Development of empirical relation for moment capacity of a concrete Prototype Bridge Deck slab reinforced with GFRP Rebars and jute Fibres.

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***Abstract*: Novel and innovative ideas are introduced in construction industry because the requirements from structure increase day by day. Enhancing strength characteristics of concrete has been a practice for long. Bridge deck slabs are exposed to heavy moving loads so cracking presents huge issue as they increase water percolation and enhances the probability of corrosion of steel reinforcing bars and the moment capacity of section reduces. This paper reveals a study to develop the equation to predict moment capacity of concrete slab reinforced with GFRP rebars and jute fibres. An experimental and analytical investigation is carried out on a prototype concrete deck Slab with a width 225mm, length 450mm and 75mm thick. Existing methods for the calculation of bending moment do not incorporate Fibres and GFRP rebars so an empirical relationship is developed based on rational concepts. The proposed equation for bending moment has two parts, the first one is the moment capacity of GFRP reinforced section and other one is moment resulting from fibre in the section. The developed model matches well with the experimental results.**

***Keywords*: Bending moment capacity, Concrete deck slabs, GFRP, Jute**

I. INTRODUCTION

Historically transportation departments face substantial maintenance cost because of repair or replacement of decks deteriorated from cracking and rusting. As bridges degrade from environmental effects and aging the joints that were designed to rotate or move longitudinally become static. In this way expected load transfer mechanism of reaction and forces internally changes which initiates cracking. Cracking leads to the penetration of water to reinforcement bars that get rusted. And area loss occurs that means loss in flexural moment capacity of the deck slab section. [1]. Concrete is very good in compression but behaves very poor under tensile loading. Steel reinforcement bars are added to the concrete to improve tensile resistance and make fracture ductile. However, Decades of research has demonstrated that because of corrosion less Properties the GFRP rebars are a better alternative [2]-[3]. There are many other benefits of GFRP bars as low self-weight and high tensile strength. Many codes and design guides have been developed for the design of FRP reinforced structures [4]-[9].

The elastic modulus of GFRP bars is very low as compared to steel. Bars generally used have modulus of elasticity around 35 to 50 GPa. This low elasticity modulus encourages high deflections and in turn results in development of cracks in structure reinforced with FRP bars. Therefore, crack width and deflection must be checked for serviceability limits. In addition, GFRP bars have a linear perfect elastic behavior in tensile test upto failure. Whereas, steel behaves elastically till yield and after that has an inelastic behavior. Since the linear elastic behavior of GFRP structures fail in brittle manner and ductility or warning before failure that is present in steel reinforced structures.

In order to cover this lack of deformability and ductility Fiber reinforced concrete is preferred with GFRP rebars. Research is found for the use of steel and synthetic fiber in concrete [10]. It is well recognized that the inclusion of steel fiber in concrete improves the mechanical properties of structure. Steel fibers increase toughness, durability and also control the development and growth of cracks [9]. Many researchers have confirmed that the addition of steel fiber enhances the ductility of over-reinforced steel reinforced beams and high-strength steel reinforced beams [11]-[12]. Different design approaches have been used for sections of concrete reinforced with GFRP rebars. Prime reason for development of different methods of design is because of different physical and mechanical properties of GFRP from steel. For the FRP reinforced concrete sections, rupture of FRP becomes the leading failure mode. And the extreme compression fiber may not attain compressive strain at the extreme compression fiber of concrete might not reach ultimate concrete strain. Once the tensile strain of FRP reaches the rupture strain, FRP no longer develops tensile resistance and the beam section fails catastrophically. The stage of concrete crushing is unattainable. On the contrary, in a steel reinforced concrete section concrete crushing, is attainable. This is the most significant difference in failure mechanism between FRP reinforced section and steel reinforced section. [13] Implemented this rationale and investigated new parameters of equivalent stress block and developed a simple equation for moment capacity evaluation for concrete reinforced with GFRP rebars given below.

$$M_n = A_f \; x \; f_{fu} \left(d - \frac{\beta_1 c_b}{2} \right) \; Eq. 1$$

$$c_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{fu}} . d \; Eq. 2$$

Where A_f is the area of GFRP rebars, f_{fu} is the Design tensile strength of GFRP rebars, d is effective depth, c_b is depth of compression zone at balanced strain condition; ε_c ultimate tensile strain of concrete; and ε_f ultimate tensile strain of FRP.

