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FLEXURAL STRENGTH OF TWO-WAY RC SLABS RETROFITTED WITH BASALT FIBER REINFORCED POLYMER (BFRP)

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ABSTRACT

Many older structures are in the need of strengthening the existing civil engineered infrastructure. The reasons are deterioration by ageing or corrosion caused by environmental factors, increase in the load because of changes in the functioning of the structure or poor design which does not meet the current limit state design requirements such as in dynamic loading scenario. The most practical solutions for retrofitting are often those that minimize the risk of structural collapse which can be done by upgrading selected critical structural components. Usage of fiber-reinforced polymer (FRP) reinforcement in structural engineering has getting more attention because of high tensile strength, light weight and non-corrosive property and many more advantages of it. As a new type of FRP material, Basalt Fiber Reinforced polymer (BFRP) have been receiving great attention in civil infrastructure, due to their excellent mechanical and chemical properties and its low price. BFRP is a new innovative material with high-tech inorganic fiber structure and functional material which in turn is a typical energy saving FRP. BFRP is the only FRP, which is inorganic with high tensile strength. The experimental work was conducted on slabs to study the effect of BFRP on flexural behavior of the slabs under the static loads, using cross wrapping technique. The BFRP was to be introduced to slabs in the form of cross wrapping at flexural zone by wet lay-up technique. Control slabs were casted and tested after 28 days under uniformly distributed loading case. Strengthened slabs were tested after 6 days of strengthening. From the experimental results it was revealed that the initial crack strength and ultimate load strength of retrofitted slabs are found to be increasing by at least 40% comparatively and stiffness of wrapping slabs are found to be increase.

KEYWORDS: BFRP, FRP, Rehabilitation, Static loading, Strengthening, Wrapping.

INTRODUCTION

Many structures are in the need of strengthening the existing civil engineer infrastructure. The reasons are deterioration by ageing or corrosion caused by environmental factors, load increase because of change of function in the structure or poor design which does not meet the current more strict design requirements such as in earthquake areas. Strengthening or retrofitting of older structures to resist higher loads and to increase ductility. A slab is a flat two dimensional planar structural element having thickness small compared to its other two dimensions. Reinforced concrete slabs are among the most commonly used structural elements. Basalt fiber (BFRP) is a new material in civil engineering compared to carbon, glass and aramid and has shown to be a promising material for infrastructure strengthening. The fibers are made from basalt rocks through melting process and contain no other additives in the manufacturing process which makes advantages in cost. Basalt fibers show comparable mechanical properties to glass fibers at lower cost and exhibit good resistance to chemical and high temperature exposure.

MATERIALS AND METHODS

Material:

Basalt is a natural, hard, dense, dark brown to black volcanic igneous rock originating at a depth of hundreds of kilometers beneath the earth and reaching the surface as molten magma. It will not undergo any toxic reaction with water or air such that no pollution of environment will happen.. The main functions of the fibers are to carry the load and provide stiffness, strength, thermal stability and other structural properties in the BFRP. BFRP has a higher strength and modulus, a similar cost, and more chemical stability compared with E-glass FRP; a wider range of working temperatures and much lower cost than carbon FRP (CFRP).

Figure 1: Stress-strain relationship of different FRP with introduction of BFRP

Table 1:Mechanical properties of different types of fibers

Fiber	Tensile strength (Mpa)	Modulus of elasticity (Gpa)	Ultimate tensile strain (%)
Carbon	1720-4500	120-580	0.5-2.1
Aramid	2600-3580	124-150	2.1-2.4
Glass	480-1600	35-51	2.0-3.5
Basalt	1300-2500	50-110	1.2-3.15

Table 2: Properties of UD Basalt fabric (BAS UNI 230)

Properties	UD Basalt Fabric (BAS UNI 230)
Fiber orientation	Uni-directional
Weight of fiber (g/m^2)	230
Fiber thickness (mm)	0.100

Ultimate elongation (percentage)	2.6
Primary fiber tensile strength (Mpa)	2100
Tensile modulus (Gpa)	105

Methodology:

FRP wrapping technique: FRP was wrapped on the tension side of the slab using the cross wrapping technique. In the cross wrapping technique, BFRP sheets were bonded onto the tension side of the slab at the mid section sparing one fourth span at the supports in a cross type manner. Since the fibers BFRP sheets were unidirectional, the sheets were bonded along the longitudinal as well as the transverse direction. In the case of cross wrapping technique, the FRP sheets were cut in to the desired width and bonded along the longitudinal and transverse directions.

Figure 2: Externally bonded BFRP sheets, Compacted concrete, Curing of slab using gunny bags

Application of BFRP Sheets to Concrete Slab: The FRP system included surface preparation and FRP application.

The surface preparation includes cleaning the surface thoroughly by sand paper and dusting, the cleaned surface must be dust free before the application of the primer. A thin layer of epoxy primer is applied onto the concrete surface using a paint brush. After the epoxy primer is applied onto the concrete surface it was cured for 24 hours. The FRP application includes a resin system made of two parts namely the resin and the hardener and the fiber sheets. The components of the resin system is applied an hour before the fiber sheets were installed.

The components of the resin system are thoroughly hand mixed for at least five minutes. The concrete surface was cleaned and completely dried before the resin is applied. A first coat of thin layer of resin was applied and the FRP fabric precut to the desired dimension was then wrapped directly onto the surface. Special attention was taken to ensure that there was no void between the FRP sheet and the concrete surface. After the application of the FRP sheet wrap, a second layer of resin was applied to the surface to allow impregnation. The second layer of FRP sheet was then impregnated on top of the first layer. Adequate pressure was applied until the resin was squeezed out. The wrapped specimen were left at room temperature to allow air curing for seven days to allow bonding of the laminates as suggested by the manufacturer.

