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EVALUATION OF SHEAR RESISTANCE OF HIGH STRENGTH CONCRETE BEAMS WITHOUT WEB REINFORCEMENT USING ANSYS

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ABSTRACT

The paper attempts to predict the shear strength of high strength concrete beams (70 Mpa) with different shear span to depth ratios (a/d = 1, 2, 3 and 4) without web reinforcement. The reinforced concrete beams are tested under shear loading and are modeled in 'ANSYS', which is Finite Element Analysis software. The test results are compared with the 'ANSYS' model results. The shear capacity evaluated using 'ANSYS' model for the beams are closer to test results. Thus a simplified equation has been evaluated using the previous database and the ANSYS model, to predict the shear capacity of high strength concrete beams without shear reinforcement.

Keywords: model, concrete beams, shear strength, shear span to depth ratio, finite element analysis, ANSYS.

1. INTRODUCTION

Utilization of high strength concrete in construction sector has increased due to its improved mechanical properties compared to ordinary concrete. One such mechanical property, shear resistance of concrete beams is an intensive area of research. To Estimate the shear resistance of beams, standard codes and researchers all over world have specified different formulae considering different parameters into consideration. The parameters considered are varying for different codes and researchers leading to disagreement between researchers, making it difficult to choose an appropriate model or code for predicting shear resistance of reinforced concrete. Therefore an extensive research work on shear behavior of normal and high strength concrete is being carried out all over the world. The major researchers include Bazant [1], Zsutty, [2] Piotr Paczkowski [3], Jin-Keun [4], Imran [5] and many more. Estimation of shear resistance of high strength concretes is still controversial therefore it's a thrust area for research.

The shear failure of reinforced concrete beams without web reinforcement is a distinctive case of failure which depends on various parameters such as shear span to effective depth ratio (*a*/*d*), longitudinal tension steel ratio (ρ), aggregate type, strength of concrete, type of loading, and support conditions, *etc*. Most of the researchers concluded that failure mode is strongly dependent on the shear span to depth ratios (*a*/*d*). Berg [6], Ferguson [7], Taylor [8] found that shear capacity of Reinforced concrete beams varied with *a*/*d* ratio. In this research, shear span-to-effective depth ratio is taken as main variable keeping all other parameters constant.

Fanning [9] evaluated reinforced and post tensioned concrete beams using the ANSYS package. Kotosov and Pavlovic [10] analyzed short shear reinforced concrete beams using 3D finite element approach to validate the rational prediction of its behavior observed in the test program. Zho [11] analyzed nonlinear behavior of reinforced concrete deep beams using a 2D finite element method. The present study concentrates on details of the finite element analysis of four shear critical high strength rectangular beams having no shear reinforcement. The finite element analysis of the tested beams is carried out in 'ANSYS' package considering perfect bond between the tension reinforcement and the surrounding concrete. The predicted results using 'ANSYS' model, have been compared with the corresponding test data.

1.1 Objectives

- Study the shear response of concrete beams without shear reinforcement varying shear span to depth ratio (a/d) from 1 to 4 (1,2,3 and 4);
- Develop and analyze the high strength concrete (HSC) beam model in ANSYS and compare the results with the test data; and
- To propose a simplified formula to predict shear strength of HSC beams without shear reinforcement.

2. MATERIALS AND METHODS

Eight reinforced high strength concrete (HSC) beams are cast and tested, under two point loading, varying the shear span to effective depth ratio (a/d). The test specimens are divided into four series. Each series consisted of two high strength concrete beams without shear reinforcement with a/d ratio 1, 2, 3 and 4. For all the series, the parameters viz., concrete proportions and percentage of longitudinal steel are kept constant. The details of the beams cast are listed in Table-1.

2.1 Test materials

Cement

Ordinary Portland cement whose 28- day compressive strength was 53Mpa was used.

Fine aggregate

Natural River sand confirming with specific gravity is 2.65 and fineness modulus 2.33 was used.

