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"SHEAR STRENGTH OF HIGH STRENGTH CONCRETE SLENDER BEAM WITH AND WITHOUT TRANSVERSE REINFORCEMENT"

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Abstract
The shear failure of HSC beams is a very complex fracture phenomenon and associated with brittle failure and it becomes very difficult to predict shear capacity by mathematical approach or empirical formulas and the various international codes are very conservative for prediction of shear strength of HSC beams so an experimental investigation has been carried out to predict the shear capacity of HSC beams and compare with the codel provision.

Keywords: Shear strength, shear failure, compressive strength of concrete, transverse reinforcement, longitudinal reinforcement, shear span to depth ratio.

Introduction:
Amount of stirrup has a direct relation on the behavior of reinforced concrete members of general structure, since the structures are possible to fail in brittle manner without any warning sign if the shear stress rides over the shear carrying capacity.

Great example of shear failure is the collapse of super-structures during Great-Hanshin Earthquake, in 1995. With respect to that evident, many of viaduct's structures constructed as a rigid-framed were destructed as shown in Figure 1-1. According to the mentioned structure, the amount of stirrup was lightly used. Therefore, the following question has been asked by many researchers for such a longtime that did the estimation of shear strength of those was miscalculated?

One of possible and discovered reason is the size effect of the structure members, which was introduced by Okamura [2]. With respect to this reason, the formula derived from the specimen in experiments, which are very tiny compare to the real structure, did not include some important factor. It can be illustrated that strength of small specimens in experiments are affected in crack propagation by the reinforcing bar, so called bond effect, which increased the fracture energy of concrete. Nevertheless, in actual, the effect of bond from the reinforcement is very tiny since the members cross-section is so large that crack propagation is not able to confine by bond effect of reinforcement. It used to clarify and accept this problem, size effect, by many researchers and the consideration in its was added as size effect term in the shear strength design formula.

Another possible problem but it does not clarify yet is the shear carrying capacity's design concept since the concept is used as the strength of concrete at either failure or shear crack load and sum up with shear resistance of web reinforcement. Why the shear strength design concept seems to be not enough, it is possible that a small amount of web reinforcement cannot maintain the shear strength resist by concrete to be the same up to yielding point of stirrup itself. The remaining and possible reason is going to study [4].

1.2 Current Use of Stirrup

As mentioned, the important factors drive shear failure in super-structure during Kobe's earthquake was explored. One factor originally based on the past design code since it used to overestimate in size-effect.

A related consideration is because Japan Society of Civil Engineering's design guide at the constructing period used allowable stress design concept, and it had required a suddenly increasing of stirrup if the allowable shear strength of concrete did not enough. Consequently, escaping from suddenly increasing of stirrup, enlarge section of member to increase the allowable shear stress in concrete was commonly done. In summary, large section and small amount of stirrup are the consequence of designing that finally destructed by the earthquake.

The shear strength of reinforced concrete beams has been extensively studied over the last 40 years. for the case of slender beams with shear reinforcement under two point loading large number of experimental and analytical works have been carried out. More over in shear reinforcement to control the inclined cracking in beams have been determined.

Despite the great research efforts, however, there is still not a simple, albeit analytically derived formula to predict and with accuracy the shear strength of slender beams. In addition, many of the factors that influence the determination of the required minimum amount of shear reinforcement are not yet known [3].

Unlike flexural failures, reinforced concrete shear failures are relatively brittle and particularly for members without stirrups can occur without warning because of this, the prime objective of shear design is to identify where shear reinforcement is required to prevent such a failure and then in a less-critical decision how much is required. Shear reinforcement, usually called stirrups links together the flexure tension and flexure compression sides of a member and ensures that the two sides act as a unit.

Shear failures involve the breakdown of this linkage and for members without stirrups, typically involves the opening of major diagonal crack. With advent of higher concrete compressive strengths and the corresponding increase in concrete tensile strengths there is concern that traditional amounts of minimum shear reinforcement may not be sufficient in high strength concrete beams. Minimum shear reinforcement must prevent sudden shear failure on the formation of first diagonal tension cracks at service loads levels.

