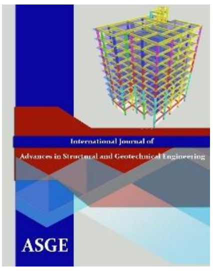
Egyptian Knowledge Bank



International Journal of Advances in Structural and Geotechnical Engineering

https://asge.journals.ekb.eg/

Print ISSN 2785-9509 Online ISSN 2812-5142

Special Issue for ICASGE'19

Flextural Strengthening of RC Continuous Beams Using CFRP Sheets

Maysoun M. Ism., M. Rabie

ASGE Vol. 03 (03), pp. 54-68, 2019

FLEXTURAL STRENGTHENING OF RC CONTINOUS BEAMS USING CFRP SHEETS

Maysoun M. Ism. [1], M. Rabie [2]

[1] *Assistant Teacher, Engineering Department, Faculty of Engineering, GUC*
E-mail:Maysounmagdi90@hotmail.com
[2] *Prof. of Concrete Structures, Faculty of Engineering, Cairo University*
E-mail: rabie_eng@yahoo.com

ABSTRACT

The survey of the literature showed the need for research on the behavior of strengthened continues reinforced concrete beams with different strengthening techniques. A wide research has been investigated on simply supported beams strengthened with CFRP composites; little work has been focused on continuous beams. Ductility is one of the issues that still need to be investigated further, as research has shown that the brittle behavior of FRP materials added to statically indeterminate Reinforced concrete beams can limit the ductility or decrease the plastic rotational deformation prior to failure. To meet this need, this study was utilized to predict the behavior of the strengthened continuous reinforced concrete beams under monotonic increasing load. This research aims to study the effect of strengthening schemes on the flexural behavior of a continuous RC beams under different parameters as changing the length of the CFRP sheets used and number of layers, Seven beams were constructed experimentally and studied to discuss experimentally two parameters which are the length and number of layers of CFRP sheets. Then a finite element models were developed to verify the experimental results by using (ANSYS). All specimens were investigated by using symmetrical strengthening configuration, and the same CFRP Area and length and width in both sagging and hogging regions. A comparison between the specimens' results from FEMs and values obtained and the experimental program was investigated. And it was concluded that both have the same trend and mode of failure. It was concluded that; the most effective parameters on the behavior of the strengthened reinforced continuous beams and the most effective parameters on the mode of failure of the strengthened beams can be easily deduced.

Keywords: CFRP sheets; Continuous R.C. beams; Strengthening; Beams Flexural behavior ; FEMs; ANSYS

INTRODUCTION

In recent years strengthening and upgrading existing structures has been among the most important challenges facing civil engineering. Either due to environmental factors or human factors as mistakes in design, construction defects, changes in the building use…etc. Traditional methods of strengthening were used in the past as introducing additional beams or by using externally post-tensioned cables, Using steel plates bonded externally to the tension face of the deficient beams has been proven a successful strengthen technique. However, the use of the steel plates has many disadvantages as corrosion, difficulty in handling and during construction. Several techniques have been developed to satisfy the strengthening and repairing demands considering the economic and technical conditions also these techniques have a huge effect on the strengthened element's behavior, load carrying capacity and serviceability requirements

Recently modern strengthening techniques are most commonly used in several structures, among the materials used for strengthening is fiber reinforced polymers (FRP), instead of the old traditional techniques as concrete jackets and bonding externally steel plates. Most of Egyptian buildings are reinforced concrete structures, in which gravity loads dominated the design. The lack of adequate design or appropriate detailing leads to the less ductility and more brittle failure of the structures. Rebuild of these structures to correct its problems is a very expensive solution. In recent years, several experimental studies have reported that both damaged and undamaged beams strengthened with externally bonded FRP sheets has a demonstrate effects on the flexural capacity of these beams with different ratios depending on the type of FRP , properties of the bonding resin, and the level of upgrading. El-Refaie et al. in 2003 [١] tested eleven reinforced concrete two span beams in flexure with externally bonded CFRP sheets. Two groups were arranged with different reinforcement ratios and one group included strengthening sheets over the central support while the second group included sheets at the soffits of each span. It was found a noticeable increase at the beams load capacity, beams exhibits less ductility compared to the control beams, Sudden failure occurs and he concluded that there was an optimum number of CFRP layers beyond which there was no further enhancement in beams capacity, Extending the CFRP sheets over the maximum bending moment zone will never prevent the peeling failure. Jiangfeng Dong et al. [٢] in 2013 studied experimentally reinforced concrete beams with external flexural FRP sheets consisting of carbon FRP and glass FRP. The investigation has examined both the flexural and flexural–shear strengthening capacities of retrofitted RC beams and has indicated how different strengthening arrangements of the sheets affect behavior of the RC beams they concluded that the flexural–shear strengthening arrangement is much more effective than the flexural one in enhancing the stiffness, the ultimate strength and hardening behavior of the RC beam. It was concluded by Bonacci and Maalej [٣] in 2000, that there must be an increase in the load carrying capacity in any strengthened specimen, as the CFRP reinforcement was added. And that increase in the load carrying capacity ranged between 10 and 35 percent for the strengthened beams compared to the control beams. Also, it was noticed that the increase in the capacity of the specimens was associated with a decrease in the deflection capacities ranging 10 and 32 percent of the control specimen at the same load. Khair Al-Deen Bsisu, Shad S. and Ryan B. [٤] investigated in 2015 the effect of width and the usage of multiple layers of FRP Sheets on strength and ductility of strengthened reinforced concrete beams in flexure. In this study, eleven beams were investigated, ten specimens which strengthened with fiber reinforced polymers of different widths and numbers of layers, Strains, and deflection at mid-span were recorded for each load increment. The data were investigated, as well as ductility and expected failure mode. The investigation concluded that the use of one layer fiber reinforced polymers wide sheets would increase the strength with a negligible decrease of ductility. Using multiple layers of wide fiber reinforced polymers sheets yielded more increase of strength but reduced ductility of the beams. Multiple narrow strips of FRP will not add to the strength but will reduce the deflection by reducing ductility. The survey of the literature showed the need for research on the behavior of strengthened continues beams with different strengthening schemes. To meet this need, this research is an experimental study to predict the behavior of the strengthened continuous reinforced concrete beams using CFRP sheets with different strengthening schemes under monotonic increasing load. And illustrate the general behavior of strengthened reinforced concrete beams using CFRP sheets. Seven Specimens were fabricated and strengthened using different strengthening scheme. A FEM was performed as verification to the experimental behavior and results; a parametric study was also investigated to discuss the effect of different parameters on the flexural behavior of the continuous reinforced concrete beams.