Coarse aggregate

Crushed Coarse aggregate of 20mm and 10 mm procured from local crusher grading with specific gravity is 2.63 was used.

Water

Portable water free from any harmful amounts of oils, alkalis, sugars, salts and organic materials was used for proportioning and curing of concrete.

Super plasticizer

In the present experimental investigations naphthalene based superplasticizer conplast337 was used for enhancing workability.

Fly ash

Class F fly ash was used acquired from KTPS, Kothagudam, Andhra Pradesh, India.

Ground granulated blast furnace slag

The slag was procured from Vizag. The physical requirements are confirming to confirming to IS 12089 1987 [12].

Tension reinforcement

16 mm diameter bars are used as tension reinforcement whose yield strength was 475Mpa.

2.2 Mix design

The high strength concrete mix design was done using Erntroy and Shacklock method [13]. By conducting trial mixes and with suitable laboratory adjustments for good slump and strength the following mix proportion was arrived as shown in Table-2.

Table-1. Reinforced beams without shear reinforcement.

#	Beam Designation	Length of beam (m)	a/d Ratio	No. of Beams
1	R01	0.7	1	2
2	R02	1.0	2	2
3	R03	1.3	3	2
4	R04	1.6	4	2

Table-2. Mix proportion of concrete.

Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (lit)	Fly ash (By mass. of cement)	GGBS (By mass. of cement)	Super plasticizer (By mass. of cement)
520	572	1144	130	5%	15%	1.5%

2.3 Specimen details

Tests are carried out on sixteen beams, simply supported under two point loading. The beam cross section adopted is 100mm x 150mm, illustrated in Figure-1 (constant for all beams). The length of beam was worked out to be 0.7m, 1.0m, 1.2m and 1.6m for corresponding a/d ratio = 1, 2 , 3 and 4 respectively. All the four series of beams are provided with 3-16 mm diameter HYSD bars as longitudinal reinforcement to avoid any possible failure by flexure. The grade of concrete (M70) is kept constant for all the beams.

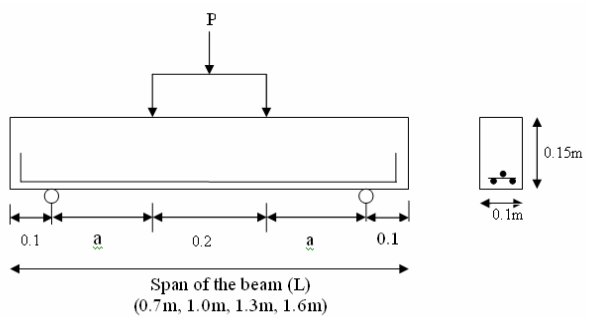

Figure-1. Details of test beams with arrangement of loads and supports.

2.4 Test procedure

The beams are tested under gradually increasing load using a 100 ton loading frame. The beam is simply supported using knife edge support which are placed on two support beams (I sections) shown in Figure-2. The specimen is loaded using a 100 ton jack which has a load cell to monitor the load. The load was transferred from the jack to specimen at two points using a spread beam. Based on the a/d ratio the support beams on which the simple supports are placed and adjusted. Two LVDT’s are provided, one at the centre of the span and other at the centre of the shear span to measure deflections. The load and deflections are monitored for every 5 seconds. The load that produced the diagonal crack and the ultimate shear crack are recorded. Crack patterns are marked on the beam. The average response of two beams tested in a series, is taken as the representative response of the corresponding series. The test set up is presented in Figures 2 and 3.

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Figure-2. Beam and LVDT arrangement in 100 ton loading frame.