To prevent brittle failures adequate reserve strength must be provided by the shear reinforcement after diagonal cracking of reinforced concrete beams. To control crack widths at service loads levels not only a minimum amount of shear reinforcement be provided but the maximum stirrup spacing must also be limited. Due to the higher tensile strength of high –strength concrete a higher cracking shear is expected and hence would require a larger amount of minimum shear reinforcement [4].

1.3 Shear Study:

1)The mechanism of shear resistance in RCC beams without web reinforcement

In a reinforced concrete members, flexure and shear combine to create a biaxial state of stress. Cracks form when the principle stresses exceed the tensile strength of the concrete. In a region of large bending moments these stresses are greatest at the extreme fibre of the member and are responsible for the initiation of flexural cracks perpendicular to the axis of the member.

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In the region of high shear force significant principle stresses also referred to as diagonal tension may be generated at a approximately 45 degrees to the axis of the member. These may result in inclined cracks. With few exceptions these inclined cracks are extensions of flexural cracks. Only in rather special cases as in webs of flanged beams, are diagonal tension cracks initiated in the vicinity of the neutral axis. The principle stress concept is of little value in the assessment of subsequent behavior unless complex distribution of stresses in the concrete after cracking is considered. Either a reinforced concrete flexural member collapse immediately after the formation of diagonal cracks or an entirely new shear carrying mechanism develops which is capable of sustaining further load in a cracked beam.

The diagonal cracking load originating from flexure and shear is usually much smaller than would be expected from principle stress analysis and the tensile strength of concrete.

This condition is largely due to the presence of shrinkage stresses, the redistribution of shear stresses between flexural cracks and the local weakening of a cross section by transverse reinforcement which causes a regular pattern of discontinuities along a beam.

In the early stages of reinforced concrete design diagonal cracking was considered to be undesirable. However, it is now recognized that diagonal cracking under service load conditions is acceptable, provided crack widths remain within the same limits accepted for flexure.
Shear strength in steel reinforced concrete beams has been the subject of many controversies and debates since the beginning of 20th century. The shear strength of reinforced concrete beams has been extensively studied over the last five decades [6].

A large number of experimental and analytical works have been carried out for the case of slender beams (having a shear span to depth ratio $a/d > 2.5$) with and without shear reinforcement under two-point loading.

Transversely loaded reinforced concrete beams may fail in shear before attaining their full flexural strengths if they are not adequately designed for shear. Unlike flexural failures, shear failures are very sudden and unexpected, and sometimes violent and catastrophic. A thorough knowledge of the different modes of shear failures and the mechanisms involved is necessary to prevent them.

Existing codes and specifications of different countries for reinforced concrete design with regard to shear differ considerably in important aspects. This only reflects the fact that we know very little about the behavior and strength of reinforced concrete subjected to shearing force in spite of the considerable number of tests and theoretical investigations made during more than half a century.

Despite the great research efforts, however, there is still not a simple, albeit analytically derived formula to predict quickly and accurately the shear strength of slender beams. In addition, many of the factors that influence the determination of the required minimum amount of shear reinforcement are not yet known [15].

II- LITERATURE REVIEW:

THEODOR KRAUTHAMMER (JAN/FEB- 1992),[1] In this paper the requirement for minimum shear reinforcement in RCC beams is evaluated based on the treatment of interface shear transfer across a crack. A key parameter for this derivation is required magnitude of contact normal stress on such interface which controls the frictional resistance. The experimental data were employed to define the required value of the normal contact stress and its corporation into the proposed approach resulted in a modified definition for shear reinforcement. This approach enabled the derivation of two useful tools for the design of interface shear resistance and minimum shear reinforcement in RCC beams. The research significance is that it provides a rational approach to determine minimum shear reinforcement requirement to ensure adequate safety. `The requirement for minimum shear reinforcement in reinforced concrete beams

MICHAEL P. COLLINS, EVAN C. BENTZ AND EDWARD G. SHERWOOD(2008),[2]

M60 grade rein This paper concludes that using the current ACI shear provisions to decide where shear reinforcement is required can be conservative for members with larger effective depths or higher stresses in the longitudinal reinforcement. Improvement to the ACI code is proposed to mitigate these weaknesses. The paper also demonstrates that the AASHTO-LRFD and Canadian CSA sectional and strut and tie provision a more uniform level of safety for all member types. Study behavior of high strength concrete leads to significant changes in codal provisions in practice around the world, it shows that HSC needs different philosophy of design and approach, computed the concrete compressive strength using standard specimens, taking different load and resistance factors to obtain specified characteristic strength, modulus of elasticity, tensile strength of concrete, minimum reinforcement for flexure and even seismic design.

