FEM Based Model on Column Behaviour with External FRP

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Abstract **- The object of the work is to evaluate the compression behaviour of circular columns with external FRP confinement using finite element modeling. The problem in hand involves six columns in two series. In first series, the property and dimension of three circular were selected to be similar in order to obtain a reasonable mean value of the results. The square column specimen were also similar with the exception of last specimen which had the corners removed to a depth of 12mm. M46.1 Grade concrete was used for the columns. The steel ratio for circular columns was adopted 1.13% and for square columns, it was 1.45%. The columns were strengthened with CFRP wraps. The thickness of each layer of FRP was 1mm. The columns were subjected to axial testing. The columns were tested up to failure. Experimental results of different authors were used to validate the analytical results obtained using ANSYS. A reasonably close agreement has been obtained between the experimental results and those from the FEM modeling. An analytical model using ANN has also been conducted and validated with the experimental results. ANN based model provided reasonable accuracy in predicting the performance of FRP wrapped concrete columns.**

Keywords— Axial stress-strain behavior, ANSYS, ANN, Column, FRP wrap, length effect

I.INTRODUCTION

Reinforced concrete columns need to be laterally confined in order to ensure large deformation under applied loads before failure and to provide adequate bearing capacity. When the CFRP wrapped concrete column is subjected to an axial compressive loading, the concrete core expands laterally. This expansion is resisted by the CFRP and therefore the concrete core is changed to a three dimensional compressive stress state. In this state the performance of concrete core is significantly influenced by the confinement pressure. Many investigations have been conducted on the behavior of CFRP-wrapped concrete column subjected to a uniaxial compressive load, it will established that fibers should be aligned along the concrete core. In practice, however, almost all the columns are subjected to an eccentric axial load which can be resolved into a uniaxial compressive and bending moment.

II.LITERATURE REVIEW

Reza Esfahani, M (2005) studied the resistance to axial compression of reinforced concrete columns wrapped with fiber-reinforced materials. The experimental part of the study included testing two series of 6 reinforced concrete columns. The first series consisted of three similar circular reinforced concrete columns, reinforced with FRP wrap. The second series consists of three similar square columns, two with sharp corners and the other with rounded corners. Grade M46.1 concrete is used for the piers. The diameter of the cylinder is 203mm and the cross section of the square column is 180 x 180mm. The proportion of steel in round columns is 1.13% and the proportion of steel in square columns is 1.45%. The pillars are reinforced with CFRP wrap. The thickness of each FRP layer is 1mm. Perform an axial test on the spine. FRP wrapping has been proven to significantly increase the strength and ductility of the cylinder. The proposed equation has a good correlation with the test results of circular columns and square columns with rounded corners. According to the test results, the FRP package did not increase the strength of the square column with sharp corners. However, compared to square columns with sharp corners, square columns with rounded corners exhibit greater strength and ductility.

Cem YALCIN and Osman KAYA (2005) conducted experiments on reinforcement of columns reinforced with FRP materials. Four cantilever reinforced concrete columns with dimensions of 200x400x1610mm were tested. A splicing and a continuous longitudinal steel bar are used as the construction control column, and the steel column is tested under constant axial load and reverse cyclic lateral load. The FRP board is wrapped around the possible hinge area. The test results show that the overlapping splicing dominates the behavior, and no difference is observed in the force-building relationship between the control column and the reinforcement. However, the ductility of columns with continuous longitudinal reinforcement increases significantly. Chapter

Hadi, M.N.S. (2006) (2006) studied the behavior of FRP-wrapped normal-strength concrete columns under eccentric loads. The physical shape of the columns depends on their application in a certain situation, but they are generally round or rectangular buildings. Six pillars with geometric shapes similar to those reported by Li and Hardy were cast and tested. The height of the column is 1.4m, the cross section is circular, and there is a waist at each end of the column. The diameter of the test area is 150 mm, and the diameter of the bending area is 235 mm. The research involved testing six eccentric load-bearing concrete columns with CFRP external restraints. In fact, adding CFRP as the external restraint of the concrete structure will effectively increase the strength of the column and improve the resisting moment formed when the axial load and the bending moment are combined.

Richart, Newman and Newman, Mander (2007) developed a stress-strain model to predict the maximum strength and deformation of confined concrete. These models were developed for concrete columns confined with steel tubes and extended to FRP confinement. These models are based on the maximum strength of concrete. They predict the reinforcement of confined concrete as a function of confining pressure. Faradics and Khalili revised Richart's empirical formula to quantify the increase in compressive strength of concrete and the non-linear expression of Newman and Newman. By substituting the maximum confining pressure that the FRP can apply, an equation was obtained to predict the strength of the confined concrete. These steel-based restraint models were found to overestimate the effectiveness of restraint pressures.