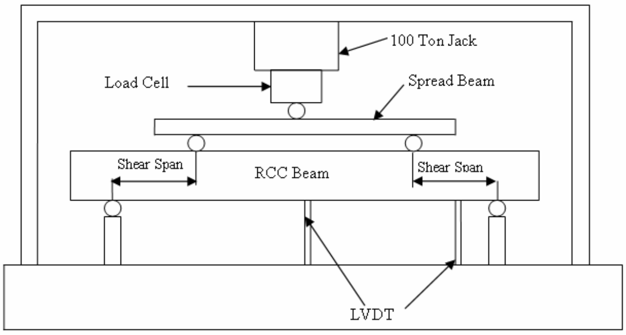

Figure-3. 100 ton loading frame with the test setup.

3. FINITE ELEMENT ANALYSIS OF HSC BEAM USING 'ANSYS'

The finite element method is a numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. ANSYS is a general purpose finite element modeling package for numerically solving a wide variety of problems which include static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems. The HSC beams with tensile reinforcement and without shear reinforcement have been analyzed using a finite element (FE) model in ANSYS. The 'ANSYS' model accounts for the non-lineraties, such as bond-slip of longitudinal reinforcements, post-cracking tensile stiffness of the concrete, stress transfer across the cracked blocks of the concrete. The analysis was carried out in stages using Newton-Raphson technique. The last sub step results after convergence of the solution are adopted.

4. MODELING OF CONCRETE AND REINFORCEMENT

The concrete has been modeled using 'SOLID65' defined as eight node brick element capable of simulating the cracking and crushing of brittle materials. The compressive strength and tensile strength are established based on test data of the specimens cast and tested along with the rectangular beams. The data was used for defining concrete ('CONCR') properties in 'ANSYS'. Before cracking or crushing, concrete is assumed to be an isotropic elastic material. After crushing, the concrete is assumed to have lost its stiffness in all directions. The concrete young's modulus is taken as 33500MPa and the Poisson's ratio as 0.2. In the present analysis a constant mesh size of 50mm is assumed. The meshed solid is presented in Figure-4.

The longitudinal reinforcement i.e., the High Yield strength deformed (HYSD) have been modeled using LINK8 3D Spar element. The 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions with large deflection capabilities. The cross sectional area of each element is given as area equivalent to each rebar. The rebar young's modulus is taken as 2 x 10^5 MPa and Poisson's ratio as 0.3. For the rebar the same mesh size as that of concrete element is adopted. Perfect bond between concrete and reinforcement is ensured between the two elements in ANSYS. The Figure-4 shows a typical beam modeled in ANSYS for a/d =1 with element mesh size of 25mm.

5. DISCUSSION ON TEST RESULTS

The variation of deflection with load of HSC beams without shear reinforcement for a/d = 1, 2, 3, and 4 are shown in Figure-5, which indicate the increase in a/d ratio has shown reduction in shear capacity of the beam. At lower a/d ratios the ultimate load was observed to be more than twice at diagonal cracking. The deflections increased with a/d ratio, which signify that at lower a/d ratios i.e., up to 2 the strut behavior and above 2 the arch behaviour of the beams. At lower a/d ratios (up to 2), the failure was observed to be sudden compared to failure pattern observed for higher a/d ratio (a/d - 2 to 4).

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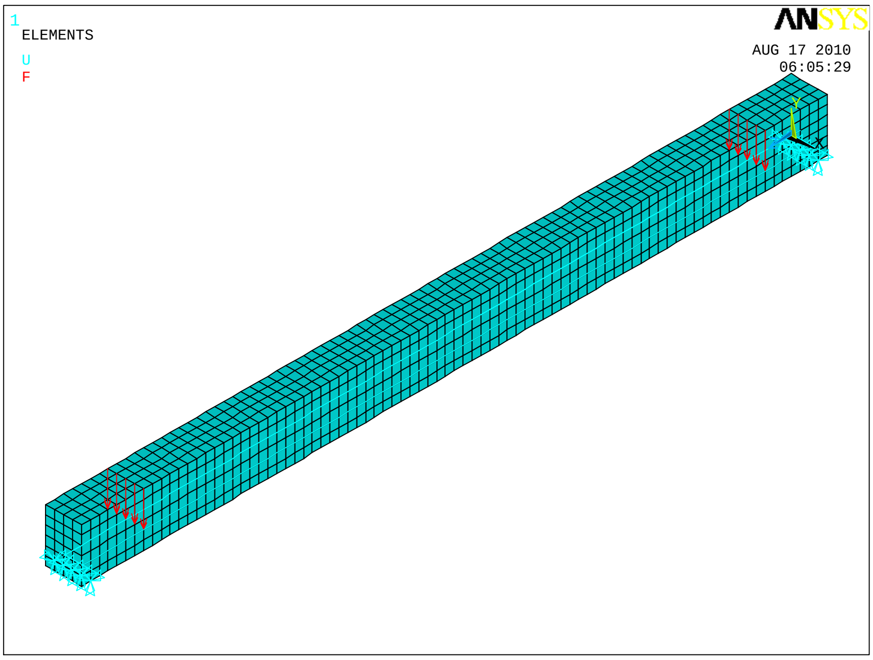


