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The Experimental Examination of the Effect of Compressive Reinforced Steel Reinforcements on the Bending Behavior of Reinforcement Reinforced Concrete Beams

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Abstract: This study attempts to experimentally examine the effect of compressive steel reinforcement usage on bending behavior of rectangular GFRP reinforced concrete beams and by constructing 12 laboratory specimens, examined fracture types, ultimate beam bending capacity, beam deflection, load of first crack, crack creating and development procedure, created tension and traction strains in the beam and the position of the neutral string at the time of loading were examined. In this research, considering the constant length and diameter of provisioned GFRP reinforcements, the effect of cross-sectional dimension increase on the bending behavior of beams with constant reinforcement cross-section is examined. In addition, the effect of using high resistance concrete instead of normal strength concrete and the effect of increasing the effective height to cross-sectional width ratio were examined on specimens bending behavior. Obtained results show that utilizing compressive steel reinforcements in GFRP reinforced concrete beams does not have a significant effect on the first crack load, but does cause an increase on the number of cracks and their development, but the produced cracks have less width. In addition, utilizing compressive steel largely reduces the elastic behavior of the beam, but increases its formability. The beam deflection curve is almost linear and signs of GFRP flow are not present. Utilizing high resistance concrete instead of normal strength concrete increases the first crack load and causes more cracks, but with less width. In addition, it is recommended that the ratio of effective height to cross-sectional width in GFRP reinforced concrete beams selected larger than 2.

Key words: Compressive reinforced steel, bending behavior, reinforced concrete

INTRODUCTION

The FRP reinforcements compared to steel reinforcements have great resistance against corrosion, are also lighter than steel, their ultimate resistance is far more than steel, in addition, they are dielectric and do not affect magnetic and radio waves. However, what has limited the usage of these reinforcements is their low elasticity module, which causes great deflection in reinforced components in contact with them. In addition, the lack of formability in components made from them and the absence of comprehensive design standards and regulations for these types of reinforcements are considered as these reinforcement's shortcomings. By eliminating or reducing these flaws, we can move towards expanding the

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application of these reinforcements, which in this path, utilizing compressive reinforcements can prove useful in alleviating these shortcomings (Faza and Ganga-Rao, 1993).

Research conducted on reinforced concrete beams with FRP reinforcement shows that considering the linear relation between tension and strain in FRP reinforcements, in reinforced concrete beams with these reinforcements, there is no present indication of yielding (Victor and Wang, 2002). In addition, width and spread of these cracks are more than their steel counterparts (Benmokrane *et al*., 1996; Vijay and Rao, 2001). The FRP reinforcement reinforced concrete beam deflections are far more than similar steel beams (about 4 times more) and the load deflection curve of these beams form and approximate a straight line (Saadatmanesh and Ehsani, 1991; Victor and Wang, 2002). In addition, utilizing high resistance concrete instead of normal strength concrete is very effective (Vijay and Rao, 2001; Yost and Gross, 2002). This sudy has recognized the utilization of compressive FRP reinforcements not economical, only for increasing FRP reinforced concrete beams bending capacity, due to the high neutral string in these beams (Vijay and Rao, 2001). ACI regulations do not recommend the utilization of FRP reinforcements as longitudinal reinforcements in columns or compressive reinforcements in bending components. However, in some cases like adjoined beams or collar assembly, placing FRP reinforcements in compressive areas is inevitable. Therefore, in these cases the amount of reinforcement insulation must be examined in order to prevent buckle. In addition, it is recommended that FRP reinforcement compressive resistance be forgone in design (American Concrete Institute, 2001).

In this study, by constructing laboratory specimens, the effect of compressive steel reinforcements are examined on the bending behavior of GFRP reinforced rectangular concrete beams. Considering the constant length and diameter of provisioned GFRP reinforcements, by changing beam dimensions, different percentages of reinforcement are examined. In similar reinforcements, the effect of utilizing high resistance concrete instead of normal strength concrete is examined and compared to reference specimens without compressive reinforcements. Meanwhile, the effective height ratio increase in respect to the cross-sectional width is examined for constant reinforcement ratio. In this research, type of fracture, ultimate beam bending capacity, beam deflection, first crack load, method of crack creation and development, tensile and compressive strain and the neutral string position whilst loading is examined and compared for the constructed specimens, in order to specify the effect of present parameter changes of the bending behavior of these beams.

