Flexural Performance of Precast Concrete Slab with Gfrp and Geogrid Reinforcement

Ruba Carolin C, Mahendran N, Vijay T J

Abstract*: *An Experimental Investigation was carried out to study the behavior of Glass fibre reinforced polymer bars (GFRP) and geo-grid reinforced precast concrete slab. Durability of reinforced concrete (RC) is mainly affected by corrosion of steel reinforcement. In Corrosive Environment, service life of GFRP and geo-grid much greater than that of steel. To overcome this, steel bars are replaced by GFRP and geo-grids materials as reinforcement. Two concrete slab specimens were cast with the dimension of 1500 ×600×125mm to study the flexure behavior. Among that, one slab specimen was cast with steel reinforcement. Another one specimen was cast with combination of GFRP bars as main reinforcement and geo-grid layer as secondary reinforcement. The specimens were tested for point loading test setup. Test results showed that the slab reinforced with combination of GFRP and geo-grid reinforcement significantly improved the energy dissipation properties by resisting force with high amount of displacement compared to conventional element. Analytical investigation was also carried out using finite element analysis to validate the force-displacement characteristics. The analytical results showed a good agreement with the experimental results.

Keywords : GFRP bars, Geogrid bars, Ductility, Stiffness and Energy Dissipation

I. INTRODUCTION

Reinforced concrete (RC) slabs are widely used as structural member in load transferring system of buildings. In the same way the steel are mainly used structural reinforcing material in all over the world. On the other hand, the reinforced concrete structures are most prone to corrosion when it directly contact to the corrosion inhibit alkalis. The life of structural member is questionable under this situation. Although a lot of corrosion resistance inhibitors and material are widely available to resist the corrosion effects of structural elements, the durability of these structural elements is being investigated. The alternative technique to overcome this problem is to replace the steel reinforcement with non-corrodible materials such as polymers, plastics and so on [1, 2, 6, 9-11, 14-17]. Various varieties of polymers are available; they can now be used as building materials on a daily basis. Polymer includes fibre reinforced polymers (FRP) [2, 6, 9, 11, 14, and 17] and geogrids [1, 10, 15, and 16] are commonly used as reinforcement materials due to their high corrosion resistance properties. Limitations to its strength properties have been applied in different sectors, such as geotechnical applications, transport applications, etc. Several studies have already been carried out in different fields of civil engineering using FRP and Geogrids as reinforcement materials. Several studies showed that glass fibre reinforced polymer (GFRP) reinforcement can substitute steel reinforcement without compromising strength in bridge deck slabs. In some studies, hollow concrete slabs reinforced with GFRP bars and hollow composite systems, providing new lightweight slabs for civil engineering constructions. The use of geo-grids as reinforcement in slab element will enhance their performance by providing more durability, ductility and more importantly, controlling crack propagation to mitigate reflective cracking. The aim of this project is to study the effect of replacement of steel reinforcement to the combination of FRP and geogrid reinforcement in RC slabs. Numerous studies have shown that glass fibre reinforced polymer (GFRP) reinforcement can replace steel reinforcement without compromising the strength of bridge deck slabs. In some studies, hollow concrete slabs reinforced with GFRP bars and hollow composite systems provide new lightweight slabs for civil engineering construction. The use of geogrids as reinforcement in the slab element will improve their performance by providing more durability, ductility and, more importantly, by controlling crack propagation to mitigate reflective cracking [1, 10, 15, 16]. The objective of this project is to study the effect on replacement of steel to the combination of FRP and geogrid reinforcement in RC slabs.

II. EXPERIMENTAL PROGRAMME

A. Test Programme

Two 1:4 scaled RC slabs were considered for the study. The dimensions of the slabs were rectangular in size 1500 mm X 600 mm with a thickness of 125 mm. The specimen with conventional reinforcement shall be designated as SRCS and the specimens with a combination of FRP and geogrid shall be designated as FGRCS. The design of the conventional slab is carried out in accordance with IS 456:2000.

