Bending Behavior of Concrete Beams with Hybrid Steel and GFRP Bars

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**Abstract.** In order to study flexural behavior of concrete beams reinforced with hybrid steel and glass fiber-reinforced polymer (GFRP) bars, nine types of beams was prepared and tested. The effect due to the inclusion of the GFRP and the ratio of reinforcement used in affecting the flexural performance of hybrid steel-GFRP beams were assessed using experimental testing and numerical simulation. The failure pattern of all hybrid beams was having the steel reinforcement yielding, followed by the concrete crushing and the GFRP bars retained their integrity. The test findings revealed that under concomitant of total area of reinforcement, the beams within a similar measure with GFRP bars near to the tensile surface, and steel bars settled deeper. The flexural performance of hybrid beams intensified when both types of reinforcement were placed at the same level thus resulting in closely the same performance as that of the conventional reinforced steel beams.

**Keywords:** Bending Performance**,** Hybrid Steel and GFRP, Reinforced Concrete Beams, Four-Point Bending,Stress, Failure modes

# INTRODUCTION

And now since the reinforced concrete (RC) structures has been introduced in the construction industry, they are popularly used all over the world in all buildings and structures of any type [1, 2, 3, 4]. Nevertheless, in terms of engineering utilize, steel reinforcement is susceptible to corrosion under specific environment and corrosion of steel bar can be the main factor to failures of the structures [5, 6, 7]. Due to that reason service life and performance of reinforced concrete structures decreases and maintenance cost increases and also the main thing is decreasing steel reserves. Therefore, steel bar is needed to replace with alternative materials in concrete structures [8, 9, 10]. The FRP bar possesses certain benefits not present in steels like corrosion resistance, light weight, high strength, dielectric properties and non-magnetic [11, 12]. Although those benefits apply, low modulus of elasticity, brittle and a lack of yielding behavior of FRP reinforcement can form large cracks and deflections in concrete structures and restrict the use of FRP reinforcement in construction. With combined use of FRP and steel bars which is also referred to a hybrid reinforcement in respect of reinforcing concrete beam, aforementioned disadvantages may be overcome and as well improve life span due to corrosion resistance of FRP bars [13, 14, 15, 16].

The main advantages of the greater elasticity of steel reinforcement and corrosion resistance of high strength tensile strength and corrosion resistance belonging to FRP reinforcement are effectively utilized by hybrid steel-FRP reinforced concrete beams. Hybrid steel-FRP RC beams have different performance in comparison with that of the FRP RC beam and steel RC beam. In recent years a significant number of researchers conducted experiments on hybrid FRP-steel reinforced concrete beams. N.D. Phan et al. [1] stated that GFRP reinforcement retains steel bar yielding and the relationship between GFRP reinforcement ratio and the yielding load of steel is linear. Thus, load bearing capacity of hybrid RC beams can be influenced by the increase of reinforcement ratio of GFRP. Other than that author has identified six modes of failure of the hybrid RC beams. B. Wei et al. [2] indicate that failures mode of hybrid RC beams occurs when concrete crushes in compression region following the yielding of the steel reinforcing and FRP reinforcement unable to rupture. The authors prepared total 12 beams: 10 hybrids RC beams and 1 steel RC beam and 1 GFRP RC beam. Z. Sun et al. [3] carried out tests on a total of 5 types of hybrid RC beams but 2 were ordinary hybrid RC beams and 3 were bundled. As amount of bundled reinforcement raised, number of cracks decreased and width of crack also expanded a bit but when steel reinforcement yielded, crack width rises very quickly. According to Yoon et al. [4], use of steel and FRP reinforcement on hybrid RC beams enhanced stiffness characteristics and ductility properties of beams. Further, experimental cracking moments of hybrid RC beam were less than theoretical cracking moments. M. A. Aiello et al, [5] demonstrated that when steel reinforcement and AFRP bars are implemented on RC concrete beam, stiffness and deflection behaviour of the beam is enhanced besides failure under flexural position can also improve. A. El Refai et al, [6] indicated that as the effective reinforcement is increased, load bearing capacity of the hybrid RC beams can also improve. W. Ge et al. [7] controlled and tested beams of steel RC, BFRP RC, hybrid RC and he noted that the performance of hybrid RC beams are similar (more likely) to the same of steel RC beams compared to performance of BFRP beams.

