

A New Structural Behavior of Self Compacting Reinforced Concrete Beams Based on VTRR

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Abstract:

Nowadays, the use of Self-compacting Concrete (SCC) is spreading worldwide because of its very attractive properties in the fresh state as well as after hardening. Several attempts have been made in the recent years to study about the strength and behavior of SCC. However, only few studies have been conducted on the strength and behavior of structural elements made on Reinforced Self Compacting Concrete beam. Therefore, an attempt has been made in the present investigation to study the effect of the strength and behavior of structural beam elements subjected to flexure. The strength of members in the design and behavior of shear strength is an important issue in structural design.

There are several modes of failure in concrete structural members like shear, flexure. Due to the fragility of concrete structures, shear failure is one of the most important and undesirable modes of failure. Hence, Reinforced Concrete (RC) members are used to resist shear failure. Because of the complexity of shear mechanisms of reinforced concrete beams and various influencing parameters, it is difficult to establish an overall model to provide accurate estimation of shear strength. Hence, exact values of shear strength are unknown. Several empirical formulas are proposed in the literature and concrete codes for the prediction of RC beams resistance.

The American Concrete Institute (ACI) and Indian Standard (IS) code has been widely used in

structural design. In the last decades, numerous works have been undertaken to improve the ability of empirical formula to predict the shear behavior of concrete structural member. Shear reinforcement is used in concrete beam to preserve the overall integrity of the concrete contribution allowing the development of additional shear forces.

Keywords

Self Compacting Concrete, Shear Capacity mechanism, Flexure Behavior, Transverse reinforcement ratio

1. Introduction

Among recently developed special concretes, a prominent position is attained by self-consolidating concrete (SCC), which is considered to be one of the greatest achievements in concrete technology. The basic feature of SCC is its ability to be poured into formworks without using vibration and maintaining good stability (i.e., no segregation). Although SCC consists basically of the same components as normal concrete (NC), its composition is quite different in order to achieve self-compacting properties. While the coarse aggregate fraction is usually limited, the powder volume is higher in a SCC. This different concrete composition leads to different mechanical properties. On one hand, the higher powder and the lower coarse aggregate content changes the granular skeleton and affects strength, modulus of elasticity and volume stability. On the other hand, in SCC

there is an improvement of the grain-size distribution and of the interfacial transition zone (ITZ), which becomes denser with respect to a normal concrete.

Shear failure in concrete is known to be brittle and catastrophic caused by shear force. In usual structural design, shear is accounted for by providing shear reinforcement such as stirrups in beams. Sometimes the shear reinforcement may be less than sufficient if the loading configuration were different from that predicted during design, such as during earthquake or at critical section reinforcement conjunctions[1].

It is one of the most important concepts in concrete structural members. RC members resist shear force using several mechanisms. It is tolerated in RC beams by providing web reinforcement. It usually takes the form of vertical stirrups, the bars that surround the longitudinal bars along the faces of the beam. The required shears strength to be provided by the web reinforcement is usually computed by formulas in concrete codes. The required area of web reinforcement or spacing of the stirrups can be determined based on the amount of predicted shear strength. As of today, due to durability requirements most of the concrete industries were using M30 grade concrete.

2. Research significance

Shear failure has been observed in many beams of reinforced concrete (RC) buildings subjected to recent severe earthquakes and shear failure has often caused the collapse of RC buildings. The previous studies on shear failure were mostly based on the experimental equations obtained statistically from many test results, or on the crude analytical models only for the strength.

But it seems to be very difficult to account for shear failure mechanism generally by these means[2].

According to this experiment study the failure mode was not affected so much by the compressive strength of concrete. It is considered to be appropriate for the observation on the dowel action and aggregate interlock that the shear span ratio, a/d is in the range of 1.5-2.5. The experimental program consisted of twelve beams of 30 MPa concrete target mean strength tested with a shear span-depth ratio equal to 2.35 as shown in the Figure 1.

