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Nonlinear Flexural Behavior of Reinforced Concrete Cantilever Beam Strengthened by Sika Wrap CFRP

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Abstract: In this research, RC cantilever beams with the application of CFRP sheets are designed and modelled to be loaded till failure. The modeling can be divided into two types, the first type is experimental modeling by casting nine specimens divided into three groups based on their length, using high strength concrete and adding CFRP sheets. The second type can be considered as a finite element modeling by ANSYS program. The results from the experimental research of the nine specimens show detailed conclusions that can be presented for beams strengthened with CFRP sheets the yielding loads ranged among 113, 111 and 106% of the yielding load of the control beam of 1.1, 1.6 and 2.1 mL, respectively. As loads increase to ultimate loads were concerned the increasing of the ultimate strength ranged among 87.7, 83.15 and 80% when compared to that of the control beams. In case of increasing the compressive strength of concrete to (60 MPa) the increased the yielding and the maximum loads by 14.5, 12.5 and 9.6 as compared by the control beams of length 1.1, 1.6 and 2.1 m, respectively. And the ultimate percentages ranged among 35, 34.5 and 31%. The percentage of differences between the experimental results and ANSYS results are relatively close and ranged by 0.8-9.2% and was considered as reliable therefore the strain values on the extreme fiber of cantilever beam was taken into account and the full image of mind about the behavior of the cantilever beam and what is the limit of length was permitted to get stand with any increasing of loads.

Key words: Flexural behavior, high strength concrete, carbon fiber reinforced polymer, strengthening, nonlinear analysis, ANSYS program

INTRODUCTION

According to, the importance of the structural joints in reinforced concrete structures is considered as the supporting center and transmitting point for the applied loads from the other members which is represented as a RC cantilever beam many researches about the nonlinear behavior of flexural strength were studied by using all variables that related to increasing durability and strength.

Some of previous researches estimated the need of strengthening or upgrading for structurally inadequate transportation infrastructure by about 40% in united states. This inadequacy of structural strength due to several reasons such as potential damage due to mechanical damage and gradually lead to change the structural functionality till reaching failure, expired design life or some errors in design and construction.

In the present time several methods for increasing the final strength of RC structural members such as various types of additives or admixtures which is used in concrete mixing design stage and there are many other methods such as strengthening the structural members externally by adding materials that have major role in strength enhancement as Carbon Fiber-Reinforced Polymer (CFRP) which has a wide spread in strengthening and rehabilitation many RC structural members. The suitable techniques is by using CFRP sheet to wrap the columns or external bonding of laminates to concrete slab and beam, so, this technique is growing and become prominent due to ease of installation, increasing strength to weight ratio, negligible clearance loss and low maintenance costs (Toutanji *et al*., 2006; Soudki *et al*., 2007).

CFRP materials have superior mechanical and physical characteristics in comparison to steel, represented by tensile and fatigue strengths due to wide

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range of temperature in maintaining these qualities. Also the easy application of handling CFRP plate or sheet which reduces the labor costs. The handling can be carried out by aid of adhesive materials which has a major role in the application of CFRP strengthened RC beam and bonding mechanism by bedding the sheet or laminates on concrete beam surface (Meier and Kaiser, 1991).

In this research, RC cantilever beams with the application of CFRP sheets are designed and modelled to be loaded till failure. The modeling can be divided to two types, the first type is experimental modeling by casting nine specimens divided into three groups based on their length using high strength concrete and adding CFRP sheets. The second type can be considered as a finite element modeling by ANSYS program, so, the applied load is an equivalent load derived from the maximum load capacity according to beam cross section and its reinforcement not that load which is obtained from the actual model by testing specimens to make a comparison between the experimental and the theoretical results by observing the convergence or divergence of the values during its behavior under the ultimate load and also, knowing the weak points of the cantilever beam joint and what is the shape of failure.

The models from the two parts are designed by reinforcing the cantilever beam specimens with steel reinforcement ratio (ρ) equal or <(ρ_{max}) to determine the ultimate load capacity through the maximum reinforcement and checking the nonlinear response according to ultimate loading.

So, it is necessary to use of nonlinear frame analysis with respect to the availability of robust and computationally efficient models for performing analyses. Nonlinear materials were simulated in frame analysis. The RC cantilever beam is preferred to be modeled as solid finite element rather than modeling or controlling plastic hinge formation. Because in the brittle materials such as concrete, the cracks may developed anywhere of that cantilever beam (Coleman and Spacone, 2001).

The good structural design of a reinforced concrete members when exposed to an extreme overload the flexure failure should be occur rather than shear. Such members are tough give ample warning before failure takes place and have often the ability to resist impacts or successive loadings. While the shear failure is considered as relatively brittle and occur surprisingly in case of beams without stirrups and therefore, the prime objective is to design a cantilever beam with a shear reinforcement to minimize the risks involved from that failure (Collins *et al*., 2008).

After modeling rigid structural members to get with stand large amount of flexural and shear loads the experimental study is based on the additional strength which is come from CFRP sheets and increasing the compressive strength of concrete f_c while varying the actual length of RC cantilever beam.

From the other side analytical study by ANSYS program gives the complete understanding of the cantilever beam behavior under the optimum conditions of materials and the fixation of the fixed support also checking the calculated design load and observing its effect through studying the behavior of starting stress and strain values according to nonlinear materials and comparing the nonlinear behavior failure through knowing the yield force (that can be distinguished from the ultimate load from detecting the magnitude of elastic and inelastic strain and what is the applied load which is equivalent to each strain) with the experimental specimens.