EXPERIMENTAL PROGRAM

The experimental program is a study to predict the behavior of the strengthened continuous reinforced concrete beams using CFRP sheets with different strengthening schemes under monotonic increasing load. The dimensions of the test specimens are shown in Fig.1.

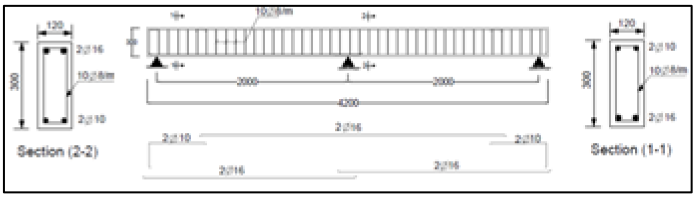


Fig. 1: Dimensions of continuous beams and reinforcement details (Units: mm)

- **Studied parameters and design**

The studied parameters of the experimental program were:

- Using unidirectional CFRP sheets as a strengthening technique to a continuous two equal spans reinforced concrete beams.
- Using CFRP sheets with different lengths as a strengthening technique in the flexure zone both in sagging and hogging zones with the same value (Symmetrically strengthened)
- Using CFRP sheets with a different number of layers.

The specimens' dimensions and reinforcement were kept constant; they were designed and detailed according to the Egyptian code, the beams sections were designed for high ductility to avoid brittle failure. As well as, the shear capacity was higher than the flexural capacity stirrups were used in order to avoid shear failure, the specimens were designed and detailed to carry gravity loads only without any precautions for the seismic load.

- **Test specimen formwork**

Wooden forms were used. The inner sides were cleaned as shown in Fig. 2; also the sides were strengthened to be fixed in place during casting. In order to attain simplicity and speed of casting, six wooden formworks had been fabricated and used; the reinforcement was arranged and placed in its proper position in the wooden forms as shown in Fig. 2

Fig. 2: Wooden formwork

- **Material properties**

Concrete mix: One mix proportion was used in this research; the mix was designed for desired 28 days compressive strength 35 N/mm2, it was designed using a locally manufactured ordinary Portland cement, the fine aggregate was cleaned and it was free from impurities. The mix proper portion by weight used in this research is shown in table 1.

Table 1: Concrete Mix Design

Cement	Fine aggregate	Coarse aggregate	W/C ratio
1	1.4	3.2	0.55

Reinforcement: Locally produced grade 52 deformed steel bars and grade 37 plain steel bars were used in this research, Grade 52 was used as main reinforcement, while grade 37 were used as stirrups.

Materials used in strengthening:

<u>Resin material:</u> Special epoxy resin was used in this research;, It consists of two components, Resin part A and hardener part B, Part A has a white color and B has a grey color, The mixing ratio component A to B = 4:1 by weight.

<u>CFRP Sheets:</u> The CFRP sheets (Carbon fibers reinforced polymers sheets)- is a unidirectional woven carbon fiber fabric for the dry application process. Fabrics (CFRP sheets) and resin are shown in Fig.3 respectively. Carbon fiber is another material for reinforcing concrete elements. Different stiffness grades are available; also they have perfect high strength and linear elastic behavior, the main use of this fiber is the active strengthening (constantly loaded). Nowadays carbon fibers are manufactured with more options as resisting alkali, acid (chemicals) as well as a Ultra Violet resistance, high fatigue resistance and low thermal expansion coefficient, they also resist fatigue corrosion. Based on tensile modulus and strength, the carbon fibers were classified into four groups, these groups are; standard modulus, intermediate modulus, and high modulus. In this study The dry fiber has a tensile strength of 4300 N/ mm2, and a tensile E-modulus of 238000 N/ mm2, the elongation at the break is 1.8 % , While the laminate has thickness 1mm/layer and ultimate load 350 kN/m width per layer and the tensile E-modulus is 28 kN/ mm2, based on the typical laminate thickness

Fig.3: CFRP and resin

- **Specimens preparation**

After placing the concrete in the formwork, the concrete was mechanically compacted using a handheld electric vibrator, as shown in Fig. 4, Specimens were cured for 10 days and 15X15X15 cm cubes were cast and cured with each specimen as control specimens to determine the mechanical properties of concrete. The Six specimens were fabricated and cast as previously discussed with cubes average compressive strength equals 35 N/mm2 . After 28 days the specimens were prepared for testing according to the different strengthening techniques. It is important to mention that the surface must be clean [5]and free of all the unwanted particles as Lubricants, dust, and dirt. A hand-held grinder was used to remove the surface layer which may contain dust and lubricants from the placement process, then the specimens were blown with compressed air to remove any excess particles as shown in Fig.4.

Fig.4: Mechanical compaction and surface preparation

The procedure of strengthening with CFRP sheets as Shown in Fig.5؛

.

