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IMPROVED PERFORMANCE OF CONFINEMENT OF RC BEAM WITH GLASS FIBRE REINFORCED POLYMER LAMINATES

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Abstract

In the last two decades, the use of advanced composite materials such as Fiber Reinforced Polymers (FRP) in strengthening reinforced concrete (RC) structural elements has been increasing. Research and design guidelines concluded that externally bonded FRP could increase the capacity of RC elements efficiently. However, the linear stress–strain characteristics of FRP up to failure and lack of yield plateau have a negative impact on the overall ductility of the strengthened RC elements. Use of FRP laminates, which consist of either carbon, glass fibers, and aramid fibers, changes the behaviour of the material to a non-linear behaviour. This paper aims to study the performance of reinforced concrete beams strengthened by GFRP laminates. This paper presents an experimental program conducted to study the behaviour of RC beams strengthened with glass fiber reinforced polymer (GFRP) laminates. The program consists of a total of twelve T-beams with overall dimensions equal to 150 mm x250mmx3000mm. The beams were tested under cyclic loading up to failure to examine its flexural behaviour. Different reinforcement ratios, fiber directions, locations and Glass fiber reinforced polymer (GFRP) laminates were attached to the beams to determine the best strengthening scheme. Different percentages of steel reinforcement were also used. An analytical model based on the stress–strain characteristics of concrete, steel and FRP was adopted. Recommendations and design guidelines of RC beams strengthened by GFRP laminates are introduced. The experimental test results showed that strengthening with GFRP significantly enhanced the flexural responses of the specimens compared with the control specimen. The first cracking and ultimate loads, energy absorption capacities, ductility and stiffness were remarkably enhanced. It was also confirmed that the bond length of the strengthened reinforcement greatly influences the energy absorption capacities, ductility and stiffness. The effect of the bond length on these properties is more significant compared to the amount of strengthening reinforcement.

Keywords: Glass fiber reinforced polymer, Fiber directions, RC beams, Cyclic loading, FRP laminates, stress–strain characteristics.

1.INTRODUCTION

The use of externally bonded Fiber Reinforced Polymer (FRP) systems has been proven to be an effective technique to rehabilitate and strengthen deficient and deteriorated structural members [1-5]. The FRP materials are known to have high stiffness, high strength to weight ratio, resistance to corrosion and ease of installation. In this external strengthening technique, the FRP materials are attached to the tension side of RC beams or girders to carry the tensile stresses by means of the epoxy adhesive [6-8]. In general, the FRP plates are bonded to the soffit of the beams and the sheets are attached at anchorage zones to provide a locking mechanism that would increase the load carrying capacity of the structural member. It should be noted that the externally bonded systems were produced in the early 1940s [9] in which steel plates were bonded to bridge girders to carry extra tensile forces introduced by the increasing number of users and vehicles. However, the introduction of FRP materials showed better performance than the conventional methods due to the several mechanical advantages of the FRP materials. Many experimental programs and numerical studies investigated different strengthening techniques in which multiple arrangements of FRP plates and sheets were used [10-19].

Hadi et al (2014) researched the systemic behaviour of hollow-core square-reinforced material support enclosed with CFRP by diverse fibre orientations. Twelve specimens (200 mm x 200 mm in cross-section, 800 mm in height as well as had a four-sided form hole of side 80 mm) had separated into four divisions with three specimens in each one. The specimens in the first orientation collection had enclosed, whereas those in the lasting group have to enclose with CFRP of dissimilar wrap combinations of three fibre orientations (0, 45, and

90 with respect to the circumferential direction). The specimens in every set had experienced beneath the three eccentricities via 0 mm, 25 mm, and 50 mm able to collapse. Investigation reactions had shown that all the enclosing presentations were enlarged both the ductility and strength of the hollow core square-reinforced material support. Though, the raise in compacting power was insignificant. The support enclosed absolutely with hoop presentation as shown to be having the maximum ductility.

