Review on rehabilitation of rc deep beams using external bonded frp and nsm technique

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Abstract. Due to a variety of reasons, including increased service loads, environmental impacts, construction errors, and mechanical impediments, the strengthening process was becoming necessary for many concrete buildings worldwide. The strengthening process is carried out in several ways, the most common of which are the Near-Surface mounted (NSM) technique and the External Bonded Reinforcement (EBR) technique. The main object of the strengthening process is to increase the strength and durability of reinforced concrete structures and reducing early failure. This research discussed the most important papers that dealt with strengthening deep beams due to their exposure to heat or extreme loads using two techniques (NSM) and (EBR). Several results were reached through experimental testing of the specimens of each research, especially the most important of them: First, making openings, when necessary, away from the loading path because the opening in the loading path reduces the capacity of the beam. Secondly, resorting to using the mechanical method when installing the fiber-reinforced polymer externally, as it greatly reduces the tearing and collapse of the sheets. Third, the number of layers must be less than three when using (GFRP) sheets in the strengthening process, as violating this will cause a decrease in the final capacity of the beam. Fourth, resorting to inclined schemes when strengthening deep beams or repairing them with various materials made of carbon fiber-reinforced polymer (FRP). Finally, it is possible to use (CFRP) bars with (NSM) technology, as this option can be relied upon to rehabilitate damaged structures.

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1 Introduction

There is a considerable aspiration within high-rise building structures to establish a spacious basement area devoid of columns, enabling its utilization for storage purposes or as a parking facility. Similarly, on the higher floors, the objective is to get enough room dimensions to the architectural blueprint. Utilizing deep beams functioning as a structural element is widely advocated to fulfill this objective. The transportation mechanism moves loads between the loading point and the support point in a diagonal trajectory. Deep beams are frequently employed in reinforced concrete structures as a fundamental component for load distribution and in shear wall constructions to effectively counteract lateral stresses. The utilization of these structures is prevalent in tall buildings and bridges owing to their advantageous attributes of ease and cost-effectiveness **[1].** Many often resort to using deep beams, as they are a structural element that can achieve this goal. The mechanism for transferring loads in these beams is in a diagonal path between the loading and support points [1].

2 Definition of RC Deep Beams

Deep beams are structural elements loaded on one side while being supported on the other side. The beams under consideration can be classified as continuous or simply supported beams. In the case of continuous beams, the *a/h* ratio (where *a* means shear span and *h* means depth of beam) is limited to a maximum of 2 for simply supported beams and a maximum of 2.5 in the case of continuous beams. In addition, it is observed that the clear span is either less than or equal to four times the overall depth of the beam **[**1**]**. Based on ACI Code 11.8, the deep beam is assumed, in the case of a distributed load, when the ratio of shear span to the depth (*a/d*) less than or equal to 5. Whereas, in the case of a beam subjected to concentrated load, it is assumed as a deep beam when (*a/d*) ratio less than or equal to 2.5 [2].

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3 Review of Shear Strengthening RC Deep Beams

The Research reviewed in this paper was divided into two categories (strengthening and repairing), as these two categories aim for one common purpose, which is the shear-strengthening process for deep beams using either FRP externally bonded or near surface mounted techniques as follows.

Strengthening of RC Deep Beams

3.1 Using Externally Bonded FRP

Over the past decade, much research has been conducted on strengthening concrete structures with external fiber-reinforced polymer (FRP) composites, and this technology has been applied to many projects in different parts of the world **[22]**. This method (EBR) is considered more vulnerable to environmental influences because it is located on the surface and does not have a concrete cover to protect it. This method affects the architectural appearance of the concrete structure and is more susceptible to early failure **[21]**. FRP composites are characterized by their resistance to corrosion and light weight, in addition to their high tensile strength **[22]**. Below, several studies that used this technique were reviewed, as follows:

El Maaddawy, T., and Sherif, S. (2009) [4] investigated the efficacy of externally bonded CFRP composite sheets for strengthening reinforced concrete (RC) deep beams with openings. The parameters considered were opening size, location of opening, and presence of CFRP sheet. Thirteen specimens were tested with (1200mm) in length, and an (80 mm) by (500 mm) rectangular cross-section, and a (1000mm) effective span. The opening diameters corresponded to height-to-depth ratios of (0.30, 0.40, and 0.5) for each shear span were inserted in the shear span. These specimens were divided into three groups. Group (A) consists of five specimens, three of which were left un-strengthened, and the remaining two specimens were strengthened externally with CFRP sheets, as these specimens contain two symmetrical openings with dimensions (200*200 or 250*250) mm³ in the middle of the shear span. Group (B) contains four specimens; three of them were un-strengthening, and one was strengthened with CFRP sheets, as the openings in these specimens were with dimensions (250*250) mm² and at a distance (75 mm) from the top face of the beam parallel to the supporting point. Finally, group (C) contains four specimens, three of which were un-strengthening, and one was strengthened with CFRP sheets. The openings in these specimens were with dimensions (250*250) mm² and at a distance (75 mm) from the bottom face of the beam parallel to the loading point. The research showed the presence of diagonal cracking control the un-strengthened beams, with the yield force ranging between (31%) and (51%) of the ultimate load. The maximum load of (291.4) was obtained in group (C), and the higher deflection of (6.3 mm) was also brought in group (B). As the applied stress increased, the cracks increased in width and spread toward the supporting and loading points. On average, the cracking load of the specimens in groups (B) and (C) was (47%) greater than that of the specimens in group (A).

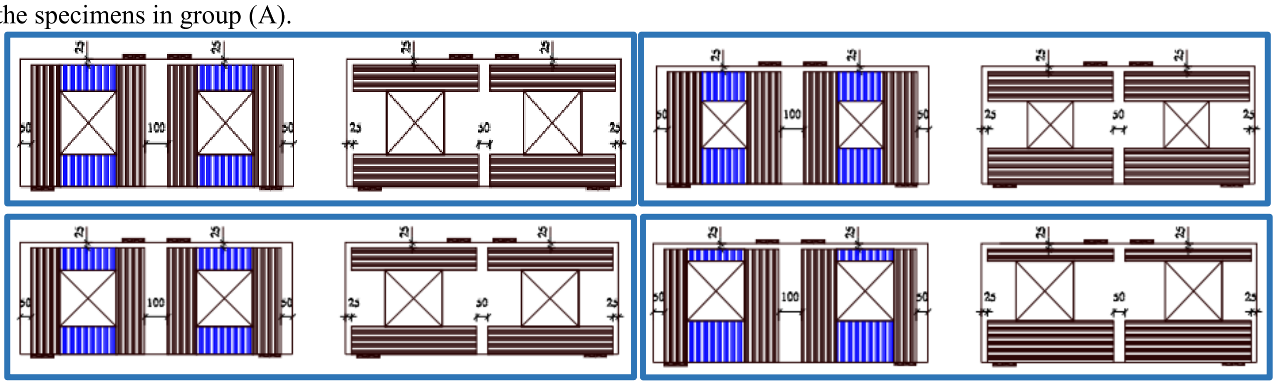


Fig (1) Strengthening Scheme by CFRP Sheets [4]

Abduljalil, B. S. (2014) [12], investigated the behavior and performance of reinforced concrete deep beams with opening strengthened with CFRP strips. The parameter considered was the orientation of the CFRP strips (45º and 90º). Eight specimens with dimensions (80*320*800) mm³ were tested. These eight specimens were divided into two control specimens, one without openings and the other containing openings. As for the remaining six specimens, they were strengthened with CFRP strips in a vertical, inclined, vertical and horizontal form together, and finally, inclined and horizontal form together. The results showed the highest increase in ultimate load (118.6 %) for the specimen that was strengthened with (CFRP) strips horizontally and diagonally with the use of square plates of (150 mm) and thickness (2 mm) to fix the strips to the upper side of the beam using a diameter bolt (6 mm).

