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FINITE ELEMENT MODELING OF RC PILES STRENGTHENED WITH GFRP COMPOSITES

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ABSTRACT

Several methods have been utilized to study the response of retrofitted concrete structural components. Experimental based testing has been widely used as a means to analyze individual elements and the effects of concrete strength under loading. While this is a method that produces real life response, it is extremely time consuming, and the use of materials can be quite costly. The use of finite element analysis to study these components has also been used. This paper presents the numerical study to simulate the behavior of retrofitted reinforced concrete (RC) Pile specimens. The study was carried out on the unretrofitted RC pile specimens designated as control pile specimens and RC pile specimens retrofitted using glass fiber reinforced plastic (GFRP) composites. The effect of retrofitting on RC pile specimens was studied. The load deflection, load strain plots obtained from numerical study is compared with the experimental plots. The numerical results compared well with experimental results.

Keywords: Finite Element Modeling Reinforced Concrete, GFRP Composites.

1. INTRODUCTION

Different methods have been utilized to study the response of structural components. Experimental based testing has been widely used as a means to analyze individual elements and the effects of concrete strength under loading. While this is a method that produces real life response, it is extremely time consuming, and the use of materials can be quite costly. The use of finite element analysis to study these components has also been used. Modeling the complex behavior of reinforced concrete is a difficult task in the finite element analysis of civil engineering structures. Only recently have researchers attempted to simulate the behavior of reinforced concrete strengthened with FRP composites using finite element method.

Arduini et al. (1997) used finite element method to simulate the behavior and failure mechanisms of RC beams strengthened with FRP plates. The FRP plates were modeled with two dimensional plate elements. However the crack patterns were not predicted in that study [1]. Tedesco et al. (1999) modeled an entire FRP strengthened reinforced concrete bridge by finite element analysis. In their study truss elements were used to model the FRP composites [2]. Kachlakev et al. (2001) used the ANSYS finite element program to model the uncracked RC beams strengthened with FRP composites. Comparisons between the experimental data and the results from finite element models showed good agreement [3]. The main objective of this investigation is to study the behavior of reinforced concrete pile specimens retrofitted with GFRP composites. This objective is achieved by conducting the following tasks: (i) Testing concrete pile specimens retrofitted with GFRP fabric (ii) Modeling the RC pile specimens using finite element software package Ansys (iii) Evaluating the ultimate loads and (iv) Comparing the analytical results with the experimental results. This paper presents the numerical study to simulate the behavior of RC pile specimens retrofitted using GFRP composites. The finite element software package ANSYS was used for this study. For the purpose of comparison, the study was carried out for the following pile specimens that were experimentally tested in the laboratory. The unretrofitted RC pile specimen under axial compression designated as (CPA), retrofitted RC pile specimen under axial compression designated as (RTPA), unretrofitted RC pile specimen under lateral load designated as (CPL), and retrofitted RC pile specimen under lateral load designated as (RTPL) were considered. The load deflection and load strain plots for the above cases obtained from numerical study were compared with the experimental load deflection plots to validate the model.

2. GEOMETRY AND MATERIAL PROPERTIES

The pile specimen consists of 130 mm diameter circular section of 2300 mm long attached with 200 x 200 mm square beams of 1000 mm length at the ends. The beams are attached at the ends to provide fixity and to facilitate load application. The geometry and the reinforcement details of the control pile are shown in Fig. 1. Concrete with cube strength of 31 MPa and reinforcing steel with yield strength of 410 MPa were used. The compressive strength of concrete and yield strength of reinforcing steel was obtained by conducting the standard tests in

Laboratory. The Young's modulus and tensile strength of the concrete were calculated as 27838 MPa and 3.8 MPa respectively. The Poison's ratio was assumed as 0.2 for concrete and 0.3 for steel rebar. The elastic modulus of steel rebar was taken as 200000 MPa. The Young's modulus and ultimate tensile stress of the glass fiber fabric material were calculated by conducting tension test on coupons. The ultimate tensile strength and Young's modulus of glass fiber fabric laminate were calculated as 265 MPa and 15,000 MPa respectively. In addition to the material properties discussed earlier, shear transfer coefficient (βt) for open and closed cracks in concrete was required for the analysis. The value of βt used in many studies varied between 0.05 and 0.25 (Bangash 1989, Barzegar 1997, Hemmaty 1998). A number of preliminary analyses were attempted in this study with various values for βt within this range to avoid convergence problems. The shear transfer coefficient of 0.2 for open crack and 0.22 for closed crack were considered in this study.