Kinjal V. Ranolia et al (2013) considered the consequence of diverse cracking and patterns in FRP enclosing on the compacting power of restricted material. Cylinders of 300 mm height and 150 mm diameter had radiated with M20 and M40grade material and experienced in a released and restricted situation with a dissimilar specimen of FRP wraps that is a one-layer full wrap and two-layer full wrap. Also, edge-crack and center-crack had launched in FRP wrap to recognize crack transmission and consequent defeat of power in the material FRP compound method. Analytical research had accomplished by ANSYS 10 software showed superior concord with investigational clarification. The failure of the pattern had taken place in the centre part constituency of the pattern while complete incarceration had provided, and it had taken place at the crown and base part in case of partially-confined patterns. Cracks in the FRP cover had affected the compacting power of the material. Crack position and crack extent influenced the compacting power of material in dissimilar ways. The loss in compacting power had supplementary in pattern with centre-crack rather than in pattern with edge-crack.

Thong Pham et al (2013) had carried out an analysis into the reinforcement of square-reinforced material support by FRP confinement and circularisation. A method had called circularization was engaged; where the segmental circular material lid had made of various material power (40 MPa, 80 MPa, and 100 MPa) had worn to change cube support into spherical support. The materiality of the circularisation technique had practically considered for a broad variety of material power (from 40 MPa to 100 MPa). The performance of the reinforcement pattern beneath various process circumstances as well as a parallel process, peculiar process (25 mm and 50 mm), and twist flexible had examined. The results revealed that by high-strength concrete (HSC) for the extra lids in sequence to reinforcement the active square-reinforced concrete (RC) support had provided higher load-carrying ability than by covers made of regular strength material. The HSC enclosed and the real cores had functioned as a compound substance besides collapse. The FRP damage at high load had experiential for the principle of evaluating the patterns ‘ability. The allocation of FRP damage to the boundary of the support part had too described by Francesco.

Micelli & Rossella Modarelli (2013) had accomplished investigational and systematic research to recognize the possessions had distressed the behaviour of FRP-confined solid. 128 patterns were equipped and experienced, 89 had reinforcement with Carbon FRP (CFRP), and Glass FRP (GFRP), and the enduring experienced as simple material orientation. Compacting pressure and hoop strains and axial had calculated to assess the stress-strain interaction, stiffness, ultimate strength, and ductility of the patterns. Results established that, in assessment with basic material, exterior captivity had created by FRP could considerably improve ductility, compacting strength, and energy incorporation ability. The property of analysis parameters had witnessed and balanced in the sequence had to show the sharpness of the automatic crisis for all. Essential propose in the sequence was enhanced to analysts and practitioners through balancing the results of the investigational study with the calculation of dissimilar logical model, derived from recognized and generally established motorized assumption. Design equations optional by CNR (Italian National Research Council) had functional by presumptuous unitary standards for protection factors and to observe the consistency of the motorized representation planned by CNR.

Strengthening of RC beams with GFRP laminates is introduced in this paper to increase both of their capacity and ductility. GFRP laminates have a non-linear stress–stain behaviour [1]. An experimental program was conducted to study the behaviour of RC beams strengthened with GFRP laminates. The program consists of a total of twelve T-beams with overall height of 250 mm and length of 3000 mm. The beams were tested in a four-point loading configuration under cyclic loading to evaluate their ductility and energy dissipation. Reinforcement ratio and location of FRP as well as fiber direction were also varied. Different steel reinforcement ratios were used in the study. An analytical model based on the stress–strain characteristics of concrete, steel and FRP was adopted. Different recommendations and design guidelines of RC beams strengthened by FRP and HFRP laminates were introduced.

2. Experimental work

The experimental program consists of testing twelve RC T-beams with overall depth and length of 250 mm and 3000 mm, respectively. The top flange was 150 mm wide and 60 mm thick, as shown in Fig. 1. The beams were simply supported with a clear span of 2750 mm. The 12-mm laminates were used as tension reinforcement with both ends bent (90°) to fulfill the anchorage criteria. The 10-mm laminates were used as hanger laminates up to the shear span zone, and 6-mm laminates were used for stirrups.

3. Experimental Set-Up

All of the RC beam specimens (control and strengthened) were tested under four-point bending until failure using an Instron Universal Testing Machine, as shown in Figure 4. One vertical linear variable differential transducer (LVDT) was placed at the mid-span of the beam to measure the deflection and ensure that the transducer touched the bottom face of the specimen. The compressive strains of the top surface of the concrete specimens were measured using a 30-mm strain gauge that was affixed at mid-span of the beam specimen. A 30-mm strain gauge was fixed at the center of the strengthening bar using Araldite epoxy adhesive to measure the tensile strain of the strengthening reinforcement. All of the tests were carried out under displacement control with the rate of the actuator set at 1.5 mm/min. All of the data were recorded at 10-s intervals using a TDS-530 data logger. The crack width of beam specimens was measured by a Dino-Lite digital microscope. The experimental setup is shown in fig 1.