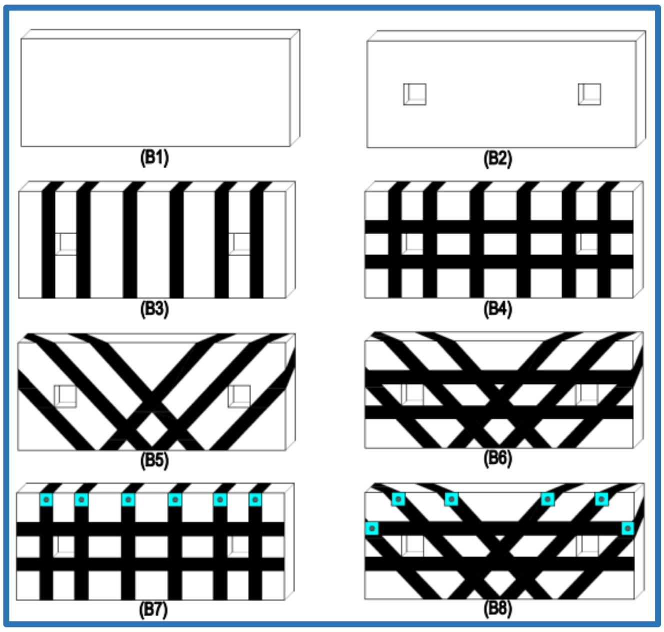


Fig (2) Strengthening Scheme by CFRP Strips [12]

Khudair, J. A. and Atea R. S. (2015) [13] studied the shear behavior when strengthening self-compacted concrete deep beams with carbon fiber-reinforced polymer sheets. The parameters considered were the length and orientation of CFRP sheets. Eleven specimens with dimensions (175*300*1600) mm³ were tested, where one specimen was considered a reference. Ten specimens were strengthened with CFRP sheets. Parameters changed in the strengthening process included the number of the member's sides strengthened with CFRP sheets (1, 2 and 3) sides, the orientation angles of the sheets (45º and 90º) and the clear distances between the sheets (20 and 50) mm. The results showed an increase in the cracking and ultimate loads of the beam in which a space (20) mm was used between the sheets, and it was strengthened with full warp CFRP sheets by 27.3 % and 24.8 %, respectively, compared with the control beam.

Lam, L. et al. (2015) [20] investigated the influence of glass chopped strand mat fiber composites (GCSM) with the mechanical anchor on the shear strength of reinforced concrete deep beams. The parameters considered were the number of strengthening layers and sides strengthened with chopped fiber-glass composites (GCSM). The study divided beams into one control beam and four which were divided into two groups using fiber composites with mechanical anchors. Each group had two beams strengthened by side bonding or U jacketing. The strength schemes were kept the same, with a cured fiber composite thickness of (2mm) and anchor spacing of (150mm) and (100mm). The beams with dimensions (1000mm) long, (100mm) thickness, and (350mm) depth were constructed. The results indicated mechanical anchoring improves shear strength and rigidity, eliminates bearing failure at anchor locations, and prevents debonding failure. For this technique, epoxy resin was more effective than polyester resin, which obtained a maximum increase in peak load and deflection of (67.97% and 28.81 %) for specimens by epoxy resin. U-wrapping was superior to both-side bonding because it provides additional anchorage at the bottom end of FRP sheets.

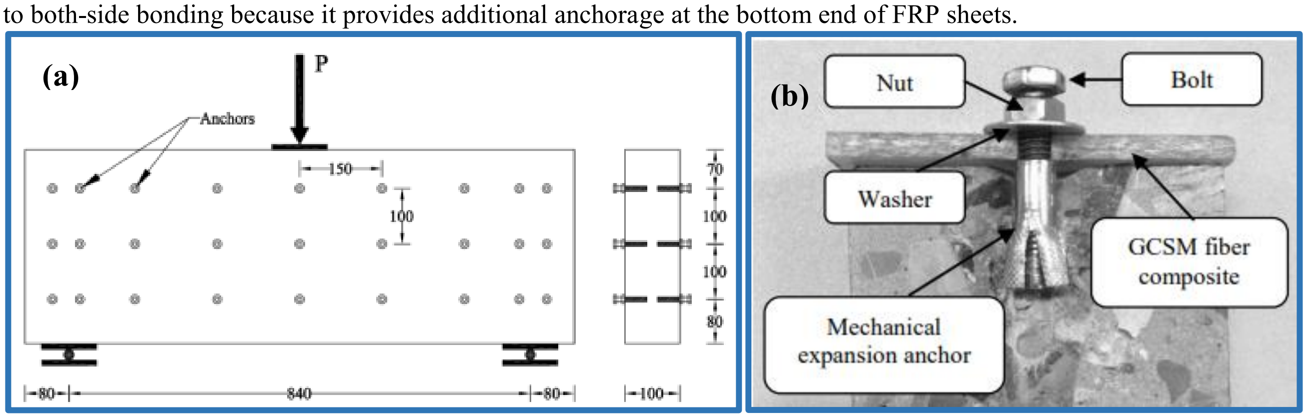


Fig (3) System and Locations of the Mechanical Anchors a) Typical Location of Mechanical Anchors (all units in mm) b) System of Mechanical Anchor [20]

Hussain, Q., and Pimanma, A. (2015) [6] conducted experiments on RC deep beams with circular openings that were strengthened with externally bonded SFRP composites. The investigated research parameters were opening size, thickness, and orientation of SFRP. The length of the beams was (1050) mm, with a rectangular cross-section measured (100 mm by 500 mm). Two circular openings, each located in one of the shear spans, were positioned symmetrically concerning the midpoint of the beam. The application of SFRP was implemented on either lateral or three (U-shaped) faces, excluding the top face. The test matrix was divided into two categories, considering the size of the web opening. Beams (3A-100 and 5A-100) exhibited an increase in ultimate loads of (77%) and (90%), respectively, compared to the control beam. Note that the numbers (3 and 5) represent the thickness of SFRP, the numbers (100 and 160) represent the diameter of the circular opening, the letter (A) refers to specimens that were strengthened on two sides, and the letter (B) refers to specimens that were strengthened on three sides in the form of (U-shaped). Similarly, beams (3A-160) and (5A-160) had maximum loads that were (64% and 101%) respectively greater than those obtained in the control beam. The deep beam specimens, namely (5B-100 and 5B-180), demonstrated an increase in ultimate loads of 40% and 26% compared to the beams (5A-100 and 5A-180), respectively.

Javed, M. A. et al. (2016) [19], evaluated the efficiency of carbon fiber-reinforced polymers in improving the shear strength of deep beams. The parameters considered were the orientation of the CFRP sheets and the presence or absence of stirrups and longitudinal bars. Eight specimens were tested with dimensions (152*381*1245) mm. These eight specimens were divided into four groups, differing in the presence of stirrups, CFRP sheets and longitudinal bars. The first group contains no stirrups, CFRP sheets, and longitudinal bars; the second group contains the stirrups and longitudinal bars. However, it did not contain CFRP sheets, and the third group did not contain the stirrups and longitudinal bars. However, it contained CFRP sheets at an angle of (45º) on both faces of the beam. Finally, the fourth group did not contain stirrups and longitudinal bars, but it contained CFRP sheets at an angle of (90º) on both faces of the beam. The results when using CFRP sheets showed an increase in the ultimate load by (37 %) when using the sheets at an angle (45º) and (32 %) when using the sheets at an angle (90º).

Abdul-Razzaq, K. S. et al. (2017) [9] investigated the possible use of steel plates for RC deep beams with web openings. The parameters taken into consideration were the opening area and its location. The test specimens were characterized by dimensions of (100*400*1000) mm³. The web reinforcement used in this study included 4mm deformed bars arranged at a vertical spacing of (88mm) and a horizontal spacing of (155 mm). Steel plates were used to reinforce openings, while the stud connections had a diameter of (8 mm). A, B, C, and D groups were based on openings shape (where group A contained a square opening, group B contained a circular opening, group C contained a horizontal rectangular opening, and group D contained (vertical rectangular openings) where reinforcing the openings with steel plates and whether or not they had screws. Un- strengthening holes decreased midspan deflection by 30% compared to the reference beam for SQ (square) 28%, for CR (circular), 24.2% for HR (horizontal rectangular) and for 35% VR (vertical rectangular). The hardness of these holes increased by (20.1%, 17%, 18%, and 28.0%) for SQ. P, CR. P, HR. P, and VR. P specimens (where P refers to the plates that were used in the strengthening process), respectively, when reinforced with 6-millimeter steel plates. The most significant reduction in ultimate shear strength was observed in horizontal rectangular openings (31.7%), while circular openings exhibited the least reduction (18%). Compared to unreinforced beams, strengthening openings with steel plates adds (9.3%, 13.2%, 9%, and 12%) to the final shear strength for square, circular, horizontal and vertical rectangular openings respectively. Welding stud connections to beams improved their absolute shear strength by (16.9%, 17.8%, 14.3%, and 26.9%) in square, circular, horizontal, and vertical rectangular holes, respectively.

