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Analysis Of Shear Strength Of GFRP – RC Beams Using An Empirical Model

Mettu Bhaskara Rao, P. J. Rao, M. V. S. Rao
[1] *Principal, Naganathappa College of engineering, Parli Vaijnath, Dist. Beed, MS (India)*
[2] Professor, Dept. of Civil Engg., ACE College of Engineering, *Hyderabad, AP (India)*
[3] Professor, Dept. of Civil Engg. JNT University, *Hyderabad, AP (India)*

ABSTRACT: The present paper reviews the research on Glass Fiber Reinforced Polymer (GFRP) flats under shear in reinforced concrete beams. Most of the failures in concrete structures in particular bridges are due to corrosion of reinforcement, particularly in aggressive environments. This has prompted researcher's world over to look for an alternative non corrosive and non metallic reinforcement for strengthening the reinforced concrete structures both in flexure and shear. The objective of the present research is to study the behavior of the beams reinforced with GFRP flats in shear and to analyze the shear strength of GFRP – RC beams using empirical model.

KEY WORGDS: Glass Fiber Reinforced Polymer (GFRP) bars and flats

1. INTRODUCTION

Concrete is the most widely used construction material worldwide. Concrete technologists world over are continuously carrying out the research to improve the performance of concrete to meet the functional, strength, economy and durability requirements. Concrete has the drawbacks of being weak in tension, porous and susceptible for environmental attack. These difficulties of plain concrete were overcome, by introducing steel as reinforcement and admixtures to improve density for better performance .The necessity for new non corrosive material has arisen because of corrosion problems associated with steel.

Glass fibre reinforced polymer (GFRP) bars and flats have been used in the present investigation to address the problem of corrosion associated with steel.

In the present study glass fibres have been used. They are made of calcium alumina borosilicate and are more economical compared to aramid and carbon fibres. These fibres are light in weight and about one third compared to that of steel. Hence weight to volume ratio is a major advantage in the use of GFRP bars while the tensile strength is comparable to that of steel.

In the present investigation glass fibre reinforced polymer (GFRP) flats were used as shear reinforcement and GFRP flats as flexural reinforcement.

Shear is an intrinsically more difficult problem to understand and propose a model. For this reason, traditional shear design methods are empirically based. Over the course of the last forty years, the results of many experimental programs have been analyzed in an attempt to understand and codify the behavior of reinforced concrete members in shear. In order to understand and codify the behavior of FRP reinforced concrete, more experimental data is required for detailed analysis. For this reason the present research work has been undertaken.

In the present work, the effect of variable parameters such as shear span/effective depth ratio, percentage of flexural reinforcement and actual compressive strength of concrete on the shear resistance of concrete was studied.

An emperical model is developed for prediction of shear strength of concrete. The theoretical and experimental shear capacities of the beams were compared and found to be in agreement.

2. EXPERIMENTAL PROGRAM:

All the beams were designed for shear, following guidelines of ACI440-R and the codal provisions of I.S.456-2000, by suitably modifying the design constants for GFRP flats. The size of the beams cast was 100mm x 150mm x 1600mm, with an effective span of 1500mm. All the beams were tested under 2-pointloading.The beams designed for shear test were provided with extra shear reinforcement in the shear span of non-test zone to avoid failure.

2.1 Shear

Tests were undertaken on beams of A, B and C series, using GFRP flats of size 25X2.5mm as shear reinforcement, with varying shear span/ effective depth (a/d) ratios of 1.5, 2.5 and 3.5. The dimensions of all the beams are 100X150 X1600mm overall and the effective length being 1500mm. M20 grade of concrete has been adopted for casting all the beams (Tables 1&2).

The A series beams consists of (1) two numbers of beams of size 100 X 150 X 1600mm, cast with one number of 10 mm Ø GFRP bar, as flexural reinforcement. In the shear test zone, single legged stirrups of 25X2.5mm size silica coated GFRP flats at 0.20%, were arranged as shear reinforcement. Under group (2) two numbers of beams, of size 100 X 150 X 1600mm, were cast with four numbers of 6 mm Ø GFRP bars, as flexural reinforcement. In the shear test zone 0.30% of shear reinforcement using single legged 25X2.5mm size silica coated GFRP flats were arranged. In group (3) two numbers of beams, of size 100 X 150 X 1600mm, were cast with two numbers of 10 mm Ø GFRP bars, as flexural reinforcement. In the shear test zone, 0.42% of shear reinforcement using single legged stirrups of 25X2.5mm size silica coated GFRP flats were arranged. In this series, the ratio of shear span to effective depth adopted was 1.5.

