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Shear strength prediction of concrete beams reinforced with FRP bars using IS: 456-2000

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Abstract: *- Ever since the inception of Indian Standard code of practice IS: 456(2000) for Plain and Reinforced Concrete, the shear strength prediction model proposed in this code have been used for the prediction of shear strength of concrete beams reinforced with steel bars only. In this paper, an attempt has been made to understand that how far the shear strength prediction based on the model proposed by IS:456(2000) will deviate from the experimental test data of concrete beams reinforced with FRP bars. A data base of 200 concrete beams reinforced with FRP rebars without stirrups published in the literature is accounted for in this study. The model originally proposed by IS: 456(2000) for the prediction of shear strength of concrete beams reinforced with steel bars accounts for compressive strength of concrete, longitudinal reinforcement ratio and shear span to depth ratio. The mean of experimental shear strength to the predicted shear strength based on IS: 456(2000) is found to be 1.59 with a standard deviation of 0.89. The prediction based on model proposed by IS: 456(2000) is found to be conservative. The results of this study reveal that modification is required for the model by IS: 456(2000) to predict the shear strength of members with FRP bars as internal reinforcement*

Keywords: *- code of practice, concrete beam, model, shear strength, prediction, FRP rebars*

I. INTRODUCTION

FRP reinforcement is mostly preferred at places where the environment is aggressive. The severe exposure condition may result in corrosion if steel is used as internal reinforcement.FRP materials are used for various marine and bridge structures as it prevents deterioration of its structural strength due to rebar degradation. FRP bars are manufactured using high strength fibre such as glass, carbon, aramic etc. embedded in a polymer matrix material. However, before the adoption of any new reinforcement in construction, extensive research is required to enable engineers to understand its fundamental behaviour and differences with conventional reinforcement. In most of the design codes for FRP reinforced members used abroad, a modification of models originally proposed for the steel reinforced beams is suggested. It is found from the literature, Bank [1] that the shear behavior of concrete members reinforced longitudinally with FRP bars has not yet been fully explored.

Researchers have since developed new models incorporating the correlation between the axial stiffness of the reinforcement and shear capacity. Tureyen & Frosch [2] and El-Sayed et al. [3] reported that some empirically calibrated equations can apparently work well for both steel and FRP-reinforced members. Guadagninini et al. [4] pointed that the mechanism of load transfer in steel reinforced beams and FRP reinforced beam are similar. No Indian standard code is available to predict the shear strength of concrete deep beams reinforced with FRP bars. This paper address how far the use of existing Indian code of practice IS: 456(2000) [4] 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. The investigation made in this paper aims to address the necessity of introducing a suitable modification to be incorporated in IS: 456 (2000) [4] 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. In this study, the shear strength of concrete beams reinforced with FRP bars is investigated. A data base of 200 concrete beams reinforced with FRP rebars without stirrups published in the literature is accounted. The model originally proposed by IS: 456(2000) [4] 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. The observation on the mean of ratio of experimental shear strength to predicted shear strength based on IS: 456(2000) [4] is presented.

II.   RESEARCH SIGNIFICANCE

The use of FRP bars in concrete structures is sustainable choice in the structures exposed to severe environment. However, the behavior and shear strength of concrete members reinforced with FRP bars as main tensile reinforcement has not yet been fully studied. The degree of certainty of using the existing model for predicting the shear strength of steel reinforced concrete beams recommended in IS: 456 (2000) [4] for the prediction of shear strength of concrete beams reinforced with FRP bars is of utmost essential, as there are no Indian codes of practices for the prediction of shear strength of concrete beams reinforced with FRP bars. The model originally proposed by IS: 456(2000) [4] for the prediction of shear strength of concrete beams reinforced with steel bars is independent of the characteristics of steel bars used in concrete beams. Hence in this paper, an attempt has been made to understand that how far the shear strength prediction based on the model proposed by IS:456(2000) [4] will deviate from the experimental test data of concrete beams reinforced with FRP bars as internal reinforcement. The model accounts for the influence of effect of the reinforcement ratio, shear span to depth ratio and concrete compressive strength. It is expected that the existing model originally proposed for the prediction of shear strength of concrete beams with steel bars needs modification. This study would help the Indian researchers to arrive at economical sections for the design of concrete beams reinforced with FRP rebars.