MATERIALS AND METHODS

Experimental procedure

RC cantilever beam: Experimental and theoretical modeling were adopted with dimensions of (150×200 mm). Nine models were classified into three groups according to, their lengths and strength. Three lengths 1.1, 1.6 and 2.1 m were adopted. Normal concrete, high strength and normal warped from top by CFRP sheet for each length were cast and investigated. The concrete mixes design for both strengths are detailed in Table 1 and 2. The strength properties of each mix is defined through testing three cubes of dimension (150×150×150 mm) and three cylinders of dimension (150×300 mm) and three prisms of dimension (100×100×500 mm) after 28 days of curing by submerging samples in water tank to compute the 28th days compressive and tensile strength of concrete and other properties.

The characteristics of the other materials such as steel and CFRP are detailed in Table 3. The longitudinal steel reinforcement distribution based on the ultimate design strength with reinforcement ratio ρ in tension zone was approximately equal to ρ_{max} and also the spacing between stirrups based on assumption of the shear reinforcement force (V_s) equal to two times the concrete shear (V_c).

The aim of steel distribution in flexure and shear is to get rid of any increase demand of reinforcement to resist the ultimate load. Therefore, any increasing the capacity limit would be based on increasing the compressive strength of concrete (f'_c) according to the concrete

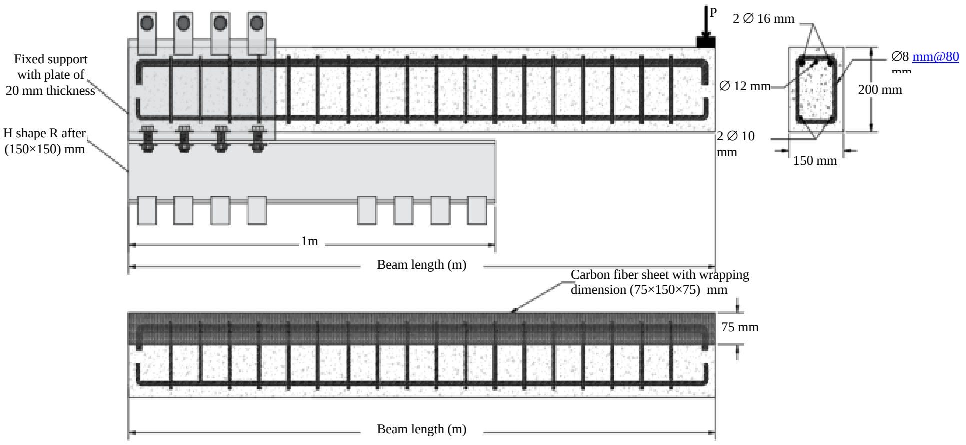


Fig. 1: Reinforced concrete cantilever beam details (in general length) and fixed steel support setup

Table 1: Mixing design characteristic of normal strength concrete

Characteristics	Content
Cement type	1
Cement (kg/m^3)	400
Sand	800
Aggregate diameter (mm)	5-19
Aggregate (kg/m^3)	1200
Water/cement ratio	0.44
Water (kg/m^3)	175
Superplasticizer	0
Slump (mm)	56

Table 2: Mixing design characteristic of high strength concrete

Characteristics	Content
Cement type	1
Cement (kg/m^3)	500
Sand	750
Aggregate diameter (mm)	5-19
Aggregate (kg/m^3)	950
Water/cement ratio	0.27
Water (kg/m^3)	135
Superplasticizer (percent of cement weight)	2%
Slump (mm)	74

Table 3: Characteristics of concrete, steel reinforcement and carbon fiber

Properties	Values
Normal strength concrete	
Compressive strength, f'c (MPa)	29.13
Rupture strength, f_r (MPa)	3.80
High strength concrete	
Compressive strength, f'c (MPa)	56.51
Rupture strength, f_r (MPa)	5.2
Longitudinal steel*	
Tension steel, as (mm^2)	515
Compression steel, as' (mm^2)	157
Yield strength, f'y (MPa)	500
Modulus of elasticity, Es (GPa)	200
Stirrups steel	
Type	No. 1
Spacing, Sv (mm)	80
Carbon fiber sheet*	
Tensile strength (MPa)	4300
Tensile E-modulus (GPa)	234
Thickness (mm)	0.13

*Ukrainian rebar of steel grade A 500 s, yield strength fy = 500 MPa, ultimate strength fu = 600 MPa, elongation = 14%, *Sika wrap 230 c/45 (woven carbon fiber for structural strengthening), area weight = 230 gm/cm^2, density = 1.76 g/cm^3, elongationat break = 1.8%

designed admixture and the application of CFRP sheets on the top surface. Figure 1 shows the details of cantilever beam reinforcement (in general length) and testing set up of fixed steel support.

Casting and specimen preparation: All beams were cast in painted plywood boxes molds with lubricating oil to be opened easily after 24 h and to prevent adhesion between the concrete surface and mold sides also to prevent the mold's surfaces from absorbing the water of mix. The fresh concrete was vibrated on a vibrator table and placed in a moist environment by casing the top face by plastic sheets. Specimens were demolded after 24 h and the curing started by submerging the specimens in large water tank for 28 days.

Also, the cubes, cylinders and prisms submerged to complete curing to be ready for testing the 28 days compressive and flexural strength of concrete. After extract all specimens from the curing tanks all sides were abraded to get rid of the hanged sand particles or other sediments and washing the top face by a clean water and dried before placing the CFRP bonded sheets.

