Shear Behaviour of Self Compacting Deep Beams

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Abstract - RC Deep beams possess narrow width, larger depth/thickness and involve congested shear reinforcement, therefore. An experimental work was performed to evaluate properties of a self-compacting concrete (SCC) known for its high deformability and good resistance to segregation and bleeding was prepared to investigate shear behaviour of deep beams thereby evaluating the performance of deep beams made with SCC. Fresh and hardened properties of normal concrete (NC) and SCC were assessed in this study. The slump flow, V-funnel tests conducted showed that the results satisfied the code requirements based on casting time. All tested beams have dimensions of 150×360×1200 mm and have been subjected to two point loads which comprised of four deep beams (four made with SCC and two with NC). Investigating parameters of this study included different web reinforcements in shear, different shear span to depth ratio for analysing the shear behaviour and performance of beams in terms of load carrying capacities, load–deflection response and failure mode.

Test results indicated that the SCC specimens with the both relatively non-congested and congested shear reinforcement conditions showed a slightly higher load carrying capacity in terms of diagonal shear cracking and ultimate loads compared to the NC specimens. A 10.2 % increase in ultimate load in comparison with that of the NC specimen was observed with the SCC specimen in congested beams. For beams with shear span to depth ratio greater than 1.0, the load deflection response shows that the beam stiffness reduces considerably. The experimental and numerical test results show that shear (vertical) reinforcement and shear span to depth ratio are the two most key parameters in controlling the behaviour of RC deep beams.

Keywords: deep beams, deflection, performance, self-compacting concrete, shear, shear reinforcement, workability

I. INTRODUCTION

RC deep beams are structural members characterized by having relatively deep section comparing to their span for which a substantial proportion of the load is transferred directly to the support through a single strut. In structural applications, deep beams are commonly used as transfer girders in buildings, bridges and offshore structures. Reinforced concrete deep beams are structural members possess narrow width, larger depth/thickness thus possessing depth much greater than normal in relation to their span, while the thickness in the perpendicular direction is much smaller than either span or depth, hence involve congested shear reinforcement. Therefore, the conventional concrete does not flow well when it travels to the web and does not completely fill the bottom part. This results in many problems in concrete such as, voids, segregation, weak bond with reinforcement bars and holes in its surface. Therefore, the self-compacting concrete (SCC) is very appropriate type for casting these members.

Self-compacting concrete (SCC) provide us with distinct advantages of due to its liquid nature over conventional vibrated concrete are: elimination of above mentioned problems such as no need to vibration where it is able to fill all spaces in the formwork and passes through reinforcing bars by its own weight, faster construction, low noise level in construction and improving quality and durability.

RC beams with the same shear and flexural reinforcements, shear failure is most likely to occur in deep beams rather than in regular beams.

II. LITERATURE REVIEW

Dr. Hassan Falah Hassan, Behaviour of Hybrid Deep Beams Containing Ultra High Performance and Conventional Concretes, Eng. & Tech .Journal, Vol.33,Part (A), No.1, 2015 The results of this work depict

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that with the increase of UHPC layer thickness (hR/h) and steel fibres volumetric ratio (Vf) leads to stiffer load deflection behavior for hybrid beams with UHPC in compression.

Stephen, J. F., & Gilbert, R. I. Experimental studies on high-strength concrete deep beams. ACI Structural Journal, 95, 382–390. In this study, 16 high-strength concrete deep beams were tested to destruction. the prime parameters considered in the investigation were shear-span to depth ratio, concrete strength (50 to 120 MPa [7250 to 17,400 psi]), and the provision of secondary reinforcement. The investigation analyses deep beam behavior and compares results obtained while experimentation .The conclusion of this investigation show that good load predictions can be obtained using the plastic truss model when combined with the Warwick and Foster efficiency factor.