YOUNG-SOO, WILLIAM D. COOK AND DENIS MITCHELL (1996), [3]

They presented on the evaluation of minimum shear reinforcement requirement in normal, medium and high strength reinforced concrete beams. 12 shear tests were conducted on full scale beam specimens having concrete compressive strength of 36, 67, 87 Mpa. Different amounts of minimum shear reinforcement were investigated including traditional amounts required by older codes. The performance of the different amounts of shear reinforcement are discussed in terms of shear capacity, ductility and crack control at service loads levels. An assessment of the 1989 ACI and 1991 CSA provision for minimum shear reinforcement. The evaluation of minimum shear reinforcement requirements in normal, medium, and high-strength reinforced concrete beams. Twelve shear tests were conducted on full-scale beam specimens having concrete compressive strengths of 36,67and 87 Mpa. Different amounts of minimum shear reinforcement were investigated, including the traditional amounts required by older codes and the amount required by 1989 ACI code. The performances of the different amounts of shear reinforcement are discussed in terms of shear capacity, ductility and crack control at service load levels. An assessment of the 1989 ACI and 1994 CSA provisions for minimum shear reinforcement is also presented based on crack control, ductility high strength concrete, minimum shear reinforcement, shear strength, splitting cracks stirrups. Based on beam support, shear strength, shear reinforcement and splitting cracks.

SONGKRAM PIYAMAHANT (2002), [4]

According to the advance concerning, the shear carrying capacity of reinforced concrete beam in concrete part after cracking should not be regard to be the same as just crack, but it should be changed. However, in that experiment, the amount of stirrup used as much larger than the minimum requirement. Nevertheless, at least, the behaviours of it after cracking like either load resistance or crack opening and crack sliding, which control the load-deformation of itself, it mainly depends on the amount of stirrup.

In summary, the shear carrying capacity of reinforced concrete beam with web reinforcement does not simply sum up that of concrete and stirrup together as Vc+Vs, but it has to concern with the interaction between them, which actually depend on amount of web reinforcement.

Y-H. BAE, J-H LEE AND Y-S YOON (2006), [5]

The ultimate high-strength equation considering size effects and arch action is presented for computing the shear strength in high-strength concrete beams without stirrups, 3 basic equations namely those for the size reduction factor and arch action factor are derived from the crack band model of fracture mechanics, analysis of previous shear equations for longitudinal reinforcement ratio and concrete strut described as a linear function in deep beams. constants of basic equations were determined using statistical analysis of previous shear testing data. while the proposed shear equation is simpler than other shear equations i.e ACI 318, CSA 34 and it gives economical predictions of shear strength and reasonable safety margin.

The conclusions drawn are that shear strength of HSC beams as a\d ratio decreased owing to higher arch action, effect of aggregate type has negligible effect on shear strength. From comparison, it was found that the IS 456 (2000) code gives most conservative results of HPC beams while, the ACI 318 (2005) and Eurocode 2 (2004) codes are comparatively satisfactory.

IMRAN A. BUKHARI* AND SAEED AHMAD (2007), [7]

In this paper, a comparative analysis on shear behaviour of high-strength concrete beams using various international design approaches like ACI, Canadian, AASHTO, European Code and the method proposed by Zararis is presented. Twenty-seven reinforced concrete beams without web reinforcement were tested under three-point loading. In addition, 95 other similar beams having similar cross-sectional dimensions, concrete strength, and loading conditions are analysed. The shear span-to-depth ratio ranged from 1 to 6 and longitudinal reinforcement ratio from 0.35% to 1.94%. Based on the analysis of total of 122 similar beams, it is observed that shear strength and failure mode depend upon shear span and longitudinal reinforcement ratio. For values of *a*/*d* ratio less than 2.5, the experimental shear strength was found greater than that predicted as per different shear design approaches; however for slender beams having *a*/*d* ranging from 2.5 to 6, the predicted shear capacity was found greater. It was noted that ACI 318-02[1] predicts shear strength more accurately for values of tensile steel ratio greater than 1%, whereas design approach proposed by Zararis is more appropriate to be used where tensile steel ratio is less than 1%.

