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Evaluation of Shear Strength Approaches of SFRC Deep Beams without Stirrups

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Abstract: The addition of steel fibres can be developed the mechanical properties and the crack control characteristics of concrete. In the last four decades, a lot of methods have been developed to estimate the shear strength of steel fiber reinforced concrete (SFRC) deep beams. In this study, seven different researchers' predictions are compared with the test beams without stirrups. Although calculating of the shear strength of steel fiber reinforced concrete deep beams is a complex phenomenon, these researchers proposed different reasonable equations. Twenty nine beams has been obtained from existing sources of RC deep beam shear test results covering a wide range of beam properties and test methods. All the equations compared with their mean values, standard deviations and coefficient of variation. It is found that the equation proposed by Ashour et al. (1992) shows good agreement with regard to existing test results, giving the less coefficient of variation value than the other equations.

Keywords: Reinforced concrete, Deep beam, Shear strength, Steel fiber

Introduction

Concrete is a brittle structural material that easily fails under the shear force due to the behavior of its low tensile strength. Thus, shear reinforcement should be included in the concrete by using stirrups or different types of fibers. Calculation method of the shear strength of a beam changes clearly depending on the shear span to effective depth ratio (α/d). When α/d is lower than 2.5, it can be called as a deep beam and all evaluations should be made according to this phenomenon. Nowadays, there are many theoretical and experimental studies in prediction of steel fiber reinforced concrete (SFRC) deep beams. Especially, predicting of the shear strength of deep beams is an important issue for researchers because the behavior of beams is complex to propose a simple empirical equation.

In order to predict the shear strength of deep beams more accurately, many researchers developed different acceptable equations. Researchers usually suggest shear equations to calculate the shear strength, and compare the equations' results with experimental ones. High-strength SFRC beams that subjected to combined flexure and shear were examined to figure out the impact of fibers on beam behavior (Ashour et al. 1992). Ashour et al. (1992) predicted an equation for the shear strength of SFRC beams and the equation showed good correlation with the experimental results. The main parameters of the equation were the steel fiber factor (F), the longitudinal steel reinforcement ratio (ρ) and α/d. Similarly, in the study of Imam et al. (1994), some high strength SFRC beams that subjected to bending moment and shear force were tested to suggest more accurate shear strength prediction. Khuntai et al. (1999) studied in shear behavior for not only normal and high strength SFRC beams but also the other factors such as F, α/d, ρ and size effect. Based on this factors, an equation was presented to estimate the ultimate shear strength.

In the study of Narayanan and Darwish (1987), to determine shear behavior of SFRC beams, simply supported rectangular beams were tested under concentrated loads. An empirical equation was suggested to calculate shear strength of SFRC deep and slender beams, comparing computed and experimental values. Similar to this research, Kwak et al. (2002) proposed shear strength equation for deep beams considering some effective parameters. Li et al. (1992) tested SFRC beams under three point bending test to examine the shear strength equation considering the flexural and splitting tensile strength and size effect. The research concluded with the fact that the fiber reinforcements turned the tensile properties improvements into shear improvements.

The aim of this research is to determine the most reasonable estimation, comparing the shear strength equations which proposed by seven researchers that exist in the literature. Therefore, this study includes 29 SFRC deep beams obtained from earlier approaches (Ashour et al. 1992; Imam et al. 1995; Kwak et al. 2002; Li et al. 1992; Lim et al. 1987; Mansur et al. 1986; Narayanan and Darwish 1987). The changing parameters that are examined with respect to various proposed empirical equations, can be summarized as follows; the volume fraction of steel fiber (V_f), compressive strength of concrete (f_c) and F, ρ and α/d.

Shear Strength of Deep Beams with Steel Fiber

Existing Shear Strength Predictions

Seven investigators (Ashour et al. 1992; Imam et al. 1994; Khuntai et al. 1999; Kwak et al. 2002; Li et al. 1992; Narayanan and Darwish 1987; Sharma 1986) predicted the shear strength of SFRC deep beams without stirrups via empirical equations. These seven various equations for evaluation of the ultimate shear strength are provided in Table 1.

Table 1. Shear Strength Equations

Researchers	Equations
Ashour et al. (1992)	$v_u = \left(0{,}7 * \sqrt{f_c} + 7F\right) * \frac{d}{a} + 17{,}2\rho * \frac{d}{a}$
Imam et al. (1994)	$v_u = 0{,}7\left(\frac{1}{\sqrt{1+\frac{d}{25d_a}}}\right) * \sqrt[3]{\rho} * \left(f_c^{0{,}44}(1+\mathrm{F}^{0{,}33}) + 870 * \sqrt{\frac{\rho}{\left(\frac{a}{d}\right)^5}}\right)$
Khuntai et al. (1999)	$v_u = \left(0{,}167\left(2{,}5\frac{d}{a}\right) + 0{,}25F\right)\sqrt{f_c}$
Kwak et al. (2002)	$v_u = 3{,}7\left(3{,}4\left(\frac{d}{a}\right)\left(\frac{f_c}{20-\sqrt{F}} + 0{,}7 + \sqrt{F}\right)^{2/3}\left(\rho\frac{d}{a}\right)^{1/3}\right) + 0{,}8(0{,}41\tau F)$
Li et al. (1992)	$v_u = 9{,}16\left((f_t)^{2/3}(\rho)^{1/3}\left(\frac{d}{a}\right)\right)$
Narayanan and Darwish (1987)	$v_u = \left(2{,}8\frac{d}{a}\right)\left(0{,}24\left(\frac{f_c}{20-\sqrt{F}} + 0{,}7 + \sqrt{F}\right) + 80.\rho\frac{d}{a}\right) + 0{,}41\tau F$
Sharma (1986)	$v_u = \frac{2}{3}f_t\left(\frac{d}{a}\right)^{0{,}25}$ $\quad f_t = 0.79\sqrt{f_c}$