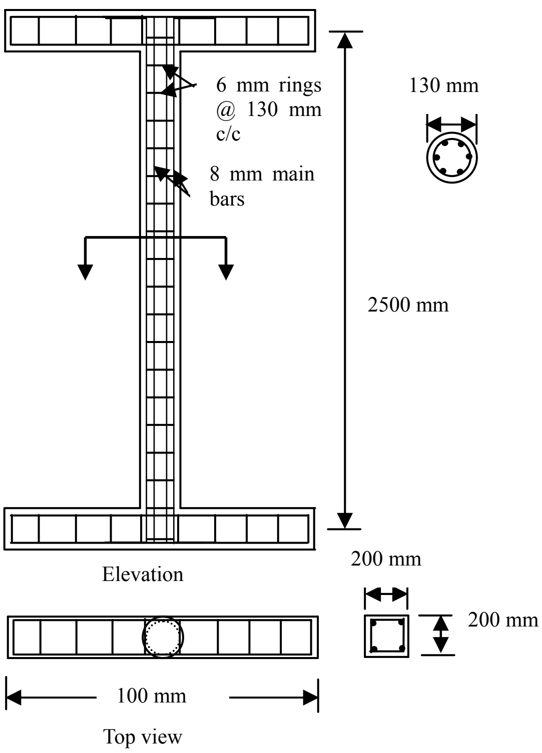

Fig 1: Geometry and Reinforcement Details of Pile Specimen

3. NUMERICAL STUDY

Solid 65 elements were used to model the concrete. The Solid 65 element has eight nodes with three degrees of freedom at each node, translations in nodal X, Y and Z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. The rebar capability of this model was not considered. All reinforcements were modeled using Link 8- 3D spar element. The Link 8 element has two nodes with three degrees of freedom at each node, translations in nodal X, Y and Z directions. The element is also capable of plastic deformation. A layered solid element, solid 46 was used to model the GFRP composites. 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. The bond between steel reinforcement and concrete was assumed as perfect in the modeling of RC control Pile specimen. The link 8- 3D spar element for the steel reinforcement was connected between nodes of each adjacent concrete solid 65 elements. Modeling of concrete and steel reinforcement is shown in Figures -2 and 3 respectively. In the retrofitted pile specimen the layered solid 46 elements used to represent the GFRP composites were attached to the finite element model of control pile specimen. Modeling of GFRP wrap for axial compression and lateral load is shown in Figures-4 and 5 respectively. To simulate the perfect bonding of GFRP sheets with concrete, the nodes of solid 46 elements were connected to the nodes of solid 65 elements at the interface so that two materials shared the same nodes.

