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Strengthening of R.C Deep Beams Using CFRP, GFRP

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ملخص البحث

يحتوى هذا البحث على دراسة سلوك القص للكمرات العميقه المقواه بالياف الكربون والياف الزجاج . وقد تضمن برنامج الأختبارات سته كمرات عميقة من الخرسانه المسلحه، و أهم المتغيرات التى تم دراستها فى هذا الأختبار هى تغير نسبه القص الي عمق الكمره (1,75&1,25) ونوع التقويه (الياف الكربون & الياف الزجاج) . وأظهرت النتائج أن نسبه الزياده للكمرات العميقه المدعمه بالياف الكربون (باختلاف نسبه القص الي عمق الكمره (1,75&1,25)) عن الكمرات العميقه الغير مدعمه هي 59.4٪ و 74.8٪ علي التوالي و وأظهرت ايضا أن نسبه الزياده للكمرات العميقه المدعمه بالياف الزجاج (باختلاف نسبه القص الي عمق الكمره (1,75&1,25)) هي 38.4٪ و 54.8٪ علي التوالي بالمقارنه مع الكمرات العميقه الغير مدعمه وان قله الانحراف ترجع الي نوع الالياف .

Abstract

The program has investigated different techniques to improve the performance of RC deep beams under two concentrated vertical loads using advanced composite materials (CFRP,GFRP Sheets).The primary aim of this research was to study the behavior of deep beams strengthened in shear by using carbon fiber, glass fiber and Knowing the behavior of the deep beams with different shear span to depth ratio a/d.

Six RC deep beams specimens , These beams were simply supported with span length L=1500 mm , total length =1900mm and cross section (140 x 450 mm).Tested beam were subjected to the effect of two concentrated loads with spacing of 560 and 160mm. The deep beam were tested and divided into three groups. The first group consists of two beams (G1.BC1.1.25, G1.BC2.1.75) each of them control beam , the second group consists of two beams (G2BCa1.1.25, G2BCa2.1.75) each of them strengthened with U shape in shear by CFRP and The third group consists of two beams also (G3.Bg1.1.25, G3.Bg2.1.75) each of them strengthened with U shape in shear by GFRP.

Keywords

Deep beams, Shear behavior, Shear span to depth ratio a/d, CFRP sheets, GFRP sheets.

Introduction

Reinforced concrete deep beams are considered useful in tall buildings, offshore structures, long-span structures and complex foundation systems. The moment capacities of deep beams are normally adequate and are not of major concern, but the shear capacity of deep beams is very important to understand since properly designed deep beams would usually fail in shear at the ultimate limit state. Deep beams are characterized by relatively small values of span to depth ratios. Because of their proportions, they develop mechanism of force transfer quite different from that in shallow beams.

Different values of the span to depth ratio (Le/d) and the shear span to depth ratio (a/d) are proposed by different design codes to define deep beams. The ACI code (2005) and The Egyptian code defines a beam to be deep beam when the effective span to depth ratio (Le/d) is less than 4, CIRIA defines a beam to be deep beam when the effective span to depth ratio (Le /d) is less than 2 for simple beams, The EC-2 defines the beam with (Le/d) less than 3 as deep beam and The candian code defines the beam with (Le/d) less than 1.25 for simple beams .

As reinforced concrete deep beams have become an important structural element, their behavior and ultimate shear strength has been the subject of many researchers devoted to determine the influence of effective parameters. Several different modes of failure have identified from the experimental studies, due to the variability in the failure, the determination of their shear capacity and identification of failure mechanisms are very complicated .The existing methods for analysis and design of deep beams consist of rational and semi-rational approaches as sectional approach or strut-and-tie Model (STM).

Only a few years ago, the construction market started to use FRP for structural reinforcement, generally in combination with other construction materials such as wood, steel and concrete. FRP exhibit several attractive properties, such as low weight to strength ratio, non-corrosiveness high fatigue strength, and case of application.

The use of FRP sheets or plates bonded to concrete beams has been studied by several researchers. Strengthening with adhesive bonded fiber reinforced polymers has been established as an effective method applicable to many types of concrete structures such as columns, beams, slabs and walls. Because FRP materials are non-corrosive, non-magnetic, and resistance to various types of chemicals, they are increasingly being for external reinforcement of existing concrete structures.

2. Methodology

The reinforced concrete deep beams consisted of three groups ,the first group is ordinary ,second and third group strengthened with CFRP,GFRP .the three groups comprised two deep beams with shear span to effective depth ratios 1.25and 1.75. CFRP,GFRP sheets are usually installed on two or three sides(U shape), or fully wrapped around the beam.

Two-sided installation is more common in strengthening because of its ease of installation and cost-effectiveness compared to the other two installation systems,but three sides(U shape) make deep beams are more strength ,decrease deflection , protect and strength the concrete cover. On this study we used the strengthening on three sides.

2.1. Details of Deep Beams

Classification the deep beam in general that all the specimens have the same dimension and reinforcement . The test specimens consisted of six reinforced concrete simply supported deep beams divided into 3 groups. The Specimens used in this research are Normal Strength Concrete beams having a total depth of 450 mm and a width of 140 mm. The length of all the specimens was 1900 mm and its clear spans are 1500 mm. All the studied beams had 9 Φ 18mm with (f_y = 420MPa) as bottom longitudinal reinforcement. The top longitudinal reinforcement consisted of 2 Φ 18mm with (f_y = 420 MPa) .The concrete dimensions and details of reinforcement of beam specimens are shown in Figure (1) ,loading and support plate dimensions and orientation are shown in Figure (2). But the specimens in tesed are different in type of strengthening and different also on shear span-to-depth ratios (a/d) .

