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Nonlinear Analysis of Reinforced Concrete Beams Strengthened with Prestressed CFRP sheets Under Cyclic Load

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ABSTRACT:- Analysis of reinforced concrete beams strengthened by prestressed CFRP sheets has been investigated in this paper. A three dimensional finite element analysis ANSYS computer program (version 9.0) was conducted to obtain the response of the strengthened beams. The eight –node brick elements(solid 65) are used for the idealization of concrete while the CFRP sheets are idealized by using three-dimensional layered elements (solid 46).The steel plates are idealized by using three dimensional solid elements (solid 45).Five beams are analyzed in study ,four with prestressed –CFRP sheets and one with non-prestressed- CFRP sheet. The effect of different level of prestress ,induced by prestressing the CFRP –sheets, on the cracking loads and flexural stiffness of the strengthened beams are studied. It is found that the cracking load and the flexural stiffness are significantly increased as the level of prestress increased. The response of the strengthened beam under cyclic loads is also conducted in terms of deflection versus number of cycles which is related to the cyclic behaviour of the constituent materials used in the beam (concrete , tension steel, and CFRP sheets).

The deformation of each these materials under cyclic loadings is presented in terms of measured strains as a percent of the number of cycles of fatigue.

The results obtained from finite element analysis are compared with available experimental results and the comparison gives good accuracy.

Keywords: Prestress ,CFRP, strengthened, cracking loads, flexural stiffness ,cyclic loads.

1- INTRODUCTION

The strengthening of reinforced concrete beam by means of externally bonded fiber-reinforced plastic (FRP) sheets has gained great attention in recent years because the strengthening technique by using(FRP) sheets presents several practical advantages due to an easy installation on site, great geometrical flexibility, high strength-to-weight ratio, good durability, fatigue resistance and low creep (Hollaway and Leeming 1999) [1]. Although bonding a FRP sheet to a beam can increase its ultimate strength, the sheet does not significantly change the cracking load or the behaviour of the beam under service load. However, by prestressing the sheet, the laminate is used more efficiently since it contributes to the load – bearing capacity under both service and ultimate conditions. Several studies were made to investigate the behaviour of the strengthening beam by externally bonded FRP with or without prestressing. Triantafillou and Deskovic (1991) [2]reported an analysis of the problem of providing the maximum achievable prestress level without experiencing a de-bonding failure in the end zone. Triantafillou et al. (1992) [3] verified their analytical model by performing an experimental test. A reasonable agreement was achieved between their model and the obtained experimental results. It was also found that excellent flexural behaviour was obtained in terms of strength, stiffness, and ductility.

(Quantrill and Hollaway 1998) [4] investigated that prestressing produced significant increase in the load which causes yield of the internal steel over a non-prestressed specimen . Wight et al. (2001) [5] studied the flexural strengthening of RC beams using prestressed sheets mechanically anchored at the ends. The results have proven effective. Multilayer application of CFRP has been tested to achieve a different prestressing profile on the concrete beam.(Nordin et al 2006) [6]examined the use of prestressed NSM FRP to strengthen RC beams under static loadings. It was found that using prestressed quadratic CFRP rods increased the cracking load, yield and ultimate loads of the strengthened beams with respect to the reference beam.Several studies were also conducted in order to investigate the fatigue behavoiur of the strengthened beams by means of FRP with or without prestressing. Shahawy and Beitelman (1999) [7]studied the effect of using different numbers of CFRP laminate layers on the fatigue behaviour of strengthened RC beams. It was found that using three layers of CFRP laminates resulted in a greater flexural rigidity of the strengthened 30 beams compared to that of the beams strengthened with only two layers of CFRP laminate. Aidoo et al. (2004) [8]studied the fatigue behaviour of a large-scale reinforced concrete bridge girder strengthened with two CFRP composite materials. It was found that the fatigue behaviour of the strengthened beams was controlled by the reinforcing steel. It was also concluded that the fatigue life of the RC beams was increased by the application of FRP strengthening due to a reduction in the tensile stress carried by the steel. They also stated that the observed increase in the fatigue life was dependant on the quality of the bond between the concrete and the composite materials. In another study, Aidoo et al. (2006) [9] carried out a study to investigate the behaviour of RC bridge girders retrofit with CFRP materials under cyclic loading. Three different methods of 33 strengthening specimens were studied: a conventional adhesive applied CFRP, NSN CFRP and a proprietary CFRP retrofit using powder actuated fasteners. They concluded in their study that in the first type of strengthening methods, the bond strength was maintained under fatigue loading. Brena et al. (2005) [10] preformed a study on the fatigue behaviour of RC beams strengthened with CFRP sheets. Two types of strengthening configurations were investigated in their study. Ekenel et al. (2006) [11] assess the effect of fatigue loading on the flexural performance of RC beams strengthened with FRP fabric. They found that FRP strengthening increased the fatigue life of the beams by decreasing the stress in the reinforcing steel and reducing the crack propagation rate.

Finally in order to validate the model and the solution of present study, a three-dimensional nonlinear finite element analysis was conducted to study the general behaviour of reinforced concrete beams strengthened by prestressed CFRP sheets under cyclic loadings .

2.TEST BEAMS OF A PREVIOUS STUDY[12] :-

2.1 Test Setup:-

Experiments conducted for this study involve five beams, four with prestressed –CFRP sheets and one non-prestressed- CFRP sheets (Shang et. al.). Different level of prestress induced by prestressing the CFRP were used as summarized in Table (1) [12]. Strain gauges were used during the prestressing process measure the actual tensile force in the CFRP sheets. The details of this prestressing set up is described separately and can be found in Shang et al (2005) while an overall picture of the anchorages and stressing equipment can be shown in Fig (1). All the beams have the same dimension of 100x150x2200mm .The reinforcement ratio was set 0.67% for the beams. One layer of CFRP was applied to the reinforced concrete beams. The reinforcement plate was 90mm wide and with an average thickness of 0.167mm. Two point loading test was used and the loads was applied to the beams from the bottom upwards so that the prestressed CFRP sheets was placed on the top side of the concrete. The beams geometry, cross-section CFRP sheets was placed on the top side of the concrete. The beams geometry, cross-section dimensions, and load setup are shown in Fig (2).Materials mechanical properties for the tested beams are summarized in Table (2).[12]

2.2 Analysis Carried out in the Present Study for the Test Beams:-

A solid element, SOLID65, is used to model the concrete in ANSYS. The solid element has eight nodes with three degrees of freedom at each node, translations in the nodal x, y, and z directions. The element is capable of plastic deformation, and cracking in three orthogonal directions. The geometry and the node locations for this element type are shown in Fig .(3) [13]

This elements is also capable of predicting the nonlinear behaviour of concrete using a smeared crack approach. This element behaves as a linear elastic material until the effective stress reaches the tensile or compressive strength at an integration point, then the stress-strain relationship of the element will be modified by introducing a plane of weakness in the direction normal to the stress to represent the cracking.

The failure surface of concrete can be specified with a minimum of two constants f'c and ft or specified with all five parameters of concrete strength by Willam and Warnke criterion[14] in addition to an ambient hydrostatic stress state. f'c and ft can be determined from simple tests. The other three parameters default to Willam and Warnke. After cracking, the tensile stress of the concrete element is set to zero in the direction normal to the crack plane but the concrete between cracks can take tensile stresses due to bond with steel bars. Typical shear transfer coefficients range from zero to one , with zero value representing a smooth crack (complete loss of shear transfer) and one representing a rough crack (no loss of shear transfer). This specification may be used for both the rough crack and the smooth crack. The higher values of the shear transfer coefficient were used to avoid convergence problems which occur when the shear transfer coefficient β in βG for open crack drops below 0.2. No serious deviation of the response occurs with the change of the coefficient; therefore, the coefficient for open crack was set to 0.3.

For concrete, ANSYS requires input data for material properties as follows:

- Elastic modulus (E_c=29700 MPa).
- Ultimate uniaxial compressive strength fc'.
- Ultimate uniaxial tensile strength (modulus of rupture, $fr = 0.62\sqrt{fc'}$ [15])
- Poisson's ratio (ν =0.2).
- Shear transfer coefficient (β_t)

  Shear transfer coefficient (βt) which is represents conditions of the crack face. The shear transfer coefficient used in present study varied between 0.3 and 0.4.
- Compressive uniaxial stress-strain relationship for concrete.

  The stress- strain relationship for the concrete model was obtained using following equations to compute the multilinear isotropic stress- strain curve for the concrete :

$$fc = \varepsilon Ec \quad for \qquad 0 \leq \varepsilon \leq \varepsilon 1 \qquad \textbf{(1)}$$

$$fc = \frac{\varepsilon Ec}{1+\left(\frac{\varepsilon}{\varepsilon^{o}}\right)^{2}} \qquad (2)$$

$$\varepsilon_{\circ} = \frac{2fc'}{Ec} \tag{3}$$

$$fc = \varepsilon\, Ec \tag{4}$$

where:

fc = stress at any strain ε , psi
ε = strain at stress fc
ε_0 = strain at the ultimate compressive strength f_c'

The multilinear isotrpopic stress- strain implemented requires the first point of the curve to be defined by the user . It must satisfy Hooks Law:

$$E = \frac{\sigma}{\varepsilon} \tag{5}$$

The multilinear curves were used to help with convergence of the multilinear solution algorithm.