Kumari, A. et al. (2018) [15] focused on experimental research on RC deep beams strengthened using externally bonded GFRP fabrics. Number of GFRP layers were considered as a parameter. Five reinforced concrete (RC) deep beams with dimensions (120*420*1000) mm³ were fabricated, by which one beam was designated as the reference beam while the other four were wrapped with glass fiber reinforced polymer (GFRP) textiles. The number of GFRP fabrics applied to these beams increases incrementally, with one, two, three, and four layers, respectively. The beams underwent testing using a two-point loading configuration. The results showed that retrofitting RC deep beams with GFRP fabrics increased their shear capacity by (10%, 13%, 45%, and 29%) for specimens wrapped with 1, 2, 3, and 4 layers of GFRP, respectively. It was obtained increasing in the first cracking load and ultimate load by (60.8 %) and (45.6 %) in the specimens with 3 layers and 2 layers of GFRP respectively. Observations indicated that the ultimate load of beams retrofitted with GFRP fabrics increases with the number of GFRP layers up to a specific number, namely three layers, after which it decreases due to alterations in its failure mechanisms.

Akbarzadeh Bengar, H. et al. (2018) [23] investigated the shear behavior of deep beams strengthened by the external bonded method (EB) or the near-surface mounted (NSM) method using (CFRP) strips. The parameters considered were the strengthening methods (NSM or EB) and the shear reinforcement ratio. The specimens tested were of dimensions (150*500*1450) mm³. The strengthening pattern adopted using (CFRP) strips was oblique (perpendicular to the line connecting the load and support points). The specimens were divided into two groups based on the ratio of reinforcing steel, with each group consisting of three specimens. These three specimens include one reference specimen and two that were strengthened with the same amount of CFRP strip by the (NSM or EB) technique. The results showed that using the (NSM) method in strengthening increased the ultimate load capacity and deflection by (18% and 16%), respectively, compared to the control beams. The results also showed higher ultimate load capacity and ultimate deflection (6% and 15%) than beams strengthened using the (EB) method.

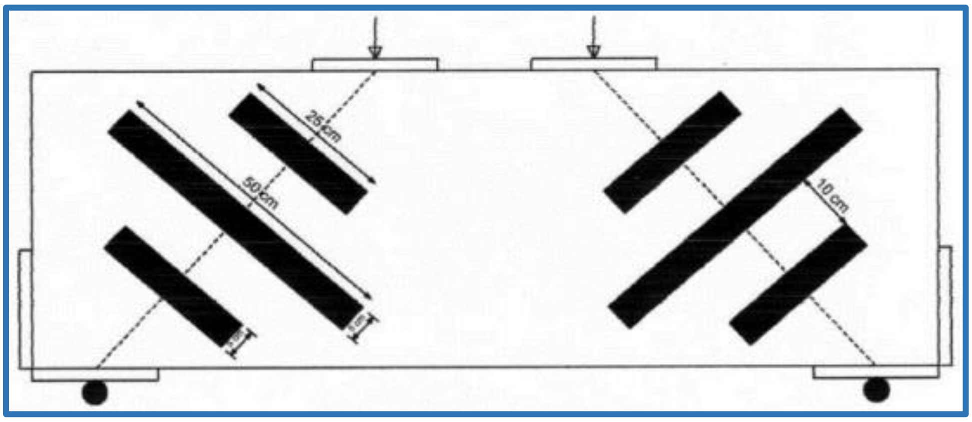
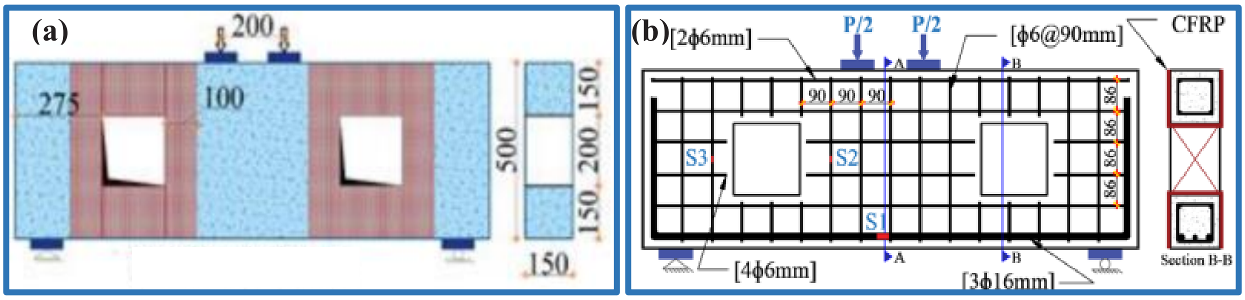


Fig (4) Strengthening Scheme Adopted by CFRP Strips [23]

Jasim, W. A. et al. (2020) [5] studied how initial cracks propagate diagonally down CFRP sheets. The parameters taken into consideration were the shear span/depth ratio, and size and location of openings. Experimental testing included 18 specimens with dimensions (150*500*1500) mm³ where the location of the openings in these specimens was changed, sometimes in the middle and other times in the end. The ratio of the shear span to effective depth was also changed, as the two values (0.9 and 1.1). The last changed factor was the size of the openings, as two types of opening sizes were used (200*200) mm² and (230*230) mm². The results showed that reducing the a/h ratio from (1.1) to (0.9) led to an increase in the failure load (6-30) %. On the other side, the increase in the size of the opening from (200*200) mm² to (230*230) mm² led to a decrease (12.85 %) in the deflection value.



Fig(5) Details of strengthening and reinforcement a) Strengthening Scheme by CFRP Sheet b) Method of Arrangement the Steel Reinforcement [5]

4 Using Near Surface Mounted

According to historical records, the first experiment with this method took place in the early 1950s. However, this technology is considered a modern concept at present. This method has the advantages of requiring less time for installation than other methods, being less susceptible to environmental influences such as fires, and being less susceptible to debonding failure with the concrete **[21]**. Below, many researches that used this technique were reviewed, as follows:

Kammona, H. H., & Al-Issawi, A. S. H. (2018) [17] tried to find out how much a reinforced concrete (RC) deep beam can take before it breaks that have been strengthened using NSM steel bars. The considered parameters were (a/d) ratio, the orientation angle of NSM steel bars, concrete compression strength, and the bars' diameter and spacing. This study examined the shear strengthening of 13 simply supported deep beams using NSM steel bars. The beams had dimensions of (200*400*1500) mm³ with 3φ16 bars as longitudinal reinforcements. The beams were categorized into three categories based on (a/d) ratios (a/d=0.85 for group one, a/d=1.136 for group two and a/d=1.42 for group three). The research demonstrated that the NSM technique yielded a notable enhancement of 20.6% in the shear resistance of reinforced concrete deep beam elements. The use of inclined NSM reinforcement bars instead of vertical bars significantly enhanced the load capacity, with an increase of (9.33%) when using a distance (100 mm) between the bars in the first group and (6.01%) when using a distance (150 mm) between the bars in the second group. The adopted strengthened technique effectively transformed the failure mode from shear failure to flexural failure. Reducing the reinforcement steel distances from (150 to 100) mm with inclined directions led to an improvement in the failure load by (5.8%) in the first group and (3.76%) when using the vertical directions in the second group, in addition to increasing the maximum load by (6.85%) if (φ12) bars were used instead of (φ8) with a distance (150 mm) between the bars. The specimen with a/d=0.85, inclined strengthening, and a spacing of 100 mm between bars achieved a maximum load of 20.6% greater than those in the control beam.