MATERIALS AND METHODS

Material Specifications

This study started from 2007 until 2008 per one year. The utilized FRP reinforcements in this research are of GFRP type, which their specifications are presented in Table 1. In these reinforcements, in order to provide more adhesiveness to concrete, two methods have been employed: (1) Winding glass filaments around the reinforcement in a spiral manner, or (2) diffusing ballast accompanied by Silica glue on the reinforcement surface. Figure 1 shows the tension-strain chart of these reinforcements. It shows a positive relationship between strain and stress border.

The utilized compressive steel reinforcements have a 300 MP yielding stress. In addition, Φ 6 reinforcements used as collars, have a 400 MP yielding stress and the $\bar{\Phi}$ 8 reinforcements yielding stress is 300 MP. Employed steel reinforcement specifications are given in Table 2. The highest discord tension showed in $\bar{\Phi}$ 6 row.

Table 1: GFRP reinforcement specifications

Number	Reinforcement diameter d_f (mm)	Reinforcement cross-sectional area A_f (mm^2)	Traction elasticity module E_f (GPa)	Ultimate tensile tensile f^*_{fu} (MPa)
#4	12.7	126.7	40.81	690

Table 2: Steel reinforcement specifications

Reinforcement type	Reinforcement diameter d_s (mm)	Cross-sectional area d_s (mm)	Elasticity module E_s (GPa)	Flow tension F_y (MPa)	Discord tension f_u (MPa)
$\bar{\Phi}$ 14	14	154	200	300	500
$\bar{\Phi}$ 8	8	50.3	200	300	500
$\bar{\Phi}$ 6	6	28.3	200	400	600

Table 3: Amount of materials present in one square meter of normal strength and high resistance concrete

Type of concrete	Cement	Water	Grit/Ballast	Sand	Micro silica	Super-lubricant	Water to cement ratio
Normal strength	450	235	810	980	-	-	0.52
High strength	450	150	810	980	50	10	0.33

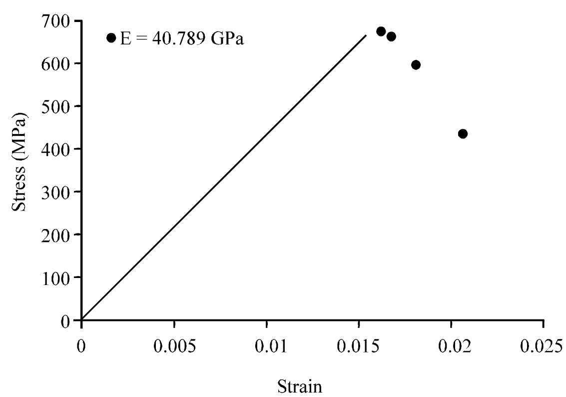

Fig. 1: Tension-strain graph

In this study, two lines of concrete, one with 40 MP nominal resistance (normal strength concrete) and the other 70 MP nominal resistance (high resistance concrete) were employed. To construct these concretes, Portland type 2 cement was used in which the largest grain diameter was 9.5 mm. Table 3 shows the amount of consumed material in order to construct one cubic meter of concrete. Water to cement ratio had decrease in high strength concrete.

Experimental Specimens

In this study, twelve beams were constructed and tested. Their length was one meter and their effective length was 90 cm. Because of the constant diameter of FRP reinforcements, in order to obtain different reinforcement percentages, beam dimensions were considered variable. Beams with the letters NCF have FRP traction reinforcements and normal strength concrete, whereas those with the letters HCF are similar to NCF beams, with this difference that instead of using normal strength concrete, high resistance concrete has been employed in their construction. Beams with NCFS and HCFS characteristics are similar to NCF and HCF beams, respectively, with the difference that compressive steel reinforcements have been employed in their construction.

Beams reinforced with FRP reinforcements are designed based on (American Concrete Institute, 2001) relations and most of them have a reinforcement ratio less than the balanced state, which are designed for yielding from the reinforcement end and only NCF4 and NCFS12 beams have a reinforcement ratio of more than the balanced state.

In constructed specimens, in order to prevent beam shear fracture, steel collars with 4 cm gaps from each other were employed. This collar placing is designed using American Concrete Institute (1999) relations. In addition, in beams without compressive steel reinforcements, in order to assemble collars, a steel wire with 2 mm diameter is positioned on the top and in place of the compressive reinforcement.

