

Experimental investigation on the shear strength of concrete beams longitudinally reinforced with GFRP bars

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ABSTRACT

The model originally proposed by IS: 456(2000) for the prediction of shear strength of concrete beams longitudinally reinforced with steel bars depends on the longitudinal reinforcement ratio and is independent of the characteristics of longitudinal bars used in concrete beams. Hence in this paper, an attempt has been made to investigate the efficacy of using IS: 456(2000) to predict the shear strength of concrete beams longitudinally reinforced with GFRP bars. In this study, eight concrete beams longitudinally reinforced with GFRP bars without stirrups were cast and tested over shear span to depth ratio between 0.5 and 1.75. The variables of experimental program are shear span to depth (a/d) ratio, longitudinal reinforcement ratio (ρ_t) and cross section of the beam. The experimental shear strength observed for these eight test beams are compared with the corresponding predicted shear strength using the model given in IS: 456(2000). The mean of experimental shear strength to the predicted shear strength based on IS: 456(2000) is found to be 1.18 with a standard deviation of 0.09 and reveals the better fit of the model by IS: 456(2000) to predict the shear strength of concrete beams reinforced with GFRP bars.

Keywords – beam, concrete, GFRP, prediction, shear strength

I. INTRODUCTION

Deterioration of reinforced concrete structures has become a serious problem in the last decades due to the corrosion of steel bars. An alternative type of reinforcement as fiber-reinforced polymers (FRP) is considered to be one of the solutions for the corrosion problem. During the last decade serious efforts were made to use FRP materials in construction industry. Behaviour and strength of concrete members depend primarily on the characteristics of concrete and reinforcement. Shear strength of concrete members is influenced by important parameters which significantly affect the design and structural detailing. Extensive studies have been reported for the shear strength of members reinforced with steel; however limited studies were made for shear strength of beams reinforced with FRP bars. This paper provides an experimental investigation to evaluate the shear strength of beams reinforced with longitudinal FRP bars without shear reinforcement.

Most of the current design provisions to compute the shear resistance of reinforced concrete members reinforced with FRP rebars follow an approach similar to that for the steel reinforced concrete members. Bank [1] reports that the models proposed by JSCE [2], BISE [3] CNR-DT 203 NRC [4], ACI 440.1R [5], ISIS-M03 [6] and CAN/CSA S806 [7]

for the prediction of shear strength of concrete beams reinforced with FRP bars are by modifying the models originally proposed for steel reinforced concrete beams. This can be attributed to the fact that the mechanism of load transfer in steel reinforced beams and FRP reinforced beam are similar and is proposed in Guadagnini et al.[8].

However, at present no Indian standard code is available to predict the shear strength of concrete beams reinforced with FRP bars. Currently Indian Standard code of practice IS: 456 [9] for plain and reinforced concrete have been used for the prediction of shear strength of concrete beams reinforced with steel bars only. The model originally proposed by IS: 456 [9] for the prediction of shear strength of concrete beams longitudinally reinforced with steel bars depends on the longitudinal reinforcement ratio and is independent of the characteristics of longitudinal bars used in concrete beams. Hence in this paper, an attempt has been made to investigate the efficacy of using IS: 456 [9] to predict the shear strength of concrete beams longitudinally reinforced with GFRP bars.

II. RESEARCH SIGNIFICANCE

In order to expand the use of FRP in new structures, a satisfactory degree of understanding is required for the behaviour of members reinforced

with FRP rebars. The aim of the current study is to investigate the concrete contribution to shear strength for beams reinforced with FRP longitudinal bars. The model originally proposed by IS: 456 [9] for the prediction of shear strength of concrete beams reinforced with steel bars is considered to predict the shear strength of FRP reinforced concrete beams without stirrups. This paper addresses how far the use of existing Indian code of practice IS: 456 [9] originally meant for the prediction of shear strength of concrete beams will help to predict the shear strength of concrete beams reinforced with FRP bars.

