Comparison of Shear Values of Concrete Beams by Different Codes and Equations for Various Shear Span to Depth Ratios

Mr. Abhijit S. Mehetre
PG Scholar Civil Engineering Department
Dr. V.V.P. College of Engineering,
Ahmednagar, India
abhijitmehetre92@gmail.com

Prof. Pankaj B. Autade
PG Guide Civil Engineering Department
Dr. V.V.P. College of Engineering,
Ahmednagar, India
pankajautade@gmail.com

Abstract-
Shear capacity of the reinforced concrete beam depends upon various parameters. On the basis of different parameters, ample studies have been done to assured the authentic deportment of shear failure. Though ample studies carried out on shear failure of concrete beam still it is controversial regarding the exact shear behaviour of reinforced cement concrete structure elements. In this work the comparative study of reinforced concrete beams having no shear reinforcement by utilizing different design approaches like ACI, Canadian, IS Code, CEP-FIP Model, Zsutty equation and Bazant equation. An attempt has been made to study shear strength of concrete beams with various shear span to depth ratios (a/d = 1, 2 & 3) and different longitudinal steel ratios with no shear reinforcement and compare the experimental results with the available shear models. Six shear models for comparison are considered namely, ACI Code, Canadian Code, IS Code, CEP-FIP Model, Zsutty equation and Bazant equation. With the discussion on shear models and the experimental studies conducted on beams with no shear reinforcement it is seen that ACI Code gives lower shear values of reinforced concrete beams as compare to the experimental values. The shear resistance of member predicted based on Canadian code, underestimates the actual shear capacity of member at all a/d ratios. CEP-FIP model shows lower values of shear capacity at all a/d ratios. The Results of Zsutty equation are close as compare to other codes and equations with experimental test data. Bazant equation gives higher Shear values than the experimental test data. The New Simplified Equation includes almost all the parameters required to predict the shear capacity of concrete beams. Therefore a single simplified equation can be used to predict the shear capacity of beams.

Keywords– shear model, shear span to depth ratio (a/d).

I. INTRODUCTION

Reinforced concrete is being used extensively in the construction industry all over the world. The use of high strength concrete has increased due to its obvious advantages like increased modulus of elasticity, chemical resistance, freeze thaw resistance, lower creep, lower drying shrinkage and lower permeability. The calculation of stresses in concrete is difficult due to its heterogeneous nature and inclusion of reinforcement further complicates the situation. Extensive research work on shear behavior of normal as well as high-strength concrete beams has been carried out all over the world. The major researchers include Ferguson , Taylor, Cossio, Berg, Mathey and Watstein , Zsutty, Kani, Elzanaty *et al*., Roller and Russel, Ahmad and Lue, Barrington, Shin *et al.*, Kim and White, Tompos and Frosh, Ahmad *et al.*, Reineck *et al.*, and many more. Despite the extensive research work, shear behavior of high-strength reinforced concrete beams is still controversial and needs further research.

Shear failure of the concrete beam depends upon various parameters. On the basis of various parameters, numerous studies have been done to assured the actual behaviour of shear failure. After a long research still it is controversial regarding the exact shear behaviour of reinforced cement concrete structure elements. Various researchers has been done the experiments on beams without web reinforcement and found the following factors influenced the shear behaviour of beams. The various factors are (i) Shear span to effective depth ratio (a/d) (ii) Longitudinal steel ratio (ρ) (iii) Aggregate type (iv) Strength of concrete (v) Type of Loading (vi) Support conditions. The intention of all the researchers is to find out the accurate judgment of shear failure or justify the shear strength capacity of structure with the most acceptable equation which is derived on the base of their respective experiments.

II. OBJECTIVES OF INVESTIGATION

1. To study the shear response of concrete beams without shear reinforcement varying shear span to depth ratio (a/d).
2. To compare the shear formulae formulated by eminent codes with the experimental test data.
3. To propose a simplified formula to predict shear strength of beams without shear reinforcement.