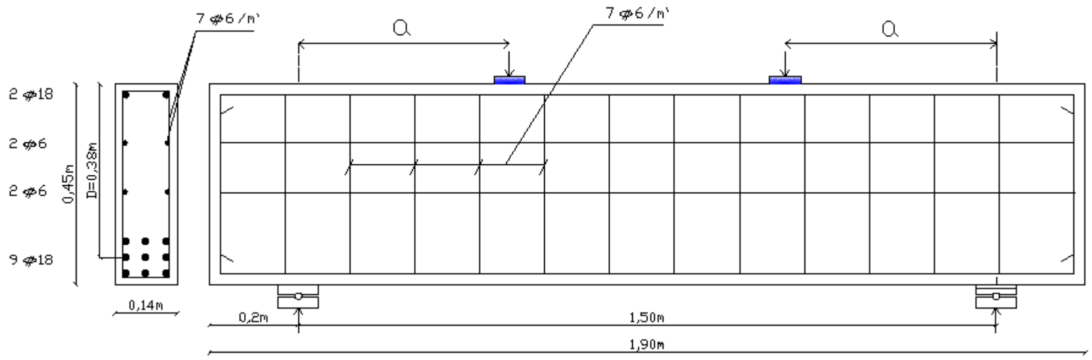


Figure (1) Concrete dimensions and details of reinforcement of a beam specimen

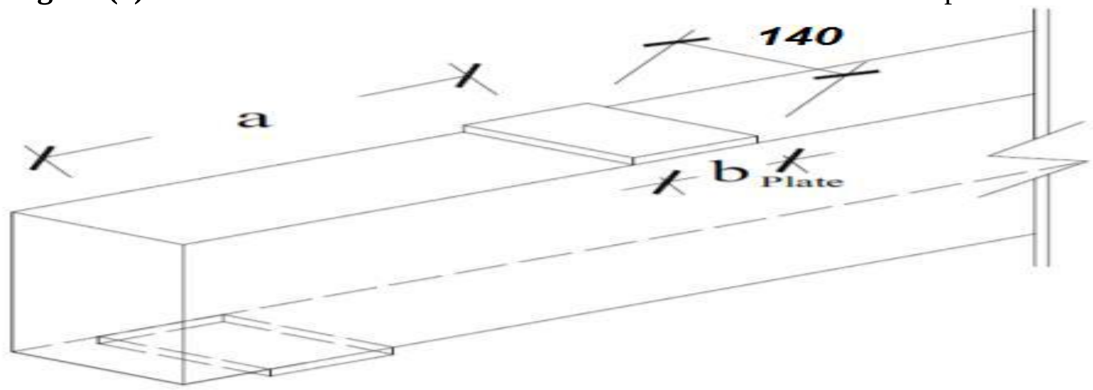


Figure (2) Loading and support plate dimensions and orientation

2.2. Materials and Methods

One layer of uni-directionally woven carbon-fiber fabric with a thickness of 0.17 mm/ply for GFRP and .13 for CFRP was wet-laid on the deep beams with a two-part epoxy resin. The direction of the fiber in the installed CFRP sheet was vertical. Table 1 lists the typical properties of the CFRP ,GFRP sheet and epoxy resin provided by the manufacturer. Both the FRP sheet and epoxy resin were supplied by Sika Company with Sikadur-330 and sikadur -31CF product data sheets. Strengthening with the CFRP and GFRP sheet was performed only on the surface of the beams between the load and support plate to cover the shear span of the deep beams. The CFRP-strengthening was cured for at least two days at ambient temperature following the manufacturer's recommendation. The support and load plates, which are 70 mm wide and 10 mm thick, fully covered the bottom and top of the beam. The deep beams were tested 28 d after casting.

A universal tensile strength testing machine was used to measure the tensile strength of steel bars. Three samples were chosen from each size of steel bars and the average taken as the final tensile strength. The test was carried out according to standard ASTM-E8 with a strain rate of 0.005 in/in/min to measure the ultimate tensile strength of the bars. The tensile strength of the reinforcing steel bars determined as described (T18) was 440 MPa, while the compressive and splitting tensile strengths of concrete were 37.02 and 3.31 MPa, respectively.

Table 1. Typical properties of CFRP ,GFRP sheets and epoxy

Materials	Tensile strength (*MPa*)	Tensile modulus of elasticity (*GPa*)	Fiber density (g/cm³)	Bond strength (*MPa*)	Thickness (*mm/ply*)
CFRP SHEET	3450	230	1.8	–	0.13
GFRP SHEET	2300	76	2.56	–	0.17
sikadur -330	30	4.5	–	>4	–

2.3. Test Procedures and Instruments

The strains in the reinforcing steel were measured using six of TML electrical strain gauges from Tokyo Sokki Kenkyujo Co., Ltd. type FLA-6-11-1L, with gauge resistance of 350 ohms and a gauge length of 10 mm. The strain gauges were attached to the steel using special epoxy adhesive after cleaning and smoothing the surface of it then insulated from the wet concrete by means of silicon coating as shown in fig (3).

Tested beams were subjected to two concentrated loads and supported at two ends and each was applied at 200 mm from end of beam for thirteen specimens as shown in fig (4) .

All beams were loaded to failure by means of vertical hydraulic jacks using a steel distribution beam with special bearing assemblies on the top face of the specimen as shown in fig (4). Linear Variable Differential Transducer (LVDT) was used to measure deflection through a computer-controlled data acquisition system as shown in fig (4). This system was used to record measurements at fixed time intervals , measurements included load from the load cell, deflection from LVDT and the strains at bottom bars, top bars and stirrups from the electrical strain gauges, using diagonal LVDT at the face of specimen perpendicular at path of shear crack to measurement the concrete strain and width of cracks as shown in fig (4) .

Before each test the beam specimen was placed on the supporting frame and the locations of applied loads and locations of LVDT's were adjusted. The LVDT's and the strain gauges were attached to the data acquisition system and their initial readings were recorded before loading of the specimen. The cracks at each incremental load were traced using a permanent marker and then take photographs of the crack extent .The test was finished when the beam was fractured or when extensive deformation was observed or when decrease in load value.