As no model has been proposed in any of the Indian codes of practices for the prediction of shear strength of concrete beams reinforced with FRP bars, an investigation is made in this paper to address the suitability of using IS:456 [9] to predict the shear strength of concrete beams reinforced with FRP bars. In this paper the shear strength of concrete beams reinforced with FRP bars is experimentally found out and compared with the corresponding predicted shear strength using IS:456 [9]. In addition, in the light of the experimental results, an attempt is made to assess the validity of using the IS: 456 [9] contribution of the shear resistance components to the ultimate shear resistance of the FRP reinforced concrete sections. The observation on the mean of ratio of experimental shear strength to predicted shear strength based on IS: 456[9] is presented.

III. PREDICTION MODEL FOR SHEAR STRENGTH

The model originally proposed for prediction of shear strength of concrete beams longitudinally reinforced with steel reinforcement by IS: 456 [9] is accounted to predict the shear strength of concrete beams reinforced with FRP bars. The shear strength of concrete V_c is given by

$$V_c = k_1 \tau_c bd \quad (1)$$

where k_1 is the shear enhancement factor accounting for the arch action in beams. τ_c is the average permissible shear stress of concrete beam. b and d are the width and depth of the beam cross section. k_1 in Eq. (1) is given by

$$k_1 = \begin{cases} 2.0d/a & ; \text{when } a/d \leq 2.0 \\ 1.0 & ; \text{when } a/d \geq 2.0 \end{cases} \quad (2)$$

The factor k_1 accounts for the load sustenance by arch action.

τ_c proposed by SP: 24 [10] is used and is given by

$$\tau_c = \frac{0.85\sqrt{0.8f_{ck}}(\sqrt{1+5\beta}-1)}{6\beta} \quad (3)$$

where, f_{ck} is the characteristic compressive strength of concrete and is computed by

$$f_{ck} = \frac{f'_c}{0.8} \quad (4)$$

where, f'_c is the cylinder compressive strength of concrete. β in Eq. (3) is the factor accounting for the influence of the longitudinal reinforcement and is given by

$$\beta = \frac{0.8f_{ck}}{6.89 p_t} > 1.0 \quad (5)$$

where, p_t is the longitudinal reinforcement ratio and is given by

$$p_t = \frac{100A_t}{bd} \quad (6)$$

TABLE 1 : DETAILS OF TEST BEAMS

Beam design ation	f_{ck} (MPa)	b (mm)	D (mm)	d (mm)	span (mm)	a/d	Longitudinal reinforcement			
							Bar details*	Tensile strength (MPa)	P_t (%)	E_r GPa
G6-a	65.3	170	500	416	990	0.50	6#16	655	0.35	40.8
G6-b	65.3	170	500	416	990	1.00	6#16	655	0.35	40.8
G6-1	59.5	170	500	405	1400	0.50	6#16	655	0.36	40.8
G6-2	59.5	170	500	405	1400	1.00	6#16	655	0.36	40.8
G6-3	45.3	100	350	270	1100	1.25	6#10	760	0.36	40.8
G6-4	45.3	100	350	270	1100	1.75	6#10	760	0.36	40.8
G4-1	40.6	100	350	270	1100	1.25	4#10	760	0.24	40.8
G4-2	40.6	100	350	270	1100	1.75	4#10	760	0.24	40.8

*total number of bars# diameter of bar in mm

where, A_f is the area of FRP reinforcement provided.

Based on the proposed model, the shear strength of eight concrete test beams reinforced with FRP bars is predicted. The shear strength of test beams predicted using the proposed model is compared with the corresponding test data.

