Effect of Shear Span to Depth Ratio and Grade of Reinforcement (Yield Strength) on Shear Strength pf High Strength Concrete With Arificial Sand

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Abstract- *The paper attempts to predict the shear strength of high strength concrete beams (60 Mpa) with different shear span to depth ratios (a/d = 1, 1.5, 2 and 2.5) without web reinforcement. The beams of various size and spans are tested for flexure and shear, to get the shear contribution of the concrete with the characteristic compressive strength of high strength concrete grade 60MPa as defined in IS 456:2000. With three types of high strength steel grades used as tension reinforcement, different geometric dimensions of the beams and replacing the fine aggregates completely with the Manufactured sand. From the test data, equations will be formed by preparing graphs with varying parameters, and effort will be taken to establish a new empirical equation for the shear contribution of HSC with and without replacement of fine aggregates by manufactured sand. Effect of replacement of NaturalSand by Manufactured sand will also be studied for its effect as compared with Natural Sand..*

Keywords- High strength concrete, concrete beams, shear strength, shear span to depth ratio, finite element analysis, ANSYS.

I. INTRODUCTION

Present era is of Infrastructure development. Every developing country like India, have major concern in this regard. Researchers all over the world have developed the techniques of making higher grades of concrete as a primary and essential material used in the infrastructure development. Taking into consideration the development of new composites, there is wide scope of improvement in the methods of design adopted by regulating codes of various countries.Use of high strength concrete (HSC having cube compressive strength more than 60Mpa) has been increased considerably during the last two decades, since it can be produced reliably in the field, using low water cementratios with high quality water reducing admixtures. In future, HSC will be used more and more when durability of the structure is an important design parameter.

Taking into consideration, the rapid utilization of natural resources like river sand, and its effect on the environment and ecology, in future there may be a state of ban on the use of natural sand and we have to search for alternatives to replace this essential ingredient of concrete. It has been experimented by the researchers that, Manufactured sand (crushed stone) or bottom ash (Pond ash) from the waste of thermal power plants, can be used as alternative material for Natural sand. [C.Mathiraja, 2013]

Many studies performed on HSC examine the behavior of HSC members. It has been observed that, HSC can bring up the shear strength, its brittleness also increases compared to normal strength concrete. In high strength concrete, there is strong interface between cement paste and aggregate. The failure surface of HSC is smoother and thus lead to weaker post cracking shear resistance, due to less aggregate interlock. [Cladera and Mari, 2005]

1.1 OBJECTIVES

1. To study the effect of artificial sand replacing natural sand on shear strength of high strength concrete.(as an overall observation)
2. To study the effect of varying shear span to depth ratio on shear strength.
3. To study the effect of various grades of high yield strength steel and
4. To propose an empirical equation to comprise these parameters.

II RESEARCH SIGNIFICANCE

Need of using high strength concrete beams is highlighted by research findings. It is noted that the compressive strengths of concrete even with 100% replacement are higher than the concrete with 0% replacement suggesting that the locally available crushed stone fine aggregate can be considered as an alternative to the river sand. Therefore replacing natural sand with artificial sand is to be studied. Use of high grade concrete is meeting the requirement of high rise structures and special structures at various civil engineering projects. Thus design procedures of RCC elements for various aspects are needed to be reassessed.

III. EXPERIMENTAL INVESTIGATION

3.1Materials and Methods

The Detailed testing program is proposed as follows, in all 9×4=36 numbers of beams with artificial sand and 3×4=12 numbers of beams with natural sand are proposed to be tested for shear flexure under two point loading test to observe load-deflection behavior and crack pattern .The test arrangement is proposed as shown in figure-1. The experimental results are proposed to be validated by Finite element analysis using ANSYS.

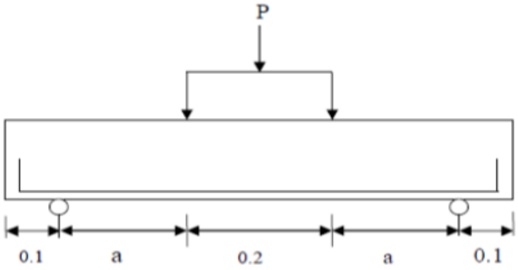


Figure-1. Proposed experimental set up for testing of beams

Thirty six reinforced high strength concrete (HSC) beams with artificial sand and twelve reinforced high strength concrete (HSC) beams with natural sand 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, 1.5, 2 and 2.5. 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 to Table-8.

Tests are carried out on thirty six beams, simply supported under two point loading. The beam cross section adopted is 150mm x 150mm. The length of beam was worked out to be 0.7m, 8.5m, 1.0m and 1.5m for corresponding a/d ratio = 1, 1.5, 2 and 2.5 respectively. All the four series of beams are provided with 2-8 mm diameter HYSD bars as longitudinal reinforcement to avoid any possible failure by flexure. The grade of concrete (M60) is kept constant for all the beams.

The beams are tested under gradually increasing load using a 120 ton Universal Testing machine. The beam is simply supported using knife edge supports which are placed on two support beams as shown in Figure-2. Based on the a/d ratio the support beams on which the simple supports are placed and adjusted. Deflection measuring devices 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.

Figure-2. Test set-up for the beam BM-B01-1-550

Table-1. Specimen with different Shear Span to Depth Ratio (a/d=1) using artificial sand

Beam Name	a/d ratio	Depth d mm	Width b mm	Span mm	a mm	Pt % Steel	No of Beam
BM-B01	1	150	150	700	150	0.25	03
BM-B02	1	150	150	700	150	0.25	03
BM-B03	1	150	150	700	150	0.25	03
						Total	**09**

Table-2. Specimen with different Shear Span to Depth Ratio (a/d=1.5) using artificial sand

Beam Name	a/d ratio	Depth d mm	Width b mm	Span mm	a mm	Pt % Steel	No of Beam
BM-B04	1.5	150	150	850	225	0.25	03
BM-B05	1.5	150	150	850	225	0.25	03
BM-B06	1.5	150	150	850	225	0.25	03
						Total	**09**

Table-3. Specimen with different Shear Span to Depth Ratio (a/d=2) using artificial sand

Beam Name	a/d ratio	Depth d mm	Width b mm	Span mm	a mm	Pt % Steel	No of Beam
BM-B07	2	150	150	1000	300	0.25	03
BM-B08	2	150	150	1000	300	0.25	03
BM-B09	2	150	150	1000	300	0.25	03
						Total	**09**

Table-4. Specimen with different Shear Span to Depth Ratio (a/d=2.5) using artificial sand

Beam Name	a/d ratio	Depth d mm	Width b mm	Span mm	a mm	Pt % Steel	No of Beam
BM-B10	2.5	150	150	1150	375	0.25	03
BM-B11	2.5	150	150	1150	375	0.25	03
BM-B12	2.5	150	150	1150	375	0.25	03
						Total	**09**

Table-5. Specimen with different Shear Span to Depth Ratio (a/d=1) using natural sand

Beam Name	a/d ratio	Depth d mm	Width b mm	Span mm	a mm	Pt % Steel	No of Beam
BM-B01	1	150	150	700	150	0.25	01
BM-B02	1	150	150	700	150	0.25	01
BM-B03	1	150	150	700	150	0.25	01
						Total	**03**

Table-6. Specimen with different Shear Span to Depth Ratio (a/d=1.5) using natural sand

Beam Name	a/d ratio	Depth d mm	Width b mm	Span mm	a mm	Pt % Steel	No of Beam
BM-B04	1.5	150	150	850	225	0.25	01
BM-B05	1.5	150	150	850	225	0.25	01
BM-B06	1.5	150	150	850	225	0.25	01
						Total	**03**

Table-7. Specimen with different Shear Span to Depth Ratio (a/d=2) using natural sand

Beam Name	a/d ratio	Depth d mm	Width b mm	Span mm	a mm	Pt % Steel	No of Beam
BM-B07	2	150	150	1000	300	0.25	01
BM-B08	2	150	150	1000	300	0.25	01
BM-B09	2	150	150	1000	300	0.25	01
						Total	**03**

Table-8. Specimen with different Shear Span to Depth Ratio (a/d=2.5) using natural sand

Beam Name	a/d ratio	Depth d mm	Width b mm	Span mm	a mm	Pt % Steel	No of Beam
BM-B10	2.5	150	150	1150	375	0.25	01
BM-B11	2.5	150	150	1150	375	0.25	01
BM-B12	2.5	150	150	1150	375	0.25	01
						Total	**03**

3.2 MIX DESIGN USING ARTIFICIAL SAND

The high strength concrete mix design is done using Indian Standard method. By conducting trial mixes and with suitable laboratory adjustments for good slump and strength the following mix proportion is arrived as shown in Table-9.