Danilo Bardaro, Orazio Manni, Paolo Corvaglia, Rossella Modarelli and Teresa Primo (2007) conducted a study on use of Fiber Reinforced Polymer (FRP) materials as confining devices for concrete columns. Bridge piers were often designed as hollow-core reinforced concrete (RC) section to obtain a reduction of the self-weight (especially in seismic zones) and a better structural efficiency in terms of strength/mass and stiffness/mass ratios. In contrast to this popularity in practice, scientific studies on the mechanical behaviour of such structural elements were limited, and the use of FRP’s for external confinement of hollow core columns and piers was an almost unknown field at the moment. In this research work both solid and hollow-core concrete specimens were tested under uniaxial compression to study the stress-strain relationship before and after FRP jacketing. A range of experimental parameters were investigated different concrete strength, type of fibers, number of wrap layers, columns shape and dimensions, and for square and rectangular sections, the corner radius and the cross sectional aspect ratio. Circular columns wrapped with FRP showed significant increase in terms of both strength and ultimate capacity compared to circular sections. However the results related to ultimate axial displacement encourage adopting this technique for seismic retrofit to fulfill higher ductility requirements in both prismatic and cylindrical columns. On the basis of the obtained experimental results, a parametric non linear finite element model was developed and caliberated with ANSYS. For the FRP-confined concrete, the Drucker-prager model, suitable for the simulation of granular materials was used while the FRP was modeled as linear elastic orthotropic and transversely isotropic material. The most convenient combination of element types was pointed out for the two different parts of the model, in terms of a compromise between accuracy and computational effort. The correct symmetries of the deformed shape of the model were achieved through the proper choice of the boundary conditions. The model calibration was carried out through a sensitivity analysis performed on the Drucker-Prager parameters. A good correlation was finally achieved between experimental and numerical data in terms of stress-strain curves.

Barbara FERRACUTI and Marco SAVOIA(2007) studied the behaviour of RC columns wrapped by composite material sheets (FRP) under axial force and cyclic bending. Cyclic constitute laws for confined and unconfined concrete in compression, for concrete under tension and for steel reinforcing bars were introduced. Numerical results were in good agreement with experimental tests. Hysterious dissipated energy for cyclic bending was estimated. Wrapping with FRP was shown to be very effective, increasing significantly ductility of columns under bending.

Tamer EI Maaddawy (2008) conducted a study on post-repair performance of eccentrically loaded RC columns wrapped with CFRP composites. Chloride-induced corrosion in reinforced concrete (RC) structures was a major worldwide durability problem. Reinforced concrete structures located in industrial regions are vulnerable to carbonation-induced corrosion due to the increased concentration of carbon dioxide. Three concrete cylinders, each having a diameter of 150 mm and a length of 300 mm, were cast from the same mix used in fabrication of the test specimens to determine the concrete compression strength. Test results showed that 4.25% steel mass loss had no noticeable effect on the strength of eccentrically loaded RC columns. AT nominal e/h of 0.3, the strength of the damaged column repaired with a full CFRP wrapping system was about 40% higher than that of the control. During the post – repair corrosion phase, full FCRP wrapping system, with an effective confinement ratio of f1/ f’c = 0.2, reduced the measured current by about 25% and 12% at fixed.

Bisby and Take (2009) using an optical measurement technique, it was found that, depending on the location of the strain measurement, the hoop strains over the surface of the FRP confined circular concrete cylinders varied by as much as 50% of the ultimate axial strain of the FRP. Although Pessiki et al. (2001) suggest that the hoop rupture strain can be related to the ultimate strain of the FRP through an efficiency factor η, it should be noted that a thorough understanding of the strain distribution around the FRP jacket was lacking in the existing literature, which only presents was isolated readings for the values for hoop strain around the circumference of the circular concrete specimens.

Antonia De Luca (2009) was focused a on study behavior of full-scale reinforced concrete members with external confinement or internal composite reinforcement. The dissertation was articulated on three studies. The study 1 represented RC columns internally reinforced with GFRP, study 2 represented RC prismatic columns externally confined by means of FRP laminates using glass and glass blast fibers and study 3 was a theoretical attempt to interrupt and capture the mechanism of the external FRP confinement of square RC columns. In study 1 was described an experimental campaign of full scale GFRP square RC columns. The size of the specimen was 0.61 x 0.61m. In this study was conducted to investigate the compressive behaviour of longitudinal GFRP bars and contribution of concrete core. The results showed the GFRP RC specimen behaved similar to steel RC specimen. In the study 2 described a laboratory testing of full-scale square and rectangular RC Columns externally confined with glass and basalt Glass FRP laminates and subjected to pure axial load. In the study were conducted to investigate how the external confinement effect ultimate axial strength and deformation. In the results showed the FRP confinement increases concrete axial strength, but it is more effective in enhancing concrete strain capacity. In the study 3 a new theoretical frame to interrupt a single parameter methodology for predicted the axial stress-strain curve for FRP confined square RC column is described. Fundamentals basic, assumption, limitation axial stress-strain graph etc., was discussed. A simple design example is presented in that paper.

Ashraf Mohamed Mahmoud (2011) analysed a finite element reinforced concrete model with ANSYS v.9 finite element program for both unstrengthened and CFRP-strengthened hollow columns using SOLID65 concrete element, its size 24 x 26 x 24 mm and LINK8 discrete steel distribution element. The CFRP was modeled using SOLID46 element, which has orthotropic properties. The deflection results were compared with an experimental and other finite element model which is performed by Lignola. These results showed the author's model is better than the Lignola's model comparing with the experimental one. A parameter study was done on the proposal model for obtaining the effect of using the GFRP instead of the CFRP in column strengthening by comparing the failure loads and the concrete and steel properties at failure. This study showed a reduction in the failure load value by an amount 0.6 to 2.8% reduction when using GFRP, indicated that the CFRP was more preferable in strengthening of the hollow column than the GFRP.

