EXPERIMENTAL INVESTIGATION ON FLEXURAL BEHAVIOR OF CONCRETE ONE WAY SLABS REINFORCED WITH HYBRID REINFORCEMENT

Sipranjali Patel[1], Niharika Patel[2]

[1]PG Scholar, Dept. of Civil Engineering, GIET University, Odisha, India
[2] Assistant Professor, Dept. of Civil Engineering, GIET University, Odisha, India

* * *

Abstract - *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.*

The main aspect of the present research is to review the analytical and experimental behaviour of Hybrid Fibre Reinforced Polymer reinforcements FRP (HFRP) reinforcements in concrete one-way slabs on the basis of more accurate modeling and analysis and to build better recommendations for more balanced design. This chapter gives the development, constituents, classification, manufacturing methods and different applications of FRP materials. The manufacturing process of new HFRP rod is also explained. Finally it presents the need for the present study and organization of the thesis.

Key Words: **HFRP Slabs, Load versus deflection curves, stress versus strain curves, load versus crack width curves**

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 spalling of the concrete due to the volume increase of the steel reinforcement (Rizkalla 2003). 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 Fibre reinforced Polymer (FRP) reinforcements suitable for such applications.

The use of FRP reinforcements in concrete structures has rapidly increased in recent years owing to their excellent corrosion resistance, high tensile strength to weight ratio, and good non-magnetization properties. The superiority of the FRP materials, in comparison with other conventional building materials like timber, steel and reinforced concrete, lies in its improved structural performance, in terms of stability, stiffness, strength and durability (Mandell 1982; Machida 1993 and 1997; Bakis et. al., 1998; Bank et. al., 1998; Hayes et. al., 1998; Katz, 1999; Nanni 2000; Dejke 2001; ACI 440. 1R-15 2015). Other factors include convenience in mass production with high quality control and relative economy.

However, concrete members reinforced with FRP bars exhibit large deflection and crack width compared with these reinforced with steel because of FRP low modulus of elasticity. Hence the design of such members is often governed by the serviceability limit-states and a general analytical method that can calculate the expected service load deflections of FRP reinforced members with a reasonable degree of accuracy would be very beneficial. As FRP bars possess mechanical properties different from steel bars, including high tensile strength combined with low elastic modulus and elastic brittle stress–strain relationship, the analytical procedure developed for the design of concrete structures reinforced with steel bars is not necessarily applicable to those reinforced with FRP reinforcements. The safety of concrete structures has been further increased and resulted in the development of Hybrid Fibre Reinforced Polymer reinforcements (HFRP) to replace steel reinforcements.

2. LITERATURE REVIEW

The objectives and scope of the present work are derived with the help of literature review.

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.

Fujisaki and Kobayashi (1995) examined the FRP bars which is set in in concrete prisms at both ends with 5 mm clear length in compression and the compressive strength of

Aramid FRP (AFRP), Carbon FRP and Glass FRP bars as 10%, 30-50% and 30-40% is than that of tensile strength results.

Saadatmanesh et al., (1997) has researched the property of FRP bars when drenched in salt solutions. From the outcomes, a decrease of 5% to 7% in tensile strength has been demonstrated.

Chin et al., (1997) observed that there is reduction in tensile and flexural strength of the FRP samples, if they immersed in salt solution.

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.

Hayes et al., (1998) has estimated a decrease in tensile strength and Young's modulus, roughly 26%, for glass/vinylester arrangement after wet/dry cycles at 4500C for 30 days.

Castro et al., (1998) introduced different anchors used for tensile testing of FRP bars and prescribed a testing plan consisting of FRP bar installed in steel tubes loaded up with high strength gypsum cement mortar.

Pantuso et al., (1998) examined the impact of distilled water and alkaline environment condition on the durability of glass fiber/polyester pultruded rods. The analyses included a procedure of one day's submerging of GFRP samples in distilled water after (23oC), and followed by drying for one day and this treatment is done for 60 days. A similar technique has been rehash for the samples implanted in cement to explore the impact of alkaline environment condition. The decrease in tensile strength has been seen at 1-7% and 6-21% for water and alkali condition.

Tang (1999) reviewed despite of low specific gravity of FRP rods as compared to steel rods; they have high tensile strength and presented excellent resistance to the elements of weather and chemical attacks. By using a reinforcing material, the fibers are generally bonded together with the help of binding agents such as resins and cement, resulting extensively in different forms and arrangements. Many theoretical and experimental works have been carried out to check the viability of using FRP to reinforce concrete structures.

