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Influence of Grid Type and Configuration on the Shear Behavior of Reinforced Concrete Beams

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Abstract

This paper presents the results of the experimental investigation on the shear performance of beams strengthened with different types of grids (i) GFRP (Glass Fiber Reinforced Polymers) mesh; (ii) geogrid; and (iii) steel mesh. The experimental program reports the test results of twelve reinforced-concrete (RC) beams strengthened internally with dimensions of 1200 mm in length, 150 mm in width, and 200 mm in depth that were constructed and tested up to failure using a four-point load configuration. One beam is considered as a control beam, and the other beams are divided into three groups; each group is strengthened with different material mesh. Various parameters were considered in this study, including the number of mesh layers, the type of reinforcement material mesh, and the strengthening configurations. The test results indicated that beams strengthened with steel meshes achieved a peak shear load of 174 kN with an increase of 66% compared with the control beam. While the development in the ultimate load for strengthened beams using GFRP ranged from 1% to 18% compared to the control beam. Insufficient improvement in the ultimate load for beams strengthened using geogrid is obtained from the experimental results.

Keywords: Shear, Steel mesh, GFRP mesh, Geogrid, Internally strengthening, Four-point bending.

1.Introduction

Strengthening of concrete structures is often necessitated for various reasons. In fact, several factors, such as material degradation, design or construction deficiencies, lack of maintenance, or increased loading demands, affect the adequacy of these structures. In addition, environmental effects like earthquakes can also reduce their safety and performance. Corrosion of steel reinforcement is another major issue, since it lowers the yielding strength by reducing the effective cross-sectional area of the bars. Completely replacing such deteriorated structures is usually very costly and time-consuming, which makes strengthening a more practical and economical solution to restore or improve strength and serviceability[1] .

Several strengthening techniques have been explored in past research, one of which involves the use of wire mesh reinforcement. Wire mesh is commonly applied in ferrocement elements with flanged sections such as channel, box, and ribbed sandwich plates. Studies have shown that the shear resistance of thin-walled sections improves when the shear span-to-depth ratio is reduced [2]. Moreover, incorporating wire mesh as external reinforcement enhances cracking resistance, increases the ultimate load capacity, and reduces deflection compared with unstrengthened control specimens[3] . As the mesh number grows, the cracks become more extensive and smaller. [4]. Investigating the shear behavior of strengthening beams by the stainless-steel wire mesh technique and permeability polymer mortar shows that the restoration greatly increases the ultimate shear capacity, stiffness, and ductility of strengthened beams [5]. The behavior of RC beams repaired in shear with wire mesh in four different techniques, including one horizontal layer of wire mesh, two horizontal layers of wire mesh, three horizontal layers of wire mesh, and one horizontal layer with one vertical layer of wire mesh, revealed that retrofitted specimens layered with three layers of ferrocement showed the greatest increases in ultimate load-carrying capacity, with 46% compared to the control beam [6]. The effect of wire mesh and traditional steel reinforcement was examined by Sumpter and Matthew [7]. The experimental results indicated that using only wire mesh as shear reinforcement in concrete specimens has a significant effect on delaying the crack, increasing the number of cracks, and reducing the crack width.

Glass fiber reinforced polymers (GFRP) can be utilized to improve the shear capacity of RC beams, according to previous experimental work [8] [9] [10] [11] [12]. The flexible nature of glass fiber sheets and ease of handling and application, in addition to their high tensile strength and stiffness, have proven that fibers are very efficient for shear strengthening of RC beams. Kachlakev and McCurry [13] showed that using GFRP as shear reinforcement was sufficient to balance the lack of steel stirrups and change the failure mode of conventional RC beams from shear to yielding of the tension steel. Sundarraja and Rajamohan [14] [1] investigate the effect of using GFRP inclined strips as external strengthening on the shear strength of concrete beams. The results show that the U-wrapping retrofitting technique is proven to be highly effective for shear strengthening compared with beams retrofitted by bonding the GFRP strips on the sides alone.