Figure-4. ANSYS modeled beam for a/d =1.

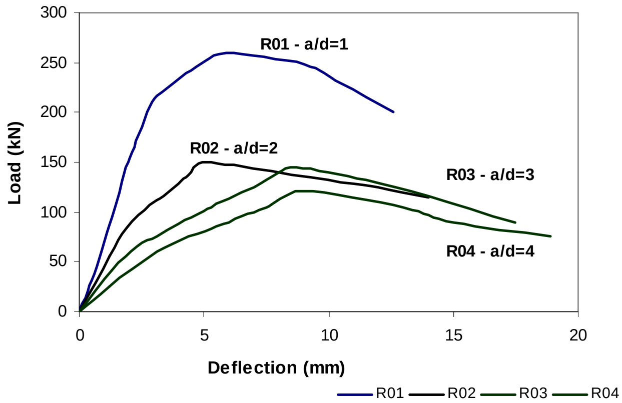
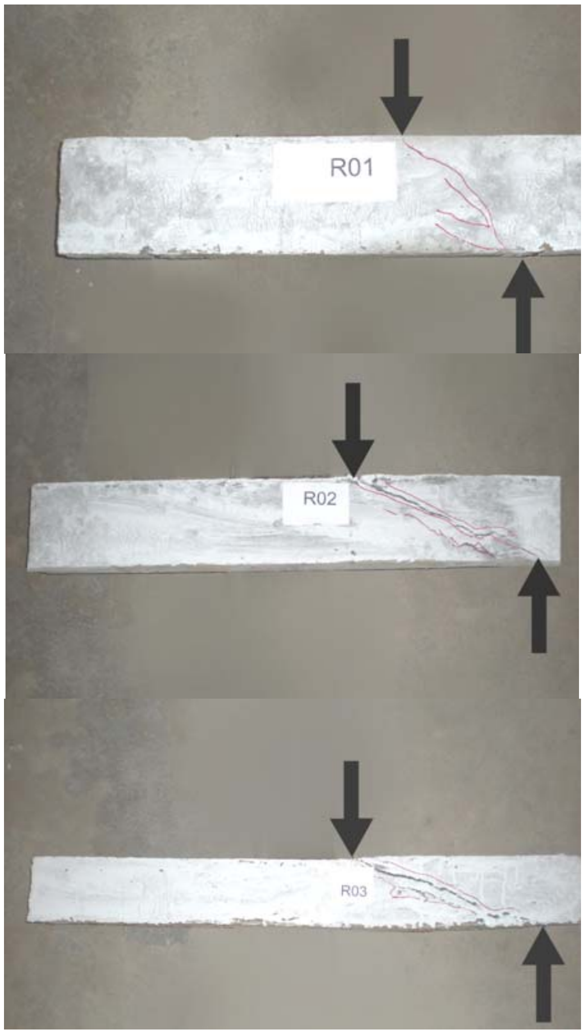


Figure-5. Load - deflection illustration for R01 (a/d=1), R02 (a/d=2), R03 (a/d=3) and R04 (a/d=4).

