Analytical and Experimental Study on FRP Confined Concrete Column

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Abstract -*Fibre reinforced polymer (FRP) is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, aramid and the polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic and phenol formaldehyde resins. FRP have been found to be particularly attractive for applications involving the strengthening and rehabilitation of structures. In this work an attempt has been made to develop a 3-D finite element model of FRP confined concrete column using ABAQUS software. A Drucker-Prager Plasticity model is used for concrete and orthotropic elasticity model is used for FRP. Also a parametric study has been carried out to evaluate the effect of number of FRP layers and corner radius on ultimate strength of concrete short columns and also validate the analytical study. A study was carried out on square column of cross section 125 x 125 mm with height 300mm with varying corner radius such as 15mm, 25mm, 35mm and 62.5mm along with control column were cast with M20 grade concrete. Confinement provided as single layer and double layer for the column by using E-Glass fibre chopped strand mat of density 450g/m^2.The columns were tested under axial compression load up to failure. From the test results, the ultimate load were compared with the analytical results.*

Key Words: FRP confined concrete column, ABAQUS software, Drucker-Prager Plasticity model, E-Glass fibre chopped strand mat

I. INTRODUCTION

The structures are usually designed to a last long time. However, sometimes structures need to be strengthened due to an increase in the applied load or deteriorated structural members, such as Reinforced concrete columns that have deteriorated due to the corrosion of reinforcing steel. To this end, the use of concrete jackets and fibre reinforced polymer (FRP) wrapping is suitable to improve the performance of columns in terms of the load carrying capacity. It is the light weight material and excellent corrosion resistance and ease of onsite handling and typical properties of FRP that make it ideal for retrofitting application. For these reason, FRP has been widely used in construction and structural rehabilitation.

Fibre-reinforced polymer (FRP) is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, or aramid, although other fibres such as paper or wood or asbestos have been sometimes used. The polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic and phenol formaldehyde resins. In recent years, using fibre reinforced polymer (FRP composites) has gained considerable attention in retrofitting and strengthening of reinforced concrete columns. The concrete column is the most critical structural member in the building because the failure of column can cause the failure of the whole structure. Square shape of concrete columns is commonly used in the construction of concrete structures and strengthening of concrete square columns is one of the most important issues relevant to strengthening, repairing and retrofitting of concrete structures. FRP jacketing is effective with respect to strength, less stiffness and weight in comparison with steel, high ductility, resistance to corrosion, and low installation cost and repair. In this regard, FRP jackets obtained a great point in the field of civil engineering to significantly increase the compressive strength and ductility of RC columns. When the concrete is subjected to axial compression, it tends to expand. This lateral expansion is restrained by the activation of FRP stressing in tension. One of the most important applications of FRP-composites is a thin layer of FRP jacket for the repairing, retrofitting and strengthening processes of concrete columns. The results of several studies showed that the FRP jacket can greatly enhance the strength and ductility of concrete columns by providing confinement to the concrete core.

II. OBJECTIVES

The main objectives of this paper were:

a) To determine the ultimate load carrying capacity of the square column based on the following effects:

1. Corner radius variation
2. Number of layer of wrapping using GFRP

b) Modeling and analyzing of the column specimen using ABAQUS software.

III. MATERIALS& PROPERTIES

3.1CEMENT

In this project Dalmia 53 Grade Ordinary Portland Cement conforming to IS 12269-1987 was used. The specific gravity of cement (3.09), fineness (0.48%),Standard Consistency(31.5%),Initial setting time (36minutes) and final setting time (360 minutes).