Geosynthetic materials, particularly geogrids, have been increasingly employed in concrete-related research. Numerous studies have explored their applications in various fields of civil engineering, including asphalt layers [15][16], retaining walls and foundations [17] [18], as well as pavements [19] [20]. However, relatively limited research has investigated the use of geogrids as an alternative to conventional transverse reinforcement in reinforced concrete (RC) members [21]. Experimental studies have examined the influence of different confinement techniques such as traditional shear reinforcement and confinement provided by geogrids combined with varying amounts of polypropylene fibres on the shear behavior of RC beams. Findings indicated that the effectiveness of geogrids as shear reinforcement was restricted, particularly when higher fiber contents were used, and their performance did not fully match that of conventional steel stirrups [22]. Further investigations into the combined use of geogrids and steel fibers demonstrated enhanced beam strength and a shift in the failure mode from brittle shear failure to a more ductile flexural failure [23]. While many studies examine externally

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bonded FRP sheets and traditional stirrups, limited experimental studies examine the effect of different grid materials on the shear strength of concrete beams. This study addresses that gap by testing twelve beams with different grid types and configurations under identical four-point bending conditions. The load-carrying capacity, failure mode, types of mesh materials, number of layers, and different configurations have been investigated.

2.Experimental Program

The research program included twelve reinforced concrete beam specimens with dimensions of 1200 mm in length, 150 mm in width, and 200 mm in depth that have been tested in this research. To investigate the shear performance and to prevent flexure failure, 2Ø16 with an ultimate stress of 666 MPa was employed at the tension zone and 2Ø12 of 697 at the compression zone as a longitudinal reinforcement. Minimum shear steel reinforcement was used, which is 10@300 mm with an ultimate stress of 691. The steel reinforcement was tested according to ASTM (A615/A615M) [24]. The target cube compressive strength was 30 MPa, and the mix of concrete proportions is presented in Table 1. The cement and aggregate were tested according to ASTM (C150/C150M) [25] and ASTM (C33/C33M) [26], respectively.

Table 1: The concrete mix proportions/1 m³

Materials	Cement kg	Water kg	Sand kg	Gravel kg	CF555 Admix liter	w/c
Weight	420	160	760	1040	7	0.38

3. Fabricated Materials

The main objective of this research is to investigate the performance of mesh material for strengthening beams in shear instead of conventional reinforcement. Tables (2 to 4) show the properties of GFRP, steel, and geogrid, respectively. All meshes were cut to the suitable length and width for strengthening the beams. Figures 1 to 4 show a mesh material being cut to fit dimensions, their processes, and their application to the steel cage.

Table 2: Properties of GFRP materials

Property	**Fiber direction**	**Tensile strength**	**Modulus of Elasticity**	**Elongation**	**Density**	**Thickness**
Value	0°Unidirectio-nal	2300 Mpa	90 Gpa	3.9%	2.54 Gr/Cm	0.30mm

Table 3: Properties of steel materials

Chemical composition					
Component	**C**	**Mn**	**Si**	**S**	**P**
Manufacturer Results	0.12≤0.2	0.45≤1.20	≤ 0.35	≤ 0.035	≤ 0.040

Mechanical properties				
Properties	**Fy Mpa**	**Fu Mpa**	**Elongation %**	**Impact value KV2 (J)**
Manufacturer Results	340≥330	460≥430	21≥17	55≥47

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Table 4: Properties of geogrid materials

Properties	Minimum carbon black (%)	Tensile strength @ 2% strain (Kn/m)	Tensile strength @ 5% strain (Kn/m)	Ultimate tensile strength (Kn/m)	Strain at ultimate tensile strength (%)
Interlock 30/30	2	10.5	21	30	13