The equation of Sharma (1986) includes tensile strength of concrete (f_t) that depends on f_c and α/d. Narayanan and Darwish (1987) and Kwak et al. (2002) introduced the ultimate bond stress (τ) that equals to 4.15MPa in their equations. In the predictions, F depending on length of fiber (L_f) diameter of fiber (D_f), volume fraction of fiber (V_f) and a constant value which called bond factor (d_f) were assigned a relative value of 0.75 for crimped fibers and 1.0 for indented fibers. These factors were involved into the fiber factor formula given by $F=(L_f/D_f)*V_f*d_f$ and α/d as in Sharma's equation. Li et al. (1992) proposed an equation as a modified form of Sharma's equation through introducing ρ. The expression of Ashour et al. (1992) incorporates the same factors that were included in the equation of Narayanan and Darwish (1987) except τ. Kwak et al. (2002) proposed a shear strength equation which has the same parameters of Narayanan and Darwish's equation, involving different constants. Similar to the expression of Ashour et al. (1992), Khuntai et al. (1999) proposed their prediction which does not include ρ. The maximum aggregate size (d_α) is considered in the prediction of Imam et al. (1994) which differs from Ashour et al.'s equation.

Experimental Shear Strength Beams

The test beams obtained from the literature divided into two different groups according to their f_c values. Some of the SFRC deep beams' f_c values less than 50 MPa so they have been called as normal strength concrete (NSC) deep beams, similarly the others have been called high strength concrete (HSC) deep beams that have f_c values which are greater than 50 MPa.

Narayanan and Darwish's (1987) beams have crimped fibers whereas the others have hooked end fibers. The beams also have different values of α/d to determine size effect and these values range from 1.0 to 2.0. In addition to α/d, V_f values range from 0.25% to 2%. The shear strength equations that obtained in the literature incorporate the length of steel fiber to diameter of steel fiber ratios (L_f/D_f) ranging from 60 to 133 and ρ values ranging from 0.011 to 0.057.

Evaluation of Shear Strength Predictions

The ultimate shear strength values of SFRC deep beams have been predicted by calculating with the seven equations and compared with the experimental data. For this comparison among the equations, the mean values (MV), standard deviations (SD) and coefficient of variation (COV) values are given in Table 2.

Table 2. Statistics of the ratios of experimental values to predictions

Researchers	MV	SD	COV
Ashour et al. (1992)	0.958	0.184	0.192
Imam et al. (1994)	0.775	0.250	0.323
Khuntai et al. (1999)	1.832	0.367	0.200
Kwak et al. (2002)	0.907	0.187	0.206
Li et al. (1992)	0.813	0.240	0.295
Narayanan and Darwish (1987)	1.119	0.245	0.219
Sharma (1986)	1.571	0.463	0.295

The proposed equations by Khuntai et al. (1999) and Sharma (1986) overestimate the ultimate shear strength of the SFRC deep beams included in this research, predicting the shear strength values approximately 83% and 57% higher than the test data respectively, whereas the equations proposed by Imam et al. (1994) and Li et al. (1992) underestimate the experimental shear strength, giving approximately 22% and 19% less values than the test results respectively. It is clearly observed that the equation proposed by Ashour et al. (1992) provides the most accurate estimation for the beams. The estimations of the equations by Kwak et al. (2002) and Narayanan and Darwish (1987) also give good agreements with regard to existing test results. When the statistics of the Table 2 were considered, it can be observed that MV corresponding to the equation by Ashour et al. (1992) is the closest value to 1, equals to 0.958 with the least COV value that equals to 0.192.

The equation of Ashour et al. (1992) should be examined in terms of α/d, V_f, f_c and ρ since the best estimation was provided by this equation according to Table 2. The expression has been examined through the following Figure 1 to figure out how it shows agreement with the phenomena for both NSC and HSC.

