INVESTIGATION ON FLEXURAL BEHAVIOUR OF CONCRETE SLABS REINFORCED WITH HYBRID REINFORCEMENTS

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ABSTRACT

Fiber reinforced polymer (FRP) composite has gained considerable worldwide and growing acceptance in the construction industry as internal reinforcement in concrete structures. The weakening of Reinforced Concrete (RC) structures has been a permanent problem mainly due to the corrosive condition of reinforcements surrounded in the concrete. Several suggestion like the use of water proofing admixtures in concrete, impermeable membranes, epoxy coated reinforcements are attempted to overcome the corrosion problem of steel reinforcement; all the efforts are not economically and commercially much feasible. In order to conquer the corrosion problem, several methods, such as epoxy coated bars, synthetic membranes, or cathode protection, have been developed as repair techniques. Non metallic reinforcement is used as the replacement to steel bars and to improve the life span of the concrete structures. The initial cost of this composite bars are high so wide distribution of this bars had not received but the maintenance cost of the structures with this type of reinforcements are comparatively lesser than conventionally reinforced structures.

Keyword:*Glass Fibre reinforced Polymer reinforcements (GFRP), CarbonFibre reinforced Polymer reinforcements (CFRP), Hybrid Fibre reinforced Polymer reinforcements (HFRP)*

1. INTRODUCTION

In the aggressive environment, concrete is vulnerable to chemical attacks, such as carbonation and chloride contamination which break down the alkaline barrier in the cement matrix. Consequently, the steel reinforcement in concrete structures becomes susceptible to corrosion. Such phenomena lead to delamination of the concrete at the reinforcement level, cracking and spilling of the concrete due to the volume increase of the steel reinforcement. Various methods were investigated to overcome corrosion in steel reinforcement by numerous researchers. A possible solution to combat reinforcement corrosion for new construction is the use of non-corrosive materials to replace conventional steel bars. High tensile strength, lightweight and corrosion resistant characteristics make Fiber reinforced Polymer (FRP) reinforcements suitable for such applications.

1.1 HISTORY OF FRP REINFORCEMENT

The idea of making composite materials by combining two different materials is not new and can be dated back to the ancient Egyptians when they used straw to reinforce their mud and make a stronger composite material. Fibre reinforced polymer is just a later version of this idea (Nanni 1993). The use of Fibre Reinforced Polymer (FRP) goes back to the 1950's after World War II in various fields such as aerospace and automotive industries. Nowadays different parts of today's vehicles are made of composites, and many large parts of modern aircraft are made out of composites as they are lighter and more fatigue resistance compared to traditional materials.

Since the 1960s many highway bridges and structures have started to deteriorate due to the corrosion problems of the reinforcing steel as a result of road de-icing salts in colder climates or marine salts in coastal areas, which accelerated the corrosion of the reinforcing steel. Many efforts has been taken in the past to overcome the corrosion of steel reinforcement such as applying a galvanized coating to the surface of the reinforcing bars, the use of epoxy coated steel reinforcing bars in 1970s (ACI 440. 1R-15 2015) and the use of stainless steel. In the late 1960s, the Bureau of Reclamation in the US developed a programme for using polymer impregnated concrete but it was not possible to use steel reinforcement with polymer concrete due to the incompatibility in thermal properties. This led Marshall Vega to manufacture glass fibre reinforced polymer as reinforcement bars (ACI 440. 1R-15 2015). In 1980s in the USA a pultrusion company entered the FRP reinforcing bar industry under the name of International Grating, Inc (ACI 440. 1R-15 2015). They developed sand coated glass FRP bars followed by the development of deformed FRP bars by Marshall Composites Inc in the 1990s. These experiments have been widened with deformed carbon FRP bars and sand coated FRP bars. In the late 1990's the use of this composite material expanded widely into civil and structural engineering in Japan, United Kingdom and the US. Since then they have developed economically and structurally viable construction materials for buildings, bridges and other applications which are in extreme chemical environments.

