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Anchor Local Stresses Indicated by Anchorage of Externally Prestressed CFRP Tendons

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Abstract: *in this paper, a simplified analytical model has been proposed to compute local stresses of the loaded anchor for externally prestressed, in the proposed technique, steel anchors are provided on either side of the concrete beam for transferring external prestressing force and these are connected to the anchor blocks by four bolts, and to avoid the problem of sliding that occurs between the anchor plate and side surface of the concrete beam, used a new technique by using structural adhesive material with a layer of sand to increase friction between the contact surface, in order to validate the technique, an experimental investigation has been carried out on anchor steel plate. Local stresses on anchor and bolts have been recorded at various stages during the experiment. Finite element analysis has been carried out by simulating the test conditions, using Ansys software, and the responses have been compared. From the analysis, it has been observed that the computed local stresses of the steel anchor and bolts are in good agreement with the corresponding experimental observations.*
Keywords: *Anchor Bolt; Strengthening; External Prestressing; Finite Element; Nonlinear; Stress.*

I. Introduction

In the engineering structures many locally stressed areas arise. The concentrated stresses arise above all in the areas of local forces (supporting location, anchorage), at the locations of openings and sudden cross-section changes. In these areas very complicated tensions appear. It is not easy to describe these tensions in isotropic materials such as steel. It is necessary to research these locally stressed areas created by the anchorage of prestressed tendons properly.

Externally prestressed CFRP tendon technique has emerged as one of the effective methods for strengthening and retrofitting existing concrete structures, failure by sliding in anchor base plate, which used to fix external prestressed tendons, is one of the catastrophic failures, which depends on the friction conditions in contact area. The mechanical action of anchor base plate with concrete in contact area is mainly by friction between two surfaces and pre-tightening bolts force, which fixed anchor plate on concrete. Thus, friction coefficient between concrete and anchor base plate is very important to prevent the anchor base plate from sliding. Behavior of externally prestressed members had been conducted as shown in reference [1], [2], [3], [4], [5]& [6], whereas limited numerical analyses and analytical studies of these structures have been carried out. Reference [1] provided the details of the optimized anchorage zone based on analytical and full-scale experimental studies. Reference [2] presented details of the 40-year-old full-scale concrete bridge girder with prestressed carbon fiber reinforced polymer plates anchored using gradient method. Reference [3] presented analytical method for calculation of moment resistance in anchor bolt connection based on a concrete beam/column analogy. Reference [4] developed a finite element methodology using Ansys finite element code for equivalent three- dimensional analysis to investigate the behavior of bolted end-plate connections. Reference [5] presented an Ansys finite element model for flush end-plate joints. Material nonlinearity, large deflection analysis and contact surfaces were included in a non-linear solution. Reference [6] described finite element analysis and modeling of structure with bolted joint using Ansys.

The objective of this study is to determine the local stresses on the anchor steel plate and bolts, which, fixed to anchor on concrete beam according to experimental and theoretical analysis. Moreover, the comparison between these two analyzed were detailed.

Brief Introduction of Beam Test with Anchor

External post-tensioned simple support rectangular beam of effective span 3.5m, with c30 concrete grade is designed. The cross-section of the beam is 16 cm 28 cm width, height respectively. CFRP tendon of 7 mm diameter. Having an average tensile strength of 1974.821 MPa is used for applying simulated external prestressing force to the test specimen. 10.9m16*252 bolts type having yield strength 345 MPa is used for fixing anchor to the concrete member. Anew technique by using the structural adhesive glue type jgn-1 material with a layer of sand between the two surfaces to increase friction between the contact surfaces. In order to validate the technique, these are used in the design for anchoring the external prestressing.

Research area is concentrated only at the anchorage zone of external prestressing, hence the bolts. Details of the beam with anchor and the strain gauge arrangement of the test specimen is shown in **Figure 1,2&3**.the bolt stresses of four load cases were measured. During prestressing stage, prestressed force was 20 kN and 38 kN separately. During vertical load test，the vertical loads were 63.32 kN and 126.06 kN respectively.