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Figure 1. Experimental Setup

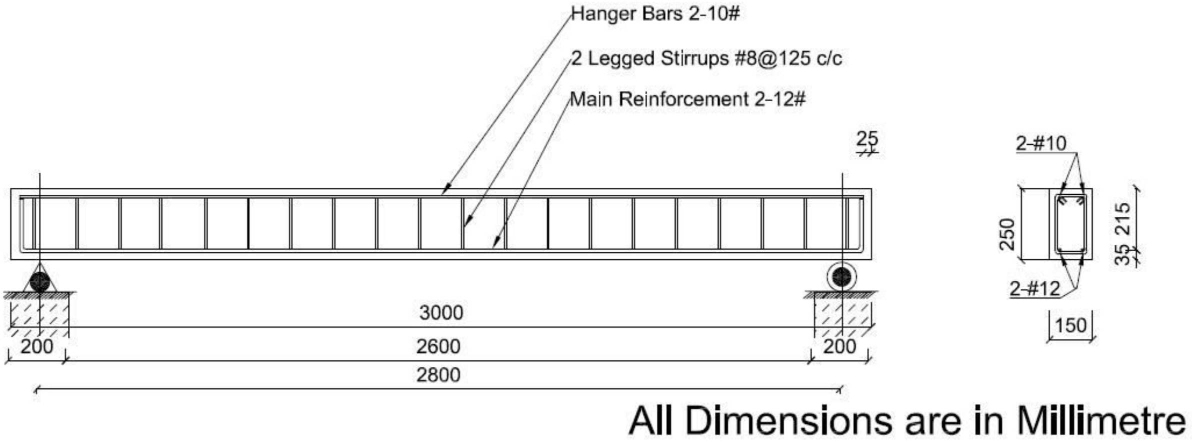

Figure 2 Reinforcement Details

TABLE 1 GFRP PROPERTIES

Sl no	GFRP Properties	Size 3mm	Size 5mm
1	Tensile properties	446.9 MPa	451.5 MPa
2	Elastic Modulus	13.965 GPa	17.365 GPa
3	Ultimate elongation	3.02%	2.60%
4	Composite ratio	1.989	3.316

4. Test Results and Discussion

4.1. First Cracking and Ultimate Load Capacities

The first cracking and ultimate load carrying capacities of the beam specimens are shown in Figure 1. The RC specimens strengthened with GFRP laminates reported a significant increase of their stiffness at the Normal stirrups and circular stirrups (Figure 2 a and b). The first crack load is very important, as the stiffness of the beam decreases after the formation of the first crack [29]. The beams with GFRP laminates improved the first cracking load to up to 4.38-times compared with the control beam. The first crack load of the normal 200mm spacing of stirrups without GFRP,3mm GFRP &5mm GFRP increases by 0%, 55% & 67% and in 100mmspacing of cellular stirrups shows 0%,50% and 61% respectively. The beams strengthened with GFRP laminates resulted in an efficient increase of the ultimate load carrying capacity, as shown in Figure 3 (a and b). The test results of all beams are given in Table 2. The test results shows that the load carrying capacity increased with the spacing of stirrups. The ultimate load of 100mm spacing of cellular stirrups shows an increase of 0%,46% &55%. The reinforced concrete beams with 100CS5 shows an increase of 100% in yield load.