The B series beams are in three groups, (1) two numbers of beams of size 100 X 150 X 1600mm, cast with one number of 10 mm Ø GFRP bar, as flexural reinforcement. In the shear test zone, no shear reinforcement was provided, as it was not required, as per theoretical calculations. Under group (2) two numbers of beams, of size 100 X 150 X 1600mm, were cast with four numbers of 6 mm Ø GFRP bars, as flexural reinforcement. In the shear test zone, 0.13% of shear reinforcement using single legged stirrups of 25X2.5mm size silica coated GFRP flats were arranged. In group (3) two numbers of beams of size 100 X 150 X 1600mm, were cast with two numbers of 10 mm Ø GFRP bar as flexural reinforcement. In the shear test zone, 0.19% of shear reinforcement using single legged stirrups of 25X2.5mm size silica coated GFRP flats at were arranged. In this series, the ratio of shear span to effective depth of 2.5 was kept.

The C series, beams are in three groups, (1) two numbers of beams, of size 100 X 150 X 1600mm, cast with one number of 10 mm Ø GFRP bar, as flexural reinforcement. In the shear test zone, no shear reinforcement was provided, as per design calculations. Under group (2) two numbers of beams of size 100 X 150 X 1600mm were cast with four numbers of 6 mm Ø GFRP bars, as flexural reinforcement. In the shear test zone, no shear reinforcement was provided, as per theoretical calculations. In group (3) two numbers of beams of size 100 X 150 X 1600mm, were cast with two numbers of 10 mm Ø GFRP bars, as flexural reinforcement. In the shear test zone, 0.10% of shear reinforcement using single legged stirrups of 25X2.5mm size silica coated GFRP flats were arranged. In this series, the ratio of shear span to effective depth of 3.5 was kept.

In all the beams, the non-test zone was reinforced by two-legged stirrups of GFRP flats of size 11mm*2.3mm at 50 mm spacing to avoid shear failure in that zone. The spacing of stirrups in the non-test zone was less than that of the spacing suggested by IS 456 as well as ACI 440 guide lines.

3. TEST RESULTS AND DISCUSSIONS

3.1 *Tests on GFRP bars and flats with and without Silica Coating:*

Tensile strength tests were conducted on plain and silica coated GFRP bars of 10mm dia. and 6mm dia., to understand the tensile behavior and to determine the modulus of elasticity. The glass fiber and resin proportion of 7:3 was used to manufacture the GFRP bars. The average tensile strength of 10mm dia. GFRP bars was found to be 380Mpa, for both plain and silica coated bars. The tensile strength of 6mm dia. bars was found to be 416 Mpa for silica coated and plain bars similar to that of pre-stressing strands. It is observed that the silica coating did not influence the tensile strength of the bars significantly. The failure pattern for plain 10mm dia. and 6mm dia. bars was brittle and associated with splintering of glass fibers. Similar behavior was observed in the case of silica-coated bars of same diameter.

3.2 Shear tests:

Eighteen beams were tested in shear (Tables 1 & 2). Figures 1 &2 show the graphs between shear force and deflection at centre.

For specimens of series A(1) (Beam Id.: A1)with shear reinforcement of single legged 25mm × 2.5mm size GFRP flats at 0.20%, the first crack has occurred at a shear value of 10.75kN and failed at an ultimate shear of 19.03 kN and the ratio of ultimate shear to shear at first crack being 1.77. For beams of series A (2) (Beam Id.: A2) with 0.30% of shear reinforcement using single legged 25mm × 2.5mm size GFRP flats, the first crack has occurred at a shear value of 13.56 kN and failed at an ultimate shear of 24.27 kN and the ratio of ultimate shear to shear at first crack being 1.79. In the case of specimens of series A (3) (Beam Id.: A3) with 0.42% of shear reinforcement using single legged 25mm × 2.5mm size GFRP flats, the first crack has occurred at a shear value of 14.78 kN and failed at an ultimate shear of 26.76 kN and the ratio of ultimate shear to shear at first crack being 1.81. In the case of specimens of series B (1) (Beam Id.:B1) with no shear reinforcement in shear test zone, the first crack has occurred at a shear value of 6.75 kN and failed at an ultimate shear of 11.01 kN and the ratio of ultimate shear to shear at first crack being 1.63.