3.2FINE AGGREGATE

Aggregate which passed through 4.75mm IS Sieve and retained on 75micron (0.075mm) IS Sieve is termed as fine aggregate. Ordinary river sand conforming IS 383-1970 was used in this project.The Nominal size of fine aggregate (2.36mm).Specific Gravity (2.69), Fineness Modulus (3.484), Moisture content (1.1%), Water Absorption (0.7%), Bulk Density in Loose state (1580.62 kg/m^3) and in Compacted state (1617.92 kg/m^3)

3.3COARSE AGGREGATE

The coarse aggregate for the works should be river gravel or crushed stone. Angular shape aggregate of size is 20mm was used.Specific Gravity (2.74), Fineness Modulus (7.51), Water Absorption (1.4%), Bulk Density in Loose state (1506.5kg/m^3)and in Compacted state (1626.74 kg/m^3)

3.4E-GLASS FIBRE CHOPPED STRAND MAT

E-Glass Fibre Chopped Strand Mat (CSM). Chopped Strand Mat (CSM) is a form of reinforcement used in Glass-Reinforced Polymer. E-glass fibre chopped strand mat (CSM) having a density of 450g/m^2 was used.

S. No	Property	Value
1.	Thickness (mm)	0.3
2.	Density (GSM)	450
3.	Young's Modulus (KN/mm^2)	70-80
4.	Tensile Strength (KN/mm^2)	2-4

Fig 3.1 E-GLASS FIBRE CHOPPED STRAND MAT

3.5 GP RESIN

General Polyester Resin. Resin is manufactured by etherification or soaping of organic compounds. The classic variety is polyester resin, manufactured by polymerization-poly addition or poly condensation reactions used as thermoset polymer for adhesives and composites.

Fig 3.2 GP RESIN

3.6 CATALYST (MEKP)

The catalyst used as MEKP (Methyl Ethyl Ketone Peroxide).

Fig 3.3 CATALYST (MEKP)

3.7 ACCELERATOR (COBALT OCTOATE)

The Accelerator (cobalt octoate) was used

Fig 3.4 ACCELERATOR (COBALT OCTOATE)

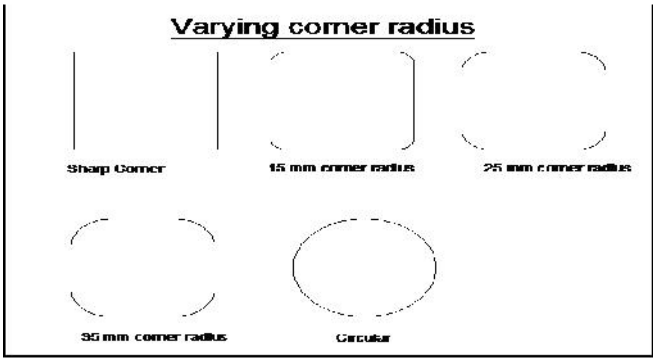
IV. Mix Design

Table 4.1 Mix Design

Cement	Fine aggregate	Coarse aggregate	Water
1	1.637	2.84	0.45

V. SPECIMEN DETAILS

Square Column Of Size125x125 x300mm



VI. ANALYTICAL STUDY

The Finite element software ABAQUS 6.12 version is used for the analytical study. The list of the modules available within Abaqus/CAE: Part, Property, Assembly, Step, Interaction, Load, Mesh, Job and Visualization are used for the modeling task.

6.1 Analytical Model of FRP Confined Concrete Column

Analytical models can be used to predict the experimental evaluation results and to design concrete specimens confined by jackets.

6.2 Modelling of Concrete

The concrete is modeled as a solid section for 3D stress-strain analysis. Material properties of the concrete used for the model are concrete damaged plasticity with concrete compression hardening and concrete tension stiffening options and elastic options. Isotropic material properties, the elastic modulus (Ex) and the Poisson's ratio (v) are input to the element.