In this study, prototype concrete bridge deck slabs are studied. Slabs have GFRP bars as longitudinal and transverse reinforcements. Jute fiber is also introduced in the concrete matrix to enhance the ductility and crack control. An empirical model is developed by using experimental result and past researches to compute moment capacity of slabs. Proposed model takes into account the role of Jute fiber along with the GFRP bars.

II. MATERIALS & METHODS

A. Test Specimen

A slab of Jute Reinforced concrete of 450mm x 225mm x 75mm is casted. Slab has a single layer of (3-Ø2) GFRP bars as longitudinal reinforcement and as transverse reinforcement Ø2 bars have been provided at a spacing of 76mm.

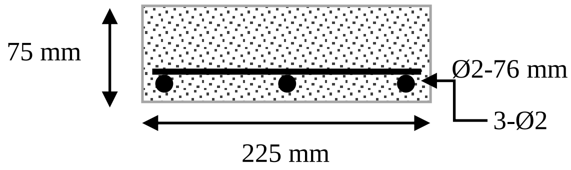


Fig. 1 Specimen Details

B. Materials

For the preparation of specimen slab, lawrencepur coarse aggregate, sand, ordinary Portland cement, fresh water, jute fibers and GFRP rebars are used. Jute fibers are available in a raw form which are prepared by hand at the rate of 50mm length. Properties of jute fibers [14] can be seen in Table 1. Chemical constituents of jute fiber are cellulose, lignin, fat, wax, water soluble materials [15]. These chemical (cellulose, wax, and lignin) can be a reason of weak connection between jute fiber and concrete mix. A simple pre-treatment is adopted in which jute fibers are soaked in water to remove dust and wax content inside water tank for approximately half an hour. After that the jute fiber is brought out of water and air dried. Prepared and hand cut length of Jute fibers are shown in Fig. 2.

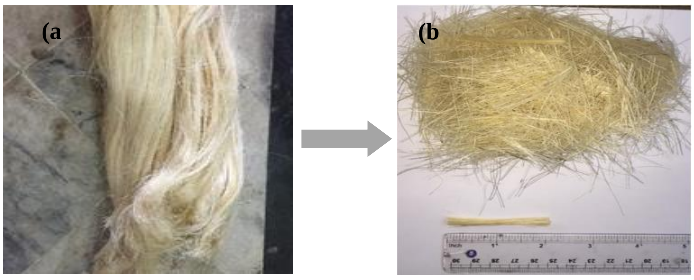


Fig. 2 Jute Fibers, a) Raw fiber, b) Dispersed Fiber

GFRP rebars have 6mm diameter and 400mm length (Fig.3). Physical Properties are determined experimentally (Table 1). The Tensile strength and ultimate tensile strain of glass fiber reinforced polymer rebar is 896 MPa and 1.94% respectively whereas density is 2200 kg/m3.

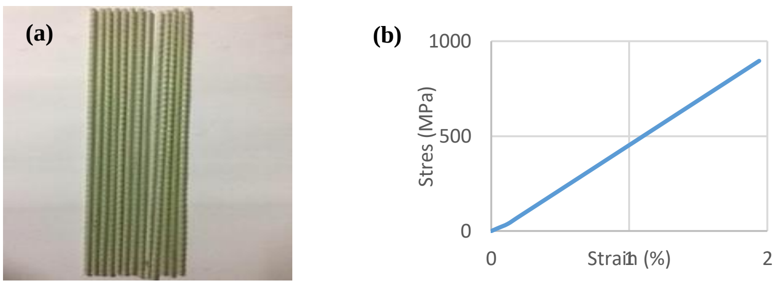


Fig. 3 GFRP rebar, a) cut length of bar, b) Tensile stress strain curve

Table 1 Mechanical properties of Glass Reinforced polymer Rebars and Jute Fibers

Dimension	Jute Fibers	GFRP bars	Unit
Density	1340	2200	kg/m3
Tensile Strength	310	896	MPa
Elastic Modulus	48	46	GPa
Ultimate tensile strain	0.72	1.94	%