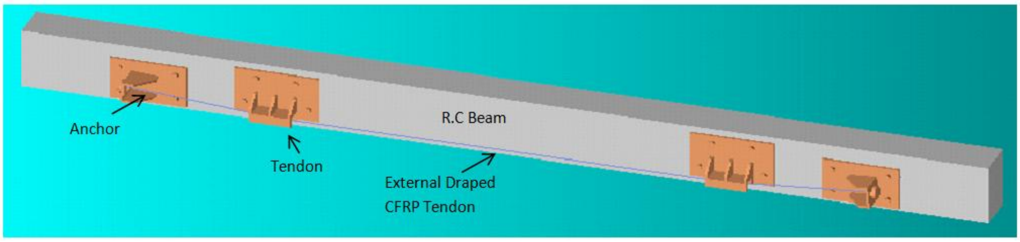


Figure 1 .a Beam Test With Anchor Ansys Model Setup

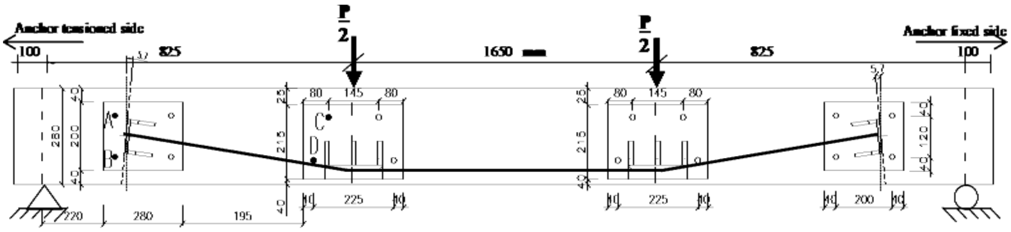


Figure 1.b Anchor Side View

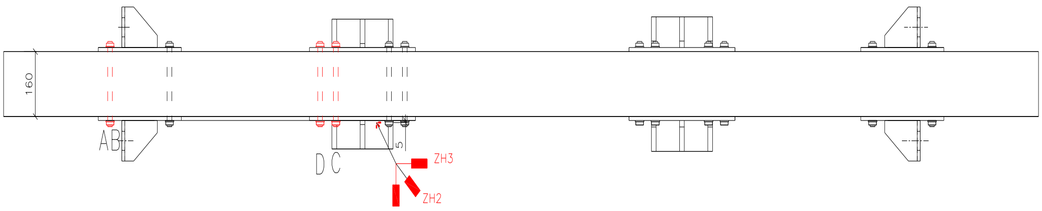


Figure 1.c Anchor Plan View & Deviator Strain Gauge Arrangement Points

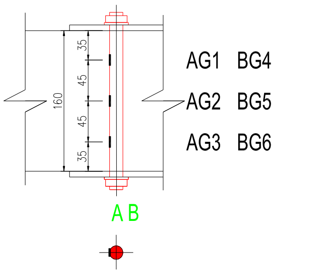


Figure 1.d Anchor Bolts A & B strain gauge Measuring-point arrangements

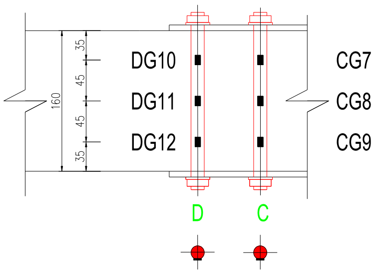


Figure 1.e Deviator Bolts C & D strain gauge Measuring- point arrangements

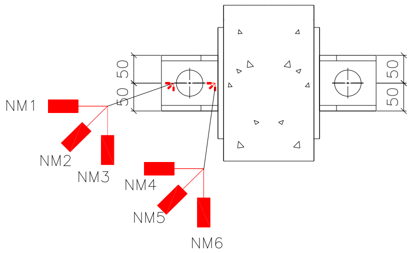


Figure1.f Anchor Strain Gauge Measuring- Point Arrangements

II. Establishment of Simulation Model

a) **Element Types**:

Based on the structure characteristic and calculation speed savings, a solid 65 element was used to model the concrete, this element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions. This element is capable of plastic deformation, cracking in three orthogonal directions, and crushing.

Solid 45 elements were used for anchor steel plates at the two sides of the beam. This element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions.

A link 8 element was used to model CFRP tendon for prestressing, 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.