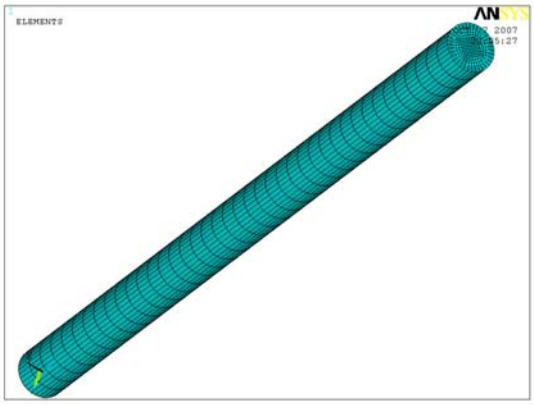

Fig 2: Modeling of Concrete using Solid65 Elements

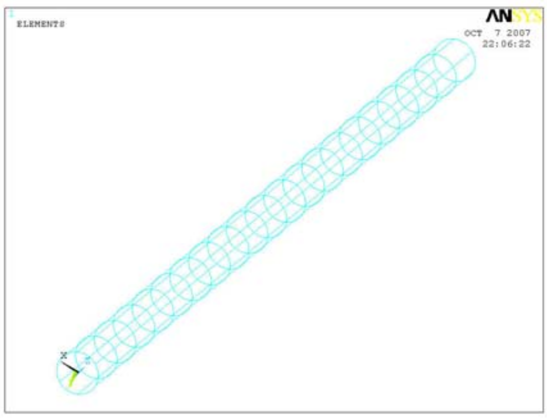

Fig 3: Modeling of Reinforcement using Link8 Elements

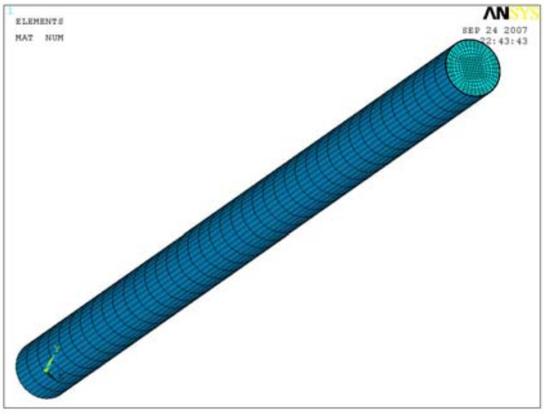

Fig 4: Modeling of GFRP Wrapping for Axial Compression

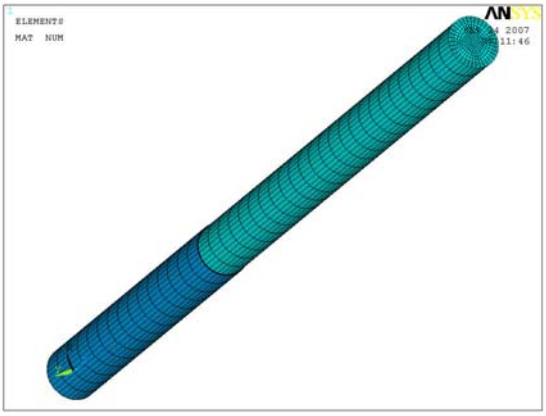

Fig 5: Modeling of GFRP Wrapping for Lateral Load

3.1 Non-linear solution

In this study the total load applied was divided in to a series of load increments (or) load steps. Newton -Raphson equilibrium iterations provide convergence at the end of each load increment within tolerance limits. The automatic time stepping in the ANSYS program predicts and controls load step sizes for which the maximum and minimum load step sizes are required. After attempting many trials the number of load steps, minimum and maximum step sizes was determined. During concrete cracking, steel yielding and ultimate stage in which large numbers of cracks occur the loads were applied gradually with smaller load increments.

4. RESULTS AND DISCUSSION

The axial load versus axial deformation plots for pile specimens CPA and RTPA obtained from numerical study along with the experimental plots are presented and compared in Figures - 6 and 7. When comparing with the experimental values, the numerical models show 20% increase in ultimate load for control pile specimen CPA and 10% increase in ultimate load for retrofitted pile specimen RTPA.

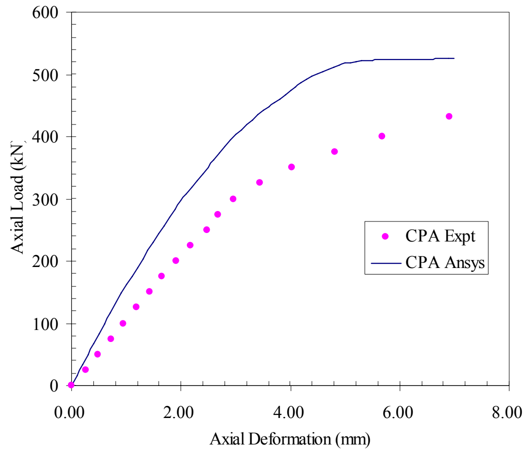

Fig 6: Comparison of Axial Load vs Axial Deformation for Control Pile Specimen

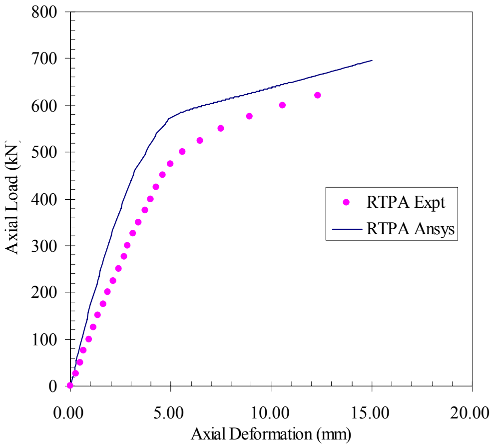

Fig 7: Comparison of Axial Load vs Axial Deformation of Retrofitted Pile Specimen

The lateral load versus lateral deflection plots for pile specimens CPL and RTPL obtained from numerical study along with the experimental study are presented and compared in Figures – 8 and 9 .