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Figure 3: Application of BFRP Sheets

Experimental Setup:
The experimental study was conducted to test the reinforced concrete slabs. This included testing a control slab and retrofitted slabs. The main objective of the investigation was to study the flexural behavior of concrete slabs retrofitted with BFRP sheets bonded onto the flexural zone of the slab. A series of three slabs were tested. The test specimens i.e., reduced scale model slabs were designed as two way slabs of 1070 mm x 1070 mm with a thickness of 90 mm and tested under uniformly distributed load. 8 mm diameter was provided along the two directions.

Test specimens were subjected to flexural test. The same testing program was applied to both controlled as well as retrofitted slabs. The specimen was also painted with lime wash in order to easily note the crack pattern of the specimen. The setup was carried out with a 25 ton loading frame, a loading jack was fixed on top of the specimen to apply load. To give the udl effect to the slab, loading channels were used such that the loads that were centrally applied were uniformly distributed on the slab as shown in figure 4. The deflection at the bottom of the slab was measured using dial gauge. Totally five dial gauge's were used for this experiment. The placement of these dial gauges are as one at the centre of the slab and other four at different points as shown in the figure 4.

The load was applied using a hand held lever with uniform increment up to the failure load. The dial gauge readings were noted down to calculate the deflection of the slab. The load was incremented manually and the readings of the dial gauge were taken at an interval of 2kN. The results and the graphs are discussed separately. The deflection was tabulated at each increment of loading. Also the complete crack patterns and the failure load were recorded in each test.

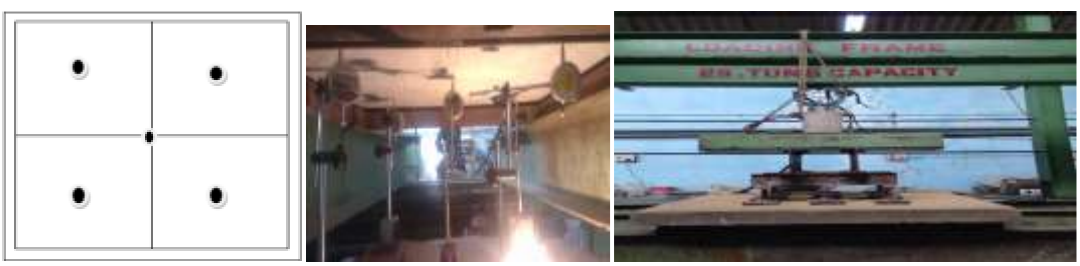

Figure 4: Layout and positioning of dial guages, Test setup

RESULTS AND DISCUSSION

Figure 5: Crack pattern of control slab and retrofitted slab, Mode of failure: De-bonding of BFRP

For the control slab the deflection was measured at the mid span and other four points. The load-deflection curve has been plotted for the same. Slabs which were retrofitted with BFRP sheets using cross wrapping technique have been subjected to uniformly distributed load and the deflection was measured up to the failure load. The load v/s deflection curves have been plotted at the mid span and other four deflections in the same graph for each of these cases.

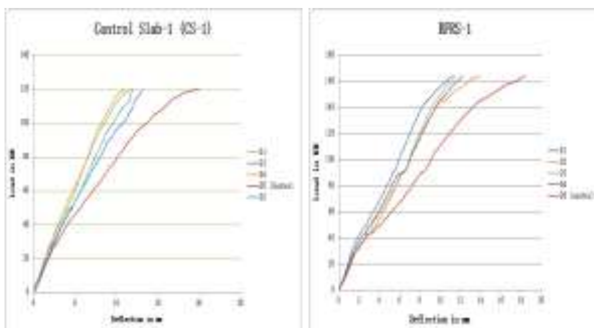

Figure 6: Load v/s Deflection Curves for Control Slab and retrofitted slab

Table 3:Comparison of experimental results

Type of slab	**Type of wrapping**	**Failure load (kN)**	**% Variation**
Control slab	-	120	-
Basalt fibre retrofitted slab	Cross type wrapping	164	36.67%
Basalt fibre retrofitted slab	Cross type wrapping	172	43.34%

CONCLUSION

This experimental study investigate the cross type BFRP wrapping effect on ultimate load carrying capacity, deflection and stiffness of slabs compared with control slab.

1. All the two-way RC slabs strengthened with BFRP in single layer were capable to take more load than the slab without strengthening (control slab).

2. The two-way RC slabs strengthened using BFRP with cross wrap technique were found to be more efficient and the load carrying capacity was increased about 40 % as compared to the control slab.

3. The cross wrapping technique introduced in retrofitting using BFRP fabric increased the load carrying capacity of slabs very effectively (around 40% increase).

Scope for further studies:

1. The BFRP retrofitted slab specimens were analyzed under static loading conditions, they can be further analyzed under dynamic loading conditions and their behavior can be studied.

2. Higher grade of concrete and the different reinforcement percent can be selected to study to effectiveness of confinement in high strength concrete.

3. The directions for the placement of the fibers on slab section can be varied such as, 30°, 45°, and 60° etc and then the behavior can be studied.

4. The analysis can be made by varying the percentage of the fiber.

5. Different wrapping technique using BFRP can be studied.

6. The analysis can be done by increasing the number of BFRP layers.

7. Analytical work carried out using software.

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