Yang, K. H., Chung, H. S., Lee, E. T., & Eun, H. C. Shear characteristics of high-strength concrete deep beams without shear reinforcements. Engineering Structures, 25, 1343–1352. In this work, the two different shear-span-to-depth (a/d) ratios were taken to study the effect of stirrup orientation on flexural response of reinforced concrete (RC) deep beams. Thus, for deep beams possessing shear deficiencies need solution with great importance. This study concluded that the 'a/d' ratio has good influence on the shear capacity, as 'a/d' ratio increases, the shear strength increases in case of short deep beam. The relative effectiveness of lateral (horizontal), vertical and inclined web reinforcement on the load capacity is mainly influenced by the 'a/d' ratio. The strength considered for investigation is flexural strength.

Choulli et al. (2008), Safety and effectiveness of SCC for use in precast pre-stressed beams. to An experimental and theoretical study was carried out by determine. In this study variables such as the concrete type, the existence of shear reinforcement, the amount of horizontal web reinforcement, and the prestressing level were experimentally varied (Choulli et al. 2008). The final results of this study showed that there was 10 % decrease in shear capacity for beams made with SCC with respect to those made with NC with the same compressive strength (Choulli et al. 2008). It was also concluded that more ductility on behalf of SCC for structural members than NC (Choulli et al. 2008).

Hassan et al. (2008), Shear strength and cracking behavior of full-scale reinforced beams made with SCC and NC. The variables of this study comprised of concrete type, beam depth, coarse aggregate content and the longitudinal reinforcing steel ratio (Hassan et al. 2008). Crack pattern, crack widths, loads at the first flexure and diagonal cracking, ultimate shear resistance, and failure modes were investigated to ascertain the behavior and performance of beams made with SCC and NC (Hassan et al. 2008). From their work, it was concluded that the ultimate shear strength of SCC beams was found to be slightly less than that of NC beams; however, the difference in ultimate strength was more reflected with a reduction of the longitudinal reinforcing steel ratio and with an increase of beam depth (Hassan et al. 2008). A comparative study was conducted using design codes to assess the applicability of equations in codes to predict the shear resistance of SCC and NC beams (Hassan et al. 2008).

Journal of Engineering and Development, Vol. 18, No.2, March 2014, ISSN 1813- 7822 36 Shear Behavior of Self Compacting Concrete Deep Beams. This study deals with shear behavior of self-compacting concrete (SCC) deep beams. The experimental work includes testing eight reinforced concrete simply supported deep beams cast using SCC. The parameters considered were shear span to effective depth ratio (a/d), concrete compressive strength and vertical web reinforcement ratio. Test results indicated that the increase in (a/d) ratio from 0.6 to 1 leads to decreases in cracking and ultimate shear strengths. Increasing the vertical web reinforcement ratio, from 0.25 % to 0.57 % leads to an increase in the ultimate shear strength by average ratio of 10.1 %.

Shah D.L, Evaluation of Shear strength of Self compacting concrete deep beam, International Journal of Advanced Engineering Technology E-ISSN 0976-3945. The aim of the research is to investigate experimentally the effect of crack and deformation characteristics of SCC with and without inclusion of steel fibres for various span-to-depth ratios of deep beams. A comparison while made shows that the shear capacities are unconservative in SCC deep beams predicted from empirical formulas provided in codes. Strut-and-Tie Model predicts fairly satisfactory comparism.

III. EXPERIMENTAL DESIGN

Following are the main investigating parameters of this study :-

a) **Shear reinforcement spacing.**
b) **Shear span to depth ratio**.

a) **Shear reinforcement spacing**:

Prior to diagonal cracking, concrete resists predominantly the applied shear stress and shear reinforcement carries almost zero stress. After the formation of diagonal cracks, a portion of the applied shear force is transferred by the shear reinforcement through truss action. Experimental results show that by increasing vertical shear reinforcement ratio (ρ_v) the shear capacity of the specimen increases.

