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FEA of Glass Fibre Wrapped Concrete

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Abstract: *Composite materials are in use for retrofitting of civil engineering structures. Due to its wide applications it has received significant attention of engineers and researchers worldwide. Composite materials have many advantages over conventional steel reinforcement which includes high specific strength to weight ratio, non corrosive, tailorability, ease of application, etc. Limited understanding of structural behaviour and information available on design criteria of composite materials is a major obstacle in infusion of this technology. In order to understand the behaviour of concrete columns wrapped with composite and to predict the behaviour of such strengthened columns in a better way, the mechanism of stress-strain distribution and development of the same in composite wraps and in concrete is required to be studied. Towards this, a nonlinear finite element analysis of glass fibre reinforced polymer (GFRP) wrapped plain concrete column has been carried out. The comparisons show that the finite element model predicts satisfactorily the confined peak axial stress and the corresponding strain of the plain concrete columns wrapped with GFRP composites.*
Key Word*: Concrete; Column; Finite Element; GFRP.*

I. Introduction

In order to understand the behaviour of confined concrete columns wrapped with GFRP and to predict the behaviour of such strengthened columns in a better way, the mechanism of stress-strain distribution and development of the same in GFRP wraps and the concrete needs to be studied. Prediction of true behaviour of GFRP wrapped concrete columns requires analytical tools, which would establish the performance behaviour of the composite concrete column. A nonlinear finite element analysis of GFRP wrapped plain concrete column has been carried out. The FE method is particularly advantageous in the modeling of non-uniformly confined concrete as it is capable of capturing complex stress variations in the concrete. In the present study, the theory of elasto-plasticity in conjunction with fracture energy based smeared cracking approach has been employed as the basic tool for the analysis.

II. Finite Element Modeling

A general purpose finite element program ANSYS 10.0 has been employed for the analysis. ANSYS has a large library of various element types. An element type is identified by a name (8 characters max.), such as SOLID65, consisting of a group label (SOLID) and a unique, identifying number (65). The element is selected from the library for use in the analysis. Following sections gives the descriptions of the elements employed in the FE modeling.

A. Reinforced Concrete (SOLID65)

3-D reinforced concrete SOLID65 element has been employed for modeling of concrete. The element is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. Other cases for which the element is also applicable would be reinforced composites and geological materials. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The geometry, node locations and the coordinate system for this element type are shown in Figure 1. There are no zero volume elements and all elements have eight nodes are the assumptions for this element.

The following two options are not recommended if cracking or crushing nonlinearities are present:

- Stress-stiffening effects.
- Large strain and large deflection. Results may not converge or may be incorrect, especially if significantly large rotation is involved.

B. FRP Composites (SOLID46)

A layered solid element SOLID46 has been used to define the GFRP composites. 250 different material layers with orientations and orthotropic material properties in each layer can be defined using this element. The element has three degrees of freedom, namely translations in nodal x, y, and z directions, at each node. Figure 2 shows the geometry, node locations, and the coordinate system for this element.

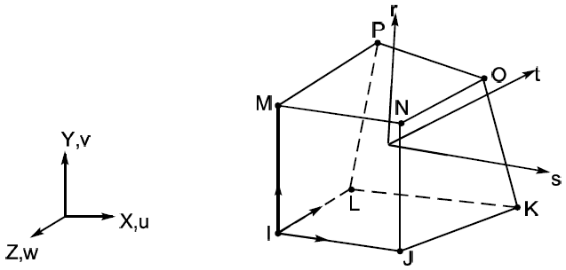

Fig. 1 3-D SOLID65 element

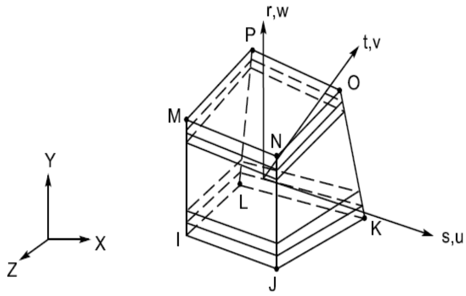

Fig. 2 SOLID46 element

The following are the assumptions and restrictions for this element:

- No slippage is assumed between the element layers.
- Stress varies linearly throughout the thickness of each layer.
- If multiple load steps are used, the number of layers may not change between load steps.
- All material orientations are parallel to the reference plane.