3.2.1 TEST MATERIALS

Cement

Ordinary Portland cement (Birla Super) whose 28-day compressive strength is 53 Mpa is used.

Fine aggregate

Crushed sand confirming with specific gravity is 2.71 and fineness modulus 5.29 is used.

Coarse aggregate

Crushed Coarse aggregate of 20 mm and 10 mm procured from local crusher grading with specific gravity is 2.75 is used.

Water

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

Super plasticizer

In the present H.R. Johnson (PC base) is used for enhancing workability.

Tension reinforcement

8 mm diameter two bars are used as tension reinforcement.

Table-9. Mix proportion of concrete.

Material	Basic Mix kg	Remark
Cement	540	
Crushed Sand	738	Saturated surface condition
10 mm	433	Saturated surface condition
20 mm	689	Saturated surface condition
Water	140	W/C ratio = 0.26
Admixture	5.4	Admixture = 1.00%

Table-10.28 days compressive Strength (N/mm^2) of concrete cubes.

Cube Designation	No. of cubes	28 days compressive Strength (N/mm2)
Cube1	1	69.78
Cube2	1	70.31
Cube3	1	68.28

3.3 MIX DESIGN USING NATURAL SAND

The high strength concrete mix design is done using Indian Standard method. By conducting trial mixes and with suitable laboratory adjustments for good slump and strength the following mix proportion is arrived as shown in Table-11.

3.3.1 TEST MATERIALS

Cement

Ordinary Portland cement (Birla Super) whose 28-day compressive strength is 53 Mpa is used.

Fine aggregate

Natural sand confirming with specific gravity is 2.66 and fineness modulus 4.97 is used.

Coarse aggregate

Crushed Coarse aggregate of 20 mm and 10 mm procured from local crusher grading with specific gravity is 2.75 is used.

Water

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

Super plasticizer

In the present H.R. Johnson (PC base) is used for enhancing workability.

Tension reinforcement

8 mm diameter two bars are used as tension reinforcement.

Table-11. Mix proportion of concrete

Material	Basic Mix kg	Remark
Cement	540	
Crushed Sand	774	Saturated surface condition
10 mm	433	Saturated surface condition
20 mm	689	Saturated surface condition
Water	140	W/C ratio = 0.26
Admixture	5.4	Admixture = 1.00%

Table-12.28 days compressive Strength (N/mm^2) of concrete cubes.

Cube Designation	No. of cubes	28 days compressive Strength (N/mm2)
Cube1	1	65.12
Cube2	1	64.34
Cube3	1	66.83

3.4 DEVELOPMENT OF SHEAR STRENGTH EQUATION FOR HIGH STRENGTH CONCRETE

Many equations have been developed by various researchers based on theoretical concepts and experimental data. Each equation has its own merit and demerits. Up till now no unique equation is available for prediction of shear strength. In this study it has been tried to find out the shear strength of rectangular reinforced beams without web reinforcement, considering Shear Span to Depth Ratio and Grade of Reinforcement and equations were developed for shear strength prediction. The shear capacity of reinforced concrete members is presently evaluated on the basis of empirical equations proposed by different International Building Codes with certain modifications in the equations for normal strength concrete. To further rationalize and generalize, these empirical equations for shear design of high strength reinforced concrete members, extensive research is required. This research is therefore an effort in this direction.

Present equation for shear strength contribution of concrete from IS 456:2000 does not take into account, the effect of various grades of the steel on the shear strength, that is to be verified by experimentation and analysis. The code provisions which guide us for assessment of the strength are really on the verge of revision for these new challenges. The properties of HSC are to be closely and practically assessed for these requirements. The review of the code provisions for different country codes for shear strength of the concrete is presented in this article.

Following are different Shear Strength equations International Building Codes & Researchers shown Table-13:

Table-13. Shear strength equations given by various codes & researchers

Codes & researchers	**Shear Strength equations**
IS 456:2000	$\tau_c = \frac{0.85\sqrt{0.8 f_{ck}}\,(\sqrt{1+5\beta}-1)}{6\beta}$
ACI	$V_c = 0.17\sqrt{f_c'}\,b_w d$
Eurocode 2	$V_c = 0.12k(100\rho f_c')^{1/3} b_w d$
Canadian Standards Association	$V_c = 0.2\sqrt{f_c'}\,bw\,d$
Egyptian Code	$q_{cu} = 0.16\sqrt{\frac{f_{cu}}{\gamma_c}}\,b_w d$
AASHTO LRFD	$V_C = 0.083\beta\sqrt{f_c'}\,b_v d_v$
Zsutty	$V_c = 2.2\left(f_c'\rho\frac{d}{a}\right)^{1/3} b_w d$
Bazant and Yu	$V_c = 1.1044\cdot\rho^{3/8} b_w\left(1+\frac{d}{a}\right)\sqrt{\frac{f_c' d_0 d}{1+d_0/d}}$
Tureyen and Frosch	$V_c = \frac{5}{12}\sqrt{f_c'}\,b_w c$
Okamura and Higai	$V_c = 0.2\frac{(100\rho)^{1/3}}{(d/1000)^{1/4}}(f_c')^{1/3}\left(0.75+\frac{1.40}{a/d}\right)^{1/3} b_w d$
Russo	$V_c = 1.13\xi\left[\rho^{0.4}(f_c')^{0.39}+0.5\rho^{0.83}f_y^{0.89}\left(\frac{a}{d}\right)^{-1.2-0.45(a/d)}\right]b_w d$
Sudheer Reddy	$V_c = 32\left(\left(\frac{f_t}{(a/d)}\right)\rho\right)^{0.8} b_w d \text{ (N)}$
CEB-FIP Model equation	$V_c = \left[0.15\left(\frac{3d}{a}\right)^{\frac{1}{3}}\left(1+\sqrt{\frac{200}{d}}\right)(100\rho f_{ck})^{\frac{1}{3}}\right]b_w d$
DIN1045-1(2001)	$V_{Rd} = \left[0{,}10k\cdot\eta_1\cdot(100\rho_l\cdot f_{ck})^{1/3}-0{,}12\sigma_{cd}\right]\cdot b_w\cdot d$
JSCE 1986	$V_c = 0.9\left[(100\rho\ f'_c)^{1/3}(d/100)^{-1/4}\right]\cdot b_w d$

3.4.1 RESULTS AND DISCUSSION

The shear equations proposed by different researchers and codes viz., ACI code, Canadian Code CSA Technical Committee, European code, IS 456-2000, Japanese Code, CEB-FIP model. These above equations are entered in a excel sheet & results are calculated by assuming certain parameters referring some research papers of various researchers and these 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) Eq.1.Therefore following Sudheer Reddy equation gives approximate Shear stress values.