Mix design ratio 1:2:3:0.70 is used with 0.5 cm long jute fibers with a fiber content of 5% by mass of cement for preparing JFRC (Table 2)

Table 2 Mix design proportion Jute Reinforced Concrete (JFRC) (1:2:3:0.7:0.05) for kg/m3

Material	Cement	Fine aggregate	Coarse Agg.	Water	Jute Fiber
JFRC	351.5	703	1054.5	246.06	18.5

Mechanical properties of concrete are determined by casting cylinders of 100mm diameter and 200 mm length. Flexural strength is determined by using prisms of 100 x 100 x 450 mm.

Table 3 Mechanical Properties of Concrete

Material	Compressive strength (MPa)	Split Tensile strength (MPa)	Flexural strength (MPa)
JFRC	20.31±0.2	2.67±0.2	8.27±0.2

C. Test Setup

ASTM C78 has been used to determine the flexural strength, energy absorption and toughness index of the slab. Loading rate of 3.3 kN/s is applied by a servo-hydro testing machine. Schematic testing setup is shown in Fig. 4.

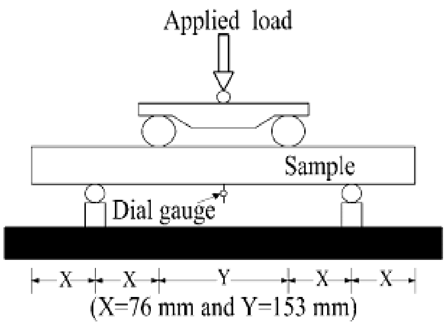


Fig. 4 Schematic sketch for testing prototype slabs

D. Analytical Modelling

In present research GFRP rebars have been used as longitudinal and shear reinforcement also Jute fibers have been used to cover the deformability, ductility and cracking issues. Moment capacity of concrete section reinforced with GFRP in plain concrete can be determined by using Urgessa et al. approach. To consider the effect of fiber in the concrete on the moment capacity of a section a model needs to be developed.

In 1930s, Whitney (1937) proposed the use of rectangular compressive stress distribution to replace the parabolic stress distribution. An average stress of 0.85f'c is used with the rectangular depth of a = β1c. Concrete below the neutral axis is ignored and total tension T is due to Reinforcing bars. Whitney's equation takes plain concrete reinforced with steel rebars in to

Consideration. In Whitney's stress block concrete strength in tension zone is neglected. That is true for normal concrete. But, for concrete reinforced with fiber in tension zone concrete does show tensile capacity. Beshara et al (2012) introduced a concept of inclusion of fiber on the moment capacity of concrete section and the enhancement in compressive strength due to fibers inclusion is proposed as a function of concrete matrix strength and fiber reinforcing index Fiber in the concrete make the effective stress distribution better as compared to plain concrete [16]. By simple assumptions Beshara provided the nominal moment capacity equation for fiber reinforced concrete with steel reinforcement as follows

$$M_r = T_s\left(d - \frac{a}{2}\right) + T_f\left(\left(t - \frac{t_f}{2}\right) - \frac{a}{2}\right)\ Eq.3$$

$$T_f = 1.64\, V_f\left(\frac{L_f}{\O_f}\right) b.t_f\ \mathrm{Eq.4}$$

Where

t=Total depth of Slab, t_f=Effective height of equivalent stress of fiber reinforced concrete in tension region, T_f=Tensile force of fiber reinforced concrete, V_f=Volume Fraction of fiber used in concrete, L_f=Length of fiber used in concrete, $\O_f$=Diameter of fiber used in concrete.