1.2 DEVELOPMENT OF FRP MATERIALS

Fiber Reinforced Polymer (FRP) is a combination of fibres and Polymer resin. The most common types of fibres are aramid, carbon, and glass fibres. In the1950 FRP has been introduced to the construction world as an alternative to the conventional reinforcements. The widespread of utilization of FRP composites resulted in various applications with various shapes. After 1970, the commercial application of FRP products has been developed. More than thirty years FRP bars and grids have been produced commercially (Nanni 1993; ACI 440. 1R-15 2015). In 1980 FRP have been improved to meet out special performance requirements and adopted in the construction of marine structures, and structures in aggressive chemical environments. Since 1986 prestressing techniques are also applied in the construction of highway bridges in various countries. The advantages of FRP materials have been accepted because of its high strength, high stiffness, less density and low cost specially used for air travel and space exploration. In 1970 FRP materials have been promoted in the market with an affordable price. Later on the researchers have been financially supported to take FRP economically into the development of research activities. After 2000, there entered many successful projects to assure the effective performance of FRP in structural field. Fibre reinforced polymer (FRP) rebar is non metallic and so is not susceptible to corrosion and it is impervious to attack by chlorides. FRP rebar will eliminate the durability problems observed in steel reinforcement and increase the service life of the structure. Moreover, FRP rebar has a high tensile strength to weight ratio which makes it more cost effective than using conventional steel rebar.

2. LITERATURE REVIEW

Jayajothi ET AL., (2013) presented the nonlinear finite element analysis to predict the failure mechanisms of RC beams strengthened by FRP laminates considering both flexural and shear modes. The load deflection characteristics and crack behaviour are observed both experimentally and analytically, ANSYS created satisfactory models to reflect the real behaviour of the full scale beams providing its potential.

Richa Pateriya ET AL., (2015) presented the results of an analytical investigation done on the behavior of concrete columns reinforced with steel, GFRP and CFRP bars. Linear analysis of 18 column specimens is accomplished using ANSYS software. The parameters investigated in this analysis includes reinforcement ratio, load bearing capacity and deformations. Also a comparative study is done amongst steel, GFRP and CFRP on the basis of these parameters.

Hind ET AL., (2016) provided a three dimensional finite element model of RC beams strengthened with FRP strips, plates or rods. The failure mechanisms such as crushing of concrete, yielding or rupture of rods, pullout failure, diagonal shear, FRP debonding have been simulated using ANSYS. Finer meshing of elements are used to achieve the degree of accuracy of the modeling. The analytical load deflection trends matches with that of experimental trends recommending ANSYS for predicting the non linear behaviour of RC structural elements.

Premalatha ET AL., (2017) has created nonlinear finite element model of GFRP and conventional RC beams, using ANSYS 16.2.the results (ultimate load and cracking behaviour) very closer to the experimental value and showing 10% variation. All the beams are failed by concrete crushing at the ultimate stage.

Krishnan ET AL., (2017) analysed the structural behaviour of square columns using ANSYS. The load carrying capacity of columns confined by GFRP sheets showed better results than column confined by CFRP sheets and unconfined RC columns. The GFRP and CFRP confinement enhanced the stiffness and ultimate load of RC columns. It has been concluded that ANSYS worked well for predicting FRP confinement of nonlinear behaviour of RC columns.

Arindom bora ET AL., (2018) has carried out the design of beam column joint reinforced with four types of FRP (GFRP, CFRP, BFRP and AFRP) reinforcements using ANSYS. From the results it is noted that there is reduced equivalent stress on the concrete due to the introduction of FRP. The ultimate equivalent stress is found to be occurred at the junction of the FRP and the beams of the beam column joint. The results obtained for the total deformation of the beam column joint are satisfactory.

Qasim and Hayder (2018) investigated the behaviour of one-way slabs (simply supported and continuous) reinforced with basalt fibre reinforced polymer (BFRP) and carbon fibre reinforced polymer (CFRP) bars under static loading. To predict the flexural behaviour of slabs, ANSYS 15 has been adopted. ANSYS yields good agreement with experimental results for both types of slabs rather than numerous values obtained by adopting equations of ACI 440.1R-15, 2015.

