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# Behaviour of GFRP R.C. Slabs in Flexure in Localenvironment — An Experimental Study

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**Abstract:** A variety of new materials in the field of concrete technology have been developed during the past three decades with the ongoing demand of construction industry to meet the functional, strength, economical and durability requirements. Though reinforced concrete has high strength and is most widely used construction material it suffers from disadvantages like corrosion of steel, susceptibility to chemical and environmental attack. In order to overcome the above deficiencies of reinforced concrete new materials (special concrete composites) have been developed over the past three decades. Glass Fibre Reinforced Polymer (GFRP) is one such material with wide range of applications. Based on the preliminary investigations on GFRP bars, an optimum fiber/resin ratio of 7:3 was arrived. The tensile strength of GFRP bars is comparable to that of the mild steel as per the tests carried out, but the modulus of elasticity is about 25–30 percentage of that of steel bars. This paper deals with the experimental investigations carried out on small slab panels supported on all four edges with effective spans of 0.9 m × 0.45 m, which is a part of large research problem undertaken with different ratios of long span to short span with different support conditions. The test results are compared with similar slab panels reinforced with conventional mild steel bars.

**Key words:** GFRP bars, steel bars, corrosion, slab panels, flexure, deflections.

## 1. Introduction

Research on concrete is a continuous process world over, to improve the performance of concrete to meet the functional, strength, economy and durability requirements. As concrete is weak in tension hither' to steel is being used in tension zone to strengthen the concrete. Depending on the type of members, different types of fibers are also used now as crack arresters in concrete. Because of corrosion problems associated with steel, necessity of new non corrosive materials has arisen.Fiber reinforced polymer (FRP) is a composite material made of fibers and resin. Glass Fibre Reinforced Polymer (GFRP) is one such composite material. Aramid, Carbon and Basalt fibers are some other fibers in use.

Extensive work was carried out in Rapid City, USA on basalt fibres and basalt reinforced concrete beams [7]. Braided or weaved FRP bars made of glass fibers are more economical, since these bars are made of Calcium Alumina Boro Silicates, which is much cheaper than both Carbon and Aramid fibers.

GFRP plain rods were also tried by P. J. Rao et al. [6] in their investigation on "Behavior of GFRP reinforced beams in Flexure". All the beams failed much below the expected load because of failure in bond. In the same investigation, they used silica coated bars in the beams which gave same flexural strength as that of conventionally reinforced beams with HYSD bars. Hence silica coated GFRP bars are directly used in the present investigations on slabs.

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Luciano et al. [5] studied the effect of reinforcement ratio, rebar diameter and rebar spacing on the behaviour of one way slabs reinforced with GFRP bars. Also, a good comparision of experimental and analytical results was made. Beams reinforced with GFRP bars will undergo larger deflections and crack widths due to the reduced stiffness of these bars [9]. Susan and Barry [8] concluded in their paper that the laterally restrained FRP slabs such as those in bridge deck slabs, exhibit arching action and show better service behavior compared to the equivalent laterally restrained steel reinforced slabs. The results of El-Ragaby et al. [2] showed the superior fatigue performance and longer fatigue life of concrete bridge deck slabs reinforced with GFRP composite bars compared to the steel reinforced ones.

Glass fibers are economical and lighter in weight compared to other fibers. Therefore, the objective of the present study is to find out the suitability of GFRP bars as flexural reinforcement in slabs. Silica coated GFRP bars with fiber resin ratio of 7:3 with a tensile strength of 360 MPa were used in the present investigation. The modulus of elasticity of these bars was found to vary between 55 GPa to 60 GPa.

## 2. Experimental Program

The proposed experimental program was divided into number of phases using different support conditions and different ratios of long span to short span. In the present paper, the experimental work related to second phase with the ratio of long span to short span of 2 was reported. All the slabs are supported on all four edges.