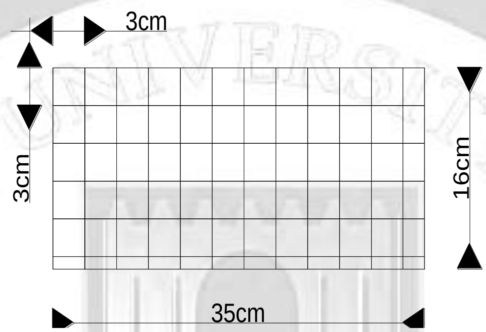

Fig. 1: Details of typical mesh

Fig. 2: Applying GFRP grid reinforcements to the steel cage

Fig. 3: Applying steel mesh reinforcements to the steel cage

Fig. 4: Applying geogrid reinforcements to the steel cage

4. Characteristics of Beam Specimens

Twelve beam specimens were cast; one beam symbolized the control beam without strengthening and was symbolized as BC, and the remaining beams were strengthened with GFRP, geogrid, and steel materials. Three groups of beams were prepared based on the type of strengthening materials. The first group consists of four beams containing GFRP mesh; the first beam was strengthened using a U-shape, whereas the other two beams were strengthened with two-sided mesh. One of those has been strengthened using two-sided mesh with a single layer, and the other one with two layers, while the last beam of this group was strengthened using two-sided GFRP mesh at 45° to the natural axis of the beam span. The second group consists of four beams strengthened using Geo-grid mesh; the first three beams were strengthened with a two-sided configuration. The first and second beams have one and two layers, respectively, whereas the third beam is strengthened with a 45° angle to the natural axis of the beam span. While the last specimens of the second group were strengthened with a U-shaped configuration. The remaining beams of the third group were strengthened with steel mesh materials; two of those beams were strengthened on two sides with one and two layers, and the last one with a U-shaped configuration. Table 5 shows the details and description of the beam specimens.

Table 5: The details and description of the beam specimens.

Symbol	Mesh type	No. of mesh layers	Strengthening technique	Inclination of mesh
BC	-----	-----	-----	-----
BS-90	steel	1	Side by side	90
BS2-90	Steel	2	Side by side	90
BS-U	Steel	1		-----
BG-90	Geo-grid	1	Side by side	90
BG2-90	Geo-grid	2	Side by side	90
BG-45	Geo-grid	1	Side by side	45
BG-U	Geo-grid	1		-----
BF-90	GFRP	1	Side by side	90
BF2-90	GFRP	2	Side by side	90
BF-45	GFRP	1	Side by side	45
BF-U	GFRP	1		-----

5. Test Results and Discussions

Table 6 illustrates a summary of the test results, including ultimate load, deflection, and mode of failure for all beams. Based on previous sections, the behavior of all tested beams will be discussed in the following items.

5.1 Ultimate Load and Mode of Failure

Table 6 summarizes and presents the results of the beam specimens that have been tested. As seen in Figure 6, the control beam failed in shear due to diagonal tension failure. The beam was loaded to a maximum of 105 kN, with a mid-span deflection of 3.86 mm. The first group, which is strengthened by GFRP mesh and consists of four beams (BF-90, BF2-90, BF-U, and BF-45), produced significant enhancement. The beam BF-90 achieved an ultimate load of 115 kN and a related mid-span deflection of 4.58 mm. The increase in load-carrying capacity is 9% over the control beam. Adding another layer in beam BF2-90 is more effective than beam BF-90; the ultimate load capacity for BF2-90 and the associated mid-span deflection are 125 kN and 5.33 mm, respectively. The improvement in load-carrying capacity is 18% compared to the control beam. The beam BF-U achieved an ultimate load of 117 kN, and the relation mid-span deflection is 5.46 mm, respectively. The enhancement in the ultimate load of this beam is 11% compared to the control beam. Obviously, based on the development in the load-carrying capacity, U-shaped strengthening is more efficient than the side-by-side scheme. Insufficient improvement in ultimate load for beam BF-45, which is 106 kN, with an associated mid-span deflection of 4.93 mm, and that was attributed to the weak joint of the inclined GFRP strips. For the second group that is strengthened by steel mesh materials that involve three beams, BS-90, BS2-90, and BS-U, beam BS-90 (strengthened with one layer in side-by-side form) attains an ultimate load of 113 kN with a mid-span deflection of 4.4 mm. This beam obtained an improvement in load-carrying capacity of 8% over the control beam. Increasing the number of layers to two layers, as in beam BS2-90, produced an enhancement in load-carrying capacity of up to 66% compared to the control beam. Whereas, the ultimate load of beam BS2-90 is 174 kN, and the relation mid-span deflection is 6.28 mm. While for beam BS-U (strengthening by U-shaped steel mesh), it has shown sufficient performance relating to BS-90. The ultimate load of BS-U is 144 kN, and the associated mid-span deflection is 6.23 mm. When compared to the control beam, this beam achieves a 37% improvement. The previous group is predicted to improve significantly, particularly beam BS2-90, which has the largest steel area. The third group that is strengthened by geogrid materials consists of four beams, which are BG-90, BG2-90, BG-U, and BG-45. Insufficient development in the load-carrying capacity for beams strengthened by geogrid is obtained from the experimental results as presented in Table 8. Both the BG-90 (two-sided with one layer of geogrid) and BG-45 (two-sided with one layer of geogrid) beams show no increase in ultimate load when compared to the control beam (two-sided at 45 angles to the beam axis); that was attributed to slip of the geogrid and reduced bond strength with concrete, particularly due to the smooth surface of the geogrid, and the associated mid-span deflection is 4.83 mm and 4.93 mm, respectively. When compared to the control beam, using two layers instead of one enhanced the load-carrying capacity by 3%. The ultimate load for beam BG2-90 is 109 kN, and the related mid-span deflection is 7.5 mm. While beam BG-U (strengthened by U-shaped geogrid) attains an ultimate load of 115 kN with a mid-span deflection of 4.9 mm. This beam obtained an improvement in load-carrying capacity of 10% over the control beam. The observed failure modes of the tested beams are summarized in Table 6. In most cases, an initial diagonal crack formed along with the longitudinal reinforcement, starting from the support and propagating toward the beam's midspan. This crack then extended to the loading point, ultimately leading to a sudden diagonal shear failure. The failure patterns of all beams are illustrated in Figures 5 to 8.