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

$$V_c = 32f_t\left(\left(\frac{\rho b_w d}{\left(\frac{a}{d}\right)}\right)\right)^{0.8} \qquad \text{.........................(2)}$$

Where,

ft- Tensile strength of concrete in Mpa.
a/d - Shear Span to Depth Ratio.
ρ - Tensile Reinforcement Ratio.
bwd - 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, 1.5, 2 and 2.5 are listed in Table-14. From Table-15 to Table-19 the shear stress & yield stress values for a/d=1, 1.5, 2 & 2.5 the graphs are plotted for three grades of steel as shown in figure-3 to figure-7. To estimate the shear resistance (Vc) a linear regression equation is set in power series for a/d=1, 1.5, 2, 2.5 as shown in figure-3 to figure-7.

The average values all four linear regression equation are calculated and following linear regression is arrived

$$y = 1.13X^{3.69}$$

From above a new equation is derived as follows,

$$\left(\frac{V_{eqn}}{V_{exp}}\right) = 1.13 \times \left(\frac{f_a}{f_y}\right)^{3.69}$$

$$\left(\frac{32}{1.13}\right) \times (SIP)^{0.8} = \left(\frac{f_a}{f_y}\right)^{3.69} \times \text{shear stress}$$

Shear stress $=((28.31\times(SIP)^{0.8}) \div (fa/fy)^{3.69}$

The above equation gives higher results than experimental results. Therefore to arrive closer results we have assumed a factor 0.7 which is multiplied with 28.31 factor gives new factor is 20.

By using this new factor a modified empirical equation is formed is as given following

$$V_c = 20\left(\left(\frac{f_t}{\left(\frac{a}{d}\right)}\right)\rho\right)^{0.8} \div \left(\frac{f_a}{f_y}\right)^{3.69} b_w d \qquad \text{......} \quad \text{...(3)}$$

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-14. Comparison of Shear strength values given by various codes & researchers with experimental values

Sr.No.	Beam Designation	AST mm^2	%	a/d	bw	d	Vu test kN	ACI 318-99 in SI units $V_c = 0.17\sqrt{f_c'}\, b_w d$	Canadian Code CSA 1994 $V_c = 0.2\sqrt{f_c'}\, b_w d$	CEB-FIP Model	Vu kN IS 456:2000	Vu EC2(2003) $V_c = 0.12k(100\rho f_c')^{1/3} b_w d$	Vu DIN1045-1(2001)	Vu kN JSCE 1986	Sudheer Reddy	ANSYS	proposed eqn
1	BM-B01-550	101	0.25	1	150	150	123.14	86.55	73.67	64.73	99.30	64.58	98.44	69.11	111.76	129.37	111.93
2	BM-B02-500	101	0.25	1	150	150	115.12	86.66	73.77	64.79	100.43	64.63	98.53	69.17	103.37	127.48	116.08
3	BM-B03-415	101	0.25	1	150	150	113.36	87.36	74.34	65.13	98.85	64.97	94.28	69.52	101.48	126.19	120.44
4	BM-B04-550	101	0.25	1.5	150	150	74.93	67.37	54.78	52.00	51.45	50.24	73.40	54.83	78.04	81.30	80.92
5	BM-B05-500	101	0.25	1.5	150	150	74.23	68.58	55.73	52.61	51.68	50.83	74.26	55.46	72.44	78.59	83.93
6	BM-B06-415	101	0.25	1.5	150	150	73.99	67.11	54.57	51.86	51.83	50.11	73.21	54.69	66.89	78.18	87.07
7	BM-B07-550	101	0.25	2	150	150	54.36	49.38	36.82	33.57	31.88	45.83	49.21	41.18	54.36	61.11	64.29
8	BM-B08-500	101	0.25	2	150	150	51.15	49.63	37.00	33.68	28.65	43.65	49.37	41.31	49.20	58.89	66.67
9	BM-B09-415	101	0.25	2	150	150	49.18	49.33	36.78	33.55	25.95	43.47	49.17	41.15	45.28	54.66	69.37
10	BM-B10-550	101	0.25	2.5	150	150	40.61	30.91	18.46	25.88	39.90	38.89	24.65	27.27	45.27	50.16	53.78
11	BM-B11-500	101	0.25	2.5	150	150	40.01	30.89	18.45	25.87	38.40	36.55	24.64	27.26	43.75	46.77	55.77
12	BM-B12-415	101	0.25	2.5	150	150	36.16	30.95	18.49	25.90	32.80	36.59	24.67	27.29	38.66	45.27	57.86

Table-15. Shear stress & yield stress values for a/d=1

For a/d=1					
Shear Stress N/mm^2			**Yield Stress N/mm^2**		
Exp	**Eqn**	**V_{eqn}/V_{exp}**	**Actual**	**Specified**	**f_a/f_y**
5.47	5.96	1.09	558.78	550	1.02
5.12	5.51	1.08	505.75	500	1.01
5.04	5.41	1.07	416.56	415	1.00

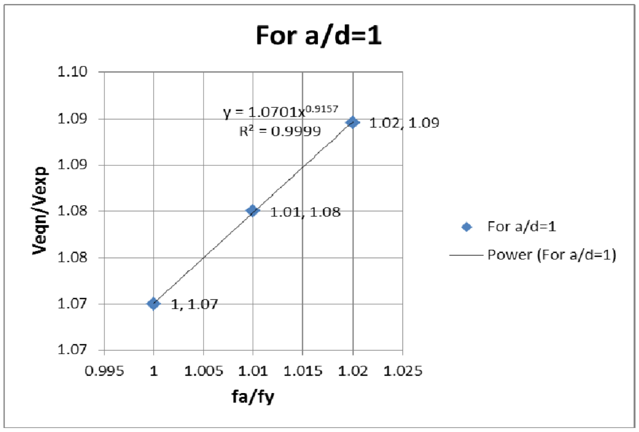


Figure-3. Shear stress ratio & yield stress ratio values for a/d=1

Table-16. Shear stress & yield stress values for a/d=1.5

For a/d=1.5					
Shear Stress N/mm^2			Yield Stress N/mm^2		
Exp	Eqn	V_{eqn}/V_{exp}	Actual	Specified	f_a/f_y
3.33	4.16	1.25	558.78	550	1.02
3.30	3.86	1.17	505.75	500	1.01
3.29	3.57	1.09	416.56	415	1.00

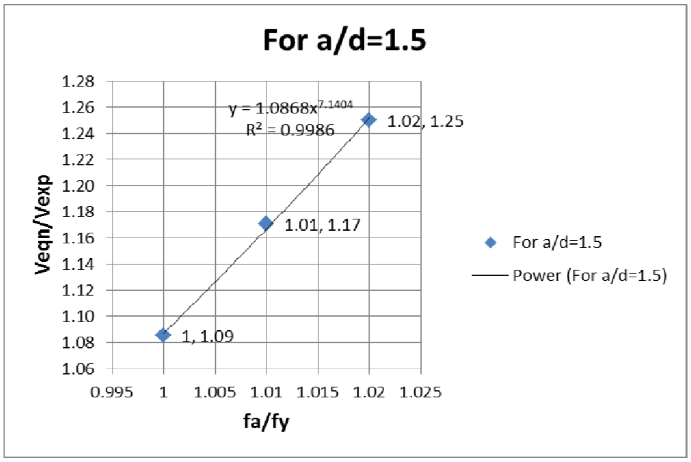


Figure-4. Shear stress ratio & yield stress ratio values for a/d=1.5

Table-17. Shear stress & yield stress values for a/d=2

For a/d=2

Shear Stress N/mm^2			Yield Stress N/mm^2		
Exp	Eqn	V_{eqn}/V_{exp}	Actual	Specified	f_a/f_y
2.42	2.90	1.20	558.78	550	1.02
2.27	2.62	1.15	505.75	500	1.01
2.19	2.41	1.10	416.56	415	1.00