Fig.(4) shows the stress- strain relationship used for this study and is based on work done by Kachlakev,et al. (2001) [16]. Point 1, defined as 0.30 f_c ' is calculated in the linear range equation(4) .Points 2,3,and 4 are calculated from equation (2) with ε_0 obtained from equation (3). Strains were selected and the stress was calculated from each strain . Point 5 is defined at fc'. Crushing occurs at ultimate strain ε_{cu} =0.003-0.005(Point 6).

A Link8 element was used to model steel reinforcement. This element is a 3D spar element and it has two nodes with three degrees of freedom – translations in the nodal x, y, and z directions. This element is also capable of plastic deformation. This element is shown in Fig(5) [13]. A perfect bond between the concrete and steel reinforcement is considered. However, in the present study the steel reinforcing was connected between nodes of each adjacent concrete solid element, so the two materials shared the same nodes. The same approach was adopted for FRP composites. The steel for the finite element models is assumed to be an elastic-perfectly plastic material and identical in tension and compression as shown in Fig(6). Poisson's ratio of 0.3 is used for the steel reinforcement.

An eight-node solid element, Solid45, is used for modeling the steel plates which are added at the supports in the beam models in order to avoid stress concentration problems. A Poisson's ratio of *0.3* were used for the plates .The element is defined with eight nodes having three degrees of freedom at each node – translations in the nodal x, y, and z directions. The geometry and node locations for this element type can be shown in Fig.(7) [13].

In order to model the CFRP composite, SOLID46 is used for this purpose. 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.

Several input data needed for the FRP composites in the finite element models which are number of layers, thickness of each layer, orientation of the fiber direction for each layer, elastic modulus of the FRP composite in three directions (E_x, E_y and E_z), shear modulus of the FRP composite for three planes (G_{xy}, G_{yz} and G_{xz}), major Poisson's ratio for three planes (ν_{xy}, ν_{yz} and ν_{xz}) . The geometry and node locations for this element type are shown in Fig.(8) [13].

In the finite element models, nodes of the FRP layered solid elements are connected to those of adjacent concrete solid elements in order to satisfy the perfect bond assumption.

Due to prestressing, the initial unloaded stresses and strains in all mediums of a prestressed beam (concrete, steel reinforcement, and CFRP sheets) will have non-zero values. Because prestressing gives rise to an initial tensile strain in the CFRP sheet in an unloaded beam, the applied load required to cause the additional strain to rupture is less than for a non-prestressed strengthened beam in which the initial strain is zero.

The general behaviour encountered is an increase in deflection values as the number of loading cycles increase because of reduction in the materials strength due to fatigue which is the phenomenon in which a repetitively loaded structure fractures at a load level less than its ultimate static strength. For instance, a steel bar might successfully resist a single static application a 300kN tensile load ,but might fail after 1,000,000 repetitions of a 200kN load[13].

The main factors that contribute to fatigue failures include:-

1- Number of load cycles experienced
2- Range of stress in each load cycle
3- Mean stress experienced in each load cycle
4- Presence of local stress concentrations

In order to perform a fatigue evaluation by using ANSYS computer program, it needs to establish:-

1- The size (the number of locations , events, and loadings).
2-Fatigue material properties which can be represented by S-N curve, a curve of alternating stress intensity ((Smax-Smin)/2) versus allowable number of cycles, identify stress locations, and define stress concentration factor.
2- Store stresses at locations of interest for various events and loadings for each location as well as the number of repetitions of each events.

2.3 Analysis Results

In order to study the nonlinear behaviour of reinforced concrete beams strengthened with prestressed- CFRP sheets under cyclic loads ,ANSYS computer program is used for this purpose.

By taking advantage of the symmetry of the beams, a half of the full beam is used for modeling. This approach reduced computational time and computer disk space requirements significantly. The half of the entire model can be shown in figures (9), (10),(11) and(12).

Because a half of the entire beam is used for the model, planes of symmetry are required at the internal faces. At a plane of symmetry, the displacement in the direction perpendicular to the plane is held at zero.

The three –dimensional finite element analysis was conducted to optain the response of the strengthened beam with different prestressing level under static load in terms of applied load–deflection .

The response of the strengthened beam under cyclic loads is also conducted in terms of deflection versus number of cycles which is related to the cyclic behaviour of the constituent materials used in the beam (concrete , tension steel , and CFRP sheets)

The deformation of each these materials under cyclic loadings is presented in terms of measured strains as a percent of the number of cycles of fatigue.

From Figures (13) ,(14) ,(15),(16) and (17) ,we can observe a remarkable increase in the cracking load when the beam is strengthened with prestressed -CFRP sheets.

Thus ,for the beam strengthened with (20% prestressed) CFRP sheets , an increase in the cracking load is obtained with small decrease in the deflection and this change in the cracking loads and deflection are about (16)% and (2.5)% for the cracking loads and deflection respectively and they are about (25)% and (20)% for the beam strengthened with (35% prestressed) CFRP sheets

For case of the strengthened with (50% prestressed) CFRP sheets, the changes are about (18) % and (49) % for the cracking loads and deflection respectively.

Thus, prestressing of CFRP strengthened sheets increases the cracking loads and gives narrower flexural crack widths and smaller deflection which is the advantageous in terms of serviceability and durability of structural element.

At yielding stage , the yielding of reinforced concrete beams is the load causing yielding in tension steel reinforcement .From these figures, we can observe an increase in the yielding load and an increase in deflection with increasing in the prestressing level. Good agreement between experimental and numerical results can be obtained.

For the case of reinforced beam with non- prestressed CFRP sheets, failure occurred by concrete crushing preceding by yielding of the tension steel reinforcement.

A further increase in the ultimate load is achieved for the case of beam strengthened with prestressed CFRP sheets.

The ultimate load for case of (20% prestressed) strengthened beam is larger than the ultimate load of the strengthened beam with non-prestressed CFRP sheets .

Thus, as the prestressing level increases, the ultimate capacity of the strengthened reinforced concrete beam increases .Beyond a given prestressed level , a reduction in the ultimate capacity is observed . This can be shown and described in Fig .(18).

Fig. (19) shows the deflection behaviour of the strengthened beam with non-prestressed CFRP sheets versus normalized number of cycles.

A slow continuous increase in the deflection with an increasing number of cycles followed a more rapid initial increase can be shown in Fig. (20) for case of strengthened beam with (35% prestressed) CFRP sheets.

A similar deflection behaviour can be shown in Fig. (21) for the case of the strengthened beam with(50% prestressed) CFRP sheets.

The strengthened beam loaded at highest load range had an initial increase in deflection after which the deflection becomes stable .This beam failed by a bond failure.

Thus , the deflection increases with increasing number of cycles for case of beam strengthened with(50% prestressed) CFRP sheets is similar to that for other beams (non-prestressed , 20% ,and 35% prestressed strengthened beams).There is an initial increase in the deflection following by stabilization until near failure with a sudden large increase in deflection just before failure. Fig . (21)

Fig.(22) plots the compressive strain in the concrete versus the percent of normalized number of cycles to failure for case of the strengthened beam with non-prestressed CFRP sheets. A small increase in the compressive strain during the first fatigue life can be shown in this figure.

Fig.(23) shows the concrete compressive strain readings versus the normalized number of cycles for the case of the strengthened beam with(35% prestressed) CFRP sheets.From this figure ,we can be noticed that the maximum strain for this case of beam is much less than it is for the non-prestressed CFRP sheets. This is due to initial tensile strain induced in compression face of the beam by prestressing.

The changes in concrete strain with the number of cycles for case of the strengthened beamwith(50% prestressed) CFRP sheets are the same to that of the strengthened beam with(35% prestressed) CFRP sheets. Fig.(24)

The maximum tensile strain in steel reinforcement versus normalized number of cycles for case of the strengthened beam with non- prestressed CFRP sheets can be shown in Fig. (25) , from this figure , we can notice initial increase in the strain range of the tension steel reinforcement due to softening of concrete .Then after that , the strain readings stabilize till one of the tension steel reinforcement fails by fatigue with an increase in the force and the strains of the second bars.

Fig.(26) plots the maximum tensile strain versus normalized number of cycles for case of the strengthened beam with(35% prestressed) CFRP sheets. Little change in the steel strains until failure after an initial change in the maximum tensile strain in steel reinforcement.

For case of the strengthened beam with(50% prestressed) CFRP sheets, Fig.(27) show that the strains in steel reinforcement .For this case stabilizes after (10) % of their fatigue live and stays stable till (90)% of their fatigue lives.

Fig.(28) and Fig. (29) show the strain readings in the CFRP sheets versus normalized number of cycles as a percent of fatigue life for case of (35%) and (50% prestressed) CFRP sheets. From Fig. (28) we can show a small increase in strains at the beginning of cyclic loadings , due to concrete softening , following by stabilization in the reading until failure.

A reduction in maximum strains readings can be shown in Fig (29) after an intial increase.

The cyclic stress-strain curve for the case of the strengthened beam with (35%) prestressed CFRP sheets for two load ranges can be shown in Fig.(30) and Fig.(31).

Fig. (32) and Fig.(33) show the cyclic stress-strain curve for the case of the strengthened beam with(50%) prestressed CFRP sheets for two load ranges.