Finite Element Model Of Concrete Column (Square Column Of Size125x125 x300mm) With Varying Corner Radius are as follows

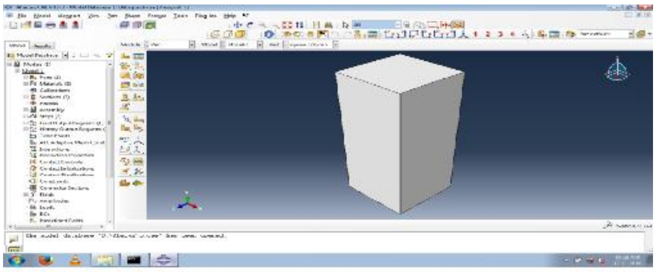


Fig 6.1 Sharp Edges

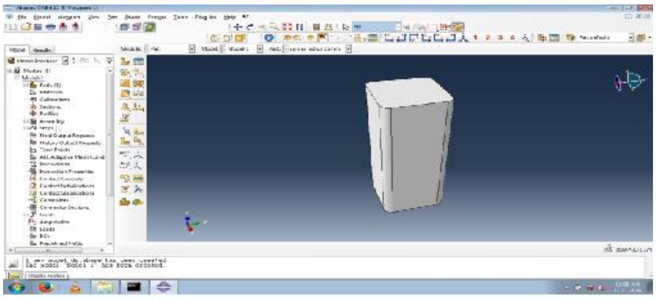


Fig 6.2 Corner Radius15mm

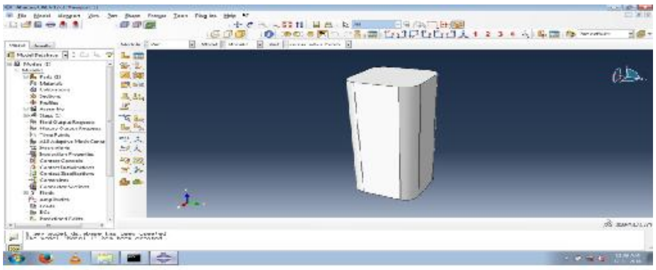


Fig 6.3 Corner Radius 25mm

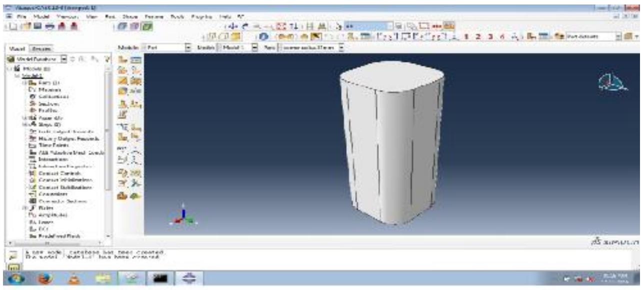


Fig 6.4 Corner Radius 35mm

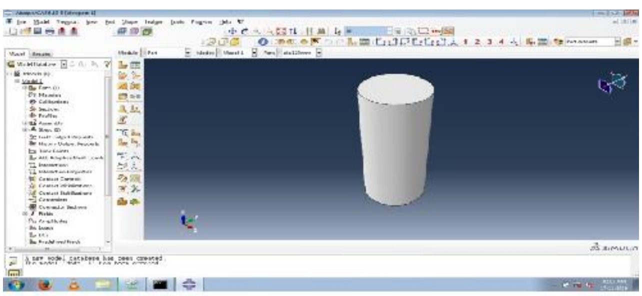


Fig 6.5 Corner Radius 62.5mm

6.3 Modeling of Jacket

Modeling of the GFRP jackets follows the same general process. By using the extrusion option and defining the centre line axis, thickness and material properties of jacket type, three dimensional shell sections are created for the jacket model. Elastic material options are used for defining material properties. The composites are orthotropic materials therefore ; nine different properties have to be input, the elastic modulus in three different directions (E_x, E_y, E_z), the shear modulus in three directions (G_{xy}, G_{yz}, G_{zx}) and the poisson's ratio in the three directions (v_{xy}, v_{yz}, v_{zx}). For single layer, the thickness was 0.3mm and for double layer it was 0.6mm.