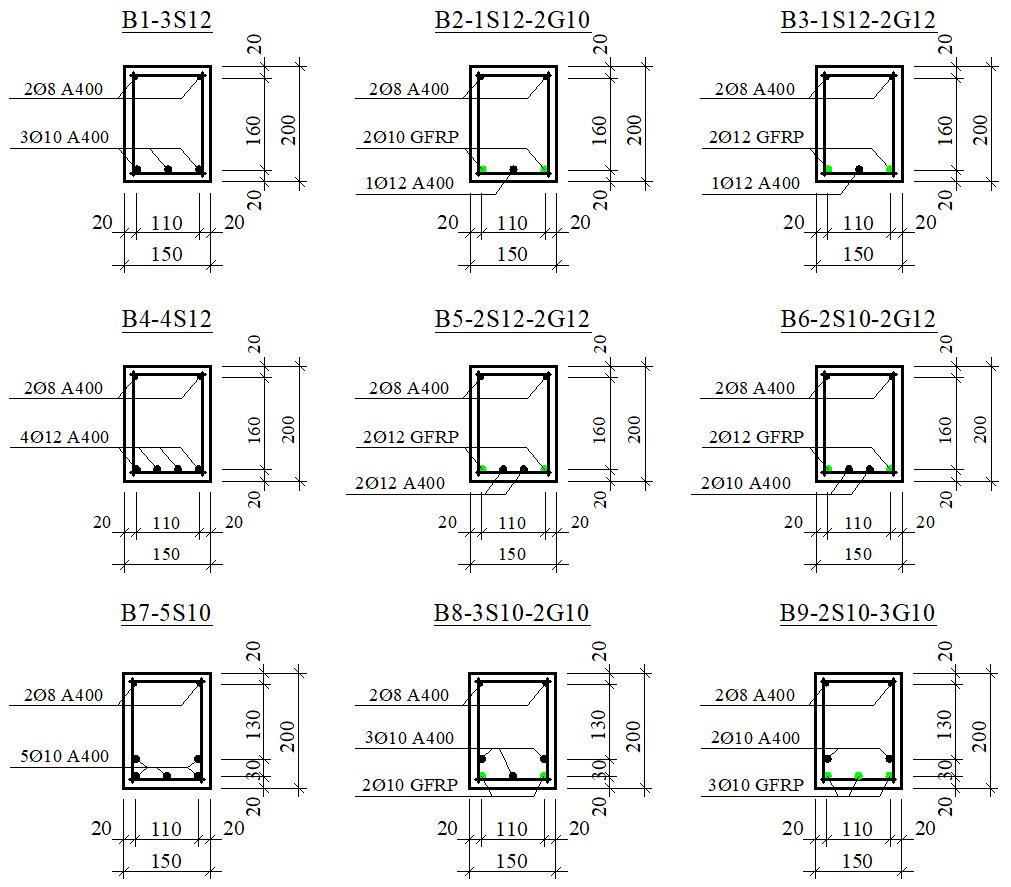
Although in majority of the countries there are own design codes or guidelines of structures reinforced with FRP reinforcement like Uzbek code ShNK 2.03.14-18, Chinese code GB 50608-2010, American guidelines ACI 440.1R-06, ACI 440.1R-15 etc., Russian code SP 295.1325800.2017, Italian guide CNR. Canadian standard CSA, CNR DT 203/2006. CSA S806–02.

# METHODS

Combined steel and GFRP reinforced concrete beams has several features of behavior that vary with those of steel reinforced concrete beams, which relies on the physical or mechanical properties of GFRP reinforced. Experimental and theoretical results, deformation and strength parameters, crack formation and type of failure, etc.) were obtained by carrying out a study on beams of combined steel-GFRP reinforced concrete. ANSYS Workbench software was used for the simulation.