CFRP reinforcement: For the strengthening RC cantilever beams, CFRP sheets (Sikawrap-230 C/45) were used. The yield strength, tensile strength and modulus of elasticity of the CFRP sheets were detailed in Table 3 are strong enough to increase the ultimate capacity of the cantilever joint. The application of CFRP sheets by size of 30 cm width bonded to concrete with organic epoxy matrix on the top beam surface to cover the full length by using a two part epoxy resin (Sikadur-330) which is easy mix and application by trowel and impregnation roller on dried and cleaned concrete surface after completing the curing period (28 days).

After applying the sikadur to the prepared substrate, place the unidirectional plain weave (CFRP sheet) on the painted concrete surface with the sika plastic impregnation roller parallel to the fiber direction until the resin is squeezed out between and through the fiber strands and distributed evenly over the whole fabric area, the specimens rest for 7 days in a room with moderate temperature (23°C) to get an epoxy resin having a tensile strength of 30 MPa tensile and elastic flexural and tensile modulus as 3800 and 4500 MPa, respectively (information was extracted from the manufacturer data sheet) (Spadea *et al*., 1996).

RESULTS AND DISCUSSION

After setting up the RC cantilever beam in fixed support instrument on flexural machine bench as shown in Fig. 2a-c the testing was conducted by applying a concentrated load at the end tip of an example symbolled beams as (CB, 1.1, 0.30) which means a cantilever beam of 1.1 m length without carbon fiber and compressive strength equal to 30 MPa.

In the experimental research, main important factors are considered as: yield to ultimate load and yield load to ultimate deflection. The results of the tested cantilever beams are given in Table 4. In this table, Py is the yield load, Pu is the maximum load capacity, Δy is the maximum deflection and Δu is the ultimate deflection.

Table 4: Results of experimental tested cantilever beams

	Load (kN)		Deflection (mm) and ductility		
Beam	Yield	Ultimate	Δy (mm)	Δu (mm)	Δu/Δy
CB, 1.1, 0, 30	36.65	44.50	2.76	20.15	7.30
CB, 1.1, C, 30	77.95	83.50	3.34	7.13	2.13
CB, 1.1, 0, 60	42.00	60.08	3.80	17.20	4.53
CB, 1.6, 0, 30	24.00	28.50	6.48	42.12	6.50
CB, 1.6, C, 30	50.67	52.30	10.83	22.32	2.06
CB, 1.6, 0, 60	27.00	38.33	7.79	33.50	4.30
CB, 2.1, 0, 30	18.25	21.70	13.36	115.33	8.60
CB, 2.1, C, 30	37.62	39.00	23.84	52.97	2.22
CB, 2.1, 0, 60	20.00	28.40	15.57	96.31	6.18

The load-deflection response of the tested composite and high strength cantilever beams at fixed support is shown in Fig. 3a-c. During initial stage of loading the response of cantilever beam is under elastic zone and the behavior is considered as linear, therefore, the cracks would not take place during this stage (Spadea *et al*., 1998). As the load increased, the first crack initiated on the top surface of the cantilever beam with slightly decreasing in stiffness till reaching the yield then the cracks extended slowly as an approximately straight and normal to the cantilever beam as shown in Fig. 4 a, b.

Width of crack also maximizes till reach final width as a failure mode at the ultimate load capacity after exceeding the yield limit which can be evaluated approximately by 85% ultimate load for cantilever beam of all different length without carbon fiber and compressive strength

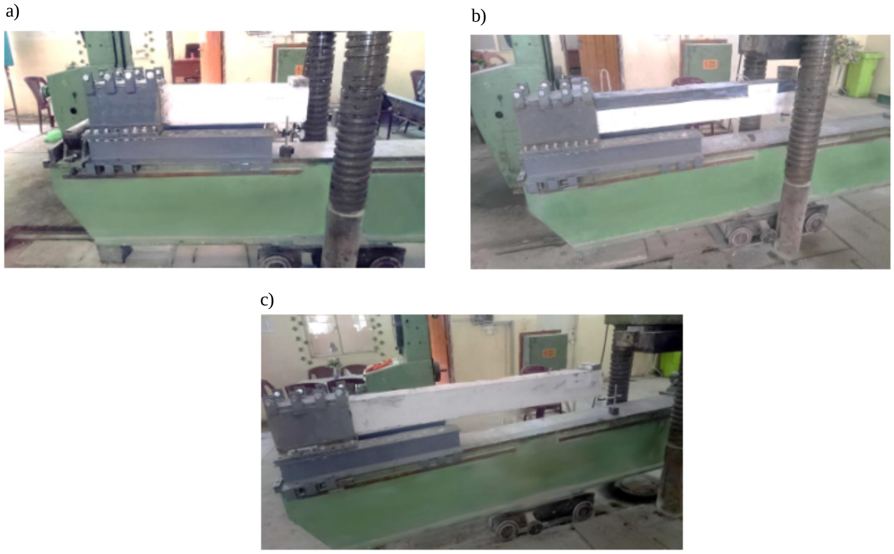


Fig. 2: Setting up of different length of cantilever beam fixed steel support setup; a) Setting up RC cantilever beam of 1.1 m with normal concrete; b) Setting up RC cantilever beam of 1.6 m with normal concrete and CFRP sheet and c) Setting up RC cantilever beam of 2.1 m with normal concrete