An increase in the maximum and minimum stresses can be shown in these figures as the load range increase and this increase will cause a reduction in the fatigue life.

CONCLUSIONS

The general behaviour of reinforced concrete beam strengthened with prestressing CFRP sheets under cyclic loads is conducted by using ANSYS computer program. The results obtained from finite element analysis are compared with other available experimental results and the comparison shows a good accuracy .A complement study is made by studying the response of the strengthened beam under cyclic loads.

The results obtained from finite element analysis can be viewed as follows:-

- Prestressing can cause effective increase in the flexural capacity of the reinforced concrete beam. For the case of the strengthened beam with non-prestressed CFRP sheets, a reasonable reduction in ductility is obtained compared with strengthened beams with prestressed CFRP sheets.
- Prestressing of CFRP sheets up to 50% of its ultimate capacity increases the flexural performance in terms of cracking ,yielding , and ultimate load, the increasing is about (18) % for the cracking load, (17.5%) for yielding load, and (11.8%) for ultimate load.
- Prestressing CFRP sheets increases fatigue limit of the strengthened beams and as the prestressing level increase ,fatigue limit of the strengthened beam increase.
- For the case of the strengthened beam with non-prestressed CFRP sheets, a fatigue rupture in the tension bar occurred .For case of the strengthened beam with(35% prestressed) CFRP sheets , a bond failure and fatigue failure in tension reinforcing bar occurred.
- For the case of the strengthened beam with CFRP sheets at high level of prestress (50% of its capacity),fatigue failure in prestressed CFRP sheets occurs before failure in tension steel reinforcement at a high load range.
- Prestressing increases the initial tensile strain in CFRP sheets and compressive strain in tension steel reinforcement.

Nomenclature

• Ultimate uniaxial compressive strength	f_c'
• Concrete elastic modulus	E_c

Steel elastic modulus	Es
Stress at any strain ε	fc
Concrete modulus of rupture	fr
Shear transfer coefficient	βt
Strain at stress fc	ε
Strain corresponding to $(0.3fc')$	$\varepsilon 1$
Ultimate compressive strain	ε_{cu}
Strain at the ultimate compressive strength	εo
Poisson's ratio	ν

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Table (1): Beam details.

Beam ID	Prestress (N)	CFRP initial stress due to prestressing (MPa)	Prestressing level (% of FRP's ultimate strength)	CFRP initial strain due to prestressing (10^{-6})
B1	0	0	0	0
B2	9000	588	20	3300
B3	16000	1046	35	6000
B4	16000	1046	35	6000
B5	22000	1438	50	8400

Table (2): Test results of material properties.

Material	Strength (MPa)	Modulus of elasticity (MPa)
CFRP sheet tensile strength	2941	207200
Longitudinal steel bars (8 mm diameter) tensile strength	309.9	224500
Steel stirrups (cold-drawn steel) yield strength	595	201200
Concrete cube compressive strength	24.9	29700

Fig.(1): Prestressing Set-up (Note That The CFRP Sheet is Being Tensioned on TheTop Surface of The Beam)[12]

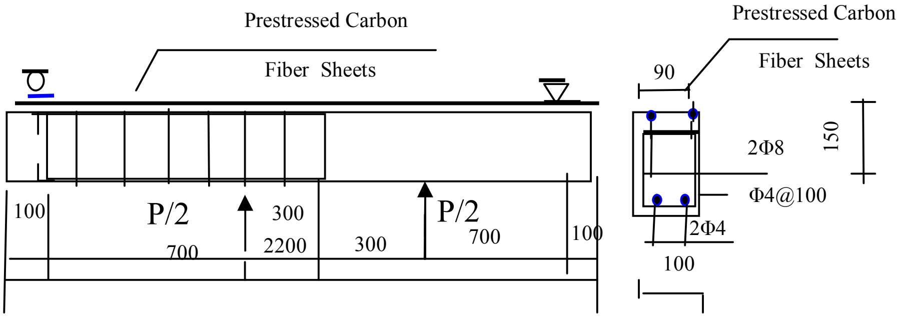
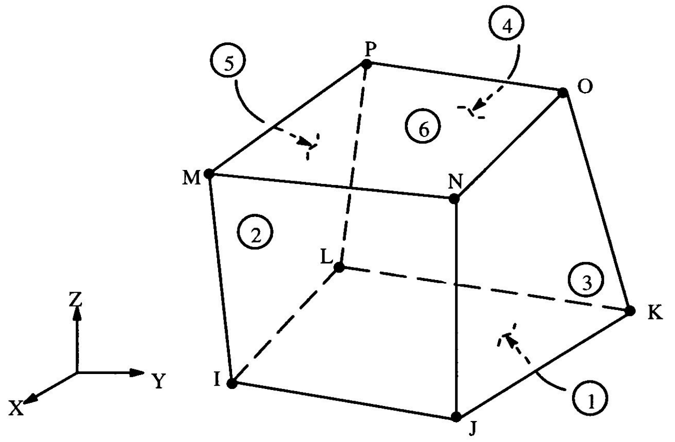


Fig.(2): Beam Details and loading Arrangement (NoteThe Load was Applied from The Bottom Upwards).



Fig(3): Solid65 – 3-D Reinforced Concrete Solid [13]

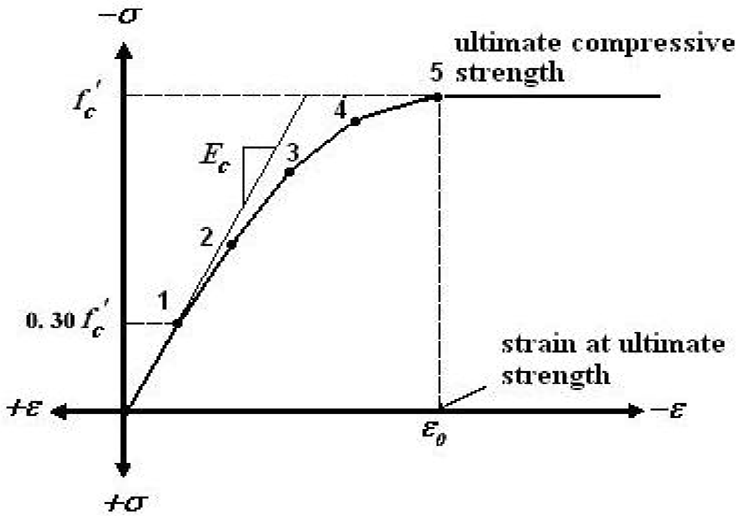


Fig.(4): Stress- Strain Relation Model for Concrete[16]

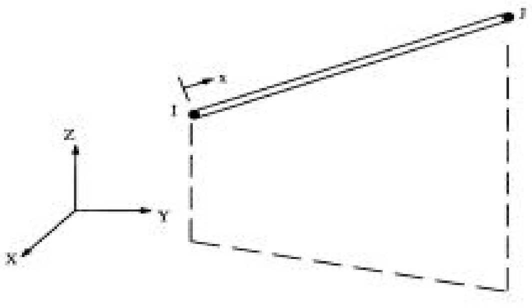


Fig.(5): Link8 Element Geometry[13].

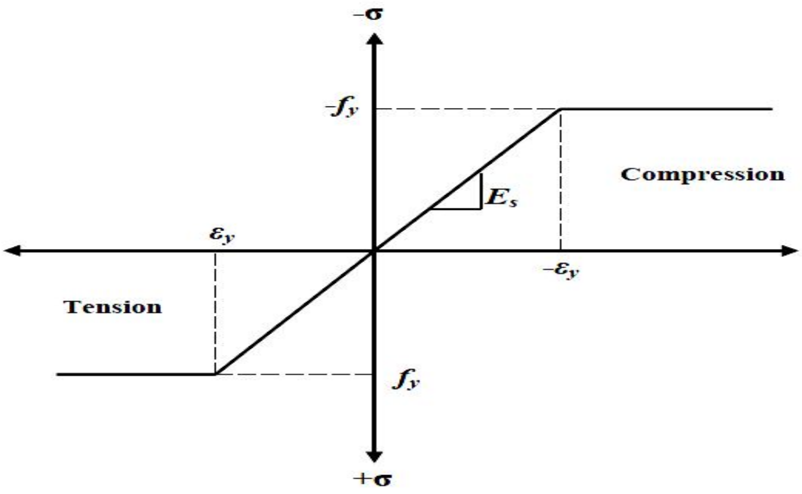


Fig.(6): Stress-Strain Curve for Steel Reinforcement.