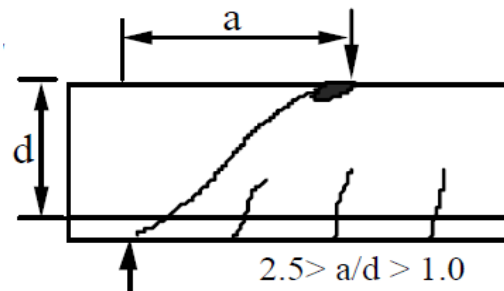


Figure 1. Failure mode of shear arm ratio.

In 1st series the beams had no web reinforcement, had taken as a control specimen named as control beam (CB), in the 2nd series the beams had the maximum spacing distance which calculated from the codes series the beams named as shear beam (SB). The mode of failure for 1st and 2nd series of beams was secured to allow for shear mode of failure. In the 3rd series minimum spacing distance throughout the beam named as flexure beam (FB) had designed to fail in flexure and in the 4th series spacing of stirrups combined with two different values of transverse reinforcement ratio (TS ratio) equal to $A_{sw} / (s \times b)$, on the central area ($L/2$) where pure bending occurs are displaced with 0.67% of TS ratio corresponding to the beams of the 2nd series, and on the remaining shear edge zone ($L/4$) on two sides stirrups were displaced with 0.33% of TS

ratio corresponding to the beams of the 3rd series, to avoid shear failure. This series of beams named as combined spacing beam (CSB). The reinforcement details of those four series of beams are shown in Figure 2[3].

The key parameters covered in this investigation are the effect of the spacing, amount of the vertical stirrups on the shear capacity and ductility of the tested beams. The study shows that the contribution of web reinforcement to the shear capacity is significant and directly proportional to the amount and spacing of the shear reinforcement.

2.1 Minimum Shear Reinforcement:

The main reasons for providing minimum shear reinforcement in RC beams are as follows

- To avoid brittle shear failure after diagonal shear crack
- To provide reserve strength even after the diagonal shear crack formation.
- To redistribution of the stresses in the region of shear span
- To impart ductility to the beam before shear failure

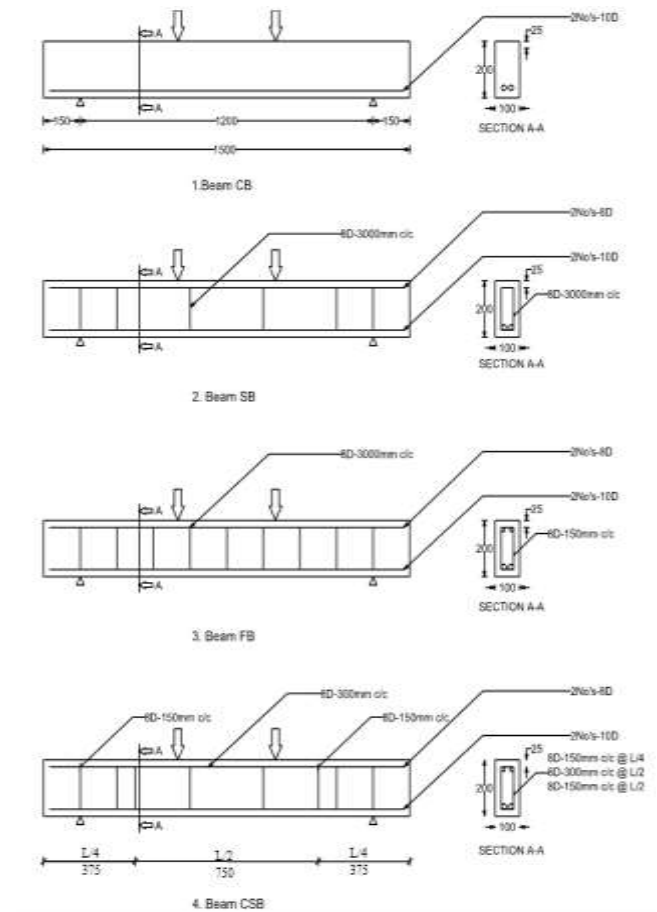


Figure 2. Geometrical characteristics of reinforcement detail of beam specimens.