For beams with 0.13% of shear reinforcement using Single legged 25mm × 2.5mm size GFRP flats, the first crack has occurred at a shear value of 9.39 kN and failed at an ultimate shear of 15.77 kN and the ratio of ultimate shear to shear at first crack being 1.68.

In the case of specimens of series B (3) (Beam Id.: B3) with 0.19% of shear reinforcement using single legged 25mm × 2.5mm size GFRP flats, the first crack has occurred at a shear value of 10.06 kN and failed at an ultimate shear of 17.00 kN and the ratio of ultimate shear to shear at first crack being 1.69.

In respect of specimens of series C (1) (Beam Id.:C1) with no shear reinforcement in shear test zone, the first crack has occurred at a shear value of 6.31 kN and failed at an ultimate shear of 9.59 kN and the ratio of ultimate shear to shear at first crack being 1.52. For beams with no shear reinforcement in shear test zone, the first crack has occurred at a shear value of 7.31 kN and failed at an ultimate shear of 11.55 kN and the ratio of ultimate shear to shear at first crack being 1.58.

In the case of specimens of series C (3) (Beam Id.:C3) with 0.10% of shear reinforcement using Single legged 25mm × 2.5mm size GFRP flats, the first crack has occurred at a shear value of 7.23 kN and failed at an ultimate shear of 11.72 kN and the ratio of ultimate shear to shear at first crack being 1.62.

As in the case of conventional beams with steel reinforcement, in the beams reinforced with GFRP bars, increase in moment of resistance and there by the shear load, has been observed with the increase in percentage reinforcement. With the increase in a/d ratio, decrease in shear load was observed which obvious (Table 3).

3.3. The Empirical model proposed for design shear strength of concrete in concrete beams reinforced with GFRP bars:

The shear strength of different slender beams of shear span to effective depth ratio greater than 2.5 (a/d >2.50) depends on three important parameters, such as the tensile strength of concrete as measured by the characteristic cylindrical strength of concrete f_c', percentage of reinforcement 'p' and shear span to effective depth ratio, '$\frac{a}{d}$'. Specifically the shear strength is directly proportional to first two mentioned parameters and inversely proportional to the later.

Accordingly the shear strength (as per Zsutty (1968))

$$v_c = a_1' \times (f_c' \times p \times \frac{d}{a})^{n_1} \quad \ldots\ldots (1)$$

Where v_c is the design shear strength of concrete

f_c' is the specified cylindrical strength of concrete
p is the percentage of reinforcement
a is the shear span
d is the effective depth of beam
and a_1', n_1 are constants

The relation between cube strength and cylindrical strengths of concrete takes the following form as

$$f_c' = k \times f_{ck} \quad \ldots\ldots. (2)$$

For convenience substituting the Equation (2) in Equation (1) and simplifying gives

$$v_c = a_1 \times (f_{ck} \times p \times \frac{d}{a})^{n_1} \quad \ldots\ldots. (3)$$

Where $a_1 = a_1' \times k^{n_1}$

Similarly for beams with shear span to effective depth ratio less than 2.5 (a/d < 2.5) loaded at the top and bottom edge ,duly accounting for arch action,
The shear strength (as per Zsutty (1968)) is given by

$$v_c = a_2 \times (f_{ck} \times p \times \frac{d}{a})^{n_2} \quad \ldots\ldots. (4)$$

a_1 , a_2 n_1 and n_2 are found by conducting the regression analysis on experimental data and the following equations are proposed:

The shear strength of different deep beams of shear span to effective depth ratio less than 2.5 (a/d < 2.50) is given by

$$v_c = 0.79 \times \sqrt[3]{f_{ck} \times p \times \frac{d}{a}}) \quad \ldots\ldots.(5)$$

The shear strength of different slender beams of shear span to effective depth ratio greater than 2.5 (a/d > 2.50) is given by

$$v_c = 0.42 \times \sqrt{f_{ck} \times p \times \frac{d}{a}} \quad \ldots\ldots. (6)$$

The shear strengths obtained as per the formulae derived by the author are comparable with the experiential values (Table 4).