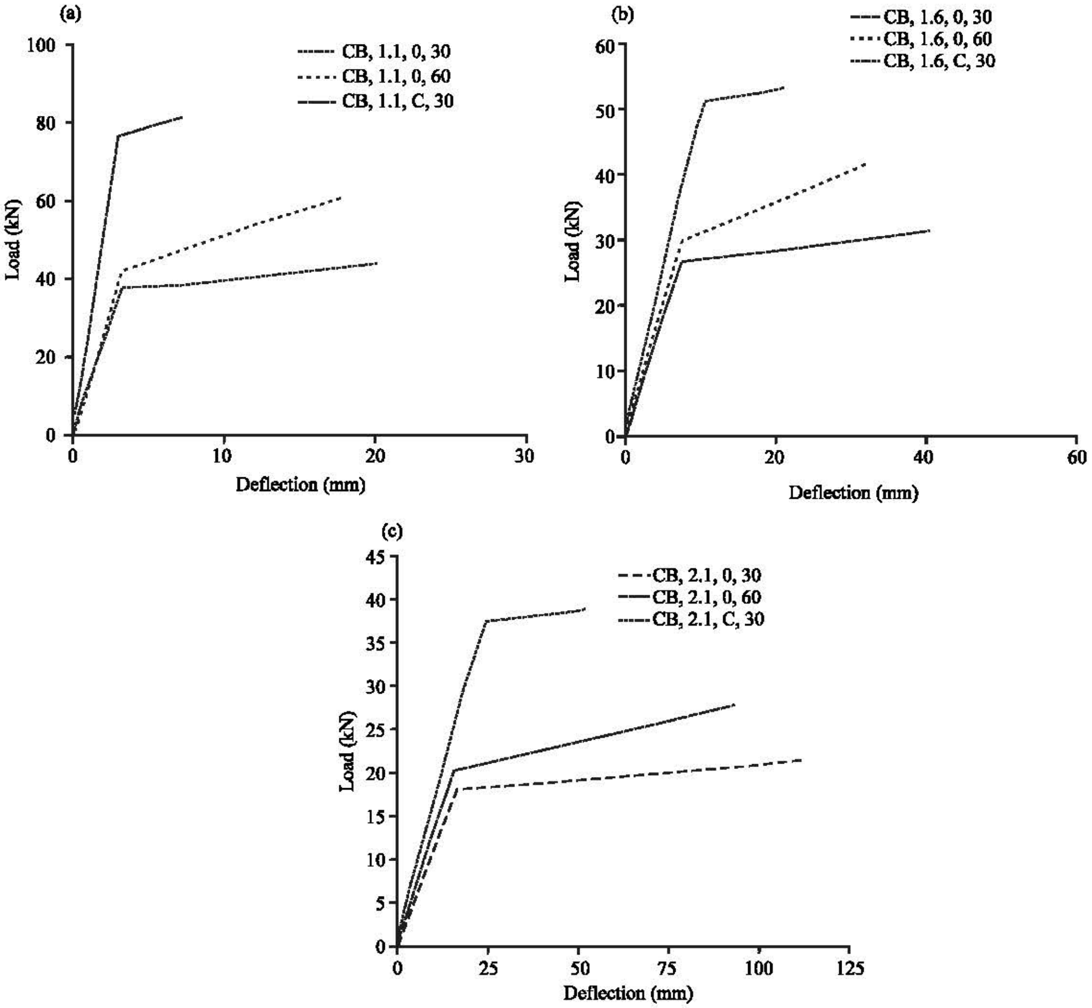


Fig. 3: Load deflection relationship for cantilever beam of different lengths; a) Load deflection relationship for cantilever beam of 1.1 m; b) Load deflection relationship for cantilever beam of 1.6 m and c) Load deflection relationship for cantilever beam of 2.1 m

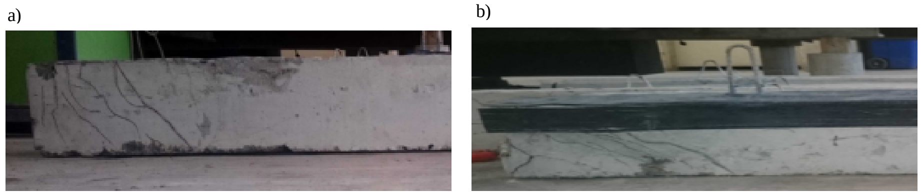


Fig. 4 a-d): Major modes of failure obtained from testing cantilever beams; a) Diagonal cracks of reinforced concrete cantilever beam without CFRP sheets; b) Diagonal cracks and CFRP debonding of reinforced concrete cantilever beam with CFRP sheets

equal to 30 MPa as (CB, 1.1, 0.30, CB, 1.6, 0.30, CB, 2.1, 0.30). For samples have CFRP sheets the yield strength is approximately 95% of the ultimate strength as (CB, 1.1, C, 30, CB, 1.6, C, 30, CB, 2.1, C, 30) which increases the cantilever beam rigidity but for cantilever beams (CB, 1.1, 0.60, CB, 1.6, 0.60, CB, 2.1, 0.60) increasing compressive strength of concrete to 60 MPa without carbon fiber give yield strength approximately about 70% of the ultimate load to give wide range of deformations before reaching failure. For continuous loading on beams the width of cracks getting expanding rapidly with the maximum width exceeding 0.32 mm and then the beam soon reached its ultimate load. Curves in Fig. 3 show a good ductile failure with large deformation in the inelastic region specially for beams with less rigidity as beams of 30 MPa and without carbon fiber with a constant steel reinforcement ratio. For this reason, a large plateau after the yielding of steel and reinforcement which means the results indicate that the constant amount of steel reinforcement and increasing the strength of beam by increasing the compressive strength of concrete to 60 MPa and casing the top surface concrete by CFRP significant effect on the moment strength of composite beams under negative bending. From the other hand during comparison of results it can find out the magnitude of ductility decreasing from 7.30 for CB, 1.1, 0.30-5.54 for CB, 1.1, 0.60 till reach 2.13 for CB, 1.1, C, 30 the same manner is found for the other beams of length 1.6 and 2.1 m. That results indicates also the significance of strengthening cantilever beam by concrete or adding carbon fiber get great advantage in maximizing the rigidity and getting less deformation and this can be clarified through te more hazardous beam of length 2.1 m when decreasing the ultimate deformation for the beam CB, 2.1, 0.30 of 115.33 mm to beam CB, 2.1, C, 30 of 52.97 mm. Also, the presence of CFRP increases the flexural strength as a increasing the final (ultimate) load from 21.70-39 kN for that beams.