Table 6: Summary of the test results of beam specimens.

Beam	Ultimate load (kN)	The increase in load capacity (%)	Ultimate deflection (mm)	Mode of failure
BC	105	-------	3.86	Shear failure
BS-90	112.92	8	4.4	Shear failure
BS2-90	174	66	6.28	Shear failure
BS-U	144	37	6.23	Shear failure
BF-90	115	9	4.58	Shear failure
BF2-90	125	18	5.33	Shear failure
BF-U	117	11	5.46	Shear failure
BF-45	106	1	9.7	Shear failure
BG-90	105	0	4.83	Shear failure
BG2-90	109	3	7.5	Shear failure
BG-U	115	10	4.9	Shear failure
BG-45	106	1	4.93	Shear failure

Fig. 5: Typical failure mode of control beam

(a)

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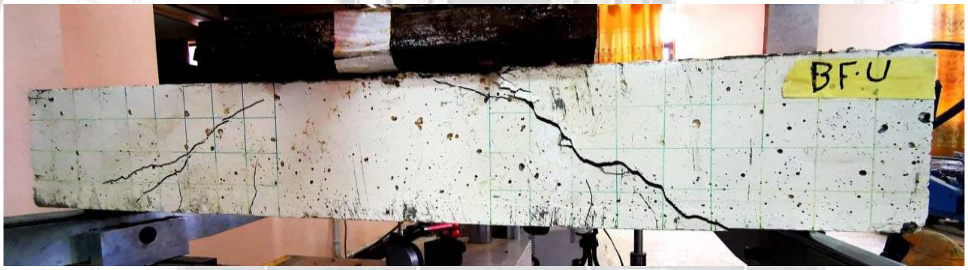
(b)

(c)



(d)

Fig. 6: Typical failure mode of beams strengthened by GFRP mesh

(a)

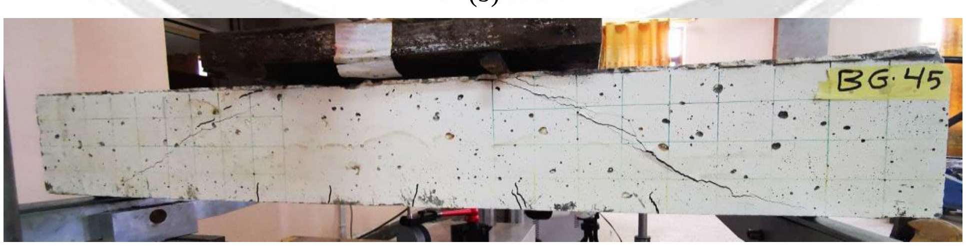
(b)

(c)

Fig. 7: Typical failure mode of beams strengthened by steel mesh

(a)

(b)



(c)

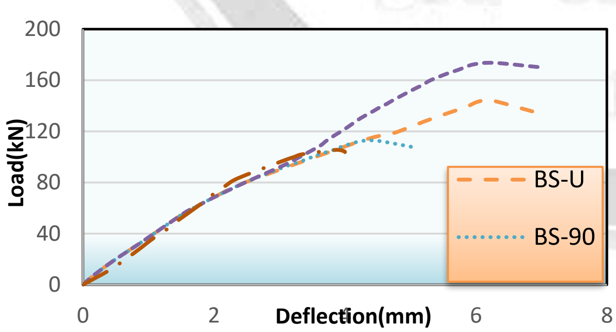
(d)