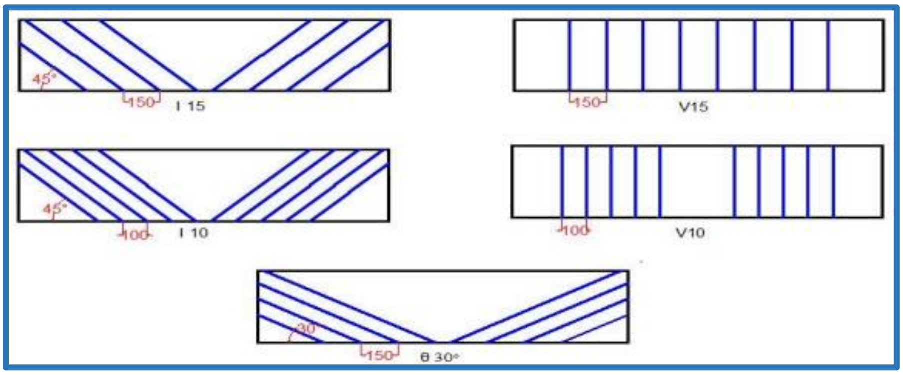
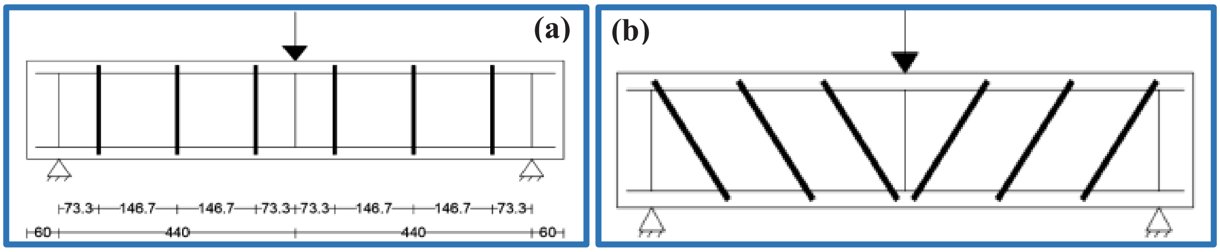


Fig (6) Strengthening Schemes by NSM Steel Bars [17]

Nafzin, A. A., & Prabhakaran, P. (2018) [28] used the steel bars by NSM technique for shear strengthening of RC beams, focusing on the effect of bar diameter and orientation on beam capacity. The results showed that increasing the diameter of the bar from (8 mm to 10 mm) led to an increase in the ultimate load of the beam by (7.79%) while increasing the diameter of the bar from (10 mm to 12 mm) gave an increase in the ultimate load of the beam by (7.57%). When installing the NSM bars at an angle (45º), the ultimate load was increased by (25.75%) compared to bars placed vertically.



Fig(7) Schemes of Strengthening a) Vertical Strengthening Scheme b) Inclined Strengthening Scheme [28]

Thamrin, R. et al. (2019) [10], studied concrete beams strengthened by steel bars using the NSM technique, as the stirrup was not contained in these beams. The parameters taken into consideration were installation angles of steel bars and longitudinal reinforcement ratios. Nine beams with dimensions (125*250*2300) mm³ were tested, including three beams that were considered control beams and six beams that were strengthened. The six specimens that were strengthened were in two groups. The first group includes three specimens that were strengthened vertically at an angle (90º), and the second group also contains three specimens, but their strengthening was done at an angle (45º) with three different ratios of longitudinal reinforcement (1 %, 1.4 % and 2.4 %) that were used in both groups. The results showed the highest increase in shear strength (104.54 %) for the specimen that was strengthened diagonally and using the longitudinal reinforcement ratio (2.4 %).

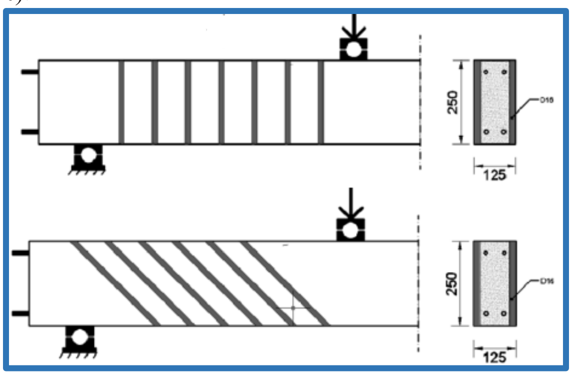


Fig (8) Strengthening Schemes by NSM Steel Bars [10]

Abdzaid, H. M., & Kamonna, H. H. (2019) [29] Studied the flexural performance of RC beams by using NSM steel bars. Focus on reinforcement region, types of CFRP sheet, and development lengths were considered. Eleven specimens with dimensions (150*225*3000) mm³ were tested under two loading points. One specimen was left without any strengthening to be considered a control specimen, while the rest were strengthened using the (NSM) technique with steel bars of different diameters (8, 10, and 12) mm. In addition to the above, there were two specimens in which the ends of the bars were fixed with CFRP sheets to prevent concrete cover separation. The results of testing all specimens showed a noticeable improvement in failure loads by (108%) compared to the control specimen. In addition to the above, it was noted that the presence of CFRP sheets as end-anchors prevents the separation of the concrete cover and shows a significant improvement in ductility.

KAMONNA, H. H., and ALKHATEEB, L. R. (2020) [14] conducted an experiment study on the strengthening of reinforced concrete deep beams with openings by near surface-mounted steel bars. Factors tested included the openings' sizes and positions, the bars' diameter and the reinforcement bar's configuration around the openings. The specimens tested were having (200*400*1500) mm³ dimensions. The ratio of shear span to depth was maintained at (1.1). Four specimens served as controls (The first specimen has no openings, and the remaining three specimens contain openings with dimensions of (150*150) mm² for (second and third) specimens and (150*250) mm² for the fourth specimen; these openings are distanced from its outer edge to the end of the beam with a distance of (175 mm) for the second specimen (225 mm) for the third specimen, and (300 mm) for the fourth specimen), while three had two openings of varying sizes and locations at each shear span. The dimensions of square and rectangular openings were (150*150 mm² and 250*150 mm²), respectively, and opening locations were chosen at the load path in the first instance and near the loading point (the openings located (50 mm) from the loading point) in the second instance. The remaining nine specimens were reinforced with NSM steel bars surrounding openings in various configurations. The study showed that opening placement significantly impacts the ultimate load. Placing openings along the load path reduces ultimate load by (12.5%) while increasing opening size decreases cracking and ultimate loads by (40% and 32%). Vertical reinforcing bars enhanced ultimate load capacity by (12% and 14%) for the beam with square openings positioned along the load path and the beam with square openings positioned near the load, respectively. Using strengthening bars in an inclined orientation has improved the beam capacity by (9.4% and 35%) for the beam with square openings positioned near the load and the beam with rectangular openings positioned at the load path, respectively.

Ibrahim, M et al. (2020) [16] investigated the efficacy of NSM hybrid carbon/glass fiber-reinforced polymer (FRP) strips in enhancing the shear capacity of inadequate shear strength reinforced concrete (RC) deep beams. The experimental variables included the number of steel stirrups used in the concrete structure strengthening (CSS) process. Twelve beams were tested with (150*400*2100) mm³ dimensions. Five beam specimens were left un-strengthened, whereas seven were strengthened by NSM-FRP. The unaligned arrangement exhibited superior performance, and the results indicated that the aligned design showed an average rise in ultimate load of (33.5) %. In contrast, the non-aligned arrangement had a higher average increase of (38.1) %. The increase in the load-carrying capacity of the NSM-FRP strengthened beams ranged between (28.8% and 55.8%). For the specimens without critical shear span (CSS) stirrups, the NSM technique increased load-carrying capacity to (55.8%). Using NSM strengthening methods resulted in enhancements in deformational properties, reductions in crack width at the ultimate load, and increases in tensile strain inside flexural steel reinforcement and compression strain on the concrete surface.

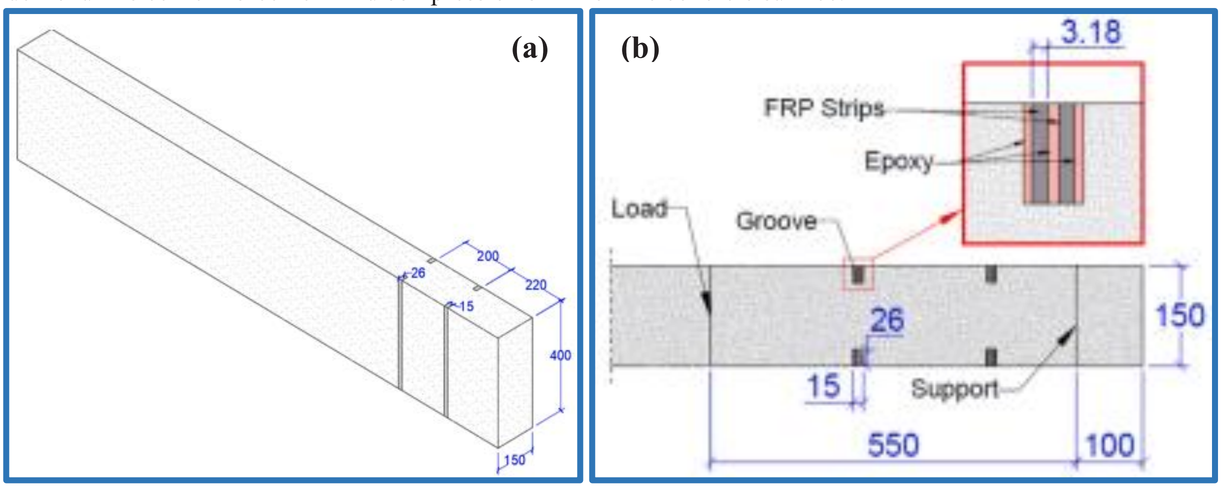


Fig (9) NSM-FRP strengthening (all dimensions in mm) a) Front View of Strengthening by NSM-FRP b) Top View of Strengthening by NSM-FRP [16]

