Finite Element Modeling and Analysis of Hybrid Plate System

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***Abstract*— This paper presents the non linear response of hybrid plate system consist of Fiber Reinforced Polymer (FRP) and ferrocement act as shell for core Reinforced Concrete (RC) by using ATENA-3D software based on Finite Element Method (FEM). In this investigation, the load displacement response of RC plate system with internal stiffened beams was carried out in the first phase and in the second phase of study, analysis of different hybrid plate system reinforced with unidirectional basalt, unidirectional carbon and bidirectional glass fiber fabric as well with ferrocement sheet was presented. Hybrid plate system with unidirectional carbon sheet exhibited the maximum load carrying capacity. Also formation of cracks in the different plate systems was monitored and all systems failed in flexure with formation of cracks on positive moment region.**

***Keywords*—Hybrid Plate System, Modeling, Analysis, Basalt Fibre, Carbon Fibre, Glass Fibre**

I. Introduction

Now days, corrosion is the main concern in Reinforced Concrete (RC) structures. To overcome this problem, Fibre Reinforced Polymer (FRP) composite sheets are the best solution in structural elements as strong and light material. FRP is a composite material made by combining two or more materials to give a new combination of properties. FRP composite is a two-phased material and is composed of fiber (e.g., E-glass, carbon, and aramid) and polymer matrix (e.g., epoxy, polyester, and vinylester resins, which are bonded at interface. FRP materials were widely accepted in infrastructure construction industry during the late 1980s and throughout the 1990s [1]. In general, strengthening techniques with FRP systems can be used to enhance the ductility as well as the flexural and shear capacity of all structural elements (i.e. columns, beams, slabs, structural walls), bridge components (i.e. piers, girders, decks). FRP application in construction sector is gaining attention in India after the Gujarat earthquake occurred in 2001[2]. Most of the experimental as well numerical work was done on Carbon Fibre Reinforced Polymer (CFRP) and Glass Fibre Reinforced Polymer (GFRP), very little attention has been given on recently developed Basalt Fibre Reinforced Polymer. Basalt fibres show comparable mechanical properties to glass fibres at lower cost and exhibit good resistance to chemical and high temperature exposure. Basalt fibres are alternative to carbon high-temperature resistant and are utilized as fire protection [7]. To reduce the cost of structural member due to FRP, ferrocement sheet along with FRP sheet which act as formwork for core RC is the economical solution.

From last two three decades, numerical simulation of reinforced concrete structures and other structural elements has become a major area of research. The Finite Element (FE) method is a numerical method for solving problems of engineering which include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. Nonlinear simulation using the models in ATENA-3D can be efficiently used to predict structural behavior. The graphical user interface in ATENA-3D provides an efficient and powerful environment for solving different problems. ATENA enables virtual testing of structures using computers, which is the present trend in the research and development world. In ATENA, concrete is represented by solid brick element, reinforcement by bar elements and FRP by shell elements. Material properties play an important role in modeling of a structure. The program ATENA offers a variety of material models for different materials and purposes. Various researchers Kachlakev et al. [3], Singhal [4] and Sanathakumar et al. [5] investigated the structural members through FE modeling.

In the first phase of the present study, Finite Element Modeling of the control RC plate system (RCPS) under the incremental loads has been analyzed using ATENA-3D software. In the second phase present study, FE modeling of the Hybrid Plate system with Ferrocement sheet along with unidirectional carbon fabric (HPS-UC-Ferro) and unidirectional basalt fabric (HPS-UB-Ferro) on tension side of same sized plate system that of the RCPS was analyzed and the load-displacement curve and the cracking behavior were also obtained.

II. Finite Element Modeling

ATENA-3D software was used for FE modeling and analysis of hybrid plate system by taking into account real material behavior in tension and compression.

A. Modeling of Concrete and Ferrocement

Concrete material and ferrocement were modeled as a 3D nonlinear cementitious2. The physical properties of 3D nonlinear cementitious2 material for concrete are given in Table 1. The values are calculated as per IS code 456:2000 and remaining were the default values. In ferrocement combined properties of mortar and wire mesh was taken as shown in Table 2. 3D solid brick element with 8 up to 20 nodes was considered for element geometric modeling of concrete and ferrocement. Figure 1 shows the uniaxial stress strain relationship used for concrete.