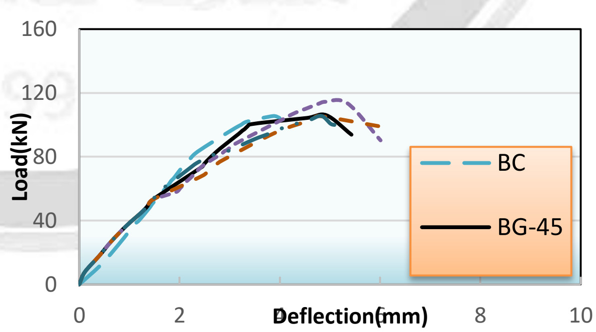
Fig. 8: Typical failure mode of beams strengthened by geogrid

5.2 Discussions

5.2.1 Effect of Type of Material Mesh

The Beams BS-90, BS2-90, and BS-U, which are strengthened by steel mesh in shear, failed at a higher load and deflection in comparison with beams strengthened by GFRP mesh and the Geo-grid EBR method. This can be related to the high yield stress, ductile behavior, and high steel quantity. The enhancement in load capacity for this group ranged from 8% to 66% compared to the control beam. While for the second group, which is strengthened by GFRP mesh and involvesfour beams (BF-90, BF2-90, BF-U, and BF-45), an improvement in the load capacity better than the beams strengthened by geogrid was achieved. The improvement in load capacity of the second group was 18% compared to the control beam, as presented in Table 5. Figure (9) shows the load-vertical deflection curves as obtained from the experimental result. Beams BF-90, BG-90, and BS-90 will be addressed in this subject to describe the influence of material on the load-deflection curve. The load-deflection curve for BF-90, as shown in Figure (9c), displayed the same linear behavior as the control beam, which was attributed to the brittle nature of glass fiber. As shown in Figure (9a), beam BS-90 has linearity performance in the load-deflection curve comparable with the control beam till 67 kN, and after that the curve seems to be more ductile due to the ductility property of steel mesh. While the load-deflection curve for all BG-90 exhibits the same linear behavior as the control beam until it reaches 70 kN, at which point the curves become more ductile.





(a) (b)

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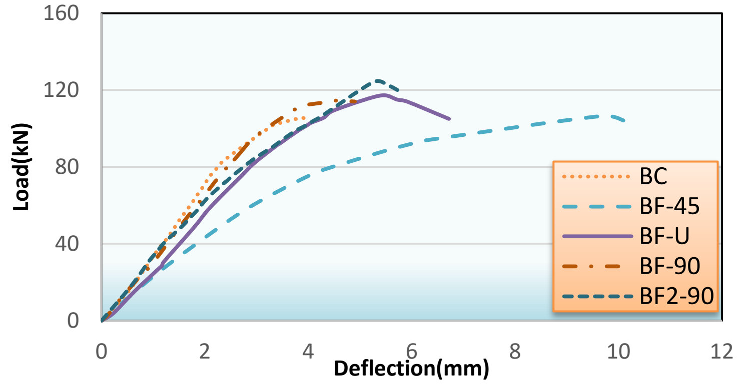
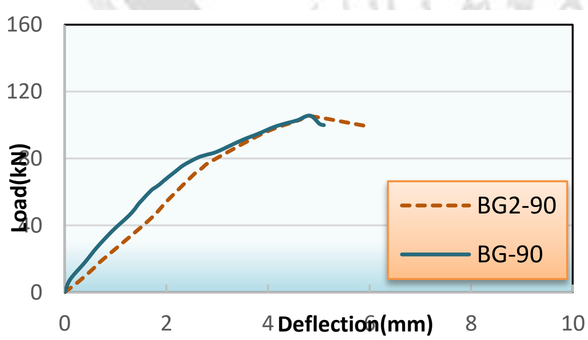


(c)

Fig. 9: Load- deflection curves for tested beams

5.2.2 Number of GFRP Layers

Six beams were investigated to assess the impact of the number of layers on beam performance: BS2-90, BS-90, BG2-90, BG-90, BF2-90, and BG-90. Figure (10) presented the load vs. deflection curve for the previously mentioned beams. Development in load-carrying capacity for beams BS2-90, BG2-90, and BF2-90 was 66%, 3%, and 18%, respectively, compared to the control beam. While the same beams, BS-90, BG-90, and BF-90, but with one layer, have improved the load-carrying capacity by 8%, 9%, and 0%, respectively, over the control beam. Generally, strengthening RC beams by two layers of material mesh showed a significant improvement in load capacity over the same beams with one layer for beams strengthened by steel and GFRP mesh, and no improvement was shown for beams strengthened by geogrid. Clearly from Figure (10c), the BF2-90 curve seems similar to beam BF-90 till 60 kN, and after that the behavior of these beams appears more ductile than BF-90. While the curve behavior of BS2-90 is less stiff than beam BS-90, which is due to the ductile characteristics of steel mesh as well as the relocation of stresses to the flexure zone. Whereas, adding another layer produced no enhancement in the load deflection curve for beam BG2-90.