IV. EXPERIMENTAL PROGRAM

An experimental test program is conducted to verify the experimental shear strength of concrete beams reinforced with GFRP bars with the corresponding predicted shear strength based on IS:456[9]. A comparison is made between the experimental results and the shear strengths calculated using IS: 456 [9]. A total of eight beams are cast and tested under four point loading by varying the shear span to depth (a/d) ratio, longitudinal reinforcement ratio, cross section and span of testing. The test beams are longitudinally reinforced with glass fibre reinforced polymer (GFRP) bars. The designation, dimensions, effective depth, longitudinal reinforcement ratio and shear span to depth (a/d) ratio of test beams are given in Table 1. The variables of the study are longitudinal reinforcement ratio and shear span to depth (a/d) ratio. The smooth and straight GFRP bars available in market are used. The longitudinal bars are anchored at the ends to avoid bond failure of the bars. The stainless steel reinforcement cages are provided at the end zone to resist the high stresses developed during loading. The length of smooth GFRP bars beyond the supports is limited to 300mm. Two GFRP bars are provided at top and number of bars at bottom is varied. The bottom longitudinal bars are externally bolted. The beams are cast and cured for 28days using moist burlap.

The beams are tested using 1000kN digital beam testing machine. The load is applied gradually. The loads at first crack and ultimate stage are recorded. The results of the GFRP reinforced beams tested over the shear span to depth ratio of 0.5 and 1.75 are presented in this paper. It is found from the literature that the experimental study on beam reinforced with FRP bars tested over shear span to depth ratio less than or equal to 1.0 is limited. Hence, eight FRP reinforced concrete beams were cast and tested. Out of the eight four were tested over a shear span to depth ratio (a/d) less than or equal to 1.0 and remaining four were tested over a/d greater than 1.0. The eight concrete beams longitudinally reinforced with glass fiber reinforced polymer (GFRP) bars are cast and tested under four-point loading. The variables of the study are shear span to depth (a/d) ratio, longitudinal reinforcement ratio, cross section and span of testing. In the initial stages

of load, the deformation is found to be gradual and linear. Cracks initiated in the shear span at mid-height of the beam, in the subsequent stages of loading. With the increase of load, formation of new cracks is observed at the tension zone in shear and flexure span of the beam. The tension zone cracks are progressed towards the compression zone. The crack near the support extended towards the loading point and lead to the formation of diagonal crack. In later stages of loading, an increase in the width of the diagonal crack is observed. The test beams failed in diagonal shear. The cracks in beam G6-1 at failure is shown in Fig.1.

V. RESULTS AND DISCUSSIONS

The load at first crack and failure in the test beams are recorded and are given in Table 2. The load carrying capacity of the GFRP beam is found to increase significantly with the decrease in shear span to depth (a/d) ratio. The increase in the load carrying capacity is attributed to the load transfer by arch action. This indicates that the shear enhancement due to arch action is important and shall be accounted for in the model for the prediction of shear strength of concrete beams reinforced with GFRP bars. The first crack load in test beam is found to be lower than fifty percent of the ultimate load. The first crack load is found to be 40 to 50 percent of ultimate load. This indicates that the cracking and failure are apart to provide sufficient warning prior to the failure of structure.

VI COMPARISON OF PREDICTION WITH EXPERIMENTAL RESULTS

The experimental shear strength of eight test beams reinforced with GFRP bars and the corresponding shear strength prediction based on IS:

TABLE 2: COMPARISON OF TEST RESULTS WITH THE PREDICTION BASED ON IS:456[9]

Beam Designation	Load at first crack (kN)	Failure load, P (kN)	$V_{c,exp}$ * (kN)	$V_{c,p}$ Eq.(1) to (6)	$\frac{V_{c,exp}}{V_{c,p}}$
G6-a	298.0	600.0	300.0	248.5	1.21
G6-b	122.4	285.0	142.5	124.3	1.15
G6-1	259.7	530.0	265.0	242.3	1.09
G6-2	109.4	255.0	127.5	121.2	1.05
G6-3	41.3	84.0	42.0	36.8	1.14
G6-4	29.0	66.0	33.0	26.3	1.25
G4-1	34.1	74.0	37.0	31.1	1.19
G4-2	20.9	60.0	30.0	22.2	1.35
Mean					1.18
Standard deviation					0.09