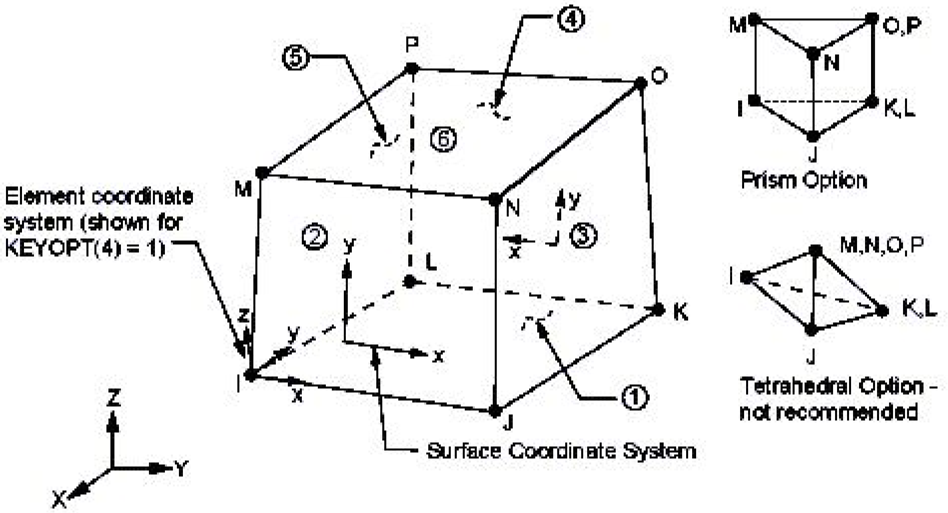
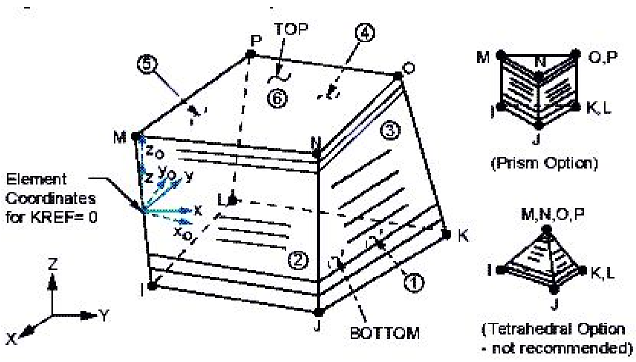


Fig.(7): Solid45 – 3-D Solid[13].



x_o = Element x-axis if ESYS is not supplied.

x = Element x-axis if ESYS is supplied.

Fig.(8): Solid 46 Layered Element Geometry[13].

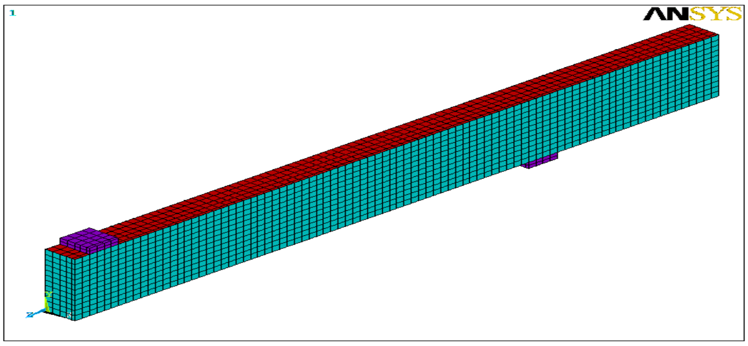


Fig.(9): Finite Element Modeling for CFRP Strengthened Beam (Iso View).

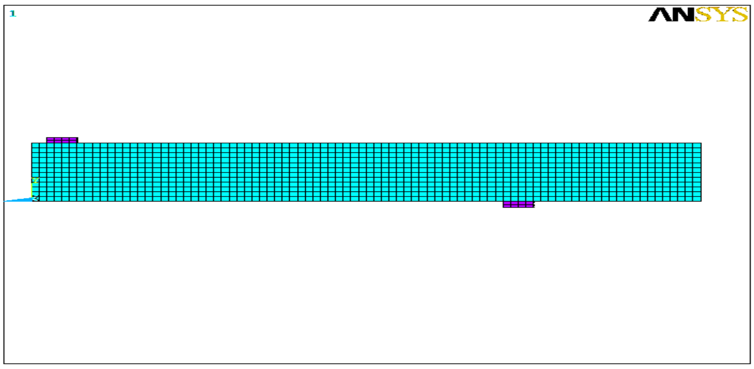


Fig.(10): Finite Element Modeling for CFRP Strengthened Beam (Right View).

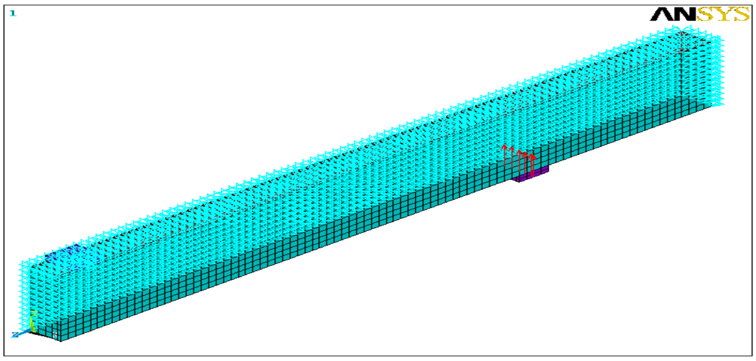


Fig.(11): CFRP Strengthened Beam with Boundry Condition.

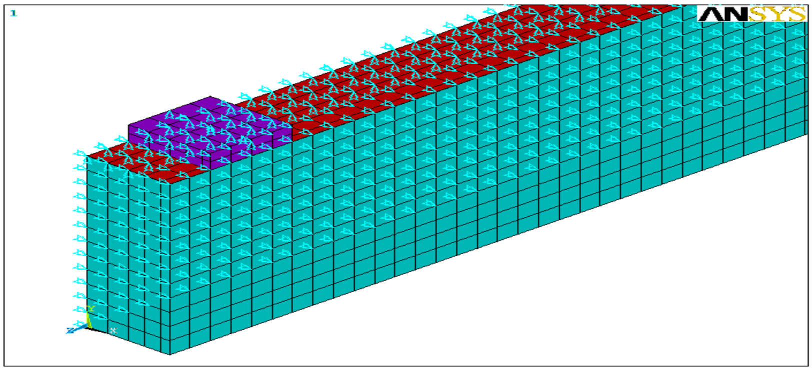


Fig.(12): Loading and boundary conditions (not to scale).

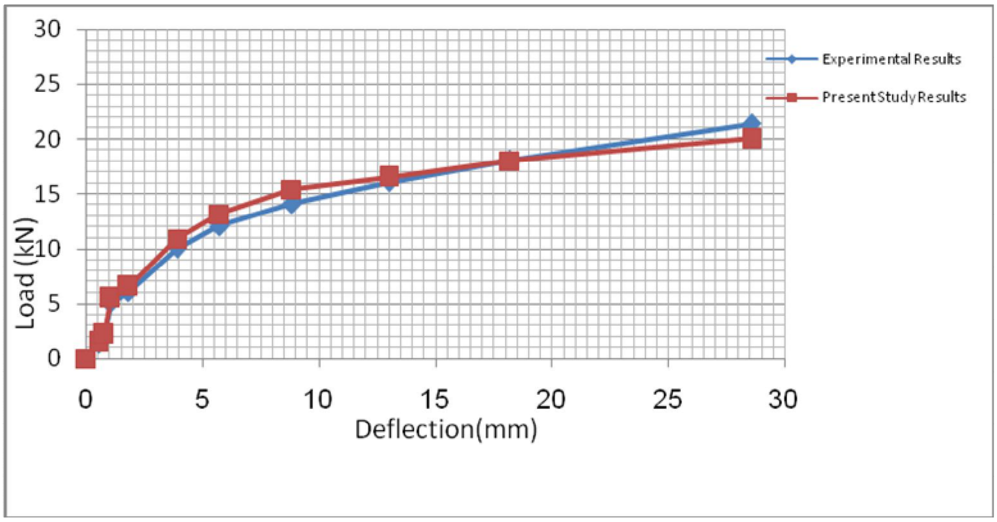


Fig.(13): Load Deflection Relationship for Case of The strengthened Beam with Non-Prestressed CFRP Sheets.

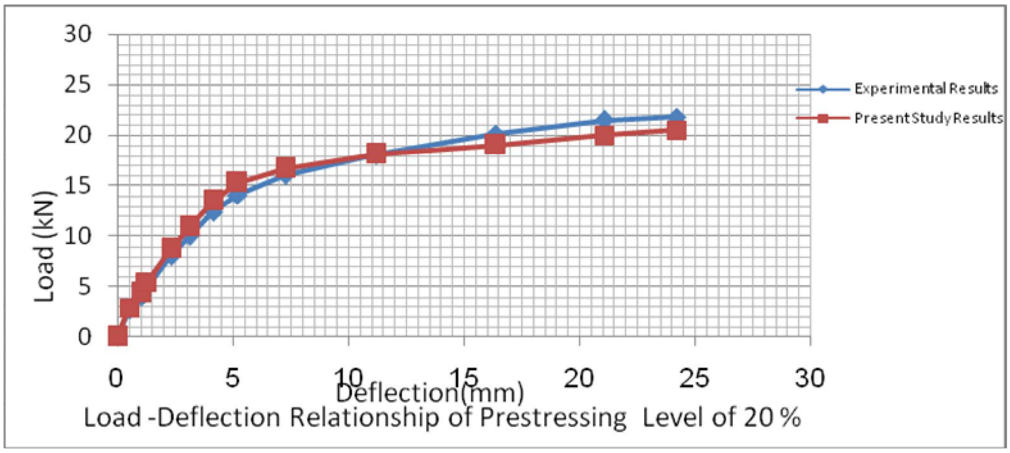


Fig.(14): Load Deflection Relationship for Case of The Strengthened Beam with 20% Prestressed CFRP Sheets.