III. MIX MATERIALS

The material details are as follows:

A. Cement

The cement used in this experimental work is “Ulttratech 53 grade Ordinary Portland Cement”. All properties of cement are tested by referring IS 12269 - 1987 Specification for 53 Grade Ordinary Portland Cement. Specific gravity of cement was 3.15.

B. Fine Aggregate

Locally available fine aggregate used was 4.75 mm size confirming to zone II with specific gravity 2.62. The testing of sand was conducted as per IS: 383-1970.Water absorption and fineness modulus of fine aggregate was 0.10% and 2.806 respectively.

C. Coarse Aggregate

Coarse aggregate used was 20mm and less size with specific gravity 2.67. Testing of coarse aggregate was conducted as per IS: 383-1970. Water absorption and fineness modulus of coarse aggregate was 0.15% and 6.013 respectively.

D. Water

The water used was potable, colorless and odorless that is free from organic impurities of any type.

E. Tension Reinforcement

The three series of concrete beams were provided with 2-16 mm, 2-12mm, 2-8mm diameter HYSD bars as longitudinal reinforcement. The bars are placed at bottom of concrete beams to carry the tensile stresses and to avoid the sudden failure of concrete beams.

IV. EXPERIMENTAL WORK AND TEST

A. Mix Design:

The majority of the construction works in study area are residential buildings with multiple floors and they are not more than three floors. The minimum grade of concrete recommended is M30 (IS: 456-2000) and a target strength of 38.25 MPa is fixed in this work. The design mix proportions for the required target strength is as follows,

Cement: Sand: Coarse Aggregate: w/c = (1:1.87:3.37:0.45)

B. Compressive Strength Test:

Compression test on the 150 mm x 150 mm x 150 mm cube specimens were conduct on the 100 ton compressive testing machine. The specimens were cured in water for 28-days. The cube compressive strength is calculated as crushing load per unit area.

Fig.1- Compressive Testing Set up

C. Different models to predict shear capacity:

Comparative analysis is made for well-known shear models which are used to calculate shear resistance of beams with no shear reinforcement. There are four codal equations and two equations given by different researchers and also one simplified equation was used for comparative analysis to calculate shear resistance of beams. The equations are as follows:

a) ACI Equation (318-02): (Ref. [1])

According to ACI Building Code 318 , the shear strength of concrete members without transverse reinforcement subjected to shear is given two equations. The simplified equation is as follows:

$$Vc = \left(0.16\sqrt{fc} + 17\,Vu \times \frac{d}{Mu}\right) bw \times d \quad (\text{For } a/d \geq 2.5)\ldots.(1)$$

$$Vc = \left(3.5 - \frac{2.5Mu}{Vu} \times d\right) \times \quad Eq\ 1 \quad (\text{For } a/d < 2.5)\ldots.(2)$$

Where,
$f\,c$ = compressive strength of concrete at 28 days in Mpa,
$b_w d$ = width and depth of effective cross section in mm,
Vu = ultimate shear force in N.
Mu = ultimate moment in Nmm.
a/d = shear span to depth ratio.

ACI Code gives the importance to Vu and Mu parameters and not considered the longitudinal steel ratio (p).

Canadian Equation :(Ref. [2])

According to Canadian Standard, the shear strength of concrete members is given by following equation:

$$Vc = 0.2\sqrt{fc}\ bw \times d\ldots\ldots..(3)$$

Canadian code has not taken into account the effect of shear span to depth ratio. It only considered the compressive strength of concrete and effective cross section of beams.

c) Shear design by CEP-FIP model :(Ref. [3])

According to CEP – FIP Model, the shear strength of concrete members is given by following equation:

$$Vc = [0.15\left(\frac{3d}{a}\right)^{2/3} \ (1 + \sqrt{200/d}\ ) x (100p\ fck)^{2/3}] bwxd\ldots(4)$$