Azeez, A. A. et al. (2023) [18] investigated the behavior of reactive powder concrete (RPC) deep beams, specifically focusing on enhancing their shear strength by using NSM-CFRP bars. The experimental setup comprised two reinforced concrete (RC) deep beam specimens, one with reactive powder concrete (RPC) and one without. The samples had a dimension of (150*500*1200) mm³, and an (a/d) ratio of (0.77). The bottom zone was reinforced with (3Ø16 mm) deformed bars, while (2Ø12 mm) bars were used for the top zone. The stirrups were spaced at a center-to-center distance of (200 mm) with a diameter of (12 mm). The study found that Reinforced Polymer (RPC) considerably increased the ultimate strength of deep beams, with RPC-containing beams increasing by (21%) compared to those without RPC. The first shear crack capacity increased considerably, with the RPC beams increasing by (133%) and (150%), respectively. In addition, the highest increase in ultimate load (25%) was determined for the specimen when using reactive concrete powder and four carbon fiber reinforced polymer bars were used in the strengthening process by (NSM) technique compared to the control beam.

5 Repairing of RC Deep Beams

5.1 Using Externally Bonded FRP

Dias, S. J., & Barros, J. A. (2008) [31] studied the effect of changing the proportion of carbon fiber-reinforced polymer laminates (CFRP) and their inclination on the efficiency of the near-surface mounted technique (NSM) used in the shear strengthening of RC beams. The parameters considered were (CFRP) laminate ratio and strengthening orientations (45º, 60º, and 90º) for each ratio. Twelve specimens with T-section and dimensions (180*400*2450) mm³ were tested. The specimens included one specimen without any shear reinforcement, one specimen with a stirrups ratio (0.1 %), one specimen with a stirrups ratio (0.24 %), in addition to nine specimens in which (CFRP) laminates were used in three ratios and each ratio had three inclinations. The steel stirrups reinforcement percentage for beams strengthened with carbon fiber-reinforced polymer (CFRP) laminates was (0.1%). The results showed an increase in load capacity by (33 %) when the strengthening process was performed with (CFRP) laminates at an angle (60º)

Dias, S. J. E., & Barros, J. A. O. (2012) [24] evaluated the effectiveness of the shear repair process by installing CFRP laminates in high-strength concrete beams with a specified amount of steel stirrups. The parameters considered were the slope and ratio of CFRP laminates, the percentage of steel stirrups present and the extent of cracking after the strengthening process with NSM-CFRP laminates. The specimens tested had a cross-section (T) with dimensions (180*400*2800) mm³ and were divided into two groups in addition to three reference specimens. The reference specimens included one specimen without stirrups, one containing (0.1%) of steel stirrups and the last with (0.16%) of steel stirrups. The first group consisted of eight specimens containing (0.1%) of steel stirrups, which were strengthened with CFRP laminates in three different directions (45º, 60º, and 90º). In comparison, the second group consisted of six specimens containing (0.16%) of steel stirrups, which were strengthened with CFRP laminates in two different directions (45º and 60º). The results showed an increase in the ultimate load ranging between (35- 62) % for the various configurations of shear strengthening with laminates compared to the reference specimens. The results also showed that the inclined laminates were better than the vertical ones. The load-carrying capacity of the strengthened uncracked beams was equivalent to that of the pre-cracked and strengthened with CFRP laminates.

Rasheed, M. M. (2016) [25] studied the experimental behavior of reinforced concrete deep beams and their retrofit efficiency when using carbon fiber reinforced polymer (CFRP) sheets. The parameters considered were the shear span ratio to depth and horizontal and vertical transverse reinforcement. Nine specimens with dimensions (115*400*1200) mm³ were tested, in which different ratios of horizontal and vertical transverse reinforcement (0.25, 0.3, 0.5 and 0.52) % were used. Retrofitting the specimens with sheets was done with two sheets in each shear span along the depth of the specimen as (U) shaped. The results showed that the percentage increase in the ultimate strength of the created deep beams ranged between (8-161) % compared to the reference beams, where the highest increase was for the specimen in which horizontal type transverse reinforcement was used, with a percentage of (0.3 %). It was shown through the results of testing specimens that the retrofit technology is a highly efficient technology due to the increased load for these beams as a result of the ability of the carbon fiber sheets to resist the additional load when applied after failure, as the common causes of the collapse of specimens were either crushing the concrete or separating some layers of concrete due to the presence of the CFRP sheets.

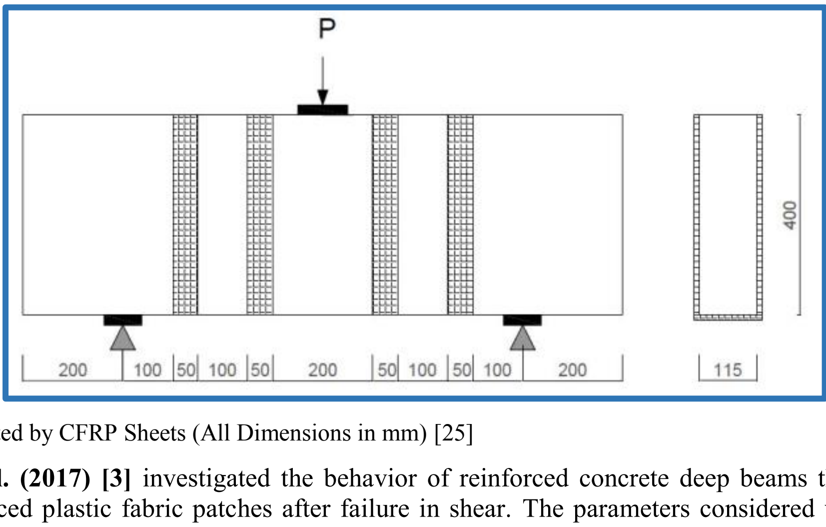


Fig (10) Details of Retrofitted by CFRP Sheets (All Dimensions in mm) [25]

Boumaaza, M. et al. (2017) [3] investigated the behavior of reinforced concrete deep beams that were repaired using fiber glass reinforced plastic fabric patches after failure in shear. The parameters considered were the mode of strengthening, number, and orientations of GFRP layers. Twelve specimens with dimensions (100*180*730) mm³ were used, consisting of 3 groups. The first group consisted of three control specimens (these specimens were not strengthened and have not been preloaded). The second group consisted of six specimens, part of which was strengthened with two layers and the other with three layers of U-shaped GFRP, knowing these samples were not loaded initially. The last group consisted of three specimens, two of which were strengthened with two and three layers of U-shaped GFRP and the last specimen of this group was strengthened using the SCR (Strips of Critical Region) method knowing, these specimens were initially loaded with 40% of the ultimate load of the control specimen. The results showed that the rehabilitated beams with two and three layers of U-shaped GFRP decreased the ultimate load compared to the control beam by a ratio of 16.1% and 13.1%, respectively. In contrast, the beams that were rehabilitated with SCR showed an increase in the ultimate load compared to the control beam by a ratio of 7.1%.