For bolts, used the solid bolt model which, is the most realistic finite element, and it was modeled by using three-dimensional brick elements, solid 45. Eight nodes and each having three degrees of freedom define the element. In addition, between the bolt shank and hole inside concrete, used node-to-node contact element 178, this element represents contact and sliding between any two nodes of any types of elements. The element has two nodes with three degrees of freedom at each node with translations in the x, y, and z directions. The element is capable of supporting compression in the contact normal direction and coulomb friction in the tangential direction. The element may be initially preloaded in the normal direction or it may be given a gap specification. In this bolt model, in order to apply clamping force over the bolt, virtual thermal deformation method is employed. In the method, the thermal expansion coefficient is assumed a unit and the temperature difference ΔT is regarded as the following relation, as shown in reference [7]:

$$\Delta T = 4P_{\circ} \Big/ \pi \times d^{2} \times E \qquad (1)$$

Where, E is the elastic modulus of the material (bolt material), an effective diameter of the bolt (d) is 16 mm, and the clamping force P_0 is 51 kN according to test data.

Figure 2 Bolt Strain Gauge Arrangement Test Setup

Figure 3-a Anchor Strain Gauge Arrangement Test Setup

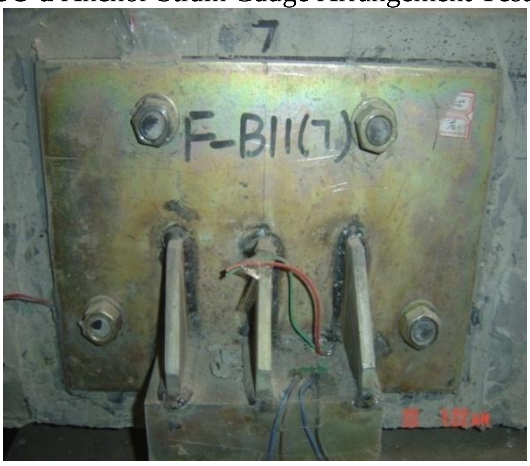


Figure 3-b Deviator Strain Gauge Arrangement Test Setup

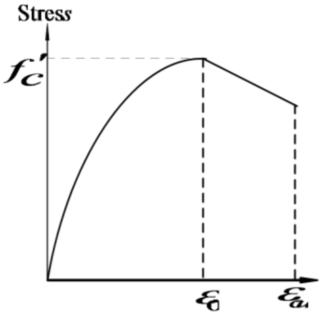
b) Material constitutive relationship

1) Concrete constitutive relationship

The Solid 65 element requires linear isotropic and multilinear isotropic material properties for properly model concrete. EX is the modulus of elasticity of the concrete (Ec), and PRXY is the Poisson's ratio (ν), Reference [8] shows that the material parameters of C30 concrete as the show in Table 1. The compressive uniaxial stress – strain relationship for the concrete model was obtained using the equations shown in Figure 4, to compute the multilinear isotropic stress- strain curve for the concrete.

Table 1 Concrete Material Property

Density (kg/mm^3)	Compressive strength (N/mm^2)	Young's modulus (N/mm^2)	Poisson's ratio
2.5e-6	30	30,000	0.2



For: $\varepsilon_c \le \varepsilon_\circ$;

$$\sigma_c = f_c'\left[1-(1-\frac{\varepsilon_c}{\varepsilon_\circ})^2\right];$$

For: $\varepsilon_\circ < \varepsilon_c \le \varepsilon_{cu}$;

$$\sigma_c = f_c'\left[1-0.15(\frac{\varepsilon_c - \varepsilon_\circ}{\varepsilon_{cu} - \varepsilon_\circ})\right]$$

Where: $\varepsilon_\circ$ =maximum compression strain ; ε_{cu} = ultimate compression strain=0.0033; σ_c =compression stress; f_c' =concrete compression strength;

Figure 4. Constitutive Relationship of Concrete in compressive[8]

2) Anchor Constitutive Relationship

The Solid 45 element is being used for the anchor steel plates on the two sides of the beam. Therefore, this element was modeled as a linear isotropic element with a modulus of elasticity for the steel (Es) Poisson's ratio (ν). Table 2, Shows the properties of anchor.