2.2 Shear in RC Beams without web reinforcements

Beams without web reinforcements or stirrups will fail when inclined cracking occurs. This type of failure referred to as diagonal tension failure as precipitates if the strength of the beam in diagonal tension is lower than its strength in flexure. This behavior is common in beams with shear arm ratio of a/d between 2.5 and 5.5. The shear span, a , is the distance between the point of application of the concentrated load and the face of the support, and d is the effective beam depth[4].

Diagonal shear failure starts with the development of a few fine vertical flexural cracks at mid span, followed by the destruction of the bond

between the reinforcing steel and surrounding concrete at the support. Thereafter, without ample warning of impending failure, two or three diagonal cracks develop at about 1.5–2 shear arm distance from the face of the support. As they stabilize, one of the diagonal cracks widens into a principal diagonal tension crack and extends to the top compression fibers of the beam. This type of brittle failure mode occurs at a relatively small deflection. The shear capacity of the beam is considered to be equal to the inclined cracking shear.

The purpose of this study is to investigate the contributions to the shear capacity of RC beams of the shear forces carried by the compression zone of concrete, dowel action of tension reinforcement, aggregate interlock and stirrups, when RC members were subjected to bending moment and shear force due to earthquakes[5].

3. Experimental Program

To study the behavior of beams, totally four series of beams were cast and each series containing of three samples, twelve reinforced concrete beams of size 100mm x 200mm x 1500mm were casted, Two numbers of 10mm diameter Fe 415 grade steel bars were provided as longitudinal tension reinforcement and two legged 8 mm diameter stirrups were provided as shear reinforcement. The beams were simply supported and subjected to symmetrical two point loading. The companion specimens such as cube, cylinder and flexure beam were also cast and tested to find the compressive, split tensile and flexural strength of concrete. Strength of hardened concrete from tested companion specimen results are shown in Figure 3[6].

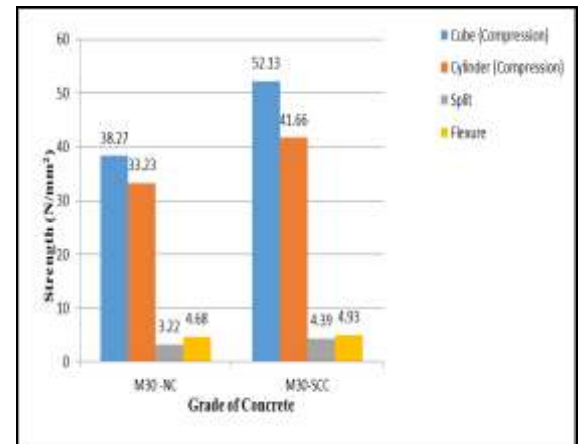


Figure 3. Test results on companion specimens of NC and SCC.

The measurements taken on each beam were deflections to the corresponding load and observation of cracks and the beam was loaded up to failure. The test result of beams are given in Tables 1. From the test results, load deflection characteristics were studied and given in Figures 4.

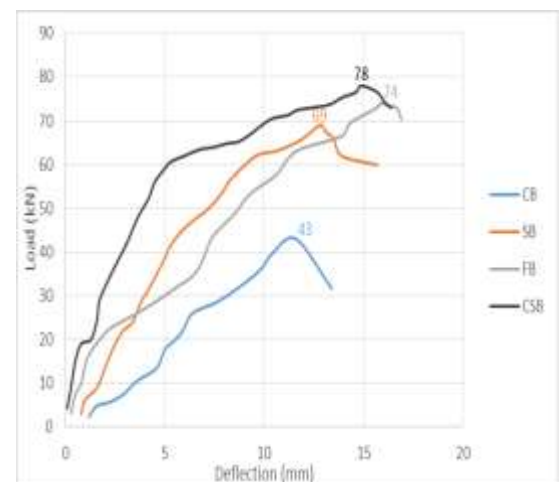


Figure 4. Load and deflection relationship.

Test results in Table 2 demonstrate that the shear reinforcement significantly enhances the ductility and stiffness of the beams, graphical representation of the results are shown in Figure 5 and Figure 6.