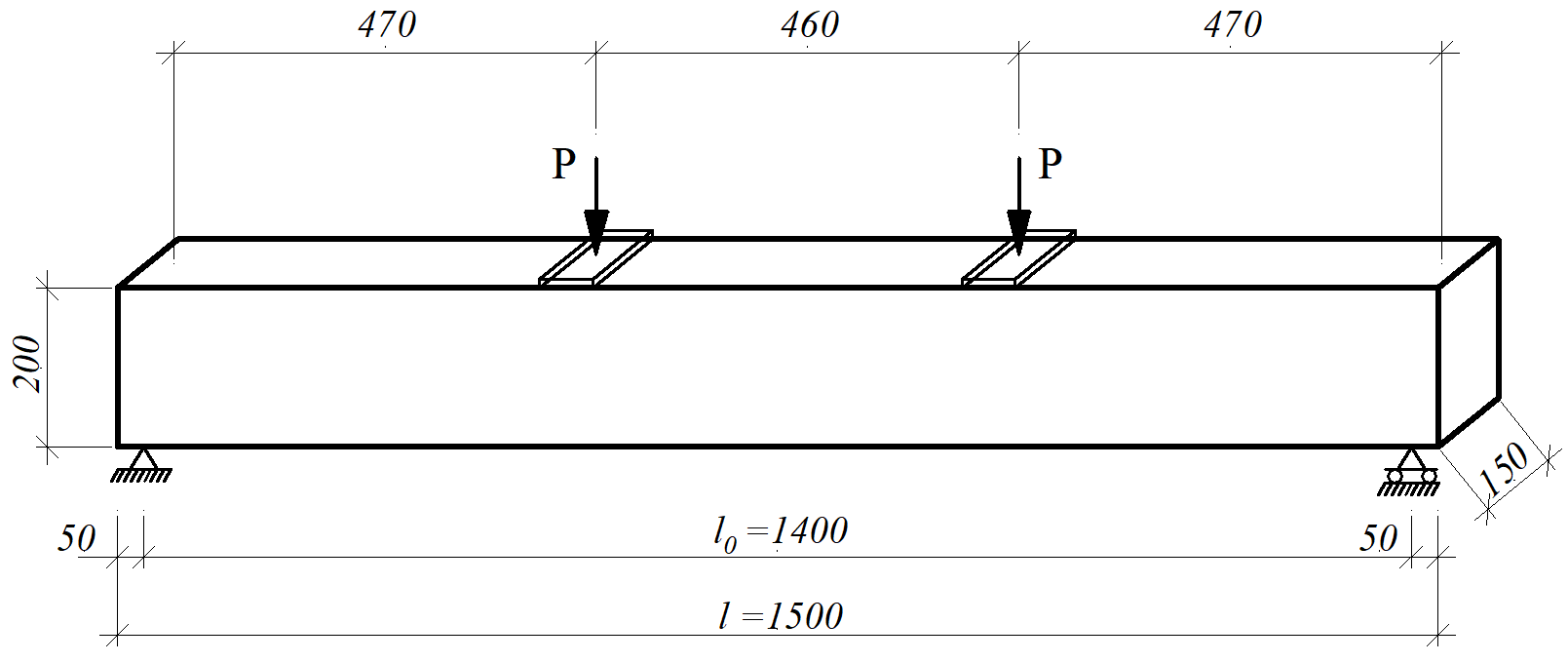
In order to test nine concrete beams, they were prepared in 3 groups. Each series has three samples. Group 1 has samples consisting of three reinforcements placed in tensile zone (B1-3S12, B2-1S12-2G10 and B3-1S12-2G12). In the 2nd group four reinforcements are assumed in one layer (B4-4S12 B5-2S12-2G12 B6-2S10-2G12). Five reinforcements are found on the tension area of group 3 and three are closer to the surface and two more are deeper in concrete. The B1-3S12, B4-4S12 and B7-5S10 specimens are made of steel only reinforcing steel rebar, i.e. are so-called control beams. In the remaining the beams a pairing of steel and GFRP bars were used (**fig. 1**).

The cross-section of the samples are *bxh=150x200 mm* and the length of *1500 mm*. Placement of rebar, concrete strength and cross section of rebar area are presented in **fig. 1**. Concrete cover thickness of longitudinal reinforcements is *a=20 mm*. The samples were tested in accordance with the requirement GOST 8829–94.