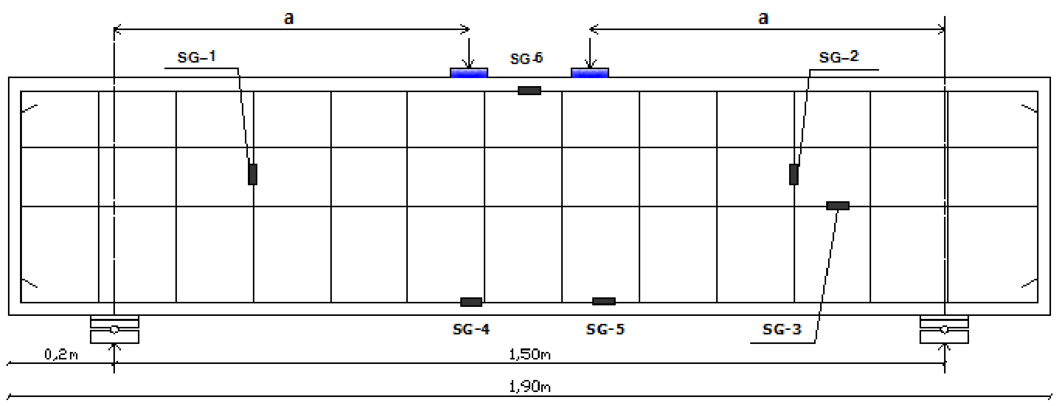


Figure (3) Location of strain gauges

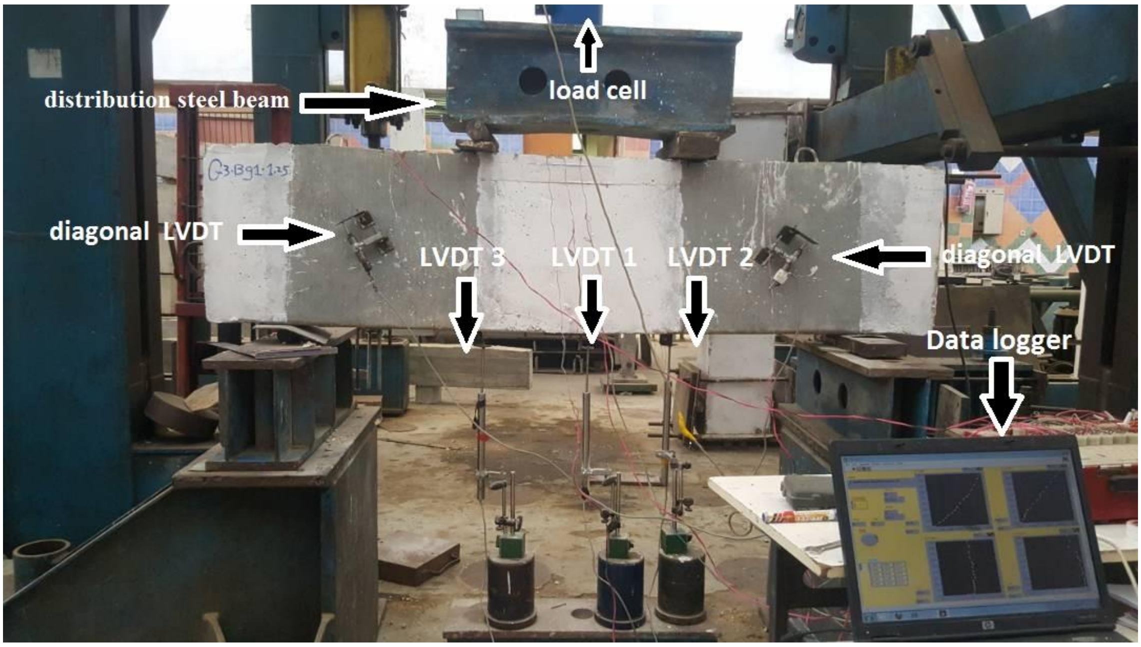


Figure (4) Test setup

3. Experimental Results

The deep beams which control and strengthened beams were tested under static loading until failure. Experimental applied load and mid span deflection were automatically recorded. The crack pattern of control and strengthened tested beams are shown in Figure 5. Test results of all tested specimens are listed in Table 2.

3.1 Crack Pattern

Shear cracks initiated in the web which connect from the loading point to the support. These diagonal cracks propagated upward to the loading point and downward to a location of support and the width of diagonal shear cracks became wider with incremental loads.

Figure 5 shows the crack pattern for specimens with and without CFRP,GFRP.

The crack pattern of the strengthened deep beams have a different shape in comparison with the control beams. There are appearance and disappearance cracks when was compare with control beams.

3.2 MODES OF FAILURE

3.2.1 Modes of Failure for Group G1

-The failure load of each beam decreased due to the increasing of shear span-to-depth ratio (a/d) for beam of shear span-to-depth ratio a/d 1.25 and 1.75 respectively .The failure load of this group(control beams) were lower than that beam strengthening with carbon or glass fiber reinforced polymer .

- For all beams of the group, the shear cracking load was about 51.1%,and 42.1% of the failure load respectively.

3.2.2 Modes of Failure for Group G2

- The failure load of each beam decreased due to the increasing of shear span-to-depth ratio (a/d) for beam of shear span-to-depth ratio a/d 1.25 and 1.75 respectively the failure load of this group were higher than that beam without strengthening by about 59.4 % and 74.6% respectively.
- For all beams of the group, the shear cracking load was about 53.5% and 61.4% of the failure load respectively.

3.2.3 Modes of Failure for Group G3

- The failure load of each beam decreased due to the increasing of shear span-to-depth ratio (a/d) for beam of shear span-to-depth ratio a/d 1.25 and 1.75 respectively the failure load of this group were higher than that beam without strengthening by about 38.4 % and 54.8% respectively.
- For all beams of the group, the shear cracking load was about 39.8% and 40% of the failure load respectively.

Table 2. Summary of test results for the tested beams:

Group No	Specimen	Shear span to depth (a/d) ratio	Strengthe-ning with	Failure load (ton)	Shear cracking loads (ton)	Max. deflection (mm)	Percenta-ge %
Group .no(1)	G1BC1.1.25	1.25	(**Ref**erence beam)	47.1	24.1	7.2	comparison
	G1BC2.1.75	1.75		32.55	13.69	5.5	comparison
Group .no(2)	G2BCa1.1.25	1.25	fully warp from load to support with U-shape CFRP sheets	75.11	40.23	6.5	59.4%
	G2BCa2.1.75	1.75		56.82	34.89	6.6	74.6%
Group .no(3)	G3BG1.1.25	1.25	fully warp from load to support with U-shape GFRP sheets	65.18	25.94	7.5	38.4%
	G3BG2.1.75	1.75		50.39	20.16	6.557	54.8%

Figure 5. Crack pattern for tested deep beams

3.3 Load Deflection Behavior

As mentioned before, the vertical deformations were measured using Linear Variable Displacement Transducers (LVDTs) of three points on each beam the first point at middle of beam and the second and third points at under two loads . The behavior of most of the deep beams demonstrated a nearly linear response up to failure because the flexural reinforcement didn't yield. It was noted that strengthening beam by externally CFRP,GFRP sheets given a good enhancement in the shear strength for the deep beams.

