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An Investigation of fan type anchorages applied to end of CFRP strips

M. Emin KARA * and Mustafa YAŞA [a]

Aksaray University, Civil Engineering Department, Aksaray, Turkey

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Abstract. CFRP strips are widely used nowadays for repair/strengthening or capacity increase purposes. Sharp bending at the ends of the CFRP strips is frequently encountered at these applications. In this study, Reinforced Concrete (RC) beam specimens that were produced with 10 MPa compression strength concrete were strengthened by using bonded CFRP strips with end anchorages to tension region. The parameters that were investigated in this study are the width of the strip, the number of applied fan anchorages and whether additional layer of CFRP patch is used or not at the strip ends. Specimens were strengthened with 100 mm wide CFRP strips with one or two anchorages at the ends. In addition CFRP patch with two and three anchorages at the ends were tested for investigating the effect of the patches. Specimens that were strengthened with three anchorages at the ends with patches were repeated with 60 and 80 mm wide CFRP strips. The most successful result was obtained from the specimen that was strengthened with 80 mm wide CFRP strips with 3 end anchorages and patches among the others at the experimental program. The numbers of anchorages that were applied to ends of CFRP strips were more effective than the width of the CFRP strips onto strength and stiffness of the specimens. Due to limited space at the ends of the strips at most three anchorages could be applied.

Keywords: RC beams; CFRP; fan type anchorages; strengthening

1. Introduction

Bonding of CFRP strips on to concrete have been widely used technique for repairing or strengthening. This subject is found its place in regulations (Turkish Seismic Code 2007, ACI Committee Report 440 2008). Many recent studies are conducted about improving load carrying capacity of reinforced concrete (RC) beams strengthened with CFRP strips. Same regulations are stated that use of high strength CFRP creates problems, when they are used with low strength concrete. Many studies are conducted about determination of stress distribution along the CFRP strips for obtaining load carrying capacity of bonded CFRP strips on to concrete (Anıl *et al*. 2010, Ferracuti *et al*. 2007, Kalfat and Al-Mahaidi 2010). There are limited amount of study about application of fan type anchorages to bonded CFRP strips under tension load (Ceroni and Pecce 2010, Smith *et al*. 2011). In these studies fan type anchorages are applied all along the CFRP strips with different spacing or applied to ends at one of the studies. There are studies about design of the

*Corresponding author, Assoc. Prof. Dr., E-mail: eminkara@aksaray.edu.tr
[a] M.Sc Student, E-mail: muastafa_yasa@msn.com

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anchorages at the ends and application of anchorages to different surfaces such as masonry e.g. (Camli and Binici 2007).

Studies about strengthening of members with CFRP strips are concentrated on improvements of bending or shear capacities of them. CFRP strips are used for improving RC beams' bending or shear capacities (El-Ghandour 2011). Similar studies are made also by using anchorages with CFRP strips. Beams are used with toppings at regular RC structures. Studies about strengthening against shear or retrofitting shear damaged T cross-sectioned beams are made by bonding of CFRP strips along the shear spans of them. CFRP strips are anchoraged to beams topping with CFRP anchorages like shown in Fig. 1 (Altın *et al*. 2010). The common result that is obtained from these studies stated that anchorages are directly affected on the behavior of specimen. Metal anchorages are used at the CFRP ends for some studies. (Anıl 2008, Belarbi *et al*. 2011).

CFRP strips are widely used also for strengthening or retrofitting of RC frames against earthquake loading. CFRP strips are bonded onto low strength masonry or such materials that are used as an infill at the openings of frames. CFRP strip ends are anchoraged to frame columns and beams by using fan anchorages. Details of fan type anchorages that are used at masonry infilled frames are given at Fig. 2. System level researches showed that the success of the application is strongly depended on the usage of end connections. CFRP strips cannot carry compression forces (Fig. 2). Usage of extra patch at the ends of CFRP strips at which start of the failure is expected is suggested at Turkish Seismic Code (Özcebe *et al*. 2003, Altın *et al*. 2008). This high strength material is obviously increased the strength of the frame, but how much of its capacity is used is not known very well. For the capacity calculation of the steel strengthening, knowing the capacities of the end anchorages helps the designer. For this reason, load carrying capacity of the CFRP strips with anchoraged both ends is investigated in this study.

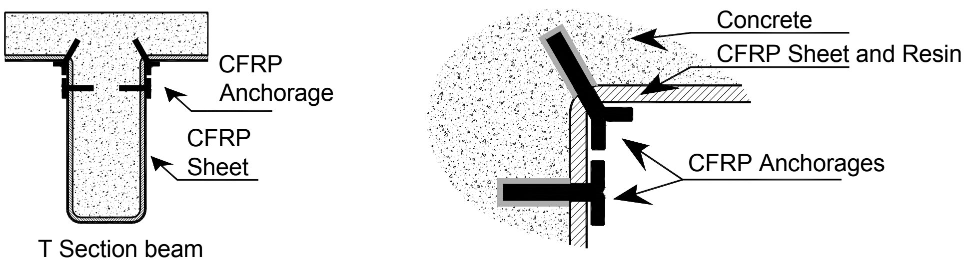

Fig. 1 CFRP anchorage application detail of RC beams (Altın *et al*. 2010)

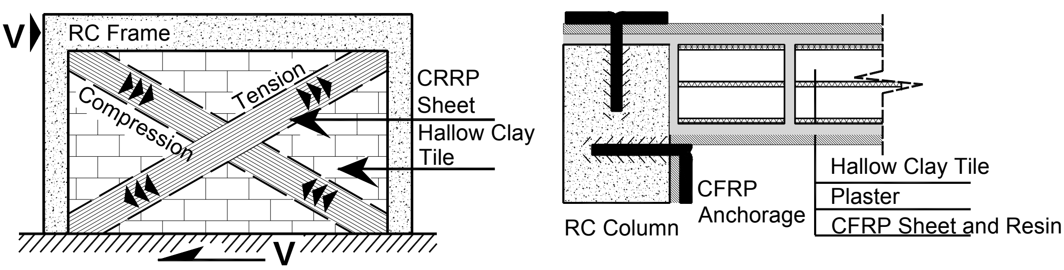

Fig. 2 CFRP anchorage application detail of masonry infilled RC frame

Main rules of the connection calculations for the steel structures are well known. Applications such as dowel, rivet and welding at the connection region must carry the service load that is applied to steel member safely. For this purpose, loads and strength of each connection region is calculated separately and detailed drawings are prepared for each of them. While detailed studies are made for the steel with very well known material properties and behavior, there is very limited amount of experimental findings and information about the load carrying capacity of connections, when the CFRP strip is anchoraged to concrete. Although this is a fact, CFRP strips are still used for the strengthening or retrofitting of damaged concrete structures or structures with high probability of damage.