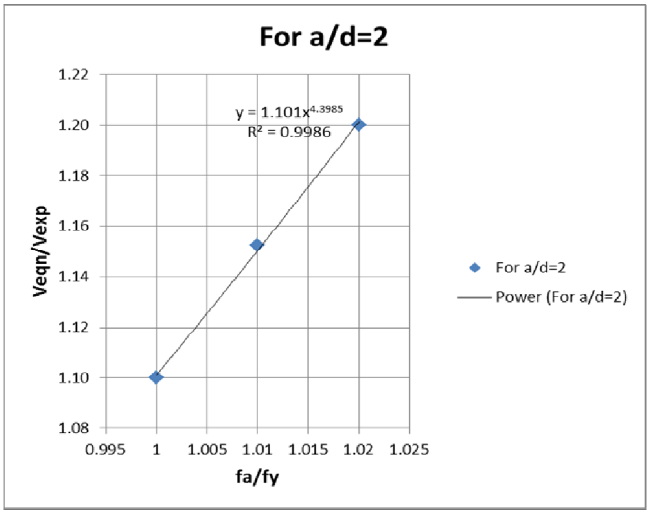


Figure-5. Shear stress ratio & yield stress ratio values for a/d=2

Table-18. Shear stress & yield stress values for a/d=2.5

For a/d=2.5

Shear Stress N/mm^2			Yield Stress N/mm^2		
Exp	Eqn	V_{eqn}/V_{exp}	Actual	Specified	f_a/f_y
1.80	2.41	1.34	558.78	550	1.02
1.78	2.33	1.31	505.75	500	1.01
1.61	2.06	1.28	416.56	415	1.00

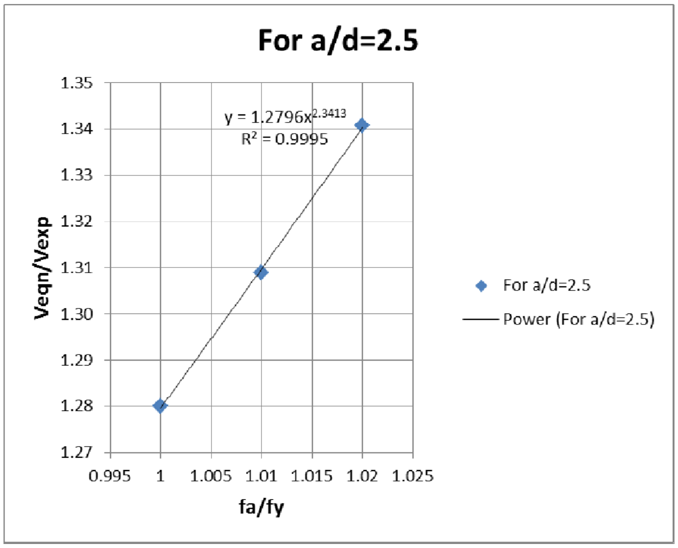


Figure-6. Shear stress ratio & yield stress ratio values for a/d=2.5

Table-19. Shear stress & yield stress values for a/d=1, 1.5, 2 & 2.5

	Veqn/Vexp			
fa/fy	**For a/d=1**	**For a/d=1.5**	**For a/d=2**	**For a/d=2.5**
1.02	1.09	1.25	1.20	1.34
1.01	1.08	1.17	1.15	1.31
1.00	1.07	1.09	1.10	1.28

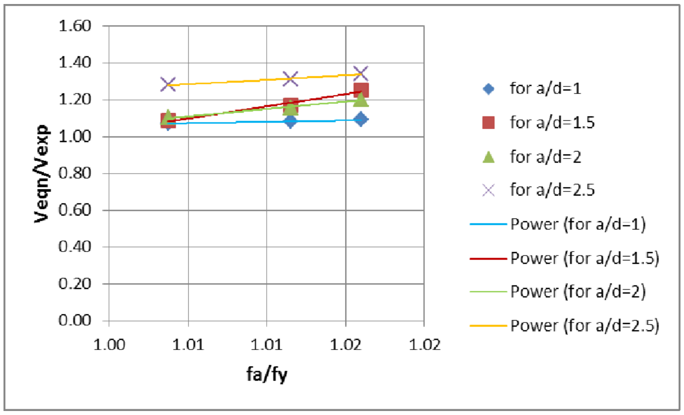


Figure-7. Shear stress ratio & yield stress ratio values for a/d=1, 1.5, 2 & 2.5

3.5 EFFECT OF ARTIFICIAL SAND REPLACING NATURAL SAND ON SHEAR STRENGTH OF HIGH STRENGTH CONCRETE

3.5.1 DISCUSSION ON TEST RESULTS

The compressive strength and split tensile strength of concrete with crushed stone fine aggregate increases up to 100% replacement and then gradually decreases. Strengths of concrete for 100% replacement are higher than those at 0% replacement, which indicates that crushed stone fine aggregate (well graded) can be utilized as a suitable alternative material for natural river sand in concrete. Crushed stone sand has lots of finer dust particle than natural sand. Which reduce the workability of concrete. To compensate this problem super plasticizer is used. Figure-3 shows the load-deflection curves for beams with varying shear span to depth ratios. Maximum load is attained for the beams designed using artificial sand than the beams designed using natural sand for three different grades of steel with same a/d ratio as shown in figure-8. Similarly maximum load is attained for the beams designed using artificial sand than the beams designed using natural sand for three different grades of steel with same a/d ratio. It describes that 100% crushed stone sand shows good strength and durability. Therefore from the study of various graphs we can conclude that maximum shear strength of concrete is achieved by using artificial sand than natural sand.

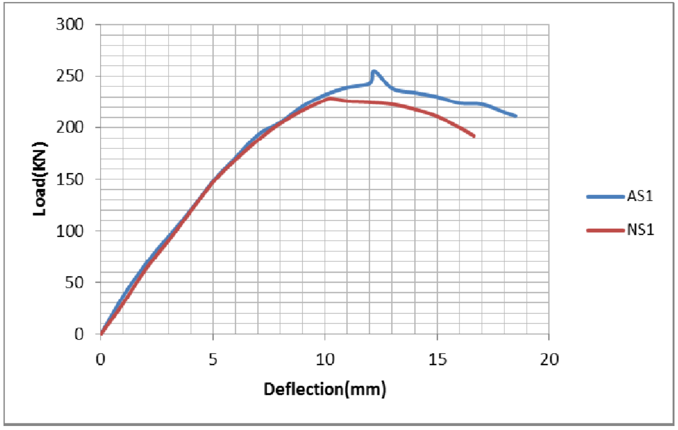


Figure-8. Load-Deflection curve for BM-B01-1-550 with a/d =1

Following Table-20 , Table-21& Table-22 shows the Experimental values and Ansys values of shear stress for a/d=1, 1.5, 2 & 2.5 for three different grades of steels which describes the shear stress decreasing as the a/d ratio increases for both beams designed with artificial sand and natural sand. Experimental results are validated by Ansys software gives the closer results. Shear stress-a/d ratio curve for beams with a/d =1, 1.5, 2 & 2.5 as shown in figure-9 and figure-10 describes the shear stress is decreasing as the a/d ratio increases for both beams designed with artificial sand and natural sand & the shear stress is increasing with the increase of yield stress of steel.