CEP – FIP Model considered all parameters required to calculate to shear strength of concrete beams but still gives lower results for all a/d ratios.

d) Shear design by Zsutty equation: (Ref. [8])

Zsutty (1987) has formulated the following equation for shear strength of concrete member

$$Vc = 2.2\,(fc\,p\frac{d}{a})^{1/3}\ bw \times d \qquad (\text{For } \frac{a}{d} \geq 2.5)\ldots(5)$$

$$Vc = \left(2.5\frac{d}{a}\right) \times Eq\ 5 \qquad (\text{For } \frac{a}{d} < 2.5)\ldots.(6)$$

Zsutty equation is more appropriate and more simple to predict the shear strength of both shorter and long beams as it takes into account size affect and longitudinal steel effect.

e) Shear design by Bazant equation (1987): (Ref. [8])

Bazant has formulated the following equation for shear strength of concrete members:

$$Vc = \left[0.54\sqrt[3]{p}\left(\sqrt{fc} + 249\sqrt{\frac{p}{(a/d)^3}}\right) \times \frac{1+\sqrt{(5.08/d0)}}{\sqrt{(1+d/25d0)}}\right] bw \times d\ldots.(7)$$

Where,
f ck = compressive strength of concrete at 28 days in Mpa,
bwd = width and depth of effective cross section in mm,
p = longitudinal reinforcement ratio
a/d = shear span to depth ratio

The Equation stated by Bazant to predict shear strength of concrete members looks complicated but takes into account all the parameters involved in predicting the shear strength of concrete members.

f) Indian Code IS 456 2000:

The design shear strength of concrete in beams without shear reinforcement is based on the percentage of longitudinal reinforcement which is calculated based on the formula:

$$\tau c = \frac{0.85}{6\beta} \times \sqrt{0.8fck}\left(\sqrt{1+5\beta}-1\right) \ldots\ldots(8)$$

Where,

$$\beta = \frac{0.8fck}{6.89Pt} > 1$$

$$Pt = \frac{100As}{bwd}$$

Where,
$f\,ck$ = compressive strength of concrete at 28 days in Mpa,
$b_w d$ = width and depth of effective cross section in mm,
Pt = longitudinal reinforcement ratio,
As = Area of steel bar in mm^2.

Using the above formula the shear strength of beams without shear reinforcement is given in IS 456: 2000. The code has not taken into account the effect of shear span/ depth (a/d) ratio.

V. SPECIMEN DETAILS

Tests were carried out on eighteen beams, simply supported under two points loading. All the beams have constant cross section of 100mm x 150mm. The length of beam were worked out to be 1.2 m for corresponding a/d ratio = 1, 2& 3 respectively. All the three series of beams were provided with 2-16 mm, 2-12mm, 2-8mm diameter HYSD bars as longitudinal reinforcement to avoid any possible failure by flexure and the grade of concrete was kept constant.

Total volume of concrete = 2 x 9 x 0.100 x 0.150 x 1.2
= 0.324 m^3

Fig.2- Beams after removal of formwork

VI. TEST PROCEDURE

The beams were tested under two point loading on 40 Ton Universal Testing Machine. The test specimens were be simply supported on rigid supports. Two point loads were applied through a rigid spread beam. Based on the shear span to depth ratio, the supports of the spread beam were adjusted. The load and deflections were monitored for every 5 seconds. The load that produced the diagonal crack and the ultimate shear crack were recorded. The average response of two beams tested in a series, were taken as the representative response of the corresponding series.

Fig.3- Testing of beam

Fig.4- Shear Cracks in Beam B4

Fig.5- Shear Cracks in Beam B8

VII. RESULTS AND DISCUSSION

As the present work focuses on evaluation of shear capacity of beams with no shear reinforcement, the tensile strength of concrete plays a vital role. The shear equations proposed by different codes cited in shear resistance models clearly disclose that shear resistance is factor of tensile strength of concrete, shear span to depth ratio (a/d) and tensile reinforcement ratio.

