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Review on Shear Behaviour of Reinforced Concrete Beam without Transverse Reinforcement

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Abstract
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. The paper presents a comparative study of reinforced concrete beams on shear behaviour having no transverse reinforcement by using various design approaches like ACI, Canadian, AASHTO, European Code, British Standard, Zararis and equation purposed by Ahmed et al.
***Keywords*-** reinforced concrete beam; Shear failure; Transverse Reinforcement; Mode of Shear failure

I. Introduction

Reinforced concrete is widely accepted material for the rapid urbanization. It is extensively used in the construction industry all over the world. The use of reinforced concrete has increased due to its noticeable advantages like high modulus of elasticity, chemical resistance, freeze thaw resistance and low creep, shrinkage and permeability. Besides these advantages, there is various mode of failure exist in reinforced concrete structure. Among of them the more predominant failure in the concrete beams and other structural component is shear failure which give no pre attention to his user. 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. [1]Among all of them, Modified compression field theory (MCFT) has been successfully applied to members without shear reinforcement.Although the use of such theories in practice remains complicated due to requirements of computer programs or spreadsheets. Recently, some simplified expressions based on the MCFT results have been derived and proposed for the Canadian code for structural concrete. 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 behaviour of normal as well as high-strength concrete beams has been carried out by major researchers Ahmad *et al.*,[2] , Kim and White[3], Ferguson[4] ,Collins et al.,[5-8] Taylor, Cossio, Berg, Mathey and Watstein, Zsutty, Kani, Elzanaty *et al*., Roller and Russel, Ahmad and Lue, Barrington, Shin *et al.*, Tompos and Frosh, Reineck *et al.*,[9] and many more in all over the world.. Despite of this existing extensive research work, assessment of exact shear behaviour of reinforced concrete beams is still controversial and needs further attention.

This paper compares the existing standard equations for the prediction of shear strength of structural elements adopted by the various country codes. The comparisons elucidate the reliability of every equation for the prediction of shear strength of the concrete beams.

II. Modes of shear failure and crack pattern: A look

When the principal tensile stress at any point reaches the tensile strength of concrete, a crack will occur and open normal to the direction of the principal tensile stress or parallel with the direction of the principal compressive stress. Therefore, concrete members subjected to shear forces at ultimate load always have inclined cracks named diagonal cracks or shear cracks. Inclined cracks can be initiated in the web of beams where is proved to be the highest shear stress region and named web shear cracks. Inclined cracks developed from former flexural cracks are called flexure−shear cracks

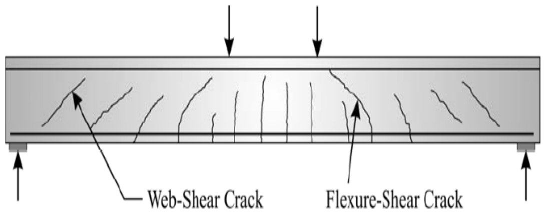

fig 1.1-Types of inclined cracks *[NCHRP Report 549 (2005)]*

The type of failure caused by these cracks, usually in a very brittle and abrupt way, is called diagonal failure or shear failure. Normally, there are five different modes of failure caused by diagonal cracks depending on the dimensions, geometries, type of loading, amount of longitudinal reinforcement and structural properties of concrete members (Fig. 1.2) as follows: (1) Diagonal tension failure (2) Shear compression failure (3) Shear tension failure (4) Web crushing failure and (5) Arch rib failure *[Pillai et al. (2003)]*. Diagonal tension failure usually occurs in concrete members with low amount of stirrups and longitudinal reinforcement. Diagonal cracks may initiate from former flexural cracks and propagate rapidly over the whole cross section of the member until collapse (Fig. 1.2.a). For concrete members with low amount of web reinforcement but adequate longitudinal reinforcement ratio to form a compression zone, shear cracks may easily initiate from former flexural cracks but do not pass through the compression zone. The failure of structure is caused by the crushing of the concrete in compression zone above the tip of the shear crack and named shear compression failure (Fig. 1.2.b). In cases that the longitudinal reinforcement loses the bond with concrete due to inadequate anchorage of the longitudinal bars or concrete cover, cracks tend to develop along the main bars until they combine with a flexural shear crack to cause shear tension failure as in the figure 1.2.c. Web crushing failure seems to be only identified in I-beams due to slender web thickness while arch rib failure usually occurs in deep beams or short span beams in which the direct force transfer from the loading location to the bearings is dominant (Fig. 1.2.d and 1.2.e). In fact, some normal modes of failure can totally be as a combination of two or more above modes of failure, for example, shear tension failure and shear compression failure.