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In SRCS specimen, the main reinforced was detailed with a diameter of 8 mm at 112 mm c / c spacing and the secondary reinforced with a diameter of 6 mm at 208 mm c / c spacing. The tar surfaced glass fiber reinforced polymer (GFRP) bar of 8 mm was used as main reinforcement with 112 mm c / c spacing in FGRCS specimen. A single layer of bi-axial geogrid with a cross-section area of 4 x 2 mm with clear mesh spacing of 46.5 x 46.5 mm was used as a secondary reinforcement. Figures 1 and 2 show the GFRP and geogrid materials used for casting the FGRCS slab. Figure 3 shows the detailing photo of combined GFRP and geogrid as a steel reinforcement replacement in the FGRCS specimen. The slab was cast and tested under the center point patch load on a shorter length using a 100kN hydraulic load cell. The slab was supported along the short side at distance of 150 mm from both ends. The clear span of the slab was kept at 1200 mm. The displacement at the loading point increased at a rate of 1.2 mm / min. The deflection at the centre of the slab was measured using linear voltage differential transducers. The wooden mould was used to cast slab specimens and the gunny bag method of curing was adopted. Figure 4 shows the casting of the FGRCS slab using wooden mould.

Fig .1. GFRP Bars

Fig .2. Biaxial Geo-grid

Fig .3. Combination of GFRP and Geo-grid reinforcement

Fig .4. FGRCS slab mould filled with concrete

B. Material Property

The tested mechanical properties of materials used in this research study are as follows,

Concrete: Tested cylinder compressive strength, flexural strength, young's modulus, poisson ratio of concrete was 25.58 Mpa, 2.94 Mpa, 22.8 Gpa and 0.2.

Steel: Tested tensile strength, young's modulus, poisson ratio of steel was 520 Mpa, 221 Gpa and 0.3.

GFRP: Tested tensile strength, young's modulus, Poisson ratio of GFRP was 754 Mpa, 51 Gpa and 0.24.

Geogrid: Tested tensile strength, young's modulus, poisson ratio of geogrid was 55 Mpa, 32 Gpa and 0.24.

III. FINITE ELEMENT ANALYSIS PROGRAMME

The finite element analysis (FEA) models were created using the ABAQUS software [4, 7, 8, and 15]. The concrete element was created using 8 noded linear brick elements (C3D8R) which are attractive due to the existence of fully automatic meshers, and the elements are very well suited. An analysis for the sensitivity of the mesh size was done to increase the accuracy of the results. The mesh size of 20 mm was used for concrete element, 15 mm for steel FRP reinforcements, 2 mm for geogrid material. The reinforcements were modeled with 2-node linear truss elements (T3D2). The embedded method was used to model the bond between the concrete and the reinforcements. The specimens of the SRCS had 2854 nodes and the specimen of the FGRCS had 5680 nodes. Pinned support conditions are induced at a distance of 150 mm from both the bottom side of the slab along a shorter length. All frame elements have been tested using the ABAQUS / Standard Algorithm. The concrete element was modeled on the built-in concrete damage plasticity model and all the reinforcement material was modeled on the plasticity material model [4, 7, 8, 13, and 15].

IV. RESULTS AND DISCUSSION

A. Load versus deflection response

Load versus displacement response is important for validating the load carrying capacity and response of the specimen under load. The load versus deflection response investigated by experimental and FEA is shown in Figure 5.

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The stress contours of the SRCS and FGRCS specimens are shown in Figures 6 and 7. Load and displacement results by experimental and FEA are tabulated in Table 1. The FEA results showed a discrepancy of 5 per cent and 13 per cent higher than the experimental results for the SRCS and FGRCS specimens. But the FEA results showed a slight increase in the final load compared to the experimental results. The FEA results showed only about 10% discrepancy in the deflection response of the SRCS specimens. But for FGRCS specimens it was around 30% more than the SRCS specimens. For both SRCS and FGRCS, the bond model used in the FEA analysis was a standard friction embedded region constraint. This may affect the exact bond behavior of GFRP and Geogrid to the concrete. This resulted in variations in the FEA results to the experimental results. The experimental yield load of FGRCS was increased by 20 per cent, but the final load showed a decrement of 10 per cent due to the loss of bond characteristics of the GFRP bars compared to the steel bars due to the deterioration of the stiffness after the yield stage. The stiffness of the FGRCS specimens was reduced by 22 percent compared to the SRCS specimen, which is also another reason for the reduction of the ultimate load carrying capacity of the FGRCS specimen. Table 2 shows the stiffness properties of the specimens. The yield and ultimate deflection increased by 40 percent and 100 percent above the SRCS specimen. The stress experienced by the FGRCS specimen was higher than that experienced by the SRCS specimen. This showed that FGRCS specimens were able to withstand higher stress before failure. This indicated that the FGRCS specimen behaved more elastically than the SRCS specimen and the FGRCS specimens behaved well by exhibiting higher load capacity during the yield stage. This response of the FGRCS specimen indicated that polymers can be used to replace steel reinforcement in RC slabs.