The failure pattern of the beams shown in Figure-6 clearly exemplify that for a/d 1 and 2 crack initiated approximately at 45 degree called as web shear crack, across the neutral axis before a flexural crack appeared . A compression failure finally occurred adjacent to the load which may be designated as a shear compression failure. For a/d 3 and 4 the diagonal crack started from the last flexural crack and turned gradually into a crack more and more inclined under the shear loading. The crack did not proceed immediately to failure, the diagonal crack moved up into the zone of compression became flatter and crack extended gradually at a very flat slope until finally sudden failure occurred up to the load point. The failure may be designated as diagonal tension failure.



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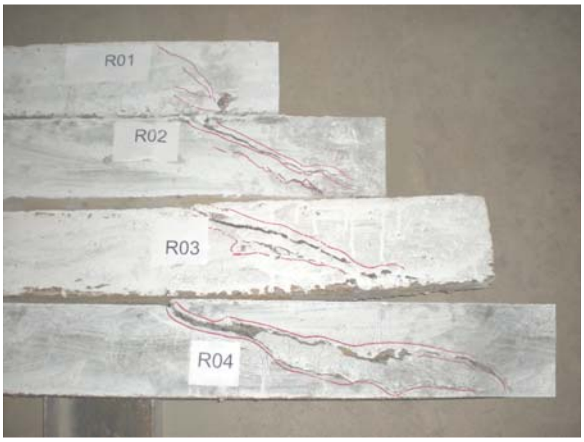

Figure-6. Crack patterns and load points of the failed specimens- R01, R02, R03 and R04.

The Load- Deflection response of HSC beams without shear reinforcement has been compared with the experimental results in Figure-7. The illustration articulate, at the initial stage of loading the ANSYS model data overlapped with the test data, where as in the post crack regime it was found to be smoother compared to experimental results. The variation in the results may be attributed to the difference in bond characteristics of concrete and reinforcement in the model and the test. The ANSYS model could predict the results modestly up to the ultimate load. The model could not predict the load-deflection response in the post crack regime as the elements are distorted above the specified limit leading to failure of the specimen. The behaviour of concrete elements modeled in ANSYS is as such that after crushing to maximum extent (that is after third crack represented in blue color in ANSYS crack and crush model) the material shows a softening behaviour in all direction resulting in distortion of all the linked elements.