Fig. 5: Steps of strengthening technique

➢ Instrumentation and loading schemes

Strain gauges: electrical resistance strain gauges with 10 mm gauge length were bonded to the control specimens. The Location of the steel strain gauges is shown in Fig.6. Also, three electrical strain gauges were installed at the surface of the CFRP sheets at the location of maximum flexural stresses in each specimen, as shown in Fig.6.

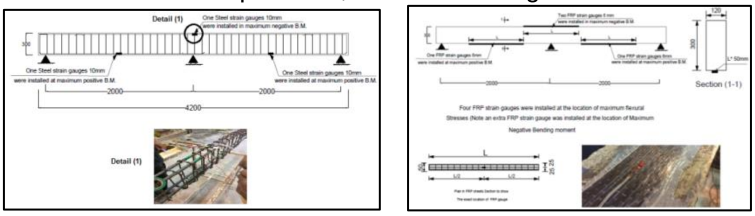


Fig. 6- Location of Steel and CFRP strain gauges

Data acquisition: All data from the load cell and strain gauges were recorded by the computer-controlled system, the load was applied by means of a hydraulic pump, and the loading hydraulic oil is controlled by a valve. The load application was at the mid-span for both spans to construct a 5-points loading test .Other instruments were used to collect and record as many data as possible from each specimen, Six LVDT were installed in each specimen to record the deflection values at three different locations to be able to ensure that the behavior of both spans is symmetric and the test is correctly performed. Fig. 7 Show the location of the six LVDT installed in each specimen. In this experimental program, all the measuring instruments and loading were connected to a computerized control station and data acquisition system.Fig. 8 shows the test set up and the location of the LVDT used to study the deformation behavior .

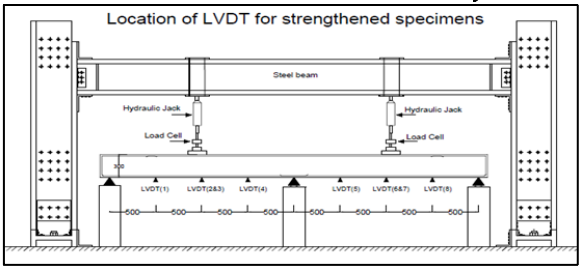


Fig. 7- test set up and location of LVD

The test set up and Loading scheme: The arranged set up was provided for a typical test arrangement used for the half-scale model of a continuous beam. Fig. 7 show the test set up. The steel supports were fixed to the rigid floor of the laboratory. A hydraulic jack was attached. One of the beam specimens supports is hinged and the other two are rollers. All the specimens were tested under monotonically increasing load. Also, rigid test beds (25X25X1.5cm) were used in each support and load application point to distribute the jack load over the cross-section. The control specimens for the strengthening were loaded until the failure is reached. Six specimens were studied with different parameters as CFRP sheets lengths and number of sheets' layers, and then they were all loaded till failure to compare their load capacity with the control specimen's behavior. The Load was applied to the specimen by using a hydraulic jack and was increased gradually till failure. The behavior of all specimens was observed and studied; all readings as steel and concrete strain were recorded to be able to obtain as much information as possible on the behavior of each specimen, to be able to compare the results. The mode of failure was also observed to be able to get a relation between these different parameters.

➢ Strengthening schemes for specimens

This section discusses in details the difference between each specimen and each strengthening technique will be discussed in details. Table 2 shows the different strengthening techniques for each specimen. See Fig. 10 for illustration of the strengthening technique.

Table 2- Strengthening schemes for specimens

Specimen's Name	Length of CFRP sheets used		Number of layers used (n)
	Positive B.M	Negative B.M.	
Ao	Control	Control	Control
A1	$L=50\% L_{total}=1$ m	$L=50\% L_{total}=1$ m	One layer
B1	$L=50\% L_{total}=1$ m	$L=50\% L_{total}=1$ m	Two layers
A2	$L=75\% L_{total}=1.5$ m	$L=75\% L_{total}=1.5$m	One layer
B2	$L=75\% L_{total}=1.5$ m	$L=75\% L_{total}=1.5$m	Two layers
A3	$L=100\% L_{total}=2$ m	$L=100\% L_{total}=2$ m	One layer
B3	$L=100\% L_{total}=2$ m	$L=100\% L_{total}=2$ m	Two layers

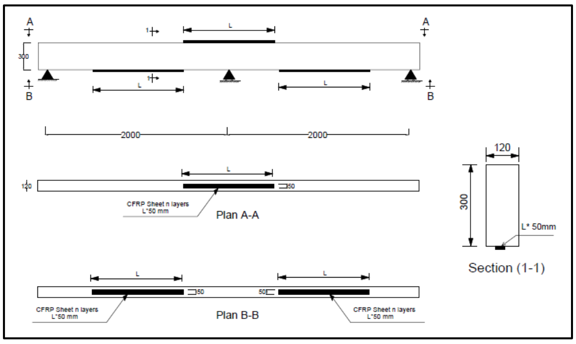


Fig.8: Strengthening technique

For the Control Specimen Ao; it was considered a reference specimen, which was used to investigate the behavior of the original specimen and to compare its testing results with these of the other specimens, the beam has 4000 mm as an overall length, and this length is divided into two spans each of 2000 mm. The beam's cross-section dimensions are 300X120 mm. The steel used at mid-spans and upper steel at the middle support is two bars of 16mm diameter, while the rest of the steel used is two bars of 10 mm diameter. Regarding the shear reinforcement, 10 bars of 8 mm diameter were used per meter. This specimen was loaded with a monotonically increased load till failure.The remaining five specimens were strengthened by using a single or a double layer of a unidirectional sheet of CFRP with width 50 mm and different lengths as mentioned in Table 5 and is applied on the required areas as shown in Fig. 9. It is important to note that the cross-section dimensions, as well as the reinforcement ratio, are exactly the same for all specimens as the reference specimen Ao. The application of CFRP sheets is symmetrical in both zones (sagging and hogging zones).