* $V_{c,exp} = P/2$

456[9] model are given in Table 2. The comparison of experimental shear strength with predicted shear strength based on IS:456[9] is given in Fig.2. The average of the ratio of the experimental shear strength of GFRP reinforced test beams to the predicted shear strength ($V_{c,exp}/V_{c,p}$) is found to be 1.18 and the standard deviation is 0.09 for the proposed model. This indicates that the shear strength prediction based on the proposed model is found to be in good agreement with the corresponding test data of this study.

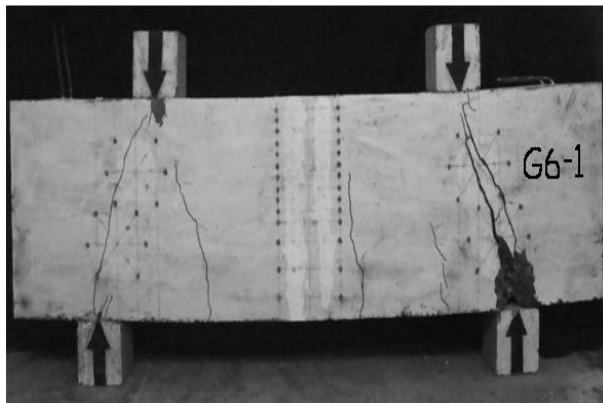


Fig 1 Crack pattern of test beam G6-1 at ultimate stage

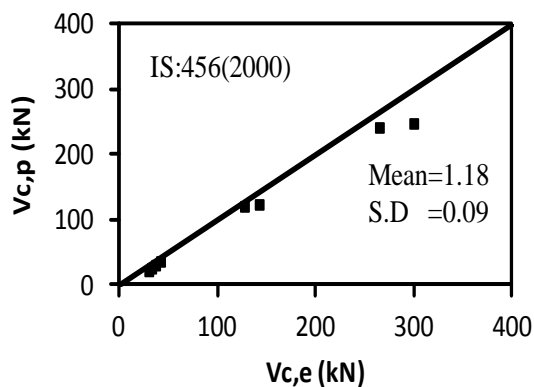


Fig 2 Comparison of experimental shear strength with predicted shear strength based on IS:456(2000)

VII. CONCLUSION

Based on the experimental and analytical study, following conclusions are arrived at.

- The shear span to depth (a/d) ratio influences the shear strength of the FRP reinforced concrete beams.
- The degradation of stiffness in the post cracking regime is significant when shear span to depth ratio is greater than 1.0. The load deflection response of test beams indicates that shear span to depth (a/d) ratio influences the behavior of GFRP reinforced concrete beams.

- The predicted shear strength of FRP reinforced concrete beam using the models proposed by IS: 456(2000) is found to be in good agreement with the corresponding experimental results.

From the experimental investigation, it is concluded that the model by IS:456[9], which is originally proposed for the prediction of shear strength of concrete beams longitudinally reinforced with steel bars is found to be suitable to predict the shear strength of concrete beams reinforced with FRP bars. However, further investigation on the model by IS: 456[9] is required for a wide range of shear span to depth ratio, longitudinal FRP reinforcement ratio and concrete compressive strength.

NOTATIONS

- a = shear span of beam, mm
- A_f = area of longitudinal tension FRP reinforcement, mm^2
- b = width of beam, mm
- d = effective depth of beam, mm
- f'_c = compressive strength of concrete, N/mm^2
- f_{ck} = characteristic compressive strength of concrete, N/mm^2
- k_1 = shear enhancement factor
- p_t = longitudinal tension reinforcement ratio
- V_c = concrete shear resistance, N
- β = longitudinal reinforcement factor
- τ_c = shear stress of concrete, N/mm^2

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