3. MATERIAL PROPERTIES

3.1 CONCRETE

Normal Strength Concrete (NSC) of grades 30MPa, 40MPa and 50MPa are used to cast the concrete one-way slabs. Ordinary Portland Cement (OPC), coarse aggregate size of 20mm and fine aggregate of size ranging up to 4.75mm sieve are used in casting the slabs and in real environmental conditions. After 28 days of curing the compressive strength of cubes are determined with 150mm size of standard test cubes using Compression testing machine and the properties of concrete are tabulated in Table 1 below.

Table 1: Properties of Concrete

Material	M30 grade of concrete	M40 grade of concrete	M50 grade of concrete
Cement, kg/m^3	425.34	430	450
Fine aggregate, kg/m^3	615.21	664	701
Coarse aggregate, kg/m^3	1181.52	1174	1163
Water, kg/m^3	191.58	165	160
Average compressive strength, N/mm^2	38	49	56

3.2 REINFORCEMENT

The properties of reinforcements are already explained in the section 3.3.2 and the values are extracted and shown in Table 2 below.

Table 2: Properties of Reinforcements used in the study

Type of Rebar	**HFRP**	**STEEL**
Properties		
Tensile Strength, MPa	1217.93	583.67
Compressive strength, MPa	746.17	435.68
Elastic modulus, GPa	50	200
Transverse Shear strength, MPa	418.4	302.5
Coefficient of linear expansion, $/^0$ C	$9x10^{-6}$	20 $x10^{-6}$

4. TEST SPECIMEN PREPARATION

The experimental program consists of eighteen one-way slabs of length 2400mm and 600mm width. The various parameters that are involved in the present study and their designations are tabulated in Table 3. The reinforcements of size 8 mm are used as secondary reinforcements in the transverse direction of slab i.e widthwise and 10 mm reinforcements are used as main reinforcements in the span direction of slab i.e. lengthwise at three different spacing viz., 186.6 mm c/c, 140 mm c/c and 93 mm c/c. Main and secondary HFRP reinforcements are tied with help of Nylon zip ties. Secondary (8mm steel/HFRP) reinforcements are spaced at 210 mm c/c. Main reinforcements are given a bottom cover of 20mm for all the slabs. Mixing of concrete is done with help of rotary mixers. The slabs are designated with the parameters of m1hρ1D1, m1hρ2D1, m1hρ3D1, m2hρ1D1, m2hρ2D1, m2hρ3D1, m1hρ1D2, m2hρ1D2, m3hρ1D2, m1sρ1D1, m1sρ2D1, m1sρ3D1, m2sρ1D1, m2sρ2D1, m2sρ3D1, m1sρ1D2, m2sq1D2, m3sq1D2 Normal moist curing is done for all slabs; After curing, grid points are marked to locate the loading points and strain measuring positions; Brass pellets are fixed to measure strains using Demouldable mechanical (Demec) strain gauge. In the next section a detailed experimental setup is explained under different loading conditions.

Table 3: Various Parameters involved in the construction of slabs

Parameters	Description	Designation
Types of reinforcements	HFRP	*h*
	Steel	*s*
Thickness of slabs	100 mm	*D*1
	120 mm	*D*2
Grades of concrete	M30	*m 1*
	M40	*m*2
	M50	*m*3
Reinforcement ratios	0.49%	*hρ1 , sρ1*
	0.65%	*hρ2 , sρ2*
	0.81%	*hρ3 , sρ3*