Common result that is obtained from the studies encountered at literature survey is the importance of the connections at ends of CFRP strips, when it is bonded to concrete surface. Nearly all member level studies gave importance to stress distribution along the strip. Failure of the system is affected from both success of the load transfer at the strip ends and load carried by the strip. In contrary of some research and regulations, load carrying capacity is more affected from success of anchorage applications than the width of the strip. For these reasons, the relation between the number of fan anchorages that took place at some regulations and width of the strip is investigated in this study. CFRP strips are bonded and anchoraged to beam with fan type anchorages at both side of the 100 mm deep notch that is situated at constant moment region of the beam. Compression strength of the concrete is determined as 10 MPa. Therefore, the most negative situation is simulated for investigating success of the CFRP strip.

2. Experimental study

2.1 Test specimens and materials

CFRP strip that can carry axial tension forces is bonded to tension region of the beam under bending moment. Dimensions and reinforcement details of the beam are given at Fig. 3. There is a 100 mm deep 1000 mm long notch at the region, where CFRP strip is bonded. Cross section at the notch region became smaller and failure is assured to be start at the constant moment region. Beam is loaded up until CFRP strip reaches its load carrying capacity under flexural tension. For this reason, three 10 mm diameter and two 8 mm diameter longitudinal bars are used at the compression and tension region of the beam, respectively. In addition, 10 MPa compression strength concrete is used for the specimens.

Experimental parameters that are investigated in this study are CFRP strip width, number of fan type anchorages at the end of strips, whether extra layer of CFRP is used or not at the strip ends. One of the specimens (Specimen-1) is tested for reference without any CFRP strips, and remaining are tested with CFRP strips bonded along the notch region. In addition, one of the specimens (Specimen-2) is tested without anchorages. Arrangement of the CFRP strip and anchorages for specimens is given at Fig. 4. One anchorage and two anchorages with 50 mm spacing are used at the ends of the CFRP strips of Specimen-3 and Specimen-4, respectively. Specimen-5 is strengthened with two anchorages and 200 × 300 mm extra layer of CFRP patch at the ends. Three anchorages with 50 mm spacing are used at the ends of Specimen-6's 100 mm wide CFRP strip. The same CFRP patch like Specimen-5 is also applied to Specimen 6 for achieving load transfer. Due to the fact that width of CFRP strip is 100 mm only, at most three anchorages can be applied with 50 mm spacing. Same connection and anchorages detail that is applied to Specimen-6 is applied to Specimen-7 and 8 that are strengthened with 80 and 60 mm wide CFRP strips,

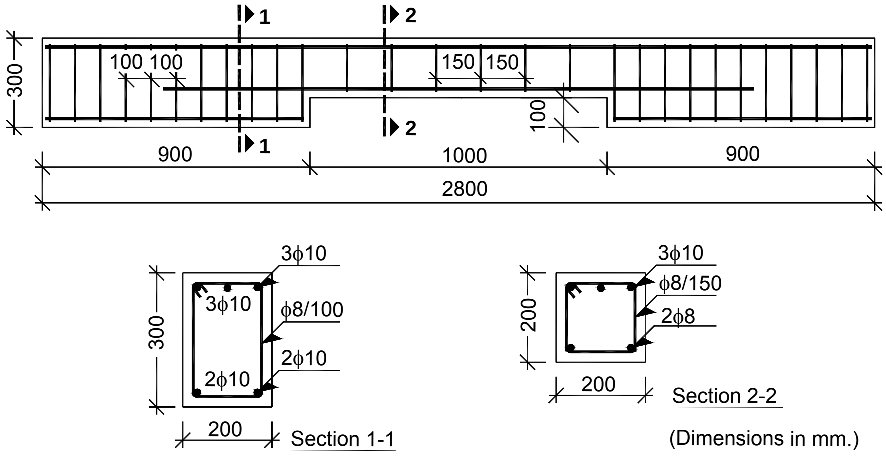

Fig. 3 Dimension and reinforcement details of the specimen

Table 1 Properties of specimens

Specimen No.	CFRP Sheets			Concrete
	Width, w_f (mm)	Number of Anchorage	Patch	f_c (Mpa)
1 (Reference)	No Sheets	-	-	11
2	100	No Anchorage	-	10.3
3	100	1	-	10.4
4	100	2	-	11.5
5	100	2	Yes	10
6	100	3	Yes	10.2
7	80	3	Yes	11
8	60	3	Yes	10.9

Table 2 Properties of reinforcement

Bar diameter (mm)	f_y (MPa)	f_{ult} (MPa)	Type
8	572	683	Deformed
10	420	686	Deformed

respectively. The details of the fan type anchorages are given at Figs. 1 and 2 that is applied to all of the specimens. The diameter and depth of the hole at which anchorages are inserted are 14 and 150 mm, respectively. CFRP anchorages are prepared from 100 × 200 mm rectangular CFRP patches by wrapping these patches around an 8 mm diameter reinforcement bar. After inserting 200 mm long anchorages to 150 mm hole, the remaining 50 mm that is protruded out from the holes are cut like fan and bonded the surface of the beam. Table 1 summarizes the specimens' properties and the mechanical properties of reinforcing bars are given at Table 2. Unidirectional Sikawrap 230-C CFRP sheets are used for the strips and Sikadur-330 two part epoxy is used for bonding them onto beams. The properties both CFRP and epoxy are summarized at Table 3.