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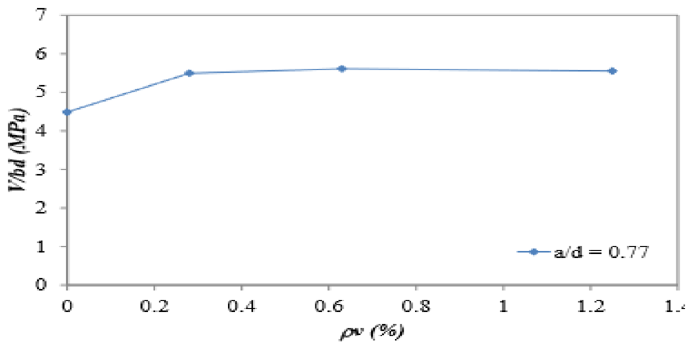

Figure 1: Effect of shear reinforcement on the shear strength of RC beams

b) **Shear span to depth ratio**:

Another critical parameter that affects the behaviour of RC beams in shear is the shear span to depth ratio (a/d). In 1967, Kani found out that there is a strong relation between the shear behaviour of RC members and their shear span to depth ratio. He also concluded that when shear failure occurs, in some cases, the beam is not developing its full flexural capacity, and this is controlled by shear span to depth ratio as shown in Figure 2.

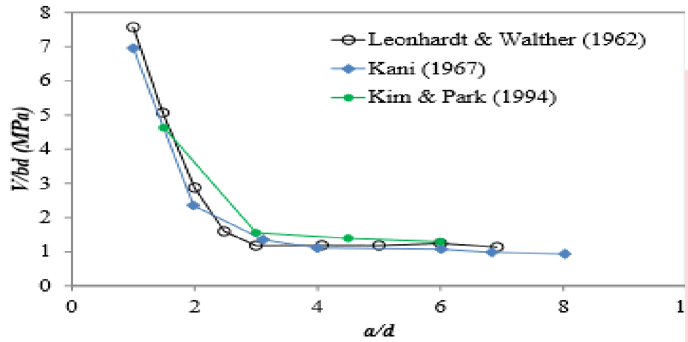

Figure 2: Effect of shear span to depth ratio on the shear strength of RC beams

The experimental work was undertaken to study the following:

- **Load vs Deflection Curves**
  In this section, curves will be plotted for deflection with respect to corresponding loads for different deep beams. The curve pattern will give clear representation of responses of different beams to the corresponding load using two point loading tests.
- **Load carrying capacities and Initial stiffness**
  The results from the two-point loading tests on the deep beam made with NC and SCC are summarized in Table. The loads at initial flexural cracking and diagonal shear cracking and ultimate loads along with corresponding deflections mid span deflections of all SCC and NC specimens are noted in table.
  The values will represent the load carrying capacities and initial stiffness of different deep beams.
- **Comparison of Normal concrete (NC) and SCC beams**
  The comparison of Normal concrete and SCC beams will be represented in the form of bar charts.
  The chart will give a clear of performance of SCC beams. The comparison will give a clear explanation for applicability of one over other.

IV. EXPERIMENTAL PROCESS

The experimental process included

- **Reinforcement/cage preparation:**
  Two types of cages were made designated with A type and B type. In A type beams 75mm (congested beams) and 100mm (non-congested beams) shear spacing was kept in case of B type beams.
- **Mould formation:**
  Before the process of batching, proportioning, weighing was started, rectangular moulds of plywood were made for beam casting. The size of mould made were 150mm (width) x 360mm (height) x 1,200mm (length). When cutting the pieces for the mould, care was taken into account that the inside measurements. The plywood pieces were fixed with the help of nails.
- **Finalising design mix:**
  The design mix was finalised after necessary trails and testing.
- **Specimen casting**
  The mixing of concrete was carried in mixer. While pacing concrete in moulds necessary care was taken to provide proper cover. Being SCC no vibration was done. The SCC was efficiently capable of passing of all voids. Cubes and deep beams were casted.
- **Final testing:**
  Slump cone test and V funnel tests were carried on fresh concrete for assessing workability of SCC.
  Two point loading tests were carried on deep beams (hardened concrete) and compression tests on beams thereby evaluating final results.

4.1 Beam Details:

BEAM DIMENSIONS:

As per provisions of various codes the dimensions of beams were finalised as:

Length of the beam (L) = 1.2 m

Depth of the beam (D) = 0.38 m

Effective depth (d), providing a cover of 40 mm = 0.34 m

Width of the beam (W) = 0.15 m

Effective length (l) = 0.8 m

Four SCC specimens and two NC are planned according to experimental variables:

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Shear span-to-overall height *a/h*, vertical shear reinforcement ratios *ρv* and horizontal shear reinforcement ratio *ρh*.