Modes of failure: The control beam failed in the conventional way for normal and high strength concrete by yielding of tensile steel reinforcement followed by crushing of concrete in compression within the first 20th cm of the top surface in the fixed support region as shown in Fig. 4a. Beams strengthened with full-length of CFRP sheets from the top surface were failed by cracking concrete from the upper surface started from point exactly at the center length of the support by formation of a diagonal shear crack toward the end length of the bottom support. Which represented an actual failure behavior. The reason of causing the cracks gathering at the left upper part is the releasing energy came from the free end of the center of support also due to experimental difficulties by getting fully fixation support because the cantilever beam tend to slip from the fixed steel support under ultimate loading. Finally, the discontinuous end behaves as poor end to start failure from the inner end of support. For the beam strengthened with a full-length CFRP the failure was due to sheet de-bonding, initiating at the center of the fixed top length and still diagonal toward the inner bottom fixed edge. De-bonding was along sheet/adhesive interface and progressed towards the butt-joint between primary sheet as shown in Fig. 4b. For beams strengthened with CFRP after de-bonding of the sheet, loading was continued until concrete crushed at mid-span region.

Theoretical analysis by ANSYS: In modelling RC cantilever beam for theoretical analysis a finite element program (ANSYS 17.2) was used to study the flexural behavior of the structural element of rectangular section strengthened by using high strength concrete and applying the CFRP sheets on the top surface. Nine models of RC beams were built (ANSYS 17.2) as follows:

- CB, 1.1, 0.30-R.C cantilever beams of 1.1 m length with normal strength concrete and without CFRP as a control beam
- CB, 1.1, C, 30-R.C cantilever beams of 1.1 m length with normal strength concrete and using CFRP sheets
- CB, 1.1, 0.60-R.C cantilever beams of 1.1 m length with high strength concrete and without CFRP sheets
- CB, 1.6, 0.30-R.C cantilever beams of 1.6 m length with normal strength concrete and without CFRP as a control beam
- CB, 1.6, C, 30-R.C cantilever beams of 1.6 m length with normal strength concrete and using CFRP sheets
- CB, 1.6, 0.60-R.C cantilever beams of 1.6 m length with high strength concrete and without CFRP sheets
- CB, 2.1, 0.30-R.C. cantilever beams of 2.1 m length with normal strength concrete and without CFRP as a control beam
- CB, 2.1, C, 30-R.C cantilever beams of 2.1 m length with normal strength concrete and using CFRP sheets
- CB, 2.1, 0.60-R.C cantilever beams of 2.1 m length with high strength concrete and without CFRP sheets

3-D solid beam elements were used to model the concrete beam and steel main rebar and stirrups while the strengthening CFRP sheet is modeled as a surface element of the strengthened materials when attached to the top face of the full length concrete beam directly as shown in Fig. 5. Perfect bonding between strengthening CFRP sheet and the concrete was assumed (Mohamed *et al*., 2013). Plane stress assumption was used for surface meshing. Nonlinear and transient option was selected to run the program. However, the specific commands and

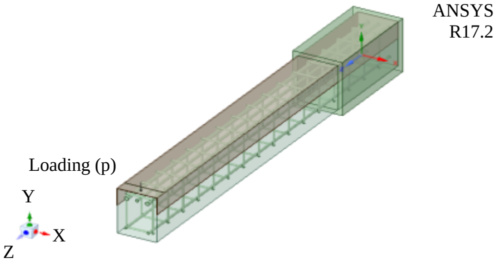


Fig. 5: Elements type of model and loading position

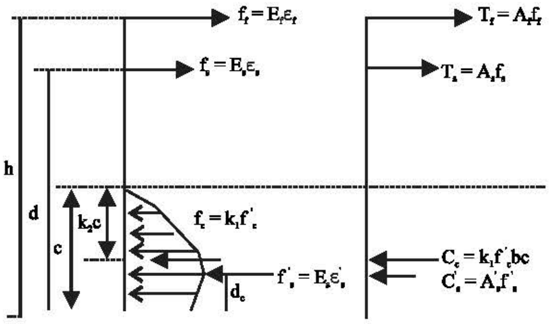


Fig. 6: Relation between nonlinear refractive index and different dye concentration

procedures that must be used for each of the steps will vary from one finite element package to another model of the analyses is shown in Fig. 5.

Modelling specimens: The modelling of the cantilever beam must be as the same as the designed specimens clarified below. All the cantilever beams specimens were of 150 mm width and 200 mm depth and classified into three groups according to the length as 1.1, 1.6 and 2.1 m were reinforced with 2 Ø10 mm diameter steel bars in the compression zone(bottom layer) and 2 Ø16 at corners of the top layer and 1 Ø12 at middle of the top layer. All the transverse reinforcement are of Ø8@80 mm steel bars as stirrups exactly as experimental program (ACI., 2005).