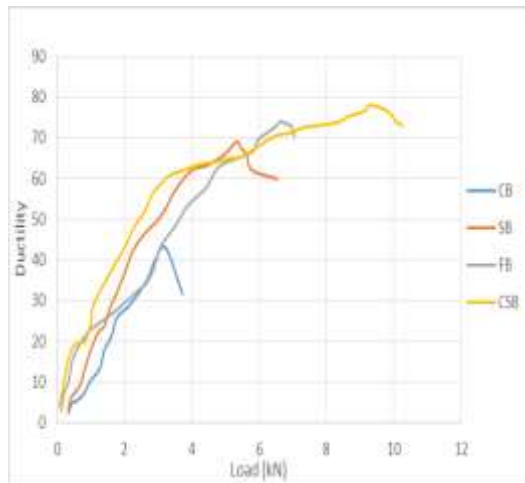


Figure 5. Applied load and ductility relationship.

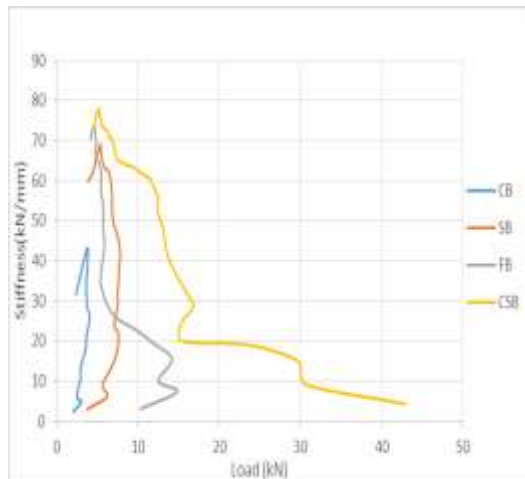


Figure 6. Applied load and stiffness relationship.

3.1 Effect of transverse reinforcement

The experimental program was conducted to study the effect of the presence, amount and spacing of transverse steel on the shear behavior of the beams. Although it had no significant effect on the initial stiffness, provision of the steel stirrups is shown to enhance the ultimate capacities and the ductility of the tested beams[8]. The enhancement increases with increasing the amount of stirrups by

decreasing the spacing between them. The shear reinforcement in the form of stirrups contributes to the behavior of the shear mechanism by improving the contribution of the dowel action and limiting the opening of inclined shear cracks, thus enhancing and persevering shear transfer by aggregate interlock. Figures 7 shows the test setup of beam under two point loading, Figure 8 shows the specimens after failure[7].

4. Discussions on test results

1st and 2nd series beam specimens failed in shear and it was observed that the shear cracks crossed the compression zone of beam section.

Whereas 3rd and 4th series of beam specimens failed in flexure in the pure bending zone between the loads.

Table 1. Experimental results

Beam Type	Stirrups spacing (mm)	First crack load (kN)	Ultimate load (kN)	Increase in ultimate load (%) ^a	Deflection corresponding to first crack load (mm)	Deflection corresponding to ultimate load (mm)
CB	0	10	43	0	3.6	11.6
SB	300	18	69	37.68	2.4	12.8
FB	150	23	74	41.89	2.4	15.9
CSB	150, 300, 150	24	78	44.87	1.6	14.9

^a Increase in ultimate load due to the presence of web reinforcement comparing with plain beam

Table 2. Ductility Stiffness index

Beam Id	Ductility	Increase in ductility (%) ^a	Stiffness (kN/mm)	Increase in stiffness (%) ^a
CB	3.222	0	3.7069	0
SB	5.333	39.58	5.3906	31.24
FB	6.625	51.36	4.6541	20.35
CSB	9.315	65.41	5.2349	29.18
^a Increase in ductility (or) stiffness due to the presence of web reinforcement comparing with plain beam				

1- Expectedly, the control beam CB with no web reinforcement had a sudden shear failure with rapid stiffness

2- Beam SB, with vertical stirrups of D8/300 mm, showed improved ultimate load carrying capacity than CB by 37.68% respectively. Failure displacement of CB is higher than those of beams SB by 9.4% respectively.