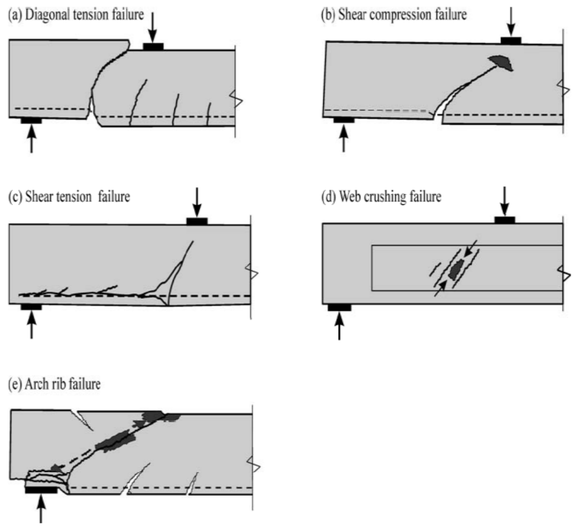

Fig 1.2−Modes of shear failure of concrete beams *[Pillai et al. (2003)].*

III. Literature Review

This section contained the various literature studies on shear behaviour and its numerical comparison with other standard code and proposed equation.

Ahmad et al(2011)[11] proposed a equation for finding out the shear strength of reinforced concrete normal beams without stirrups. A total of 334 data sets for normal beams without web reinforcement have been extracted from past research .All these 334 cases were reported to have failed in shear. They had a compressive strength in the range of (12.2 MPa≤ *fc'* ≥ 69 MPa),the shear span to depth ratio, a/d, ranged from (2 to 8.67) and tensile reinforcement ratio (ρ_w) ranged from (.35 to 6.64 %) .Among from data the equation prepared which is applicable in general loading conditions to find the shear force.

$V_c = vc/b_w d = 1.637(\rho_w\ fc')^{0.35}(V\ d/M)^{.3}\ (MPa)$

The BS shear strength prediction equation for steel-reinforced Portland cement concrete normal members without web reinforcement has this form

$V_{c=.}\ .79\ (100\ \rho_w)^{.333}(400/d)^{.25}(fc'/20)^{.333}$

Where (400/d) should not be taken less than 1.0, *fc'* must be ranged from 20 to 32 MPa, and ρ_w must also be ranged from .15 to .3 %.

Table 1 shows that ACI and BS codes have closest value of coefficient of variation and range, but the BS codes has lower values of mean and standard deviation ,which are 1.04 and 0.18 respectively than ACI code. However, the value of mean which is 1.04 for BS-code due to unsafe values of RSSV(relative shear strength value) which are 150 values from RSSV less than 1.0.

Table 1.comparison between vc_{test} and $vc_{estimated}$ for 334 normal beams without stirrups. Ahmad et al(2011)

Equation	ACI	BS	Proposed Equation
Mean	1.30	1.04	1.33
Standard Deviation	0.22	0.18	0.16
C. O.V	17.32	17.63	11.93
Min RSSV	0.69	0.70	0.98
Max RSSV	1.91	1.97	1.76
Range	1.22	1.27	0.78
Unsafe design No<1	36	150	1

The result shows the proposed formula has the best representation of cracking shear strength because it has the lowest values of standard deviation, coefficient of variation and range. These values are lower by about 11%, 31 % and 36 % than other results of codes for reinforced normal beams without web reinforcement, respectively. The proposed equation led to the smallest percentage of unsafe design. This means that the proposed equation is safer than those equations of the ACI and BS codes. As characteristic strength of concrete, % of reinforcement and a/d ratio change, the safety factor given by ACI and BS codes become change. The proposed equation gives almost a constant safety factor in all cases. Hassan, et. al.,(2008)[12] reported that the ACI 318-05 is unconservative for the large size concrete beams without web reinforcement.The expression need to account for the size effect and the reinforcement chracterstics. it can observed

Table -2 Details of test specimens **Hassan, et. al.,(2008)**

Specimen	Group A		Group B		Group C	
	G-1.9-51	M-1.9-51	G-1.9-38	M-1.9-38	G-2.7-32	M-2.7-32
Shear span-depth ratio (a/d)	1.9	1.9	1.9	1.9	2.7	2.7
Concrete compressive strength, MPa (psi)	51(7400)	51(7400)	38(5500)	38(5500)	32(4650)	32(4650)
Type of longitudinal reinforcement	G*	M^+	G*	M^+	G*	M^+
Bottom reinforcement ratio, %	0.72	0.44	0.72	0.44	0.72	0.44
Top reinforcement ratio, %	0.36	0.22	0.36	0.22	0.36	0.22
Diagonal cracking load, kN (kips)	670 (150)	670 (150)	670(150)	670 (150)	445(100)	445(100)
Failure load, kN (kips)	871 (195)	1560(350)	753(170)	1364(306)	552(124)	638(143)
Predicted failure load using ACI 318-05, kN (kips)	1103(248)	1917(431)	1103(319)	1418(319)	690(155)	690(155)
$P_{Test}/P_{\text{ACI 318-05}}$	0.8	0.81	0.68	0.96	0.80	0.92