A total number of 15 slabs were cast dividing into 3 groups, each group consisting of 3 slabs with GFRP reinforcement and remaining 2 slabs control specimens with mild steel reinforcement. The thickness of the slab in all the groups was 75 mm and the dimensions of the slab are 0.6 m × 1.05 m with effective spans of 0.45 m × 0.9 m respectively in the two directions. In the 1st group, there are three slabs with 6mm silica coated GFRP bars at 100 mm c/c (1.12%) in the short span direction at bottom and 6 mm silica coated GFRP bars at 175 mm c/c in long span direction and two slabs (control specimens) using 6 mm mild steel bars with 85 mm c/c in the short span direction and 160 mm c/c in the long span direction. In the second group, the spacing of GFRP bars in short span and long span directions were 150 mm c/c (0.84%) and 260 mm c/c respectively while for control specimens, the spacing of steel bars were 125 mm and 235 mm c/c respectively. In the third group, the spacing of GFRP bars in short and long span directions were 200 mm c/c (0.75%) and 350 mm c/c respectively while for control specimens, the spacing of steel bars were 165 mm and 300 mm c/c respectively. For control specimens using 6 mm mild steel bars the cover and lever arm have been so adjusted to give same theoretical moment as in groups 1, 2 and 3. For each group, 2 control specimens were cast.

All the slabs were under reinforced. The moment of resistance was calculated as per Bureau of Indian Standards IS456:2000 and the guidelines given by ACI 440 for beams reinforced with GFRP bars. The stress block of IS456 was used with little modifications.

## 3. Test Procedure

Uniformly distributed load was applied on the entire slab by using a steel box filled with sand covered with a thick plate at top and the load applied through a hydraulic jack. The proving ring used was of capacity 250 kN with a least count of 0.25 kN. The load was applied at an increment of 2.5 kN and the central deflection of the slab was measured for each increment of the load. Least count of the dial gauge used was 0.01 mm. Dial gauge was removed immediately after the formation of the first crack. The test set up is shown in plate 1. The failure of GFRP bars in direct tension is splintering type failure and the bars failed in tension are shown in plate 1a.

## 4. Test Results and Discussions

The load carrying capacity of slabs reinforced with GFRP bars are almost equal to that of the corresponding control specimens. The experimental values in all the slabs are higher by 1 to 20 percent than the theoretical values of corresponding slabs (Table 1). Similar trends were observed for moments also (Table 2). Figs. 4 and 5 show the relation between theoretical and experimental moments. There is a variation in theoretical and experimental moments for beams with 0.75% reinforcement (both for GFRP and MS). But there is not much variation in these moments for 0.84 and 1.12% reinforcement. The post cracking strength improved with increased flexural reinforcement. As the percentage reinforcement increased to 1.12%, there is a markable difference between first crack load and ultimatemate load (Figs. 6 and, 7).

**Table 1 Test results of slab panels.**

| S.No | Reinforcement Material | Effective Span (m) 0.45 × 0.9 | % of reinforcement | Ly/Lx | Theoretical Ultimate load(kN) | Experimental | | $\frac{P_u}{P_{cr}}$ |
|---|---|---|---|---|---|---|---|---|
| | | | | | | First Crack Load $P_{cr}$ (kN) | Ultimate Load $P_u$ (kN) | |
| 1 | GFRP | 1 | 1.12% | 2 | 96.2 | 67.6 | 96.66 | 1.43 |
| | | 2 | 0.84% | 2 | 66 | 57.15 | 69.16 | 1.21 |
| | | 3 | 0.754% | 2 | 50 | 54.56 | 61.66 | 1.13 |
| 2 | M.S | 1 | 1.12% | 2 | 96.2 | 64.52 | 95 | 1.21 |
| | | 2 | 0.84% | 2 | 66 | 55.6 | 65 | 1.17 |
| | | 3 | 0.754% | 2 | 50 | 47.24 | 60 | 1.27 |

**Table 2 Comparison of Theoretical and Experimental Moments.**

| Reinforcement Material | Effective Span (m) 0.45 × 0.9 | Bending Moments | | % variation |
|---|---|---|---|---|
| | | Theoretical (kNm) | Experimental (kNm) | |
| GFRP | 1 | 2.43 | 2.455 | 1.2 |
| | 2 | 1.67 | 1.75 | 4.6 |
| | 3 | 1.265 | 1.56 | 19 |
| M.S | 1 | 2.43 | 2.4 | 1.23 |
| | 2 | 1.67 | 1.64 | 1.8 |
| | 3 | 1.265 | 1.52 | 16.8 |