Shear design by Simplified equation

Following equation is the simplified equation for shear strength of concrete member

$$Vc = 2.5\,(fc\,p\frac{d}{a})^{1/3}\ bw\ x\ d\ \ x\left(1.7\frac{d}{a}\right)\ (For\ \frac{a}{d} < 2.0)\ldots\ldots\ldots.(9)$$

$$Vc = 2.5\,(fc\,p\frac{d}{a})^{1/3}\ bw\ x\ d\ \ x\left(2.5\frac{d}{a}\right)\ (For\ 2.0 \le \frac{a}{d} < 3.0)\ldots.(10)$$

$$Vc = 2.5\,(fc\,p\frac{d}{a})^{1/3}\ bw\ x\ d\ \ \ldots\ldots\ldots(For\ \frac{a}{d} > 3.0)\ldots\ldots\ldots\ldots.(11)$$

The test specimens are divided into three series. Each series consisted of six concrete beams with no shear reinforcement with a/d ratio 1, 2 & 3. For all the series, concrete proportions were kept constant and vary the percentage of longitudinal steel. The details are listed in the Table I below:

TABLE I
REINFORCED BEAMS WITHOUT SHEAR REINFORCEMENT:

Serial No	Beam Designation	Length of beam (m)	a/d Ratio	Longitudinal Reinforcement Ratio (p)%	No. of Beams
1	B1	1.2	1	2.7	2
2	B2		2	2.7	2
3	B3		3	2.7	2
4	B4		1	1.51	2
5	B5		2	1.51	2
6	B6		3	1.51	2
7	B7		1	0.67	2
8	B8		2	0.67	2
9	B9		3	0.67	2

Comparison of the experimental results (ACI code, Canadian Code, IS Code, CEPFIP model, Bazant equation and Zsutty equation) reveals that a/d ratio significantly effects the shear capacity of the concrete beams. Most of the equations are under estimating the shear capacity at lower a/d ratios. The results tabulated in Table II (A) and Table II (B)

TABLE II (A)
PREDICTED AND EXPERIMENTAL RESULTS

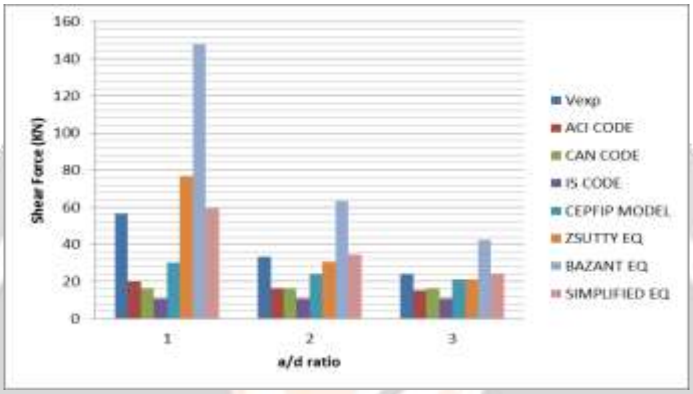
ID	p%	a/d	Vexp (kN)	Vpredicted (kN)			
				ACI CODE	CAN CODE	IS CODE	CEPFIP MODEL
1	2.7	1	56.5	19.98	16.43	10.86	30.253
2	2.7	2	33.5	16.56	16.43	10.86	24.015
3	2.7	3	24	15.42	16.43	10.86	20.979
4	1.51	1	47.5	16.99	16.43	8.850	24.930
5	1.51	2	29	15.07	16.43	8.850	19.786
6	1.51	3	18.5	14.42	16.43	8.850	17.284
7	0.67	1	40	14.85	16.43	6.798	19.014
8	0.67	2	24.5	14	16.43	6.789	15.091
9	0.67	3	13.5	13.71	16.43	6.789	13.183