**FIGURE 1.** Dimensions and loading scheme of the beam

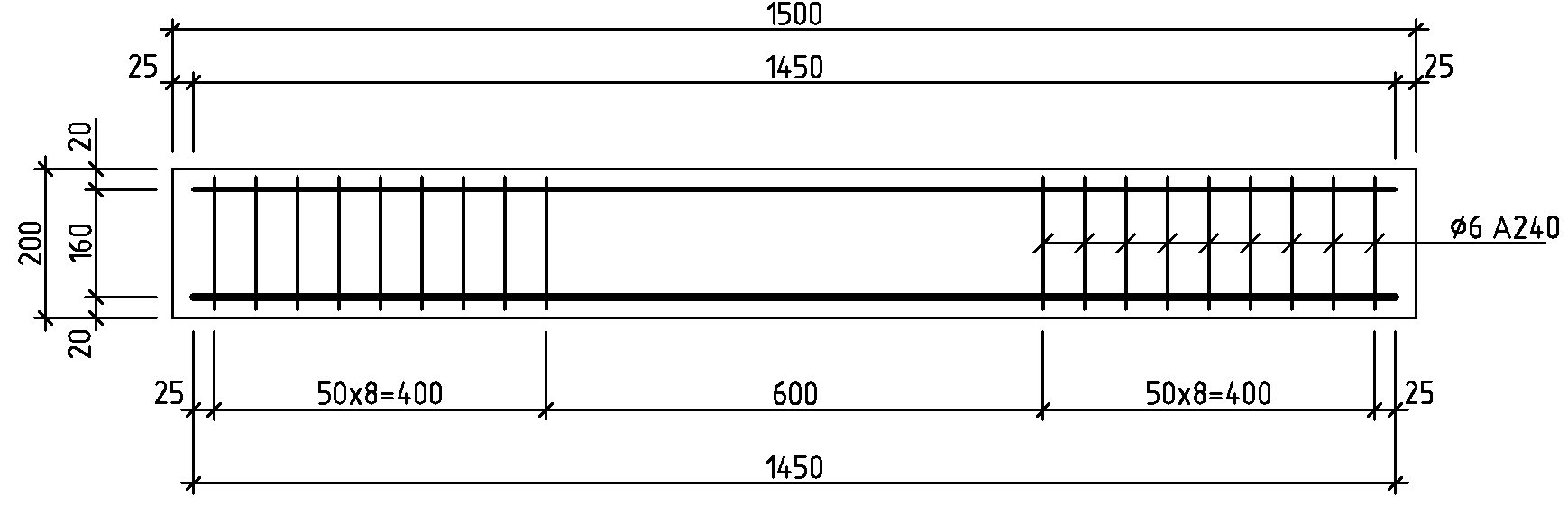
Experimental testing was conducted in the construction test laboratory of "Bunyodkor-3" LLC, located in Namangan city, and was carried out on a PSU-125 hydraulic machine with a capacity of 125 tons. Through a distributor and two supports, a hydraulic jack applied the load in two symmetrical positions separated by distance *l0/3*. The distance between the supports are *1400 mm* **(Fig. 2)**



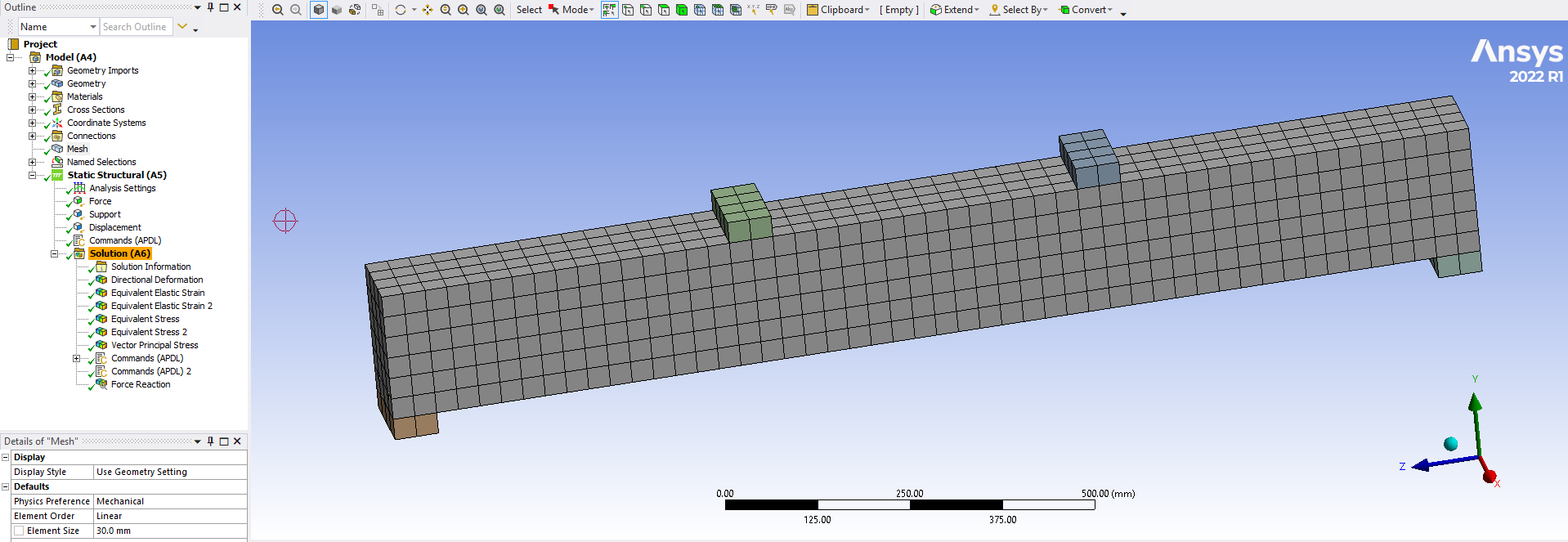
**FIGURE 2.** Dimensions and loading scheme of the beam