Table-20. Experimental values of shear stress for a/d=1, 1.5, 2 & 2.5

EXPERIMENTAL						
	Fe415		**Fe500**		**Fe550**	
	Shear stress N/mm2		**Shear stress N/mm2**		**Shear stress N/mm2**	
a/d	**AS**	**NS**	**AS**	**NS**	**AS**	**NS**
1	5.04	4.23	5.12	4.54	5.47	5.08
1.5	3.29	2.72	3.30	2.79	3.33	2.92
2	2.19	1.74	2.27	1.82	2.42	1.95
2.5	1.61	1.21	1.78	1.33	1.80	1.41

Table-21.Ansys values of shear stress for a/d=1, 1.5, 2 & 2.5

ANSYS						
	Fe415		**Fe500**		**Fe550**	
	Shear stress N/mm2		**Shear stress N/mm2**		**Shear stress N/mm2**	
a/d	**AS**	**NS**	**AS**	**NS**	**AS**	**NS**
1.00	5.61	4.63	5.67	4.99	5.75	5.26
1.50	3.47	2.94	3.49	3.04	3.61	3.36
2.00	2.43	2.03	2.62	2.23	2.72	2.28
2.50	2.01	1.54	2.08	1.67	2.23	1.75

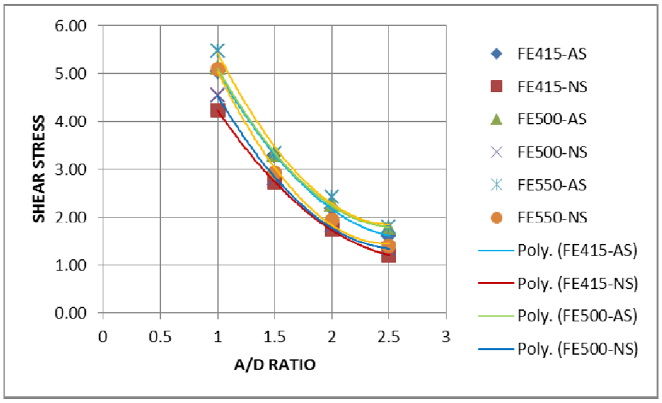


Figure-9. Shear stress-a/d ratio curve for beams with a/d =1, 1.5, 2 & 2.5

Table-22. Experimental &Ansys values of shear stress for a/d=1, 1.5, 2 & 2.5

	EXPERIMENTAL		ANSYS	
	NS	AS	NS	AS
a/d ratio	Shear Stress N/mm2	Shear Stress N/mm2	Shear Stress N/mm^2	Shear Stress N/mm2
1	5.08	5.47	5.26	5.75
1	4.54	5.12	4.99	5.67
1	4.23	5.04	4.63	5.61
1.5	2.92	3.33	3.36	3.61
1.5	2.79	3.30	3.04	3.49
1.5	2.72	3.29	2.94	3.47
2	1.95	2.42	2.28	2.72
2	1.82	2.27	2.23	2.62
2	1.74	2.19	2.03	2.43
2.5	1.41	1.80	1.75	2.23
2.5	1.33	1.78	1.67	2.08
2.5	1.21	1.61	1.54	2.01

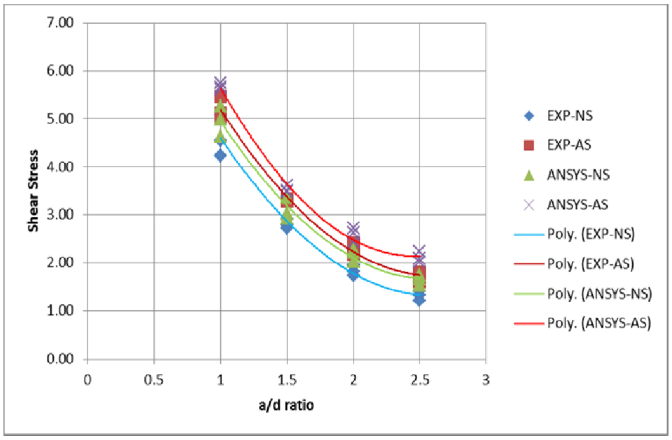


Figure-10. Shear stress-a/d ratio curve for beams with artificial sand & natural sand

3.6 EFFECT OF VARYING SHEAR SPAN TO DEPTH RATIO ON SHEAR STRENGTH

3.6.1 DISCUSSION ON TEST RESULTS

The variation of deflection with load of HSC beams designed using artificial sand and natural sand for three grade of steels without shear reinforcement for a/d = 1, 1.5, 2, and 2.5 are shown in figure-11 and figure-12, 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 1.5 the strut behavior and above 1.5 the arch behaviour of the beams. At lower a/d ratios (up to 1.5), the failure was observed to be sudden compared to failure pattern observed for higher a/d ratio (a/d – 1.5 to 2.5).

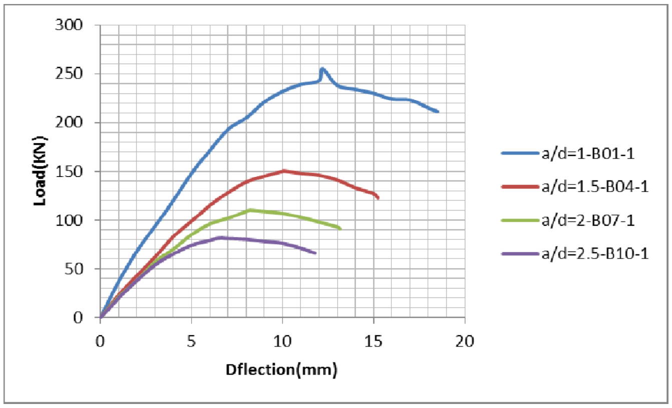


Figure-11. Load-deflection illustration for B01-1(a/d=1), B04-1(a/d=1.5), B07-1(a/d=2) and B10-1(a/d=2.5) with artificial sand

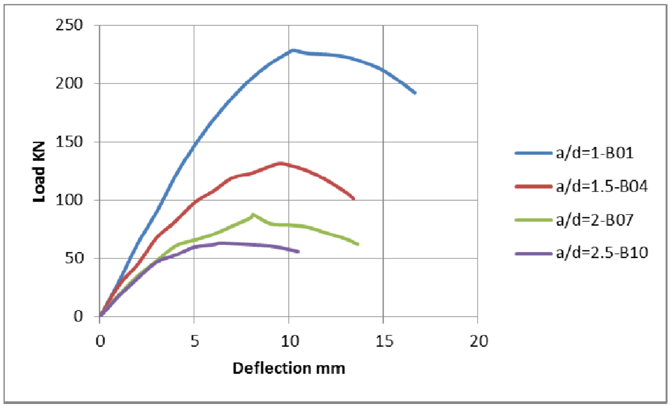


Figure-12. Load-deflection illustration for B01(a/d=1), B04(a/d=1.5), B07(a/d=2) and B10(a/d=2.5) with natural sand

Shear stress-a/d ratio curve for beams designed using artificial sand and natural sand for three grade of steels with varying a/d ratios 1, 1.5, 2 & 2.5 as shown in figure-13 and figure-14 describes the shear stress is decreasing as the a/d ratio increases for both beams designed with artificial sand and natural sand. . Experimental results are validated by Ansys software are found closer to the results.

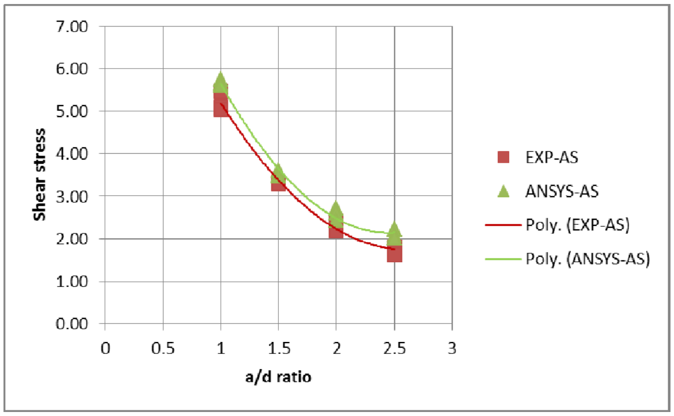


Figure-13. Shear stress-a/d ratio curve for beams with artificial sand

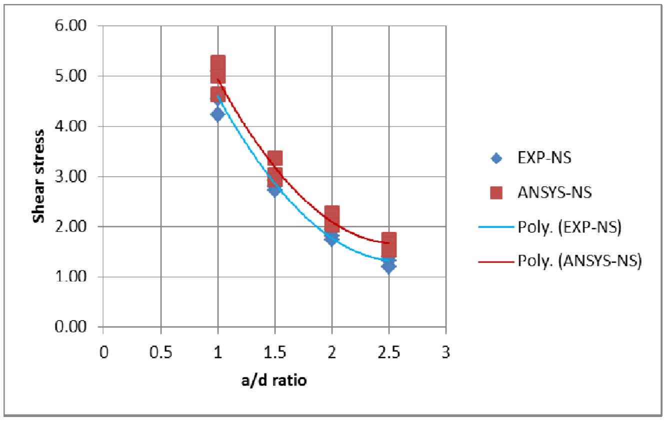


Figure-14. Shear stress-a/d ratio curve for beams with natural sand

Table-23. Experimental &Ansys values of shear stress for beams with artificial sand