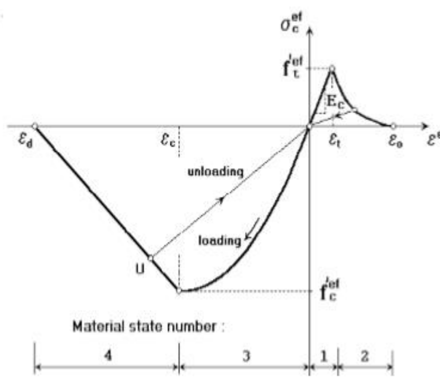

Fig. 1 Uniaxial stress-strain relationship of concrete [6]

TABLE I. MATERIAL PROPERTIES OF CONCRETE

Elastic Modulus	2.854E+04
Poisson Ratio	0.2
Tensile Strength, F	2.106E+00
Compressive Strength	-2.210E+01
Coefficient of Thermal Expansion	1.200E-05
Crack shear stiff. Factor	20.0
Specific fracture energy	5.266E-05

TABLE II. MATERIAL PROPERTIES OF FERROCEMENT

Elastic Modulus	3.130E+04
Poisson's ratio	0.200
Tensile strength	3.050E+00
Compressive strength	-2.620E+01
Coefficient of thermal expansion	1.200E-05

B. Modeling of Reinforcement

Bilinear elastic perfectly plastic law was assumed for reinforcement as shown in Figure 2. Steel of grade Fe-500 of 8 mm diameter were used as reinforcement. The properties of these bars are shown in Table 3.

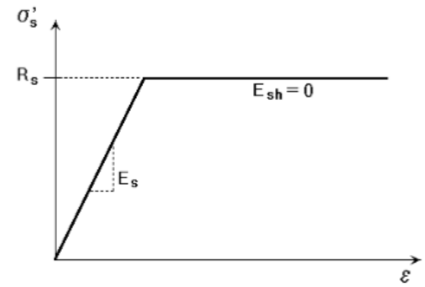

Fig. 2 Bilinear stress strain law for reinforcement [6]

TABLE III. MATERIAL PROPERTIES REINFORCEMENT

Elastic Modulus	2.000e+05
Yield Strength	500
Reinforcement type	Bilinear
Specific Material weight	7.850E-02
Coefficient of Thermal Expansion	1.200E-05
In compression	Active

C. Modeling of FRP

FRP was modelled as 3D shell element (Ahmed shell element) having 20 nodes isoparametric brick element as shown in Figure 3. Unidirectional carbon and basalt fabric provided by Arrow Technical Textiles Pvt. Ltd., Mumbai, India and bidirectional glass fabric provided by Ludhiana Proof Insulation Co. Ludhiana, India were considered for FRP. Epoxy resin was prepared from base Epoxy-LY556 (Density 1.15-1.2 g/cm³ and viscosity 10000-120000 mPa s) and hardener HY-951 (Specific gravity at 25 °C-0.98 g/cm³ and viscosity 10-20 mPa s) using mixed ratio 100:10 (Base: Hardener). Table 4 showed the material properties of used fabric provided by manufacturers but further composite properties were calculated by testing in laboratory as shown in Table 5 which were used in modeling.

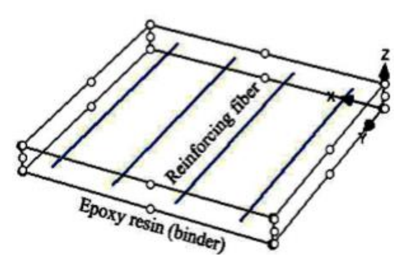

Fig. 3 Shell element for FRP [3]

TABLE IV. PROPERTIES OF FRP PROVIDED BY MANUFACTURE

Fabric	Thickness (mm)	Tensile Strength (MPa)	Area Weight (g/mm^2)
Carbon	0.111	≥ 3500	200
Basalt	0.115	2100	300

TABLE V. EXPERIMENTAL PROPERTIES OF FRP

Fabric Composite Family	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at break (%)
Unidirectional Carbon Epoxy	1166.75	150.35	0.776
Unidirectional Basalt Epoxy	452.5	26.00	1.74

III. RESULTS AND DISCUSSION

Brick elements were selected for the meshing with 50 mm mesh size. Vertical displacement was restrained at all four edges from bottom side for simply supported end conditions. Each load increment was considered for 0.1 mm vertical displacement. Newton Raphson solution was adopted with each iteration update for 40 numbers of iterations.