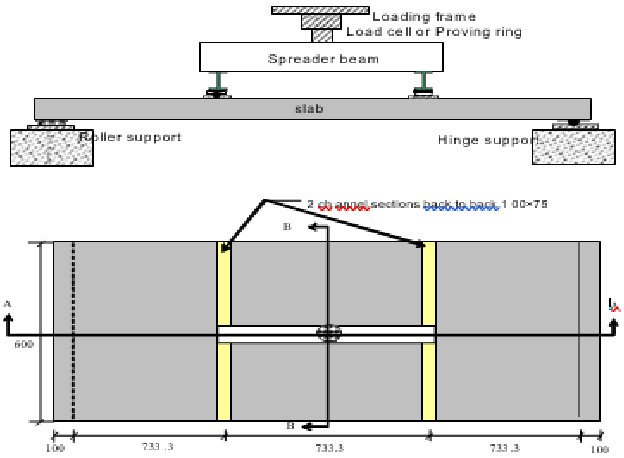

Fig. 1: Experimental Test setup

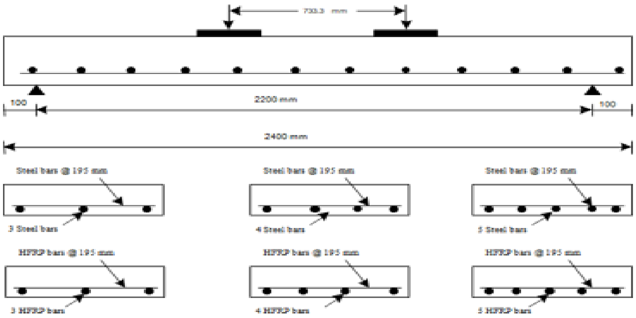

Fig. 2: Reinforcements Details for HFRP and Conventional Slabs

Fig. 3: Test set up for Static loading

Fig. 4: Test set up for Static loading under loading condition

5. RESULTS & DISCUSSIONS

Table 4: Experimental Results

Sl No	Designation of slabs	*Pu* (kN)	*Mu,* kNm	Ultimate Deflection (mm)
1	*m1hρ1D1*	40	16	97.63
2	*m1hρ2D1*	42.5	17	89.54
3	*m1hρ3D1*	45	18	80.44
4	*m2hρ1D1*	47.5	19	79.18
5	*m2hρ2D1*	50.25	20	77.72
6	*m2hρ3D1*	55	22	74.56
7	*m1hρ1D2*	57.5	23	70.80
8	*m2hρ1D2*	60	24	69.24
9	*m3hρ1D2*	75	30	58.45
10	*m1sρ1D1*	25	10	42.42
11	*m1sρ2D1*	27.5	11	40.71
12	*m1sρ3D1*	30	12	39.38
13	*m2sρ1D1*	27.5	11	36.75
14	*m2sρ2D1*	30	12	31.28

15	*m2sp3D1*	32.5	13	30.12
16	*m1sp1D2*	35	14	30.6
17	*m2sp1D2*	30	12	30.55
18	*m3sp1D2*	27.5	11	35.95

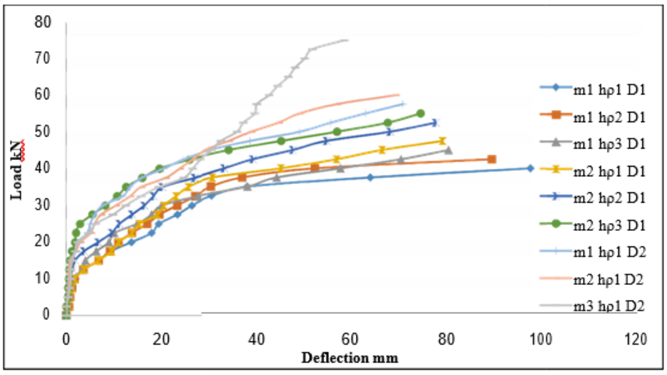

Chart -1: Comparison of Load versus Deflection for all HFRP slabs.

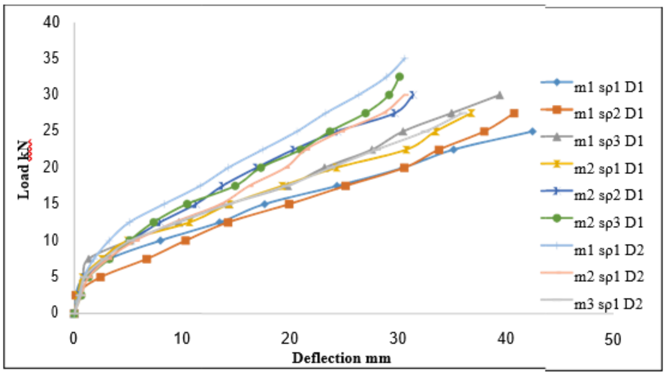

Chart -2: Comparison of Load versus Deflection for all conventional slabs

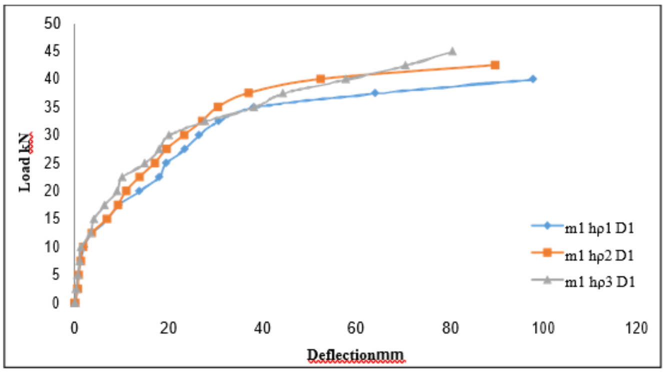

Chart -3: Comparison of Load versus Deflection for HFRP slabs with different reinforcement ratio