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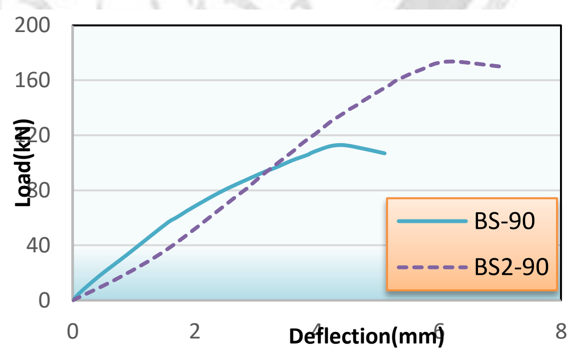

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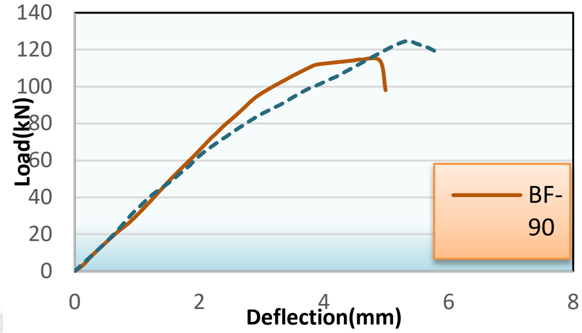
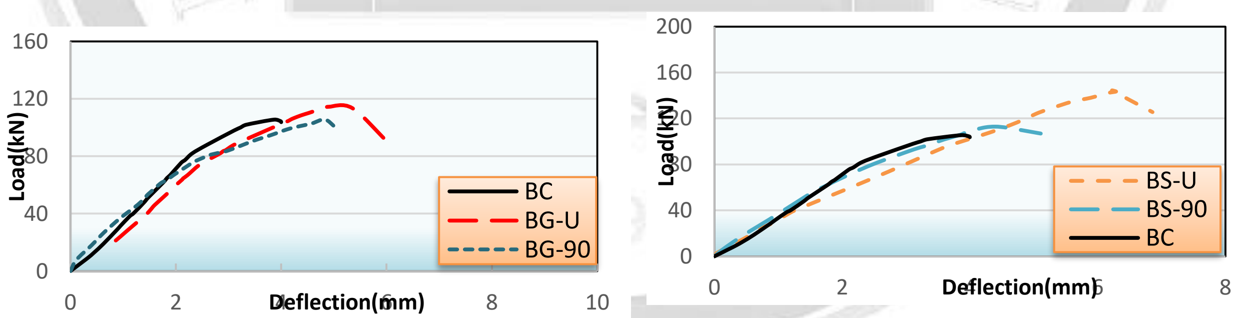


(c)

Fig.10: Load-deflection curves for beams with one and two layers

5.2.3 Strengthening Configuration

In the current study, three different strengthening configurations were investigated: U-wrap, two-sided, and two-sided with angle. The assessment of this item depends on beams strengthened with one layer only. The U-wrapped beams, which are BS-U, BF-U, and BG-U, resulted in a 37%, 11%, and 10% increase in strength, respectively, over the control beam. While for beams strengthened by side-by-side schemes, which are BS-90, BF-90, and BG-90, gained an increase in strength of about 8%, 9%, and 0%, respectively, over the control beam. This was expected because that U-shape has better performance than the two-sided configuration due to the increased attached area with concrete in particular. The load capacity of the BG-45 and BF-45 beams strengthened by two-sided angles was insufficient, with a 1% increase over the control beam, and that can be related to bond slip of strips from the concrete. The results show that the U-wrapped beam had higher strength than the two-sided beam and the two-sided beam with an angle configuration. Figure (11) presented the load vs. deflection for beams strengthened with side-by-side and U-shaped configurations. The behavior of those beams indicated that the U-shape improved the performance of strengthened beams well compared to beams strengthened by side-by-side.