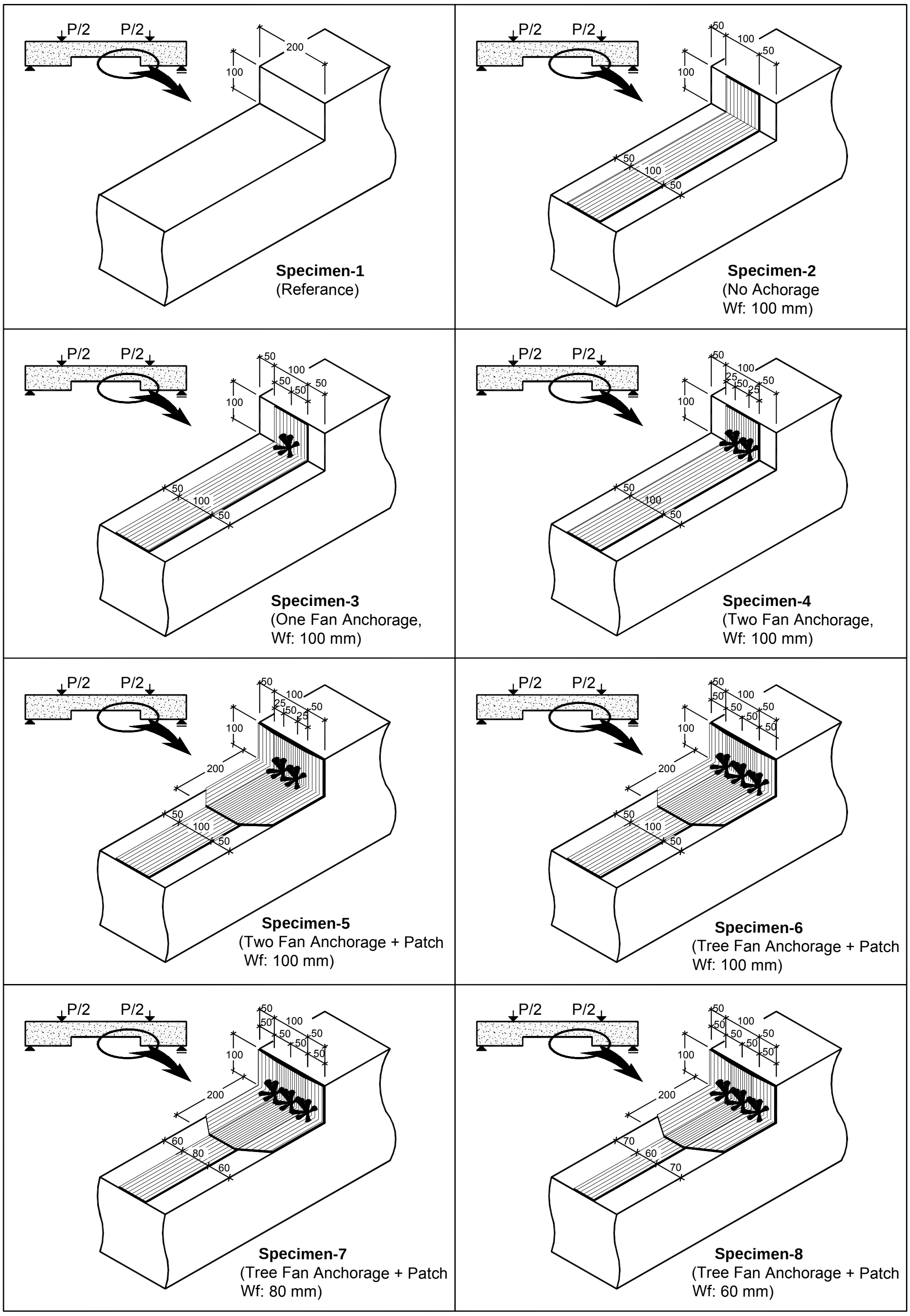

Fig. 4 Details of specimens

2.2 Bonding procedure

The same bonding procedure is applied to all specimens, while bonding and anchoraging of the CFRP strips. Firstly surfaces of the casted specimens on which CFRP strips will be bonded are prepared. Surfaces are roughened by a mechanical grinding machine until aggregates are exposed and then brushed and cleaned by vacuum cleaner. Prepared Sikadur-330 epoxy is spread over the surfaces of beam up to 1.5 mm thickness. Then CFRP strips are laid on to surfaces at which epoxy is spread over, and CFRP strips are pushed with a roller for soaking the applied epoxy. Finally the 14 mm diameter holes at which anchorages are inserted are cleaned with compressed air before epoxy is injected. After injecting epoxy, the prepared anchorages that are shown at Fig. 5(a) are inserted into holes. The protruded parts from holes are opened like a fan and bonded onto surfaces. The details of the bonding procedure are shown at Fig. 5. Completed specimens are cured 15 days under laboratory conditions before testing.

2.3 Experimental setup

Details of the experimental setup and instrumentation are shown at Fig. 6. Load is applied to specimens by using 1300 mm long reaction beam and is measured with 100 kN capacity load cell. Cyclic load is increased monotonously, while mid-point and support displacements are measured. Strain measurements are taken from 5 points along the CFRP strips. Loading is applied up to a point at which tension reinforcement is yielded or CFRP strip is damaged. At the beginning, load controlled cycles are applied with 5 kN load increase at each cycle and after failure loading continued with displacement controlled cycles.