All plate systems were analyzed under displacement control load applied gradually at the top face. Figure 4 shows load displacement response of all plate systems. HPS-UC-Ferro and HPS-BC-Ferro were found to be 75.23 percent and 57.83 percent more capable of load carrying capacity as compared to RCPS.

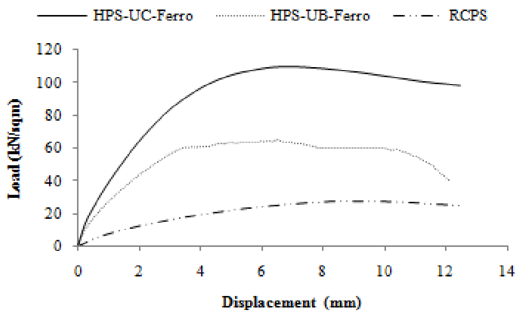

Fig. 4 Load-displacement curves

Figure 5 depicts the increase of crack width with the increase of load on all plate systems. It is observed that HPS-UC-Ferro and HPS-UB-Ferro have 74.66 kN/m^2 and 52.99 kN/m^2 load carrying capacity respectively corresponding to 0.3 mm crack width whereas RCPS has only 25 kN/m^2 load carrying capacity.

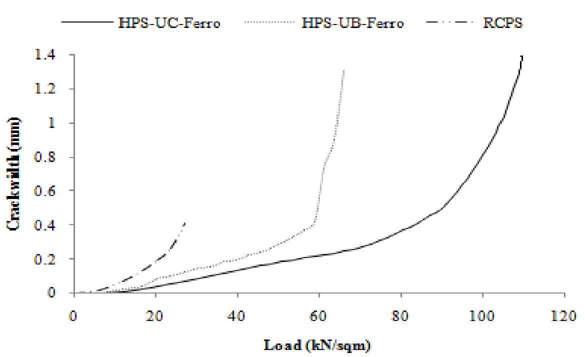

Fig. 5 Increase of crack width with increasing load

The variation of crack pattern due to applied load is plotted in Figure 6. At the early stages of loading, the behavior of plate system has been observed to be elastic until the appearance of the first crack. The crack has been initiated at the centre of the plate and the cracks gradually propagate towards the end of the free edge on the tension face side as the loading progressed. It has been observed that micro-cracks appeared in the structure when the plate system is in linear zone as shown in Figure 6a. The cracks keep on increasing as the load and the deflection increases as depicted in Figure 6b. But crack pattern was different in HPS-UC-Ferro and HPS-BC-Ferro due to internal stiffened beams which results in local failure instead of global failure as shown in Figure 6c.

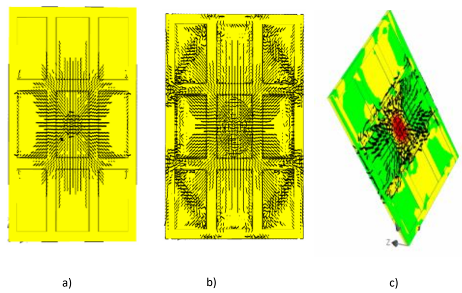

Fig. 6 Crack pattern a) at 0.3 mm crack width b) at maximum load of RCSP c) at maximum load of HPS-UC-Ferro and HPS-BC-Ferro

IV. CONCLUSIONS

In the present work, the main conclusions drawn from the study are listed below:

1. Load carrying capacity increases with the application of FRP fabric and ferrocement at the tension side. Hybrid plate system with unidirectional carbon fabric (HPS-UC-Ferro) showed the maximum load carrying capacity.
2. In HPS-UC-Ferro, the cracks appear lesser and the crack width also reduces corresponding to 0.3mm crack width as compared to reinforced concrete plate system (RCPS).
3. The cracks start appearing at the centre and move from centre towards the free edges in RCPS and major damage occurred at the centre but HPS-UC-Ferro and HPS-UB-Ferro have local failure instead of global failure.

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