Fig.9a: Control Specimen Ao crack pattern

Fig.9b: the mode of failure for Specimen A1

Fig. 9C: the mode of failure for Specimen B1

Fig. 9d: the mode of failure for Specimen A2

Fig.9E: the mode of failure for Specimen B2

Fig. 9F: the mode of failure for Specimen A3

Fig. 9g: the mode of failure for Specimen B3

RESULTS DISCUSSION

Cracks were observed and traced for each load level, as well as, the immediate observation on the specimens' behavior during the test and the modes of failure; the contribution of each source of information to the behavior of the specimens are covered. All specimens were tested to observe their capacity and compare the strengthened specimens and the control specimens, and that allows the comparison between the different strengthening techniques, as well as, the observation of different properties as ductility, stiffness, and deformation of each specimen.

- **Strength evaluation and Mode of failure**

The cracking pattern is recorded carefully during the test, information about the failure mechanism is noticed and concluded from the cracking pattern and modes of failure, this section discusses the observations of each strengthened specimen. As well as, The strain values and deflection which were measured automatically at each load step and recorded.Table 3 and 4 show a summary or the results of each specimen and failure mode.

Table 3: shows the ductility and failure load

Specimen number	Description	Failure Load (t)	% of capacity increase	Max. deflection (mm)	% Ductility decrease / control
Ao	Control	12.5	,,,,,,	13	…
A1	1m/ 1 Layer	15	20%	2.53	82%
B1	1m/ 2 Layers	15	20%	2.75	85.40%
A2	1.5m/ 1 layer	15.25	22%	3.06	83.80%
B2	1.5m/2 Layers	15.5	25%	3.5	90%
A3	2m/1 layer	16	28%	3	78.20%
B3	2m/ 2 layers	14	12%	1.75	85.30%

Table 4: shows the mode of failure of each specimen

Specimen number	Steel yield load (t)	First crack Load(t)	Mode of failure	
			Mid-span	Above support
Ao	10	6	Concrete Crushing	Concrete Crushing
A1	11.5	4	Debonding (0.0038)	Rupture (0.018)
B1	10.5	5	Debonding (0.0068)	Debonding (0.0064)
A2	11	6	Rupture (0.018)	Partially debonding (0.0066)
B2	11	6	Debonding (0.00818)	Debonding (0.0056)
A3	11	6	Rupture(0.0016 8	Rupture (0.0175)
B3	10.5	6	Debonding (0.00108	Debonding (0.0035)

- **Comparison between results**

The results of each specimen were discussed in table 3 and 4 respectively. To clarify each specimen behavior a comparison will be discussed to study the change in behavior, Stiffness as well as the failure mode.

Comparison between specimens A1 and B1:

Both specimens have the same cross-section; both are strengthened by using CFRP sheets with dimensions (1000*50 mm) at the locations of the maximum flexure stresses. The only parameter considered for these specimens is the number of layers. Fig. 10 shows the difference in ductility. This figure shows that the ductility increases in case of using one layer of CFRP by 8.7%. While the capacity increases by 10% in case of using two layers. Stiffness is almost the same. Mode of failure at hogging zone is a rupture in case of using one layer with length 1m while de-bonding in case of using two layers. Also, shows a comparison between CFRP sheets strain for specimen A1 and B1 the relation between the steel load strain in specimens A1 and B1 for both sagging and hogging bending moment is also discussed and shown in fig.[10]

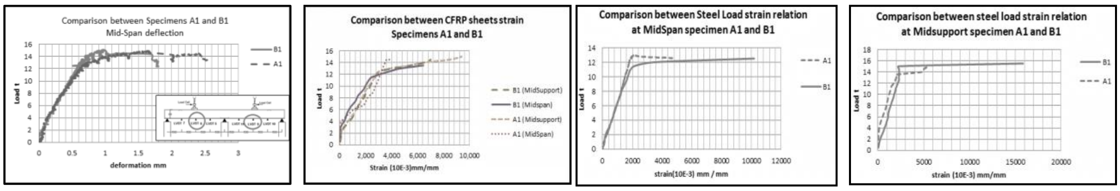


Fig.10- Comparison between specimen A1 and B1 deflection, CFRP strain-load, steel strain load relation respectively

Comparison between A2 and B2

Both specimens have the same cross-section; both are strengthened by using CFRP sheets with dimensions (1500*50 mm) at the locations of the maximum flexure stresses. The only parameter considered for these specimens is the number of layers. Fig. 11 shows the difference in ductility. This figure shows that the ductility increases in case of using one layer of CFRP by 21.5%. While the capacity increases by 5% in case of using two layers. Stiffness in case of two layers is more than one layer. Mode of failure at the hogging zone is de-bonding in both specimens and ruptures at mid-span in both cases. A comparison between CFRP sheets strain for specimen A2 and B2 is also shown in figure 11. The relation between the steel load strain in specimens A2 and B2 for both positive and negative bending moment is discussed.