TABLE II (B)
PREDICTED AND EXPERIMENTAL RESULTS

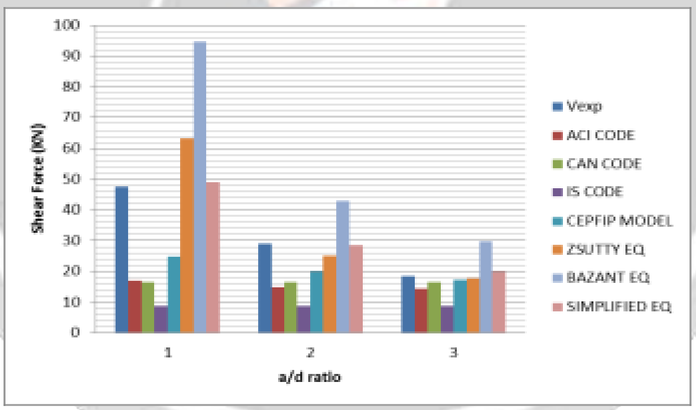
ID	p%	a/d	Vexp (kN)	Vpredicted (kN)		
				ZSUTTY EQ	BAZANT EQ	SIMPLIFIED EQ
1	2.7	1	56.5	76.904	147.7	59.43
2	2.7	2	33.5	30.519	63.53	34.68
3	2.7	3	24	21.328	42.53	24.24
4	1.51	1	47.5	63.360	94.71	48.96
5	1.51	2	29	25.144	42.77	28.57
6	1.51	3	18.5	17.572	29.83	19.97

7	0.67	1	40	48.326	51.76	37.34
8	0.67	2	24.5	19.178	25.38	21.79
9	0.67	3	13.5	13.403	18.81	15.23

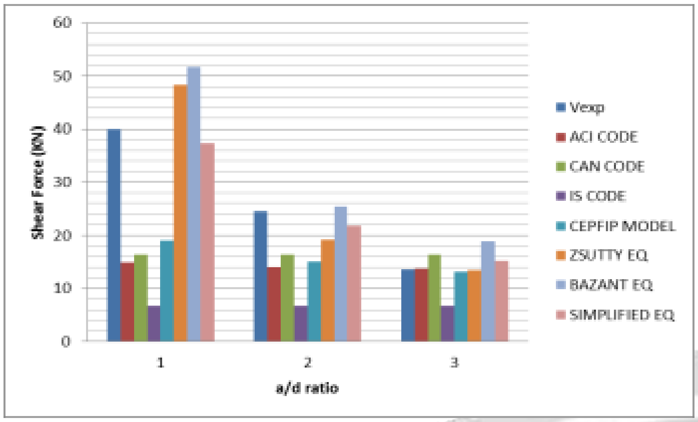
The variation of shear force with a/d ratio of concrete beams with no shear reinforcement for p = 0.027, 0.0151 and 0.0067 are shown in Graph 1, 2 and 3, which indicate the increase in a/d ratio has shown reduction in shear capacity of the beam.



Graph-1: Shear Force *Vs* a/d ratio (for p = 0.027)



Graph-2: Shear Force *Vs* a/d ratio (for p = 0.0151)



Graph-3: Shear Force *Vs* a/d ratio (for p = 0.0067)

VIII. CONCLUSIONS

With the discussion on shear models and the experimental studies conducted on beams with no shear reinforcement the following conclusions can be drawn:

1. If Longitudinal Reinforcement Ratio (p) is increases shear capacity of concrete beams without shear reinforcement is also increases. This is because of as the diameter of bar increases the dowel action is more predominant to resist shearing.
2. From the experimental results it is clear that as shear span to depth ratio increases from 1 to 3 the shear capacity of concrete beams without shear reinforcement is decreases i.e. for 2.7% steel it is 56.5 kN, 33.5 kN, 24 kN.
3. Comparing experimental test data with various codes & equations, the discussion may be concluded as follows:
   i. ACI code underestimates the shear capacity of concrete beams with no shear reinforcement. It gives lower shear values of RC beams as compare to the experimental values. This is because of ACI Code consider parameters like shear span to depth ratio, compressive strength of concrete only not consider the effect of longitudinal steel ratio.
   ii. The shear resistance of member predicted based on Canadian code, underestimates the actual shear capacity of member at all a/d ratios. Canadian code has not taken into account the effect of shear span to depth ratio and longitudinal steel ratio. Canadian Code only has taken compressive strength of concrete into account.
   iii. The results of CEB-FIP model shows lower values of shear capacity at all a/d ratios. CEB-FIP model takes all parameters required to calculate shear capacity of concrete beam i.e. compressive strength of concrete, longitudinal steel ratio, shear span to depth ratio and the size effect of the member, but still underestimates shear capacity of the beam.
   iv. Shear resistance of members using Zsutty Equation closely predict the shear capacity of concrete beams with no shear reinforcement. The Results of Zsutty equation are very close as compare to other codes and equation with experimental data as Zsutty equation includes all parameter in his formula.
   v. The shear capacity calculated using Bazant equation indicates that the equation gives higher Shear values than the experimental test data as he includes the parameter d_0 i.e. Maximum size of coarse aggregate.
4. The New Simplified Develop Equation includes almost all the parameters required to predict the shear capacity of concrete beams. The equation gives +3% to -3% varying results to the experimental results. Therefore a single simplified equation can be used to predict the shear capacity of beams with a/d = 1, 2 & 3.

ACKNOWLEDGEMENT

Experimental work was carried out using the facilities in Civil Engineering Department laboratory of Dr.V.V.P. COE, Ahmednagar. I wish to thank Prof. P.B. Autade, my guide, Prof. U.R. Kawade, HOD Civil Department for their valuable Suggestions and authorities for their kind support. I also wish to thank the laboratory staff for their help and support during experimental work.

REFERENCES

[1] ACI Committee 318, Building Code Requirements for Structural Concrete (ACI 31802)and Commentary (318R02).Farmington Hills, Mich.: American Concrete institute, 2002.

[2] CSA Technical Committee on Reinforced Concrete Design, A23.3-94: Design of Concrete Structures. Rexdale, Ontario: Canadian Standards Association, December 1994.

[3] European CEB-FIP Model Code. London: Thomas Telfair, Services, 1990.

[4] American Association of State Highway and Transportation Officials, AASHTO-LRFD Bridge Specification. 1st edn. Washington, D. C.: AASTO, 1994.

[5] P.D. Zararis, "Shear Strength and Minimum Shear Reinforcement of Reinforced Concrete Slender Beams," ACI Structural Journal, 100(2)(2003), pp. 203–214.

[6] R. Taylor, "Some Shear Tests on Reinforced Concrete Beams Without Shear Reinforcement", Magazine of Concrete Research, 12(36)(1960), pp. 145–154.

[7] T. C. Zsutty, "Shear Strength Predictions for Separate Categories of Simple Beam Tests", ACI Journal, Proceedings,68(2)(1971), pp. 138–143.

[8] Sudheer Reddy L,RamanaRao NV, Gunneswara Rao TD, "Shear resistance of high strength concrete beams without shear reinforcement, "International Journal of Civil and Structural Engineering,vol.1,pp.101-113,2010.

[9] S.H. Ahmad, A.R. Khaloo, and A. Poveda, "Shear Capacity of Reinforced Concrete Beams", ACI Journal, Proceedings, 82(2)(1986), pp. 297–305.

[10] W. Kim and R.N. White, "Shear Critical Cracking in Slender Reinforced Concrete Beams", ACI Structural Journal,96(5)(1999), pp. 757–765.

[11] K.H. Reineck, D. Kuchma, K.S. Kim, and S. Marx, "Shear Database for Reinforced Concrete Members without Shear Reinforcement", ACI Structural Journal, 100(2) (2003), pp. 240–249.