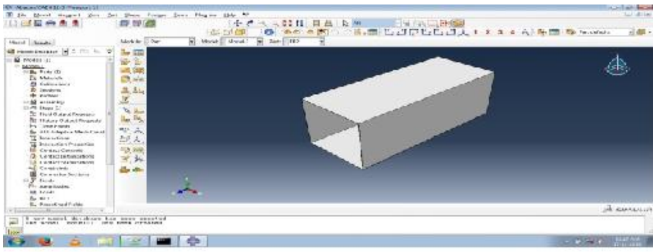


Fig 6.6 Finite Element Model of FRP

6.4 Step, Loads And Boundary Conditions

Geometric nonlinearities were accounted for stress analysis. FEA was used for the static stress analysis. The riks option allows for stepwise solving of post-peak analysis of models. In this model, the Z-axis of the coordinate system coincides with the axis of the concrete block. The boundary conditions are: 1) one end of the surface was fixed i.e al the six degrees of freedom on that surface were constrained. 2) An axial compressive load was applied on the top surface. The axial pressure load was increased gradually until the FRP fails.

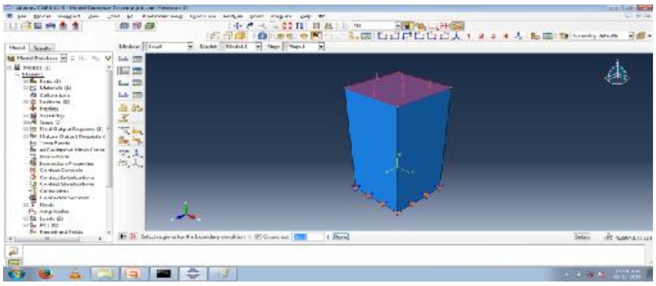


Fig 6.7 Boundary Conditions And Loading Condition of FRP Confined Concrete

6.5 Meshing of FRP Confined Concrete

The density of the element mesh has a great influence on the results of the geometrically nonlinear analysis. Since increasing the amount of elements in the model rapidly increases the computational cost of the analysis, it is reasonable to find an optimal combination between the accuracy of the results and the size of the model. The global element size is defined as 10 while meshing the concrete column. The geometry and nodal location of the element are shown in figure