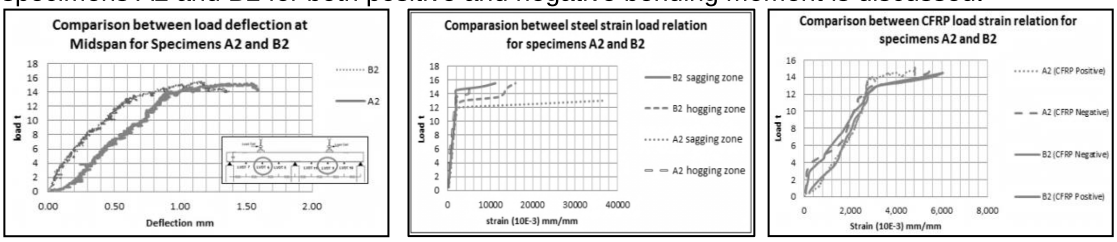


Fig.11: Comparison between specimen A2 and B2 Mid-span deflection, steel strain load relation and CFRP sheets strain respectively

Comparison between A3 and B3

Both specimens have the same cross-section; both are strengthened by using CFRP sheets with dimensions (2000*50 mm) at the locations of the maximum flexure stresses. The only parameter considered for these specimens is the number of layers. Fig.12 shows the difference in ductility. This figure shows that the ductility increases in case of using one layer of CFRP by 15%. While the capacity increases by 3% in case of using two layers. Stiffness is almost the same. Mode of failure for one layer is rupture while de-bonding in case of using two layers. Fig. 12 shows a comparison between CFRP sheets strain for specimen A3 and B3. Fig. 12 shows the relation between the steel load strain in specimens A3 and B3 for both sagging and hogging zones. It is important to notice that he capacity of B3 is smaller than the capacity of beam B1 because of the debonding in case of longer sheets with multiple layers. Debonding occurs and not rupture due to the multiple CFRP sheets layers used in this specimen

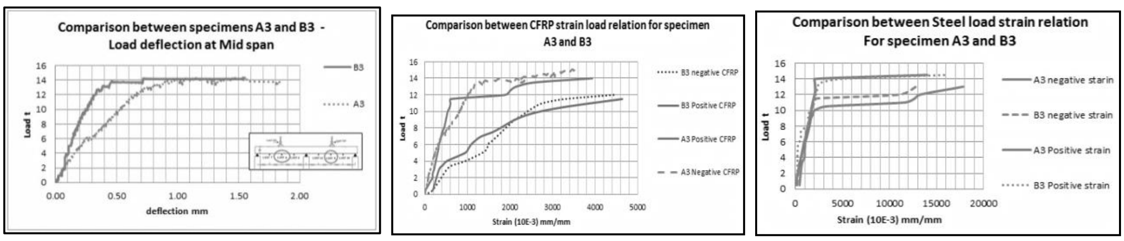


Fig.12- Comparison between specimen A3 and B3 Mid-span deflection, CFRP sheets strain and steel strain load relation

Comparison between Group A and Group B

These two groups mainly discuss the strengthening techniques using different variables as the number of layers and the length of the CFRP sheets used. Fig. 13 shows that specimen A1 is the most ductile specimen (least length of CFRP sheets used 1m), and A3 is the stiffest specimen (Largest length of CFRP used 2m). Higher capacity is for specimen A3 (largest length of CFRP sheets used). The large difference in stiffness and ductility is shown in Fig. 13, Fig. 14 shows that beam B3 is the least ductile specimen with the highest stiffness (Maximum length of CFRP used 2m). Beam B1 is the most ductile specimen (Least length of CFRP sheets used). The large difference in stiffness and ductility is shown in Fig. 14. As the control specimen has a larger ductility and lesser stiffness than any strengthened specimen. Fig. 15 shows a comparison between the mid-span load deflection relation for all specimens in group A and group B with respect to the control specimen Ao.

Table5: Difference in behavior and mode of failure between group A and group B

Group	Group A	Group B
Ductility	More	Less
Stiffness	Less	More
Capacity	Less	More
Mode of failure above Mid-support	Rupture	De-bonding
Mode of failure at Mid-span	Rupture	De-bonding

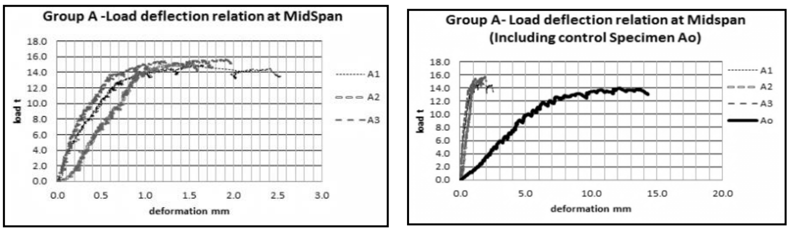


Fig.13 : Group A Load deflection relation at Mid-span and Including Control specimen

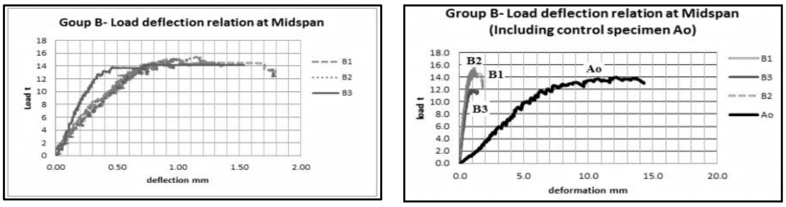


Fig. 14: Group B- Load deflection relation at Mid-span and Including Control specime

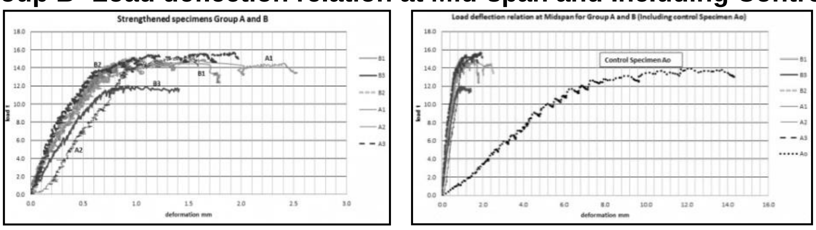


Fig. 15: Strengthened specimens Group A and Group B and including specimen

FINITE ELEMENT MODELING

This part represents the finite element models which solve the reinforced concrete continuous beams discussed previously in the experimental program. Finite elements programs such as ABACUS, ANSYS ….etc. are well known and commonly used to solve any complicated structural engineering problems, and it has high capabilities to predict and stimulate the nonlinear behavior of reinforced concrete beams [6]. An ANSYS finite element model is used to study the behavior of continuous reinforced concrete beams strengthened by using CFRP sheets. A comparison will be discussed -between the experimental models and the analytical models using ANSYS to study the behavior of seven full-scale reinforced concrete beams (with different strengthening techniques). The finite element models show good prediction and agreement with observations and data resulted from the experimental program.