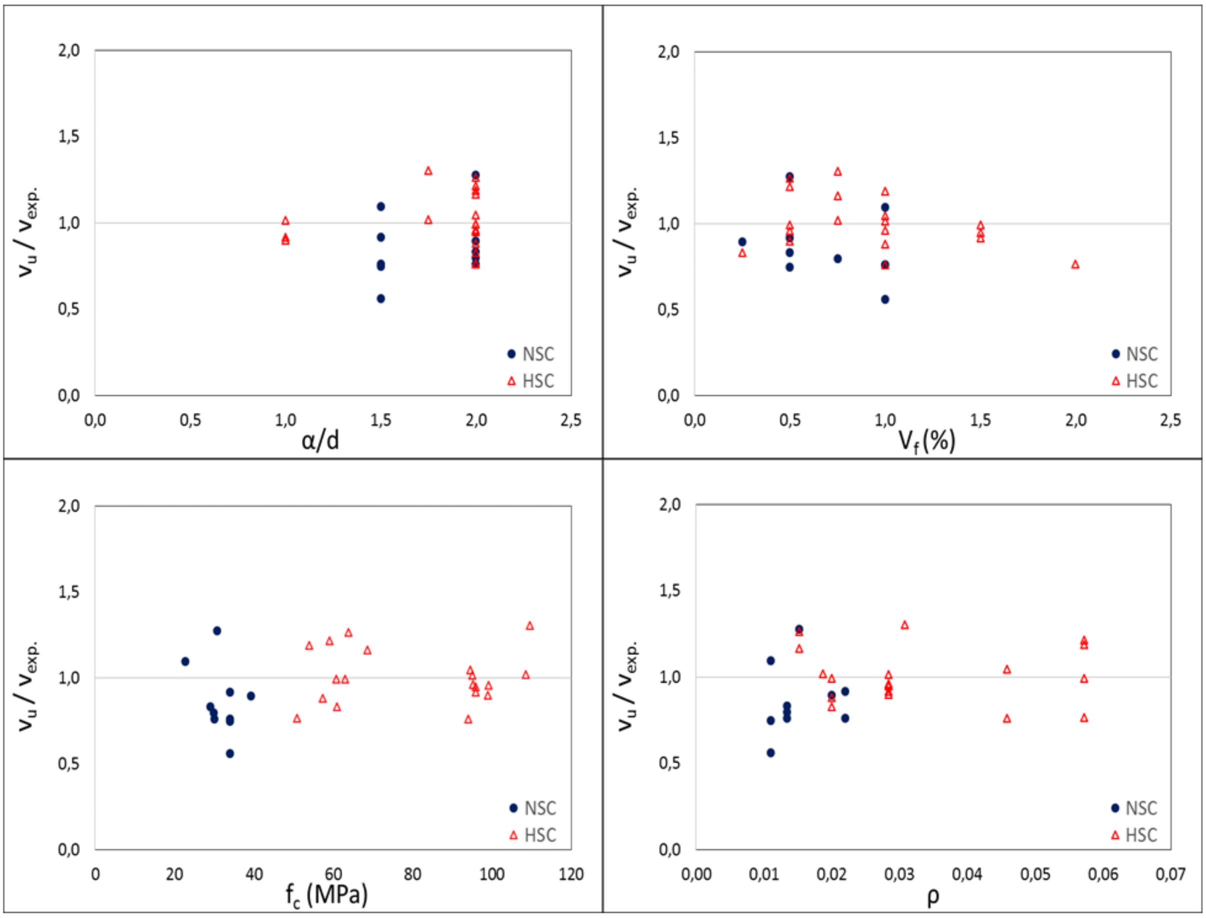

Figure 1. Comparison of test results with Ashour et al.'s prediction

The experimental data of this research were limited for NSC and HSC deep beams to determine how the equation predicts the shear strength whereas α/d, V_f, f_c and ρ change respectively. As shown in Figure 1, the calculated values by the equation to experimental one of the ultimate shear strength ratio $v_u/v_{exp.}$ yields large scatter in the results for both NSC and HSC deep beams when the α/d is higher than 1. However, $v_u/v_{exp.}$ Values range from 0.902 to 1.014 when α/d is 1, hence it can be said that the equation shows good agreements with regard to existing test results if α/d equals to 1 with a success ratio which is approximately 96%. Even if ρ shows changing values from 1.1% to 5.7% or V_f shows changing values from 0.25% to 2%, $v_u/v_{exp.}$ also provides a large scatter in the results. If f_c is higher than 50 MPa, the predictions are more reasonable though the equation gives the results that are a little far from the experimental shear strength values through decreasing f_c. It can be concluded that, α/d and f_c are more critical than V_f and ρ for the ultimate shear strength predictions that obtained from the equation.

Conclusion

When the ultimate shear strength predictions of SFRC deep beams by seven researchers' equations obtained in the literature, the consequences were determined as follows:

Sharma (1986) and Khuntai et al. (1999) overestimate the ultimate shear strength of the SFRC deep beams, on the other hand Imam et al. (1994) and Li et al. (1992) predict the ultimate shear strength, giving lower values than the test results.

The predictions of Kwak et al. (2002) and Narayanan and Darwish (1987) are more reasonable with a realistic approach of the ultimate shear strength. The best prediction of the ultimate shear strength of SFRC deep beams was provided by Ashour et al. (1992), yielding predictions near to experimental data and the lowest COV value.

Changing of V_f and ρ have no significant impacts on the ultimate shear strength prediction of the equation by Ashour et al. (1992) for NSC and HSC deep beams. When α/d equals to 1 or f_c is high, Ashour et al. (1992) equation has the most accurate estimations.

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