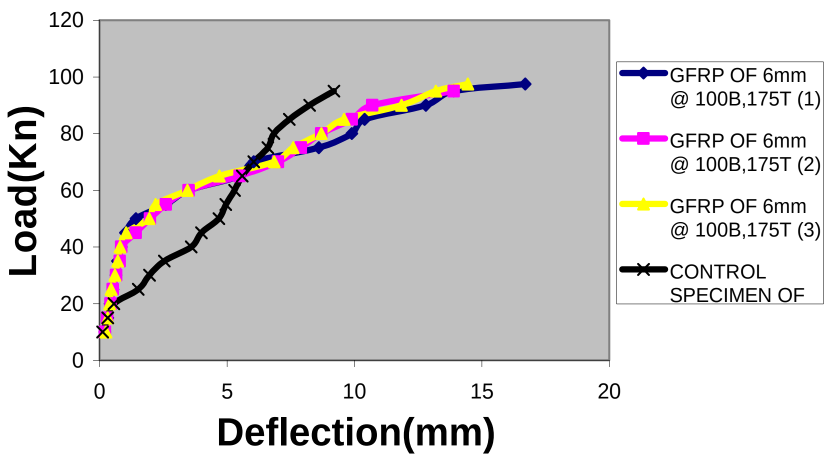


**Fig. 1 A typical load vs. deflection graph (Group 1).**

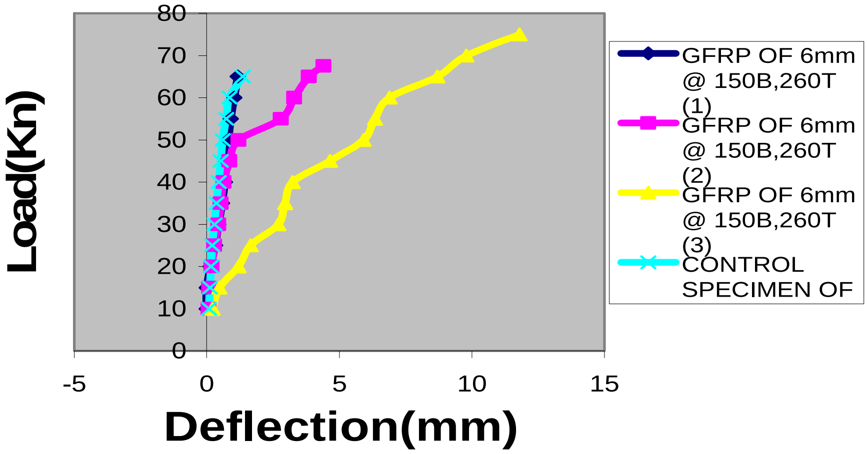


**Fig. 2** A typical load vs deflection graph (Group 2).

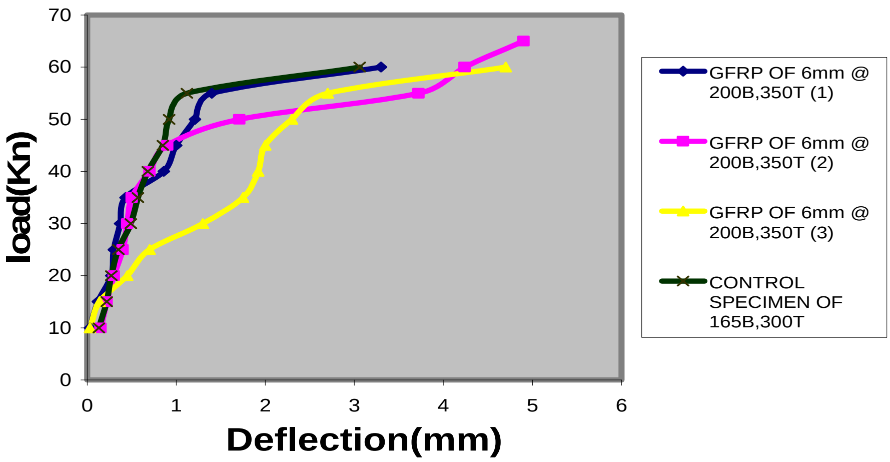


**Fig. 3** A typical load vs. deflection graph (Group 3).

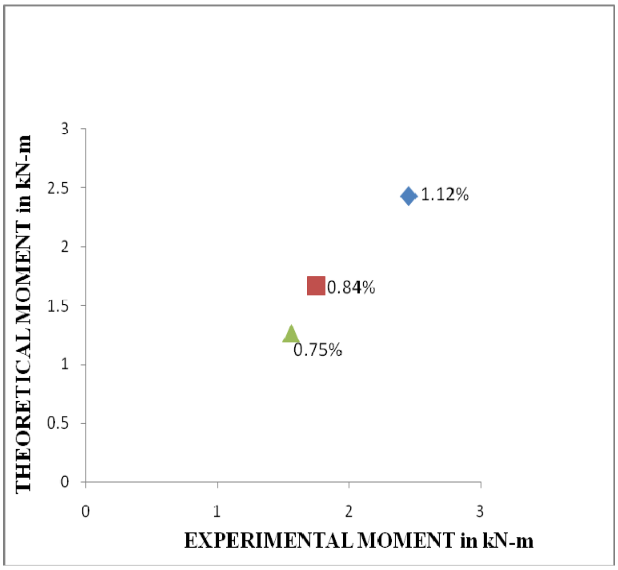


**Fig. 4** Comparison of theoretical and experimental moments of GFRP beams.

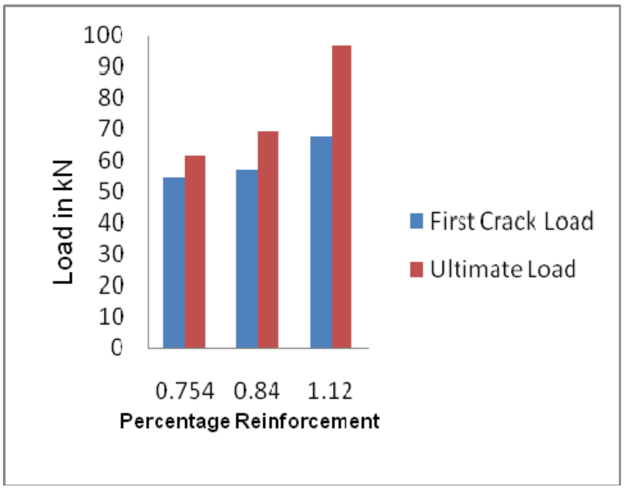


**Fig. 6** Variation of ultimate and first crack loads with percentage reinforcement (GFRP).

**Plate 1 Test setup.**

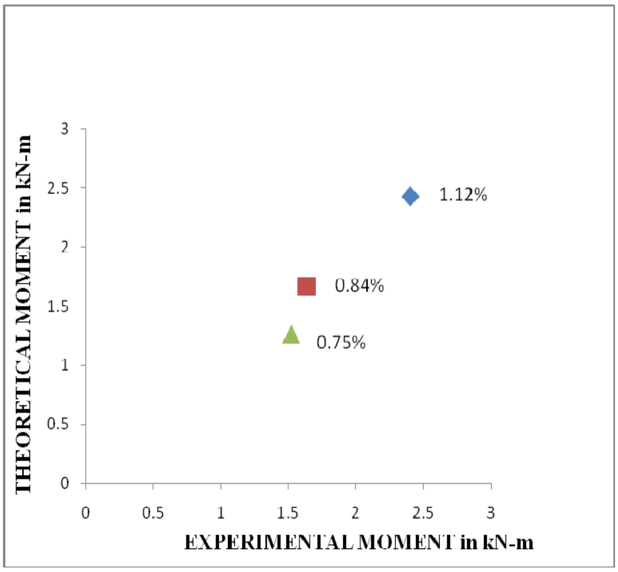


**Fig. 5 Comparison of Theoretical and Experimental Moments of MS Beams**

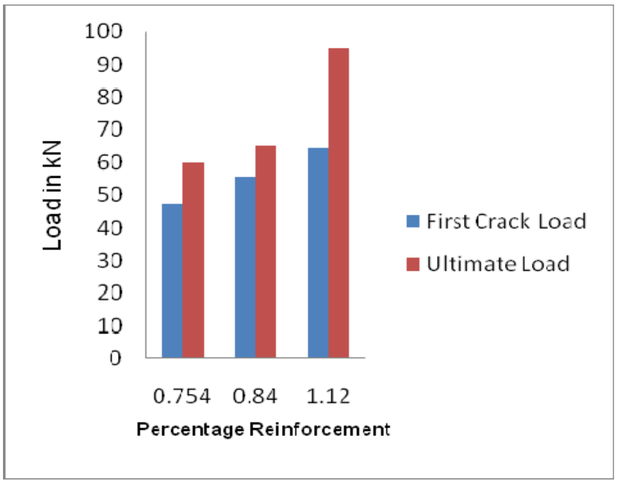


**Fig. 7 Variation of ultimate and first crack loads with percentage reinforcement (MS).**

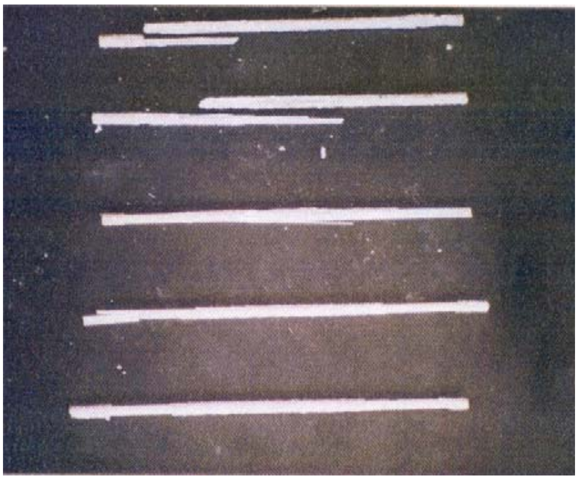