4. Conclusions:

This investigation was devoted to the study of the behavior of concrete beams reinforced with glass fiber reinforced polymer bars and flats under shear. The experimental study consisted of tests on about eighteen beams involving various parameters viz. shear span/effective depth ratio, stirrup spacing, measurements of shear at first crack and at ultimate, deflections, and strains. The analytical phase of the study included shear strength predictions at ultimate of concrete beams reinforced with glass fiber reinforced polymer bars and flats under shear as per the codal provisions (IS 456: 2000).

The following conclusions are drawn based on the findings of the tests reported here:

1. It was observed that the failure of beams was not sudden, though the failure of GFRP bars was sudden and associated with splintering of fibres in direct tension (Table 3).
2. The ratios of ultimate shear to shear at first crack from table 3 indicate that the beams with GFRP reinforcement exhibit fairly good deformability.
3. The performance of silica coated GFRP bars in shear was comparable to that of steel bars of equivalent strength.
4. In spite of brittle splintering type of failure of GFRP bars in direct tension; as a composite material in GFRP-RC beams showed considerable margin between the first crack and ultimate loads, there by indicating large deformability (Table 3).
5. The values of design shear strength of concrete for GFRP-RC beams as calculated using the empirical formula proposed by the author (Table 4) are rational and in close agreement with experimental values and the the percentage variation with experimental values is 0 to 9.

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1. Bhaskara Rao Mettu was born in Andhra Pradesh in 1948. He received M.Tech (Structures) in Civil Engineering from the University of JNTU Anantapur in 1990 and the Ph. D degree in Civil Engineering from the University of JNTU Hyderabad in 2011. He is currently Professor in Civil Engineering Department with the NH College of Engineering, Maharashtra, Where he is the Principal of the Institution. He worked in various positions in Engineering colleges and Diploma Institutions. He is having around 34 years of experience in teaching and managing educational institutions and 8 years experience in research and industry. He is the author and editor of various books such as water supply and Sanitary Engg. , Quantity Surveying etc. for Vocational Intermediate Board, Andhra Pradesh and author of text book "Quantity Surveying" for diploma syllabus of Kerla State. Dr. Rao is a life time member of FIE, MISTE. His areas of interest are Structural Engineering and special Concretes.

2. P. Jagannadharao did his under-graduation, graduation and Ph. D degrees in civil engineering from Andhra University (India). He is currently Professor at ACE College of Engineering, Hyderabad. He Served for 35 long Years in J.N.T.U College of Engineering Kakinada and Ananthapur in different cadres. Dr. P. J Rao is having total service of 45 years besides one year of industrial experience. He was formerly member of Board of Studies JNTU Autonomous Colleges at Kakinada, Anantapur & Hyderabad and Academic Council of JNTU & Vasavi Engineering colleges Hyderabad. He is also a member of panel of experts for staff selections at Andhra, Nagrjuna and JNT Universities. His research area focuses on FRCC and GFRP-RC beams and slabs.

3. M V Seshagiri Rao received Ph.D and M.Tech degrees in Structures discipline in Civil Engineering. He is currently Professor at Civil Engineering Department at JNTU College of Engineering, Hyderabad. Dr. Seshagiri Rao is having experience of around 30 years in teaching and around 8 years in research and industrial experience. He is also a life time member of

FIE, MISTE, MICI. His research work focuses Structural Engineering, special Concretes, Non Destructive testing, retrofitting.

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Table 1: Details of test beam specimens