In Fig. 2, we show a schematic of the tested device and pattern of samples' breaking with testing jack. Table 4 shows the sample characteristics contains: width, height, effective height, effective length and used materials.

Constructed beams are removed from their molds after 24 h, placed and kept under damp sacks and nylon for 28 days. After this period, specimens were kept in the laboratory environment until test time. The beams were tested and loaded, 105 days after construction.

Table 4: Tested beam specifications

f'_c	Shear reinforcement reinforcement	Type of compressive type	ρ_b	ρ	Traction reinforcement	Effective height d (mm)	Height h (mm)	Width b (mm)	Effective l_e(mm) length	Beam name
41.4	Φ6 40 mm	-	0.00878	0.00487	#4	200	230	130	900	NCF1
41.4	Φ6 at 40 mm	-	0.00878	0.00745	#4	170	200	100	900	NCF2
41.4	Φ6 at 40 mm	-	0.00878	0.00741	#4	190	220	90	900	NCF3
41.4	Φ6 at 40 mm	-	0.00878	0.00990	#4	160	190	80	900	NCF4
73.9	Φ6 at 40 mm	-	0.01343	0.00741	#4	190	220	90	900	HCF7
73.9	Φ6 at 40 mm	-	0.01343	0.00990	#4	160	190	80	900	HCF8
41.4	Φ8 at 40 mm	Φ14	0.00878	0.00487	#4	200	230	130	900	NCFS9
41.4	Φ8 at 40 mm	Φ14	0.00878	0.00745	#4	170	200	100	900	NCFS10
41.4	Φ8 at 40 mm	Φ14	0.00878	0.00741	#4	190	220	90	900	NCFS11
41.4	Φ8 at 40 mm	Φ14	0.00878	0.00990	#4	160	190	80	900	NCFS12
73.9	Φ8 at 40 mm	Φ14	0.01343	0.00741	#4	190	220	90	900	HCFS13
73.9	Φ8 at 40 mm	Φ14	0.01343	0.00990	#4	160	190	80	900	HCFS14

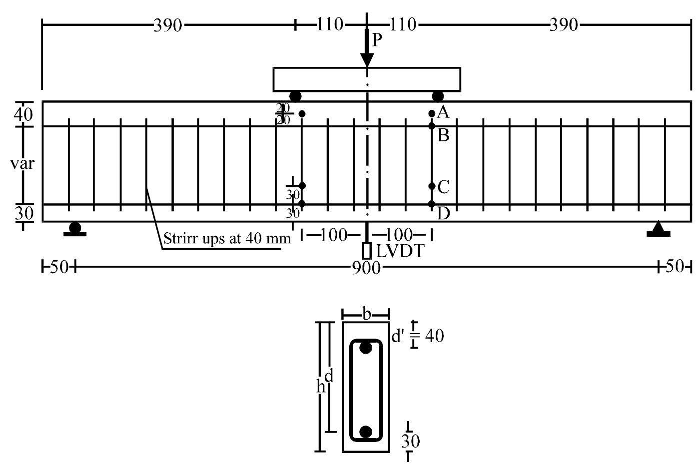

Fig. 2: Constructed specimen specifications

In addition, whilst constructing the beams, in order to determine compressive resistance of the concrete, samples were taken from the provisioned concrete, which were then tested in order to determine compressive resistance at the time of the test.

Experiment Method

As can be seen in this Fig. 2, in order to obtain pure bending in the middle section of the beam, two concentrated loads each having 110 mm distance from the center of the beam are utilized. The total load (P) is applied to a rigid steel beam through a jack which is designed to transfer the load, thereafter through this steel beam, using two steel cylinders in the desired position, the load is applied to the concrete beam as two point loads a beam displacement measuring device is placed in the middle of the beam to measure its deflection in the center. The load-applying jack and deflection measurement device are connected to a data-recording device, which records the applied load as Kilo Newton and the deflection as millimeters. In order to measure strain, as seen in Fig. 2, buttons are placed in positions A, B, C and D by which strains can be measured using a mechanical displacement measurement device with a precision of 0.001 mm. All beams are loaded to yielding limit in one stage and results have been recorded.