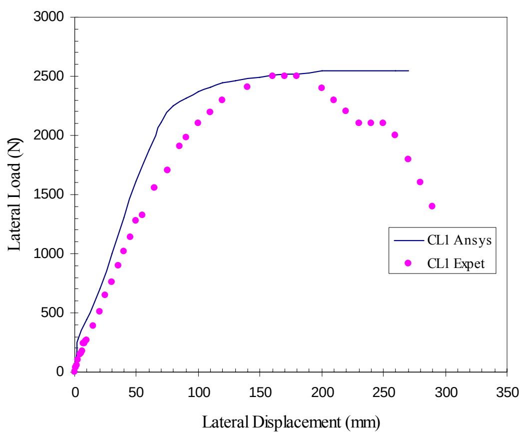

Fig 8: Comparison of Lateral Load vs Lateral Displacement for Control Pile specimen

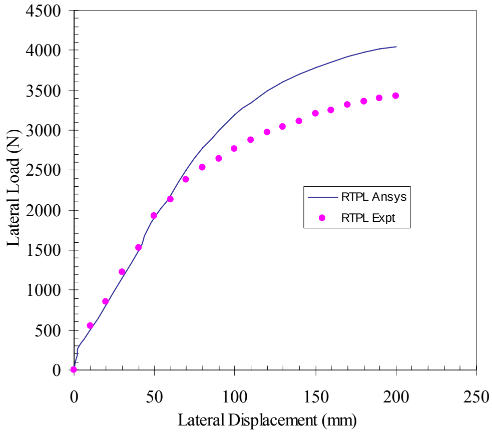

Fig 9: Comparison of Lateral Load vs Lateral Displacement for Retrofitted Pile specimen

4.1. Crack Patterns

The crack patterns in the pile specimen obtained from numerical study is compared with the experimental study for control pile specimen CPL in Figures -10 and 11 which are very similar.

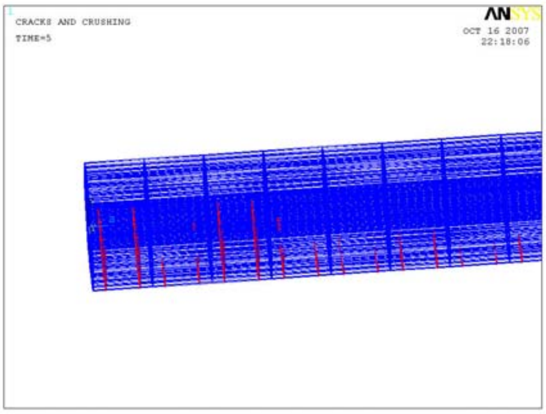

Fig 10: Crack patterns under Lateral Load from Ansys

Fig 11: Crack patterns under Lateral Load from Experiments

4.2. Lateral Load Vs Strain in Reinforcement

Load Versus strain in Reinforcement obtained from numerical study and Experiment for control pile specimen CPL is shown in Figure. 12.

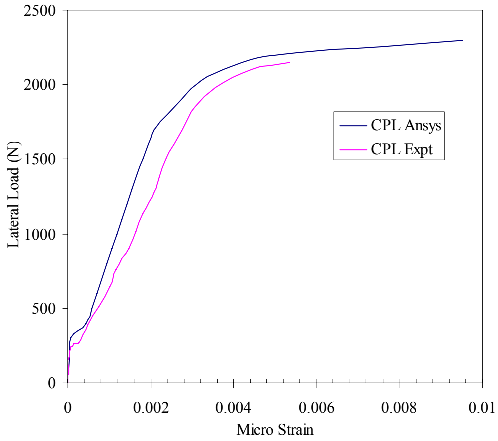

Fig 12: Lateral Load vs Tensile Strain in Longitudinal Reinforcement

5. CONCLUSION

A finite element analysis has been carried out to study the behaviour of RC Pile specimens strengthened with GFRP composites under different loading conditions. The numerical results show good agreement with the experimental values. At ultimate stage there is a difference in behavior between the control and retrofitted pile specimens though not significant. This numerical modeling helps to track the crack formation and propagation especially in case of retrofitted pile specimens in which the crack patterns cannot be seen by the experimental study due to wrapping of GFRP composites. This numerical study can be used to predict the behavior of retrofitted reinforced concrete pile specimens more precisely by assigning appropriate material properties.

6. REFERENCES

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