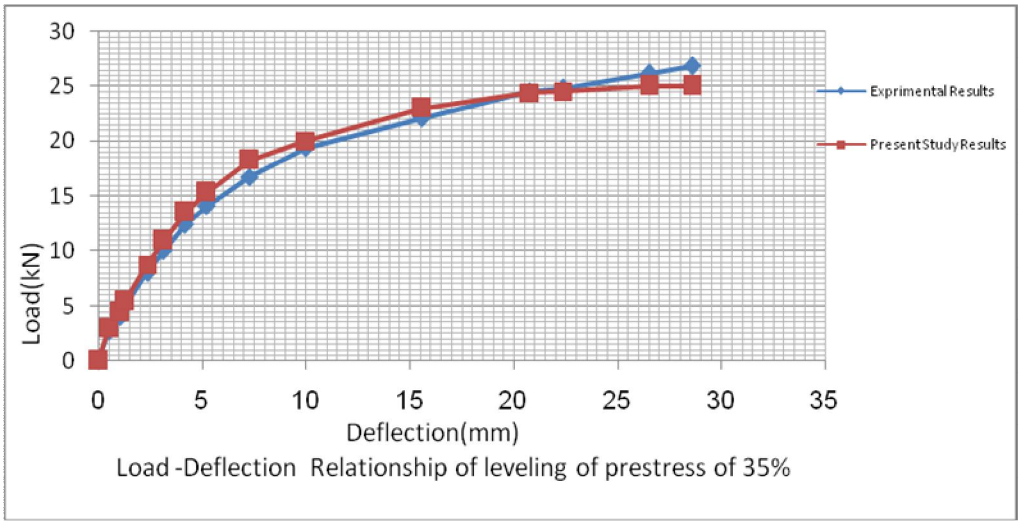


Fig.(15): Load Deflection Relationship for Case of the strengthened beam with 35% Prestresssed CFRP sheets.

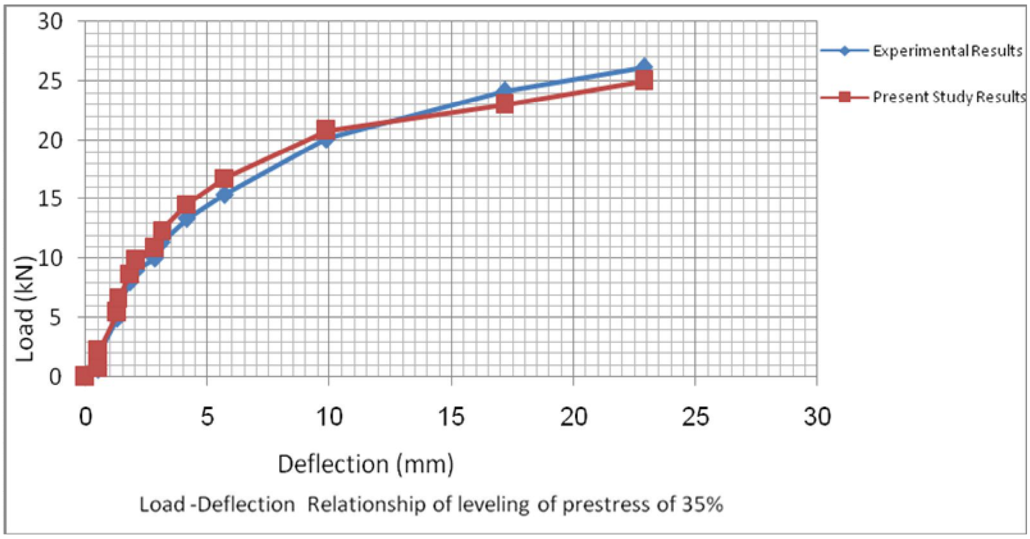


Fig.(16): Load- Deflection Relationship for Case of The Strengthened Beam with 35% Prestressed CFRP sheets.

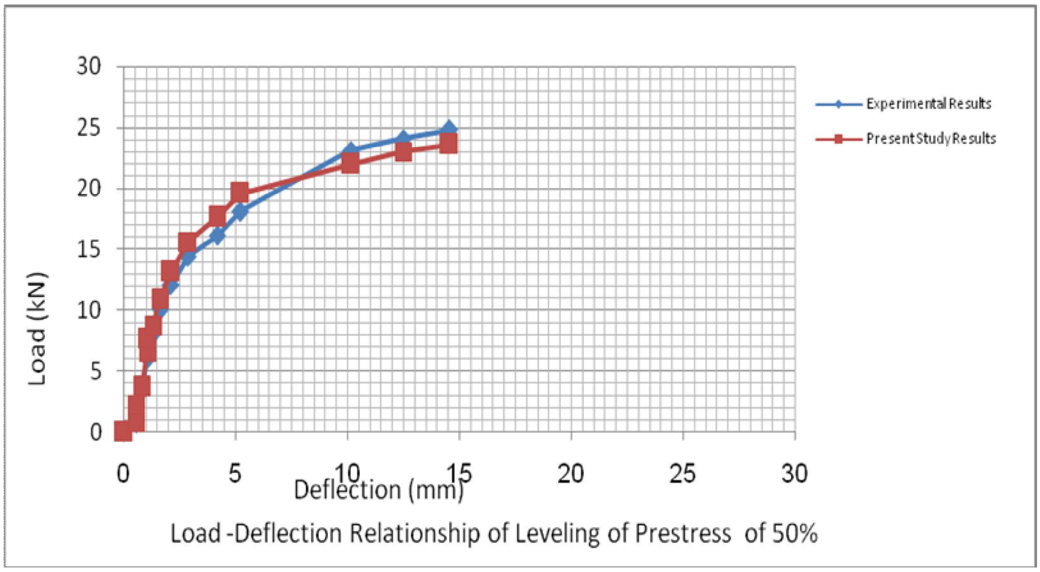


Fig.(17): Load- Deflection Relationship for Case of The Strengthened Beam with 50% Prestressed CFRP sheets.

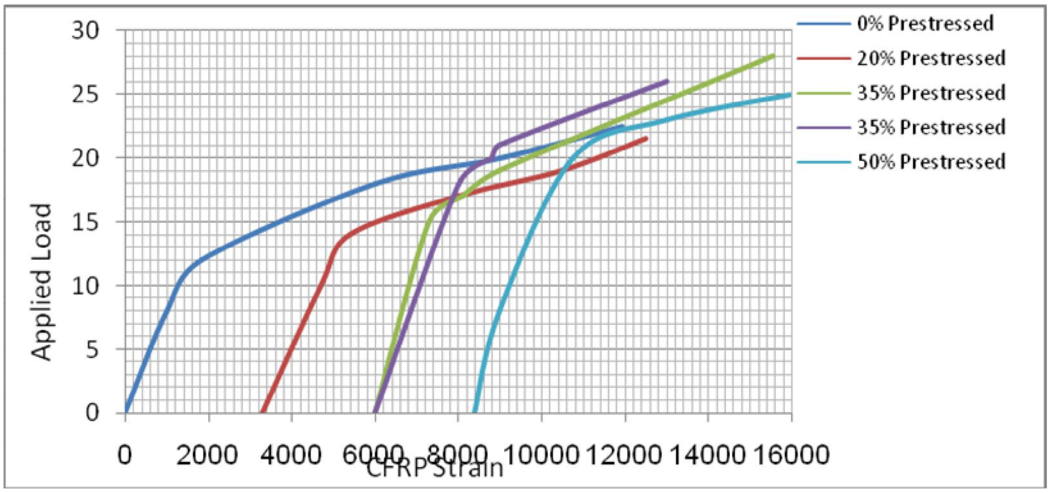


Fig.(18): Strains in The CFRP Sheet Versus Applied Load.

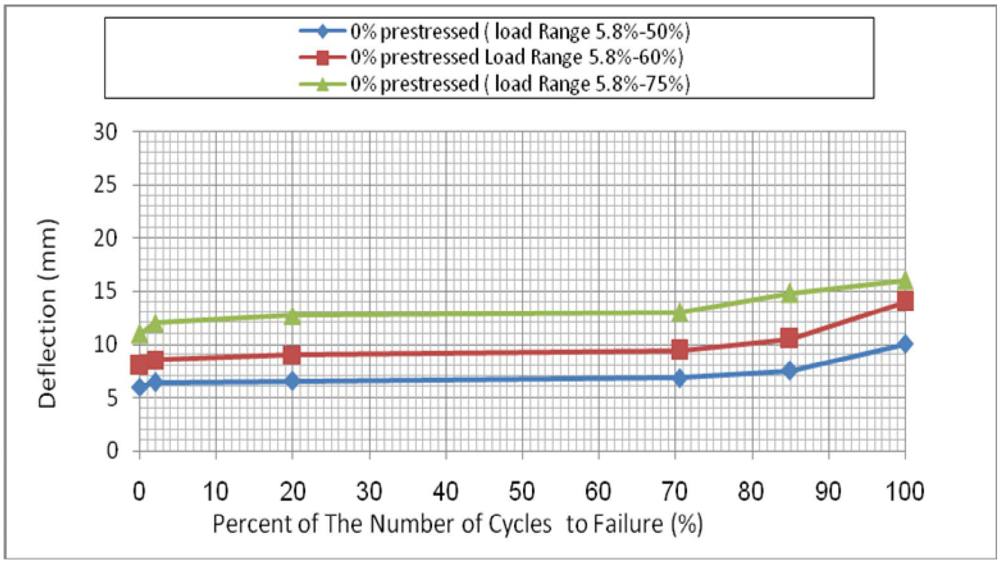


Fig.(19): Deflection Versus Normalized Number of Cycles for the 0% Prestressed Level.