I.C. Yeh (1998) developed an demonstrating the possibilities of adapting Artificial Neural Network (ANN) to predict the compressive strength of high-performance concrete. A set of trial batches of HPC was produced in the laboratory and demonstrated satisfactory experimental results. This study led to the following conclusions. 1) A strength model based on ANN is more accurate than a model based on regression analysis; and 2) it is convenient and easy to use ANN models for numerical experiments to review the effects of the proportions of each variable on the concrete mix.

Sergio Lal and Mauro Serra (1997) developed a model based on neurocomputing, for predicting, with sufficient approximation, the compressive strength of cement conglomerates. First, the principles of connectionism are briefly recalled. Some neural networks are then constructed in which the different mix-design parameters of a variety of cement conglomerates, i.e. the compressive strength, are associated. The experimental data obtained during construction of the 'Alto Sulcis Thermal Power Station' at Portovesme, Italy, were used in the tests. The availability of a substantial amount of data enabled the method to be suitably calibrated and satisfactory results were obtained for evaluating the mechanical properties of different concrete mixes.

Jian, Sanjeev Kumar and Sudhir Misra (2006) conducted a study on modeling the compressive strength of concrete using Artificial Neural Network (ANN), Seven ANN model were developed to model the compressive strength of concrete at various stages. The feed-forward ANNs were trained using back-propagation with momentum factor method. The data in terms of cement, water, coarse aggregate, sand and compressive strengths of concrete at 3-days, 7-days and 28-days were considered. The authors reported that the ANN models for estimating 28-days compressive strength based on early age strengths (3-days or 7-days) were found to perform better than the ANN models developed based on the concrete mix proportion data.

III. ANALYTICAL METHOD ANSYS

A. Test Plan

Experimental program involves six columns in two series. In first series, the property and dimension of three circular were selected to be similar in order to obtain a reasonable mean value of the results. The square column specimen were also similar with the exception of last specimen which hard the corners removed to a depth of 12mm. M46.1 Grade concrete has been used for the columns. The steel ratio of circular column has been adopted 1.13% and square column has been adopted 1.45%. The columns were strengthened with CFRP laminates. The thickness of each layer of FRP was 1mm. The columns were subjected to axial tests. The columns were tested up to failure.

B. Materials

The concrete mix design of all specimens was based on the CSA code (5). The concrete mixture and properties are given in Table 1. The cylinder concrete compressive strength, f'_c, for all specimens was 46.1MPa. The reinforcement material, which was applied horizontally to the columns, was the Tyfo SCH- 41S Composite Fiber System. This system consists of Tyfo S Epoxy and Tyfo SCH-41S reinforcing fabrics. The Tyfo SCH-41S is a unidirectional carbon fabric with aramid cross fibers. It has been custom stitched, with the carbon material oriented in the 0° direction, and aramid fibers at 90°. The Tyfo S epoxy material used for bonding applications is a two-component epoxy matrix material. The system properties are summarized in Tables 2 and 3. The FRP was applied in accordance with the methods recommended by the manufacturer of Tyfo SCH-41A Composite Fiber Systems.

TABLE 1. Concrete Mixtures and Properties

Material	**Volume (m^3/m^3)**	**Mass (kg/m^3)**	**Concrete properties**
Water	0.164	164	Compressive strength (f'_c) = 46.1 MPa
Cement	0.130	410	Slump=80mm
Air	0.06	-	Water to Cement Ratio = 0.4
Coarse Aggregate	0.409		Maximum Aggregate Size =20mm
Fine Aggregate	0.237	623	Air Volume = 6%
	1.000	2281	

TABLE 2. Tyfo SCH-41S System Properties.

Description	**Ultimate Tensile Strength, f_{FRP}**	**Tensile Modulus E**	**Thickness**
Primary Carbon Fiber 0° Aaramid fiber 90°	876 MPa	72.4 GPa	1.0 mm

C. Test specimens

To determine the effect of FRP wraps on column strength, 3 circular and 3 square columns were manufactured and tested. The details of the column specimens are shown in Fig 1 and 2. The properties and dimensions of three circular columns were selected to be similar in order to obtain a reasonable mean value of the results. The square column specimens were also similar with the exception of Specimen C which had the corners removed to a depth of 12mm. the circular and square column properties were selected to yield similar theoretical load carrying capacity without considering the effect of FRP. All specimens were wrapped using two layers of FRP. The thickness of each layer of FRP was 1 mm.

TABLE 3. Epoxy Material Properties

Tensile Strength	**Tensile Modulus**	**Elongation Percent**	**Flexural Strength**	**Flexural Modulus**
72.4 MPa	3.18 GPa	5.0 %	123.4 MPa	3.12 GPa

D. ANSYS Modeling

ANSYS modeling is generally performed by mapped meshing or free meshing. Mapped mesh modeling is a procedure in which meshes are generated in even order. Free mesh modeling is the one in which the meshes are generated in random. In this thesis work, mapped mesh modeling is adopted.