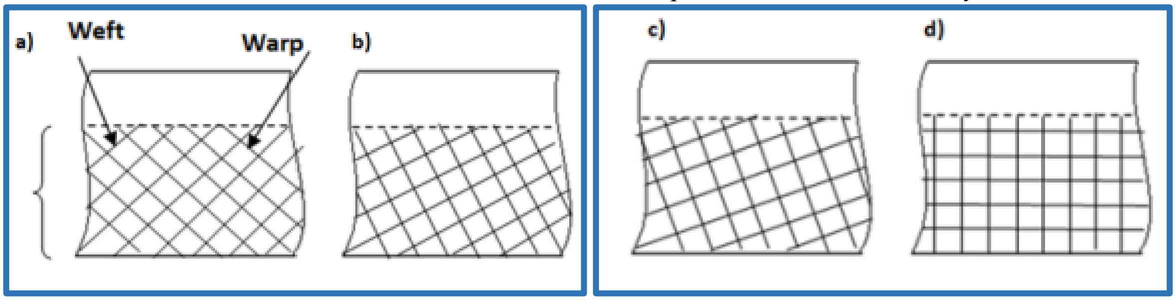


Fig (11) U Shape Reinforcement by Different Orientations a) +45/-45 b) 30/60

c) 20/70 d) 0/90 [3]

Yu, F. et al. (2019) [27] conducted experimental studies on several pre-cracked sleeves of reinforced concrete beams strengthened with carbon fiber-reinforced polymer strips. The parameters considered were the different distances between the CFRP strips (100 and 150) mm, the different shear span to depth ratios of the specimen (1.3, 2.17 and 3.49), and the degree of pre-cracking (0, 0.4 and 0.8). Eighteen specimens with dimensions (150*150*2100) mm³ were tested. An analysis was conducted to determine the impact of CFRP strip spacing, shear span ratio, and pre-cracked degree on strengthened specimen's failure mode, shear capacity, load-deflection curve, and moment-curvature relationship. For specimens with varying structural parameters, three failure modes associated with the failure of CFRP strips were observed, bonding failure, debonding failure, and fracture failure. Furthermore, it has been observed that the specimen's shear capacity, ultimate deflection, and bending stiffness increase as the spacing of CFRP strips decreases. The increase in the shear capacity of reinforced concrete (RC) beams strengthened with CFRP strips is less pronounced as the degree of pre-cracking rises compared to non-cracked beams. The degree of pre-cracking has a negligible impact on the rigidity of beams reinforced with CFRP strips.

Al-Bayati, N. A. et al. (2021) [11] worked to encourage the use of easy-to-use materials with lightweight and high efficiency in rehabilitating reinforced concrete buildings. The parameters considered are the arrangement and distribution of the carbon fiber-reinforced polymer segments. Six specimens with dimensions (150*400*1400) mm³ were tested. One of these specimens represents a reference specimen, while the remaining five specimens were loaded with 60% of the ultimate load of the reference specimen and then rehabilitated. The details of the rehabilitation process with CFRP strips were in different patterns, they were the U-shaped vertical pattern, the horizontal pattern, combined vertical and horizontal pattern, the inclined pattern perpendicular to the load path, and a pattern included covering the shear span region only. The results showed an increase in the ultimate load by (27.27%) for the specimens that were rehabilitated according to the inclined pattern or the vertical and horizontal patterns combined together.

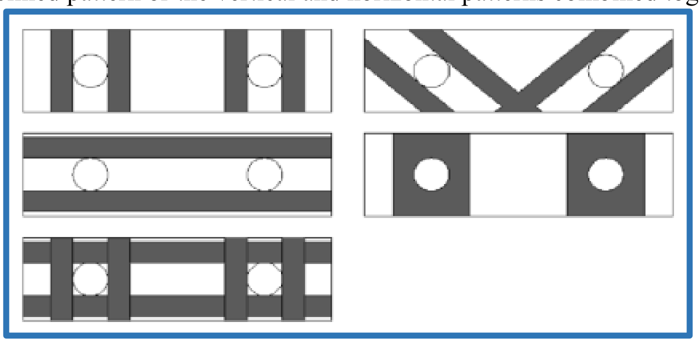


Fig (12) The Five Schemes Adopted in Retrofitting by CFRP Strips [11]

6 Using Near Surface Mounted

De Lorenzis, L., & Nanni, A. (2001) [30] investigated the behavior of RC beams strengthened in shear with (FRP) bars using the near-surface mounted (NSM) technique. The parameters considered were the distance between the bars (5 and 7) inches, the pattern of strengthening (45º and 90º), the presence of internal shear reinforcement and the fixation of the ends of the bars. Eight specimens were tested with a T-shaped section with dimensions (15*16*120) cubic inches. Two were reference specimens, and six were specimens strengthened with (FRP) bars. The results showed an increase in the strength of the beams that were strengthened with (FRP) bars using the (NSM) technique by (106 %) in the absence of steel stirrups compared to the control beams. The strengthened beams also showed an increase in strength by (35 %) compared to the non-strengthened beams, and this indicates that (NSM) bars can have a significant effect even with the availability of shear reinforcement.

Raheem, A. L. D. (2015) [2] examined the efficacy of using NSM CFRP as a rehabilitation technique for shear in deep beams after (50-60%) of the beams have been damaged. The parameters considered were the inclination of FRP rods and the damage ratio. A study was conducted on five beams with (150*400*1000) mm³ dimensions subjected to a static two-point load test. After that, the specimens underwent a process of re-rehabilitation using the near surface mounted (NSM-CFRP) technology. The rehabilitation of deep beams using (NSM-CFRP) increased shear strength by (9.5%-17.1%) compared to the control beam. Crack width decreased by (44.44%), with an average of (1.8mm) for rehabilitated beams. However, the increase in shear could be more significant than (17%) if the bond between the CFRP bar and concrete becomes stronger or if alternative installation techniques are used. Additionally, higher increases in ultimate and cracking loads of (17.14 %) and (12.5 %) in the beam strengthened with FRP rod at an angle of (45º) and a distance of (150) mm between rods.

Samad, A. A. A et al. (2017) [8] described the findings of a scientific investigation conducted to examine the efficiency of NSM-CFRP anchors in improving the shear capacity of RC deep beams. The parameter considered was the distance between CFRP bars. A study was conducted on beams with (140*450*1200) mm³ dimensions. Four reinforced concrete (RC) deep beam test specimens, namely (R1, R2, R3, and R4), were strengthened using CFRP anchor bars in R1 and R2 at 100 mm c/c and in R3 and R4 at 150 mm c/c). Among the beams tested, beam R1 exhibited the most significant increasing ratios of ultimate and shear loads (25.68 % and 25.5 %), respectively, compared with the control beam. Beam R2 exhibited increasing ratios of ultimate and shear loads (24.7% and 24.7%), respectively, compared with the control beam. However, the ultimate and shear load capacities of beams R3 and R4 decreased when the distance between CFRP support bars increased from (100-150) mm (c/c). Furthermore, the strengthened reinforced concrete beams exhibited a higher degree of rigidity, resulting in a decrease in deflection ranging from (6.1% to 16.3%) compared to the control beam.

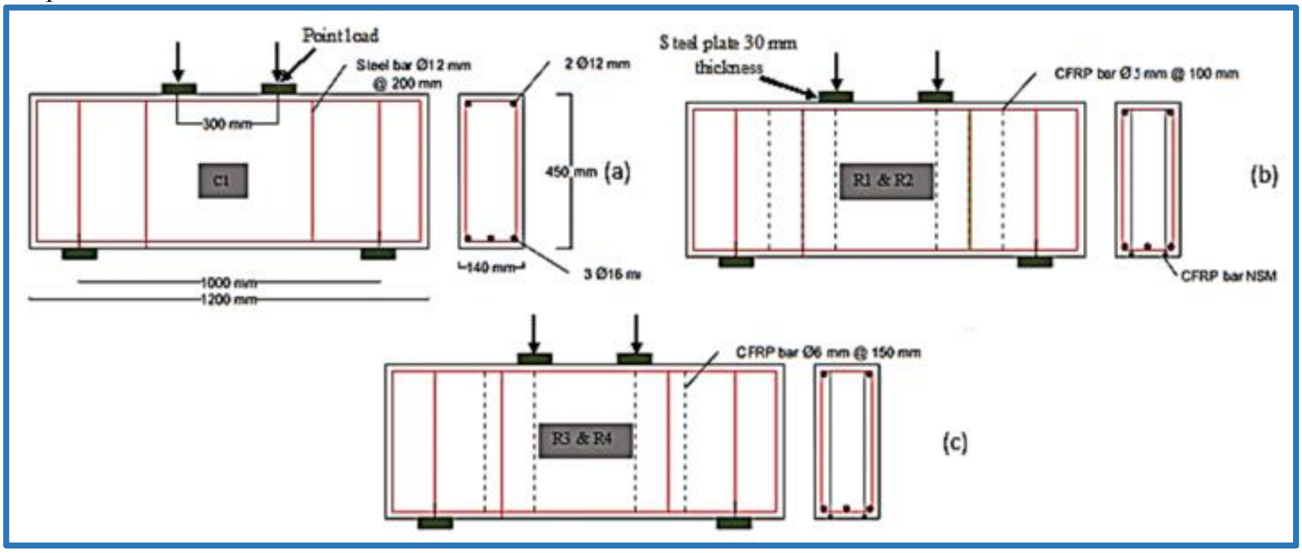


Fig (13) a) Control Beam b) CFRP Anchor Bars at (100mm) c/c in Beams (R1 & R2) c) CFRP Anchor Bars at (150mm) c/c in Beams (R3 & R4) [8]

Raheem Hassan, D. (2018) [26] studied the behavior of reinforced concrete deep beams strengthened with carbon fiber reinforced polymers (CFRP) bars using near surface mounted (NSM) technology. As parameters, the presence or absence of stirrups in beams were considered. A total of (18) reinforced concrete deep beams (140*450*1200) mm³ in dimensions underwent testing. Both beams possess an identical (a/d) ratio of (0.864). The orientation of all CFRP NSM bars was determined to be either (0/90º or 45º/135º) degrees, with stirrup spacing schemes of (100 mm or 150 mm). The results indicate that the shear capacity of all deep beams (with or without stirrup reinforcement) enhanced by (17% to 141%) when reinforced or repaired with CFRP-NSM bars.