S.No.	Size of Beam mm	‘a/d’ ratio	Flexural reinforcement	Percentage of flexural reinforcement,‘p’	Shear reinforcement in shear test zone	Stirrup spacing ¾ d in mm	Calculated stirrup spacing in mm	Adopted stirrup spacing in mm	Percentage of shear reinforcement
1	100×150×1600 mm	1.5	1-10mm dia. silica coated GFRP bar	0.67	Single legged stirrups of 25mm×2.5mm size silica coated GFRP flats	88	123	130	0.20
2	100×150×1600 mm	1.5	4-6mm dia. silica coated GFRP bars	0.95	Single legged stirrups of 25mm×2.5mm size silica coated GFRP flats	90	82	85	0.30
3	100×150×1600 mm	1.5	2-10mm dia. silica coated GFRP bars	1.34	Single legged stirrups of 25mm×2.5mm size silica coated GFRP flats	88	57	60	0.42
4	100×150×1600 mm	2.5	1-10mm dia. silica coated GFRP bar	0.67	Single legged stirrups of 25mm×2.5mm size silica coated GFRP flats	88	348	No shear reinforcement required as per calculations	-
5	100×150×1600 mm	2.5	4-6mm dia. silica coated GFRP bars	0.95	Single legged stirrups of 25mm×2.5mm size silica coated GFRP flats	90	199	200	0.13
6	100×150×1600 mm	2.5	2-10mm dia. silica coated GFRP bars	1.34	Single legged stirrups of 25mm×2.5mm size silica coated GFRP flats	88	126	135	0.19
7	100×150×1600 mm	3.5	1-10mm dia. silica coated GFRP bar	0.67	Single legged stirrups of 25mm×2.5mm size silica coated GFRP flats	88	1618	No shear reinforcement required as per calculations	-
8	100×150×1600 mm	3.5	4-6mm dia. silica coated GFRP bars	0.95	Single legged stirrups of 25mm×2.5mm size silica coated GFRP flats	90	513	No shear reinforcement required as per calculations	-
9	100×150×1600 mm	3.5	2-10mm dia. silica	1.34	Single legged stirrups of	88	261	265	0.10

			coated GFRP bars		25mm×2.5mm size silica coated GFRP flats				

Table 2: Reinforcement details of beams

Beam Id. name	Flexural reinforcement	Shear reinforcement	
		Non test zone	Test zone
	GFRP bars	Two legged 25x2.5mm size GFRP flat stirrups at	Single legged 25x2.5mm size GFRP flat stirrups at
A1	1No. - 10mm dia. $(p = 0.67)$	0.51%	0.20%
A2	4Nos. - 6 mm dia. $(p = 0.95)$	0.51%	0.30%
A3	2Nos. - 10mm dia. $(p = 1.34)$	0.51%	0.42%
B1	1No. - 10mm dia. $(p = 0.67)$	0.51%	No shear reinforcement required as per calculations
B2	4Nos. - 6 mm dia. $(p = 0.95)$	0.51%	0.13%
B3	2Nos. - 10mm dia. $(p = 1.34)$	0.51%	0.19%
C1	1No. -10mm dia. $(p = 0.67)$	0.51%	No shear reinforcement required as per calculations
C2	4Nos. - 6 mm dia. $(p = 0.95)$	0.51%	No shear reinforcement required as per calculations
C3	2Nos. - 10mm dia. $(p = 1.34)$	0.51%	0.10%

Table 3: Test results of beams

Beam Id. name	Shear at first crack(Vf) kN	Ultimate shear (Vu) kN	Ratio of Ultimate Shear and shear at first crack(Vu/Vf)	Remarks
A1a	9.98	19.00	1.90	$p = 0.67$ and $\frac{a}{d} = 1.5$
A1b	12.17	19.60	1.61	
A2a	12.93	24.30	1.88	$p = 0.95$ and $\frac{a}{d} = 1.5$
A2b	15.20	24.48	1.61	
A3a	16.06	28.37	1.77	$p = 1.34$ and $\frac{a}{d} = 1.5$
A3b	14.14	24.89	1.76	
B1a	6.85	11.56	1.69	$p = 0.67$ and $\frac{a}{d} = 2.5$
B1b	6.01	11.00	1.83	
B2a	10.93	16.72	1.53	$p = 0.95$ and $\frac{a}{d} = 2.5$
B2b	9.29	15.14	1.63	
B3a	11.33	18.70	1.65	$p = 1.34$ and $\frac{a}{d} = 2.5$
B3b	9.10	16.20	1.78	
C1a	6.73	10.07	1.50	$p = 0.67$ and $\frac{a}{d} = 3.5$
C1b	6.60	9.11	1.38	
C2a	6.73	12.13	1.80	$p = 0.95$ and $\frac{a}{d} = 3.5$
C2b	6.77	10.63	1.57	
C3a	6.86	12.42	1.81	$p = 1.34$ and $\frac{a}{d} = 3.5$
C3b	6.66	11.13	1.67	

Table 4: Comparison of design shear strength of concrete as per experimental value, empirical formula