E. Element Properties

There are three types of elements used in this analytical work, they are

- Solid 65 - Concrete Element
- Solid 46 – FRP Element
- Link 8 - Steel Element

Solid 65-3D reinforcement concrete

Assumptions and Restrictions

- Cracking is permitted in three orthogonal directions at each integration point.
- If cracking occurs at an integration point, the cracking is modeled through an adjustment of material properties which effectively treats the cracking as a “smeared band” of cracks, rather than discrete cracks.
- The concrete material is assumed to be initially isotropic
- Whenever the reinforcement capability of the element is used, the reinforcement is assumed to be “smeared” throughout the element.
- In addition to cracking and crushing, the concrete may also undergo plasticity, with the Drucker-Prager failure surface being most commonly used. In this case, the plasticity is done before the cracking and crushing checks.

Description

SOLID 65 allows the presence of four different materials within each element; one matrix material (e.g. concrete) and a maximum of three independent reinforcing materials. The concrete material is capable of directional integration point cracking and crushing besides incorporating plastic and creep behavior. The reinforcement (which also incorporates creep and plasticity) has uniaxial stiffness only and is assumed to be smeared throughout the element. Directional orientation is accomplished through user specified angles.

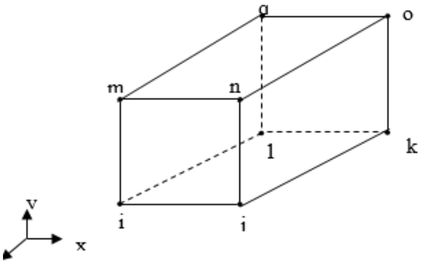


Fig 1- Solid 65 Element

LINK 8: 3-D Spar

Link 8 is a par which may be used in a variety of engineering applications. This element can be used to model trusses, sagging cables, links, springs, etc. The three-dimensional spar element is a uniaxial tension-compression element with three degrees of freedom at each node: translation in the nodal x, y, and z direction. As in a pin-joined structure, no bending of the element is considered. Plasticity, creep, swelling, stress stiffening, and large deflection capabilities are included.

Assumptions and Restrictions

The spar element assumes a straight bar, axially loaded at its ends, and of uniform properties from end to end. The length of the spar must be greater than zero so nodes I and J must not be coincident. The area must be greater than zero. The temperature is assuming to vary linearly along the spar.

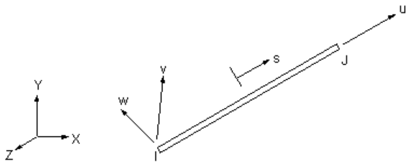
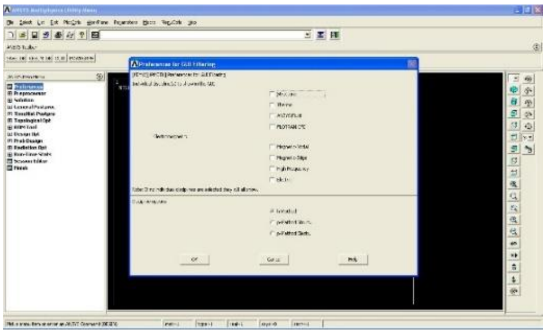


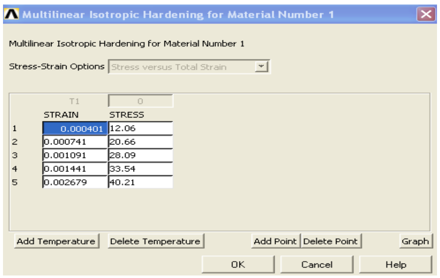
Fig 2- Link 8 Element

Modeling Using ANSYS
Step 1 Go to Preferences and opt for Structural, h- method and Click Ok.



Inputs in Material Model:

Solid – 65



Multilinear Isotropic Hardening for Material Number 1

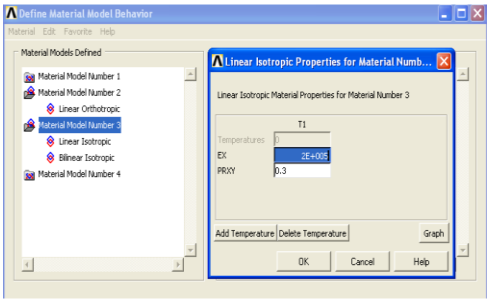
Multilinear Isotropic Hardening for Material Number 1

Stress-Strain Options: Stress versus Total Strain

T1: 0

	STRAIN	STRESS
1	0.000401	12.06
2	0.000741	20.66
3	0.001091	28.09
4	0.001441	33.54
5	0.002679	40.21

Link 8



Define Material Model Behavior

Linear Isotropic Properties for Material Numb...