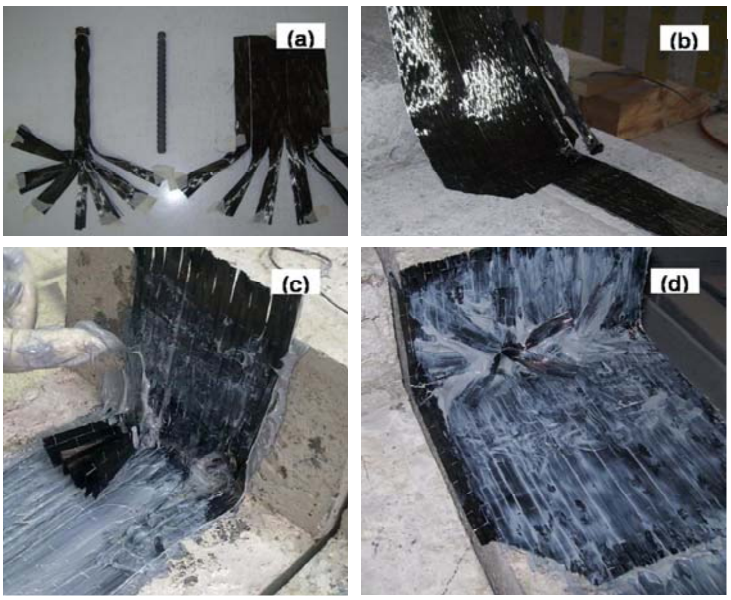

Fig. 5 Bonding Procedure: (a) CFRP Anchorages; (b) CFRP strip, anchorage and patch for Specimen-7; (c) Anchorage application of Specimen-4 before fan part opened; (d) Specimen-6 after CFRP anchorage application completed)

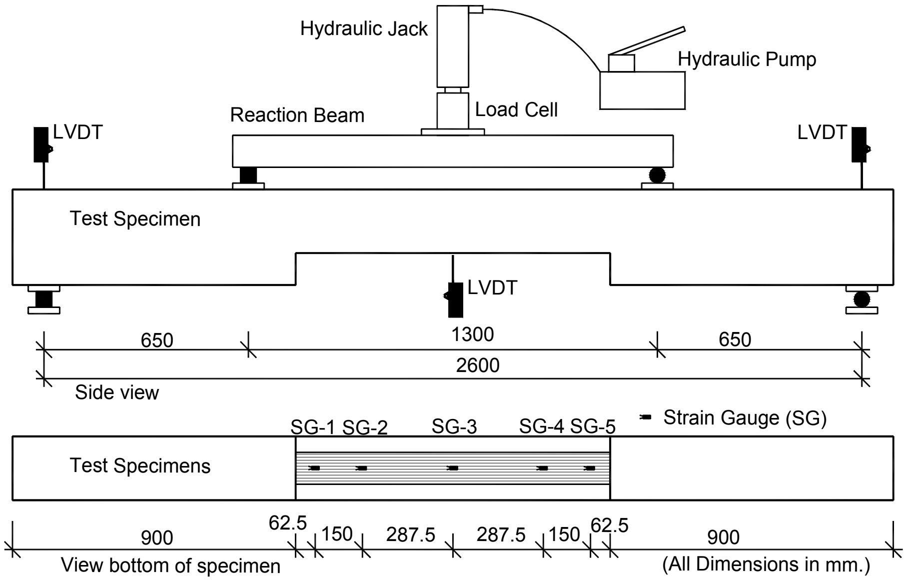

Fig. 6 Test setup and Instrumentation

3. Experimental results and evaluation

3.1 Behavior of test specimens and failure modes

Results of the experiments are summarized at Table 4. Strength, stiffness and failure modes of CFRP strips are taken into account during evaluations. Tension reinforcement of Specimen-1 is yielded at 24 kN load level. Specimen showed ductile behavior and many bending cracks are observed at tension region. Load-displacement graphs of the specimens are presented at Fig. 7. Photos of the specimens after finishing the experiments are given at Fig. 8. Although Specimen-2 that is strengthened with CFRP strips without anchorages carried nearly the same amount of load with Specimen-1, Specimen-2's initial stiffness and stiffness at maximum load are 1.9 and 1.2 times larger than the Speciemen-1's stiffnesses, respectively. CFRP strip is debonded from concrete