RESULTS

Examining Beam Fracture Methods

The NCF1 beam has FRP traction reinforcement with aρ_{fb} ratio. By loading this beam, the first bending crack occurs at 23.466 kN and between the two loads. By increasing the load, other bending cracks occur in positions between the two loads. In addition, large shearing cracks with high slopes occur outside and near the load application concentrated. At 180 kN load, a large shearing crack is formed in 45 degrees of the supports. Finally, the beam was demolished with the disruption of the beam middle compressive concrete at 197.71 kN (Fig. 3-6).

The NCF2 beam has an FRP reinforcement ratio of ρ_f which is more than the NCF1 reinforcement beam. Undoubtedly, this increase has resulted from the constant reinforcement cross-sectional area and reduction of beam dimensions. In loading this beam, the first crack occurred at 15.349 KN and in the center of the beam. By increasing the load, shear cracks with high slopes were formed outside and near the loading concentrated. At around 130 KN, compressive concrete started to demolish and finally at 141.11 KN load, the compressive area concrete disrupted and the beam broke into two parts from the middle and therefore the reinforcement disrupted (Fig. 3-6).

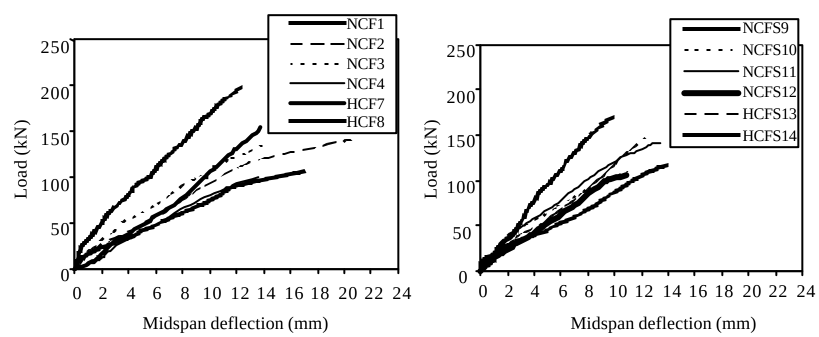

Fig. 3: Middle beam opening load-deflection curve

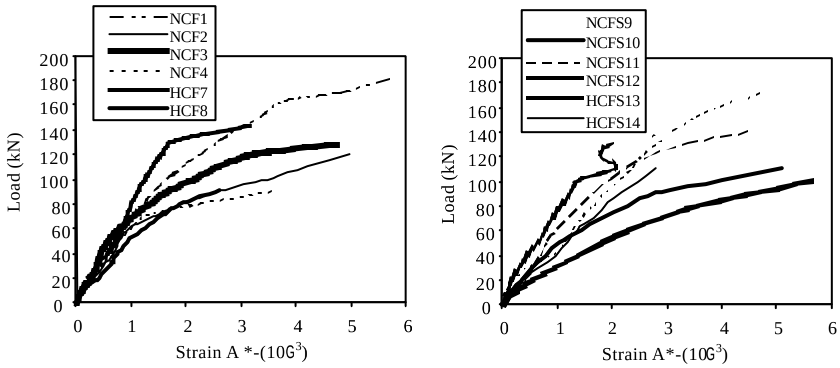

Fig. 4: Beams A load-negative bending strain curve

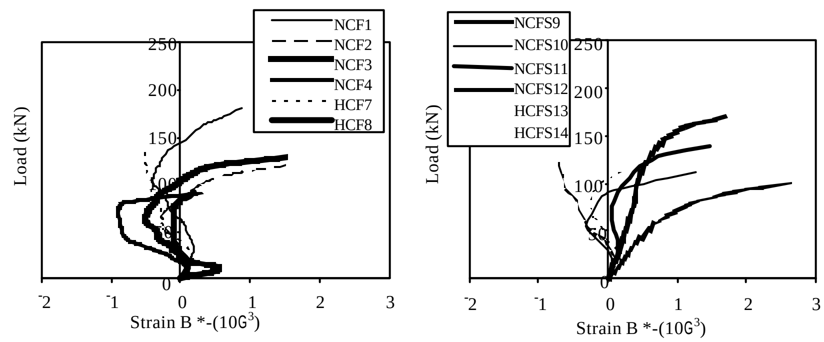

Fig. 5: Beams B load-negative bending strain curve

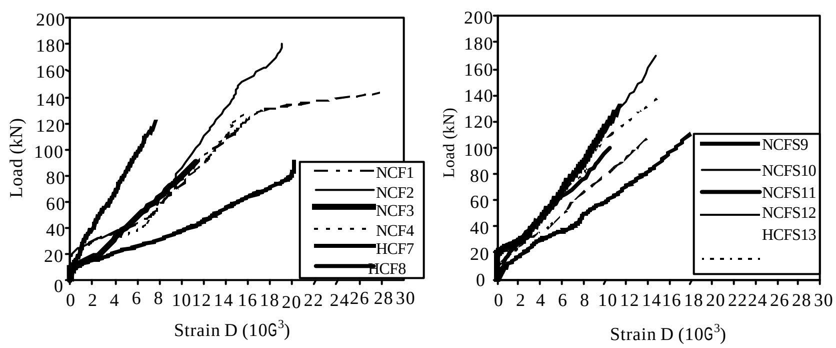

Fig. 6: Beam D load-bending strain curve

Beam NCF3 has similar reinforcement ratios to NCF2, but its effective height to cross-sectional area ratio is larger. This ratio is 2.11 in beam NCF3. The first crack in loading this beam occurs in the pure bending are at 12.5 kN. Thereafter, we have no new cracks and developments from 20-38 kN loading. Finally, the compressive area concrete starts to demolish at 134.95 kN.

In beam NCF4, the dimensions have shrunk to an extent that the FRP reinforcement ratio in the cross-section stands higher than the balanced state. In this beam, the reinforcement ratio is equal to $\rho_f = 0.00990 = 1.13\rho_{fb}$. The first crack load in this beam is 9.642 kN and occurs in the bending area near the load application point. By increasing the load, finally, at 100.94 kN the beam's middle, compressive area concrete starts to demolish.

Beam HCF7 is similar to NCF3 with only higher concrete resistance. In this beam, the first crack occurred at 18.203 KN in the center of beam. The number and spread of cracks were more than of beam NCF3. By increasing the load, the compressive area concrete near one of the concentrated loads started to disrupt and finally at 154.05 kN break into complete separate parts and complete demolition of the concrete the compressive area of the reinforcement disrupted.