Linda M. Vanevenhoven (2010) demonstrated and analyzed that a combined design equation for pultruded columns using for LRFD concept with reliability indices that are alike to those used for conventional concrete materials. The article are also illustrate that clear in different reliability indices are acquired for the different manufacturer make available on equations even though identical permissible stress design safety factors are suggested by all firm.

Kumaran ET AL., (2012) focused the reliability analysis and design of concrete one-way slabs reinforced with Glass Fiber Reinforced Polymer (GFRP) bars based on the enhanced a better statistical data. By Using First Order Reliability Method (FORM), the basic randomness with respect to material properties, it is analyzed and pretend with the help of Monte Carlo simulations. The desired margins of safety, expressed in terms of safety factors, can thus be related to the probability of failure Pf or target reliability β.

Young Hoon Kim (2012) assessed the time variant flexural moment capacity and structural reliability of bridge deck made up of different types and size of GFRP bars. It has been found that probability of failure is less than values accepted by AASHTO.

Arabshahi (2017) studied to assess precision for FRP bars are under reliability of the available relations to computation of effective moment of inertia in concrete beams. Branson relation for effective moment of inertia is used and modified in concrete members. For this reason, different reliability indexes are evaluated in concurrence with Monte Carlo simulation technique. In addition to that, the experimental results from different studies are used to assess accuracy of the available relations. Based on this investigation, the most accurate and reliable relations are identified. Furthermore, a new more reliable and accurate relation based on numerical methods will be proposed.

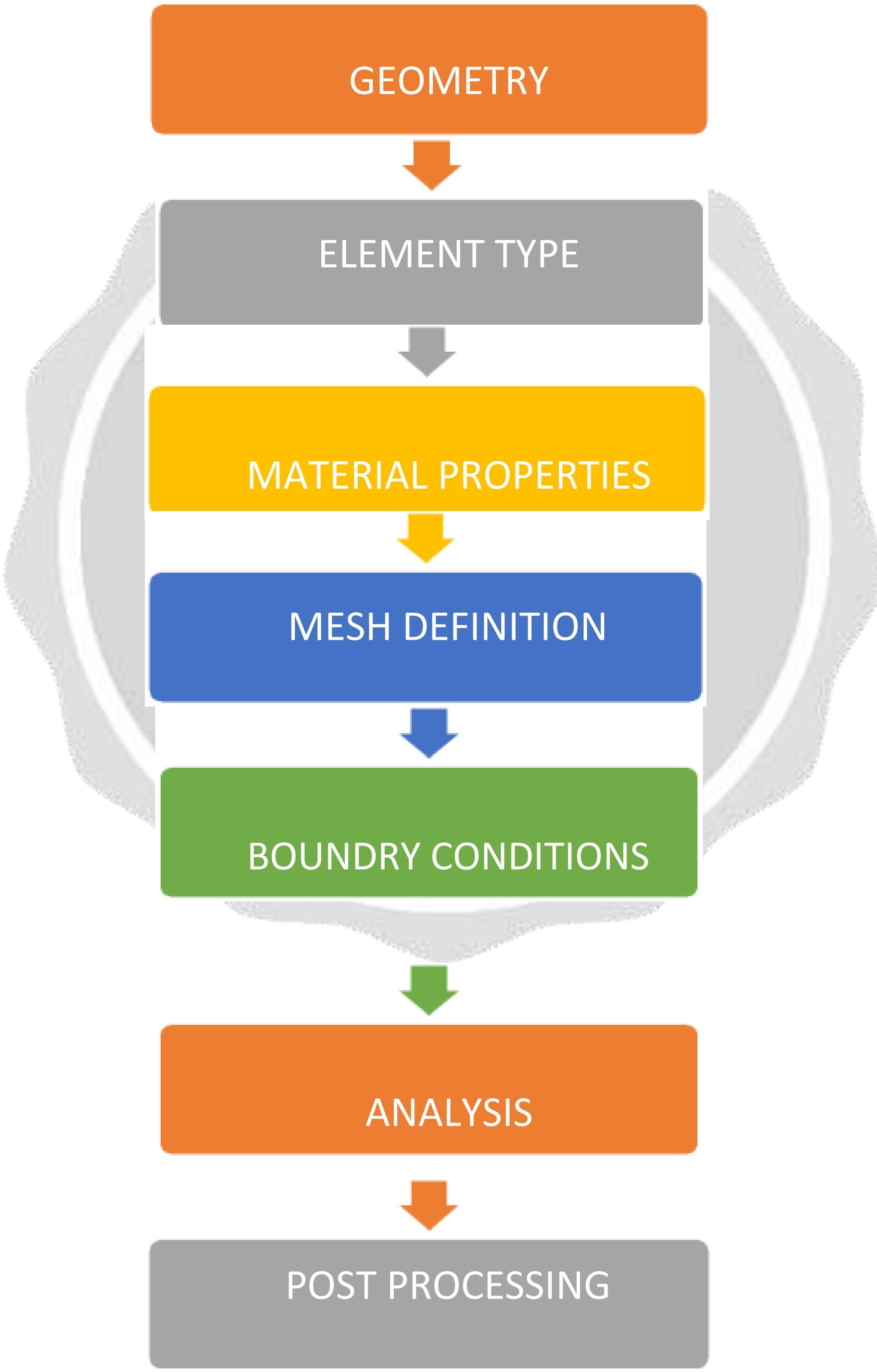
ACI 440.1R-15, (2015) Composed a report on the function of FRP bars as an internal reinforcement for the flexural members. The following points have been arrived solely on the basis of this report.