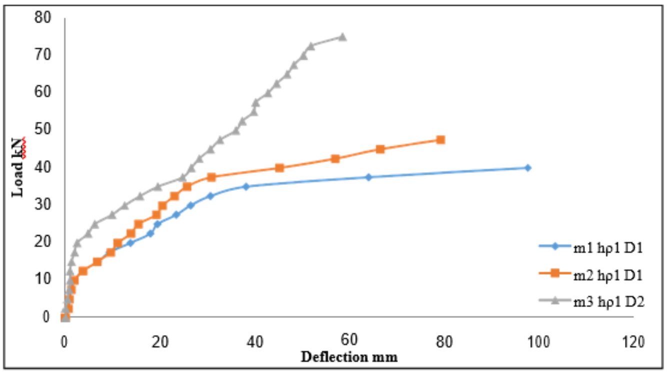

Chart -4: Comparison of Load versus Deflection for HFRP and conventional slabs with different grades of concrete

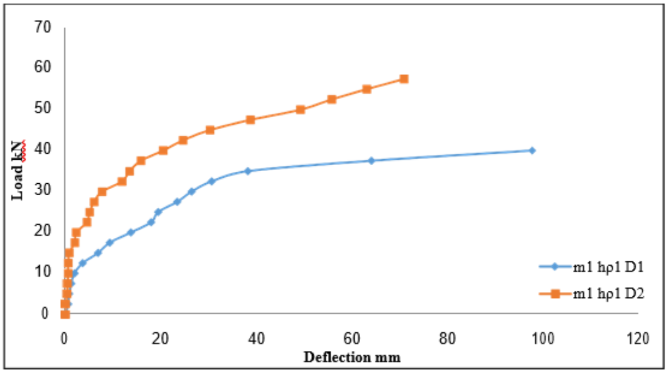

Chart -5: Comparison of Load versus Deflection for HFRP slabs with different thickness of slabs

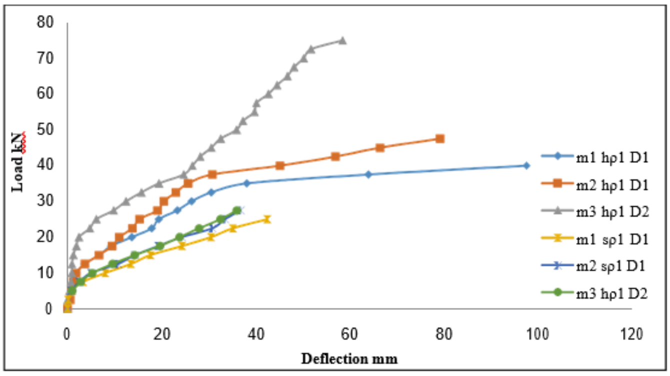

Chart -6: Comparison of Load versus Deflection for HFRP and conventional slabs with different grades of concrete

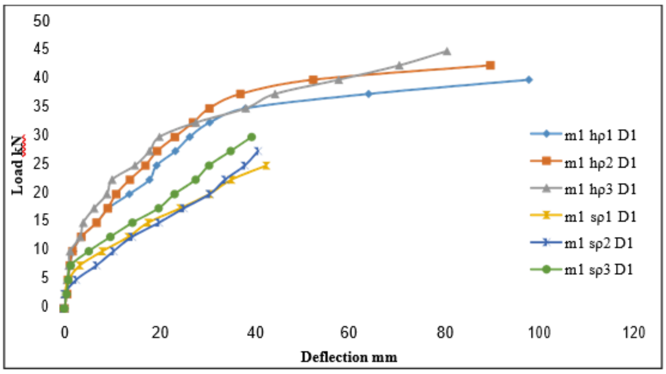

Chart -7: Comparison Load versus Deflection for HFRP and conventional slabs with different reinforcement ratios

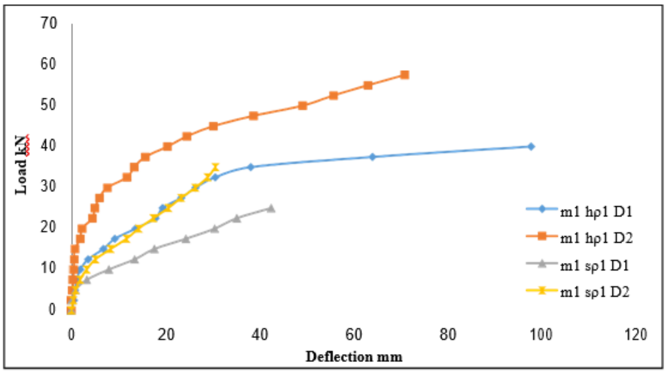

Chart -8: Comparison Load versus Deflection for HFRP and conventional slabs with different depths of slabs