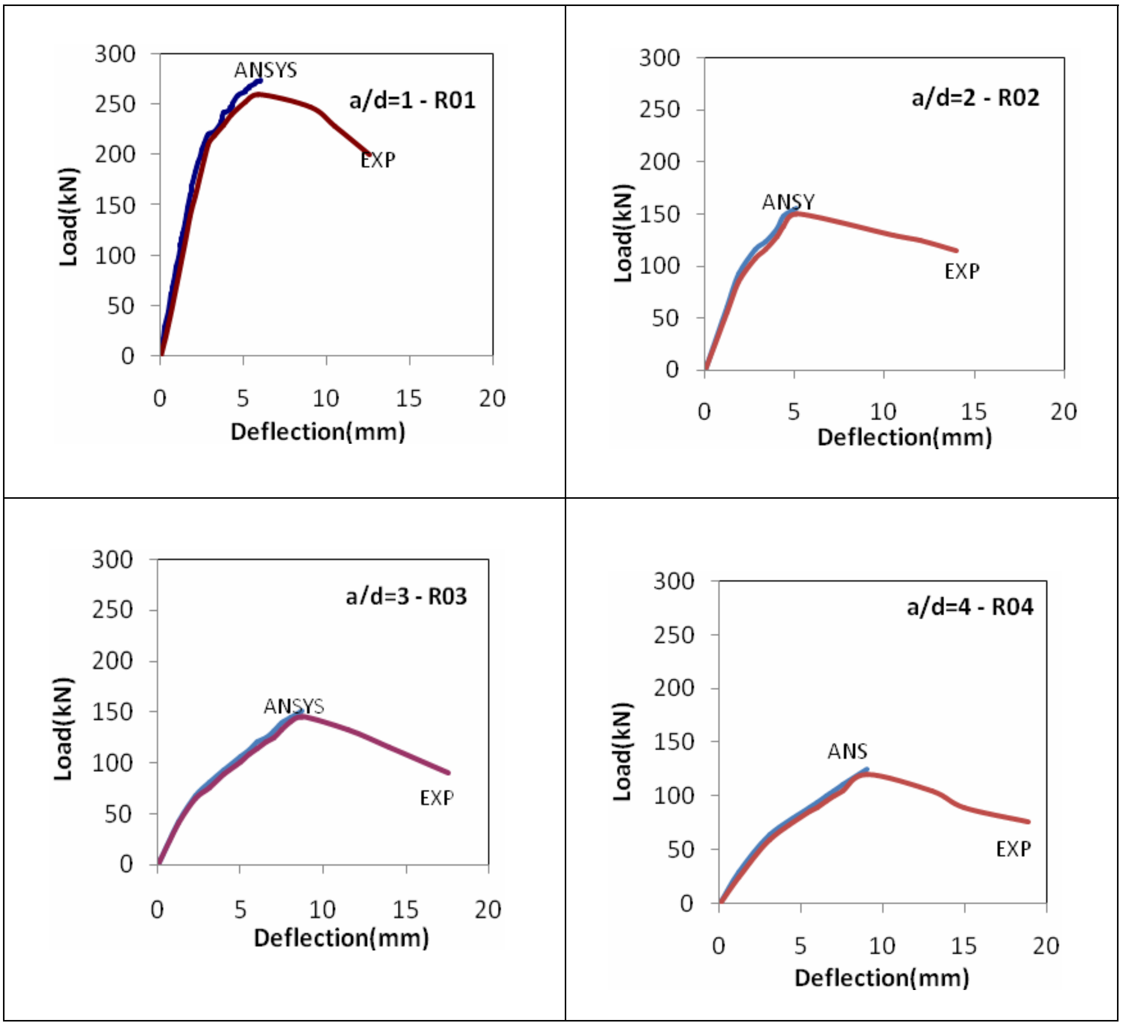

Figure-7. Comparison of response of load - deflection for experimental and ANSYS results for a/d =1, 2, 3 and 4.

The first crack observed in the shear span during the testing of the beam was found to be similar in the ANSYS predicted model. In further stages of loading of ANSYS predicted model the cracks propagated through

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the shear span and new cracks emerged at the constant moment zone at the loads closer to ultimate load. The orientations of cracks predicted by the model are inclined in the shear span region and vertical in constant moment region. The crack patterns and the order of cracks predicted by ANSYS model are in confirming with experimental observations. During the test process, at ultimate load the inclined crack in shear span widened and concrete under the load point crushed. The ANSYS model predicted the crushing of concrete at ultimate by indicating large distortion of element nodes. The crack patterns indicate purely shear failure at a/d =1 and 2 and shear – flexure failure at a/d =3 and 4. The crack pattern observed in ANSYS model at failure is illustrated in Figure-8.

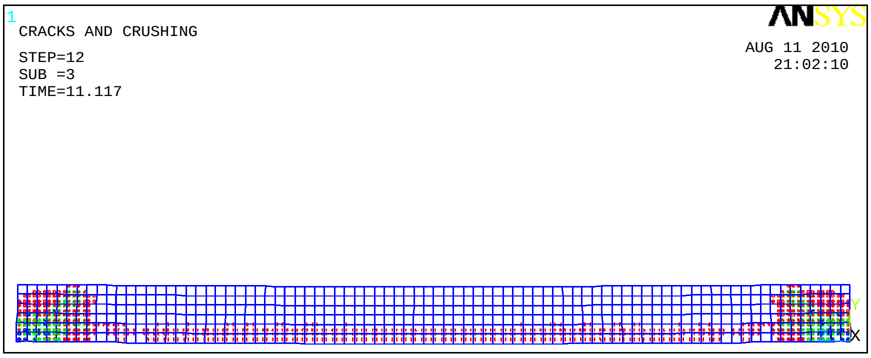

Figure-8. Crack pattern of ANSYS modeled beam at failure.