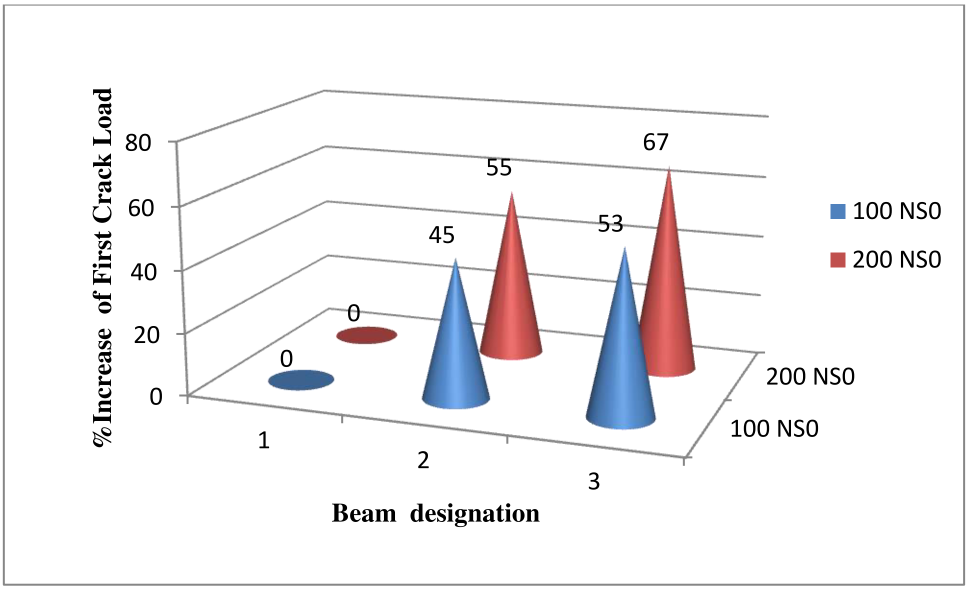

Figure 2 (a) % variation of first load crack for Normal stirrups

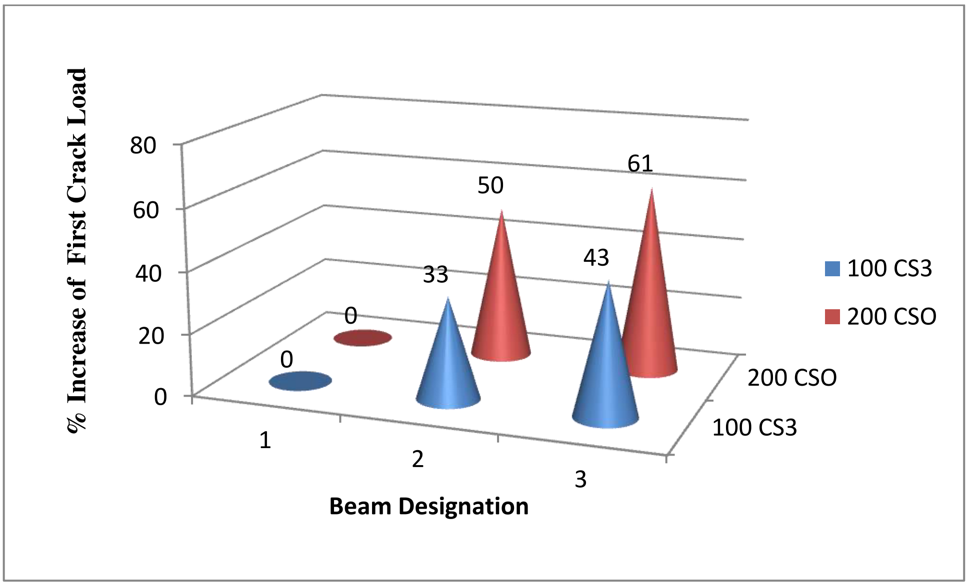

Figure 2 (b) % variation of first crack load for cellular stirrups

TABLE 2 TEST RESULTS OF BEAMS

Sl.No.	Beam Designation	FCL (kN)	YL (kN)	UL (kN)	Width of Crack (mm)	No. of Cracks
1	200 NS 0	10	25	50	0.4	8
2	200 CS 0	12.5	27.5	57.5	0.44	11
3	100 NS 0	15	30	60	0.5	13
4	100 CS 0	20	35.5	65	0.58	16
5	200 NS 3	22.5	42.5	90	0.64	18
6	200 CS 3	25	50	100.5	0.72	21
7	100 NS 3	27.5	54.5	110	0.8	23
8	100 CS 3	30	60	120.5	0.88	25
9	200 NS 5	30	64.5	130	0.98	27
10	200 CS 5	32.5	68	135	1.2	28
11	100 NS 5	32.5	70	142.5	1.34	30
12	100 CS 5	35	72.5	145	1.52	33