4.2 Reinforcement details:

Two types of reinforcements were given,

In type A beams, 4 bars of 10 mm dia is used in two layers as tensile reinforcement and 2 bars of 10 mm dia is used as compressional reinforcement. Two legged 8 mm dia stirrups are provided @ c/c spacing of 70 mm. So they are designated as congested beams. A lateral cover of 40 mm is provided on both sides.

In type B beams longitudinal reinforcement provided is same as that of type A beams, but in shear reinforcement c/c spacing of 8 mm dia two legged stirrups is 100 mm.

Thus beams casted were varied in shear (vertical reinforcement) spacing (S), S1 and S2.

A Type Beam (spacing S1) = 75mm (congested beams)

B Type Beam (Spacing S2) = 100mm (non-congested beams)

All specimens are planned to have same concrete compressive of 25MPa.

Fig. below shows the detail of all specimens that have rectangular cross section with size of 150mm×360mm×1200mm.

L/D = 2.1

A Type Beams:

Stirrup spacing = 75 mm

Vertical Reinforcement = 0.41 %

B Type Beams:

Stirrup spacing = 100 mm

Vertical Reinforcement = 0.32%

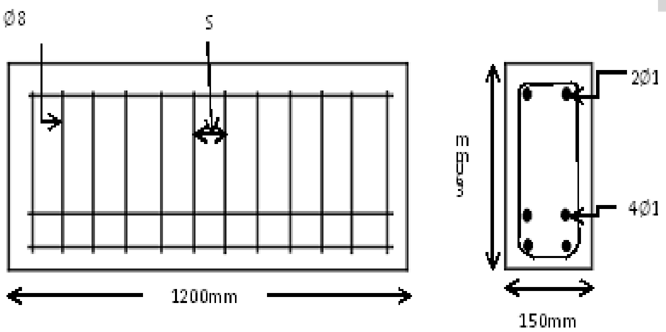

Figure 3: Reinforcement details

Figure 4: Type A (congested beam)

Figure 5: Type B (non-congested beam)

V. Mix Proportion

Cement (kg/m^3)	Fly ash (kg/ m^3)	Silica Fume (kg/ m^3)	Coarse aggregate (kg/ m^3)	Fine aggregate (kg/ m^3)	w/p
388	163	30	772	740	0.38

Fine and coarse aggregate combinations were mixed for 90 s in a mixer. Cement and filler combinations were added into the aggregate mixes and remixed for 60 s all together in dry state. The water and SP were mixed in a flask and poured slowly into the mixer while mixing. The total mixing time was five minutes with the rotating speed of 45+1 cycle/min of the mixer. The casting immediately followed mixing, after carrying out the tests for fresh properties. The top surface of the specimens was scraped to remove excess material and achieve smooth finish. The specimens were removed from moulds after 24 h and cured in water till testing or as per requirement of the test.

For testing 6 cubes (150x150x150 mm) were casted, three for first casting and three for second casting respectively. All specimens are planned to have same concrete compressive of 25 MPa. Deep beams in this experimental study are specimens that have rectangular cross section with size of 150mm×360mm×1200mm. 6 deep beams were casted with 4 made with SCC and two of NC. Out of 4 SCC beams, 2 comprised of congested reinforcement while two with non congested reinforcement.

VI. Tests and Results

Following tests were conducted on fresh concrete and hardened concrete (specimens)

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a) SLUMP CONE TEST

Many trials of different mixes were done before finalising the ratios. The following are the results of the concrete which was actually used in the casting of beams:

Table 1: Test results of slump cone test

	FIRST TEST	SECOND TEST	AVERAGE RESULT	RANGE
FIRST CASTING	620 mm in 4 S	630 mm in 4 S	625 mm	600-750 mm in 5 seconds
SECOND CASTING	655 mm in 4 S	660 mm in 4 S	660 MM	600-750 mm in 5 seconds