Al-khreisat, A. et al. (2023) [7] examined the effectiveness of (NSM-CFRP) ropes in enhancing the shear capacity for RC deep beams subjected to heat-induced damage. The parameters utilized in this study were the direction of the rope with angles (45º and 90º) degrees, the rope diameter and the spacing between the ropes (150 mm, 200 mm). A study was conducted on ten beams with (190*450*1900) mm³. A set of five beams was subjected to thermal treatment for three hours of exposure to a temperature of (650°C) inside a convection oven with dimensions (0.8*2*2.5) mm³, while another group of five samples remained unheated. The control specimen experienced a 20% decrease in load-carrying capacity and shear failure after exposure to (650°C). The study found that the ultimate load capacity increased by (46% for the beam repaired by ropes at an angle of 45º and a distance of 150 mm between these ropes, 48% for the beam repaired by ropes at an angle 45º and a distance of 200 mm between these ropes, 38% for the beam repaired by ropes at an angle of 90º and a distance of 150 mm between these ropes and 19% for the beam repaired by ropes at an angle of 90º and a distance of 200 mm between this ropes). It was obtained a maximum load of (32.63 %) for the specimen that was strengthened with CFRP ropes at an angle of (45º and a distance of 200 mm) between them, achieving the best strength ratio of (48%) in general at a 45º, and more specifically at a 200 mm spacing. In addition, RC deep beam shear strength subjected to (650°C) was evaluated for three hours, and discovered that heat reduced a beam's ultimate load capacity by (20%).

7 Summary of Research Articles

The research papers discussed in this research were summarized in three tables based on the details of the specimens for each research and the method of strengthening these specimens by (NSM or EBR) technique, as shown in Tables (1, 2, and 3).

Table (1) Number and Dimensions of Specimens and Adopted Parameters for each Research

NO.	Author's Name	Parameters	Dimension of Specimens (mm)	Number of Specimens
1	El Maaddawy, T., and Sherif, S. (2009) [4]	opening size, location of opening, and presence of CFRP sheet	80*500*1200	13
2	Abduljalil, B. S. (2014) [12]	the orientation of CFRP strips (45º and 90º)	80*320*800	8
3	Khudair, J. A. and Atea R. S. (2015) [13]	length and orientation of CFRP sheets (45º and 90º), number of strengthening sides	175*300*1600	11
4	Lam, L. et al. (2015) [20]	number of strengthening layers and sides strengthened with chopped fiber-glass composites (GCSM)	100*350*1000	5
5	Raheem, A. L. D. (2015) [2]	changing angles orientation of FRP rods and the beam loaded ratio from the ultimate load	150*400*1000	5
6	Hussain, Q., and Pimanma, A. (2015) [6]	opening size, thickness and orientation of SFRP	100*500*1050	8
7	Javed, M. A. et al. (2016) [19]	orientation of the CFRP sheets and the presence or absence of stirrups and longitudinal bars	152*381*1245	8
8	Samad, A. A. A et al. (2017) [8]	distance between CFRP bars	140*450*1200	5
9	Abdul-Razzaq, K. S. et al. (2017) [9]	openings shape	100*400*1000	13
10	Boumaaza, M. et al. (2017) [3]	number and orientations of GFRP layers	100*180*730	12
11	Kumari, A. et al. (2018) [15]	number of GFRP layers	120*420*1000	5
12	Kammona, H. H., & Al-Issawi, A. S. H. (2018) [17]	(a/d) ratio, the orientation angle of NSM steel bars, concrete compression strength, the bars' diameter and spacing between bars	200*400*1500	13
13	Thamrin, R. et al. (2019) [10]	angles of installation steel bars and longitudinal reinforcement ratios	125*250*2300	9
14	Jasim, W. A. et al. (2020) [5]	shear span/depth ratio, size and location of openings	150*500*1500	18
15	KAMONNA, H. H., and ALKHATEEB, L. R. (2020) [14]	size and position of openings in addition to diameter of bars	200*400*1500	13
16	Ibrahim, M et al. (2020) [16]	number of FRP strips (2, 3 and 4), number of steel stirrups at the CSS (0, 2 and 3) and stirrups interaction at the CSS	150*400*2100	12
17	Al-Bayati, N. A. et al. (2021) [11]	arrangement and distribution of the carbon fiber-reinforced polymer segments	150*400*1400	6
18	Azeez, A. A. et al. (2023) [18]	The effect of the presence or absence of reactive powder concrete through a comparison between two specimens	150*500*1200	2

19	Al-khreisat, A. et al. (2023) [7]	direction of the ropes and spacing between the ropes	190*450*1900	10
20	Akbarzadeh Bengar, H. et al. (2018) [23]	shear reinforcement ratio	150*500*1450	6
21	Nafzin, A. A., & Prabhakaran, P. (2018) [28]	bar diameter and it's orientation	150*200*1000	7
22	Abdzaid, H. M., & Kamonna, H. H. (2019) [29]	reinforcement region, types of CFRP sheet, and development lengths	150*225*3000	11
23	Dias, S. J., & Barros, J. A. (2008) [31]	CFRP laminate ratio and strengthening orientations	180*400*2450	12
24	Dias, S. J. E., & Barros, J. A. O. (2012) [24]	orientation, ratio of CFRP laminates, and ratio of existing steel stirrups	180*400*2800	17
25	Rasheed, M. M. (2016) [25]	shear span to depth ratio, horizontal and vertical transverse reinforcement	115*400*1200	9
26	Yu, F. et al. (2019) [27]	distances between the CFRP strips, degree of pre-cracking, and shear span to depth ratio	150*150*2100	18
27	De Lorenzis, L., & Nanni, A. (2001) [30]	distance between bars, pattern of strengthening, presence of internal shear reinforcement and the fixation of the ends of the bars	381*406.4*3048	8
28	Raheem Hassan, D. (2018) [26]	presence or absence of stirrups	140*450*1200	18

Table (2) Pattern of Strengthening and Results for all Research Adopted EBR Technique

NO.	Author's Name	Mode of Strengthening	Outcome of Improvements
1	El Maaddawy, T., and Sherif, S. (2009) [4]	CFRP sheets in a way horizontal or vertical on both sides of the openings	(72%) when the openings are located at the top of the beam compared with control beam
2	Abduljalil, B. S. (2014) [12]	CFRP strips in a vertical, inclined, vertical and horizontal form together, and finally, inclined and horizontal form together	(118.6 %) for the specimen that was strengthened with (CFRP) strips horizontally and diagonally together
3	Khudair, J. A. and Atea R. S. (2015) [13]	CFRP sheets in different sides (1,2 and 3) and angles (45º and 90º)	(27.3%) when the strengthening process was done for full-warp CFRP sheets