Table 2 Anchor Material Properties

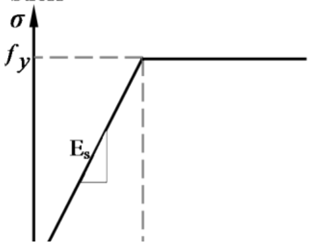
Density (kg/mm^3)	Young's modulus (N/mm^2)	Yield strength (N/mm^2)	Poisson's ratio
7.8e-6	200,000	345	0.3

3) Bolts Constitutive Relationship

The Solid 45 element is being used for the head, nut and shank of the bolt. This element was modeled as a linear isotropic element with a modulus of elasticity for the steel (Es) and Poisson's ratio (ν) and with bilinear isotropic property as shown in Figure 5 ,for head and nut of the bolt, Table 3, shows the properties of the bolt. Moreover, with a thermal coefficient equal unit & difference temperature 0.00127 according to equation (1) for bolt shank applied force. Table 3, Shows the properties of bolt.

Table 3 Bolt Material Properties

Density (kg/mm^3)	Young's modulus (N/mm^2)	Yield strength (N/mm^2)	Poisson's ratio
7.8e-6	200,000	345	0.3



For: $\varepsilon_s \le \varepsilon_y$: $\sigma_s = E_s \varepsilon_s$;

For: $\varepsilon_s > \varepsilon_y$: $\sigma_s = f_y$;

Where: f_y = yield stress; E_s =Elastic modulus; ε_y =yield strain.

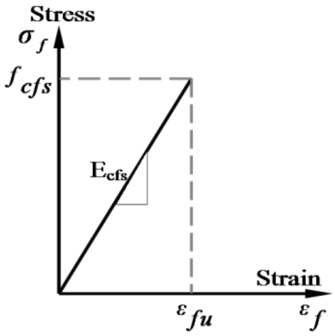
Figure 5. Constitutive Relationship of Steel [8]

4) CFRP tendon Constitutive Relationship

The Link 8 element is being used for the external CFRP tendon for prestressing in the two sides of the beam, and it is assumed to be bilinear isotropic with effective tensile strength of CFRP. This element was modeled, as a linear isotropic element with a modulus of elasticity for the CFRP (ECFR) and PRXY is the Poisson's ratio (ν), also this element modeled as multilinear isotropic by using a multilinear stress-strain curve developed using the equation shown in Figure 6. Table 4, shows the properties of CFRP tendon. Anchor plan & front view after meshing according to Ansys shown in Figure 7.

Table 4 CFRP Bar Material Properties

Cross section (mm^2)	Young's modulus (N/mm^2)	Tensile strength (N/mm^2)	Poisson ratio
38.485	150,000	1974.821	0.26



$\sigma_f = E_{cfs}\varepsilon_f \Rightarrow \varepsilon_f \le \varepsilon_{fu}$;

$\sigma_f = f_{cfs} \Rightarrow \varepsilon_f > \varepsilon_{fu}$;

Where: σ_f = tensile stress; E_{cfs} =Elastic modulus;

ε_f =tensile strain;