- **Element Types**

The concrete was modeled using the element SOLID65 [7]. This element is capable of modeling the nonlinear behavior of concrete in tension and compression. A solid element is used to model the concrete. The solid element description is eight nodes with three DOF at each node, translations in the nodal x, y, and z directions. The element is capable of cracking and plastic deformation in three orthogonal directions. The steel reinforcing
Bars were modeled using the element LINK8 [7]. This element is defined by two nodes, each having three translational degrees of freedom. The element is also capable of plastic deformation. The CFRP sheets were modeled using the element SOLID46 [7] A layered solid element is used to model the CFRP composite. The element allows for up to 100 different material layers with different orientations and orthotropic material properties in each layer. The element has three degrees of freedom at each node, translations in the nodal x, y, and z directions. The loading and support plates were modeled using SOLID45 [7] this element is defined by eight nodes and has three degrees of freedom at each node, Translations in the nodal x. y and z directions. The element has plasticity, creep, stress stiffening, swelling, large deflections and large strain capabilities.

- **Material properties**

Concrete: Brittle material and has very different behavior in compression and tension. The tensile strength of concrete is 8-15% of the compressive strength Numerical expressions were constructed in 1964 by Desayi and Krishnan. Also it was modified in 1997 by Gere and Timoshenko [8].
Steel: The steel for this model was assumed to be an elastic-perfectly plastic material identical in both tension and compression. Modulus of elasticity 200000 MPa, Yield Stress 400 MPa, Poisson's ratio v = 0.3
CFRP sheets: This material is considered to be linear Isotropic as it is a unidirectional element, Tensile strength 4300 MPa, Elongation at break (ultimate failure strain) 1.8%, Thickness = 0.131 mm, Modulus of elasticity = 238000 MPa

- **Modeling methodology**

The full beam is used for modeling with proper boundary conditions with mesh size 25 mm. An exact stimulation for the reinforced steel and the stirrups were used in this modeling. Full bond strength between the concrete and steel reinforcement was considered. Fig. 16 shows the ANSYS model investigated. Fig. 27 shows the strengthened models.

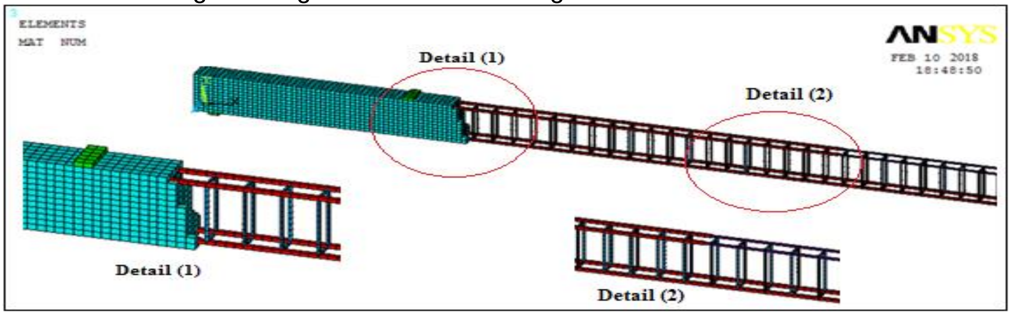


Fig. 16: ANSYS Ao

Comparison between the Experimental and FEM results

Load-deflection behavior

In general, the load deflection values for the beams from the finite element analyses are accurate with the experimental data. The finite element load-deflection values in the linear stage are accurate and best stimulation to the experimental data. After first cracking, the stiffness of the finite element models differs from the experimental. There are several effects that may cause the higher stiffness in the finite element models. As micro cracks which were presented in the concrete for the experimental beams, and it could be an effect of drying shrinkage in the concrete. It is should be kept in consideration that the finite element models are not including the micro cracks which reduce the stiffness of the experimental beams. Also, the assumption of the perfect bond between the concrete and steel reinforcing in the finite element analyses is not accurate for the experimental beams, as slippage occurs, the composite action between the concrete and steel reinforcing is lost. Thus, the stiffness of the experimental data is expected to be lower than for the finite element models. Fig. 17 show a comparison between the FEM and experimental results in deflection. Fig. 18 shows the control specimen deformation