Beam ID	$\frac{A_f}{b_w \times d} \times 100$	**As per experimental value(kN)**	**As per empirical formula(kN)**	**Percentage of variation**
A1	0.67	1.62	1.63	0
A2	0.95	2.04	1.83	5
A3	1.34	2.23	2.05	4
B1	0.67	0.94	0.97	-2
B2	0.95	1.33	1.35	-1
B3	1.34	1.46	1.55	-3
C1	0.67	0.80	0.82	-1
C2	0.95	0.95	0.98	-1
C3	1.34	0.99	1.16	-9

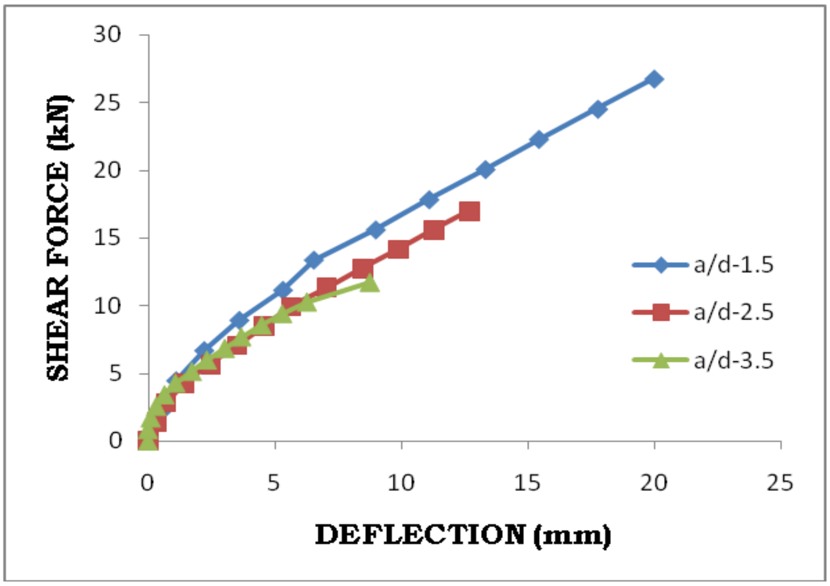

Figure 1: SHEAR FORCE Vs DEFLECTION AT CENTRE IN BEAMS (a/d=1.5, 2.5&3.5; p = 1.34)

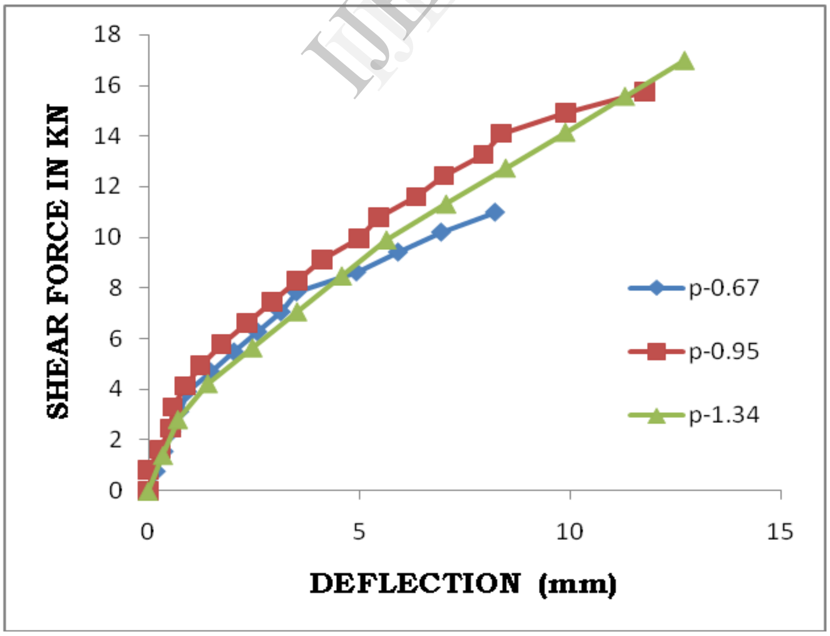

Figure 2: SHEAR FORCE Vs DEFLECTION AT CENTRE IN BEAMS (a/d=2.5; p=0.67, 0.95&1.34)

Plate 1 Computerized universal testing machine with set up