Figure 6. Constitutive Relationship of CFRP Bar

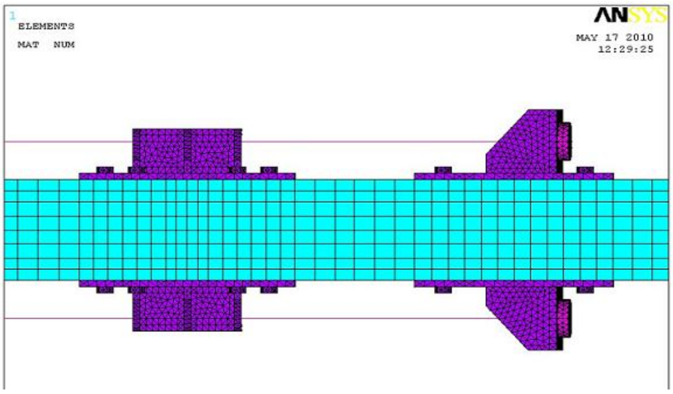


Figure 7.a Beam test & Anchor Plan View after Meshing

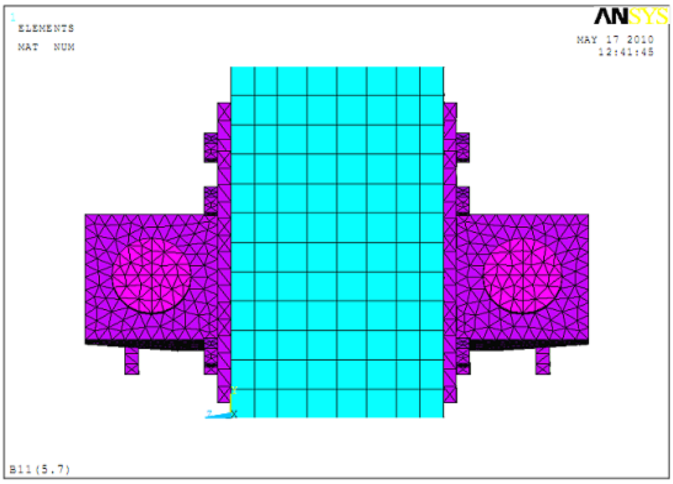
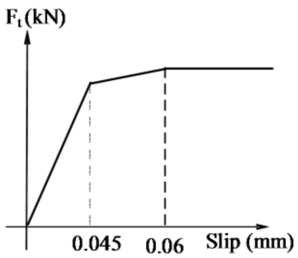


Figure 7.b Beam test & Anchor Front View after Meshing

c) Interface between concrete and anchor steel plate elements

Interface property between the concrete and steel plate was simulated by using contact 178 –element, 3D point to point contact, in the normal interface direction, the interface element consisting of 20 springs linking concrete and anchor combination node in three directions was used. Tangential interface direction property, used COMBIN39-element, which is a unidirectional element with nonlinear generalized force-deflection capability, and Tangential stiffness was decided on force – displacement relationship illustrated in Figure 8, and Table 5.



$F_t = 2176S \Rightarrow$

$(S \le 0.045mm)$;

$F_t = 2266.7S \Rightarrow$

$(0.045 < S \le 0.06)$;

$F_t = F_t \Rightarrow (S > 0.06)$;

Figure 8. Sliding Force – Slip Relationship of the Interface element

Table 5 Concrete –Anchor Plate Interface Element

Springs In The Directional Normal To Interface	Springs In The Directional Tangential To Interface
Assuming that under compressive stress the interface is as anchor plate, thus the normal stiffness is kN= (200,000) A, per unit length. This value divided into 20 combine nodes according to the effective area of each node. Where: kN; normal stiffness of spring in the direction normal to the interface. A: effective area (mm2)= 332*185=61420 mm^2	In the horizontal interface direction combin39 was proposed. The slip force – slip relationship, which obtained from the curve shown in Figure 6, divided into 20 combine nodes according to the effective area of each node. Where: Ft: force in the direction tangential to the interface (N) S: slip(the deformation of the spring)(mm)

d) Model Boundary Conditions

Displacement boundary conditions are needed to constrain the model to get a unique solution. To ensure that the model act the same way as the experimental beam, boundary conditions need to be applied at where the supports exist. The support was modeled in such a way that a roller was created.

III. COMPARISON BETWEEN THE THEORETICAL AND EXPERIMENTAL ANALYSIS RESULTS

Depending on the results of the analysis obtained from the experimental and theoretical analysis according to the model analyzed above, comparison

between these results of the local stresses, in the bolts strain gauge arrangement points as required to measure these stresses according to experiment. These comparisons have been clarified as shown in the **Figures 9~14**. The Figures show that the computed stresses of the bolts are in good agreement with the corresponding experimental observations.

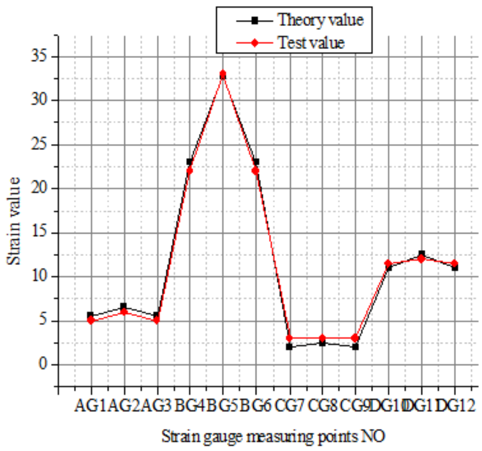


Figure 9. a Anchor & Deviator Bolts Strain at Measuring Points ($\mu\varepsilon$) for Prestressing Stage -20 kN