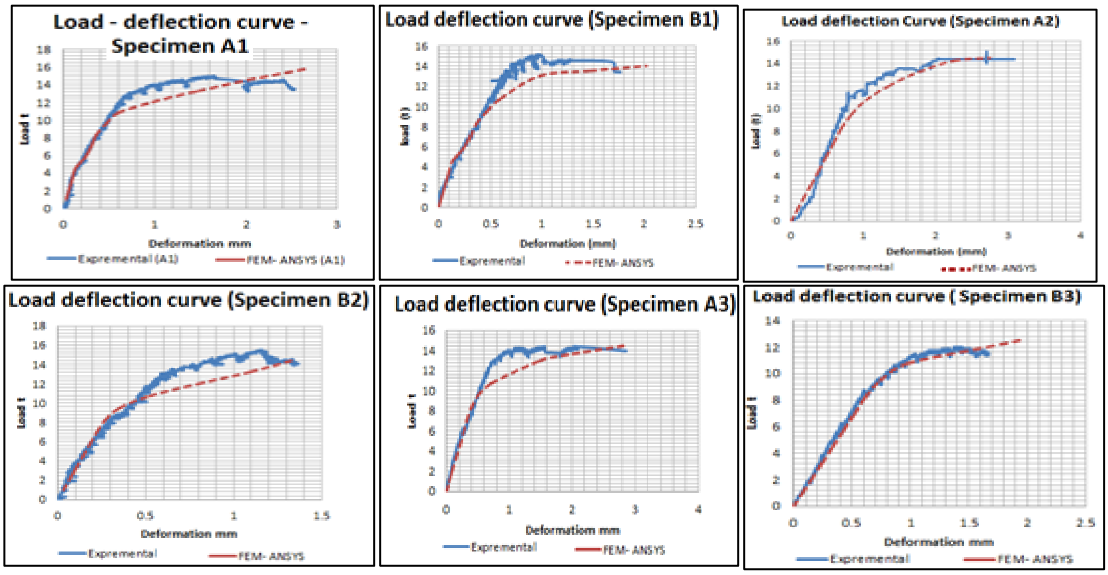


Fig. 17- Load deflection comparison FEM and Experimental Specimens

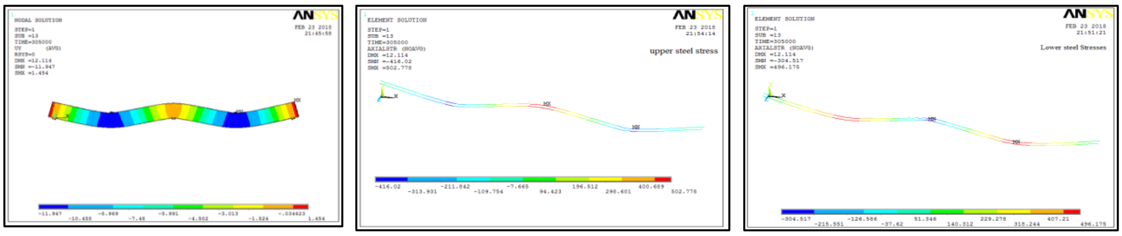


Fig. 18- control specimen deformation and steel stresses

The finite element analysis correlates well and showed high accuracy with those from the experimental data. In the nonlinear range, the trends of the finite element and the experimental results are generally similar. The finite element analysis supports the experimental results that the main steel bars at mid-span and above the mid-support for the control beam have reached the yield values at failure .

Stresses in concrete

The stresses in concrete were stimulated from the finite element model and the values result in an accurate stimulation to the experimental results and the normal behavior of the concrete beam, which assures that the loading schemes are symmetric and best representing to the experimental program done. As zones expected to be under compression or tension were presented in the model.

Evaluation of Crack Patterns for Concrete

At each applied load step, The ANSYS records a crack pattern. The cracks appear at the loading location on the control beam model. The appearance of the cracks reflects and stimulates the failure modes for the beams. Also, the cracking patterns Show the best stimulation to the experimental values, also assure that the loading schemes are symmetric and best representing to the experimental program. Fig. 36 shows the control specimen crack pattern. Fig. 19 shows the deformation and the crack pattern for specimen A0.

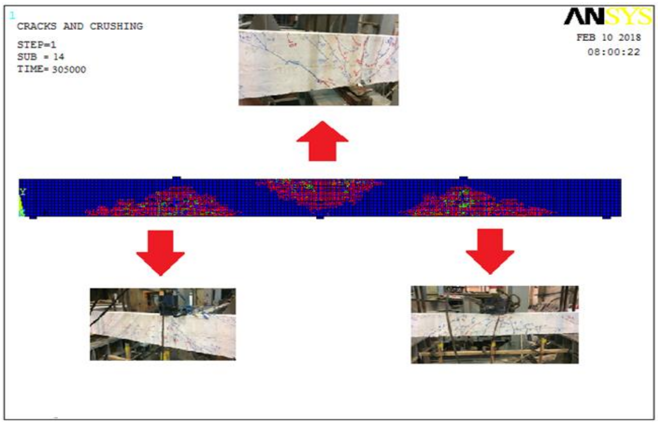


Fig. 19: FEM Crack pattern Specimen Ao

Due to investigation and comparison between the FEM results and the experimental results it was concluded that; The finite element models show good prediction and agreement with observations and data resulted from the experimental program. Table 12 shows the percentages of differences between the FEM values and the experimental results for each specimen. The maximum difference between both values in all the specimens is not more than 15%. Where F.L. is the failure load and ∆ represents the deformation

Table 12- The percentages of differences between the FEM values and the experimental results

	Experimental		FEM		Difference in values	
	F.L. t	Δ mm	F.L t	Δ mm	% forces	% Δ
Ao	12.5	13	12.75	10.8	2%	17%
A1	15	2.53	15.75	2.652	5%	5%
B1	15	2.75	14	2.5	7%	9%
A2	15.25	3.06	14.5	2.756	5%	10%
B2	15.5	3.5	14.5	3	6.50%	15%
A3	16	3	15	2.845	7%	5%
B3	14	1.75	12.5	1.83	11%	4.4%