Linear Isotropic Material Properties for Material Number 3

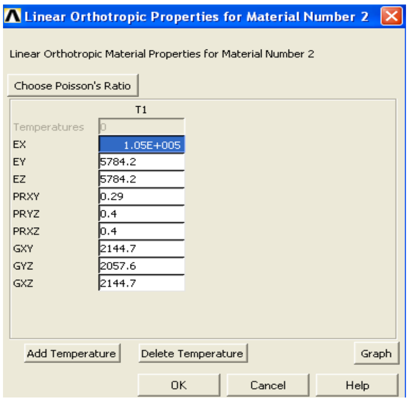
T1

Temperatures: 0

EX: 2E+005

PRXY: 0.3

Solid 46



Linear Orthotropic Properties for Material Number 2

Linear Orthotropic Material Properties for Material Number 2

T1

Temperatures: 0

EX: 1.05E+005

EY: 5784.2

EZ: 5784.2

PRXY: 0.29

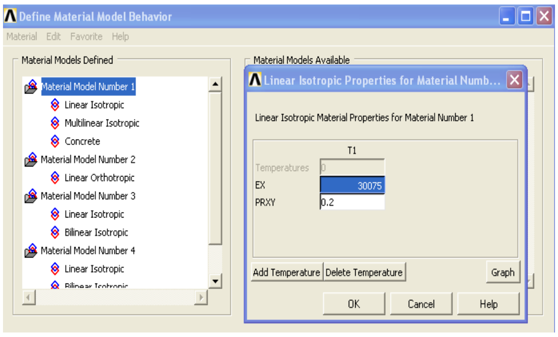
PRYZ: 0.4

PRXZ: 0.4

GXY: 2144.7

GYZ: 2057.6

GXZ: 2144.7



Define Material Model Behavior

Linear Isotropic Properties for Material Numb...

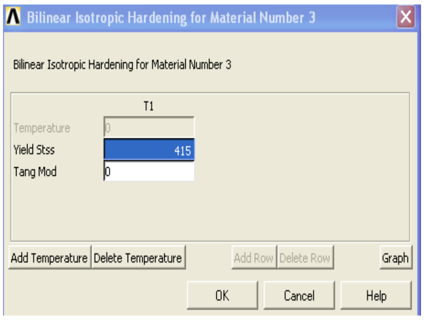
Linear Isotropic Material Properties for Material Number 1

T1

Temperatures: 0

EX: 30075

PRXY: 0.2



Bilinear Isotropic Hardening for Material Number 3

Bilinear Isotropic Hardening for Material Number 3

T1

Temperature: 0

Yield Stss: 415

Tang Mod: 0

Interferences of ANSYS Modeling

- Load and deflection value obtained through non linear finite element modeling agree well with the test data obtained from reinforced concrete column with and without wrapping.
- The failure mechanism of confined and unconfined reinforced column is modeled quite well using finite element analysis and the failure load predicted is very close to failure load obtained from source data.
- The results obtained through FEM analysis for the control specimen varies from 8.62-31.23% for ultimate load and 5.88-32.5% for ultimate deflection.

FIG.3 Load Vs Displacement -A Circular

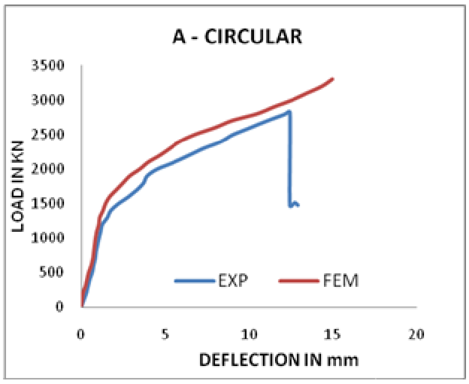
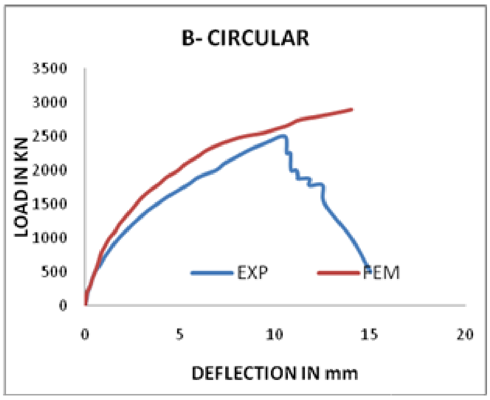


FIG.4 Load Vs Displacement -B Circular



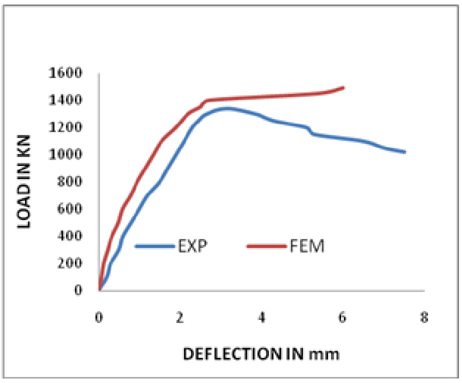
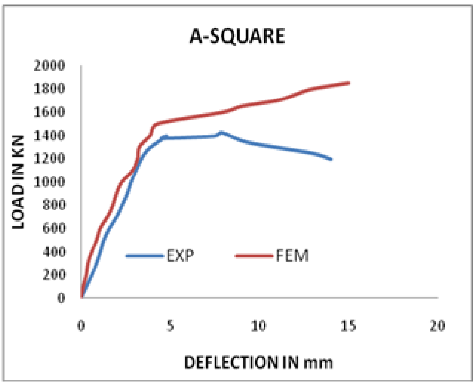
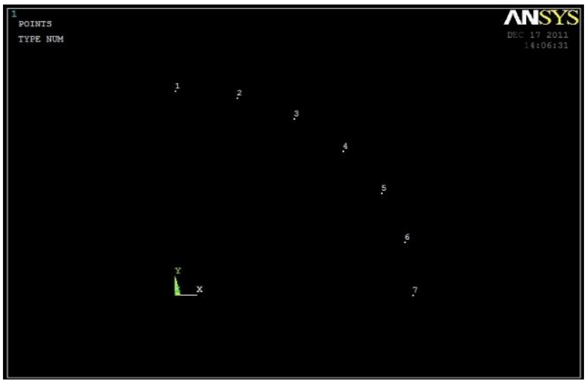