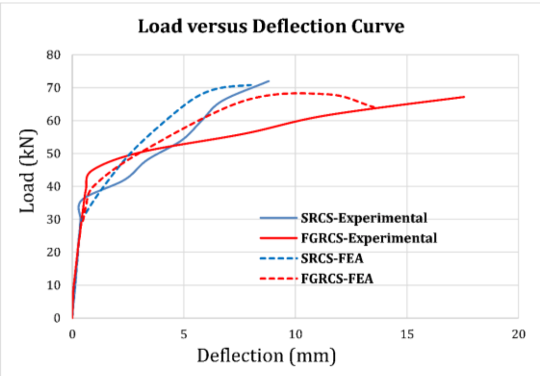

Fig .5. Load versus deflection response curve

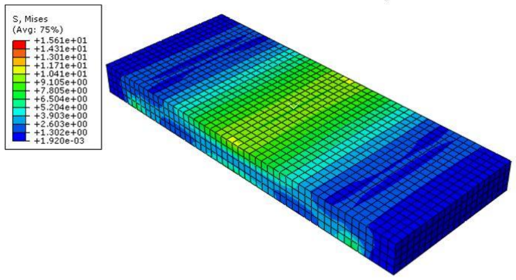

Fig .6. Stress contour of SRCS specimen

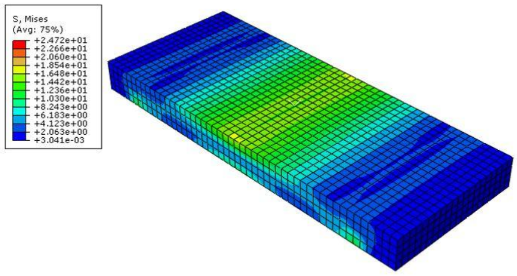

Fig .7. Stress contour of FGRCS specimen

B. Energy dissipation and Ductility properties

The area under the load deflection curve is defined as the energy dissipation property. The ratio of ultimate deflection to yield deflection is defined as ductility. The properties of energy dissipation and ductility are important to validate the structural element for its inelastic response under the load. Figure 8 shows the cumulative energy dissipation curve. The experimental results of the energy dissipation and ductility properties are seen in Table 2. FGRCS specimens behaved well as SRCS specimens in their energy dissipation and ductility properties. The yield of energy dissipation and ultimate energy dissipation of the FGRCS specimen was increased by 2.12 and 2.16 times the SRCS specimen. The ductility of the FGRCS specimens increased by 47% compared to the SRCS specimens. This showed that the inelastic performance of the FGRCS specimen was better than that of the SRCS specimen. This is evident from the fact that the GFRP and geogrid polymer combinations can be used to replace the steel reinforcement.

Table-I Results of Load and Displacement

	Experimental Results				FEA Results			
Specimen	**Yield load (kN)**	**Yield Displacement (mm)**	**Ultimate load (kN)**	**Ultimate Displacement (mm)**	**Yield load (kN)**	**Yield Displacement (mm)**	**Ultimate load (kN)**	**Ultimate Displacement (mm)**
SRCS	21.00	0.25	72.00	8.80	20.00	0.27	70.80	8.00
FGRCS	25.20	0.34	67.20	17.56	22.40	0.28	64.10	13.50