The values of maximum deflection of beam are shown in table (2).

Comparing the deflections of beams at the same load the deflections were inversely proportional to strengthening are shown in Figure 6.

For beam specimens G3.Bg1.1.25 and G2B.Ca1.1.25 which strengthening u shape with glass and carbon fiber reinforced polymer sheets , it was found the vertical deflection decreased by about 34.7% and 51% respectively from G1.BC1.1.25 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.25.
For beam specimens G3.Bg2.1.75 and G2BCa2.1.75 which strengthening u shape with glass and carbon fiber reinforced polymer sheets , it was found the vertical deflection decreased by about 34.2% and 53.1% respectively from G1.BC2.1.75 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.75.
For beam specimens G2.Bca1.1.25 which strengthening u shape with vertical carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the vertical deflection decreased by about and 32.7% from G2.Bca2.1.75 which was strengthening u shape with carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load .
For beam specimens G3.Bg1.1.25 which strengthening u shape with vertical glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the vertical deflection decreased by about 25.3% from G3.Bg2.1.75 which was strengthening u shape with glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load .

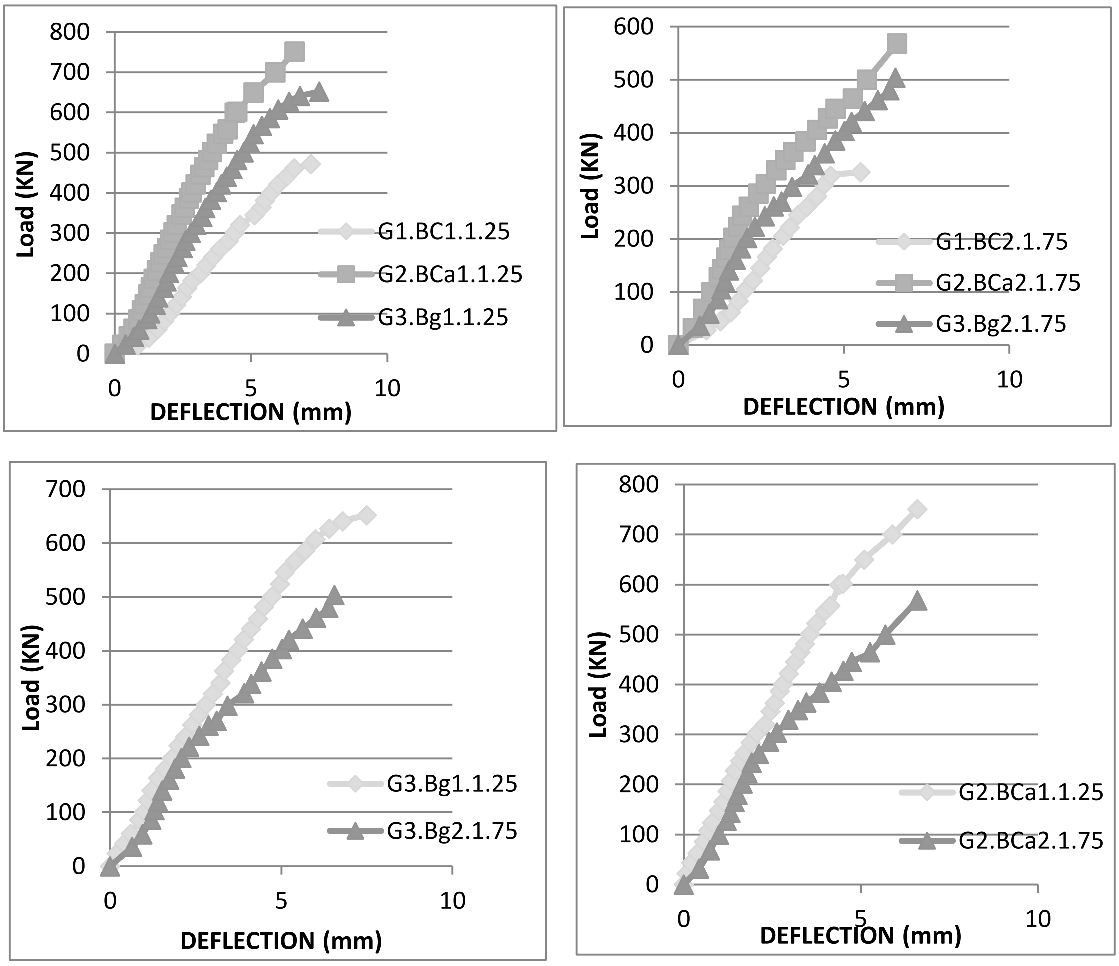


Fig. 6 Load deflection relationships for tested beams

3.4 CRACK WIDTH

The crack width was measured to determine the maximum crack width through the span of each tested beam from zero up to the failure load. Comparing the crack width of beams at the same load the crack width was inversely proportional to the strengthening are shown in figure (7).

For beam specimens G3Bg1.1.25 and G2BCa1.1.25 which strengthening u shape with glass and carbon fiber reinforced polymer sheets, it was found the crack width of beams decreased by about 47.5% and 78% respectively from G1.BC1.1.25 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.25.

For beam specimens G3.Bg2.1.75 and G2.BCa2.1.75 which strengthening u shape with glass and carbon fiber reinforced polymer sheets, it was found the crack width of beams decreased by about 51% and 77% respectively from G1.BC2.1.75 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.75.

For beam specimens G2.Bca1.1.25 which strengthening u shape with vertical carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the crack width of beams decreased by about 83.4% from G2.Bca2.1.75 which was strengthening u shape with carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load . For beam specimens G3.Bg1.1.25 which strengthening u shape with vertical glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the crack width of beams decreased by about 88.1% from G2.Bg2.1.75 which was strengthening u shape with carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load .