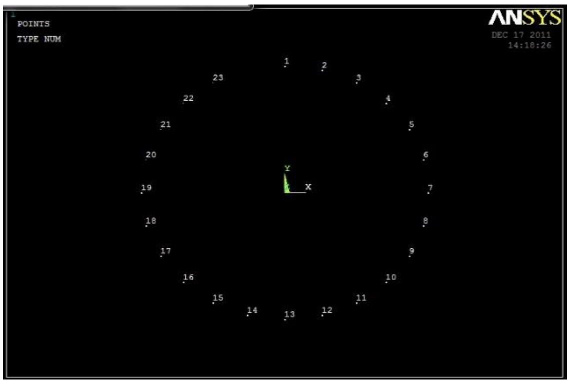
FIG.6 Load Vs Displacement -B Square

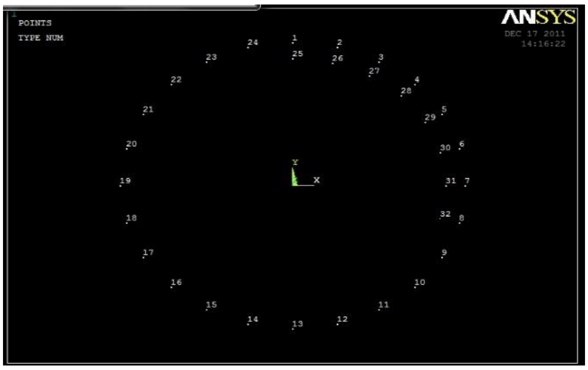
FIG.5 Load Vs Displacement -A Square

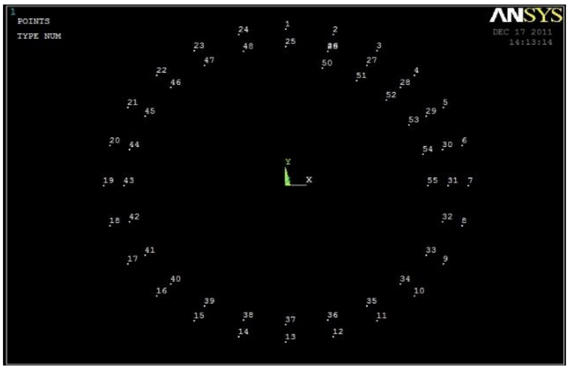


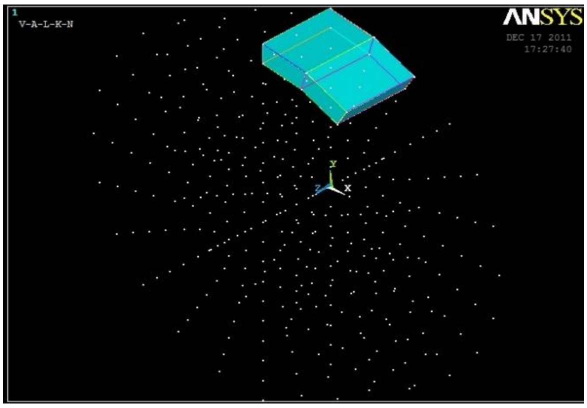
Modeling Procedure for Circular Columns

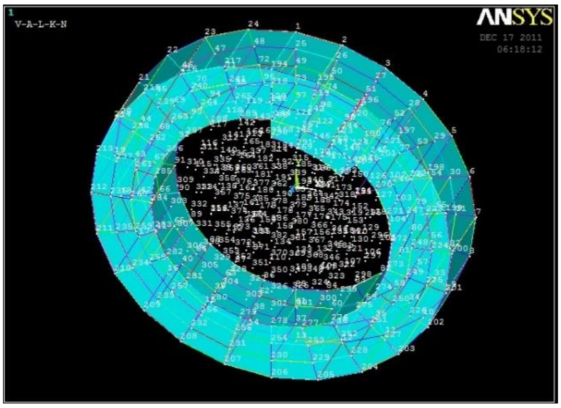


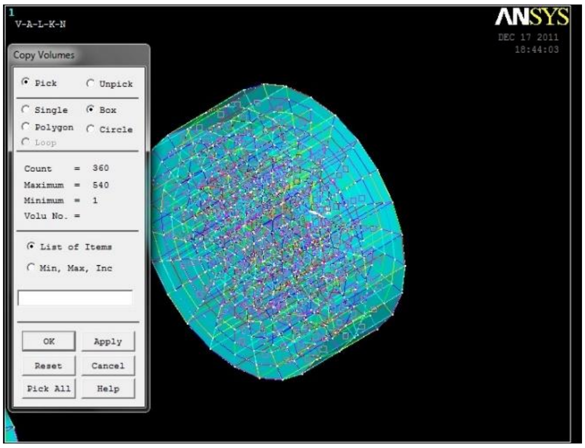












● Pick ○ Unpick
○ Single ● Box
○ Polygon ○ Circle
○ Loop

Count = 360
Maximum = 540
Minimum = 1
Volu No. =

● List of Items
○ Min, Max, Inc

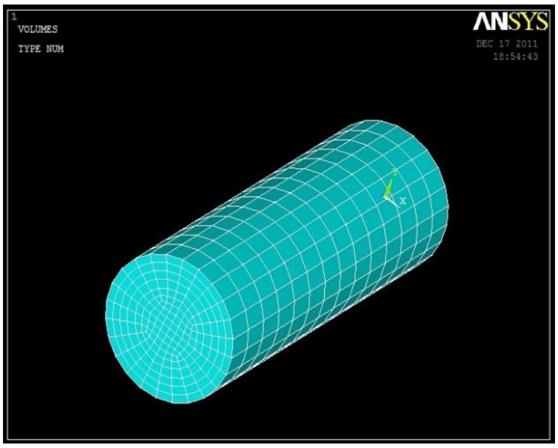


TABLE 4 % Error of Experimental and ANSYS results

S. No	Specimen Classification			Size of the specimen	f_{ck} MPa	FRP tk mm	Exp results		FEM results	
	Researcher	Specimen Designation	FRP TYPE				P_{ul}	δ_{ul}	δ_{ul}	% error
1	M.N.S.HADI	R	-	205mm φ	20	-	2740	5.95	5.4	9.24
2		1C	Carbon	205mm φ		1	2361	5.75	5.1	11.3
3		1F	Aramid	205mm φ		1	2384	6.42	6.1	4.98
4		2C	Carbon	205mm φ		3	2469	6.32	5.9	6.64
5		2F	Aramid	205mm φ		3	2523	8.37	8	4.42
6		3C	Carbon	205mm φ		5	2551	7.06	6.6	6.51
7		3F	Aramid	205mm φ		5	3025	5.7	4.9	14.03
8	M.Reza Esfahani & M.Reza Kianoush	CA	Carbon	205mm φ	46.1	1	2798	12.3	11.3	8.13
9		CB	Carbon	205mm φ		3	2488	11.6	10.4	10.34
10		CC	plain	205mm φ		0	2324	10.6	9.6	9.43
11		SA	Carbon	180X180mm		1	1417	7.4	6.6	10.81
12		SB	Plain	180X180mm		0	1343	3.3	3	9.09

IV. ARTIFICIAL NEURAL NETWORK BASED MODELING