As, it can be clearly seen from the slump cone test that the SCC made satisfies the necessary criteria set. Vibration process is altogether eliminated. Hence, the mix proportions finalised are efficient.

b) V FUNNEL TEST

Table 2: Test results of V funnel test

	FIRST TESTING	SECOND TESTING	RANGE
FIRST CASTING	9 SECONDS	9 SECONDS	8-12 s
SECONDCASTING	10 SECONDS	10 SECONDS	8-12 s

As, it can be clearly seen from the results of V funnel test that the SCC made satisfies the necessary range set in both castings. Hence no vibration an compaction is required

c) RESULTS OF BEAM TESTING

Table 3: Test results of V funnel test

BEAM NOTATION	FIRST CRACKING LOAD (KN)	DIAGONAL CRACKING LOAD (KN)	ULTIMATE LOAD (KN)	DEFLECTION AT FIRST CRACKING LOAD (y) (mm)	DEFLECTION AT ULTIMATE LOAD (u) (mm)	a/d
CONTROL BEAM A	127	216	308	0.6	2.8	**0.78**
A-75-250	135	248	343	0.4	3.6	**0.78**
A-75-350	124	218	283	0.5	3.1	**1.1**
CONTROL BEAM B	102	195	280	0.7	2.5	**0.78**
B-100-250	112	222	320	0.45	3.8	**0.78**
B-100-350	98	202	263	0.6	2.8	**1.1**

The table contains the values of first cracking load, diagonal load, deflection at first cracking load and deflection at ultimate load. It can be noted that the load carrying capacities and into of SCC deep beams with a/d ratio 0.78 is higher as compared to NC beams and a/d ratio 1.1 in both cases of congested beams(75mm) and non-congested beams(100mm). Also it can be seen the load carrying capacities of congested beams is higher than non-congested beams.

Figure 6: Shear failure of Deep beam

6.4 Load Carrying Capacities and Initial Stiffness:

The results from the two-point loading tests on the deep beam made with NC and SCC are summarized in Table. The loads at initial flexural cracking and diagonal shear cracking and ultimate loads along with corresponding deflections mid span deflections of all SCC and NC specimens are noted in table. The NC-100 and SCC-100 specimens with stirrups spaced at 100 mm along the span are considered to be relatively non-congested shear reinforcement condition. The initial flexural cracking load of the NC-100 and SCC-100 specimens was 102 and 112kN, respectively, while the diagonal shear cracking load of NC-100 and SCC-100 specimens was 195 and 222kN, respectively. Diagonal shear cracks were measured within the shear span of the tested deep beams during the two-point loading tests. 8.9% and 12.16% increases in initial flexural and diagonal shear cracking load in comparison with that of the NC-100 specimen were observed with the SCC-100 specimen. Also the ratios of the diagonal shear cracking load to the ultimate load of the NCC-100 and SCC-100 specimens was 13.9 and 14.3% of the ultimate loads, respectively. Hence it clearly depicts that the SCC beams with relatively non-congested shear/vertical reinforcement showed a moderately higher load carrying capacity than the corresponding NC specimen. Congested reinforcement that is NC-75 and SCC-75 specimens with stirrups spaced at 75 mm shear reinforcement spacing along the span. The initial flexural cracking load of the NC-75 and SCC-75 specimens was 127 and 135kN, respectively, while the diagonal shear cracking load of the NC-75 and SCC-75 specimens was 216 and 248kN, respectively. This

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also showed slightly higher increase in initial flexural and diagonal shear cracking load in comparison with that of the NC. The ultimate load capacity of the NC-75 and SCC-75 specimens was 308 and 343kN, respectively. 5.9% and 12.9% increases in initial flexural and diagonal shear cracking load in comparison with that of the NC-75 specimen were observed with the SCC-75 specimen. It is noticed that the SCC specimen with congested shear reinforcement showed higher load carrying capacities. The ultimate load was measured at shear-compression failure of the deep beam under two point loading tests. A 10.2 % increase in ultimate load in comparison with that of the NC-75 specimen was observed with the SCC-75 specimen. The calculated ratios (percentage) between diagonal shear cracking load to ultimate load of the congested (NCC-75 and SCC75) specimens were 29.8 and 27.6% of the ultimate loads, respectively. Thus a comparatively similar shear performance was observed by SCC specimen with respect to NC specimen even in the case of congested beams with large amount of reinforcements. This corresponds to the findings by Bouzoubaaˆ and Lachemi (2001) and Lachemi et al. (2005). Large resisting capacity of the deep beams was observed after the first diagonal shear cracks by the arch action in compressive struts.