From each group one specimen is encased with full length by the CFRP sheets. It should be noted that the designed force which is applied for cantilever beams strengthened by CFRP sheet calculated according to the stress-strain relationship for concrete in compression is also assumed to be linear elastic. This assumption is valid since both the actual stress and strain in concrete extreme fiber and the strain of concrete ($\varepsilon_c = 0.003$) (ACIC440., 2002). Then the yield moment my should be calculated from (Fig. 6). As the following Eq. 1:

$$My = k_1 k_2 f'_c bc^2 + A'_s E_s \varepsilon'_s (c-d_c) + A_s f_y (d-c) + A_f E_f \varepsilon_f (h-c) \quad (1)$$

$$\varepsilon_c = \frac{c}{h-c}\varepsilon_{ff} \leq 0.003 \quad (2)$$

Where:

$k_{1,2}$ and c = Coefficients which determined in a stage before the ultimate strength

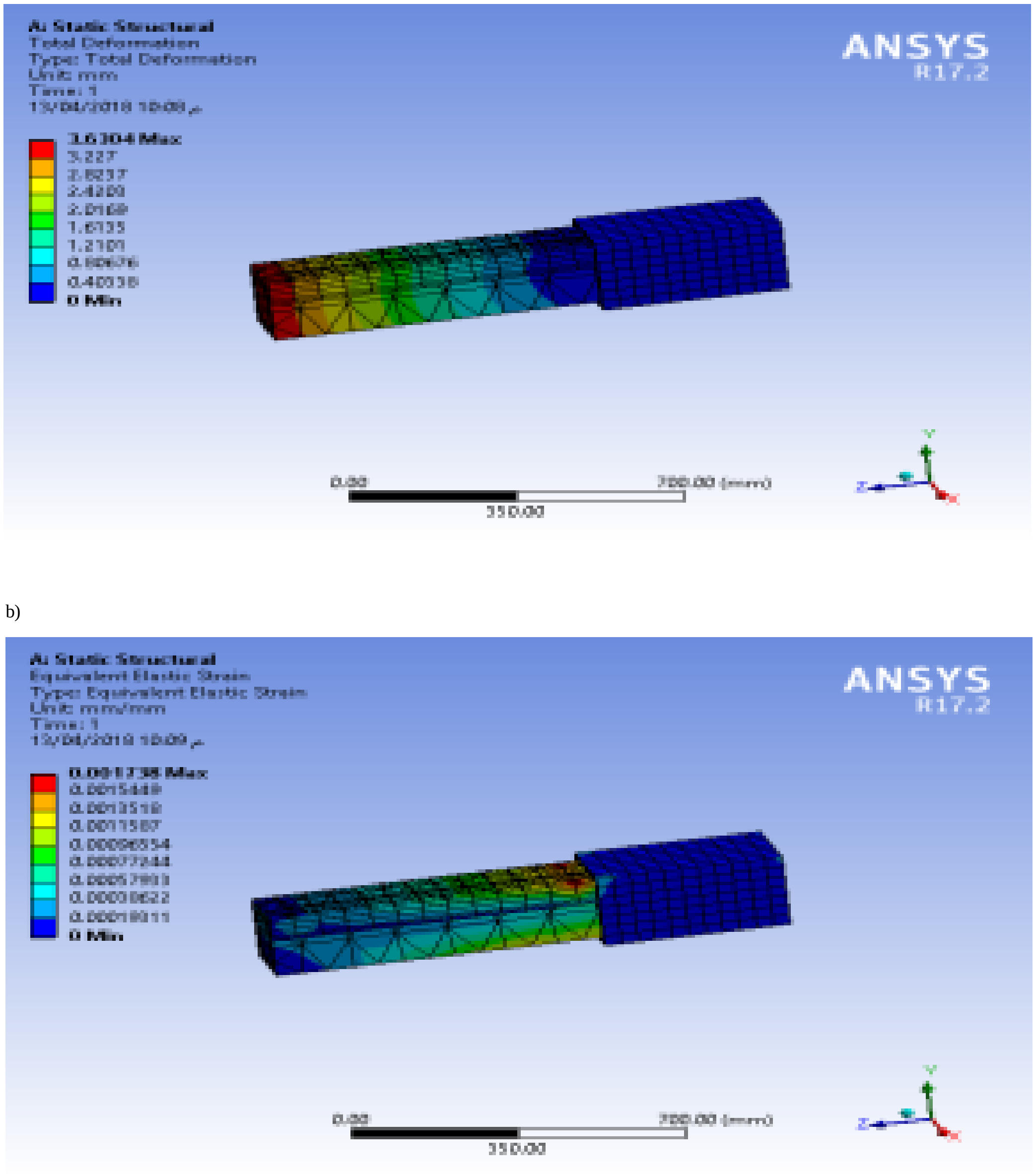
ε_{ff} = The FRP strain at beam failure

Table 5 shows the comparisons between the results of the measured yield (load-deflection) and the theoretical yield (loads-deflection) that give just elastic strain without entering in the plastic strain. From the comparison results it indicates that the experimental failure (yield) load of the tested cantilever beams (CB, 1.1, C, 30, CB, 1.6, C, 30 and CB, 2.1, C, 30) were higher than the ANSYS values by a little bit due to additional strength of bonding as increasing the amount of epoxy resin and making as possible as full bonding between the concrete surface and the CFRP sheet to get rid of the probability early failure bonding. Furthermore, the cantilever beams were designed according to ACI-318 M code under the condition of the reinforcement design. Therefore, the other beam specimens were able to carry more loads by a little bit after the yielding of the internal steel bar that permit to withstand a larger measured load than ANSYS values for all cantilever beams except the beam (CB, 1.1, 0.30) which is due to exceptional experimental research conditions.