III.   EXISTING MODEL FOR SHEAR STRENGTH OF CONCRETE BEAMS REINFORCED WITH STEEL BARS

The model originally proposed for the prediction of shear strength of concrete beams longitudinally reinforced with steel reinforcement by IS: 456(2000) [4] is given which accounts for the influence of steel bars and arch action. The predicted shear strength of concrete $V_{c,p}$ is given by

$$V_{c,p} = k_1 \ \tau_c bd \qquad (1)$$

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

$$k_1 = \begin{cases} 2.0\,d/a & \text{when } a/d \le 2.0 \\ 1.0 & \text{when } a/d \ge 2.0 \end{cases} \qquad (2)$$

The factor k_1 accounts for the load sustenance by arch action. τ_c proposed by SP:24 (1983) [6] is given by

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

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

$$f_{ck} = \frac{f_c'}{0.8} \qquad (4)$$

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

$$\beta = \frac{0.8 f_{ck}}{k_0 \ p_t} > 1.0 \qquad (5)$$

where p_t is the longitudinal steel reinforcement ratio and k_0 is the coefficient of longitudinal reinforcement ratio and is given by 6.89. p_t is given by

$$p_t = \frac{100 A_s}{bd} \qquad (6)$$

Where, A_s is the area of steel longitudinal reinforcement.

Table 1 Experimental Database of Test Specimens

Reference	Number of beams	Type of FRP rebars	Variables of study				
			f_{ck} (MPa)	b (mm)	d (mm)	a/d	p_t (%)
Farghaly & Benmokrane [7]	2	GFRP	61.6	300	1088-1097	1.14-1.15	0.16-0.32
	2	CFRP	48.4	300	1106-1111	1.13	0.16-0.33
El-sayed et al.[8]	4	CFRP	49.2	250	326	1.30-1.69	0.50-1.09
	4	GFRP	50.6	250	326	1.30-1.69	0.16-0.34
Razaqpur et al.[9]	6	CFRP	65.3	300	200-400	3.5-6.0	0.15-0.19
Zeidan et al.[10]	4	CFRP	30-61.3	150	280	2.5-5.0	0.11-0.21
Bentz et al.[11]	6	GFRP	43.7-57.5	450	188-937	3.26-4.05	0.09-0.45
Thomas[12]	14	GFRP	28.1-65.3	170	270-416	0.5-1.75	0.22-0.35
Nehdi et al.[13]	7	GFRP	44.0-60.0	150	150-350	1.36-2.33	0.25-0.44
	8	CFRP	43.3-78.8	150	150-350	1.36-2.33	0.72-1.44
Thomas[14]	4	GFRP	68.7-69.3	100	550	0.36	0.07-0.27
Ashour [15]	6	GFRP	34.0-59.0	150	167-263	2.53-3.99	0.08-0.23
El-Sayed et al.[3]	3	CFRP	54.5-62.5	250	326	3.07	0.54-1.07
	3	GFRP	54.5-62.5	250	326	3.07	0.17-0.33
El-Sayed et al [16]	2	CFRP	78.7	250	326	3.07	1.10-1.41
	3	GFRP	54.5-78.7	250	326	3.07	0.34-0.44
Guadagnini et al [4]	3	GFRP	50.3-56.1	150	223	1.12-3.36	0.27
El-Sayed et al.[17]	3	CFRP	50.0	1000	106.5-165.3	6.05-6.23	0.21-0.64
	5	GFRP	50.0	1000	159-160	6.17-6.49	0.16-0.50
Wegian & Abdalla[18]	5	GFRP	37.5	500	200	4.00	0.08-0.30
	2	CFRP	37.5	500	200	4.00	0.14-0.0.33
Razaqpur et al.[19]	7	CFRP	50.6-61.2	200	225	1.82-4.22	0.17-0.60
Lubell et al.[20]	1	GFRP	50.0	450	970	3.14	0.09
Yost et al.[21]	12	CFRP	75.3-101.7	141-143	141-143	6.36-6.45	0.22-0.50
Tariq & Newhook [22]	6	GFRP	42.6-54.0	160	325-346	2.75-3.54	0.14-0.30
	6	CFRP	42.6-54.0	130	310	3.06-3.71	0.41-0.88
Gross et al.[23]	12	GFRP	99.5	152-203	224-225	4.06-4.08	0.24-0.49
Li & Wang [24]	4	GFRP	81.6-98.0	114-117	128	2.64-4.91	0.35-0.52
Tureyen & Frosch [2]	4	GFRP	49.6-53.2	457	360	3.40	0.18-0.35
	2	AFRP	50.3-53.2	457	360	3.40	0.21-0.43
Yost et al.[25]	18	GFRP	45.3	178-279	224-225	4.06-4.08	0.21-0.43
Alkhrdaji et al.[26]	3	GFRP	30.1	178	279-287	2.61-2.69	0.14-0.43
Deitz et al.[27]	5	GFRP	33.7-38.5	305	157.5	4.51-5.80	0.14
Michaluk et al.[28]	2	GFRP	82.5	1000	104-154	8.44-12.5	0.15-0.19
Mizukawa et al.[29]	1	CFRP	43.3	200	260	2.69	0.80
Duranovic et al. [30]	2	AFRP	41.1-47.6	150	210	3.65	0.28-0.29
Swamy& Aburawi [31]	1	GFRP	42.5	254	222	3.15	1.55
Vijay et al. [32]	2	GFRP	38.7-56.0	150	265	1.89	1.4
Zhao et al.[33]	3	CFRP	42.8	150	250	3.00	0.75-1.51
Nakamura & Higai [34]	2	GFRP	28.3-34.7	300	150	4.00	0.18-0.24
Tottori & Wakui [35]	9	CFRP	55.6-58.6	200	325	2.15-4.31	0.46
Nagasaka et al.[36]	2	AFRP	28.6-42.6	250	265	1.78	0.51
TOTAL	200	-	28.3-101.7	114-1000	104-1111	0.36-12.50	0.11-3.02