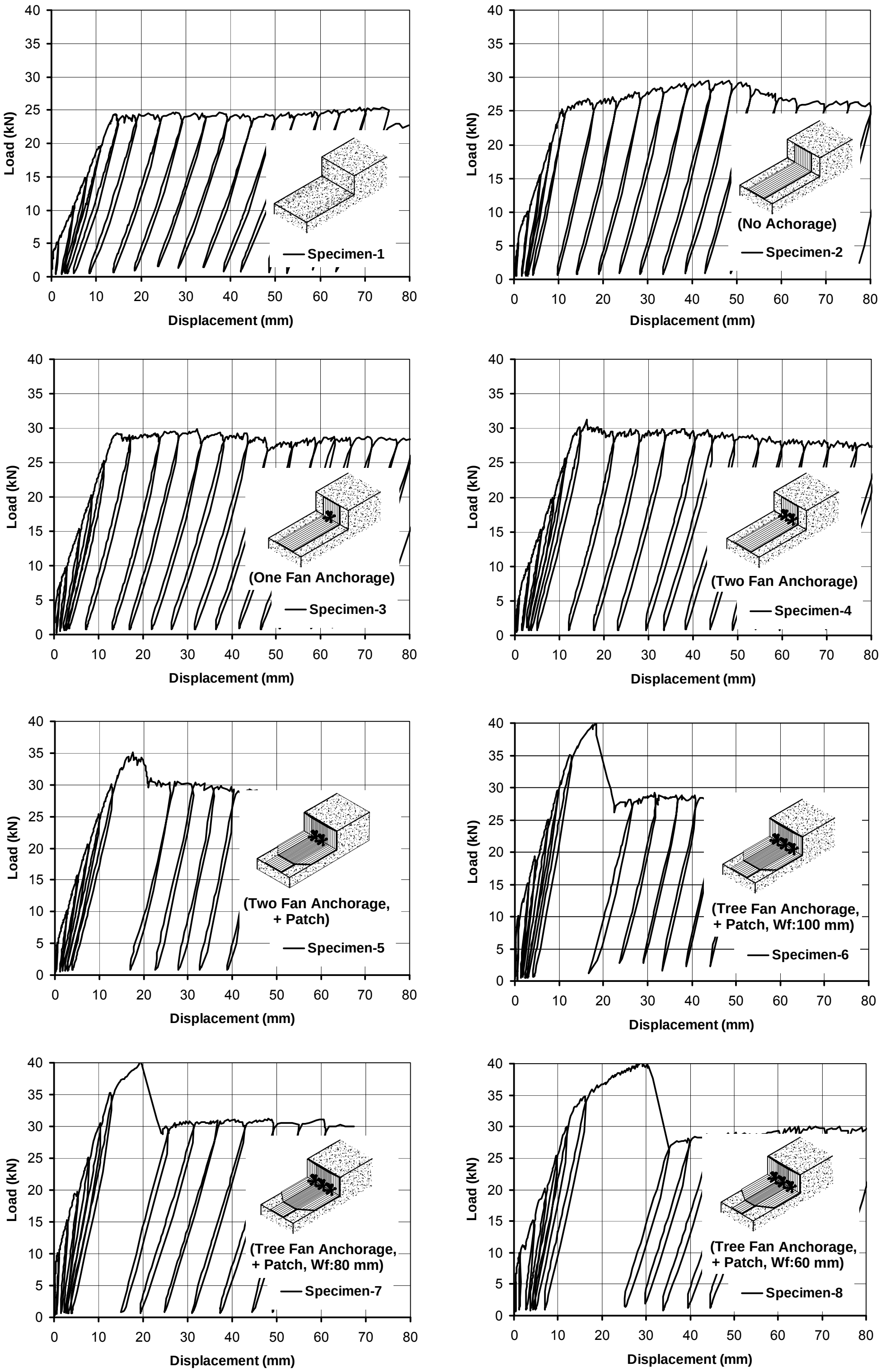

Fig. 7 Load- displacement graphs of specimens

just at the ends, and no bending cracks are observed at the notch region (Fig. 9(a)). Specimen-3 that is strengthened with CFRP strip with one fan anchorages at each end is carried 29 kN load. This specimen is 3 times stiffer than reference specimen initially. CFRP strip of this specimen is debonded from ends like the specimen without anchorages (Fig. 8). Specimen-4 that is strengthened with CFRP strips with two anchorages is carried 29% more load than reference specimen. But stiffness value is not increased like expected. Specimen-4 is failed with the rupture of both CFRP strip between two anchorages and anchorage. Specimen-2, 3 and 4 had nearly the same stiffness at maximum load. Average strength of these specimens is 29% larger than that of reference specimen. Therefore for improving the strength and behavior of the specimens, some extra precautions are needed at the ends of the CFRP strips.

An additional 200 × 300 mm rectangular CFRP patch is used at the ends of CFRP strips of Specimen-5. This specimen is carried 35 kN load, therefore its capacity is 13% more than the Specimen-4 without patches. Although initial stiffness is increased 30%, stiffness at maximum load is not changed significantly. Application of these additional patches at the ends of strip is also not changed the failure mode significantly like shown at Fig. 8. As can be seen from Fig. 9(b), strip is debonded from the concrete at right side only and specimen is failed with rupture of patch and anchorage. Specimen 2, 3, 4, and 5 is failed after debonding of CFRP strips from ends and cracks are propagated from debonded side of the notches. CFRP strips are not debonded from concrete surface at the other regions. Specimen-6 that is strengthened with 50 mm apart three anchorages and patches is carried 40 kN load. Strength is increased 14% compared to Speciemn-5 with two anchorages. Initial stiffness of this specimen is 11.7 times and 1.3 larger than the reference specimen and Specimen-5, respectively. It is 30% stiffer at maximum load level than reference specimen. Specimen 6 is failed due to rupture of the anchorages. Strip or patches are not ruptured. Many bending cracks are observed like the reference specimen and CFRP strip is debonded from the concrete surface. The width of the CFRP strip is reduced at Specimen-7 and 8 for obtaining failure along the CFRP strips, but not at the ends.

Table 4 Experimental results

Specimen No.	Load (kN)		Stiffness (kN/mm)				Failure modes
	Max.	Ratio+	Initial	Ratio++	At max. load	Ratio++	
1	24	-	4.39	-	1.75	-	Flexure
2	25	1.04	8.17	1.9	2.10	1.2	Debonding of CFRP strip
3	29	1.21	13.14	3.0	2.10	1.2	Rupture of CFRP anchorage
4	31	1.29	14.65	3.3	2.05	1.2	Rupture of CFRP anchorage and tear of patch sheet
5	35	1.46	19.04	4.3	2.15	1.2	Rupture of CFRP anchorage
6	40	1.67	51.47	11.7	2.32	1.3	Rupture of CFRP anchorage
7	40	1.67	49.30	11.2	2.17	1.2	Rupture of CFRP anchorage
8	40	1.67	30.34	6.9	1.43	0.8	Rupture of CFRP anchorage and tear of patch sheet

+ Ratio = Max. lateral load / Maximum lateral load of Specimen-1

++ Ratio = Stiffness of specimen / stiffness of Specimen-1

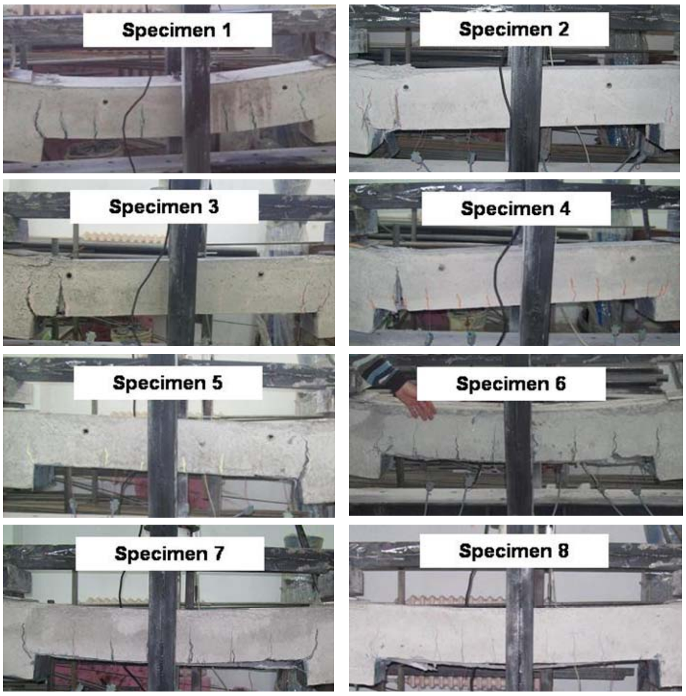

Fig. 8 Specimen crack patterns after failure

Fig. 9 Failure mode of specimens

Specimen-7 is strengthened with 80 mm wide CFRP strip that is anchoraged by using three anchorages, and also patches are utilized at the ends of strip. But this specimen is failed by showing similar behavior like Specimen-6 that is strengthened with same anchorage detail and 100 mm wide strip (Fig. 8). Specimen-7 initial stiffness and stiffness at maximum load is reduced 4% and 6% compared to Specimen-6 stiffnesses, respectively.