But in the present study an easier approach by [17] is used to determine the tensile force in jute fiber that is $T_f = \frac{P_{mf} - P_{mc}}{2}$ where P_{mf} and P_{mc} are maximum flexural load taken by the JFRC and PC. This can be explained by the concept that the concrete mix in the PC and JFRC are the same so the additional load taken by JFRC can be associated to the presence of Jute fiber in it. PC at peak load starts cracking and section is reduced supporting lesser loads whereas in JFRC these cracks are bridged to a higher load therefore takes more load

In eq. 3 $T_s\left(d-\frac{a}{2}\right)$ deals with the moment capacity from the steel rebars and $T_f\left(\left(t-\frac{t_f}{2}\right)-\frac{a}{2}\right)$ this caters the moment capacity by the presence of fibers. Taking this and Urgessa's approach in background we develop a model as follows

$$M_r = A_f \; x \; f_{fu}\left(d-\frac{\beta_1 c_b}{2}\right)+T_f\left(\left(t-\frac{t_f}{2}\right)-\frac{a}{2}\right) \; Eq.5$$

Basic Assumptions of the method

- Plane section remains plane even after bending, and therefore the strain distribution is linear
- Perfect bond is considered between GFRP and Concrete that means strain at any level in the concrete is same as strain in the GFRP reinforcement [16]
- It is supposed that concrete will start crushing once its strain raised to 0.003 [9].

III. RESULTS

The results of the flexural test of slab are shown in Table 4. From the failure of the slab (Fig. 5a) it can be seen that the crack starts from almost mid span and it is vertical. As soon as load was incremented the crack width increased. After the formation of flexural cracks around the mid-span, new vertical cracks began propagating closer to the supports as the load increased. During the formation of these new cracks, already formed cracks around the mid-span continued to propagate throughout the height of the slab, close to the compressive zone. Also, the already formed cracks began to widen, right beneath the loading point. At the point of failure, the GFRP reinforcement bars ruptured at the region of maximum bending moment. This caused the flexural cracks around the mid-span to widen significantly, causing concrete cover to spall off in tension.

Table 4 Flexural strength and energy absorption parameters of specimen slab

Flexural Strength (kN)	Ultimate Load (kN)	F.EI (J)	F.E.M (J)	F.E.P (J)	F.E (J)	F.T.I (-)
26.7	13.5	9.33	190.67	149.68	349.68	37.48

Energy absorption capacities of the slabs were calculated using numerical integration of load-midspan deflection graph (Fig 5b). The space beneath load deflection curve from F.E1 to max load (F.E.M) is noted as energy absorption. The F.E.P of JFRC is more than PC samples. The entire area under curve is sum of F.E1, F.E.P, and F.E.M is derived as entire F.E.

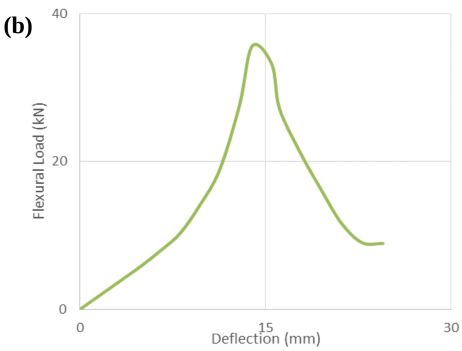
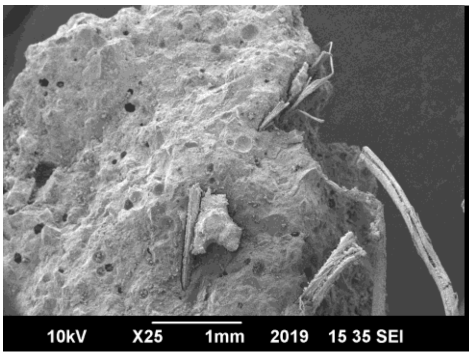


Fig. 5 a) Tested Specimen, b) Load Deflection curve of specimen

At the initiation of crack, effect of jute fiber could be seen as they tried to bridge the cracks. This can also be observed in the SEM image at failure surface (Fig.6). Broken jute fibers at the failure surface prove a good bond of the fibers with concrete matrix. This brittle behavior follows in the line of previous studies.