The test data of various FRP bars, namely carbon fibre reinforced polymer (CFRP), aramid fiber reinforced polymer (AFRP) and glass fiber reinforced polymer (GFRP) are considered in this study and the details of data base are given in TABLE 1.CFRP is carbon fibre reinforced polymer, AFRP is aramid fiber

reinforced polymer and GFRP is glass fiber reinforced polymer in TABLE 1. Hence the TABLE 1 accounts for the various types of FRP bars used as internal reinforcement in the construction site.

The ranges of design parameters for the 200 experimental database of test specimens without stirrups are given in TABLE 1. The variables of beams in the published literature are type of fiber reinforced polymer (FRP) bar, strength of concrete (f_{ck}), size of the beam $(b \, and \, d)$, shear span to depth (a/d) ratio and longitudinal reinforcement ratio (p_t). The reinforcement ratio of FRP bars (p_t) in the beam specimens is found to be in the range between 0.18 and 2.76 percent. The concrete compressive strength (f_{ck}) is found to be in the range between 28.3 and 101.7 MPa. The shear span-to-depth ratio (a/d) is found to be in the range between 0.36 and 12.5.

In this study, based on the existing Indian code of practice for plain and reinforced concrete IS: 456 (2000) which is originally meant for the prediction of shear strength of concrete beams reinforced with steel bars is accounted to predict the shear strength of 200 concrete beams presented in Table 1. The mean of ratio of experimental shear strength to predicted shear strength based on IS: 456(2000) [5] with the corresponding experimental data is presented.