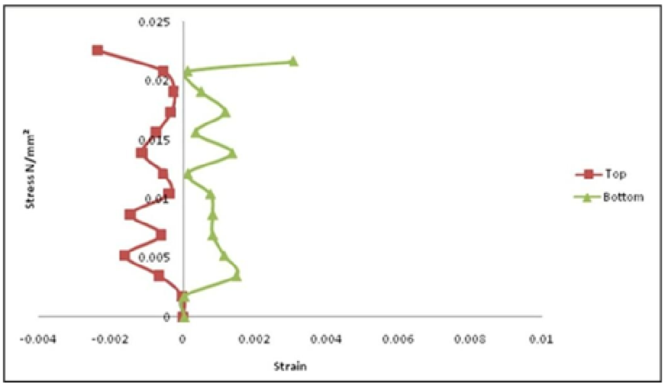

Chart -9: Comparison of stress versus strain for HFRP slab for m1hρ1D1 at top and bottom levels

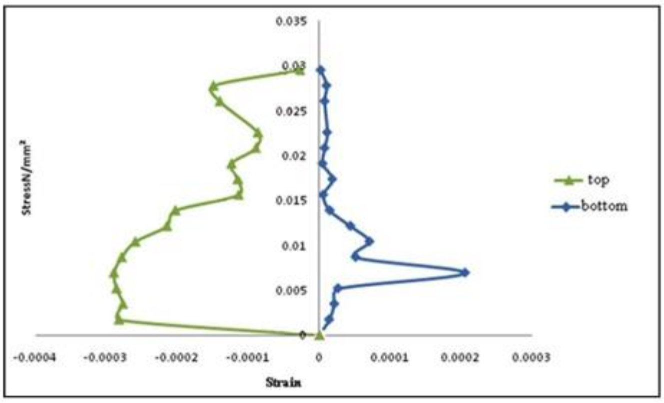

Chart -10: Comparison of stress versus strain of Steel for m1sρ1D1 at top and bottom levels

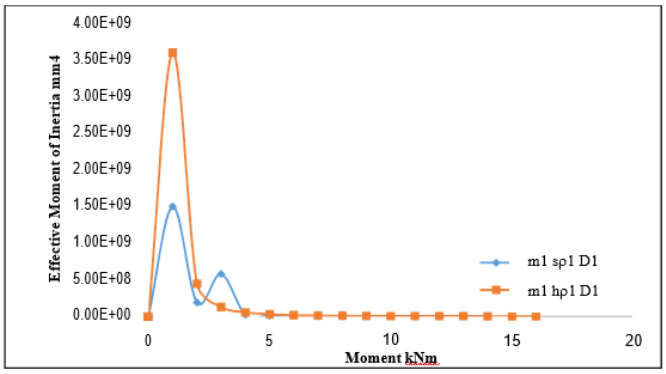

Chart -11: Comparison of Experimental Effective Moment of Inertia versus Moment for HFRP and conventional slabs

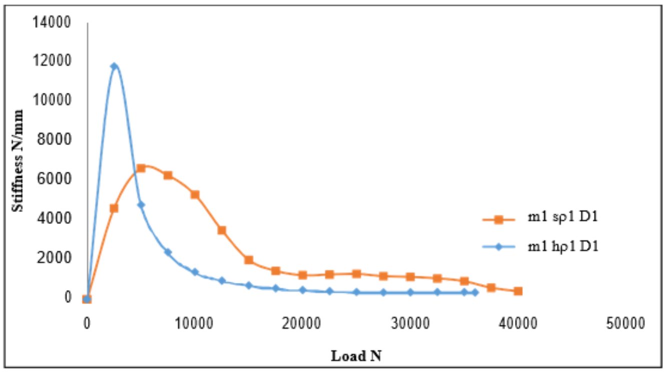

Chart -12: Comparison of Experimental Stiffness versus Load for HFRP and conventional slabs