Connection details that are used at Specimen-8 CFRP strip are the same with Specimen-6 and 7. Width of the strip is reduced to 60 mm. Specimen-8 is carried 40 kN like the Specimen-6 and 7. Initial stiffness is 41% less than that of Specimen-6. Due to the fact that CFRP strip behaved like tension bar, it is debonded from concrete surface completely all along the strip length at maximum load level. Failure occurred with rupture of middle anchorage and CFRP patches are debonded from both sides (Fig. 9(c)). The stiffness values of the Specimen-8 are the lowest of all specimens that are strengthened with three anchorages.

Failure of the strips can be seen from the load-displacement graphs that are given at Fig. 7 clearly. This change is more distinct at Specimen-6, 7 and 8 that are strengthened with three anchorages. As can be seen from the photos that are taken after finishing experiments, specimens with three anchorages are failed like the reference specimen without CFRP strip. Many bending cracks are observed at the notch regions. Response envelope curves that are given at Fig. 10 are used for comparing the behaviors of the specimens.

As can be seen from the envelope curves, strength of the specimens that are strengthened with three anchorages are better that the others. Specimen-8 that is strengthened by using 60 mm wide CFRP strip and three anchorages with patches is made the largest displacement up to failure. Specimen-6 and -7 are strengthened with 100 and 80 mm wide CFRP strips, respectively. Although width of the CFRP strip that is used at Specimen-7 is 20% smaller than that of Specimen-6, they are carried nearly same amount of load and are behaved similarly. Anchorage spacing is chosen as a 50 mm for the two and three anchoraged specimens. Due to low concrete

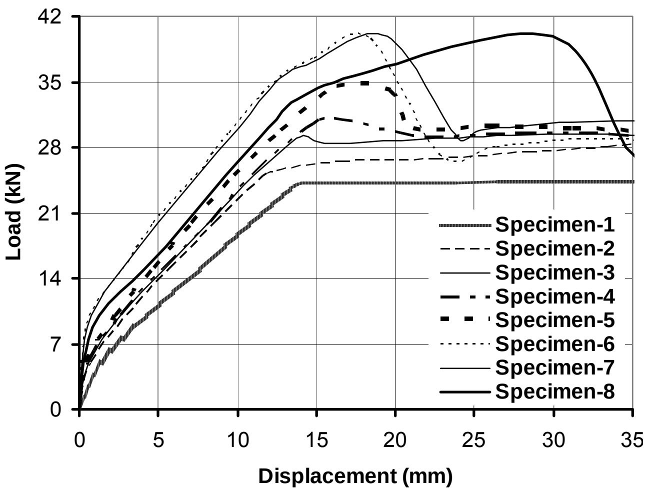

Fig. 10 Response envelope curves of specimens

Table 3 Properties of CFRP and epoxy resin

CFRP (Sikawrap-230C)	
Weight (g/m^2)	230 $\pm$ 10
Density (g/m^3)	1.76 x 10^{-6}
Thickness (mm)	0.131
Tensile strength (MPa)	4300
Elastic modulus (MPa)	234000
Max. strain of fiber (%)	1.8
Resin (Sikadur 330)	
Tensile strength (MPa)	30
Elastic modulus (MPa)	3800

compression strength like 10 MPa, if inadequate anchorages spacing is used, anchorages can pull away from the concrete. Although this is an avoidable failure mode, this failure type is not observed at any one of the specimens. Specimens are failed with rupture of the anchorages partly or completely.

3.2 Strain behavior of CFRP strips

One of the aims of this study is to obtain how high the average strain along the CFRP strip is. For this purpose, five strain measurements are taken from the specimens and observation is done whether CFRP strip has worked like a tension bar or not. It is crucial to use costly CFRP strips with maximum efficiency. According to catalogue information that is given at Table 3, CFRP elongation can be 1.8%. Stress-strain curve of the material is given at Fig. 11. When the maximum elongation point of 1.8% and origin is connected with a line, the slope of the line gave the elastic maximum load. Stress levels of the strips are determined by using the strain measurements and

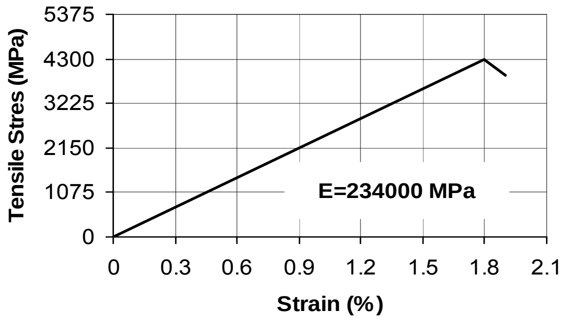

Fig. 11 Stress-Strain curve of CFRP (Sikawrap 230-C)