As stirrups for the beams, *Ø6 A240* reinforcement is applied. Stirrup space is *50 mm* in near support zone, but there were not any stirrups in center of the beam. All reinforcements are connected to each other using wires with a diameter of *0.9 mm* **(Fig. 3).**

Modeling of the beam in ANSYS Workbench, the beam was divided into finite elements with dimensions of *25 mm*. The Drucker-Prager model was used to input the mechanical properties of concrete, while Solid185 function was used for reinforcements. Nonlinear properties of all materials were taken into account **(Fig. 4).**



**FIGURE 3.** Placement of reinforcing cage in the beam



**FIGURE 4.** Numerical model of the beam in ANSYS

# RESULTS AND DISCUSSION

The number of failure modes of a combination of steel-GFRP reinforced concrete beams is 6 (according to the previous works). The chain of the failure modes is organized by the reinforcement ratio increase. The tensile strength of concrete is low and the strength of concrete where the crack was incised was not taken into consideration in this section since it was in the tensile region [1].

**Failure mode 1** (,  and ): After rupturing of GFRP reinforcement, steel bar yields and rupture, but concrete does not crush.

**Fail ure mode 2** (,  and ): Steel bar yields, then GFRP reinforcement rupture, and concrete crushes in compression zone.

**Failure mode 3** ( and  occurs simultaneously and ): Steel reinforcement yields, GFRP bar rupture, and concrete crushes at the same time (balanced reinforcement ratio).

**Failure mode 4** (,  and ): Before concrete crushes, steel bars yielding, but GFRP reinforcement does not rupture.

**Failure mode 5** ( and  occurs simultaneously and ): Steel bars yielding and concrete crushes occurs at the same time. Stress of GFRP reinforcement is less than ultimate strength (balanced reinforcement ratio).

**Failure mode 6** (,  and ): Concrete crushes in the compression zone, but steel reinforcement does not yield and remains in elastic stage, and GFRP reinforcement stress is less than ultimate value.

According to the results of numerical modeling and experimental tests, the failure modes of all combined steel-GFRP reinforced concrete beams are failure mode 4 **(Fig. 5).**

At the end of load bearing capacity of the beam, failure started from steel bars that was reached to yielding point then concrete stress in compression zone was reached compressive tensile strength, but GFRP did not rupture. The reason for that its strength is higher than A400 class steel reinforcement, and its strain is greater than the ultimate value at the yield point of steel.

**TABLE 1.** Applied load and ultimate moment capacity of the samples

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Beam ID** | **Experiment** | | **ANSYS** | |
| **Applied load P, kN** | **Ultimate moment Mu, kN‧m** | **Applied load P, kN** | **Ultimate moment Mu, kN‧m** |
| B1-3S12 | 109 | 25.43 | 111 | 25.9 |
| B2-1S12-2G10 | 114 | 26.6 | 107 | 24.97 |
| B3-1S12-2G12 | 135 | 31.5 | 113,5 | 26.48 |
| B4-4S12 | 136,5 | 31.85 | 128,1 | 29.89 |
| B5-2S12-2G12 | 125 | 29.17 | 118,6 | 27.67 |
| B6-2S10-2G12 | 121 | 30.1 | 112,4 | 26.23 |
| B7-5S10 | 116 | 27.07 | 108,7 | 25.36 |
| B8-3S10-2G10 | 116,5 | 27.18 | 106,5 | 24.85 |
| B9-2S10-3G10 | 126,5 | 29.52 | 105,7 | 24.66 |

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| B1-3S12 | B4-4S12 |
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| B2-1S12-2G10 | B5-2S12-2G12 |
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| B3-1S12-2G12 | B6-2S10-2G12 |