							EXPERIMENTAL		ANSYS	
Sr.No.	Beam Designation	AST mm^2	p%	a/d	bw	d	Shear force Exp kN	Shear Stress Exp N/mm2	Shear force Ansys kN	Shear Stress Ansys N/mm2
1	BM-B01-550	101	0.25	1	150	150	123.14	5.47	129.37	5.75
2	BM-B02-500	101	0.25	1	150	150	115.12	5.12	127.48	5.67
3	BM-B03-415	101	0.25	1	150	150	113.36	5.04	126.19	5.61
4	BM-B04-550	101	0.25	1.5	150	150	74.93	3.33	81.30	3.61
5	BM-B05-500	101	0.25	1.5	150	150	74.23	3.30	78.59	3.49
6	BM-B06-415	101	0.25	1.5	150	150	73.99	3.29	78.18	3.47
7	BM-B07-550	101	0.25	2	150	150	54.36	2.42	61.11	2.72
8	BM-B08-500	101	0.25	2	150	150	51.15	2.27	58.89	2.62
9	BM-B09-415	101	0.25	2	150	150	49.18	2.19	54.66	2.43
10	BM-B10-550	101	0.25	2.5	150	150	40.61	1.80	50.16	2.23
11	BM-B11-500	101	0.25	2.5	150	150	40.01	1.78	46.77	2.08
12	BM-B12-415	101	0.25	2.5	150	150	36.16	1.61	45.27	2.01

Table-24. Experimental &Ansys values of shear stress for beams with natural sand

							EXPERIMENTAL		ANSYS	
Sr. No.	Beam Designation	a/d	d mm	b mm	Span mm	% steel	Shear force Exp kN	Shear Stress Exp N/mm2	Shear force Ansys kN	Shear Stress Ansys N/mm2
1	BM-B01-1-550	1	150	150	700	0.25	114.26	5.08	118.39	5.26
2	BM-B02-1-500	1	150	150	700	0.25	102.21	4.54	112.32	4.99
3	BM-B03-1-415	1	150	150	700	0.25	95.10	4.23	104.25	4.63
4	BM-B04-1-550	1.5	150	150	850	0.25	65.63	2.92	75.62	3.36
5	BM-B05-1-500	1.5	150	150	850	0.25	62.85	2.79	68.31	3.04
6	BM-B06-1-415	1.5	150	150	850	0.25	61.27	2.72	66.24	2.94
7	BM-B07-1-550	2	150	150	1000	0.25	43.81	1.95	51.28	2.28
8	BM-B08-1-500	2	150	150	1000	0.25	40.87	1.82	50.10	2.23
9	BM-B09-1-415	2	150	150	1000	0.25	39.23	1.74	45.76	2.03
10	BM-B10-1-550	2.5	150	150	1150	0.25	31.68	1.41	39.33	1.75
11	BM-B11-1-500	2.5	150	150	1150	0.25	29.89	1.33	37.61	1.67
12	BM-B12-1-415	2.5	150	150	1150	0.25	27.12	1.21	34.67	1.54

Experimental &Ansys values of shear stress for beams designed with artificial sand and natural sand are compared as shown in Table-23 and Table-24 which found nearer. The failure pattern of the beams designed using artificial sand and natural sand shown in figure-15 to figure-18 clearly exemplify that for a/d =1 and 1.5 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 =2 and 2.5 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.

Figure-15. Crack pattern of the failed specimen BM-B02-1-500

Figure-16. Crack pattern of the failed specimen BM-B05-1-500

Figure-17. Crack pattern of the failed specimen BM-B10-1-550

Figure-18. Crack pattern of the failed specimen BM-B12-415

3.7 EFFECT OF VARIOUS GRADES OF HIGH YIELD STRENGTH STEEL

3.7.1 DISCUSSION ON TEST RESULTS

In this experimental study shows the effect of various grades of high yield strength steel on shear strength of High strength concrete. There are three grades of steels are used whose yield strengths (grade-1=558.78 N/mm2, grade2=505.75N/mm2 & grade3=416.56 N/mm2) are different. Experimental &Ansys values of shear stress for Grade 1 steel of 550 Mpa with artificial sand shown in Table-25 and Shear stress-a/d ratio curve for grade 1 steel with artificial sand shown in figure-19 indicates that for same grade of steel with the increase of a/d ratio the shear stress decreases. Similarly, the Experimental &Ansys values of shear stress for Grade 2 steel of 500 Mpa and Grade 3 steel of 415 Mpa with artificial sand shown in Table-26 and Table-27 and Shear stress-a/d ratio curve for grade 1 steel with artificial sand shown in figure-20 and figure-21 indicates that for same grade of steel with the increase of a/d ratio the shear stress decreases. It shows that grade 1 steel whose yield strength is more gives higher values of shear strengths than grade 1 & grade 2. Therefore from the experimental results we can conclude that shear strength increases with the increase in yield strength of steel.

Table-25. Experimental &Ansys values of shear stress for Grade 1 steel with artificial sand

Grade 1 steel 550 Mpa		
	Shear Stress N/mm2	
a/d ratio	Exp	Ansys
1	5.47	5.75
1.5	3.33	3.61
2	2.42	2.72
2.5	1.8	2.23

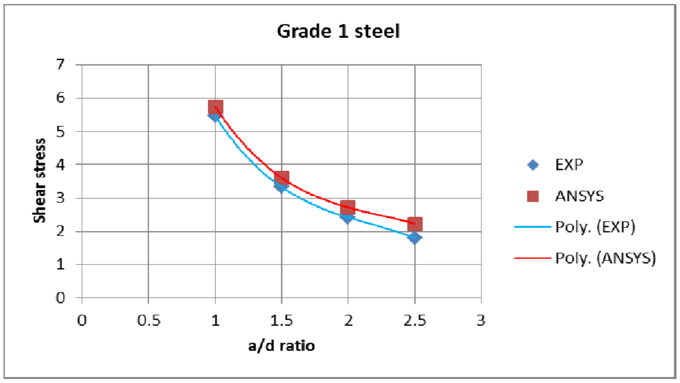


Figure-19. Shear stress-a/d ratio curve for grade 1 steel with artificial sand

Table-26. Experimental &Ansys values of shear stress for Grade 2 steel with artificial sand

Grade 2 steel 500 Mpa		
	Shear Stress N/mm2	
a/d ratio	Exp	Ansys
1	5.12	5.67
1.5	3.30	3.49
2	2.27	2.62
2.5	1.78	2.08

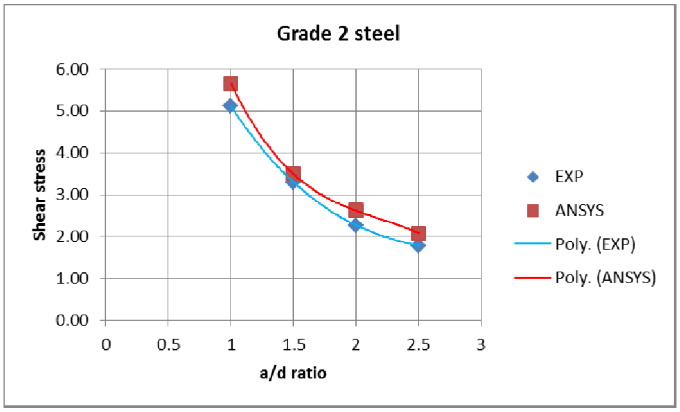


Figure-20. Shear stress-a/d ratio curve for grade 2 steel with artificial sand

Table-27. Experimental &Ansys values of shear stress for Grade 3 steel with artificial sand