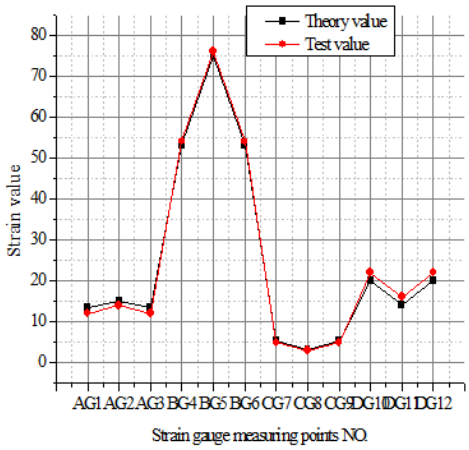


Figure9 .b Anchor & Deviator Bolts Strain at Measuring Points ($\mu\varepsilon$) for Prestressing Stage-38 kN

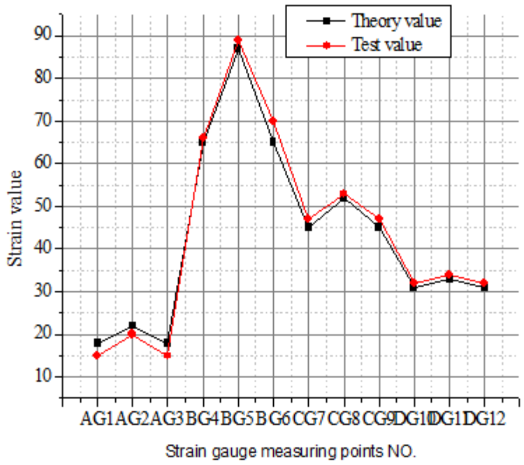


Figure 10. a Anchor & Deviator Bolts Strain at Measuring Points ($\mu\varepsilon$) for Loading Stage – 67.17 kN

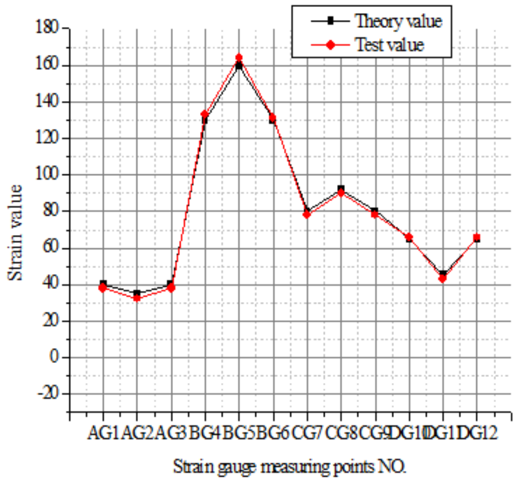


Figure 2

Figure 10. b Anchor & Deviator Bolts Strain at Measuring Points ($\mu\varepsilon$) for Loading Stage –126.52 kN

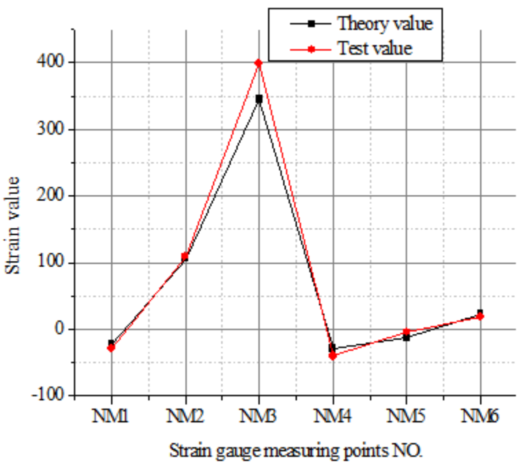


Figure 11. a Anchor Strain at Measuring Points ($\mu\varepsilon$) for Prestressing Stage – 20 kN