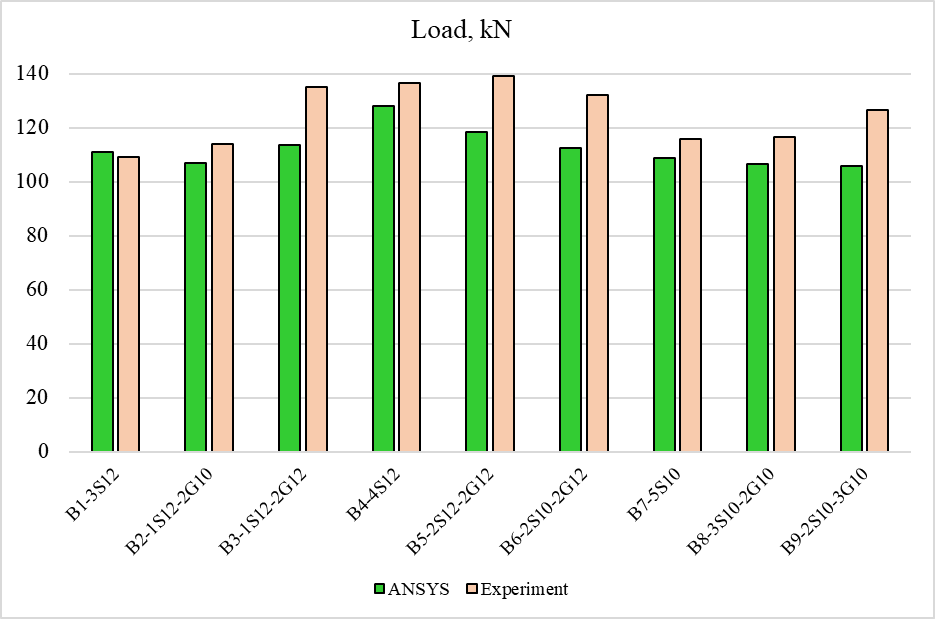
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| B7-5S10 |
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| B8-3S10-2G10 |
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| B9-2S10-3G10 |

**FIGURE 5.** Failures of concete beams in experimental test

In **fig. 6** indicated in table 1 ultimate load is given by ANSYS and experimental test. In group 1 samples, the load carrying of beams reinforced as a combination reinforcement was found to be 23.9% higher than that of the steel reinforced concrete beam B1-3S12 and combined steel-GFRP reinforced concrete beam B3-1S12-2G12, whereas in numerical difference it was found out as 2.4%. The content of the reinforcement cross-section in the tensile segment of a beam of the B2-1S12-2G10 beam is less than that of the "control beam", however, in the experiment the carrying ability is increased by 4.6 percent, whereas, in the ANSYS, it is 3.6 percent less.

In contrast to group 1, it can be seen that beams in group 2, steel reinforced concrete beams have higher bearing capacity than combined beams (**table 1** and **fig. 6**). Combined beams B5-2S12-2F12 with the same percentage of reinforcement with control beam were smaller in the experiment by 8.4% and theoretically by 7.4% compared to B4-4S12 with steel reinforcement.

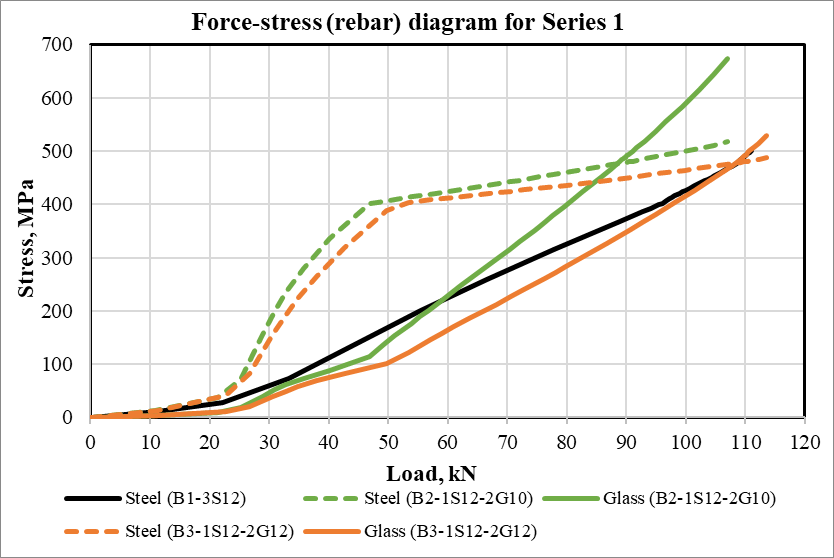
Group 3 specimens have the same percentage of reinforcement in all beams, but double layer of reinforcement are placed in the tensile zone. According to the results obtained from ANSYS, capacity of the beams is almost close to each other. In the experimental results, the load-bearing capacity of the control beam B7-5S10 and combined reinforced beam B8-3S10-2G10 is almost equal (116 kN and 116.5 kN, respectively). But the strength of the B9-2S10-3G10 sample were higher than the control beam by 9.1% (**fig. 6**).