IV.   COMPARISON OF PREDICTION WITH EXPERIMENTAL DATA

The shear strength of 200 specimens published in various literatures is predicted using the model proposed considered in this study and compared with corresponding test data and given in Fig 1. From Fig 1, it is clear that the shear strength prediction shows wider deviation from the experimental shear strength for higher values of experimental shear strength. Hence the model needs modification to account for the wider range of experimental shear strength.
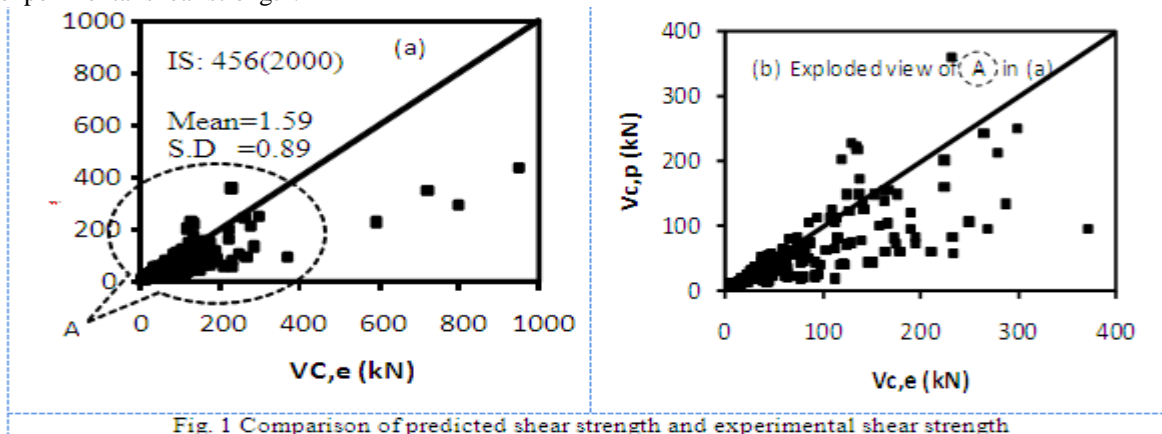

Fig. 1 Comparison of predicted shear strength and experimental shear strength

The observed value of mean of the ratio of experimental shear strength to the predicted shear strength and standard deviation for concrete beams having $a/d < 2.0$, $a/d \geq 2.0$ and for all a/d ratios is given in Table 2. From Table 2, the observed value of mean of $V_{c,e}/V_{c,p}$ for 49 concrete beams having $a/d < 2.0$ is found to be 2.38 with a standard deviation of 1.21. It indicates that dispersion of points is found to be significant when shear span to depth ratio is less than 2.0 which may be attributed to the variation of experimental set up and workmanship of preparing the specimens. The mean of ratio of experimental shear strength to predicted shear strength using the model considered in this study is found to be 1.33 and the standard deviation is found to be 0.56 for 151 concrete beams having $a/d \geq 2.0$. The mean of ratio of experimental shear strength to predicted shear strength using the model considered in this study given by Eq. (1) to (6) is found to be 1.59 and the standard deviation is found to be 0.89 for 200 concrete beams of all shear span to depth ratios ranging from 0.36 and 12.5.

Table 2 Comparison of mean and standard deviation of beams having $a/d \leq 2.0$ and $a/d \geq 2.0$

a/d ratio	Number of beams	Observed value of Mean of $V_{c,e}/V_{c,p}$	Observed value of Standard deviation
$a/d < 2.0$	49	2.38	1.21
$a/d \geq 2.0$	151	1.33	0.56
All a/d	200	1.59	0.89

Results of this study indicate that the prediction based on the model given by Eq. (1) to (6) requires modifications to account for the influence of shear span to depth ratio, the strength and stiffness characteristics of FRP reinforcing bars and the behaviour of concrete beams when FRP bars are used in place of steel bars to get a good agreement with the test data of 200 beams given in Table 1. The IS: 456(2000) [5] model accounts for wide range of compressive strength of concrete, shear span to depth ratio and longitudinal reinforcement ratio.

V.   CONCLUSIONS

The analytical study on predict the shear strength of 200 concrete beams reinforced with FRP bars published in the literature using IS: 456(2000) [5] for the model originally proposed for the prediction of shear strength of concrete beams reinforced with steel bars is carried out. Based on this study, it may be concluded that model given by IS: 456(2000) [5] need modification for the realistic prediction of shear strength FRP reinforced concrete beams.

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