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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*

# **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.

# **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.

#  **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 is given by

 (1)

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

  (2)

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

 (3)

where,  is the characteristic compressive strength of concrete and is computed by

 (4)

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

 (5)

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

 (6)

Where,  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 |
| --- | --- | --- | --- |
| (MPa) | b(mm) | d(mm) |  |  (%) |
| 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, size of the beam, shear span to depth  ratio and longitudinal reinforcement ratio. The reinforcement ratio of FRP bars in the beam specimens is found to be in the range between 0.18 and 2.76 percent. The concrete compressive strength 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.

# **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.



 The observed value of mean of the ratio of experimental shear strength to the predicted shear strength and standard deviation for concrete beams having ,  and for all ratios is given in Table 2. From Table 2, the observed value of mean of for 49 concrete beams having 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 . 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 and 

|  |  |  |  |
| --- | --- | --- | --- |
| a/d ratio | Number of beams | Observed value of Mean of  | Observed value of Standard deviation |
|  | 49 | 2.38 | 1.21 |
|  | 151 | 1.33 | 0.56 |
| All  | 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.

# **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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