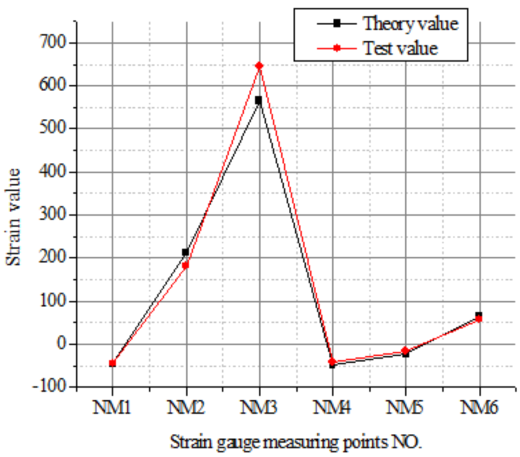


Figure 11. b Anchor Strain at Measuring Points ($\mu\varepsilon$) for Prestressing Stage – 38 kN

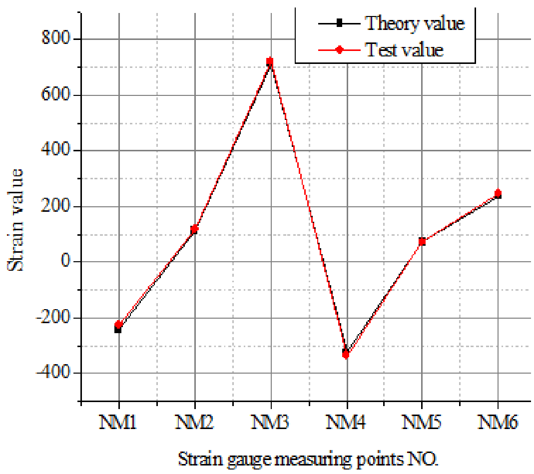


Figure 12. a Anchor Strain at Measuring Points ($\mu\varepsilon$) for Loading Stage – 67.17 kN

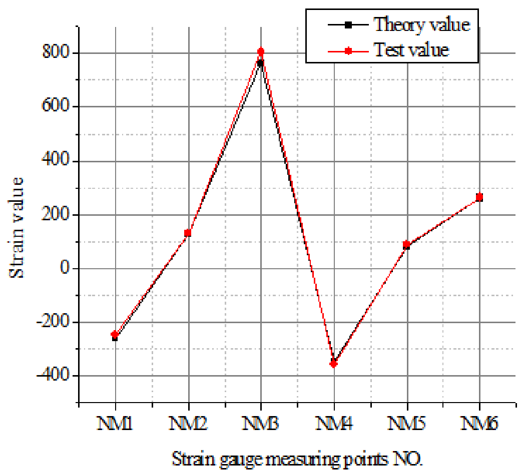


Figure 12 b Anchor Strain at Measuring Points ($\mu\varepsilon$) for Loading Stage –126.52 kN

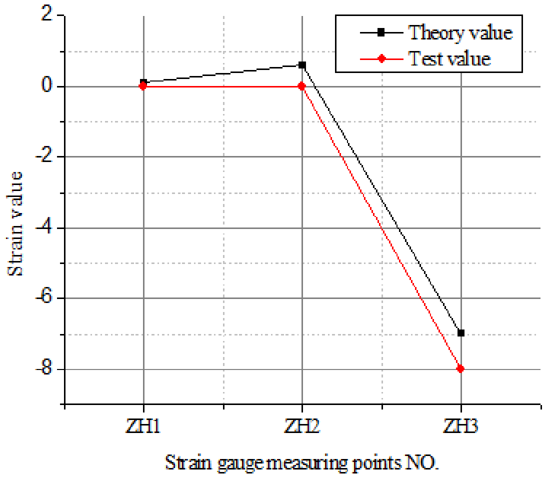


Figure 13. a Deviator Strain at Measuring Points ($\mu\varepsilon$) for Prestressing Stage-20 kN

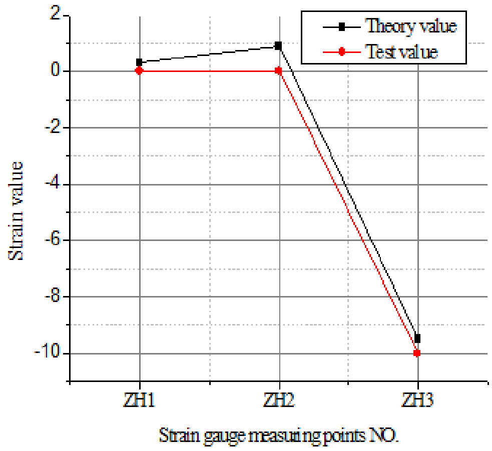


Figure 13. b Deviator Strain at Measuring Points ($\mu\varepsilon$) for Prestressing Stage-38 kN