**FIGURE 6.** Ultimate load of samples (ANSYS vs Experiment)

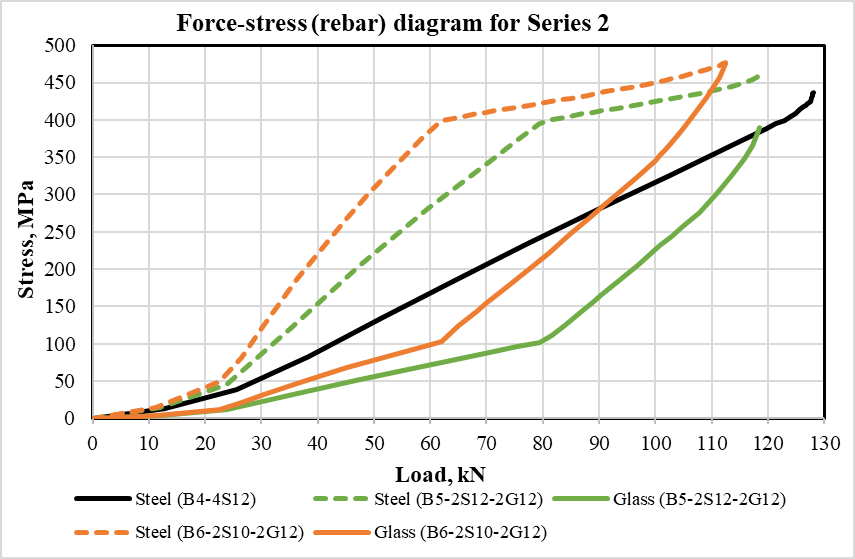
It is known that after concrete cracks in tensile zone, stresses transfer to reinforcement. Often, in reinforced concrete beams, when the steel reinforcement achieves yield strength, it deforms in the compression side and the resistance of the beam stops. In composite concrete beams however, the stress on the FRP rebar augments after the steel has attained the yield point. It is below presented that when the load is applied to the beams the stresses that are created in steel and GFRP rebar.

***Group 1 samples.*** The stresses in the tensile zone were mainly received by the concrete until the applied load was 0.2Pu, (Pu - ultimate load) then the stresses were transferred to the reinforcements. The stresses in the steel reinforcement before the failure of the specimen were equal to 500.75 MPa (Fig. 7). In samples B2-1S12-2G10 and B3-1S12-2G12, when the applied load value is 0.2Pu, the concrete resistance in the tensile zone reaches ultimate strength, and reinforcements started to receive the loads. At the load value (0.4..0.45)Pu, the stresses of the reinforcement reached the yield point (σy=400 MPa), while the stress value in the GFRP is less than 100 MPa. In the next step of loading, the stresses were mainly taken by GFRP rebar. The stresses in steel reinforcement at failure of the beam were 517.13 MPa in B2-1S12-2F10 and 488 MPa in B3-1S12-2G12, and 673.94 MPa and 528.63 MPa in GFRP, respectively (**Fig. 7**).

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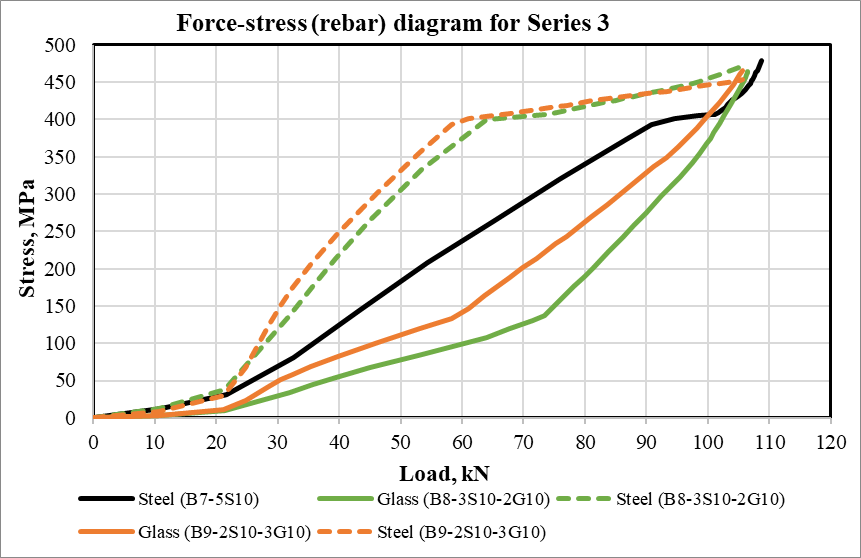
**FIGURE 7.** Load-stress relationship for rebar in Group 1