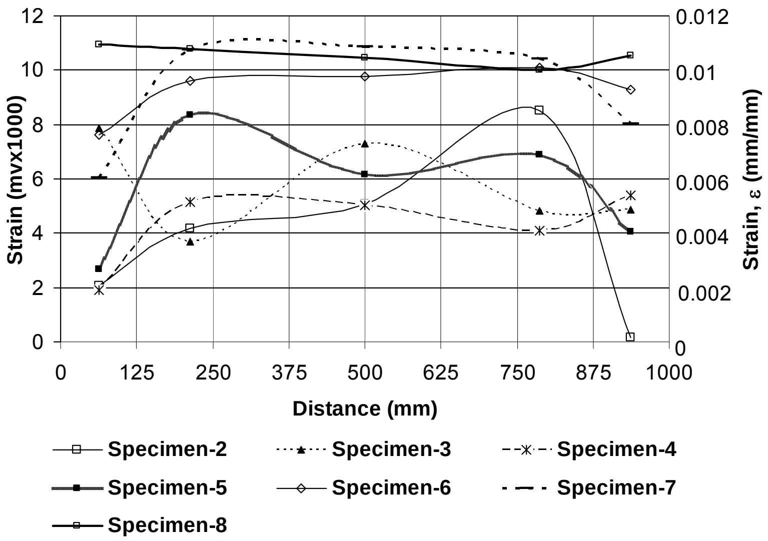

Fig. 12 Strain distribution of CFRP strips

modulus of the material as 234000 MPa. According to this, graph is assumed to be linear up to elastic modulus. The distributions of the maximum strains along the CFRP strips are given at Fig. 12. As can be seen from the figure, the strains are significantly larger for the specimens with three anchorages. The distributions of strains are also important like the steel members. It is aimed such that CFRP strips are worked like tension bar. But, strain distributions are changed significantly all along the strips except the Specimen-8. Specimen-8 is failed with unwanted rupture of middle anchorage and the outer two anchorages remained undamaged. First and fifth strain measurements of specimens at which patches are used are taken from the patches. For this reason, the elongation of the below strip cannot measured completely. Although the strength of the specimens that are strengthened with three anchorages with patches are nearly the same, different CFRP strip widths like 100, 80 and 60 mm are used, and strains are differ among them around 10%. By using Fig. 11 and linear proportion, Table 5 is prepared. As can be seen from the table, any one of the specimens can reach the tension strength of 4300 MPa that is given at Table 3. CFRP is used with 60% capacity. According to second, third and fourth strain gauge measurement, Specimen-7 is made the largest elongation. Measured load-strain graph are given at Fig. 13 for the selected specimens.

3.3 Analytical capacity calculation of specimens

Analytical load carrying capacities of the specimens are computed by using ACI 440 Committee Report (2008). Mechanical properties of CFRP that are given in Table 3, and the compressive strength and modulus of elasticity for the beams are used for the calculations. The assumptions made, while computing the analytical ultimate capacity of the specimens is similar to the assumptions made for the bending moment capacity of reinforced concrete beams. The approach that is used for the analytical calculations is summarized at Fig. 14 and equations are also shown at Eq. (1), (2) and (3). It is assumed that the strain and stress distribution created by the influence of bending moment is linear, and the sections perpendicular to the neutral axis before deformation remain perpendicular after deformation. Specimens are assumed to reach the ultimate capacity with crushing of concrete in maximum moment zone, since the compressive strength of concrete is greater than their shear strength, and strain value at CFRP strip is computed using the assumption of linear strain distribution (Eq. (1)). Then the location of neutral axis is computed by using the equilibrium of tensile force on CFRP strip, reinforcements and compressive force on the concrete at the top of the section (Eq. (2)). As a result, ultimate moment capacity of the section as perpendicular the location of neutral axis computed from the equilibrium of horizontal forces and

Table 5 Maximum and average CFRP strip strain and stress values of specimens

Specimen No.	ε_{max} (mm/mm)	σ_{max} (MPa)	$\varepsilon_{average}$ (mm/mm)	$\sigma_{average}$ (MPa)
2	0.0085	1989	0.004	936
3	0.0079	1849	0.006	1404
4	0.0054	1264	0.004	936
5	0.0083	1942	0.006	1404
6	0.010	2340	0.009	2106
7	0.011	2574	0.009	2106
8	0.011	2574	0.011	2574