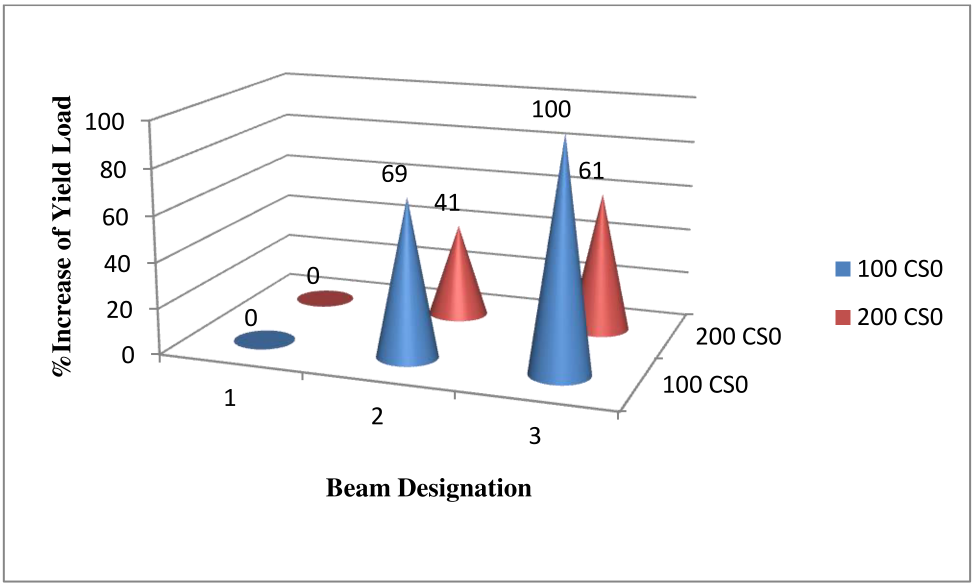

Figure 3 (a) % variation of Ultimate load for Normal stirrups

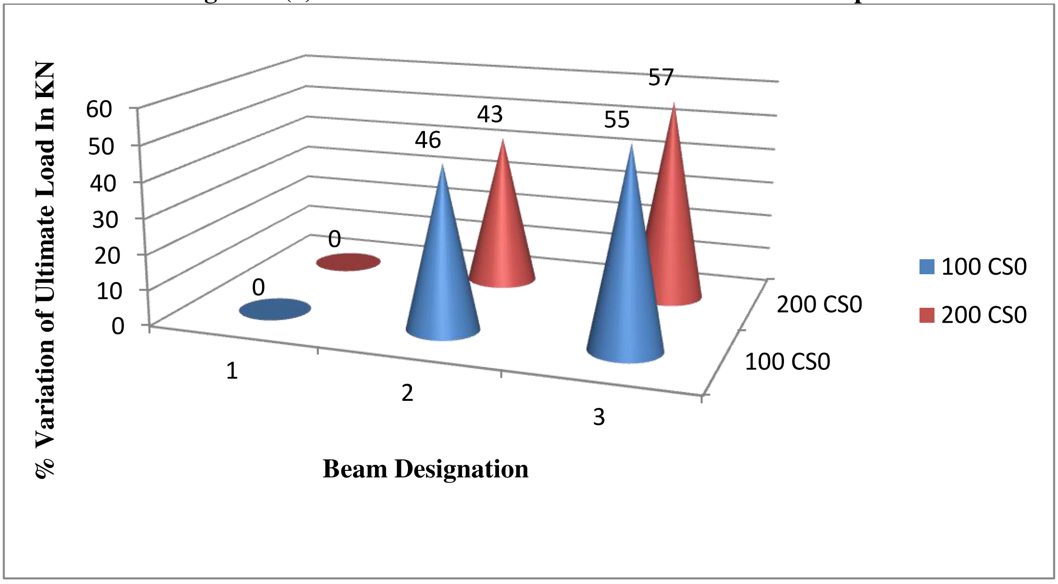

Figure 3 (b) % Variation of Ultimate load for cellular stirrups

4.2. Load-Deflection Behavior

The load versus deflection curves for RC beam specimens strengthened with GFRP laminates are shown in Figure 4. As seen in the figure, the load-deflection curves exhibit tri-linear stages, as per the usual failure mechanism, which is followed by cracking of concrete to reinforcement yielding, yielding to ultimate and ultimate to failure. The behavior of all strengthened specimens followed linear and elastic patterns in the first stage, due to the full flexural rigidity of the beam. The GFRP laminates greatly influence the load-deflection curves over the control beam in the first stage. The second stage starts from the yielding of the tension reinforcement, at this stage, GFRP laminates control the number and width of cracks, as the maximum tensile stress of concrete exceeded the flexural strength of concrete. The rate of increasing deflection was found to be higher than the previous stage, which resulted in decreased stiffness of the beam. The final stage is the ultimate load to failure of the specimen. At this stage, the load gradually reduced and rapidly increased the deflection due to the linear stress-strain characteristics of the GFRP laminates [31]. The crack width of 200 CS5 increases by 63.3% compared to 200NS by 59.18%.The no of cracks of 200NS 5 has an increased value 70.3%.