Beam HCF8 is similar to NCF4 with only higher concrete resistance. In this beam, the first crack occurred at 13.81 KN. The number and spread of cracks were more than of beam NCF4. By increasing the load, at 106.42 kN the pressure are concrete started to disrupt, which by removing the load, acted completely elastic and returned to its primary state and only the pressure area concrete had demolished and shed to a great extent.

Beam NCFS9 is similar to NCF1, but its only difference with compressive steel reinforcements is the method of construction. The first crack load of this beam which occurs because of bending in the center of the beam is 25.879 kN which does not have a significant increase compared to NCF1. In addition, the cracking pattern of this beam is very similar to NCF1. By increasing the load, the width of the cracks increase and finally at 170.28 kN, suddenly the FRP traction reinforcement disrupts, however, due to the presence of compressive steel reinforcements which provide better solidity and resistance for compressive concrete, beams in contrast with other non compressive reinforcement models do not break into complete separate parts. It is evident that by utilizing compressive steel reinforcements in this beam, the type of failure changes from concrete compressive breakage to reinforcement disruption.

Beam NCFS10 is similar to beam NCF2 with the difference that steel reinforcements have been employed in its construction. The first crack in this beam occurs at 13.8 kN and in the bending area near one of the loading concentrated. By continuous loading of this beam, more cracks with less width and more spread compared to NCF2 developed, but the overall crack patterns are similar to NCF2. Finally, at 110.37 kN, the compressive area concrete faced disruption. Under the concrete disrupted area, a crack with a wide width had developed. After removing the load, the beam did not return to its primary state and a significant amount of deflection created due to the initial loading remained, which the reason for this is the presence of the compressive steel reinforcement which has eliminated the elastic behavior of the FRP reinforced concrete beam.

Beam NCFS11 is similar to NCF3 with the difference that compressive steel reinforcements have been employed in NCFS11. By applying loads, the first crack occurs at 13.814 kN and divulges in form of bending somewhere between the two loads. The crack pattern of this beam is very similar to NCF3. By increasing the load, the compressive area concrete disrupts at 141.98 kN. Like beam NCFS10, a very wide crack develops under the compressive concrete disruption area, which did not close after removing the load. This is recognized as an effect of compressive steel reinforcements.