6.5 Load-Deflection Response:

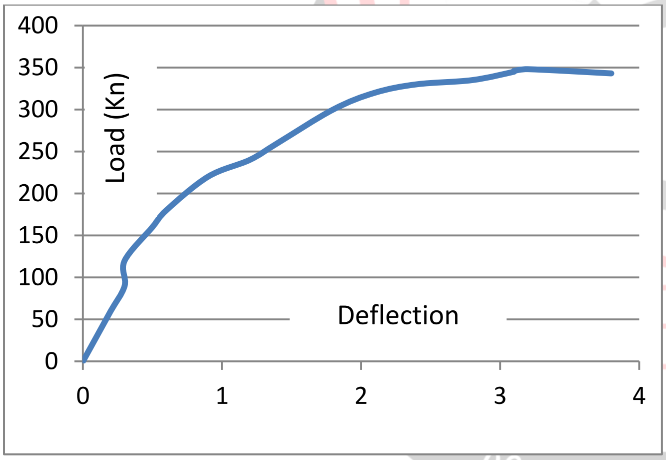

Figure 7: Graph of load vs deflection for Congested beam (a/d=0.78)

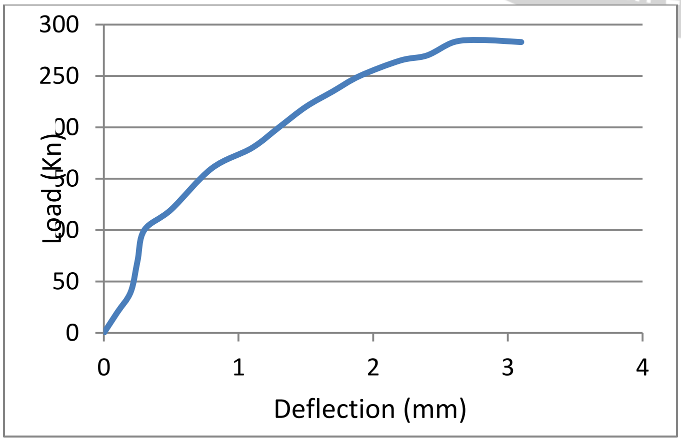

Figure 8: Graph load vs deflection for Congested beam (a/d=1.1)

In the above graphs it can be clearly seen, for beams with shear span to depth ratio 1.1, the load deflection response shows that the beam stiffness reduces considerably after developing the first diagonal crack.

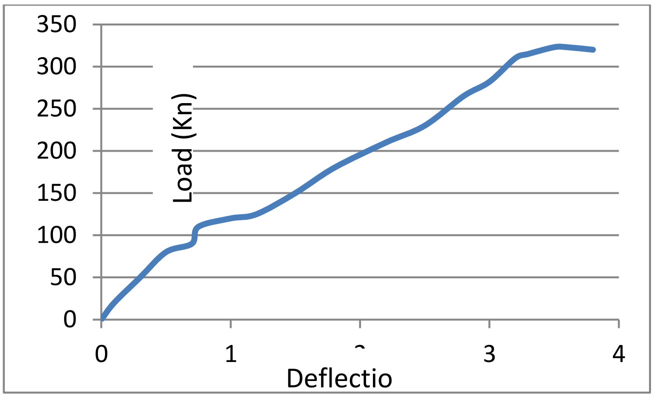

Figure 9: Graph load vs deflection for Non-Congested beam (a/d = 0.78)