III. Material Properties

This section presents the material properties, input data required for concrete and glass fibre reinforced polymer used for the FE analysis.

A. Concrete: Input Data for SOLID65 element

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

- Elastic modulus (E_c)
- Uniaxial compressive strength (f_{co})
- Uniaxial tensile strength (modulus of rupture, f_t)
- Poisson's ratio (υ)
- Shear transfer coefficient (β_t)
- Uniaxial stress-strain relationship for concrete in compression (σ-ε)

Elastic modulus and tensile strength of concrete is evaluated by following equation as per ACI: 318 2005.

$$E_c = 4730\sqrt{f_c^{'}} \qquad (1)$$

$$f_t = 0.63\sqrt{f_c^{'}} \qquad (2)$$

Poisson's ratio (μ) = 0.2

The program requires the uniaxial stress-strain (σ-ε) relationship for concrete in compression. The model developed to predict the confined concrete strength and the corresponding strain is given by the following equations:

$$\frac{f'_{cc}}{f'_{co}} = 1 + k_1 \frac{f_l}{f'_{co}} \qquad (3)$$

$$\frac{\varepsilon_{cc}}{\varepsilon_{co}} = 1.75 + k_2 \frac{f_l}{f'_{co}} \qquad (4)$$

where, k_1 = 3.10 and k_2 = 20 are the confinement effectiveness coefficients obtained from the analysis of the experimental test data.

To predict the stress-strain response of GFRP confined concrete the expression proposed by Lam and Teng (2003) has been used, which is given by:

$$f_c = E_c\varepsilon_c - \frac{(E_c - E_2)^2}{4 f'_{co}}\varepsilon_c^{\,2} \qquad \text{for } \left(0 \le \varepsilon_c \le \varepsilon_{co}\right) \qquad (5)$$

$$f_c = f'_{co} + E_2\varepsilon_c \qquad \text{for } \left(\varepsilon_t \le \varepsilon_c \le \varepsilon_{cu}\right) \qquad (6)$$

$$E_c = 4730\sqrt{f'_{co}} \qquad (7)$$

$$E_2 = \frac{f'_{cc} - f'_{co}}{\varepsilon_{cc}} \tag{8}$$

The model adopted for failure criteria is capable of predicting failure for concrete materials. Both cracking and crushing failure modes may be accounted for. The two input strength parameters - i.e. uniaxial tensile and compressive strengths are needed to define a failure surface for the concrete.

B. FRP Composites

The inputs for this material are: Layer thickness, Fiber orientation, Elastic modulus, Shear modulus, Poisson’s ratio. Maximum stress failure criterion has been employed to check the failure of the FRP composite elements.

IV. Modeling and Meshing

For the present study five concrete column specimens wrapped with GFRP were chosen for the analysis purpose. The specimens were of 150 mm diameter and 300 mm height. Analysis results in the form of prediction of peak axial strength and corresponding strain have been investigated to gain a clear understanding of the confinement effect. Taking advantage of symmetry for plain concrete specimens only a quarter of the model with full height was created. For modeling circular columns a cylindrical coordinate system was created in the active working plane. The circumferential area was selected and extruded with desired thickness along its normal so as to create a GFRP wrap. The generated model was meshed using mapped mesh which helps in controlling the number of elements. The mesh size would vary with the dimension of the model. Element attributes were assigned to the respective elements. The solid cylinder (i.e. concrete) was meshed with SOLID65 and the hollow cylinder (i.e. FRP composite) with SOLID46 elements.

V. Boundary Conditions and Loading

The Z-axis of the coordinate system coincides with the axis of all the FE models. The X and Y axis represent the radial and hoop directions of the cylinder respectively. The boundary conditions for GFRP wrapped plain concrete cylinders are:

(1) Base of the column is fixed.
(2) Symmetric boundary conditions are applied at the two cut surfaces parallel to the axis of the column. Figure 3 (a-b) shows the mesh and the boundary conditions for GFRP wrapped concrete cylinder.