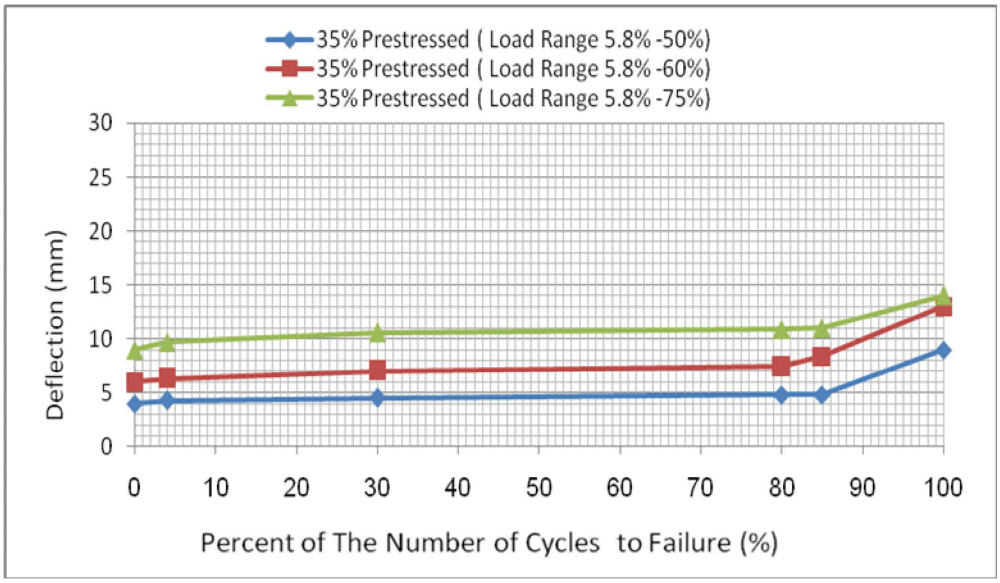


Fig.(20): Deflection Versus Normalized Number of Cycles for the 35% Prestressed Level.

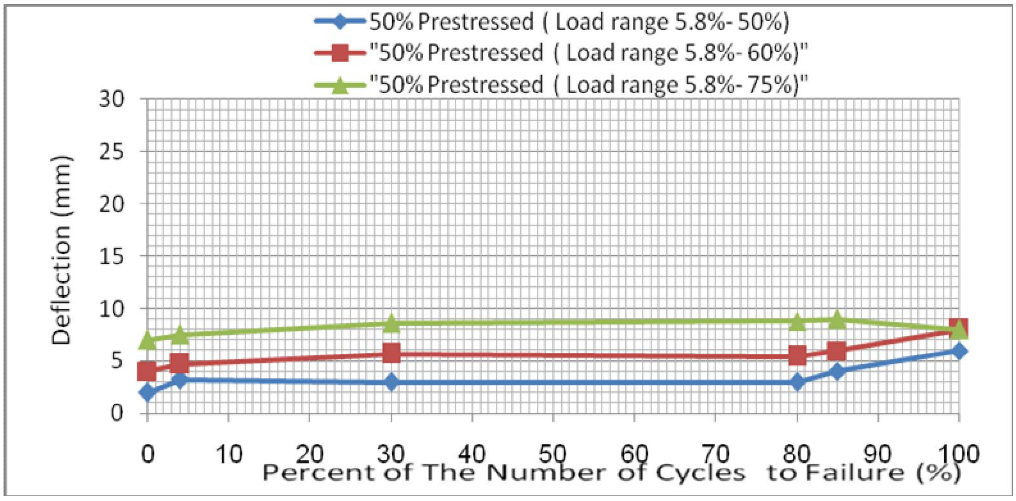


Fig.(21): Deflection Versus Normalized Number of Cycles for The 50% Prestressed Level.

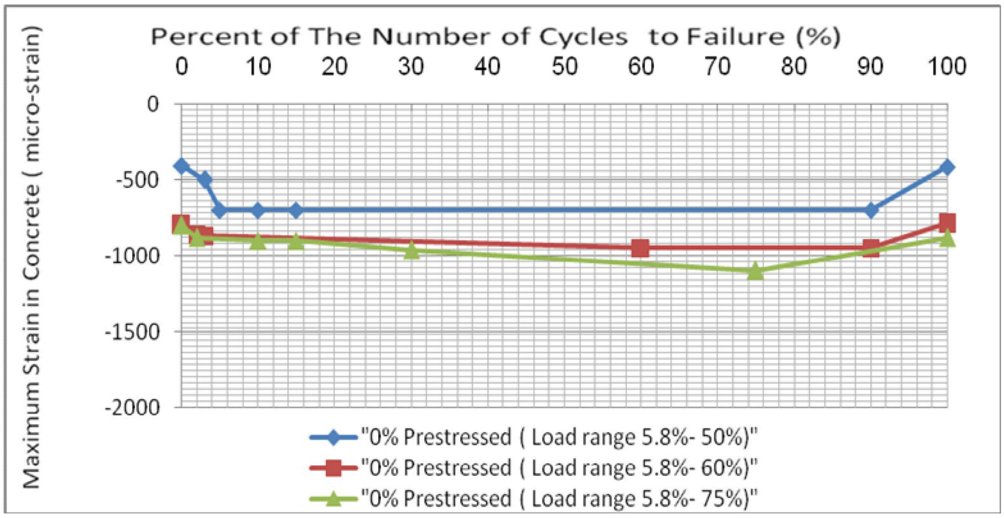


Fig.(22): Strain in Concrete Versus Normalized Number of Cycles for The Non-Prestressed Strengthened Beams.

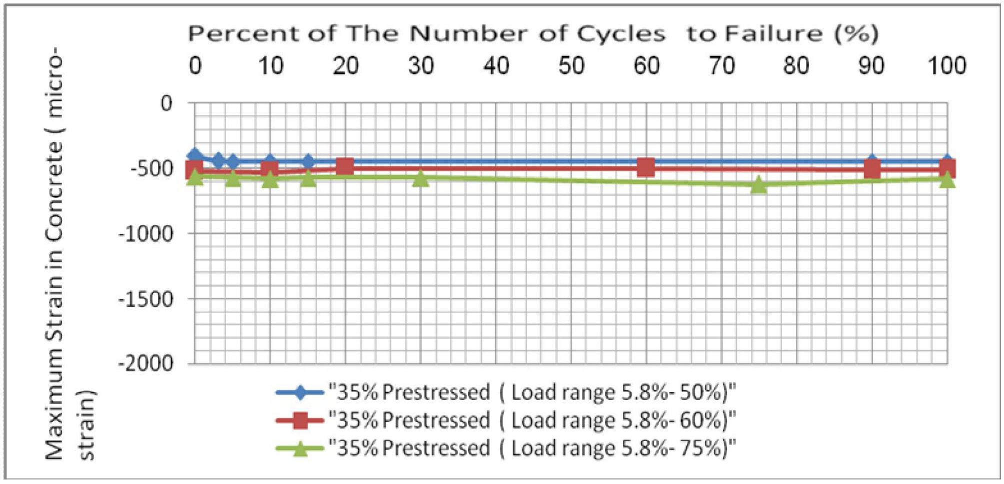
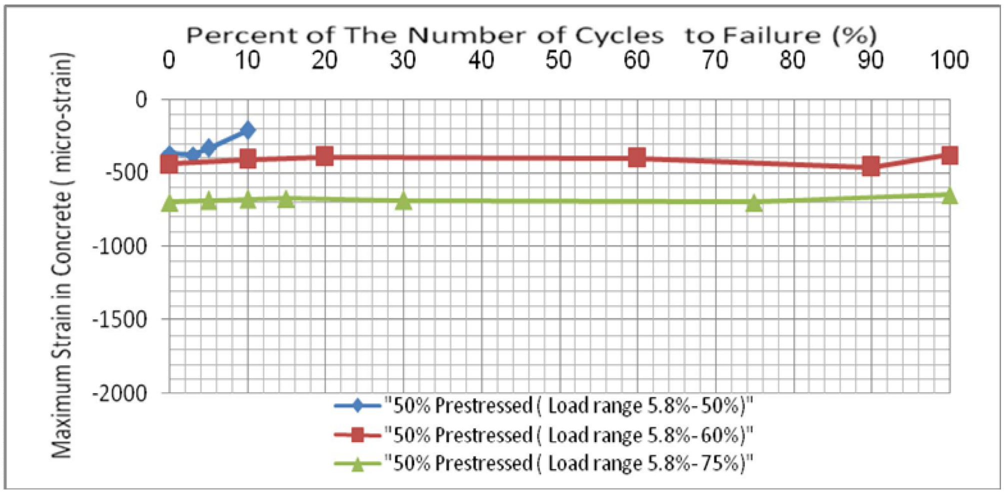


Fig.(23): Strain in Concrete Versus Normalized Number of Cycles for The 35% Prestressed Strengthened Beam.