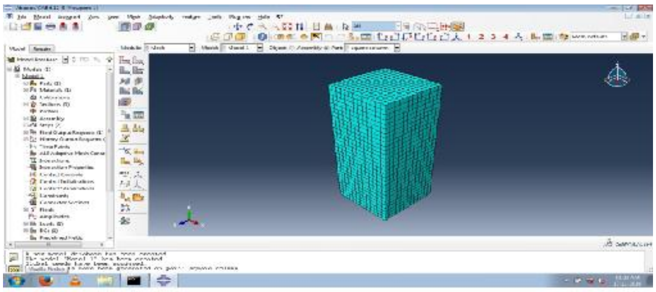


Fig 6.8 sharp edges

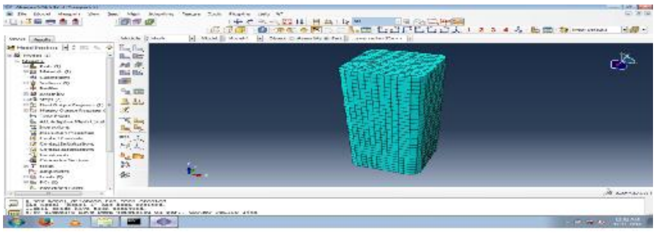


Fig 6.9 corner radius 15mm

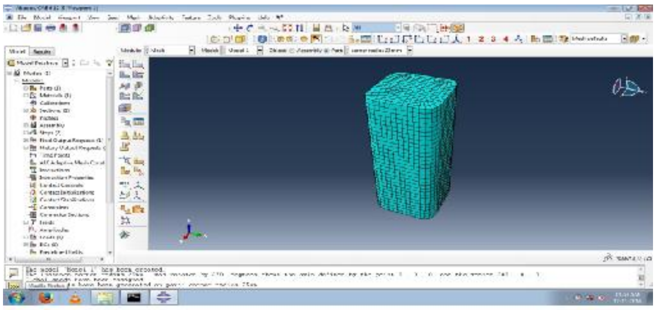


Fig 6.10 corner radius 25mm

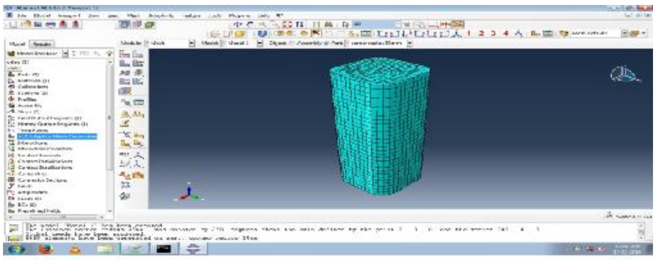


Fig 6.11corner radius 35mm

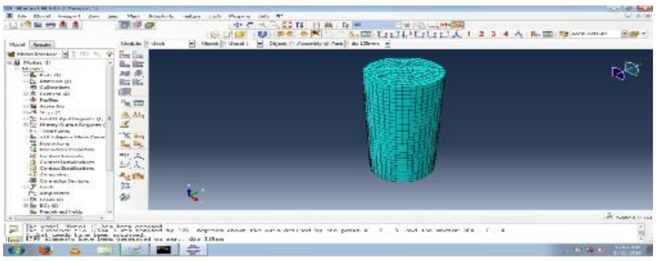


Fig6.12corner radius 62.5mm

6.6 Solution Method

After meshing, analysis part was done. For the analysis in this study, only one time steps per analysis was needed. The Newton’s method was used for the solution of non-linear problems. From the results, the stress strain values were taken from the XYplot.