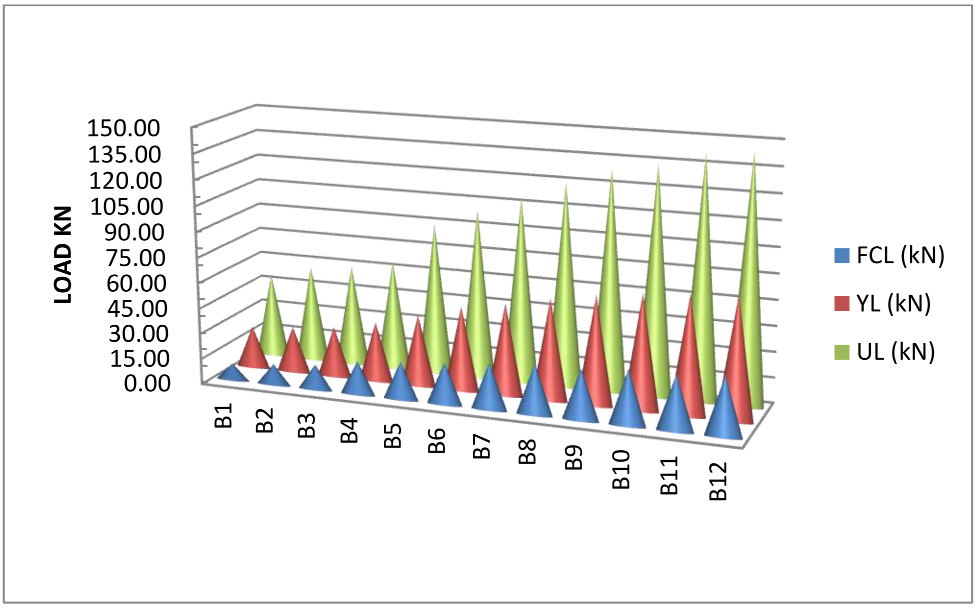

Figure 4 Load –deflection graph

4.3. Cracking Behaviors

As is known, concrete cracks when its tensile stress exceeds the limiting tensile strength of the designated concrete [34]. The crack formation and propagation in concrete depends on the tensile strength. When the principal tensile stress in the beams exceeds the concrete tensile strength, flexural cracks occur in the vertical direction [35]. The load versus crack widths of the beam specimens are shown in Figure 5. The crack width of the specimens was measured beyond their yield load, which might be close to the ultimate load carrying capacity of the specimen using a Dino-Lite digital microscope within the location of the main reinforcement at constant moment zones at various load levels. The trend of the curves of the 8-mm Ø GFRP-strengthened specimens was almost linear, while the 10-mm Ø curves are steep compared with the control specimen. The crack widths were significantly reduced by ~80% and 83% for 8-mm Ø and 84% and 88% for 10-mm Ø SNSM-GFRP laminates at 40 kN and 60 kN, respectively. Thus, all of the GFRP-strengthened specimens reported reduced crack widths at all load levels compared with the control specimen, which is attributed to the increased stiffness of the beams due to the GFRP laminates. The total number of cracks and the average crack spacing for beams are listed in Table 2. Thus, as expected, the strengthening by GFRP has a significant effect, as it increased the number of cracks and subsequently reduced the average crack spacing of the specimens. The yield load of the normal 100 spacing of stirrups shows a decrease in 0%,41% &61% compared to the 100mm cellular stirrups of 0%,69% &100%.

