat slabs were made and tested until collapse. One specimen was made without strengthening and four specimens were strengthened using CFRP bars. They were placed inside the grooves. Two specimens were reinforced using CFRP slides attached to the concrete slab surface from the outside. A segment that gives the same tensile strength as CFRP poles in order to reinforce the joint between flat slabs and edge columns against perforated shear to evaluate the NSM technique.

1. Specimens strengthened using NSM-CFRP technique increased punching shear strength by 17%-32% compared to the control specimen and specimens strengthened using EB-CFRP technique increased punching shear strength by 8%-11% compared to the control specimen.

2. The specimens that were strengthened using the NSM-CFRP technique increased the final stiffness by 15%-48% compared to the reference specimen and the specimens that were strengthened using the EB-CFRP technique increased the final stiffness by 18%-33% compared to the reference specimen From the results it is clear that the use of the NSM-technology CFRP is better for flat slab reinforcement.

3. The specimens that were strengthened using NSM-CFRP technology at a distance d from the shaft face give greater resistance to puncture shear and stiffness compared to the specimens that were strengthened using the same technology but at a distance of d/2 from the shaft face.

4. The strengthening process depended mainly upon the area CFRP whether it was double or single. The double area showed cracking stiffness and shear punching capacity than those compared to the single area CFRP.
5. Laboratory experiments proved that all the tested specimens were significantly reduced cracks in the punching shear area around the column compared to the control specimen.

6. Another type discussed in this paper was the application of the analytical specimen. Its purpose was to gain the expected ultimate capacity of shear punching for edge slab-column connection strengthening using CFRP. It described how the strengthening area and the position of CFRP matched the tests conclusions. The predicted load of shear punching for strengthened specimens using NSM-CFRP bar was overvalued by 14% compared to results of test. However, the strengthened specimens using EB-CFRP strips, the obtained shear punching load was overrated by 27%.

## REFERENCES

[1] Malalanayake, M. L. V. P., Gamage, J. C. P. H., & Silva, M. A. L. (2017, December). "Experimental investigation on enhancing punching shear capacity of flat slabs using CFRP".

In 8th International Conference on Structural Engineering and Construction Management (ICSECM2017), Kandy, Sri Lanka.

[2] Abdullah, A., Bailey, C. G., & Wu, Z. J. (2013). "Tests investigating the punching shear of a column-slab connection strengthened with non-prestressed or prestressed FRP plates". Construction and Building Materials, 48, 1134-1144.

[3] El-Sayed, K. M., Khalil, N. N., & Omar, M. I. (2016). Repair and strengthening of RC flat slab connection with edge columns against punching shear. *Advances in Research*, 1-22.

[4] Silva, M. A. L., Gamage, J. C. P. H., & Fawzia, S. (2019). Performance of slab-column connections of flat slabs strengthened with carbon fiber reinforced polymers. Case Studies in Construction Materials, 11, e00275.

[5] Dissanayaka, R. H. M., Silva, M. A. L., Magallagoda, L. P. G., & Gamage, J. C. P. H. (2018, December). Physical behavior of CFRP retrofitted reinforced concrete slab-column connections. In International Conference on Sustainable Built Environment (pp. 458-469). Springer, Singapore.

[6] Esfahani, M. R., Kianoush, M. R., & Moradi, A. R. (2009). Punching shear strength of interior slab–column connections strengthened with carbon fiber reinforced polymer sheets. Engineering Structures, 31(7), 1535-1542.

[7] Soudki, K., El-Sayed, A. K., & Vanzwol, T. (2012). Strengthening of concrete slab-column connections using CFRP strips. Journal of King Saud University-Engineering Sciences, 24(1), 25-33.

[8] Askar, H. S. (2015). Repair of R/C flat plates failing in punching by vertical studs. Alexandria Engineering Journal, 54(3), 541-550.

[9] Meisami, M. H., Mostofinejad, D., & Nakamura, H. (2014). Punching shear strengthening of two-way flat slabs with CFRP grids. Journal of Composites for Construction, 18(2), 04013047.

[10] Abdel-Kareem, A. H. (2019). Punching Strengthening of Concrete Slab-column Connections Using Near Surface Mounted (NSM) Carbon Fiber Reinforced Polymer (CFRP) Bars. *Journal of Engineering Research and Reports*, 1-14.

[11] Akhundzada, H., Donchev, T., & Petkova, D. (2019). Strengthening of slab-column connection against punching shear failure with CFRP laminates. Composite Structures, 208, 656-664.

[12] Sharaky, I. A., Torres, L., & Sallam, H. E. M. (2015). Experimental and analytical investigation into the flexural performance of RC beams with partially and fully bonded NSM FRP bars/strips. Composite Structures, 122, 113-126.

[13] Sharaky, I. A., Torres, L., Comas, J., & Barris, C. (2014). Flexural response of reinforced concrete (RC) beams strengthened with near surface mounted (NSM) fibre reinforced polymer (FRP) bars. Composite Structures, 109, 8-22.

[14] Almusallam, T. H., Elsanadedy, H. M., Al-Salloum, Y. A., & Alsayed, S. H. (2013). Experimental and numerical investigation for the flexural strengthening of RC beams using near-surface mounted steel or GFRP bars. Construction and Building Materials, 40, 145-161.

[15] Kotynia, R. (2012). Bond between FRP and concrete in reinforced concrete beams strengthened with near surface mounted and externally bonded reinforcement. Construction and Building Materials, 32, 41-54

[16] Sun, Z. Y., Wu, G., Wu, Z. S., & Luo, Y. B. (2011). Flexural strengthening of concrete beams with near-surface mounted steel–fiber-reinforced polymer composite bars. Journal of reinforced plastics and composites, 30(18), 1529-1537.

[17] Abdel-kareem AH, Debaiky AS, Makhlouf MH, Abdel-baset M. Shear Strengthening of RC Beams with FRP using (NSM) Technique. Advances in Research, SCIENCEDOMAIN international. 2019; 19(4):1-20.

[18] Rizzo, A., & De Lorenzis, L. (2009). Behavior and capacity of RC beams strengthened in shear with NSM FRP reinforcement. Construction and Building Materials, 23(4), 1555-1567.

[19] Rahal, K. N., & Rumaih, H. A. (2011). Tests on reinforced concrete beams strengthened in shear using near surface mounted CFRP and steel bars. Engineering Structures, 33(1), 53-62.

[20] Jalali, M., Sharbatdar, M. K., Chen, J. F., & Alaee, F. J. (2012). Shear strengthening of RC beams using innovative manually made NSM FRP bars. Construction and Building Materials, 36, 990-1000.