Grade 3 steel 415 Mpa		
	Shear Stress N/mm2	
a/d ratio	Exp	Ansys
1	5.04	5.61
1.5	3.29	3.47
2	2.19	2.43
2.5	1.61	2.01

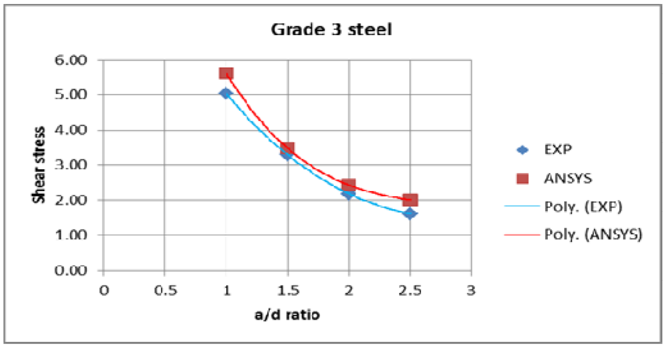


Figure-21. Shear stress-a/d ratio curve for grade 3 steel with artificial sand

Experimental &Ansys values of shear stress for three grades of steel of 550 Mpa, 500 Mpa and 415 Mpa with artificial sand shown in Table-28and Shear stress-grade of steel curve for three grades of steel with artificial sand shown in figure-22 indicates that for same a/d ratio=1 with the increase of grade of steel the shear stress increases. Similarly, the Experimental &Ansys values of shear stress for three grades of steel of 550 Mpa, 500 Mpa and 415 Mpawith artificial sand shown in Table-29, Table-30 and Table-31 and Shear stress-grade of steel curve for three grades of steel with artificial sand shown in figure-23, figure-24 and figure-25 indicates that for same a/d ratio=1.5, 2 & 2.5 with the increase of grade of steel the shear stress increases.

Table-28. Experimental &Ansys values of shear stress for a/d=1 with artificial sand

For a/d=1		
	Shear Stress N/mm^2	
Grade of steel	Exp	Ansys
415	5.04	5.61
500	5.12	5.67
550	5.47	5.75

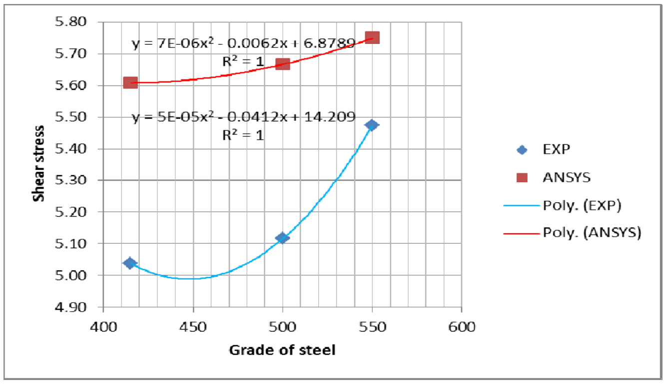


Figure-22. Shear stress-Grade of steel curve for a/d=1 with artificial sand

Table-29. Experimental &Ansys values of shear stress for a/d=1.5 with artificial sand

For a/d=1.5		
	Shear Stress N/mm^2	
Grade of steel	Exp	Ansys
415	3.29	3.47
500	3.30	3.49
550	3.33	3.61

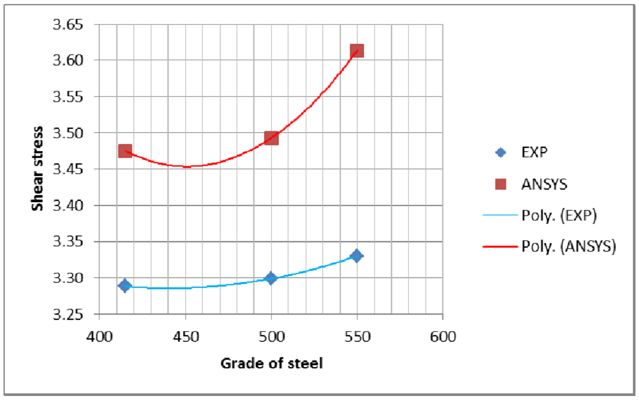


Figure-23. Shear stress- Grade of steel curve for a/d=1.5 with artificial sand

Table-30. Experimental &Ansys values of shear stress for a/d=2 with artificial sand

For a/d=2		
	Shear Stress N/mm^2	
Grade of steel	Exp	Ansys
415	2.19	2.43
500	2.27	2.62
550	2.42	2.72

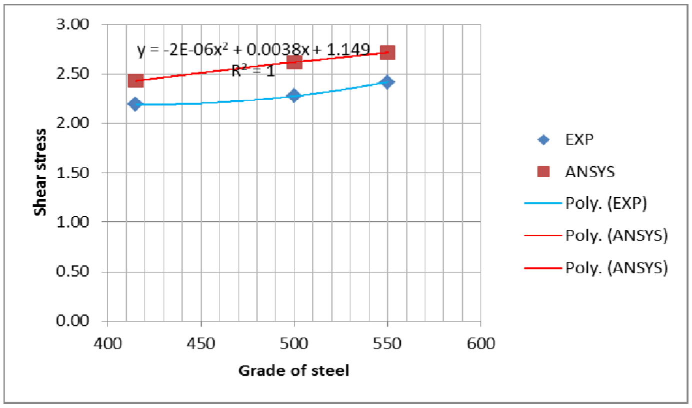


Figure-24. Shear stress- Grade of steel curve for a/d=2 with artificial sand

Table-31. Experimental &Ansys values of shear stress for a/d=2.5 with artificial sand

For a/d=2.5		
	Shear Stress N/mm^2	
Grade of steel	Exp	Ansys
415	1.61	2.01
500	1.78	2.08
550	1.80	2.23

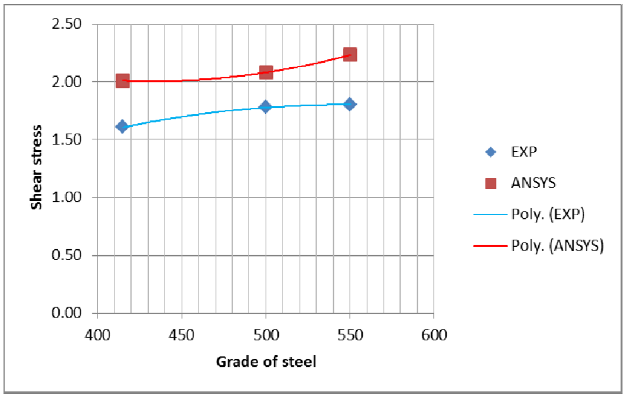


Figure-25. Shear stress- Grade of steel curve for a/d=2.5 with artificial sand

3.8 EVALUATION OF SHEAR RESISTANCE OF HIGH STRENGTH CONCRETE BEAMS USING ANSYS

3.8.1 MODELING OF CONCRETE AND REINFORCEMENT

The concrete has been modeled using ‘SOLID183’ defined as eight node planar quadrilateral element capable of simulating the cracking and crushing of brittle materials. This element is defined by 8 nodes or 6 nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element may be used as a plane element (plane stress, plane strain and generalized plane strain) or as an axisymmetric element. This element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic 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 38729.23MPa and the Poisson’s ratio as 0.2. In the present analysis a constant mesh size of 5 mm is assumed.