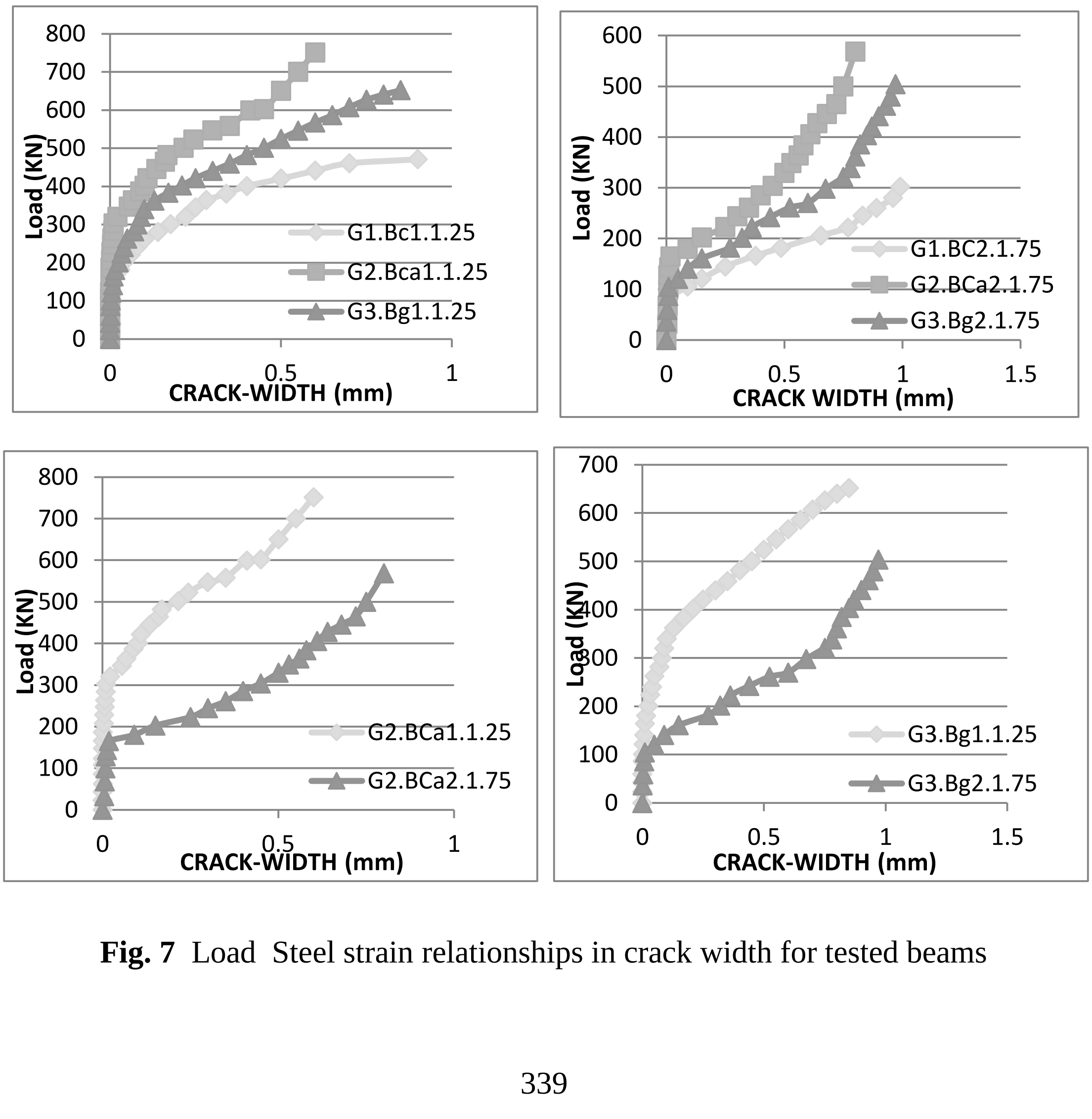


Fig. 7 Load Steel strain relationships in crack width for tested beams

3.5 STEEL STRAIN

3.5.1 LONGITUDINAL STEEL STRAIN

The steel strain measured during testing by using electric strain gauges mounted on the beam longitudinal reinforcement. Comparing the steel strains in longitudinal steel of beams the strengthening not greatly affected in the steel strains in longitudinal steel of beams are shown in figure (8) .

For beam specimens G3Bg1.1.25 and G2BCa1.1.25 which strengthening u shape with glass and carbon fiber reinforced polymer sheets, it was found the steel strains in longitudinal steel decreased by about 19.3% and 30.7% respectively from G1.BC1.1.25 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.25. For beam specimens G3.Bg2.1.75 and G2.BCa2.1.75 which strengthening u shape with glass and carbon fiber reinforced polymer sheets, it was found the steel strains in longitudinal steel decreased by about 13% and 20% respectively from G1.BC2.1.75 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.75. For beam specimens G2.Bca1.1.25 which strengthening u shape with vertical carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the steel strains in longitudinal steel decreased by about 14% from G2.Bca2.1.75 which was strengthening u shape with carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load . For beam specimens G3.Bg1.1.25. which strengthening u shape with vertical glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the steel strains in longitudinal steel decreased by about 7% from G3.Bg2.1.75 which was strengthening u shape with glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load .