Experimental results verification: To verify the experimental results it is compared with results from ANSYS 17.2 workbench application. Through modelling nine models and applying a concentrated force calculated from the stresses and forces of beam cross section according to the equilibrium of Fig. 6. The results are closed enough and the percentage of difference is <10% in case of comparing the yield force and yield deflection of experimental results with that resulted from the ANSYS Software. Depending on the closeness of the comparison results, the strain results can be reliable during this stage and showing the total strain in the concrete extreme fiber to check weather if the cantilever beam still in yielding stage due to the applied force and the derivation of the yielding moment. The total deflection and strain of the cantilever end tip is obvious for each group's length in case of cantilever beam as shown in Fig. 7.

Table 5: Results of tested cantilever beams by ANSYS

	Load (kN)			Deflection (mm)			
Beam	Yield Experimental	Yield ANSYS	Percentage of difference (%)	Δy Experimental	Δy ANSYS	Percentage of difference (%)	Strain (mm/mm) $_{ANSYS}$
CB, 1.1, 0, 30	36.65	36.89	1.77	2.76	2.50	9.20	0.001030
CB, 1.1, C, 30	77.95	77.45	0.64	3.34	3.28	1.79	0.001760
CB, 1.1, 0, 60	42.00	41.79	0.50	3.80	3.63	4.47	0.001178
CB, 1.6, 0, 30	24.00	23.77	0.96	6.48	6.36	1.85	0.001047
CB, 1.6, C, 30	50.67	50.38	0.57	10.83	10.74	0.83	0.001842
CB, 1.6, 0, 60	27.00	26.86	0.52	7.79	7.17	7.96	0.001212
CB, 2.1, 0, 30	18.25	17.78	2.57	13.36	12.76	4.49	0.001370
CB, 2.1, C, 30	37.62	37.11	1.36	23.84	23.55	1.22	0.002650
CB, 2.1, 0, 60	20.00	19.80	1.00	15.57	14.41	9.18	0.001370


a)

b)

Fig. 7: Continue

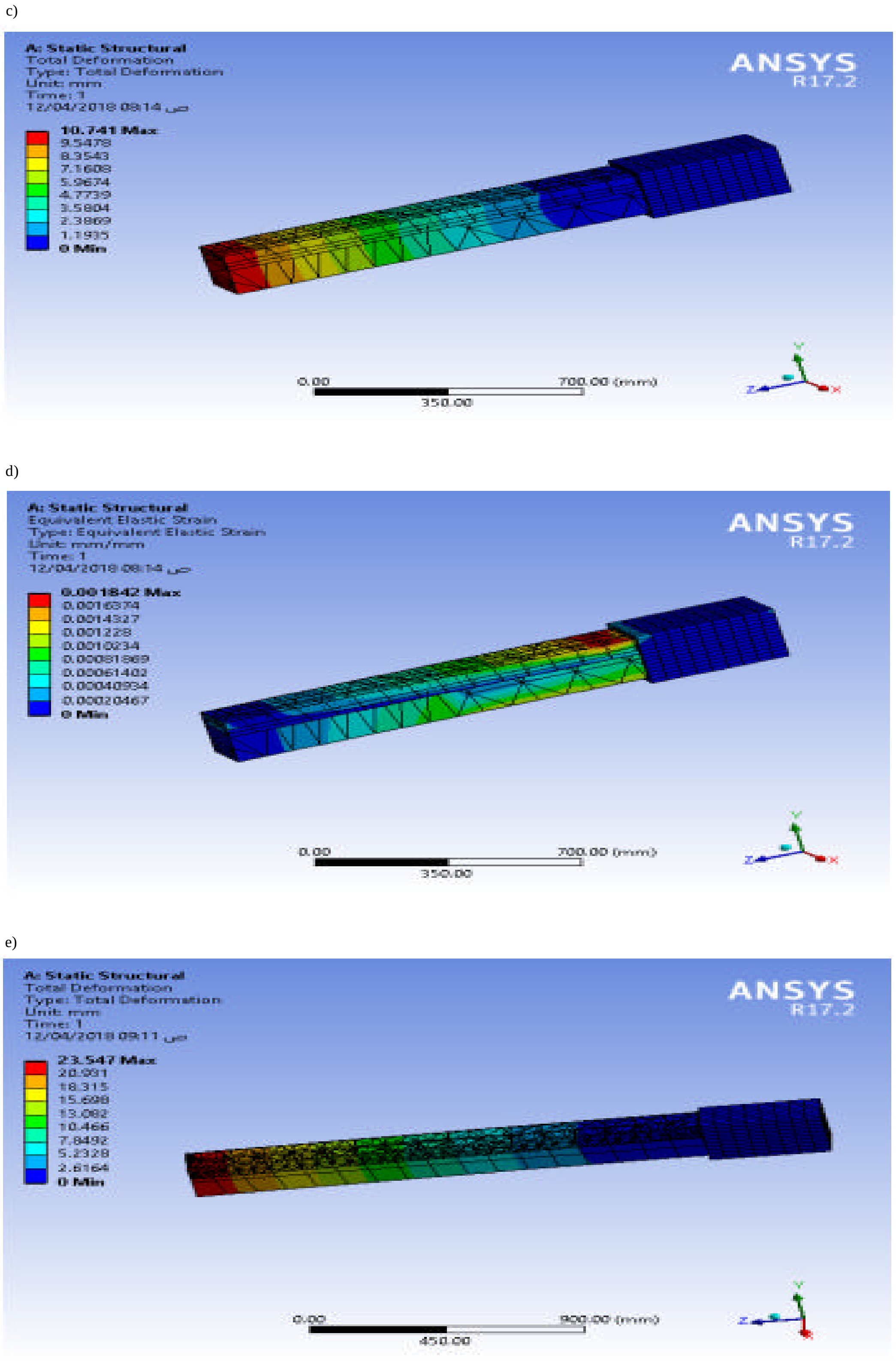


Fig. 7: Continue

f)