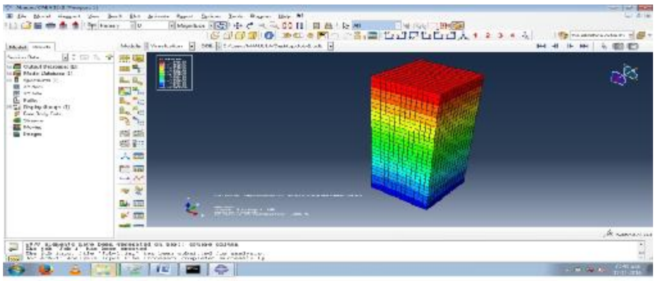


Fig 6.13 sharp edges

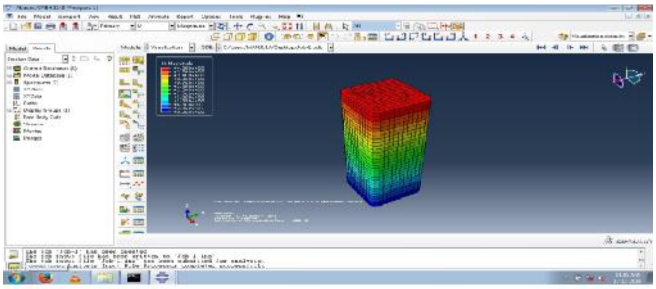


Fig 6.14 corner radius 15mm

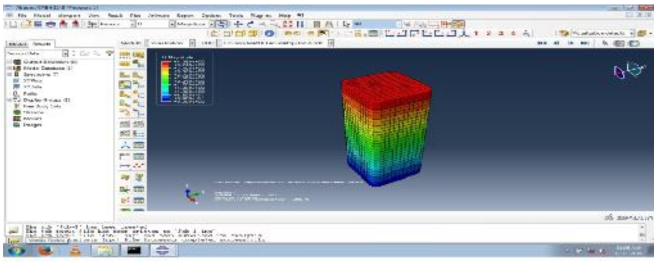


Fig 6.15 corner radius 25mm

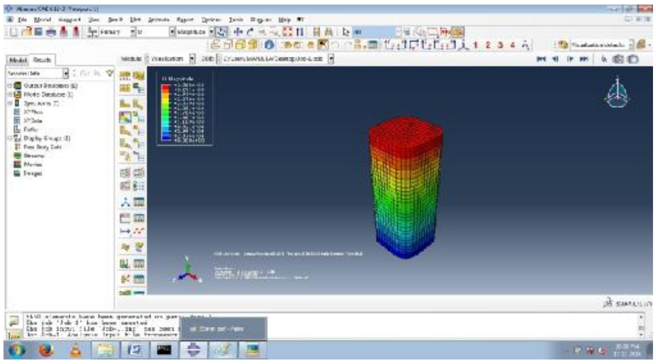


Fig 6.16 corner radius 35mm

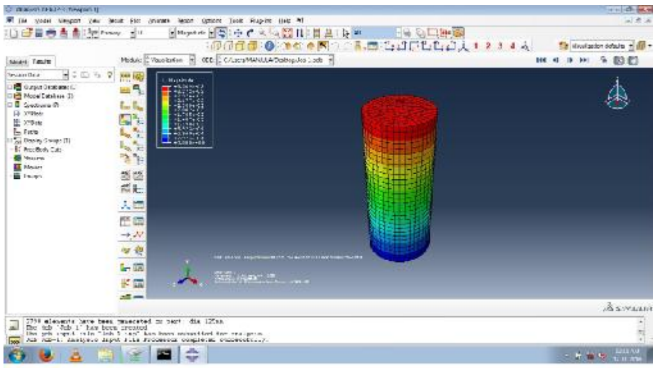


Fig 6.17 corner radius 62.5mm

Table 6.1 Analytical Ultimate Load Carrying Capacity

S. No	Specimen Detail	Ultimate Load (Kn)		
		Un Wrapped Specimen	One Layer Wrapped Specimen	Two Layer Wrapped Specimen
1	Sharp edge specimen	230	241	257
2	Corner radius of 15mm	227	245	280
3	Corner radius of 25mm	224	259	305
4	Corner radius of 35mm	220	285	330
5	Corner radius of 62.5mm	215	297	355

6.7 Stress Strain Values

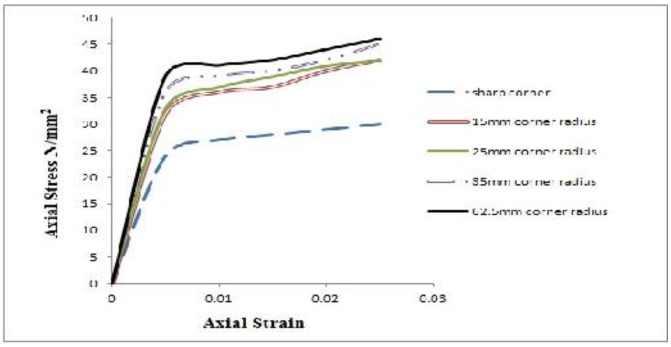


Fig 6.18 Analytical Stress Strain Curve of Unconfined Concrete Column Specimens With Varying Corner Radius

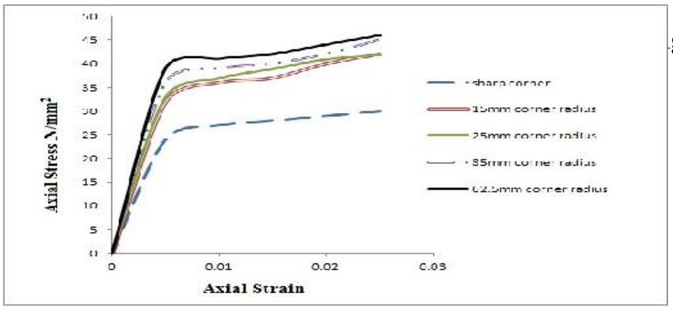


Fig 6.19 Analytical Stress Strain Curve of Single Layer FRP Confined Concrete Column Specimens With Varying Corner Radius