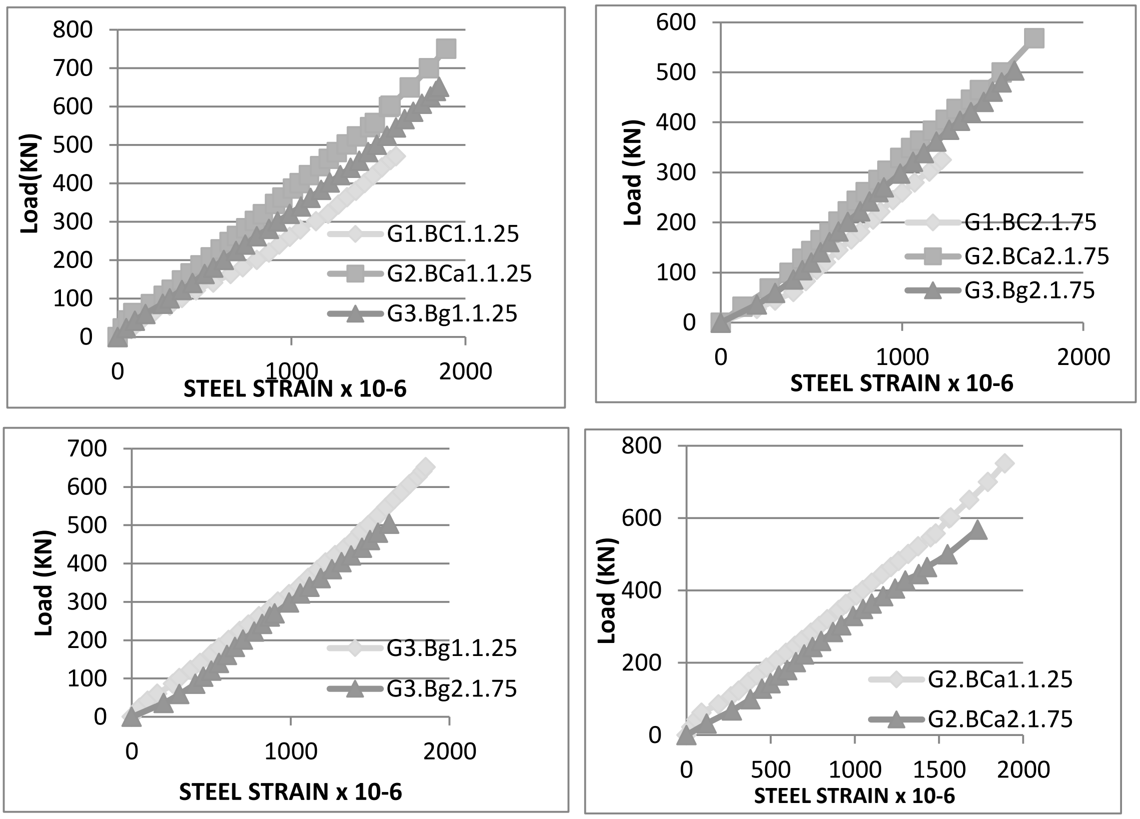


Fig. 8 Load Steel strain relationships in Longitudinal steel for tested beams

3.5.2 UPPER STEEL STRAIN

The steel strain measured during testing by using electric strain gauges mounted on the beam upper reinforcement. Comparing the steel strains in upper steel of beams the strengthening not greatly affected in the steel strains in upper steel of beams are shown in figure (9) . For beam specimens G3Bg1.1.25 and G2BCa1.1.25 which strengthening u shape with glass and carbon fiber reinforced polymer sheets, it was found the steel strains in upper steel decreased by about 17.2% and 27.7% respectively from G1.BC1.1.25 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.25. For beam specimens G3.Bg2.1.75 and G2.BCa2.1.75 which strengthening u shape with glass and carbon fiber reinforced polymer sheets, it was found the steel strains in upper steel decreased by about 21.2% and 24.4% respectively from G1.BC2.1.75 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.75. For beam specimens G2.Bca1.1.25 which strengthening u shape with vertical carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the steel strains in upper steel decreased by about 20.3% from G2.Bca2.1.75 which was strengthening u shape with carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load . For beam specimens G3.Bg1.1.25 which strengthening u shape with vertical glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the steel strains in upper steel decreased by about 12.5% from G3.Bg2.1.75 which was strengthening u shape with glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load .

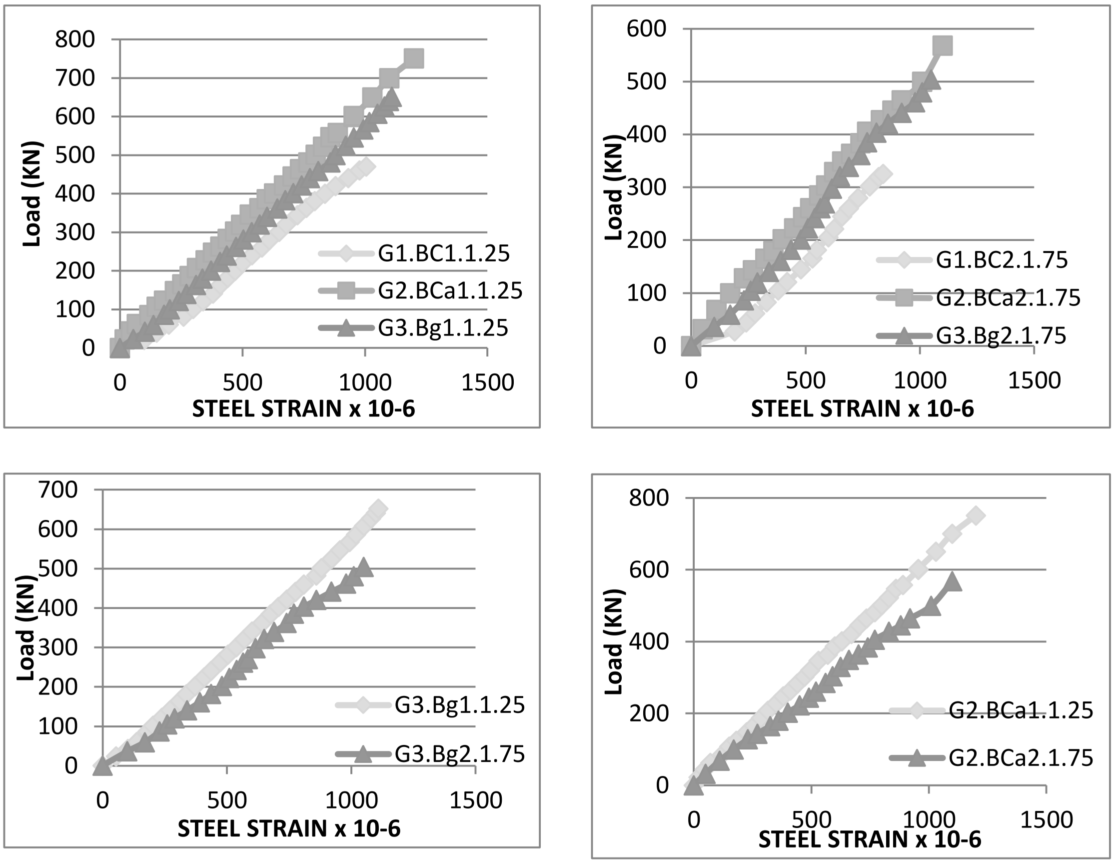
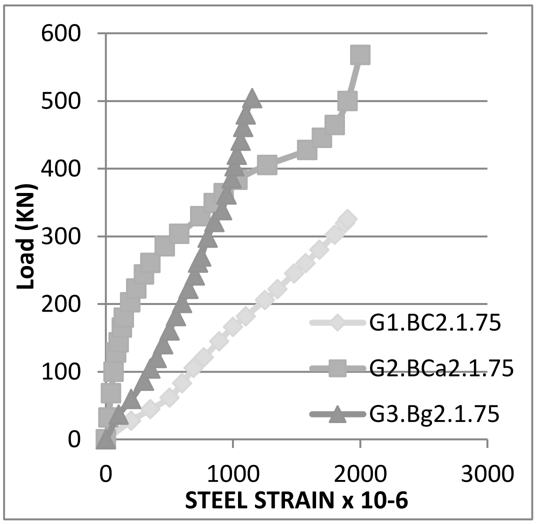