**Plate 1a Tension test specimens of 6 mm Dia silica coated GFRP bars after failure.**

**Plate 2 Failure pattern of GFRP slab of first group with 1.12% reinforcement.**

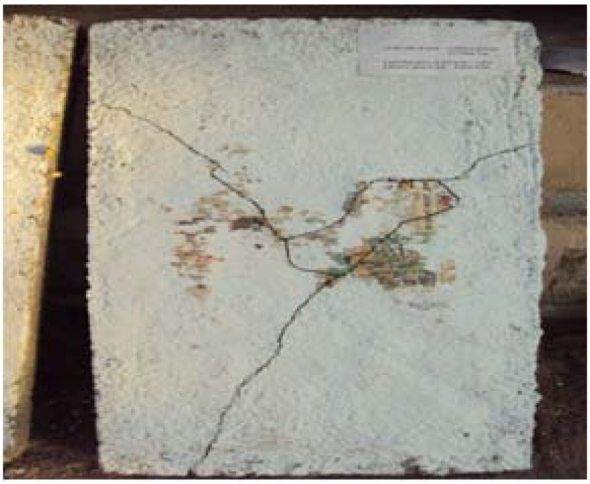

**Plate 3 Failure pattern of GFRP slab of first group with 0.84% reinforcement.**

**Plate 4 Failure pattern of GFRP slab of first group with 0.75% reinforcement.**

**Plate 5 Failure pattern of MS slab of first group with 0.75% reinforcement.**

The load vs deflection graphs (figures 1,2 and3) depicts that the failure of slabs with GFRP bars is gradual though the failure of GFRP bars in direct tension was observed to be sudden and brittle with a splintering type of failure. The margin between first crack load and the ultimate load observed also indicates the deformability of slabs.

The crack pattern that was observed in both GFRP and mild steel reinforced slabs are same till first crack. The first crack load and ultimate load in both cases are nearly same. The slab with MS bars as flexural reinforcement (0.75%) showed cracks in the longer span direction only (Plate 5) while the slabs with same percentage of GFRP bars cracked in two mutually perpendicular directions (Plate 4). The number cracks increased in slabs with GFRP bars as percentage flexural reinforcement increased (Plates 3 and 2).

## 5. Conclusions

- The load carrying capacity of slabs using silica coated GFRP bars as reinforcement is almost the same as compared to conventionally reinforced slabs with mild steel reinforcement.
- Failure loads and moments in slabs with silica coated GFRP reinforcement are higher than the theoretical values both for GFRP reinforced slabs and the conventionally reinforced slabs.
- The crack pattern of GFRP and mild steel reinforced slabs are similar.

Both GFRP reinforced slabs and conventionally reinforced control slabs showed almost equal deflections throughout.

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