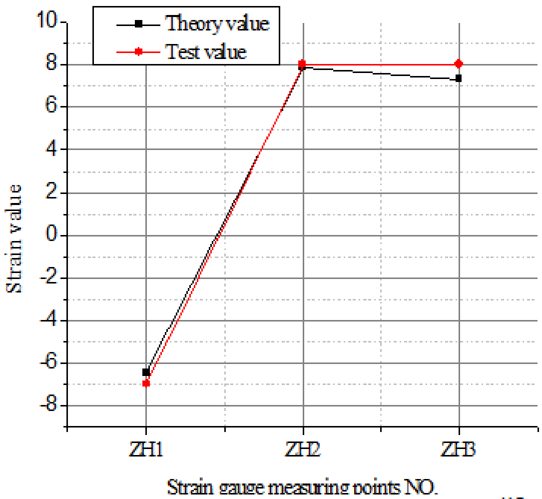


Figure 14. a Deviator Strain at Measuring Points ($\mu\varepsilon$) for Loading Stage – 67.17 kN

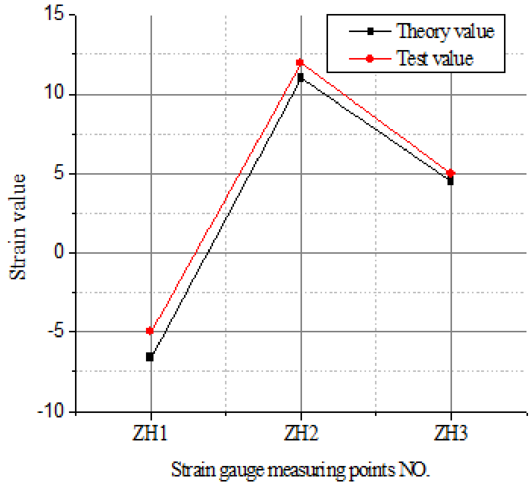


Figure 14. b Deviator Strain at Measuring Points ($\mu\varepsilon$) for Loading Stage –126.52 kN

IV. CONCLUSIONS

In this paper, a model is configured by ANSYS program to calculate the local stresses in the side external anchor and bolts fixed anchor to R.C beam side, which used to fix external prestressed CFRP tendons for strengthening this test beam. The analysis takes into account contact between the anchor plate and concrete beam, also between the bolt and hole, stresses were calculated in regions extremely affected by the application of the prestressing force and beam loading compared these theoretical results with experimental results, as described above, It is noted that the theoretical and experimental stresses values in the bolts are very small and all that is due to the use of a new technique to increase the friction force between the concrete beam and anchor interface, which makes almost of the resulting force from the prestressing and applied load on beam resist by this high friction force. Therefore, this technique is used with high interest and can be used to strengthening all concrete beams by using external prestressing. After working Ansys model successfully, using the same variables and properties which, used in the experiment , have been making a comparison between the results obtained from Ansys model and results of the experiment in each of the bolts and the anchor as specific strain gauge measuring points arrangements . Based on the theoretical analysis and experimental study of the anchor, the following conclusions can be drawn and suggestions made:

Based on the theoretical analysis and experimental study of the anchor, the following conclusions can be drawn and suggestions made:

- The graphs shown that the majority of the stress values in the bolts for all loading stages are almost identical.

- Interface tangential property can be simulated by tangential stiffness, which can be realized in the model by distribution spring's stiffness, spring can use COMBIN39- nonlinear element. Interface's tangential stiffness can be obtained according to the relationship between tangent force and slipping displacement by test.
- Normal stiffness of the interface between Bolt and inside concrete can be simulated by normal stiffness, which can be realized in the model by distribution spring's stiffness, spring can use contact 178 –nonlinear element. Normal stiffness of the interface can be decided by glue property.
- for the technology used between the concrete beam side and anchor steel plate, which used to increased friction between the two interface, greatest effects on the increase or decrease the stresses in the bolts, it should be of interest to this area in the representation of the Ansys model.
- Simulation analysis method for Stresses of anchor bolt is valid, can be used during design.

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