3- Beam FB, with vertical stirrups of D8/150 mm, showed improved ultimate load and post peak behavior. The ultimate load of this beam FB (D8/150 mm) is higher than those of beams by 41.89% and 6.75% respectively comparing with the CB and SB which indicates the beneficial effect of decreasing the spacing between stirrups. Also, the failure displacement of FB is higher than those of beams CB and SB by 27% and 7.8% respectively.

4- Beam CSB, with vertical stirrups of D8/3000 mm on center zone were pure bending occurs and D8/150 for both shear edge zones, significantly showed improved ultimate load and post peak behavior. The ultimate load of this beam is higher than those of beams CB, SB and FB by 44.87%, 11.54% and 5.13% respectively. The failure displacement of CSB is higher than those of beams CB, SB and FB by 22.15%, 14.1% and -6.71% respectively[9].

4.1 Mode of failure of tested specimens

Failure of beam exhibited the role of steel stirrups in changing the mode of failure and increasing the ultimate load, the descending branch of the curves had a real relation with the amount and spacing of web reinforcement.

For specimens CB1 to CB3 the shear cracks started without any sign of flexural cracks, and it failed due to shear failure characterized by diagonal shear tension.

For specimens SB1 to SB3, it was observed that the first early cracks were vertical flexural cracks occurred in the specimens at mid span and near mid span sections, and upon increasing the applied load, a series of flexural cracks were formed at the bottom in the shear span region and gradually propagated toward the loading point while no crack had been observed at beam ends. By increasing the applied load and at intermediate loading stages, a new series of flexural cracks was formed in the shear span region then joining the loading and supporting points[12].

For specimens FB1 to FB3, it was observed that the first early cracks were vertical flexural cracks occurred in the specimens at mid span and near mid span sections, and upon increasing the applied load, the cracks were propagated through the first crack with less length of flexure crack compared with SB beams while no cracks were appeared on the shear span area and on reaching 80% of the ultimate load small length shear cracks will appeared on above the neutral axis of the beam while not reaching the top surface of the compressive zone. After reaching the ultimate load the beam remains constant at the yielding point and at the same time deformation of beam was appeared[11].

For specimens CSB1 to CSB3, it was observed that the first early cracks were vertical flexural cracks occurred in the specimens mid span and

upon increasing the applied load, the cracks were propagated through the first crack with less length of flexure crack same as by the FB beams while no cracks were appeared on the shear span area and on reaching 90% of the ultimate load small length widely diverged shear cracks will appeared on above the neutral axis of the beam while not reaching the top surface of the compressive zone. All cracks are appeared in pure bending area of the beam only. The number of flexure cracks is 20% less when compared with FB beams. After reaching the ultimate load the beam remains constant at the yielding point and at the same time deformation of beam was appeared[10].

5. Conclusions

Based on the result of companion specimen's investigation, the following conclusions are drawn: The compressive strength of SCC was found to be improved compared with the NC. Also the SCC shows 26.6% higher compressive strength when compared to NC. SCC is very useful in concreting through the congested reinforcement. The use of SCC increases the pump ability of the concrete; this reduces the labour cost and increases the safety at the work site. It improves the economy of the concreting work. Therefore, SCC proves to be more advantageous in the field application than the normal concrete.

Based on the study in beam element herein, the following conclusions have been drawn:

(1) The shear reinforcement in the form of stirrups significantly contributes to the shear behavior of wide beams by improving the contribution of the dowel action, and limiting the opening of inclined shear cracks, thus its effect in the form of vertical

stirrups on shear capacity of wide beams should be considered.

(2) The contribution of web reinforcement to the shear capacity is proportional to the amount of shear reinforcement. The increase in the shear capacity ranged from 0%, 37.68%, 41.89% and 44.87% for the range of CB, SB, FB and CSB tested beams.

(3) The shear reinforcement amount significantly enhances the ductility of the beams. Also, as the spacing between the web reinforcement decreased, the ductility and stiffness of the specimen found to be increased.

(4) The stiffness and ductility was also found to be increasing gradually both in CB and SB as well as in FB and CSB Beams.

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