CONCLUSION

Using one layer of CFRP is more effective than using two layers, as there is a slight increase in capacity but not very effective. the probability of debonding failure is higher when the number of layers increases, So the separation that occurs between the surface of the concrete and the sheets leads to the decrease in the efficiency of the sheets (it is not used completely till failure the debonding occurs before the failure of the sheets) in this case there is an insignificant increase in strength but the ductility decreases to a great extent, also the effectiveness covers both perspectives the ductility and the capacity. Using multiple layers of wide fiber reinforced polymers sheets yielded more increase of strength but reduced ductility of the beams. Multiple narrow strips of FRP will not add to the strength but will reduce the deflection by reducing ductility. It was concluded that, As the length of CFRP sheets increases the capacity increases as well . The main failure mode above the support (hogging zone) in case of using one layer is rupture, while in case of using two layers is de-bonding. The main failure mode at the mid-Span in case of using one layer is rupture, while in case of using two layers is de-bonding. This shows that the major mode of failure occurred at the mid-span is de-bonding while above the support is rupture. A comparison done between Group A (using one layer of CFRP sheets) and Group B (using two layers of CFRP sheets) and it was concluded that؛ Specimens strengthened with one layer of CFRP sheets are more ductile than Specimens strengthened by two layers of CFRP sheets. The specimens capacity increases when two layers of CFRP sheets were used as a strengthening technique The failure mode at the hogging and sagging zones is usually rupture in case of using one layer. The failure mode at the hogging and sagging zone is usually debonding in case of using two layers. The ductility of specimens strengthened with one layer of CFRP sheets may reach 21% more than the specimens strengthened with two layers. While the variation in specimens capacity could be increased by about 10% in case of using two layers instead of one layer. Beam B3 (strengthened using two layers with length 2m CFRP sheets as a strengthening technique) is the least ductile specimen with the highest in stiffness Beam B1 (strengthened using one layer with 1m CFRP sheets long) is the most ductile specimen (Least length of CFRP sheets used). The control specimen has a larger ductility and lesser stiffness than any strengthened specimen.

The results of the finite element program :
From the finite element analyses a comparison of the load-tensile strain and the experimental data for the main steel at mid-span and above the support, the finite element analysis correlate well and showed high accuracy with those from the experimental data .In the nonlinear range, the trends of the finite element and the experimental results are generally similar. The finite element analysis supports the experimental results that the main steel rebar's at mid-span and above the mid-support for the control beam has reached the yield values at failure. The load deflection values for the beams from the finite element analyses are accurate with the experimental data .The finite element load-deflection values in the linear stage are accurate and best stimulation to the experimental data. After first cracking, the stiffness of the finite element models differs from the experimental data . Higher stiffness in the finite element models were observed and that was due to micro cracks which were presented in the concrete for the experimental beams and could be an effect from drying shrinkage in the concrete. It is should be kept in consideration that the finite element models are not including the micro cracks which reduces the stiffness of the experimental beams . The assumption of the perfect bond between the concrete and steel reinforcing in the finite element analyses will not be accurate for the experimental beams. As slippage occurs, the composite action between the concrete and steel reinforcing is lost. Thus, the stiffness of the experimental data is noticed to be lower than for the finite element models. The concrete stresses were observed from the finite element model and the values results an accurate stimulation to the experimental results and the normal behavior of the concrete beam .The cracks propagations and scheme correlates well with the experimental pattern at the same load level .It is clear that the finite analysis models underestimate the strengths of the beams . The finite element model will never consider the small cracks occurs in beams due to handling or due to shrinkage also the interlocking between the cracked faces and the crack branching process is also neglected during modeling . The material properties assumed in FEMs models may be imperfect .Crack patterns obtained from the finite element analyses agree very well with the experimental study .The finite element analysis using ANSYS is a very accurate representation to the real properties which is performed experimentally. The numerical results obtained are in high agreement with the experimental; therefore, this technique is very effective in investigations, especially in case of performing parametric studies.

RESEARCH CONTRIBUION

The main contribution of this study is:
Study the flexural behavior of strengthened continuous RC beams using CFRP Sheets.
Study experimentally the effect of different strengthening scheme by changing the length and number of layers of the CFRP sheets used in the strengthening technique .

FUTURE RECOMMENDATIONS

The following recommendations are found to be important for the future research work:

- Studying the strengthening behavior of continuous beams with multi-span.
- Study unsymmetrical Span lengths for two spans or multi spans continuous reinforced concrete beams.
- Studying different parameters as the change of the cross-section dimensions. For the strengthened beams, and record the behavior change.
- Study different loading schemes as seismic behavior of continuous beams strengthened with CFRP sheets.

- Study the behavior of the repaired defected continues concrete beams.
- Study the behavior of continuous concrete beams with openings and study the effect of openings on its behavior.

REFERENCES

١. El-Refaie, S. A., Ashour, A. F. and Garrity, S. W. (2003) Sagging and hogging strengthening of continuous reinforced concrete beams using CFRP sheets. ACI Structural Journal, 100 (4): 446-453.

٢. Jiangfeng Dong, Qingyuan Wang , Zhongwei Guan , "Structural behaviour of RC beams with external flexural and flexural–shear strengthening by FRP sheets" Composites: Part B 44 (2013) 604–612

٣. J. F. Bonacci and M. Maalej, "Behavioral Trends of RC Beams Strengthened with Externally Bonded FRP." Journal of Composites for Construction Vol. 5, Issue 2 (May 2001)

٤. Khair Al-Deen Bsisu, Shad S., and Ryan B., "The Effect of Width, Multiple Layers, and Strength of FRP Sheets on Strength and Ductility of Strengthened Reinforced Concrete Beams in Flexure.' Jordan Journal of Civil Engineering, Volume 9, No. 1, 2015.

5. Grace, Hutchinson and Suo 'Moisture-induced Debonding in Concrete-epoxy Interface" The Hong Kong Institution of Engineers Transactions, Vol 19, No 3, pp33-38 Paper T0835-201102; 10 August 2011

6. P. Jayajothi, R. Kumutha, and K. Vijai. " Finite element analysis of FPP strengthened RC beams using ANSYS" ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 14, NO. 4 (2013) PAGES 631-642.

7. ANSYS – Release Version 12.A finite element computer software and user manual for nonlinear structural analysis

8. Z.Hassan, A. G.Sherif and A.H.Zamaraw. "Finite element analysis of reinforced concrete beams with opening strengthened using FRP." Ain Shams Engineering Journal Volume 8, Issue 4, December 2017, Pages 531-537.