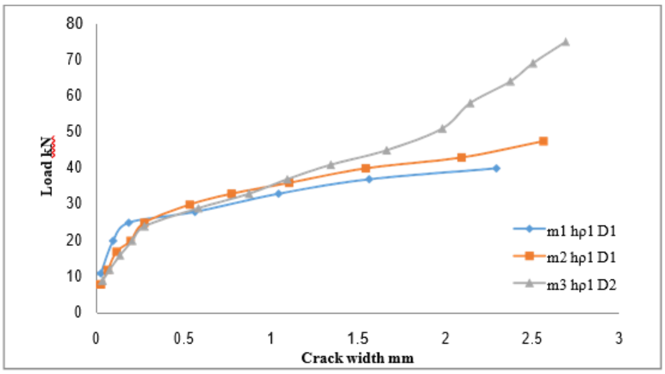

Chart -13: Comparison of Load versus crack width for HFRP slabs differing with grade of concrete

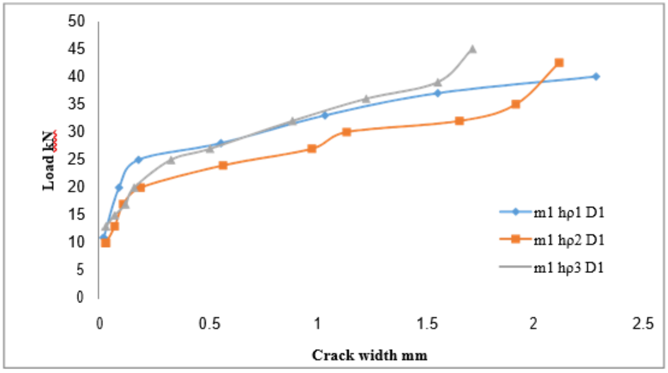

Chart -14: Comparison of Load versus crack width for HFRP slabs differing with reinforcement ratio

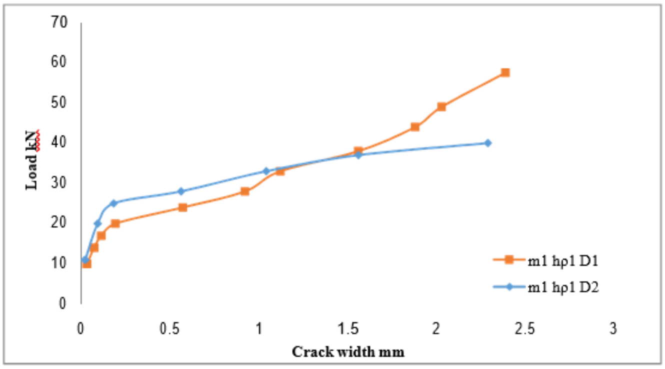

Chart -15: Comparison of Load versus crack width for HFRP slabs differing with depth of slabs

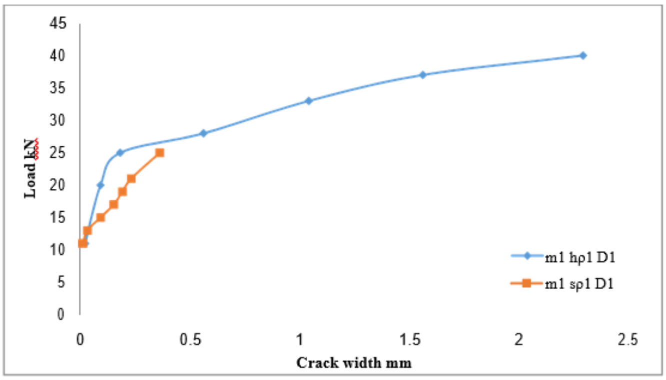

Chart -16: Comparison on Load versus crack width between HFRP slabs and conventional slabs