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4	Lam, L. et al. (2015) [20]	different layers of glass fiber composites (GCSM) with two types of resins (polyester or epoxy)	(67.97%) in ultimate load when double-layered glass fiber composites (GCSM) with epoxy resin were used, which the U-shaped strengthening process took place compared with control beam
5	Hussain, Q., and Pimanma, A. (2015) [6]	Apply (SFRP) on three sides (U-shaped) or two sides and different thicknesses (3 and 5) mm	(130 %) in ultimate load when using (SFRP) in three sides (U-shaped) with thickness (5 mm) compared with control beam
6	Javed, M. A. et al. (2016) [19]	CFRP sheets in a way horizontal or vertical (45º or 90º)	increasing in ultimate load, (37 %) when using the sheets at an angle (45º) and (32 %) when using the sheets at an angle (90º).
7	Abdul-Razzaq, K. S. et al. (2017) [9]	openings strengthening using steel plates and stud connectors	(31.7 %) in ultimate shear strength was observed in horizontal rectangular openings compared with control beam
8	Boumaaza, M. et al. (2017) [3]	different number of GFRP layers and different orientations (0/90, 20/70, 30/60 and +45/-45)	(10.5 %) in ultimate load when using one ply composite patch as U-shaped compared with control beam
9	Kumari, A. et al. (2018) [15]	Strengthening of a specimen by changing the number of GFRP layers	(45 %) when using three strengthening layers of GFRP
10	Jasim, W. A. et al. (2020) [5]	CFRP sheet	(6-30) % when reducing the a/h ratio from (1.1) to (0.9), using the openings (200*200) mm and its location in edges
11	Al-Bayati, N. A. et al. (2021) [11]	CFRP segments in different modes horizontal, vertically and inclined	(27.27 %) in final load when rehabilitated according to the inclined pattern or the vertical and horizontal patterns combined together
12	Akbarzadeh Bengar, H. et al. (2018) [23]	inclined CFRP strips	increasing in ultimate load capacity and ultimate deflection (6% and 15%)

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13	Dias, S. J., & Barros, J. A. (2008) [31]	CFRP laminates by different orientations	increasing in load capacity by (33%) when CFRP laminates at an angle (60º)
14	Dias, S. J. E., & Barros, J. A. O. (2012) [24]	CFRP laminates by different orientations	increase in the ultimate load ranging between (35- 62) %
15	Rasheed, M. M. (2016) [25]	U shape CFRP) sheets	increasing in the ultimate strength between (8-161) %
16	Yu, F. et al. (2019) [27]	CFRP strips by different distance between them	The degree of pre-cracking has a negligible impact on the rigidity of beams reinforced with CFRP strips

Table (3) Pattern of Strengthening and Results for all Research Adopted NSM Technique

NO.	Author's Name	Mode of Strengthening	Outcome of Improvements
1	Raheem, A. L. D. (2015) [2]	FRP rods in different angles (45 and 90) and different spacing between rods (100 and 150) mm	(17.14%) in ultimate load for beam strengthened with FRP rode at an angle of (45º) and a distance of (150 mm) between rods compared with control beam
2	Samad, A. A. A et al. (2017) [8]	Using (CFRP) bar with longitudinal reinforcement as anchors in the tension region, in addition to using it by (NSM) technique and with different spacing (100 and 150) mm	(25.68 % and 25.49 %) in ultimate load and shear force respectively, when using NSM-CFRP with spacing (100 mm)
3	Kammona, H. H., & Al-Issawi, A. S. H. (2018) [17]	The strengthening was done by changing the angle of the steel bars (45º and 90º), the spacings between them (100 and 150) mm and their diameters (8 and 12) mm.	(20.6 %) when using angle of the steel bars (45º), (a/d=0.85) and spacing between bars (100 mm)
4	Thamrin, R. et al. (2019) [10]	steel bars in a way horizontal or vertical (45º or 90º)	(104.54 %) in shear strength for the specimen that was strengthened diagonally and using the longitudinal reinforcement ratio (2.4 %)

5	KAMONNA, H. H., and ALKHATEEB, L. R. (2020) [14]	Strengthening process as a vertically, inclined, vertically and horizontally together	(35 %) in beam capacity when using strengthening bars at the inclined shape with a diameter (10 mm), the openings were located in the middle of the loading path
6	Ibrahim, M et al. (2020) [16]	Including the stirrups in the critical shear span (CSS) region at times and not including them at other times in addition to using NSM-FRP bars	(38.9 %) in ultimate load founded that the best performance can be obtained when the configuration is not aligned with the FRP strips and stirrups (not aligned means no interaction between FRP strips and stirrups) and increasing 55.8 % in load carrying capacity for the specimens without CSS stirrups
7	Azeez, A. A. et al. (2023) [18]	CFRP bars in a way vertically	(25 %) in ultimate load for the specimen with reactive powder concrete and four CFRP bars
8	Al-khreisat, A. et al. (2023) [7]	CFRP ropes in different modes vertically and inclined (45º and 90º), changing the rope diameter and the spacing between the ropes (150 mm, 200 mm)	(48 %) in ultimate load capacity when using the ropes at angle (45º) and spacing between ropes (200 mm)
9	Nafzin, A. A., & Prabhakaran, P. (2018) [28]	NSM Steel bars using vertical and horizontal schemes	increasing in ultimate load by (25.75%) when installing the NSM bars at an angle (45º)
10	Abdzaid, H. M., & Kamonna, H. H. (2019) [29]	NSM technique by using steel bars	improvement in failure loads by (108%)
11	De Lorenzis, L., & Nanni, A. (2001) [30]	NSM technique by using FRP bars with different orientations	increase in strength by (35%)
12	Raheem Hassan, D. (2018) [26]	NSM technique using CFRP bars	improvement in shear capacity by (17% to 141%)

8 Conclusions

Below, the most important conclusions reached by the researchers for all research that was reviewed during this paper are summarized, in which different parameters were taken into consideration regarding the procedure of the strengthening process, which was carried out in different modes, as follows:

The use of CFRP sheets in the process of strengthening openings led to an increase in shear strength of (66-71) % when the opening was in the middle of the shear span, an increase in shear strength of (72 %) when the opening was located at the top of the beam, and an increase in shear strength of (35 %) when the opening was located at the bottom of the beam.

To achieve the most significant improvement when using CFRP strips, it is preferable to make them horizontally and diagonally together, with using a square plate to fix these strips to the upper side of the beam using a bolt.

Using a mechanical method to stabilize the fibers reinforced polymer externally improves the shear strength and rigidity of the reinforced concrete deep beam and it prevents the rupture and failure of the sheets to a great extent.

The shear strength increased by approximately more than (17 %) when using CFRP bars, provided the bonding process between the CFRP rod and the concrete is stronger.

Using fiber-reinforced polymer externally and installing it mechanically improves the shear strength of beams containing openings, as applying it on three sides in the form of (U-shaped) gives better results than two sides in the strengthening process.

The use of (CFRP) bars using (NSM) technology, in addition to the use of (CFRP) as longitudinal steel bars in tension region gives good structural performance and can be considered a good option for repairing structural members damaged by shear.

Welding stud connectors before casting samples to strengthen steel plates increases the final shear strength of the beam with openings, as the highest strength was obtained when there are horizontal rectangular openings.

Strengthening critical regions with strips gives clear superiority and better results than U-shaped Strengthening, as failure changes from sudden to flexible, so that the structural member gives a warning before failure.

The maximum limit for using the number of (GFRP) layers in the strengthening process is (3 layers) where the maximum carrying capacity reaches (45 %) greater than un-strengthened specimen. This capacity decreases when the number of layers becomes more than (3).

It is not preferable to use (CFRP) sheets in models with a (a/d=1.1) ratio because the change that may occur in the load causing the first diagonal crack is very slight.

When there is an urgent need to make openings, it is preferable to make them as small as possible so that they serve the purpose and are far from the loading path because the closer the opening to the loading path, the more significant decrease in the ultimate load**.**

It is preferable to resort to the NSM technique for samples that do not contain critical shear span stirrups (CSS), as this technique helps in improving the load-carrying capacity by (55.8 %)**.**

When rehabilitating a damaged structural member with CFRP strips, it is recommended to make these strips inclined, or both vertically and horizontally together, as these patterns improve the ultimate load by (27.27 %) of the control beam**.**

Concrete reactive powder increases the deep beam's ultimate strength by a quarter and increases the initial shear crack capacity by one and a half times compared to the control beam**.**

To obtain the best results when using CFRP ropes to strengthen or repair deep beams, it is preferable to make these ropes at an angle (45º) with the horizontal axis and spaced (200 mm) center to center.

9 Recommendations for Future Studies

Study the behavior of reinforced concrete deep beams containing openings directly below the load points and strengthen these beams with the NSM-technique.

Study the behavior of reinforced concrete deep beams containing asymmetrically distributed openings and strengthen these beams with the NSM technique.

Studying the behavior of reinforced concrete T- deep beams containing openings, and strengthening them with the NSM technique.

Study the behavior of strengthened reinforced concrete deep beams under vertical and horizontal loading together using (FRP) materials.

Study the behavior of strengthened deep reinforced concrete beams under dynamic and sustained loads using (FRP) materials.

Study the behavior of strengthened deep reinforced concrete beams under the influence of repeated load using (FRP) materials.

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