The longitudinal reinforcement i.e., the High Yield strength deformed (HYSD) have been modeled using eight node SOLID183 planar quadrilateral element. The eight node SOLID183 planar quadrilateral element is a uniaxial tension-compression element with two degrees of freedom at each node: translations in the nodal x, y 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 105 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-26shows a typical beam modeled in ANSYS for a/d =1 with element mesh size of 5 mm.

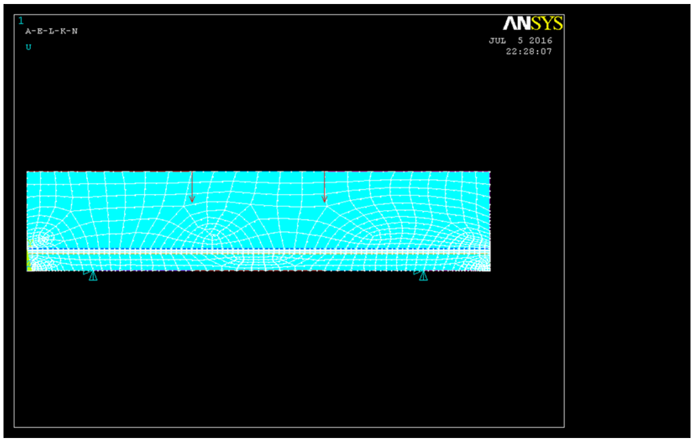


Figure-26. ANSYS modeled beam with loadings & supports for a/d=1

3.8.2 DISCUSSION ON TEST RESULTS

The Load- Deflection response of HSC beams designed using artificial sand and natural sand with varying shear span to depth ratios grade of steel without shear reinforcement has been compared with the experimental results in figure-27 and figure-28. 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.

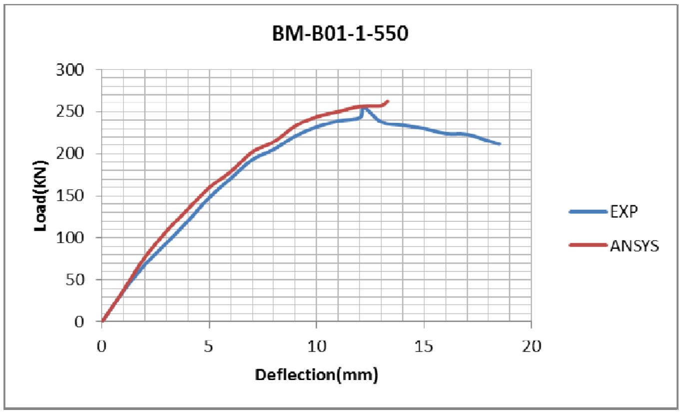


Figure-27. Load-deflection response for beam BM-B01-550 with a/d =1

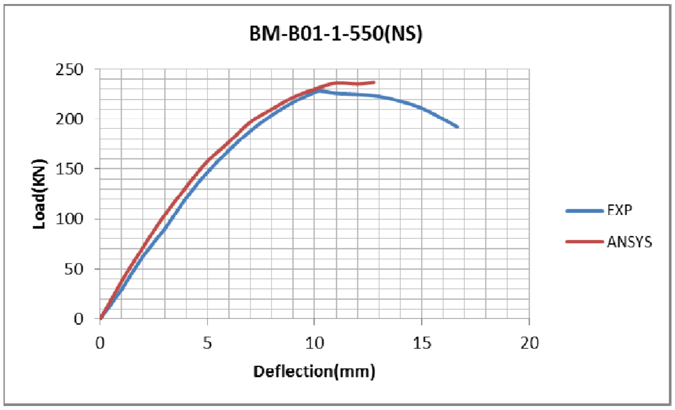
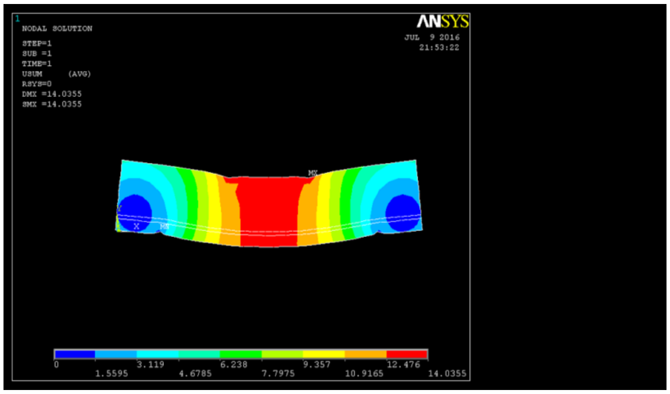


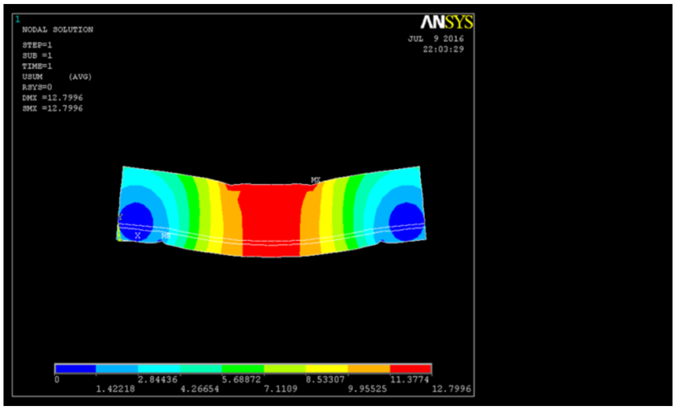
Figure-28. Load-deflection response for beam BM-B01-550(NS) with a/d =1

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 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 load by indicating large distortion of element nodes. The crack patterns indicate purely shear failure at a/d =1 and 1.5 and shear–flexure failure at a/d =2 and 2.5. The crack pattern observed in ANSYS model at failure is illustrated in figure-29 and figure-30



```
1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM      (AVG)
RSYS=0
DMX =14.0355
SMX =14.0355
```

Figure-29. Crack pattern of ANSYS modeled beam BM-B01-1 at failure.



```
1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM      (AVG)
RSYS=0
DMX =12.7996
SMX =12.7996
```

Figure-30. Crack pattern of ANSYS modeled beam BM-B01-1 at failure.

IV. CONCLUSIONS

With the discussion on shear models and the experimental studies conducted on HSC beams the following conclusions can be drawn:

1. It has been found that as the shear span to depth ratio (a/d) increases, the reserve strength theultimate shear stress decreased. Therefore the shear span to depth ratio (a/d) of the beam hasdefinite influence on the reserve strength, the cracking shear stress and the ultimate shearstress of HSC slender beams with minimum web reinforcement.
2. The failure in most of the beams has been caused due to diagonal tension cracking.
3. The workability of concrete decreases with increase in percentage of crushed sand.
4. Considering fast development in metros and other developing cities, it is high time toestablish a theory which is economic, durable, safe and acceptable using the sustainable highgrade concrete.
5. High Strength Concrete beams tested in the present investigations showed bursting type of failure at the ultimate loads.

6. The equation (Eq. 3) stated above includes almost all the parameters required to predict theshear 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, 1.5, 2 and 2.5.
7. As the longitudinal reinforcement ratio increases, the ultimate shear stress increases.
8. It has been found that shear strength increases with the increase in yield strength of steel.
9. The longitudinal reinforcement ratio, strength of the concrete, shear span to depth ratio, valueand depth of the beam are the most influencing parameters in the deformational and shearbehaviour of the HSC beams with web reinforcement.
10. The ANSYS model closely predicted the diagonal tension failure and shear compression failure of high strength concrete beams without shear reinforcement as observed in experiment.
11. Ultimate load decreases as a/d ratio increases. In the same manner, mid-span deflections at ultimate load increase as the values of a/d ratio increase; flexural behavior is more associated with a beam action as a/d ratio increases.
12. Strengths of concrete for 100% replacement are higher than those at 0% replacement, which indicates that crushed stone fine aggregate (well graded) can be utilized as a suitable alternative material for natural river sand in concrete.

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