An Artificial Neural Network (ANN), often just called "neural network"(NN), is a mathematical model or computational model based on biological neural networks. It consists of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase.

The experiment data provided byM.Reza Esfahani, M.N.S.Hadi has been used for training the network. Network has been trained for ultimate stress, ultimate load, axial deflection, lateral deflection, axial strain, lateral strain.

A. Training Procedure

The following steps are involved in a training procedure.

B. Formation of Input Parameters

The input parameters include

- FRP tube thickness
- Ultimate load
- Ultimate stress

From these input parameters the networks has been trained.

C. Formation of Target Parameters

Output values were considered as the target parameters. These values taken from the experimental results.i.e.

- Axial deflection
- Lateral deflection
- Axial strain
- Lateral Strain

D. Training Data

Training has been taken from the experimental results of the earlier studies Network has been applied for these data. Experimental results were shown in Table 6.1 to E. Training the Network

Before training the neural network, the network parameters have to be fixed. The neural network parameters were stored in a persistent file, and the parameters include the following,

- The number of input layer
- The number of output layer
- The input and the target patterns essential for training were written to a text file and this file was read from the program during training process.

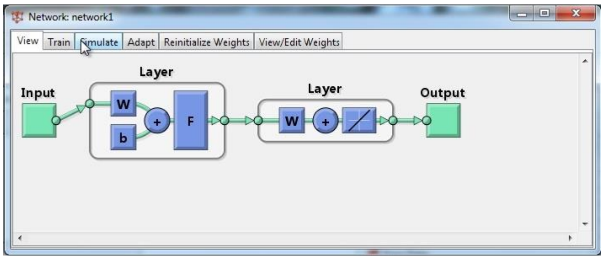
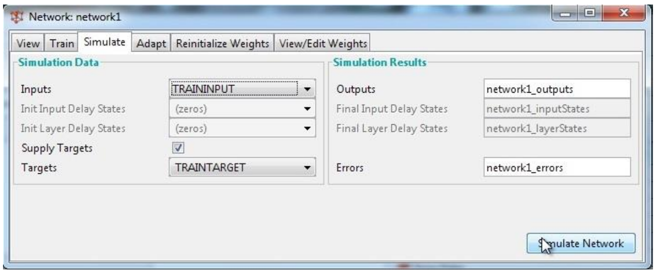