Beam NCFS12 is similar to NCF4 with the difference that compressive steel reinforcements exist in NCFS12. The first crack appeared in bending form at 12.49 kN in the middle of the beam. The number and spread of cracks within this beam were more compared to NCF4, but with less width. By increasing the load, the compressive area concrete disrupted at 105.55KN and like other beams with compressive steel reinforcements, a wide crack appeared under the disrupted concrete area, however, in this beam, this crack had less width (Fig. 3-6).

Beam HCFS13 is similar to HCF7 with difference that it employs compressive steel reinforcements. The first crack appears at 23.47 KN in the bending area. The crack pattern is similar to HCF7, but the number and width of cracks were more than HCF7, but with less width. By increasing the load, the compressive area concrete started to disrupt and finally at 146.58 kN, by the complete demolition of the concrete the compressive area of the reinforcement disrupted, however, due to the presence of compressive steel reinforcements, the beam did not break into two separate parts.

Beam HCFS14 is entirely similar to HCF8 with the difference that compressive steel reinforcements have been employed in its construction. The first crack in this beam occurs at 15.1 kN and in the pure bending area near one of the loading concentrated. The number and spread of cracks in this beam are more than HCF8, but with less width. By passing the 100 kN load, more deflection was evidenced and finally, at 116.51 kN due to concrete disruption, the compressive area was demolished. In this beam, no wide crack appeared under the disrupted concrete area.

By examining the cracking method of the beams, it is evident that considering constant FRP reinforcement cross-sectional area, reducing cross-sectional dimensions results in first crack load reduction. In addition, it can be seen that utilizing compressive steel reinforcements in FRP reinforced concrete beams does not have a significant effect on the first crack load and only slightly increase it. However, using high resistance concrete significantly increases the first crack load. Utilizing FRP reinforced compressive steel reinforcements creates more cracks with a wide spread, but with less width. In addition, it extensively prevents the sudden fracture of the beam and can prevent the complete separation of the beam to two separate pieces after the disruption of the FRP reinforcement and increases structure formability. However, utilizing compressive steel eliminates the elastic behavior of FRP reinforced beams and significantly prevents the return of the beam to its primary state after load removal. In addition, utilizing high resistance concrete increases the number and spread of cracks, but reduced crack widths. For example, the methods of disruption of some of the specimen beams are displayed in Fig. 7a-d.

Examining Beam Deflections

By drawing the load curve based on the opening deflection for experimental specimens, it can be seen that this curve is almost a straight line with a mild and even slope for FRP reinforced concrete beams. This shows the complete elastic behavior of the FRP reinforcement, which gives elastic behavior to concrete. As shown in the charts, the overall

Fig. 7: Methods of disruption of some of the specimen beams; (a) NCFI, (b) HCF7, (c) NCFS9, (d) HCFS13

form of the load-opening center deflection in concrete beam with similar FRP dimensions and reinforcement, are very close to each other and utilizing compressive steel reinforcements, increasing concrete resistance or both, has not made any significant changes in the overall curve. Utilizing compressive steel reinforcements in normal strength concrete constructed beams and high resistance concrete constructed beams only has little effect on reducing beam deflection, which this matter is even more evident in higher ratio reinforcement.

As can be seen, in beams without compressive reinforcements, the load deflection curve of beams constructed with normal strength concrete is closer to a straight line, however, the corresponding curve for beams constructed with high resistance concrete winds around the straight line of the normal strength concrete beam curve and has more and less deflection in different positions of the curve. Overall, we can say that increased concrete resistance does not have a significant effect on the deflection of FRP reinforced beams. In addition, reduction in cross-sectional dimensions in constant reinforcement results in significant increase in the deflection of FRP reinforced beams and this matter is evident in all circumstances. In addition, it can be said that increase in effective height relative to cross-sectional width in all circumstances, results in a slight reduction in beam deflection. Hence, it is advised that in FRP reinforced beams, this ratio be considered more than 2.