G* refers to Grade 60 steel, M^+ refers to high-strength steel

from table 2 the ACI 318-05 overestimate the capacity of concrete beams reinforced with either conventional or high strength steel. The predicted capacity was independent of the concrete compressive strength and therefore, identical capacities were predicted for G-1.9-51 and G-1.9-38.The behaviour is strongly influenced by the a/d and the stress level in bar in the case of high strength steel. As the formula adopted by the by the ACI 318-05 for calculating the capacity of compressive strut was taken as $.51f_c^{'}$, where $f_c^{'}$ is the specified compressive strength of concrete. the compressive capacity of the strut is independent of the tensile strain in the reinforcement. The failure load predicted by ACI 318-05 for the a/d ratio 2.7 is more than the actual failure load. The ACI 318-05 design method considerably overestimated the shear strength of large size concrete beams constructed without web reinforcement. It should be noted that the ACI shear provision were based on testing shallow beams, which did not account for the size effect of large size beams **Sudheer, R.L., et al** (2010) [13]deals with the review of available data base and shear models to predict the shear strength of reinforced concrete beams without web reinforcement. An attempt has been made to study shear strength of high strength concrete beams (70 Mpa) with different shear span to depth ratios (a/d = 1, 2, 3 & 4) without web reinforcement and compare the test results with the available shear models. Five shear models for comparison are considered namely, ACI 318, Canadian Standard, CEPFIP Model, Zsutty Equation and Bazant Equation. the equations are as follows

ACI Equation (318-02)

$V_c = (.16\sqrt{fc} + 17\ Vu \times d/Mu)\ b_w \times d$ (For a/d≥2.5) (1)

$V_c=(3.5-2.5M_u/V_u \times d)$ (For a/d < 2.5) (2) *fc*= compressive strength of concrete at 28 days in Mpa. $b_w d$= width and depth of effective cross section in mm. M_u V_u= factored moment and factored shear force at cross section Karim et al (2000) have expressed certain imperfection in above equation (1) as it underestimates the effect of shear span to depth ratio on shear resistance.

Canadian Equation

$$V_c = .2\sqrt{fc}\ b_w \times d \quad (3)$$

fc= compressive strength of concrete at 28 days in Mpa, bwd= width and depth of effective cross section in mm the Canadian standard has not considered the effect of shear span to depth ratio and longitudinal tension reinforcement effect on shear strength of concrete

Shear design by CEP-FIP model

$$V_c = [.15(3d/a)^{2/3} (1+\sqrt{200/d}) \times (100p\ f_{ck})^{2/3}]\ b_w x d \quad (4)$$

fc= compressive strength of concrete at 28 days in Mpa,$b_w d$= width and depth of effective cross section in mm,p=longitudinal reinforcement ratio

CEP-FIP equation taked into formula the size effect and longitudinal steel effect,but still underestimates shear strength of short beams.

Shear design by Zsutty equation

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

$$Vc = 2.2\ (fc\ p\ d/a)^{1/3}\ b_w \times d \text{ (For a/d≥2.5)} \quad (5)$$

$$Vc = (2.5\ d/a) \text{ (For a/d≥2.5)} \quad (6)$$

fc= compressive strength of concrete at 28 days in Mpa,$b_w d$= width and depth of effective cross section in mm,p=longitudinal reinforcement ratio a/d= shear span to depth ratio more of researchers suggested that 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. Sam and Hong(2006) reported that that the Zustty's equation has given the best model amongst the models studied.

Table 3 :Predicted and Experimental Results However for beams with strirrups, MCFT provides most accurate results.