Table-II Energy Dissipation, Ductility and Stiffness properties

Specimen	**Yield energy absorption (kN mm)**	**Ultimate energy absorption (kN mm)**	**Ductility**	**Stiffness (kN/m)**
SRCS	2.46	459.10	35.20	3.43
FGRCS	5.21	989.88	51.83	2.67

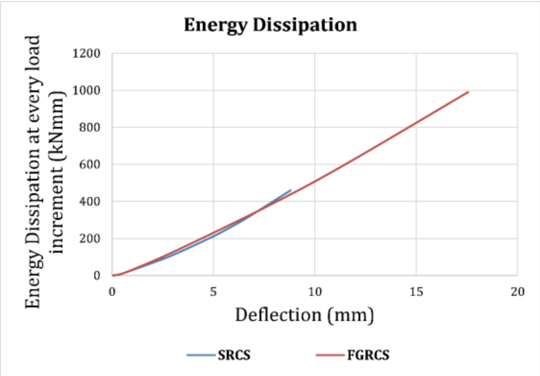

Fig .8. Energy dissipation curve

C. Stiffness properties

The stiffness is defined as the ratio of the load to the corresponding deflection at any point of loading. The stiffness parameter helps to validate the rigidity of the specimen at the loading stage. The stiffness parameter is shown in Table 2. The stiffness degradation curve for different specimens is shown in Figure 9. From Figure 9, the initial stiffness of the SRCS and FGRCS specimens is 100.2 N / mm and 180.25 N / mm respectively. This showed that the FGRCS specimens behaved in initial stiffness by 80 per cent higher than the SRCS specimen. The ultimate stiffness of Figure 9 for the SRCS and FGRCS specimens is 8.18 N / mm and 3.83 N / mm respectively. The yield and final stiffness of the FGRCS specimen was 22 percent and 114 percent lower than that of the SRCS specimens. This showed that the FGRCS specimen showed enhanced behavior up to the yield stage and after the yield stage, the degradation of stiffness was remarkably higher than the SRCS specimen.

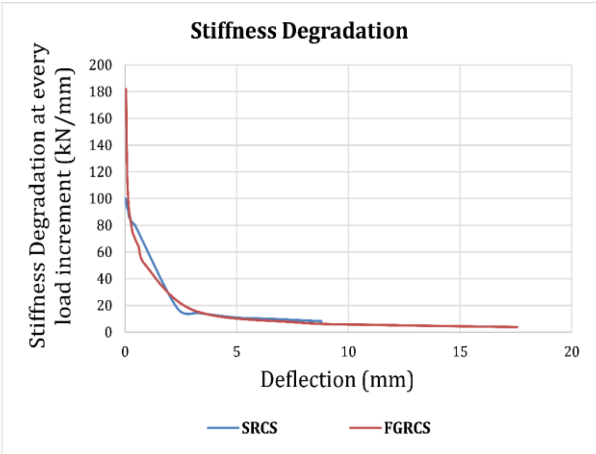

Fig .9. Stiffness Degradation curve

V. CONCLUSION

Flexural patch loading tests on two RC slab specimens were carried out and presented in this paper. In order to validate the experimental results, a finite element analysis was performed using Abaqus software to predict the load displacement response of the RC slab specimens. The following conclusion was drawn on the basis of experimental and analytical results.

1) The results of the finite element analysis showed considerable agreement with the experimental results. There was a greater discrepancy in deflection was found than the loading properties due to the limitation of the bonding characteristics between the polymer surfaces to the concrete.

2) The stiffness properties of the FGRCS specimen showed a great improvement in the yield stage, resulting in a good load carrying capacity at the yield stage. However, the stiffness degradation was increased beyond the yield stage, resulting in a reduction in the ultimate load carrying capacity of the FGRCS specimen.

3) The deflection properties of the FGRCS specimen have

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been improved in yield and ultimate stages. This improved the ductility of the FGRCS specimens.

4) The energy dissipation of FGRCS specimen increased at all stages of loading due to the high elastic behavior of the FGRCS specimen compared to the SRCS specimen.

The above results show that the replacement of GFRP and geogrid polymer for steel reinforcement significantly improves structural properties such as load capacity, energy dissipation and ductility.

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