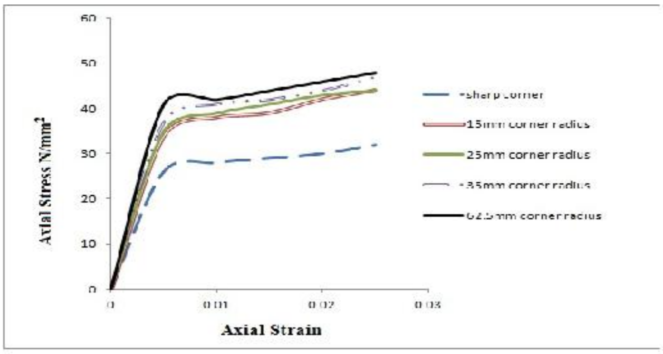
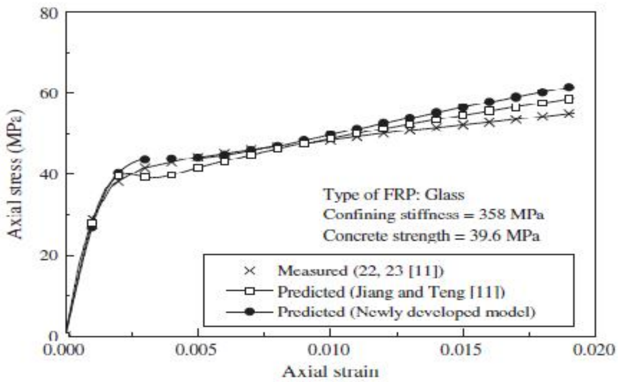


Fig 6.20 Analytical Stress Strain Curve of Double Layer FRP Confined Concrete Column Specimens With Varying Corner Radius

6.7 VALIDATION OF THE MODEL

The model from the analysis is being validated using the experimental results obtained from the journal "Axial and lateral stress–strain model for FRP confined concrete"A.K.H. Kwan, C.X. Dong, J.C.M.Ho, Engineering Structures 99 (2015) 285–295.

The stress – strain plot for the FRP confined column obtained from the experimental results are shown in fig 6.16. These results are used for validation of the model done in the present study. The stress-strain plot for the FRP confined column as obtained from FEM analysis is shown in Fig 6.21



g 6.21 Stress – Strain Plot As Obtained From Reference Journal

6.8 Summary

The comparison between the experimental results and the results predicted by FEA show that the FEA results are reliable. The above FEA model was also validated using an analytical model, which is developed using the basic fundamental principles involved. The present FE model can be utilized as a tool develop a very large test database with taking into account all the possible ranges of the parameters affecting the confined concrete strength. Based on the test database a design oriented confinement model can be developed to predict the strength and ductility of the FRP confined concrete column

VII.EXPERIMENTAL STUDY

Table 7.1 Compressive strength results:

Average Compressive Strength Cube(150mm x 150mm x 150mm)	
7^{th} Day	28^{th} Day
17.70 N/mm^2	29.20 N/mm^2

Table 7.2 Specimen Details

S. No	Square Column Size (Mm)	Corner Radius(Mm)	No of Specimen
1	125 X125 X 300	0	3
2	125 X125 X 300	15	3
3	125 X125 X 300	25	3
4	125 X125 X 300	35	3
5	125 X125 X 300	62.5	3

Fig7.1 Unconfined Concrete Column Specimen With Varying Corner Radius

(Sharp Edges, 15mm, 25mm, 35mm And 62.5mm)

Table 7.3 Experimental Ultimate Load Carrying Capacity

S.No	Specimen Detail	Ultimate Load (Kn)		
		Unwrapped Specimen	One Layer Wrapped Specimen	Two Layer Wrapped Specimen
1	Sharp edge specimen	248	255	270
2	Corner radius of 15mm	240	260	290
3	Corner radius of 25mm	234	272	337
4	Corner radius of 35mm	228	294	360
5	Corner radius of 62.5mm	220	305	380