Javier Malvar (1995) has considered the tensile behaviour of FRP bars by utilizing ASTM D 3916-84 and recommended that the tensile properties rely upon the surface distortions of the FRP rods.

Bank ET AL., (1998) conducted the diffusion test on E-glass/vinylester FRP rods and demonstrated that the temperature influences the moisture content at immersion point. At last, it has been recommended that the material degradation during the testing period has been indicated as increased voids and moisture substance.

3. FINITE ELEMENT MODELING

Finite Element Method (FEM) is a numerical technique to find approximate solutions of structural analysis. It is very useful in the computation of structural analysis problems in wide range of construction industries, but it is most commonly used in the aeronautical, biomechanical and automotive industries. This method divides the whole complicated structure into simpler or smaller elements to simplify the analysis. Hence, FEM is utilized to signify the structural performance of the one-way slabs experimented in the current research.



3.1 MATERIAL PROPERTIES

Sl. No	Compressive strength of concrete N/mm^2	Modulus of elasticity N/mm^2	Poisson's ratio
1	38	3X10^4	
2	49	3.5 X 10^4	0.2
3	56	3.7 X 10^4	

Table 3.1 Properties of Concrete

3.2 LOADING AND BOUNDARY CONDITIONS

The finite element model considered in this study, dimensionally replicate the full scale one-way slab. Totally eighteen one-way slabs with varying reinforcements, reinforcement ratio, grade of concrete and thickness of slab are modeled. The slabs are rectangular in plan with a width 600 mm and spanned 2400mm with two thicknesses of 100 mm and 120 mm. The eighteen full size slabs are modeled using Finite Element Analysis (FEA) and are subjected to two point loads similar to experimental conditions, as depicted in Fig. 4.4. Roller and pinned supports are provided to create simply support conditions. A three dimensional non linear finite element analysis is carried out for numerically evaluating the performance of one-way slabs. The load conditions and support conditions for both conventional and HFRP reinforced slabs are same. The slab is modelled as three dimensional brick element with 8 nodes having 3 Degree of Freedom (DOF) at each node. A unique feature of this element is the treatment of non linear properties. This element has plasticity, stress stiffening, large deflection and greater strain capabilities. There are two restrictions associated with this element namely, all elements must contain eight nodes and zero volume elements are not allowed. Modelled HFRP reinforcement; creation of link 180 element; Modelling of Slab; Loading and support condition the comparison between ANSYS and experimental results.