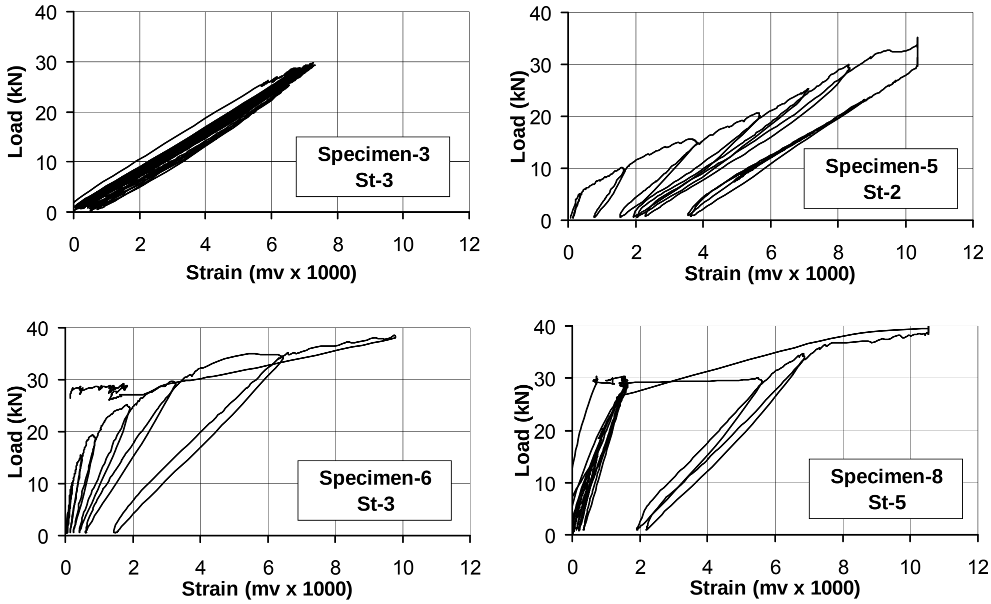

Fig. 13 Example of load-strain graphs

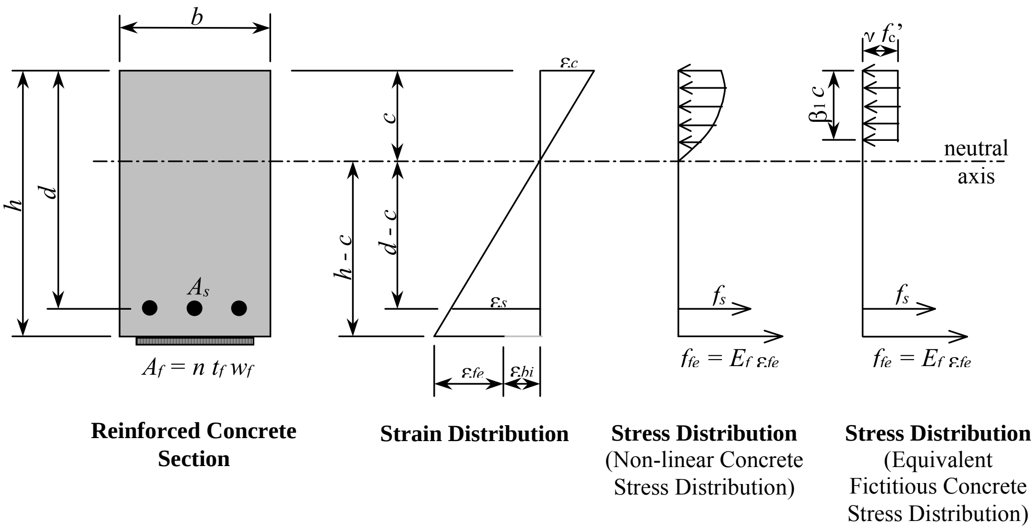

Fig. 14 Analytical capacity calculation approach of specimens

the value of shear force necessary to reach this moment value are computed and compared with the experimental results (Eq. (3)). The comparison of analytical and measured capacity values are given in Table 6.

$$\varepsilon_{CFRP} = 0.003 \times \left(\frac{h-c}{c} \right) \tag{1}$$

Table 6 Comparison of analytical and experiment capacities

Spec. No.	Ultimate capacity (kN)		Ratio **
	Analytical*	Experimental	
1	23.65	24	0.99
2	35.66	25	1.43
3	35.89	29	1.24
4	38.40	31	1.24
5	34.95	35	1.00
6	35.42	40	0.89
7	35.13	40	0.88
8	32.57	40	0.81

* Analytical capacity values of specimens are calculated according to ACI440 Committee Report
** Ratio of analytical capacity to experimental results

$$\begin{aligned} 0 = f_{AC} \cdot c \cdot b - \left(\frac{c - d_1}{c} \times 0.003 \right) \times A_{s1} \times E_{steel} \\ - \left(\frac{d - c}{c} \times 0.003 \right) \times A_{s2} \times E_{steel} - n_{CFRP} \cdot t_{CFRP} \cdot w_{CFRP} \cdot E_{CFRP} \cdot \varepsilon_{CFRP} \end{aligned} \tag{2}$$

$$M_{cal} = F_{CFRP} \times \left(h - \frac{c}{2} \right) + F_{s2} \times \left(d - \frac{c}{2} \right) - F_{s1} \times \left(\frac{c}{2} - d_1 \right) \tag{3}$$

While computing the ultimate capacities of the specimens, the effects of CFRP anchorages onto the ultimate capacity are not included. The equations that are used for computing are included only the effect of unidirectional bending moment and the contribution of strips placed parallel to that direction. Average analytical capacities are found to be 6% greater than the experimental capacities for all of the specimens. The ratio of the analytical values to experimental results is changing from 1.43 to 0.81.

4. Conclusions

CFRP strips are widely used for strengthening or retrofitting of concrete structures. In general, CFRP anchorages are used for connecting the CFRP strips to concrete structures. In this study, the details of the CFRP fan type anchorages at the ends of CFRP strips under tension are investigated. Concrete with 10 MPa compression strength is used for simulating the most unfavorable condition. The findings of this study are summarized below;

- The most unwanted failure types of CFRP anchorages can be cited as pulling away of anchorage or fracture of concrete with anchorage like a conical shape. Although low concrete compression strength like 10 MPa and in sufficient number of anchorages with 50 mm spacing and 150 mm depth is used, these unwanted failure types of anchorages are not observed at any one of the specimens.

- Usage of one or two anchorages at the ends of 100 mm wide CFRP strips does not give successful results, when strength and behavior are taken into account. Failures of the strips are occurred at the connection region of the anchorage and strip.
- Addition of the extra patch layer for improving the behavior of 100 mm wide CFRP strips that are strengthened with two anchorages are not improved the strength and behavior as expected.
- Specimen that is strengthened with 100 wide CFRP strip with three anchorages and extra patch layer shows fairly better behavior than the specimen with one and two anchorages. CFRP strip behaves like tension bar and strip is debonded all along the notch from the concrete surface.
- Specimen that is strengthened with 80 mm wide CFRP strip with three anchorages and extra layer of patch is showed the same behavior and strength like the specimen with 100 mm wide CFRP strip. Although it is the most successful specimen of experimental program, only 60% capacity of the CFRP material is used. Failure of this specimen is occurred due to rupture of fan part of anchorages at the connection region.
- The purpose of manufacturing of Specimen 8 that is strengthened with 60 mm wide CFRP strip is to obtain CFRP strip rupture, but this purpose cannot be achieved. Specimen is showed similar behavior like the other specimens with three anchorages. Authors thought that 200 mm wide CFRP patch is came up to broad and due to rupture of the patch two anchorages at the edges cannot carried enough load. Only the middle anchorage can carry the load effectively. Failure of this specimen is occurred due to rupture of fan part of anchorages at the connection region like the other specimens.
- Rupture of the CFRP strip is not occurred at the middle for any one of the specimens. The most successful design is came out to be the one at which 80 mm wide CFRP strip with three anchorages and patch is used, when the strength, behavior and cost are concerned.
- Analytical load carrying capacities of the specimens are computed by using ACI 440 Committee Report (2008). The equations that are used for computing are included only the effect of unidirectional bending moment and the contribution of strips placed parallel to that direction. Average analytical capacities are found to be 6% greater than the experimental capacities for all of the specimens. The ratio of the analytical values to experimental results is changing from 1.43 to 0.81.

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