Fig 7.2 Single and double layer FRP Confined Concrete Column Specimen With Varying Corner Radius

(Sharp Edges, 15mm, 25mm, 35mm And 62.5mm)

7.1Testing procedure

After the strengthening of specimens, the axial ultimate load test is performed. The bearing surfaces of the test frame shall be wiped clean and any loose sand or other material removed from the surface of the specimen which are to be in contact with the compression patterns. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen with the help of plump bob. No packing used between the faces of the test specimen and the steel paten of the test machine. The load shall be applied without shock and increased continuously at the particular rate until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features in the type of failure shall be noted.

Fig 7.3 CTM

Fig 7.4 failure crack pattern of single and double layer FRP confined concrete column with varying corner radius (Sharp Edges, 15mm, 25mm, 35mm And 62.5mm)

VIII. CONCLUSION

A 3D finite element analysis is used to study the mechanical behaviour of concrete columns strengthened with GFRP wrapping. A Drucker-Prager Plasticity model is used to simulate the FRP confined concrete column. The analytical curves of axial stress vs axial strain are compared well with the reference journals for the column varying with corner radius. Results from finite element analysis using ABAQUS software shown good agreement with the experimental results. For unconfined concrete column, the ultimate load carrying capacity is decreased by increasing the corner radius. For FRP confined concrete column, the ultimate load carrying capacity is increased by increasing the corner radius . Thus, from the above results, the circular shaped column is more effective for FRP confined method of strengthening.

REFERENCE

1. Jijin V.1, Preetha Prabhakaran (2015) 'Comparative study on GFRP jacketed RC columns and CFRP jacketed RC columns of different shapes' international journal of engineering research and general science volume 3, issue 5, september-october ,2015 ISSN 209-2730.

2. Kinjal V Ranoliaa, B K Thakkarb, J D Rathodb(2012) 'Effect of Different Patterns and Cracking in FRP Wrapping on Compressive Strength of Confined Concrete' procedia engineering 51(2013) 169-175.

3. Lei-Ming Wang, Yu-Fei Wu (2007) 'Effect of corner radius on the performance of CFRP-confined square concrete columns: Test' Engineering structures 30(2008)493-505.

4. Lo a S.H, A.K.H. Kwan a, Y. Ouyang a, J.C.M. Ho b, (2015) 'Finite element analysis of axially loaded FRP-confined rectangular concrete column' Engineering structureas 100(2015) 253-263.

5. Matthys.S; H.Toutanji; L.Taerwe (2006) 'Stress-Strain Behaviour Of Large Scale Circular Columns Confined With FRP Composites' Journal of structural engineering @ ASCE2006.132:123-133.

6.Manuel A. G.Silva and Carlos C.Rodrigues (2006) 'Size And Relative Stiffness Effects On Compressive Failure of Concrete Column Wrapped With Glass FRP' journal of materials in civil engineering @ ASCE 2006.18:334-342.

7. Mazzucco.G, V.A. Salomoni, C.E. Majorana, C. Pellegrino, C. Ceccato(2016) 'Numerical investigation of concrete columns with external FRP jackets subjected to axial loads' Construction and Building Materials 111 (2016) 590–599.

8. Rahul Ravala, Urmil Daveb(2013) 'Behavior of GFRP wrapped RC Columns of different shapes' procedia engineering 51(2013)240-249.

9. Sushil S. Sharmaa, Urmil V. Daveb, Himat Solankic (2012) 'FRP Wrapping for RC Columns with Varying Corner Radii' procedia engineering 51(2013) 220-229.

10. A.K.H. Kwan, C.X. Dong, J.C.M.Ho,(2015) 'Axial and lateral stress–strain model for FRP confined concrete' Engineering Structures 99 (2015) 285–295.

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