FIG. 7 Network 1

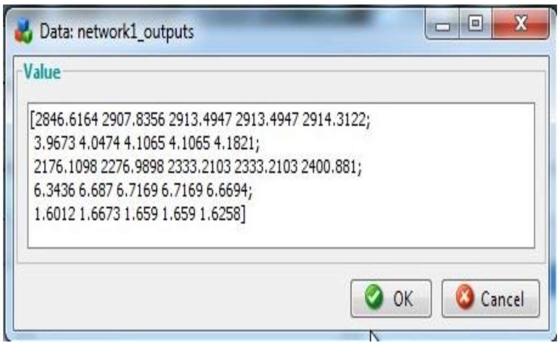
TABLE 5 % Error of Experimental and ANN results

S.No	Specimen Classification			fck MPa	FRP tk mm	Exp results		ANN			
	Researcher	Specimen Designation	FRP TYPE			P_{ul}	δ_{ul}	P_{ul}	δ_{ul}	% error	
										P_{ul}	δ_{ul}
1	M.N.S. HADI	R	-	20	-	2740	5.95	2846	6.34	3.72	6.55
2		1C	Carbon		1	2361	5.75	2424	6.18	2.612	7.47
3		1F	Aramid		1	2384	6.42	2276	6.68	4.74	4.04
4		2C	Carbon		3	2469	6.32	2333	6.71	5.812	6.17
5		2F	Aramid		3	2523	8.37	1754	7.9	5.94	5.61
6		3C	Carbon		5	2551	7.06	2487	6.62	6.59	6.23
7		3F	Aramid		5	3025	5.70	2900	6.2	8.06	8.77
8	M.Reza Esfahani & M.Reza Kianoush	CA	Carbon	46.1	1	2798	12.3	2930	11	4.71	10.57
9		CB	Carbon		3	2488	11.6	2575	12.9	3.96	11.20
10		CC	plain		0	2324	10.6	2434	12.1	4.73	14.15
11		SA	Carbon		1	1417	7.4	1517	8.4	7.05	13.51
12		SB	Plain		0	1343	3.3	1223	3.7	8.93	9.09



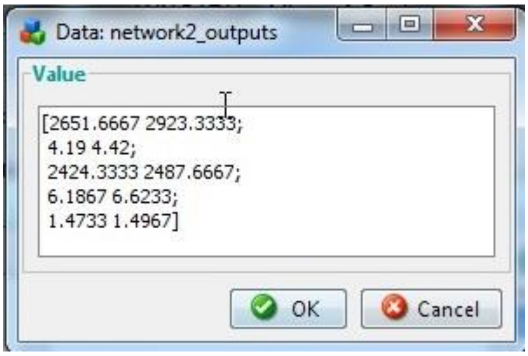
Inputs: TRAININPUT
Init Input Delay States: (zeros)
Init Layer Delay States: (zeros)
Supply Targets: ☑
Targets: TRAINTARGET
Outputs: network1_outputs
Final Input Delay States: network1_inputStates
Final Layer Delay States: network1_layerStates
Errors: network1_errors

FIG.8 Network 1: Simulate



```
[2846.6164 2907.8356 2913.4947 2913.4947 2914.3122;
 3.9673 4.0474 4.1065 4.1065 4.1821;
 2176.1098 2276.9898 2333.2103 2333.2103 2400.881;
 6.3436 6.687 6.7169 6.7169 6.6694;
 1.6012 1.6673 1.659 1.659 1.6258]
```

FIG.9 Network 1: Outputs



```
[2651.6667 2923.3333;
 4.19 4.42;
 2424.3333 2487.6667;
 6.1867 6.6233;
 1.4733 1.4967]
```

FIG.10 Network 2: Outputs

F. Interferences of ANN Modeling

The Generalized Regression Neural Network (GRNN) model produces more accurate results but at the cost of increased dependence on computers for making them work. The following conclusions are derived from GRNN model.

- The GRNN models takes steel ratio, type of FRP wrap and wrap thickness as input and predicts yield load, yield deflection, ultimate load and ultimate deflection.
- GRNN based computational models proposed in this study is an effective way for predicting the performance of CFRP wrapped reinforced concrete columns with very small error levels.
- The result obtained through ANN modeling for the specimens varies from 6.62-26.89% for ultimate load and 2.25-19.74% for ultimate deflection.

G. Comparison of Experimental Results with ANN Results

- Results of ANN compared with the experimental results were quite satisfactory.
- The Percentage Error was in the range of 0.6% to 14.3686% for the training data and in the range of 0.5733% to 18.5261% for testing data. These error values are reasonably small.

V. CONCLUSION

Observations on the Experimental Source Data & Predicted Values

In this work effect of FRP laminates on the RC Columns have been studied. A comparative study of Experimental, ANSYS and ANN is presented in the succeed sections.

- The load deflection behaviors for all columns were studied from source data. The Experimental and Analytical load deflection values of different authors are tabulated in Table 5
- From the results tabulation, the analytical deflection is higher than the experimental deflection is noted.
- The ultimate load predicted by finite element analysis showed a good agreement with the experimental source data. Whereas the ultimate load predicted through Artificial neural network showed considerable variation from the experimental source data.
- The deflection at ultimate load predicted by finite element analysis and Artificial Neural Network showed a good agreement with the experimental source data.
- Time consumed by Artificial Neural Network for predicting the values of ultimate load and deflection was very less when compared to finite element analysis.

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