Fig. 5: Crack patterns of conventional slabs

Fig. 6: Crack patterns of HFRP slabs

6. CONCLUSIONS

1. Load deflection response due to static loading shows a greater reduction in stiffness in the case of HFRP reinforced slabs than the conventional slabs. For conventional slabs, a wider deflection occurs due to its yielding nature, whereas HFRP reinforced slabs show no yielding of reinforcements but a larger deflection occur due to load increments.
2. The flexural response of RC members is divided into two distinct stages. The first stage describes the uncracked portion of the member, and the second describes the cracked portion of the member.
3. In the second stage, the concrete tensile resistance reduces due to cracks and so that the tensile loads are carried entirely by the reinforcement. The flexural stiffness of a RC member is greatly reduced in this stage, but the cracked response remains well above that of a member that is fully cracked. This is possible only, due to good bonding and the by transferring mechanism of rebar, some of the tension to its surroundings, which leads to the contribution of concrete between individual cracks.
4. On further loading, the tensile stress increases to develop additional cracks. The process continues until crack spacing reduces in such a way not to develop new cracks. Such crack pattern is termed as the stabilized crack pattern in which additional load widens existing cracks, with limited effects on flexural stiffness.
5. The slab m1hρ1D1 shows 6.25 % increase in load carrying capacity than m1hρ2D1 slab whereas the deflection is 1.09 times greater m1hρ2D1 than slab. The slab m1hρ1D1 shows 12.5 % increase in load carrying capacity than m1hρ3D1 slab whereas the deflection is 1.21 times greater m1hρ2D1 than slab.
6. The load carrying capacity of HFRP slab m1hρ1D1 poses 6.25 % and 12.5 % m1hρ2D1 and m1hρ3D1 slabs
7. By increasing the thickness by 20 mm the load carrying capacity increases by
8. By increasing the grades of concrete, m2hρ1D1shows 18.75 % and m3hρ1D2 shows 87.5% higher strengths and at the same time, and 1.8 times lesser deflections than m1hρ1D1slab. Owing to it, the ultimate deflection and the crack width also reduce substantially.
9. The strain distributions across the thickness of HFRP slabs are shown above. HFRP reinforcements in tension side of the concrete slabs behave similar to the HFRP reinforcements tested under pure tension (Tensile test specimen) Reflecting good bonding between concrete and HFRP reinforcements. The concrete surface strain in HFRP reinforced slabs shuttles between 1.5 to 2 times greater than the conventional slabs under the similar load level. The experimental observations resembles to the observations made by the authors (Benmokrane 1995, Theriault 1998 and Craig 1998).
10. Experimental contributions on Crack widths and Crack patterns are shown clearly. The first crack appears at the middle of the slab and develops slowly across the width of the slab. When more loads is applied gradually, new cracks are developed on the slabs. At the same time, the existing crack has been widened. This is continued up to 75% of ultimate load and then the formation of new split up into smaller cracks close to the main bars. All the slabs experience flexural type of failure. At ultimate load, HFRP reinforced slabs experience concrete crushing and Steel reinforced slabs show the flexural type of failure. Fig.3.41 and Fig.3.42 depict the crack pattern of slabs for various parameters.
11. Crack pattern of slab m3hρ1D2 in which the rupture of HFRP rebars has been noticed with a pronounced shrinking stating that the slab is designed as under reinforced slab.
12. The ultimate load carrying capacities of HFRP reinforced slabs are increased and the corresponding deflections, strains and crack width are reduced by increasing the thickness, grade of concrete, reinforcement ratio of the slabs. This is mainly attributed due to the almost closer values of the modulus of elasticity for HFRP reinforcements and concrete in addition to the linear elastic behaviour of HFRP reinforcements.
13. There is a direct relationship between the strain in the reinforcing bars and the crack width. Codal provisions

recommend a value of 0.002 as a strain limit in HFRP reinforcing bars to control crack width. At strain value of 0.002, the crack width for HFRP slabs ranges from 0.3 to 1 mm whereas for conventional slabs it has been observed very negligible less than 0.1 mm.

REFERENCES

[1] Abdalla, H.A. (2002), Evaluation of deflection in concrete members reinforced with Fibre Reinforced Polymer (FRP) bars, Journal of composite structures, Vol.56(1), April pp.63-71.

[2] Achillides, Z., and Pilakoutas, K. (2004), Bond Behavior of Fiber Reinforced Polymer Bars under Direct Pullout Conditions, ASCE Journal of Composites for Construction, Vol. 8(2), March pp. 173-181.

[3] Aiello,M.A., and Ombres,L. (2000), Load – deflection analysis of FRP reinforced concrete flexural members, Journal of composite construction, Vol.4(4), Nov., pp.164-17.

[4] Al-Harthy, A., and Frangopol, D.M. (1994), Reliability assessment of prestressed concrete beams, Journal of Structural Engineering, Vol.120(1), April pp.180-199.

[5] Al-Sunna, R., Pilakoutas, K., Hajirasouliha, I. and Guadagnini M. (2012), Deflection behaviour of FRP reinforced concrete beams and slabs: An experimental investigation. Composites Part B: Engineering, Vol.43(5), March, pp. 2125 - 2134.

[6] Al-Salloum, Y., Sayed, S., and Almusallam, T. (1997), Behavior of Concrete Beams Doubly Reinforced by GFRP bars, Non-Metallic (FRP) Reinforcement for Concrete Structures, Proceedings of the Third International Symposium, Vol. 2, Nov., pp 471-478.