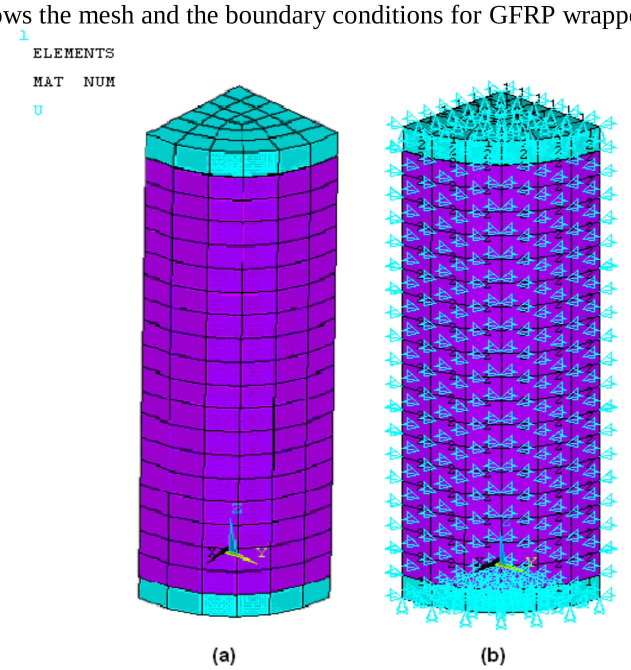

Fig. 3 (a) FE Model; (b) Boundary Conditions

On all the FE models a uniform displacement load is applied at the top surface nodes in the axial direction. The axial displacement load is increased gradually until the GFRP fails.

VI. Results and Discussions

The peak axial strength and corresponding strain from the finite element analysis of all the chosen specimens was compared with the theoretical values. The maximum deviation of the finite element analysis results with the theoretical values is found to be 8% and 4% for the prediction of peak confined concrete strength and corresponding strain for the single layer of FRP whereas for double layer of FRP it is 4% and 9%, respectively. A reasonably good correlation is observed between the finite element results and the theoretical values.

Table no 1. Comparison of Theoretical Values and FEA Results for single layer

Sample No.	Thickness of GFRP (mm)	f'_{co} (MPa)	f'_{cc} (Theoretical)	f'_{cc} (FEA)	ε_{cc} (Theoretical)	ε_{cc} (FEA)	$\frac{f'_{cc,FEA}}{f'_{cc,TH}}$	$\frac{\varepsilon_{cc,FEA}}{\varepsilon_{cc,TH}}$
1	1.2	20.00	44.80	46.20	0.0195	0.0197	1.03	1.01
2	1.2	25.00	49.80	53.74	0.0163	0.0170	1.08	1.04
3	1.2	30.00	54.80	55.41	0.0142	0.0146	1.01	1.03
4	1.2	35.00	59.80	59.12	0.0127	0.0124	0.99	0.98
5	1.2	40.00	64.80	64.96	0.0115	0.0118	1.00	1.03

Table no 2. Comparison of Theoretical Values and FEA Results for two layers

Sample No.	Thickness of GFRP (mm)	f'_{co} (MPa)	f'_{cc} (Theoretical)	f'_{cc} (FEA)	ε_{cc} (Theoretical)	ε_{cc} (FEA)	$\frac{f'_{cc,FEA}}{f'_{cc,TH}}$	$\frac{\varepsilon_{cc,FEA}}{\varepsilon_{cc,TH}}$
1	2.4	20.00	69.6	72.30	0.0355	0.0324	1.04	0.91
2	2.4	25.00	74.6	76.41	0.0291	0.0296	1.02	1.02
3	2.4	30.00	79.6	78.92	0.0248	0.0252	0.99	1.02
4	2.4	35.00	84.6	81.63	0.0218	0.0221	0.96	1.01
5	2.4	40.00	89.6	85.94	0.0195	0.0182	0.96	0.93

VII. Conclusion

Numerical analysis of GFRP wrapped plain concrete column using a general purpose finite element analysis program ANSYS has been presented in this paper. Four GFRP wrapped concrete columns were modeled and analyzed. The non-linear behaviour of the concrete in compression has been idealized by employing an elasto-plastic strain hardening model. The comparisons show that the finite element model has a good agreement with the theoretical results of plain concrete columns wrapped with GFRP composites.

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