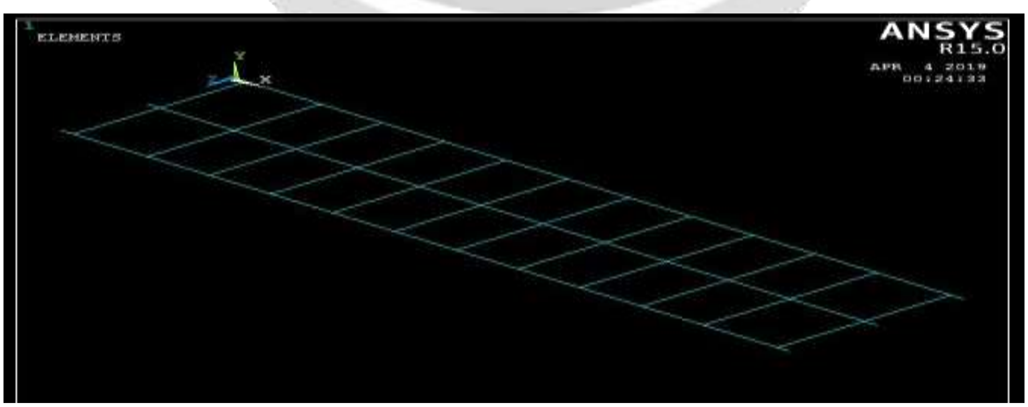


Fig.3.1 Modelled HFRP reinforcement

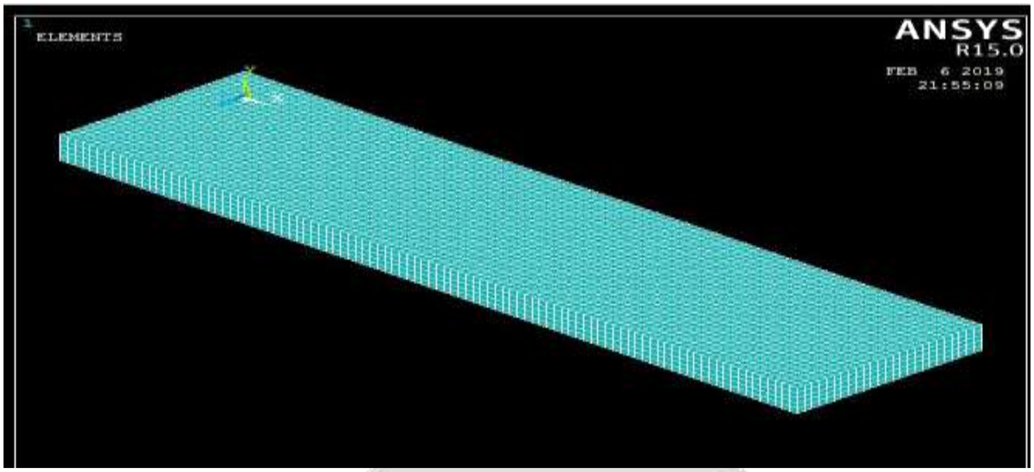


Fig.3.2 Modelling of Slab

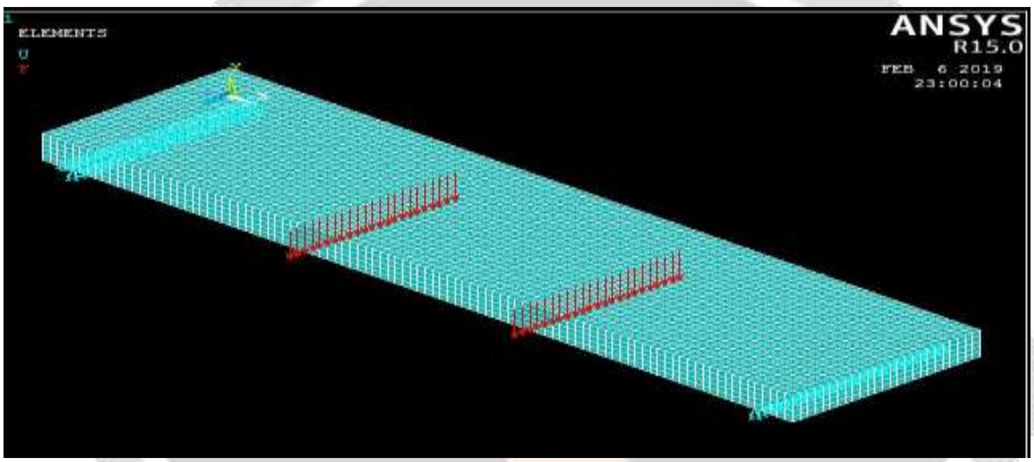


Fig 3.3 Loading and support condition

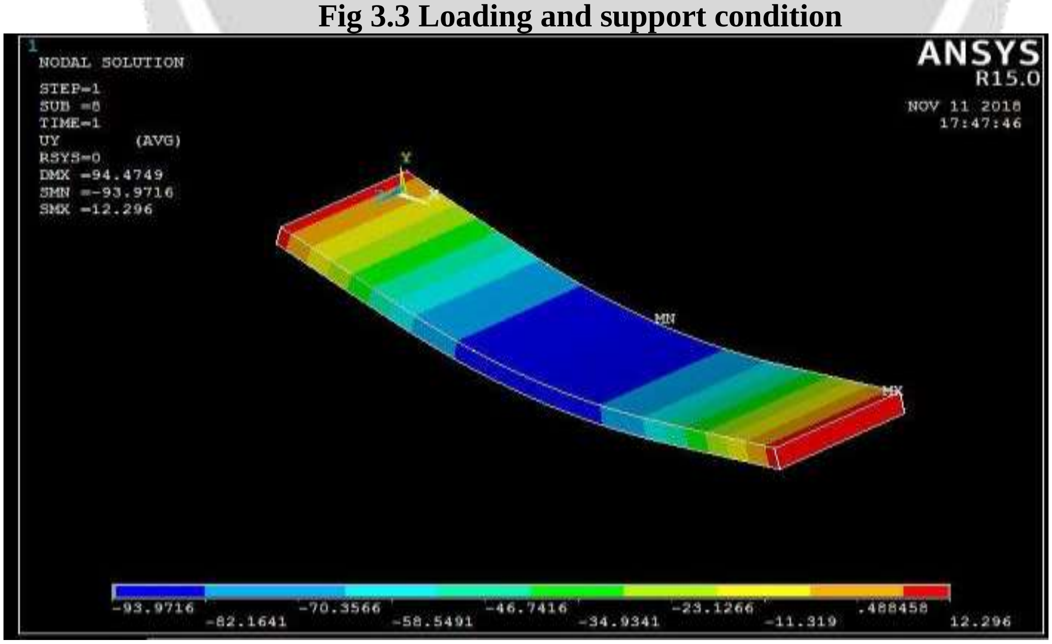


Fig.3.4 Deflected profile of HFRP $M_1H \quad {}_1D_1$ **slab**

4. CONCLUSIONS

Load -deflection graphs drawn exhibits the accordance between experimental and FEM (ANSYS) observations. The reduced deflection of FEM is due to the rigidness of meshing. The results also confer about the effect of tension stiffening and the bond slip. From the comparison it has been observed that experimental deflections vary from 1.03 to 1.37 times higher than the FEM deflections. Reliability index and resistance factors have been evaluated using LRFD concept. Monte Carlo Simulation (MCS) is implemented for generating random parameters. Finally as an conclusion a higher reliability index is suggested for HFRP reinforcement ratio equal to or below one to avoid HFRP rupture mode of failure, Based on these studies, the reliability indices β varies from 3.664 to 3.36 for all

5. FUTURE SCOPE

- The long-term properties of HFRP reinforcements under different exposure conditions with different types of fibres and matrix composition needs to be assessed by rigorous experimental study.
- Application of rigorous reliability studies incorporating the experimental observations can be extended to HFRP reinforced concrete columns, beam-column connections, beams under torsional loading conditions, etc.

- Investigations on the fatigue characteristics of HFRP reinforced concrete slabs need to be experimented.
- The finite element study on the non linear aspects of the behaviour of HFRP reinforced concrete slabs needs to be studied under repeated loading conditions
- The study can be extended to other structural components also.

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