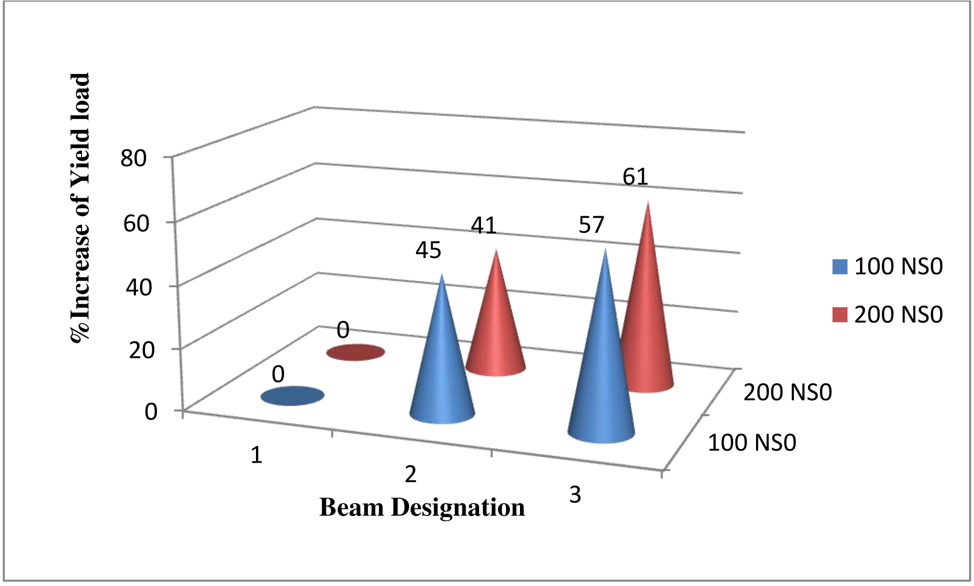

Figure 5 (a) % variation of Yield Load for Normal stirrups

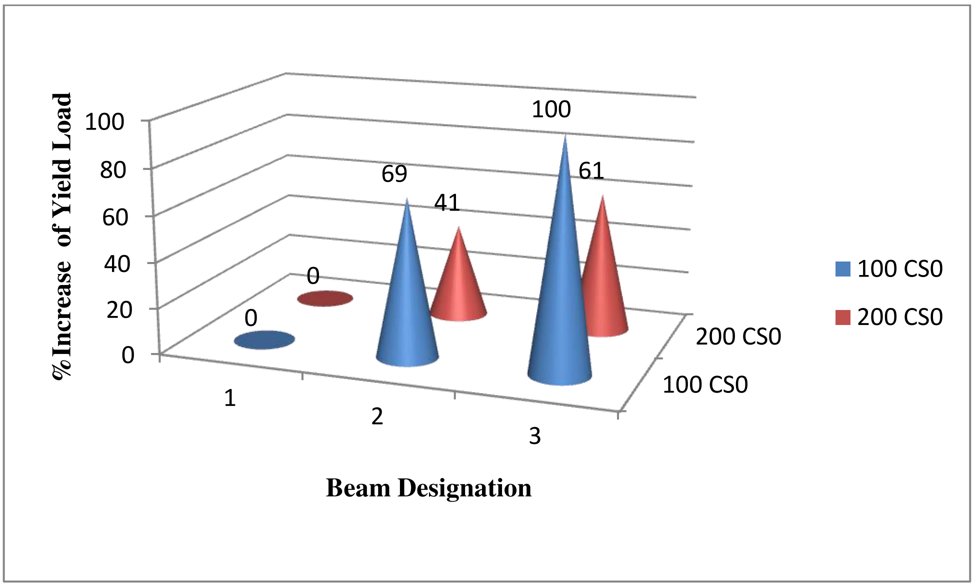

Figure 5 (b) % variation of Yield Load for cellular stirrups

4.4. Failure Modes

The failure modes of the control and all GFRP-strengthened beam specimens are shown in Figure 6. The specimens reported a very similar failure mode, i.e., flexural failure, yielding of tensile steel, followed by crushing of the concrete in the compression zone. First, a fine flexural crack was developed at mid-span and gradually propagated towards the neutral axis of the specimen. Further flexural cracks were developed and continued to widen as the load increased; however, the presence of -GFRP laminates controlled the crack width up till failure of the strengthened specimens compared with the control specimen. The leading flexural cracks began and propagated along the depth of the specimen section at the maximum bending moment region. Once those cracks were extended to nearly the full depth of the section, then the specimen fails. Few shear cracks were initiated between the spreader loading point and support of the specimen; however, final failure of the specimen was not affected by those shear cracks. The final failure of the strengthened specimens was flexure and crushing of concrete at top-most compression zone of the section. It is the most momentous mode of failure in GFRP-strengthened specimens in contrast to the specimens strengthened using CFRP with different bond lengths, which had concrete covering the separation failure modes [19]. The NSM-FRP-strengthened RC beams failed by debonding of the FRP reinforcement and epoxy adhesive [16]. Most of the NSM strengthened beams with small embedment length of CFRP strips failed via debonding [36]. Hence, the bond performance of GFRP laminates exceeds that of CFRP laminates to concrete.