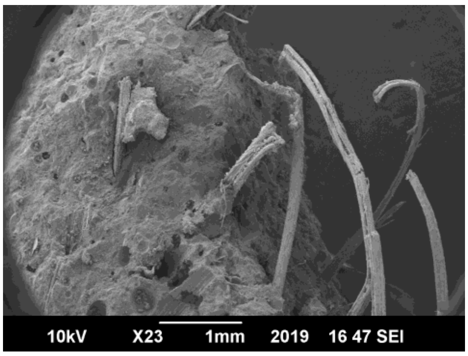


Fig. 6 SEM Images

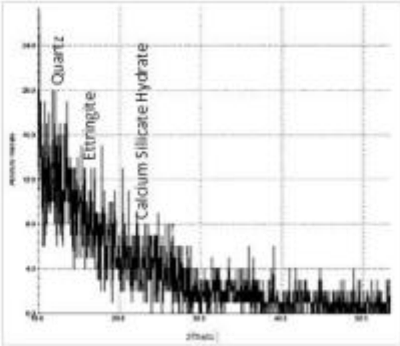


Fig. 7 XRD analysis of JFRC

The 2theta values are presented on x-axis ranging from 10° to 50° and absolute intensity values on y-axis from 0 to 240 for JFRC. XRD (Fig confirms the finding that Ettringite structure increases by adding Jute in the concrete mix. Also quartz has a proportion higher in JFC than PC.

Result from the experimental evaluation has been shown in Fig. 4 as well as theoretically analyzed values have also been plotted. The results show that Experimental value of moment capacity is more than Urgessa et al method. This is because in the Urgessa et al. method no consideration has been given to strength of fiber in concrete. In the modified model presented above value of moment capacity is 6.5% less than the experimental value.

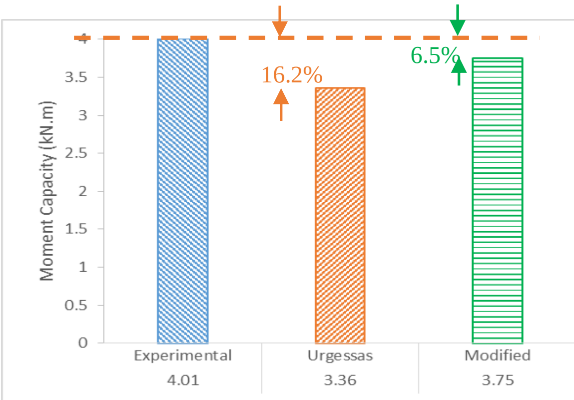


Fig. 8 Comparison of moment capacities.

This difference may be reasoned that an easier empirical approach is used in computations of T_f. Instead of using 0.5 x (P_{mf}-P_{mc}) 0.53 factor can be used with the difference term.

$$T_f = 0.53 \text{ x } (P_{mf} - P_{mc}) Eq. 6$$

By using this factor the value from model approximately matches the experimental value.

IV. CONCLUSIONS

In this paper and empirical model is developed by using the set of values from experimental work. And, considering previous works by various researchers to compute the moment capacity of slab section with GFRP in Jute fiber reinforced concrete.

- The results show that Experimental value of moment capacity is more than Urgessa et al method
- In the modified model proposed the .

By Introduction of the factor σ moment capacity from the proposed model approximately matches the experimental value.

V. RECOMMENDATIONS

- Validation of the proposed approach to compute force T_f in is recommended
- The combination of other FRP bars i.e. CFRP and different natural fibers can be studied.

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