Fig(24): Strain in Concrete Versus Normalized Number of Cycles for The 50% Prestressed Strengthened Beam.

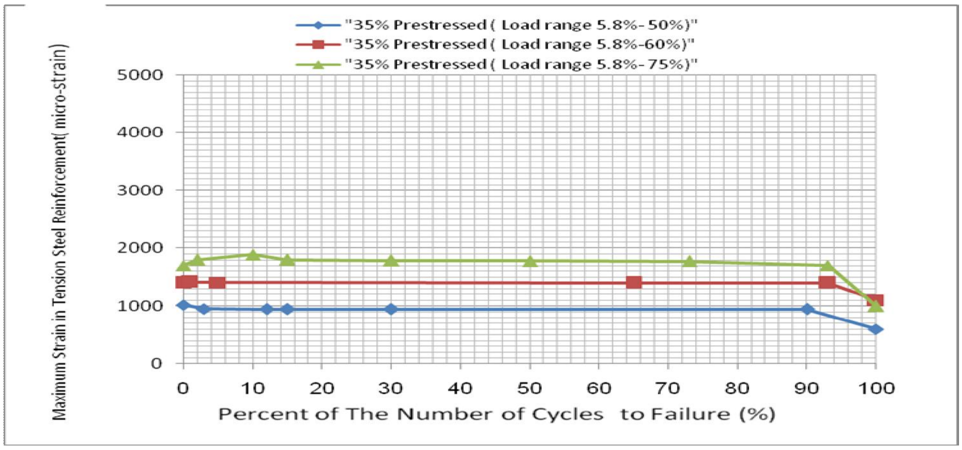


Fig.(25): Strain in The Tension Steel Reinforcement Versus Normalized Number of Cycles for The 35%Prestressed Strengthened Beam.

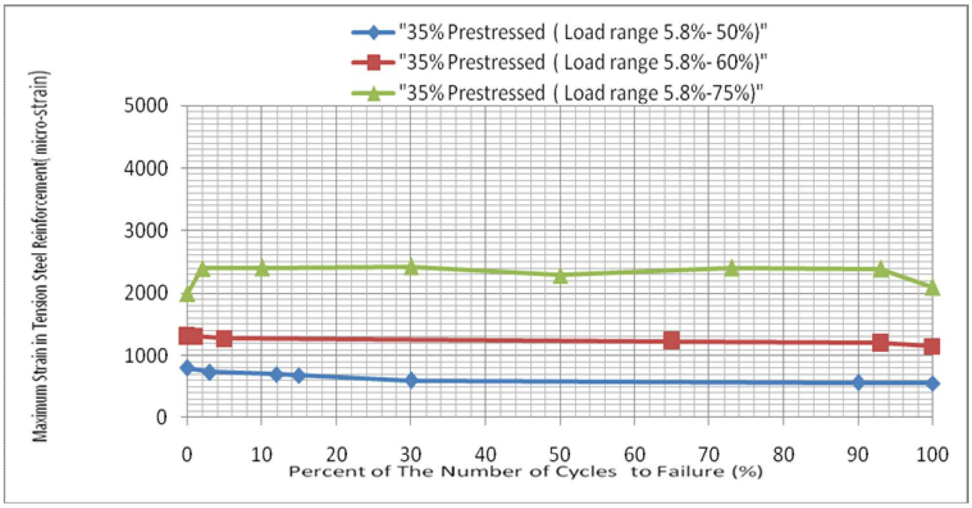


Fig.(26): Strain in The Tension Steel Reinforcement Versus Normalized Number of Cycles for The 35% Strengthened Beam.

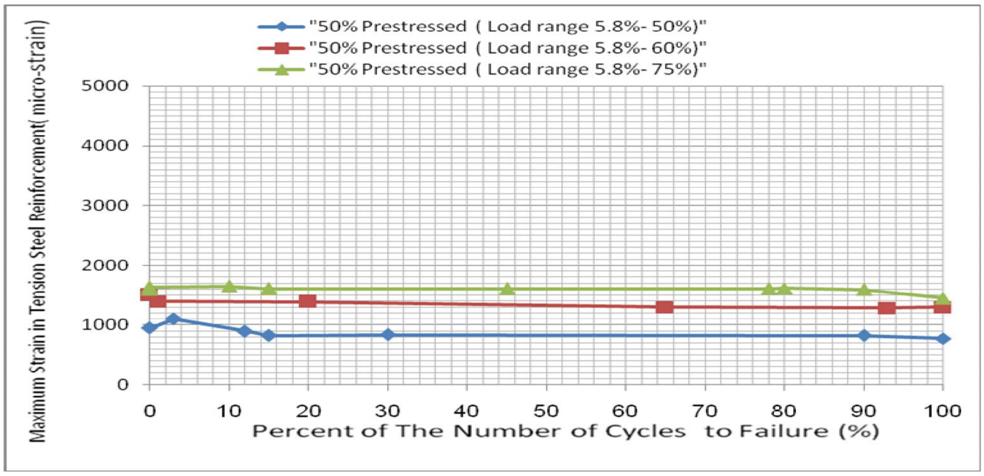


Fig.(27): Strain in The Tension Steel Reinforcement Versus Normalized Number of Cycles for The 50% Prestressed Strengthened Beam.

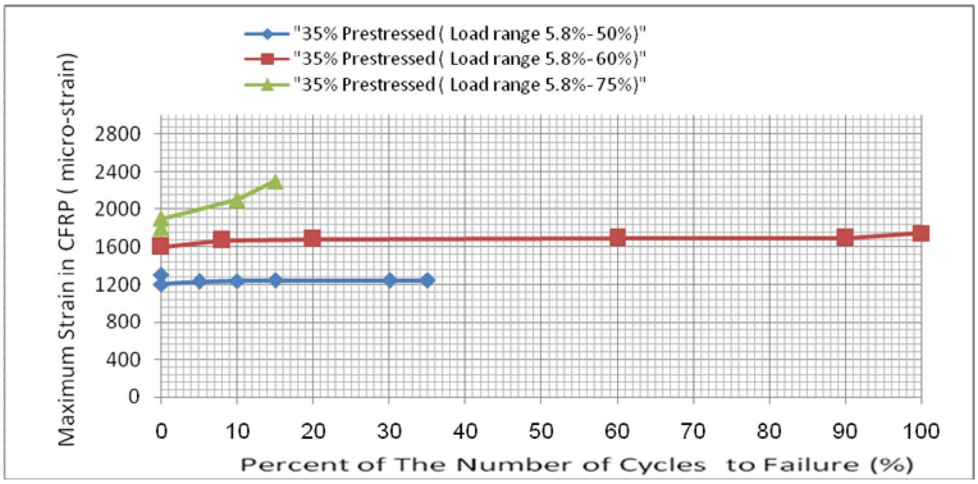


Fig.(28): Strain in the CFRP Sheet Versus Normalized Number of Cycles for the 35% Prestressed Strengthened Beam.

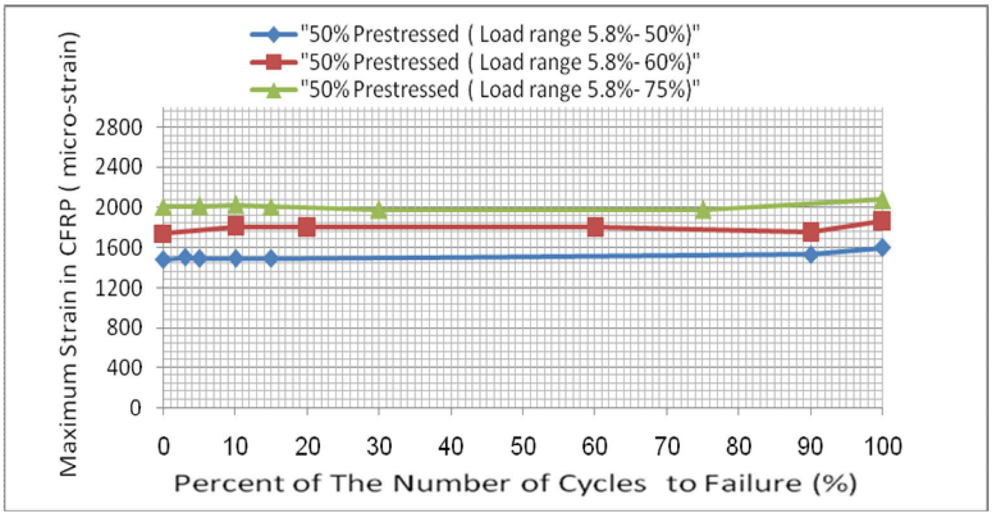


Fig.(29): Strain in the CFRP Sheet Versus Normalized Number of Cycles for The 50% Prestressed Strengthened Beam.