[7] Al-Salloum, Y., Sayed, S., and Almusallam, T. (1996), Some Design Considerations for Concrete Beams Reinforced by GFRP Bars, First International Conference on Composite Infrastructure (ICCI-96), Jan., pp 318-331.

[8] Alkhrdaji, T., Wideman, A., Belarbi, A., and Nanni, A. (2001) Shear strength of GFRP RC beams and slabs, proceedings CCC 2001, Journal of composites in construction, Portugal, Oct., pp. 409-414.

[9] Ansys (2010), ANSYS Release 13.0, Finite Element Analysis System, SAS IP, Inc.

[10] Arindom, B., Tejaswini, M.L., Kiran, S.M. (2018), Finite Element Analysis of Different Types of FRP on Beam-Column Joint International Journal of Engineering Research & Technology (IJERT) Vol. 7(5), May, pp.416-422.

[11] Arabshahi, A., Gharaei-Moghaddam, N., and Tavakkolizadeh.,M. (2017), ,Reliability analysis of available relations and suggestion of a new formula for effective moment of inertia in concrete beams with FRP bars reinforcement, SMAR-2017 fourth conference on smart monitoring assessment and rehabilitation of structure, At Zurich, Switzerland, 13-15 Sep., pp.1-8.

[12] Ashour, AF., Habeeb, MN. (2008), Continuous concrete beams reinforced with CFRP bars, Structural Buildings, Vol.161(6), May, pp.349–357.

[13] Ayman S Mosallam, Alemdar Bayraktar, Mohamed Elmikawi, Selim Pul and Suleyman Adanur., (2015), Polymer Composites in Construction: An Overview, SOJ Mater Sci Eng Vol. 2(1), Feb., pp.25.

[14] Bakis, C.E., Boothby, T.E., and Jia, J. (2007), Bond Durability of GFRP Bars Embedded in Concrete Beams. Journal of Composites for Construction, Vol.11(3), August, pp. 371-380.

[15] Bakis, C.E., Freimanis, J., Gremel,D. and Nanni, A.(1998), Effect of resin material on Bond and tensile properties of unconditioned and conditioned FRP reinforced rods, Proceedings of 1st International conference on durability of fibre reinforced polymer (FRP)composites for construction, Sherbrooke, Aug., pp. 525-535.

[16] Bakis, C.E., Boothby, T.E., and Jia, J., (2007), Bond durability of Glass Fibre Reinforced Polymer bars embedded in concrete beams, Journal of composites for construction, Vol.11(3), June, pp.269-277.

[17] Bank, C.L., Puterman, M., and Katz, A. (1998), The effect of material degradation on Bond properties of fiber reinforced plastic reinforcing bars in concrete, ACI Materials Journal, Vol. 95(3), Oct, pp.232-243.

[18] Barris, C., Torres, Ll., Turon, A., Baena, M. and Catalan., A. (2008), An experimental study of the flexural behaviour of GFRP RC beams and comparison with prediction models. Composites Structures Vol.91(9), Dec., pp. 286-295.

[19] Barris, C., Torres, Ll., Turon, A., Baena, M. Catalan., A. (2008), Experimental study of the flexural Behaviour of GFRP Reinforced Concrete Beams, Fourth International Conference on Composites in Civil Engineering (CICE 2008), Zurich, Switzerland, Dec.,.

[20] Benmokrane, B., Tighiouart, B., and Challal, O. (1996), Bond Strength and Load Distribution of Composite GFRP Reinforcing Bars in Concrete, ACI Materials Journal, Vol. 93(3), Jan., pp.254-259.

[21] Benmokrane.B., Challal, O., and Masmoudi, R., (2004), Residual Tensile Properties of GFRP reinforcing bars after loading in severe Environments, ASCE Journal of composites for construction, Vol. 10(5),Oct, pp. 370-380.

[22] Bischoff, B.H., and Paixao, R. (2004), Tension stiffening and cracking of concrete reinforced with glass fiber reinforced polymer (GFRP) bars, NRC Research press, Canadian Journal of civil Engineering, Vol.31,July, pp. 579- 588.

[23] Bischoff, B.H., and Scanlon, A. (2007), Effective Moment of Inertia for Calculating Deflections of Concrete Members Containing Steel Reinforcement and Fiber Reinforced Polymer Reinforcement. ACI Structural Journal, Vol.104(1), Jan., pp. 68 – 75.

[24] Cosenza, E., Manfredi, G., and Real fonzo. R., (1997), Behaviour and modeling of bond of FRP rebars to concrete, Journal of composites for construction, ASCE, Vol.1(2), May, pp. 40-5.