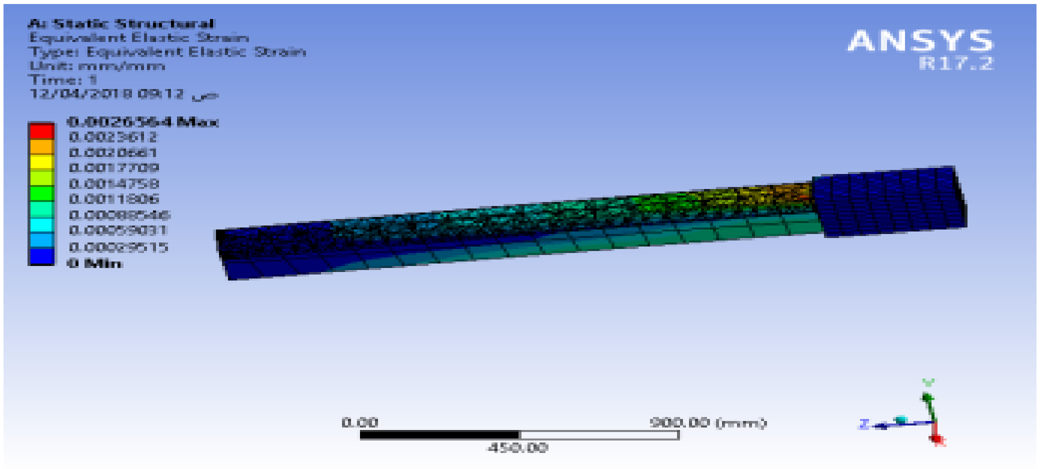


Fig. 7: Deformation and strain of RC cantilever beam with CFRP Models for each group; a) Total deformation for 1.1 m cantilever beam; b) Equivalent elastic strain for 1.1 m cantilever beam; c) Total deformation for 1.6 m cantilever beam; d) Equivalent elastic strain for 1.6 m cantilever beam; e) Total deformation for 2.1 m cantilever beam and f) Equivalent elastic strain for 1.1 m cantilever beam

CONCLUSION

Experimental and analytical program were carried out to study the effect of many variables which are applied on the flexural behavior of RC cantilever beams strengthened by CFRP sheet and high strength concrete in comparison to the reference or control specimens of normal strength concrete. The results from the experimental research of the nine specimens show detailed conclusions that can be presented for beams strengthened with CFRP sheets, the yielding loads ranged among 113, 111 and 106% of the yielding load of the control beam of 1.1, 1.6 and 2.1 m length, respectively, depending mainly on the bond strength of CFRP sheet and the properties of the epoxy resin. As loads increase to ultimate loads were concerned, the increasing of the ultimate strength ranged among 87.7, 83.15 and 80% when compared to that of the control beams, depending mainly on the area of CFRP sheet and the mode of failure mode of that beams. The relatively closed percentages of increment even the changing length of the cantilever beams.

In case of increasing the compressive strength of concrete to (60 MPa), the increased the yielding and the maximum loads by 14.5, 12.5 and 9.6% as compared by the control beams of length 1.1, 1.6 and 2.1 m, respectively. And the ultimate percentages ranged among 35, 34.5 and 31%. That means the enhancement of concrete strength to increase the yield load and also the ultimate by reaching approximately more than two times the ultimate strength of the normal concrete. Obviously, the magnitude of increment decreases gradually for both yield and ultimate load comparisons. From the other hand, the ductility decreases gradually in a uniform descending when the rigidity of the beam increases, so, this decreasing gave a great advantages in minimizing the total deformation through little deflection observed.

For verifying the reliability of the analytical model and the equations, nine cantilever beams were tested. Meanwhile the general purpose finite element software ANSYS was used to investigate the behavior of the composite beam, the nonlinear behavior of the material properties, crushing of the concrete and steel slippage from concrete and CFRP sheet de-bonding. The results from testing and finite element analysis show that the prediction of the deflection by the proposed analytical method was sufficiently accurate in designing a cantilever and the procedure can be used in further study on continuous composite beams.

And the percentage of differences between the experimental results and ANSYS results are relatively close and ranged by 0.8-9.2 and was considered as reliable, therefore, the strain values on the extreme fiber of cantilever beam was taken into account and the full image of mind about the behavior of the cantilever beam and what is the limit of length was permitted to get stand with any increasing of loads. And evenly it can be concluded beside which parameter has greater benefit in strengthening the cantilever beam specially in the fixed zone, the ANSYS 17.2 research bench has a useful usage in modelling and giving reliable results and gives the value of strain and stress for concrete surface, steel reinforcement rebar and CFRP instead of using strain gauges for every material as the aforementioned. Therefore, ANSYS can be considered as a qualified software and may replace the experimental research and what contain from tiredness, lost time, cost and research hazard.

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