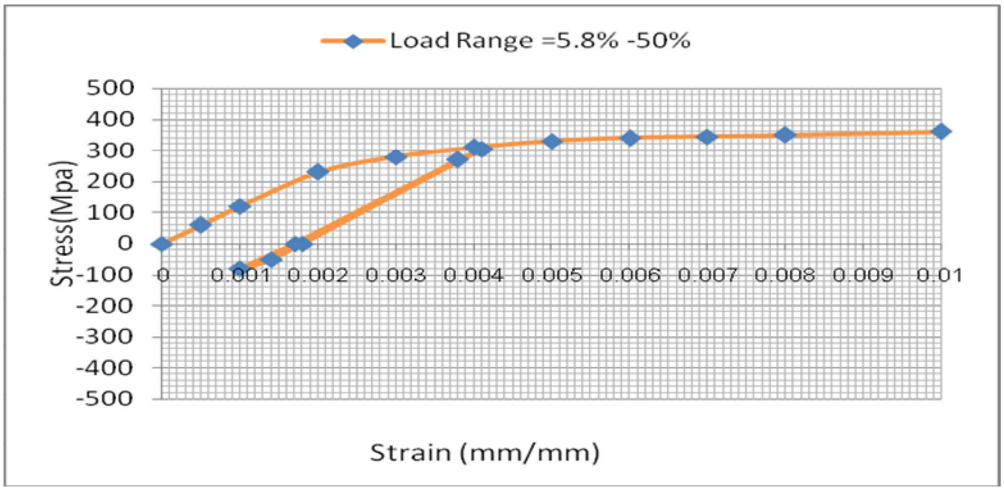


Fig.(30): Cyclic Stress-Strain Curve for the 35% Prestressed Strengthened Beam at Load Range (5.8%-50%).

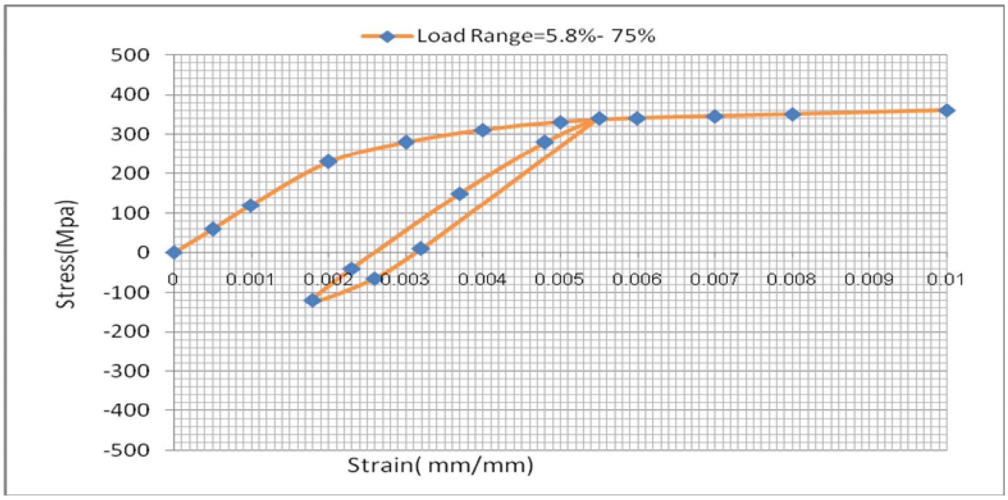


Fig.(31): Cyclic Stress-Strain Curve for the 35% Prestressed Strengthened Beam at Load Range (5.8%-75%).

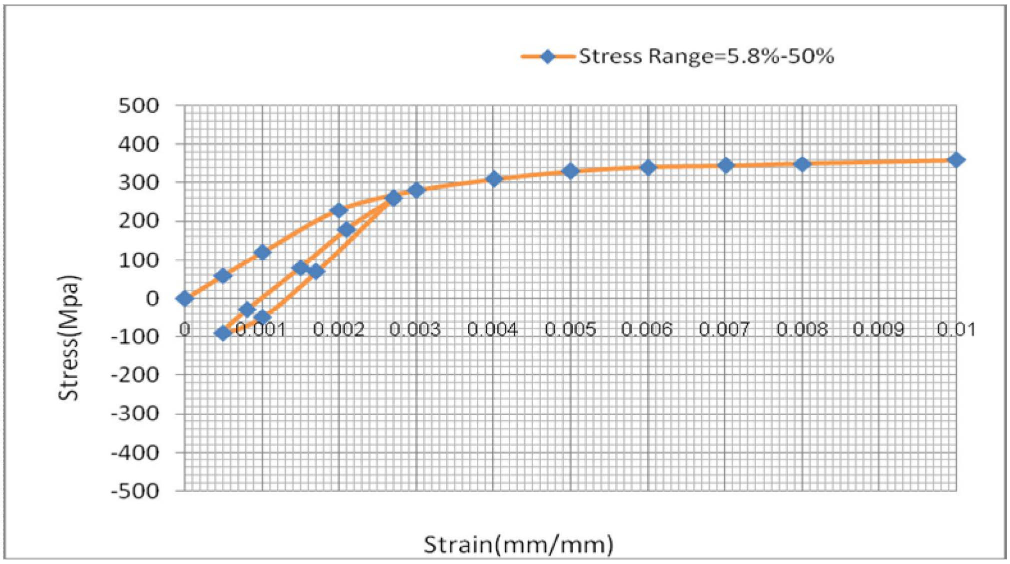


Fig.(32): Cyclic Stress-Strain Curve for the 50% Prestressed Strengthened Beam at Load Range (5.8%-50%).

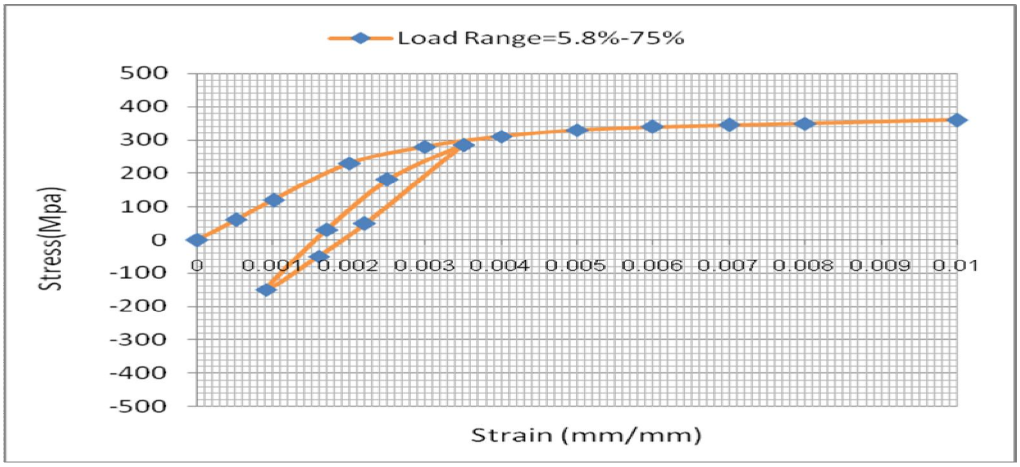


Fig.(33): Cyclic Stress-Strain Curve for the 50% Prestressed Strengthened Beam at Load Range (5.8%-75%).

السلوك اللاخطي للعتبات الخرسانية المقواة باستخدام بوليمرات الكاربون مسبقة الإجهاد تحت تأثير الأحمال الدورية

جنان لفتة عباس
مدرس مساعد، كلية الهندسة، جامعة ديالى

الخلاصة

إن السلوك اللاخطي للعتبات الخرسانية المقواة باستخدام بوليمرات الكاربون مسبقة الإجهاد تم دراسته في هذا البحث المختصر . لقد تم استخدام طريقة العناصر المحددة باستخدام برنامج (ANSYS) لهذا الغرض . لقد تم التمثيل لهذه العتبات باستخدام العناصر الصلدة الثلاثية الأبعاد لتمثيل الكونكريت (SOLID 65) والعناصر الصلدة الثلاثية الأبعاد لتمثيل مناطق الإسناد (SOLID 45) وكذلك الصفائح الطبقية الثلاثية لتمثيل بوليمرات الكاربون (SOLID 46) .

تتضمن هذه الدراسة خمسة عتبات ، أربعة منها مقواة باستخدام بوليمرات الكاربون مسبقة الإجهاد بمستويات مختلفة من الإجهاد أما العتبة المتبقية مقواة باستخدام بوليمرات الكاربون غير مسبقة الإجهاد .

إن تأثير مستويات الإجهاد للصفائح على قيمة أحمال التشقق ومقدار الصلادة تم دراستها . ومن خلا ل هذه الدراسة تم الاستنتاج بأنه قيمة أحمال التشقق وقيمة الصلادة سوف تزداد مع زيادة مستوى الإجهاد .

كذلك فان سلوك هذه العتبات تحت تأثير الأحمال الدورية تم استنتاجها كدراسة مكملة في صيغة توضح العلاقة مابين قيم الاود وعدد مرات التحميل والتي تتعلق بسلوك المواد الداخلة في تكوين هذه العتبات والمتمثلة ب(الكونكريت ، حديد تسليح الشد ، بوليمرات الكاربون) . ان التشوه الحاصل في هذه المواد تحت تأثير الأحمال الدورية تم توضيحها في صيغة توضح العلاقة مابين قيم الانفعال كنسبة من عدد دورات التحميل وان النتائج المحصلة من طريقة التحليل باستخدام العناصر المحددة تم مقارنتها مع النتائج العملية المتوفرة وان نتائج المقارنة اعطت نتائج جيدة .

الكلمات الدالة : الإجهاد المسبق ، بوليمرات الكاربون ، العتبات المقواة ، أحمال التشقق ، صلادة الانثناء ، الأحمال الدورية .