Beam ID	f_c' Mpa	a/d	V_{exp} (kN)	$V_{predicted}$ (kN)				
				ACI CODE	CAN CODE	CEP-FIP MODEL	ZSUTTY EQ	BAZANT EQ
R01	70	1	129	35.36	24.19	51.75	131.79	62.90
R02	70	2	78.5	27.36	24.19	52.31	52.31	32.51
R03	70	3	55.5	24.69	24.19	36.56	36.56	28.35
R04	70	4	42.5	23.35	24.19	33.22	33.22	27.14

Shear design by Bazant equation(1987)

$$Vc = .54\sqrt[3]{p}\ (\sqrt{fc} + 249\ \sqrt{p/(a/d)^3})\ x\ \frac{1+\sqrt{5.08/d_0}}{\sqrt{1+d/(25d_0)}}\ bw \times d$$

The Equation stated by Bazant (1987) 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. The experimental results and theoretical value obtained for shear capacity are shown in table 3.it revealed from the table ACI code underestimates the shear capacity of high strength concrete beams without web reinforcement. Canadian code has not taken into account the effect of shear span to depth ratio. The shear resistance of HSC member predicted based on Canadian code, underestimates the actual shear capacity of member at all a/d ratios. Shear capacity of the HSC members predicted based on CEPFIP model, showed lower values at all a/d ratios. Shear resistance of HSC members using Zsutty Equation closely predict the shear capacity of high strength concrete beams without web reinforcement. To estimate the shear resistance (Vc) a linear regression equation was set in power series

$$Vc = 32((ft /(a/d))p)0.8\ bw\ d$$

The proposed equation can fairly estimate the shear resistance of HSC beams without stirrup reinforcement, under shear loading. Imran, A. B., et al. (2008[14]) present a paper in which a comparative analysis on shear behavior of high-strength concrete beams using various international design approaches like ACI , Canadian , AASHTO , European Code and the method proposed by Zararis is presented. Twenty-seven reinforced concrete beams without web reinforcement were tested under three point loading. The experimental shear strength was found greater than that predicted as per different shear design approaches; however for slender beams having a/d ranging from 2.5 to 6, the predicted shear capacity was found greater. It was noted that ACI 318-02 predicts shear strength more accurately for values of tensile steel ratio greater than 1 %, whereas

design approach proposed by Zararis is more appropriate to be used where tensile steel ratio is less than 1%.Based on test results of 27 beams and tests conducted earlier on 95 similar beams, It is observed that: When shear span-to-effective depth ratio increases from 2 to 3, relative flexural strength decreases, however, this decrease is dependent upon the tensile steel ratio as the greater the steel ratio, the lower is the difference. On further increase of a/d ratio from 3 to 6, The relative flexural strength increases and a valley of diagonal shear failure was observed in the vicinity of shear span–to-depth ratio equal to 3. For a constant value of a/d ratio, the relative flexural strength decreases and failure load increases with an increase in longitudinal reinforcement ratio. Comparison of test results with various approaches reveals that the experimental shear strength is more in conformity with ACI 318-02 than other design approaches for beams having tensile steel ratio higher than 1 %. Current ACI 318 shear strength equation could be unconservative for lightly reinforced high-strength concrete beams having tensile steel ratio < 0.58%. However, it is observed that approach proposed by Zararis predicts shear capacity more effectively for values of tensile steel ratio less than 1%.. The current shear design approaches in various codes underestimate the shear carrying capacity of high-strength concrete beams up to shear span-to-depth ratio 2.5 and overestimate for slender beams having a/d ranging from 2.5 to 6. Analysis of the research results revealed that shear strength and failure mode depends on shear span and longitudinal reinforcement ratio. Ahmad,S.H., et al (2011) [2] present , an analytical study is conducted to evaluate the predictive accuracy of Euro code EC2 equation or 11 other empirical equations proposed in the literature by several researchers for predicting
the shear capacity of deep reinforced concrete beams. The results indicate that for normal strength as well as high strength reinforced concrete deep beams, the Euro code EC2 predictions are overly conservative. Among the eleven (11) empirical equations, empirical equation proposed by Karim et al is identified to be superior to the other proposed equations.

IV. Conclusion

Experimental study done by the various researchers is imply the shear behaviour cannot be controlled by taking one parameter .There is a number of parameter and take care of every parameter is important. Following are the parameter.

- Shear span to depth ratio effect more dominant on the load transfer mechanism and propagation of crack in the beam during the loading condition. As soon as shear span to depth ratio is increased. The beams more prominent to flexural failure.
- Analysis of the research results revealed that shear strength and failure mode depends on shear span and longitudinal reinforcement ratio.
- The use of high strength steel (known as microcomposite multistructural formable (MMFX) can change the mode of failure.
- The shear strength and failure mode is largely depend upon the percentage of tensile reinforcement. The ductility zone can be taken care by the tensile reinforcement without brittle
- The load carrying capacity is more with less deflection if the a/d ratio is less

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