Examining the a Load-Negative Bending Strain Curve

In fact the A strain is a compressive area concrete strain positioned in the center of the beam measured 2 cm from the farthest string of compressive concrete. The A load-negative bending strain curve for experimental specimens are displayed in Fig. 4. By examining these charts, it is observed that utilizing compressive steel in FRP reinforced concrete beams a state that the beam has a reinforcement ratio of less than balanced state, does not have significant effect on the compressive strain of the concrete. However, in the state that the beam has a reinforcement ration of more than balanced state, the presence of compressive steel reinforcements results in significant increase in compressive concrete strain, in which the curve turns into a semi-parabola and no sign of a sudden concrete disruption, can be seen within. In addition, it can be said that utilizing high resistance concrete instead of normal strength concrete in loads near the ultimate load results in created strain reduction and therefore, provides better resistance against disruption. By having a constant reinforcement cross-sectional area, reduction in the cross-sectional area results in a significant increase in concrete compressive strain. In addition, the effective height to cross-sectional width ratio in beams with similar reinforcement ratios, results in reduction in concrete compressive strain.

Examining the B Load-Negative Bending Strain Curve

Compressive strain is considered positive and traction strain is positive (Fig. 5). These curves show the amount of strain based on different loads in 4 cm distance from the farthest compressive string, which in compressive steel reinforcements, with the help of these curves, compressive reinforcement strain can be obtained. In addition, with its help, neutral string changes can be observed to some extent.

By using charts, it is observed that utilizing compressive steel reinforcements in FRP reinforced concrete beams causes the neutral string position to stand lower during the loading stage, which this matter is seen more in beams with a reinforcement percentage higher than the balanced state. In addition, utilizing compressive steel reinforcements in FRP reinforced beams constructed from high resistance concrete, does not have a significant effect on the position of the neutral string. In beams constructed from high resistance concrete, the neutral string position is higher than specimens constructed from normal strength concrete, which based on the greater resistance of concrete, seems natural.

Examining D Load-Bending Strain Curve

Results obtained from the C load-bending strain curve are very similar to the D load-bending strain curves, which this shows the suitable adhesiveness of FRP to the concrete and the appropriate transfer of tensions and strains. Therefore, here we will examine the D load-bending strain curves that indicate the traction reinforcement strain shown in Fig. 6. In FRP reinforced concrete with a reinforcement ratio of $\rho_f = 0.00487$ utilizing high resistance concrete instead of normal strength concrete has negligibly reduced FRP strain. In addition, employing compressive steel reinforcements had a more reducing effect in FRP strain. Thus, in FRP reinforced beams with a reinforcement ratio $\rho_f = 0.00745$ which the effective height to cross-sectional width ration is equal to 1.7, the beam behavior is completely opposite the previous state and utilizing high resistance concrete has resulted in significant increase in FRP strain. In addition, the presence of compressive steel reinforcements had a even greater increasing effect on strain. While in other specimens with similar reinforcement percentages, but with an effective height to cross-sectional ratio of 2.11, utilizing high resistance concrete does not have significant effect on FRP strain and the two curves are very close to each other, however utilizing compressive steel reinforcements in beams constructed from both normal strength and high resistance concrete results in an almost equal reduction in FRP strain.

In charts with a reinforcement ratio of $\rho_f = 0.00990$, utilizing high resistance concrete instead of normal strength concrete has resulted in significant reduction in FRP strain. In addition, employing compressive steel reinforcements in beams constructed from normal strength concrete has reduced the strain to an even lower level. However, utilizing compressive steel reinforcements in beams constructed from high resistance concrete and with the same FRP strain reinforcement percentage, has not had significant effect on FRP strain. Therefore, it can be said that in a state that the beam has an FRP reinforcement percentage more than balanced level, utilizing high resistance concrete or compressive steel reinforcement plays a very effective role in reducing FRP reinforcement strain.

In beams constructed from normal strength concrete with equal FRP reinforcement strain cross-sectional area, cross-sectional area reduction results in a dramatic increase in FRP strain. However, in beams constructed from high resistance concrete and beams with compressive steel reinforcements, this relation is seen with much less effect and in some loads, cross-sectional dimension reduction has resulted in only a negligible strain reduction. In beams constructed from normal strength concrete, increase in the effective height to cross-sectional width causes an increase in FRP strain, yet in beams constructed from high resistance concrete and beams with compressive steel reinforcements, this event has not had much effect on FRP reinforcement strain.