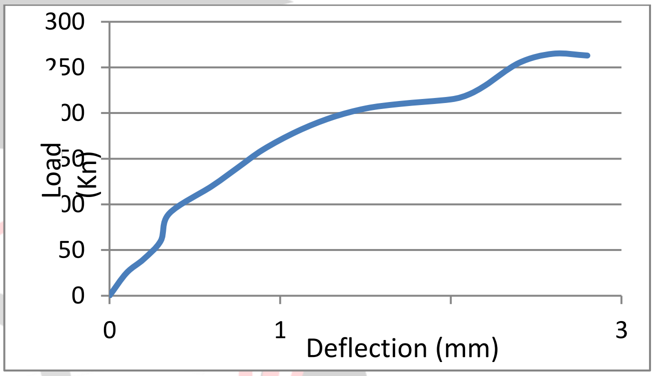

Figure 10: Graph load vs deflection for Non Congested beam (a/d=1.1)

The applied load versus mid-span deflection curves for all 4 SSC beams are shown in above figures. As expected, the initial stiffness and overall response of the specimens differ depending on the shear span to depth ratio. As it can be clearly seen that for beams with shear span to depth ratio greater than 1.0, the load deflection response shows that the beam stiffness reduces considerably after developing the first diagonal crack. This stiffness degradation decreases with decreasing shear span to depth ratio. No significant stiffness reduction was observed after the formation of diagonal cracks for beams with shear span to depth ratio less than 1.0. As expected, specimens of the same shear span to depth ratio but higher stirrup (shear reinforcement) spacing shows a higher drop in stiffness after the formation of the first diagonal crack. An additional predictable change in stiffness is observed after yielding of the main flexural reinforcement. The ultimate load pattern for all figures follows similar pattern. However a slightly abrupt failure in case of congested beams.

6.6 COMPARISON BETWEEN NC AND SCC BEAMS:

The comparison between NCC and SCC beams with same a/d ratio of 0.78 is tabulated below. It was observed that there is substantial increase in shear loads and ultimate loads of beams made with SCC as compared to NCC.

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However change was more pronounced in non-congested beams in shear loads, but ultimate loads was comparable in both cases. There was 8.5 % and 13.9% increase in shear loads in congested and non-congested beams respectively. The increase in ultimate load was almost 14% increase in both cases.