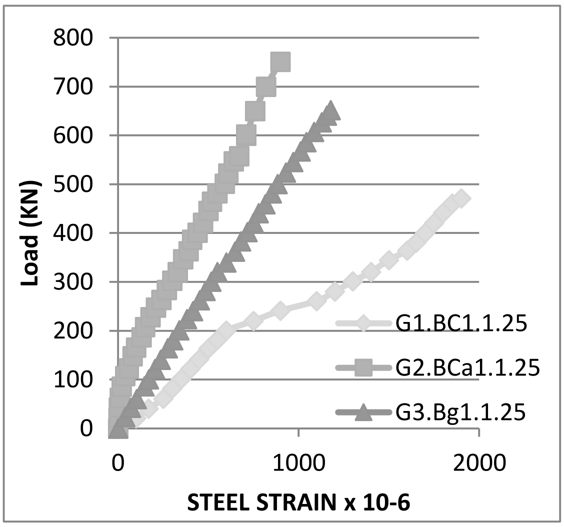
Fig. 9 Load Steel strain relationships in upper steel for tested beams

3.5.3 VERTICAL STIRRUP STEEL STRAIN

The steel strain measured during testing by using electric strain gauges mounted on the beam vertical stirrup . Comparing the steel strains in vertical stirrup steel of beams are shown in figure (10).

For beam specimens G3Bg1.1.25 and G2BCa1.1.25 which strengthening u shape with glass and carbon fiber reinforced polymer sheets, it was found the steel strains in vertical stirrups decreased by about 62.7% and 79.2% respectively from G1.BC1.1.25 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.25. For beam specimens G3.Bg2.1.75 and G2.BCa2.1.75 which strengthening u shape with glass and carbon fiber reinforced polymer sheets, it was found the steel strains in vertical stirrups decreased by about 56% and 84.8% respectively from G1.BC2.1.75 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.75. For beam specimen G2.Bca1.1.25 which strengthening u shape with vertical carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the steel strains in vertical stirrups decreased by about 67.7% from G2.Bca2.1.75 which was strengthening u shape with carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load . For beam specimens G3.Bg1.1.25 which strengthening u shape with vertical glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the steel strains in vertical stirrups decreased by about 35.5% from G3.Bg2.1.75 which was strengthening u shape with glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load .





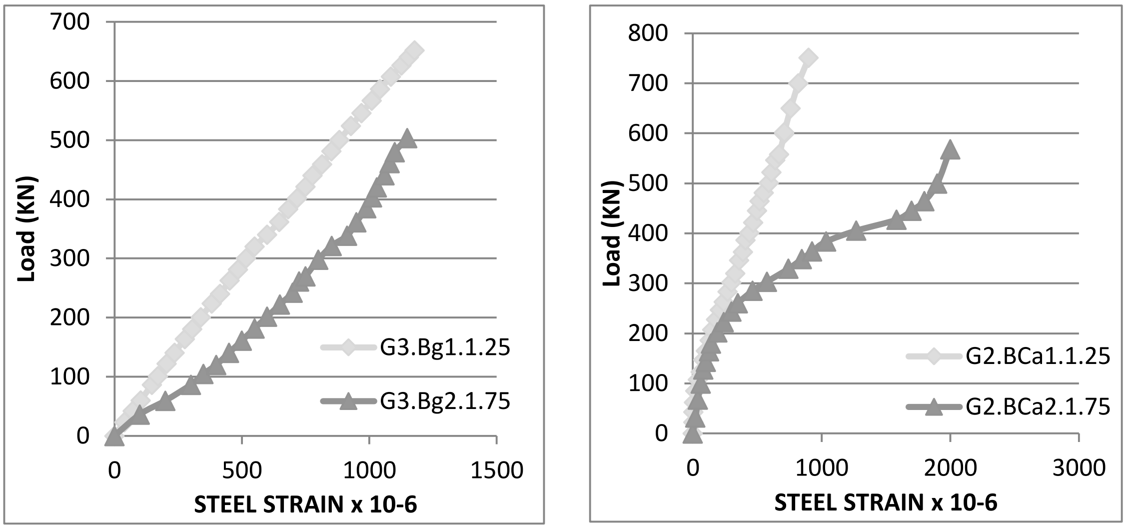


Fig. 10 Load Steel strain relationships in vertical stirrups for tested beams

3.5.4 HORIZONTAL STIRRUP STEEL STRAIN

The steel strain measured during testing by using electric strain gauges mounted on the beam horizontal stirrup . Comparing the steel strains in horizontal stirrup steel of beams are shown in figure (11)**.**

For beam specimens G3Bg1.1.25 and G2BCa1.1.25 which strengthening u shape with glass and carbon fiber reinforced polymer sheets, it was found the steel strains in horizontal stirrups decreased by about 54.5% and 77.3% respectively from G1.BC1.1.25 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.25. For beam specimens G3.Bg2.1.75 and G2.BCa2.1.75 which strengthening u shape with glass and carbon fiber reinforced polymer sheets, it was found the steel strains in horizontal stirrups decreased by about 30% and 47.6% respectively from G1.BC2.1.75 which was no strengthening (control beam) at the same load in shear span-to-depth ratios (a/d) =1.75. For beam specimens G2.Bca1.1.25 which strengthening u shape with vertical carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the steel strains in horizontal stirrups decreased by about 75.9% from G2.Bca2.1.75 which was strengthening u shape with carbon fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load . For beam specimens G3.Bg1.1.25 which strengthening u shape with vertical glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) = 1.25 , it was found the steel strains in horizontal stirrups decreased by about 63% from G3.Bg2.1.75 which was strengthening u shape with glass fiber reinforced polymer sheets at shear span-to-depth ratios (a/d) =1.75 at the same load .