Considering the aforementioned topics, it can be said that strain and following it, tension in FRP reinforcements is very much influenced by different factors like concrete resistance, cross-sectional dimension relations, reinforcement percentage, compressive steel reinforcement usage, amount of applied load etc. Therefore, forecasting precise FRP behavior and determining fracture type in the beam is very difficult, therefore the presented relations for designing FRP reinforced beams is very conservative.

DISCUSSION

Considering experiment results summarized in Table 5, it is observed that utilizing high resistance concrete instead of normal strength concrete or using compressive steel reinforcements in beams with reinforcement lower than balanced level and the effective

Table 5: Experiment results summary (CFC: Compressive fracture of concrete, SDC: Simultaneous disruption of concrete and reinforcement (The beam suddenly breaks in two)

Beam name	First crack load (KN)	Ultimate --- deflection (mm)	Ultimate experiment bending capacity M_{ue} (KN m)	Ultimate experiment load P_{ue} (KN)	Type of fracture
NCF1	23.466	12.328	33.611	197.71	CFC
NCF2	15.349	20.518	23.989	141.11	CFC
NCF3	12.5	13.952	22.942	134.95	CFC
NCF4	9.642	13.651	17.160	100.94	CFC
NCF7	18.203	13.753	26.289	154.05	SDC
HCF8	13.810	16.964	18.091	106.42	CFC
NCFS9	25.879	9.825	28.948	170.28	CFC
NCFS10	13.80	10.987	18.763	110.37	CFC
NCFS11	13.814	13.433	24.137	141.98	CFC
NCFS12	12.490	10.845	17.944	105.55	CFC
HCFS13	23.470	12.283	24.919	146.58	CFC
HCFS14	15.10	13.850	19.807	116.51	CFC

height to cross-sectional width is less than 2, results in the reduction in ultimate bending capacity. However, in beams where the effective height to cross-sectional width is more than 2, in both states of reinforcement more and less than the balanced level, utilizing high resistance concrete or placing compressive steel reinforcements increases the ultimate bending capacity of the cross-section. In beams constructed from high resistance concrete with an effective height to cross-sectional width of more than 2, when a reinforcement percent is lower than balanced level, utilizing compressive steel reinforcements results in reduction in the ultimate bending capacity of the beam. On the contrary, when the reinforcement percentage is more than the balanced level, utilizing compressive steel reinforcements results in an increase in the ultimate ending capacity.

CONCLUSIONS

Utilizing compressive steel reinforcements in FRP reinforced concrete beams reduces the elastic behavior of the beam to great extent, but increases the formability of the structure and desirably prevents the sudden breakage and division of the beam into two parts.

Utilizing compressive steel reinforcements and high resistance concrete in FRP reinforced beams causes more cracks, but with less width.

In FRP reinforced concrete beams with an equal reinforcement cross-sectional area, the first crack load reduces with the reduction of cross-sectional dimensions. In addition, utilizing compressive steel reinforcements does not have significant effect on the first crack load, hence, utilizing high resistance concrete instead of normal strength concrete, increases the first crack load in all circumstances.

The load deflection curve in FRP reinforced concrete beams is almost a straight line with no evidence of FRP flow. The increase in concrete resistance does not have significant effect on the deflection of FRP reinforced concrete beams, yet utilizing compressive steel reinforcements in beams constructed from both normal strength and high resistance concrete only provides very little reduction in beam deflection, which this event is more visible in higher reinforcement ratios.

Utilizing compressive steel reinforcements in FRP reinforced concrete beams in a state where the beam has a reinforcement ratio lower than balanced level, does not have significant effect on the compressive strain of concrete. However, in a state where the beam has a reinforcement ration higher than balanced level, the presence of compressive steel reinforcements in FRP reinforced concrete beams significantly increases compressive concrete strain.

Utilizing compressive steel reinforcements in FRP reinforced concrete beams causes the neutral string position to place lower while loading. This event is seen more in beams with higher reinforcement percentage than balanced level. In addition, utilizing compressive steel reinforcement in FRP reinforced beams constructed from high resistance concrete, does not significantly effect the neutral string position.

Utilizing compressive steel reinforcements is more effective in beams with a reinforcement ratio more than balanced level and causes reduction in the produced deflection and strain in the FRP reinforcement and helps with the integration of compressive concrete.

It is advised that the effective height to cross-sectional width ratio of FRP reinforced concrete beams, especially in beams with compressive steel reinforcements and beams constructed from high resistance concrete, be considered more than 2.

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