***Group 2 samples.*** The normal stresses in the steel reinforcement in B4-4S12 increased slowly up to *0.2Pu*. After that, the stresses increased linearly until the sample failure. The normal stress of steel bar at failure was 436.86 MPa. In B5-2S12-2G12, the stress was taken by the concrete in the tensile zone until *0.2Pu*, when the applied load was *0.69Pu*, the steel reinforcement reached the yield point (400 MPa), and the normal stress in FRP rebar was equal to 110.56 MPa. As a result of load increase, GFRP reinforcement normal stress increased rapidly. The normal stress in steel reinforcement at failure of the beam was 458.83 MPa, while in GFRP bar it was 390.37 MPa. When the applied load was *0.54Pu*, steel reinforcement reached the yield point in the sample of B6-2S10-2G12, stress in GFRP was 102.82 MPa. At the end of the bearing capacity of the beam, the normal stresses in the steel and GFRP reinforcement were equal to each other (475 MPa). It can be seen that there is a large reserve in the strength of GFRP rebar in Group 2 samples, that is, 51% in B5-2S12-2G12 and 41% in B6-2S10-2G12 (**Fig. 8**).



**FIGURE 8.** Load-stress relationship for rebar in Group 2

***Group 3 samples.*** In all samples, concrete in tension zone received tensile normal stresses at *0.2Pu*. At *0.87Pu* in B7-5S10, the steel reinforcement reached the yield strength. It was possible to clearly see yield point and restrengthening. The bearing capacity of the beam was ended when ultimate load was 108.7 kN, and the normal stress in the steel reinforcement was 478.64 MPa. In the B8-3S10-2G10 beam, steel reinforcement reaches the yield point at *0.6Pu*, while stress in GFRP rebar is 108.05 MPa. When the applied load was 106.5 kN, the stress increased up to 474.34 MPa in steel reinforcement and 464.79 MPa in GFRP. In the B9-2S10-3G10 beam, it reaches yield strength at *0.55Pu*, stress in steel reinforcement reached 453 MPa and 466.15 MPa in GFRP rebar before beam's failure. The effectiveness of using the strength of GFRP in the combined reinforced beams of this group of samples was 58%. As the amount of GFRP bar increases in composite beams, steel yielding occurs earlier than ordinary reinforced concrete beams (**Fig. 9**).



**FIGURE 9.** Load-normal stress relationship for rebar in Group 3

# CONCLUSIONS

In this article, normal stresses in steel and GFRP reinforcement, the capacity of reinforced concrete beams with combined steel-GFRP reinforcement, ANSYS and the results of experimental tests have been analyzed. As the results show, the following conclusions are being drawn:

* There are six failure modes of combined steel-GFRP RC beams, and all series of the beams corresponded to failure mode 4, that is, first the steel reinforcement reaches its yield strength, then concrete crushed, but GFRP rebar does not rupture.
* The strength obtained on group 1 and group 3 samples reinforced beams were greater than that of steel reinforced concrete beams whereas, group 2 samples reinforced beams had less load-carrying capacity compared to that of the control beams.
* As failure of combined reinforced concrete beams started from steel reinforcement and concrete in compression zone, there is an unused reserve of GFRP reinforcement. It was 16% and 34% in group 1, 51% and 49% in group 2, and 42% in group 3 samples.

# FUTURE SCOPE

These observations of the present study highlight the huge promise of hybrid reinforcement of steel-GFRP in concrete beams, uncovering improvements in flexural strength, ductile and durability behavior with particular reinforcement patterns. Although the studies have shown rather positive results, there are still numerous ways in which the further research may be developed and expand the knowledge base and improve the general acceptability of the hybrid reinforcement technologies in structural concrete. An attractive area future work is optimization of reinforcement ratios and position strategies. Although in this study we have tested a combination of the steel and GFRP bars placed in different depths and layers in the tensile region, a parametric study would be of value in which different ratios of reinforced materials are deployed using different spacing and bar diameters where generalized recommendations can be made depending upon the condition of the structure. More sophisticated methods of optimization can be applied to determine the optimal reinforcement pattern that would produce the maximal strength and serviceability at the lowest cost of materials; these include genetic algorithms or machine-learning models. The other field to be considered is the long term monotonic behaviour of hybrid reinforced concrete beams under environmental and sustained conditions of loading environment. Although the present study has considered short time performance with a static loading condition, it is necessary to conduct research with regard to the creep, shrinkage, thermal cycling and corrosion effect on long-term performance in an environment where such systems can truly be exposed to the real life effects. Of specific concern, the effect of steel corrosion on the long-term bonding character of GFRP bars in concrete has to be closely monitored. Structural health monitoring systems Real-time structural health monitoring systems could be embedded in hybrid-reinforced elements to obtain in-situ long-term performance data that can be used to provide invaluable information on lifecycle cost analysis and predictive maintenance planning.

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