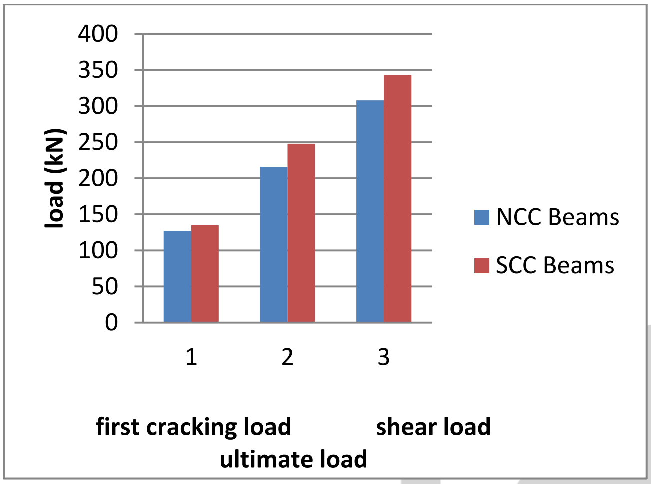

Figure 11: Comparison bar chart for NC and SCC Congested beams

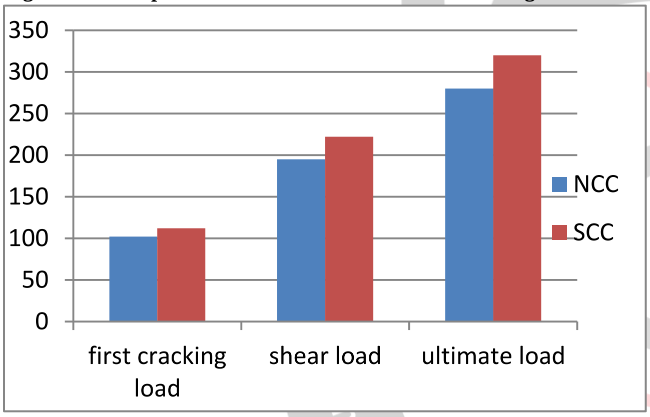

Figure 12: Comparison bar chart for NC and SCC non-congested beam

VII. CONCLUSIONS

A sequence of experimental tests were undertaken out to evaluate fresh properties of SCC and to investigate the shear behavior and performance of deep beams made with SCC during two point loading tests. In the first stage fresh properties of the NC and SCC were assessed based on the slump flow, and V-funnel tests. The workability and compacting ability were also observed in case to confirm fresh properties of Self compacting concrete. Shear behavior and performance of RC deep beams having two different shear reinforcements and with different shear span to depth ratio were. The findings of the present study are:

The slump flow, V-funnel tests conducted to assess the fresh properties of SCC concrete showed that the results satisfied the code requirements. The time involved in casting of SCC beams were notably less compared to that of the NC specimens in both the cases of relatively non-congested and congested shear reinforcement conditions. It can be noted that the load carrying capacities and into of SCC deep beams with a/d ratio 0.78 is higher as compared to NC beams and a/d ratio 1.1 in both cases of congested beams(75mm spacing) and non-congested beams(100mm). Also it can be seen the load carrying capacities of congested beams is higher than non-congested beams. The SCC specimens with the same shear span to depth ratio but higher stirrup (shear reinforcement) spacing show a higher drop in stiffness after the formation of the first diagonal crack. It was found that the SCC specimens showed similar reserved shear resisting strength by the arch action compared to NC specimens It was seen that all specimens made with SCC and NC possess nearly the same initial stiffness.

REFERENCES

[1] Dr. Hassan Falah Hassan, Behaviour of Hybrid Deep Beams Containing Ultra High Performance and Conventional Concretes, Eng. & Tech .Journal, Vol.33,Part (A), No.1, 2015

[2] Stephen, J. F., & Gilbert, R. I. Experimental studies on high-strength concrete deep beams. ACI Structural Journal, 95, 382–390.

[3] Yang, K. H., Chung, H. S., Lee, E. T., & Eun, H. C. Shear characteristics of high-strength concrete deep beams without shear reinforcements. Engineering Structures, 25, 1343–1352

[4] Hassan et al. (2008), Shear strength and cracking behavior of full-scale reinforced beams made with SCC and NC.

[5] Champion J. and Jost P. (1998), “Self compacting concrete: Expanding the possibility of Concrete Design and Placement”, Concrete International, V.22, No.4, pp. 159-178.

[6] Okamura H. and Ouchi M. (2003), “Self compacting concrete”, JACT, V.1, No.1, pp.5-15.

[7] ACI committee 318-2008, “Building code requirements for reinforced concrete”, American concrete institute, Detroit.

[8] EFNARC (2005): “The European Guidelines for Self-Compacting Concrete Specification, Production and Use”.

[9] Hassan, A. A. A., Hossain, K. M. A., & Lachemi, M. (2008). Behavior of full-scale self-consolidating concrete beams in shear. Cement and Concrete Composites, 30, 588–596.

[10] Okamura, H. (1999). Self-compacting high performance concrete. Tokyo: Social System Institute.

[11] Arabzadeh, A., A. Rahaie, and R. Aghayari, A simple strut-and-tie model for prediction of ultimate shear strength of rc deep beams. International Journal of Civil Engineering, 2009. 7(3): p. 141-153.

[12] Brown, M.D. and O. Bayrak, Design of deep beams using strut-and-tie models-part I: Evaluating US provisions. ACI Structural Journal, 2008. 105(4).

[13] Bazant, Z.P. and J.-K. Kim, Size effect in shear failure of longitudinally reinforced beams. ACI Journal, 1984. 81(5): p. 456-468.

[14] Syroka-Korol, E. and J. Tejchman, Experimental investigations of size effect in reinforced concrete beams failing by shear. Engineering Structures, 2014. 58: p. 63-78.

[15] Angelakos, D., E.C. Bentz, and M.P. Collins, Effect of concrete strength and minimum stirrups on shear strength of large members. ACI Structural Journal, 2001. 98(3).

 DOI : 10.18231/2454-9150.2018.0454