(a) (b)

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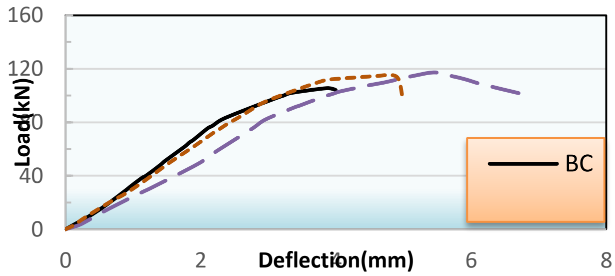

(c)

Fig.11: Load-deflection curves for beams with different configurations

6. Conclusions

This study was conducted to examine the shear performance of RC beams strengthened with different types of grids. The following conclusions were made from the experimental program:

1. All the strengthened beams show better performance compared with the control beam.

2. In general, beam specimens with steel mesh reinforcement perform better performance than the others, with an increase in the ultimate load of 66% for a beam with two layers of steel mesh.

3. Beams strengthened with GFRP mesh using one layer and two layers showed a 9% and 18% increase, respectively, in shear capacity over the control beam.

4. Insufficient development in the load-carrying capacity for beams strengthened by geogrid is obtained from the experimental results.

5. The mode of failure for all strengthening beams is shear diagonal crack due to the rupture of material meshes.

6. Using two layers of GFRP and steel meshes attained a significant additional gain in shear capacity for strengthening beams.

7. The use of a U-shaped configuration shows better performance than a two-sided configuration due to the increased attached area with concrete.

8. Adopting internal mesh strengthening can be a practical solution for thin beams where the control of section dimensions is important. Additionally, mesh reinforcement proved less steel weight over the beam's section.

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تأثير نوع وشكل الشبكة على سلوك القص للعوارض الخرسانية

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الخلاصة

تهدف الدراسة من الحاجة إلى تحديد الأساليب والمواد والتقنيات التي يمكن أن تساهم في تقوية الهيكل الخرساني المسلح. تقدم هذه الرسالة نتائج التحقيق التجريبي حول أداء اجهادات القص للعتبات مقوى بأنواع مختلفة من الشبكات (1) شبكة GFRP البوليمرات مقوى بالألياف الزجاجية،) و (2) شبكة Geogrid، و (3) شبكة الحديد. توضح التحريات العملية نتائج فحص اثني عشر عتبة من الخرسانة المسلحة(RC) مقوى داخليًا، بأبعاد 1200 مم في الطول، و 150مم في العرض، و200مم في العمق، تم بناؤها واختبارها حتى الفشل باستخدام نظام تحميل متماثل في نقطتين. تعتبر العتبة الأولى بمثابة عتبة مرجعية بينما تنقسم العتبات الأخرى إلى ثلاث مجموعات؛ تتكون المجموعة الأولى من أربع عتبات خرسانية ويتم تقويتها بواسطة شبكة GFRP بينما تحتوي المجموعة الثانية على ثلاث عتبات خرسانية مقوى بشبكة فولاذية اما العتبات المتبقية من المجموعة الثالثة، معززة بمواد شبكة Geogrid.تم الحصول على النتائج العملية والتي تشمل الحمل والهطول والفشل لجميع العتبات المفحوصة. المتغيرات التي درست هي بما في ذلك عدد طبقات الشبكة ونوع شبكة مواد التقوية وانماط التقوية. فشلت جميع العتبات في فشل القص القطري بسبب الانزلاق وتمزق الشبكة. تشير نتائج الاختبار إلى أن العتبات الخرسانية مقوى باستخدام شبكة فولاذية كتقوية للقص تعطي أداً ء عاليًا مقارنة بأي عينة أخرى حيث تعمل على تحسين قدرة تحمل الأحمال بنسبة تصل إلى 66٪مقارنة مع العتبة المرجعية. بينما يتراوح التحسين في الحمل النهائي للحزم مقوى باستخدام GFRP من 1٪إلى 18٪مقارنة بالعتبة المرجعية. بينما، أظهرت النتائج التجريبية تحسنًا غير كاف في الحمل النهائي للعتبات التي تم تعزيزها باستخدام نوع شبكة Geogrid.

الكلمات الدالة: – القص، الشبكة الفولاذية، شبكة Geogrid، شبكة GFRP، تقوية داخلية، انحناء رباعي النقاط.