As the present research work focuses on enhancement of shear capacity of HSCB without web reinforcement, the tensile strength of concrete plays a vital role. The shear equations proposed by different researchers and codes viz., Bazant [1], ACI code [14], CSA Technical Committee[15], CEB-FIP model [16] 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, the tensile strength of concrete and tensile reinforcement ratio has a direct proportionality relation and shear span to depth ratio (a/d) has a inverse proportionality relation. Therefore to estimate the shear capacity of HSCB the parameters viz.., tensile strength of concrete, shear span to depth ratio (a/d) and tensile reinforcement ratio are taken into account in form of Shear Influencing Parameter (SIP).

$$SIP = \left(\frac{f_t}{\left(a/d\right)} \right) \rho \qquad \text{.....................} (1)$$

f_t - Tensile strength of concrete in Mpa.
a/d - Shear Span to Depth Ratio.
ρ - Tensile Reinforcement Ratio.

The influence of shear resistance, which is taken as average value of the two specimens with the SIP calculated using Eq.1 is illustrated in Figure-9. To estimate the shear resistance (V_c) a linear regression equation is set in power series.

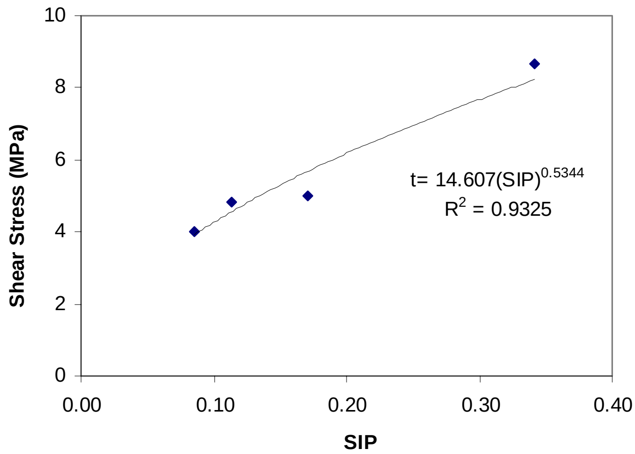

Figure-9. Variation of shear strength with shear influencing parameter (SIP).

$$V_c = 15\left(\left(\frac{f_t}{\left(a/d\right)} \right) \rho \right)^{0.5} b_w d \ \text{(N)}\text{..................} (2)$$

where

$b_w d$ - Width and depth of Effective cross section in mm.
The empirical shear stress values calculated from the Eq.2 and the shear stress values obtained by testing the beams for shear span to depth (a/d) ratio = 1, 2, 3 and 4 are listed in Table-3. The values clearly signify that the experimental and empirical values fall within +5% and -5% variation. Thus the proposed equation can fairly estimate the shear resistance of HSC beams without stirrup reinforcement, under shear loading.

Table-3. Experimental and empirical shear stress.

a/d Ratio	Experimental shear stress (MPa)	Empirical shear stress (MPa)
1	8.67	8.77
2	5.00	6.20
3	4.83	5.06
4	4.00	4.38

6. CONCLUSIONS

With the discussion on shear models and the experimental studies conducted on HSC beams without shear reinforcement the following conclusions can be drawn:

- The equation (Eq. 2) stated above includes almost all the parameters required to predict the shear capacity beams without shear reinforcement. Therefore a single simplified equation can be used to predict the shear capacity of HSC beams with a/d = 1, 2, 3 and 4.
- The ANSYS model closely predicted the diagonal tension failure and shear compression failure of high strength concrete beams with out shear reinforcement as observed in experiment.

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