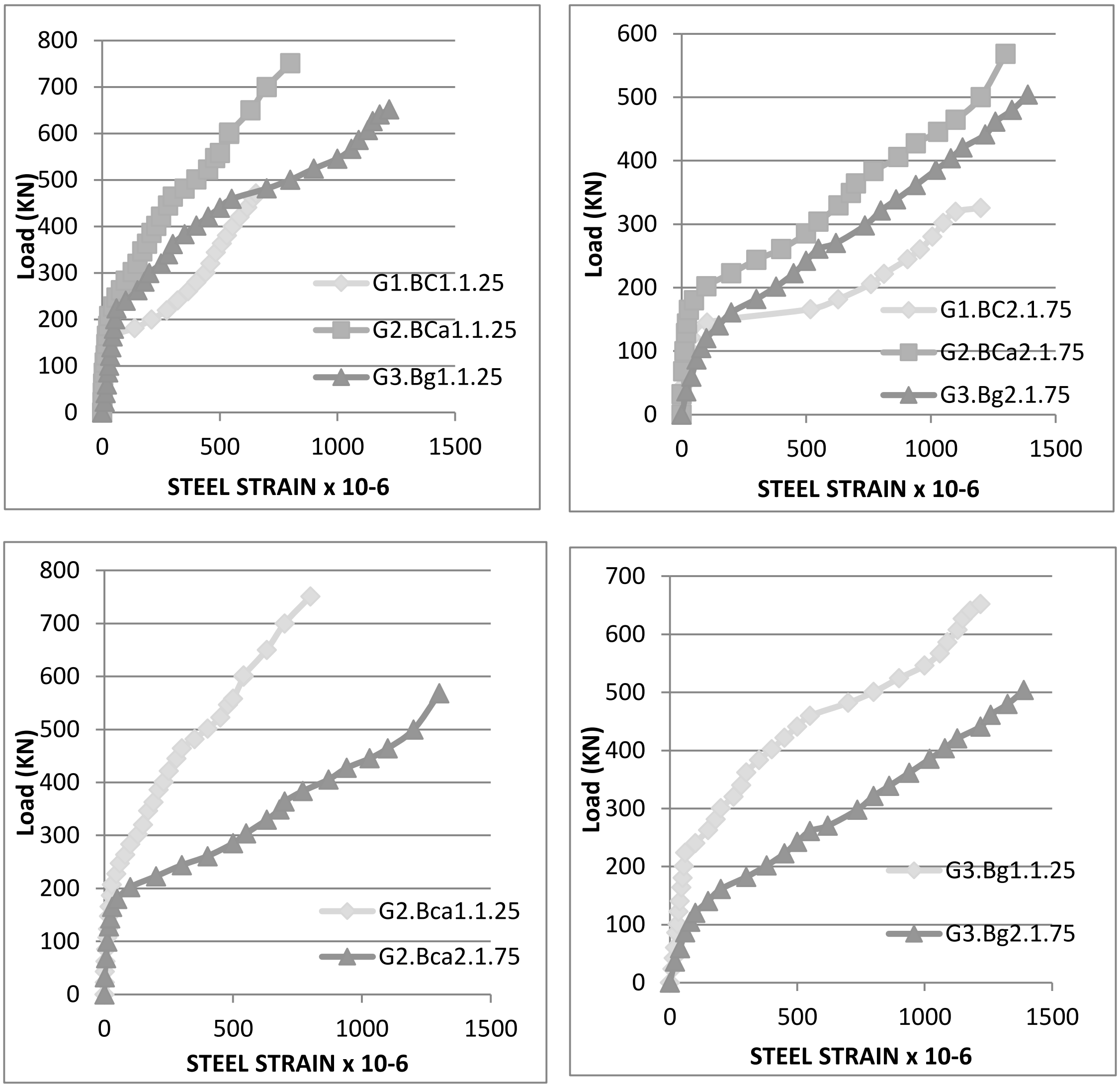


Fig. 11 Load Steel strain relationships in longitudinal bars stirrups for tested beams

4. Conclusions

The experimental investigations which were carried out in this study led to the following conclusions:

1) In general higher ultimate loads were achieved for beams strengthened with CFRP sheets as compared with un strengthened (control beam) and beam strengthened with GFRP.
2) For Deep (a/d=1.25 and 1.75) beams failed in shear, which strengthened with CFRP sheets compared with control beam the average increase in ultimate load was 59.4 to74.6% respectively .
3) For Deep (a/d=1.25 and 1.75) beams failed in shear, which strengthened with GFRP sheets compared with control beam the average increase in ultimate load was 38.4 to54.8% respectively.

4) The decreased in deflection for beams attributed to the type of FRP sheet and the less deflection show in carbon type.
5) The number of flexural and shear cracks in all beams was more than the similar beams strengthened , repair with FRP sheets.
6) In all tested deep beams the failure mode of strengthened deep beams is a diagonal shear crack caused of all FRP sheets located in the shear zone .
7) The shear span-to-depth ratio (a/d) is an important factor that actively controls the shear failure mode of deep beam and consequently effect on the improve shear strength and The test results also indicated that the ultimate shear strength of the tested beams considerably increased with the decrease of the shear span to depth ratio.
8) The ductility of deep beams that strengthening with FRP sheets is significantly reduced.

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