4.5. Energy Absorption Capacity

The energy absorption capacity is an essential structural property of RC elements, while existing structures are repaired, strengthened or upgraded with strengthening materials or techniques [37]. The energy absorption capacity is defined as the energy absorbed by the unit cross-sectional area of the specimens computed at any displacement terminal point [38,39]. The energy absorption capacity was determined using the area of the load versus deflection curve (at mid-span) up to the failure of the specimens. The ultimate load and energy absorption capacities of the specimens are demonstrated. The use of GFRP 8-mm Ø and 10-mm Ø laminates shows an improvement in the energy absorption capacity of up to 38% and 48%, respectively, compared with the control specimen. Increasing the amount and bond length of the strengthening reinforcement of GFRP progressively enhanced the ultimate load and energy absorption capacities. The GFRP laminates carry the loads up to the failure of the beams. The energy absorption capacity was reduced by ~49%, while the NSM technique was used to strengthen RC beams using FRP laminates [21].

4.6. Ductility

The ductility of an RC beam can be defined as its capability to endure inelastic deformation without reduction of load carrying capacity before failure [39]. The significant aspect of ductility of any structures is a precaution in advance of failure. Ductile RC structures provides ample warning before failure, whereas for brittle structures, it provides little or no warning prior to failure [35]. The deflection ductility index is attained [36] from load-deflection diagram of the specimens using the following equations.

$$\mu_{\Delta u} = \frac{\Delta_u}{\Delta_y} \qquad (1)$$

$$\mu_{\Delta f} = \frac{\Delta_f}{\Delta_y} \qquad (2)$$

Where $\mu_{\Delta u}$ and $\mu_{\Delta f}$ the deflection ductility index at maximum load and at failure load, respectively, and Δ_u, Δ_f, and Δ_y, are the deflection at the maximum load, failure load and yield load respectively.

TABLE 3 DUCTILITY DETAILS OF TESTED BEAM

Sl.No.	**Beam Designation**	**Def. @ FCL (mm)**	**Def. @ YL (mm)**	**Def. @ UL (mm)**	**DEFLECTION DUCTILITY**	**ENERGY DUCTILITY**
1	200 NS 0	0.95	2.6	9.24	3.55	6.746
2	200 CS 0	1.05	2.85	10.82	3.769	9.13
3	100 NS 0	1.12	3.2	12.1	3.78	6.37
4	100 CS 0	1.16	3.65	14.54	3.96	7.885
5	200 NS 3	1.28	3.98	16.6	4.17	8.61
6	200 CS 3	1.34	4.18	18.76	4.48	8.59
7	100 NS 3	1.48	4.33	20.34	4.69	9.89
8	100 CS 3	1.64	4.62	22.5	4.87	9.98
9	200 NS 5	1.86	5.16	24.8	4.806	10.4
10	200 CS 5	2.1	5.82	26.2	4.502	10.05
11	100 NS 5	2.46	6.28	28.1	4.47	10.32
12	100 CS 5	3.1	6.85	30.4	4.43	10.48

5. CONCLUSIONS

Strengthening or upgrading becomes necessary when the structural elements cease to provide satisfactory strength and serviceability. Fiber Reinforced Polymer (FRP) composites can be effectively used as an external reinforcement for upgrading such structurally deficient reinforced concrete structures. The most common types of FRP are aramid, glass, and carbon; AFRP, GFRP, and CFRP respectively. Based on testing 12 beams and the experimental study, the following conclusions can be drawn:

1.The beams strengthened with external GFRP laminates with 200NS5 has a maximum value upto 67% in the first crack load .

2.The beams with external GFRP laminates with 100CS5 has a maximum increase of 100% in the yield load.

3.The beams with external GFRP laminates with 200NS 5 has a maximum value upto 62% in the ultimate load.

4.The crack width of 200CS 5 shows a maximum value upto 63.3% .

5.The no of cracks of the beams with external GFRP laminates of 200NS5 has a maximum value up to 70.3%

6.The beams with external GFRP laminates of 200NS5 ha an increased value upto 87.67%in energy absorption.

7.All beams with GFRP laminates exhibit flexure failure.

8.None of the beams exhibited premature failure of the laminates.

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