GURAY ARSLAN (2008), [8]

This study presents alternative cracking shear strength equations for slender reinforced concrete (RC) beams without stirrups. More than 80 data have been obtained from existing sources of RC beam shear test results covering a wide range of beam properties and test methods. The proposed cracking shear strength equations are applied to existing test data for normal strength concrete (NSC) and high-strength concrete (HSC) slender beams and the results are compared with those predicted by the ACI 318 equations. It can be also noted that the test results are in better agreement with proposed cracking shear strengths. However, because the test data for high-strength concrete members are very limited, further research is required to verify these equations.

The cracking shear strength equation for slender reinforced concrete high strength beams without stirrups are developed based on test results and experimental investigations of wide range beams based on their properties and test methods, the equations are applied both for NSC and HSC beams, it is noted that test results are in better agreement with proposed cracking shear strength for HSC based on compressive strength, cracking shear strength, shear span at depth, dowel action and diagonal tension and the equation obtained are compared with different national codes which shows significant scatter between the experimental values and codel provisions.

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I- EXPERIMENTAL INVESTIGATIONS:

Preliminary Investigation:

To produce HSC (M70), various tests on ingredients i.e. cement, sand and coarse aggregate and trial mixes cubes were cast using a low water binder ratio (< 0.3), carried out and chemical admixture suitably and using ACI 211 code. The mix proportion at which the required strength of concrete and other values has been discussed. Required cube and cylindrical strength after achieving has been tabulated. Variable and constant parameters in the experiment have been detailed and described.

Table 3.10: Details of beam specimens

SERIES	BEAM	l_e (mm) effective length	bxd (mm) c/s of beam	a/d shear span to depth	ρ (%) longitudinal steel ratio	S(mm) Spacing of shear steel
A	B1	900	125x130	2.5	1.8	150
	B2	900	125x130	2.5	1.8	225
	B3	900	125X130	2.5	1.8	300
	B4	900	125X130	2.5	1.8	-
B	B5	900	125X130	2.5	3.2	150
	B6	900	125x130	2.5	3.2	225
	B7	900	125x130	2.5	3.2	300
	B8	900	125X130	2.5	3.2	-
C	B9	900	125X100	3.25	1.8	150
	B10	900	125x100	3.25	1.8	225
	B11	900	125X100	3.25	1.8	300
	B12	900	125X100	3.25	1.8	-
D	B13	900	125X100	3.25	3.2	150
	B14	900	125X100	3.25	3.2	225
	B15	900	125X100	3.25	3.2	300
	B16	900	125X100	3.25	3.2	-
E	B17	1500	125X130	4.25	1.8	150
	B18	1500	125X130	4.25	1.8	225
	B19	1500	125x130	4.25	1.8	300
	B20	1500	125X130	4.25	1.8	-
F	B21	1500	125X130	4.25	3.2	150
	B22	1500	125X130	4.25	3.2	225
	B23	1500	125X130	4.25	3.2	300
	B24	1500	125X130	4.25	3.2	-
G	B25	1500	125X100	5.5	1.8	150
	B26	1500	125x100	5.5	1.8	225
	B27	1500	125X100	5.5	1.8	300
	B28	1500	125X100	5.5	1.8	-
H	B29	1500	125X100	5.5	3.2	150
	B30	1500	125X100	5.5	3.2	225
	B31	1500	125X100	5.5	3.2	300
	B32	1500	125X100	5.5	3.2	-

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IV-RESULTS & DISCUSSION:

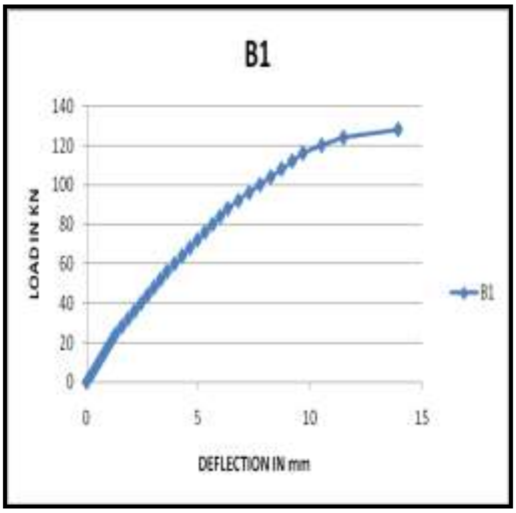
Failure Patterns of HSC Beams:

Fig. 5.1: B1/1.8/2.5/150

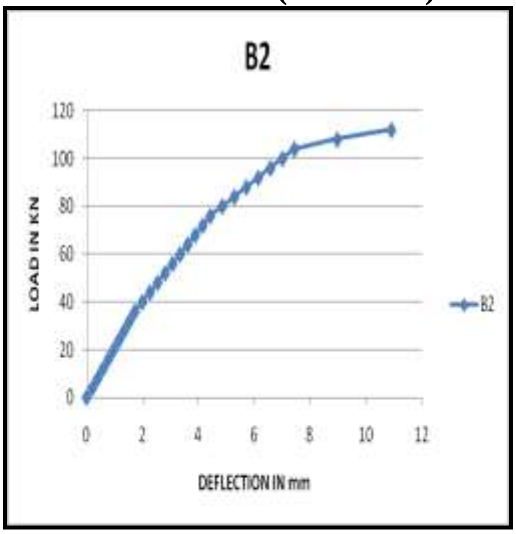
The beam with 1.8% longitudinal reinforcement, a/d ratio of 2.5 and shear reinforcement 6mm Dia with spacing 150 mm failed in shear. A gradual load was applied with an increment of 4 KN to the beam and every increment of the load, deflections were recorded. The beam cracked at a load of 32 KN with cracks simultaneously appearing on the beam. As the load further increased, the beam deflected more with formation of more number of flexural cracks, shear crack formation.

At the load of 128 KN the beam failed suddenly in shear at the left support and the deflection was 13.94 mm.

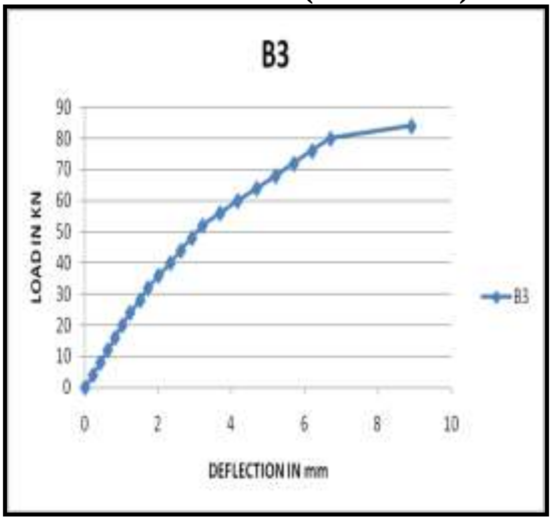
Load V/S Deflection Graphs for HSC Beams:



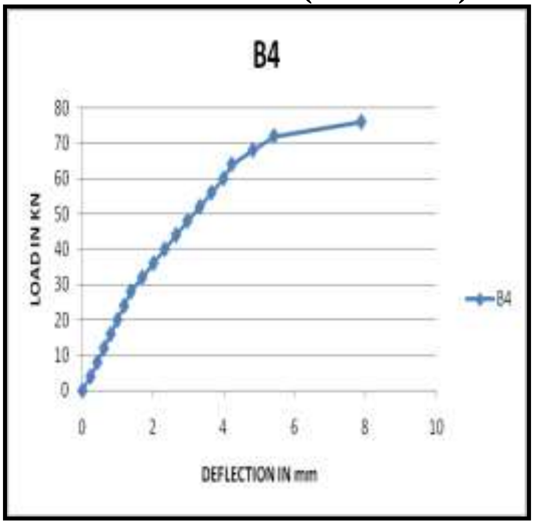
Graph 5.1: Load V/s Deflection forHSC Beam 1 (1.8/25/150)



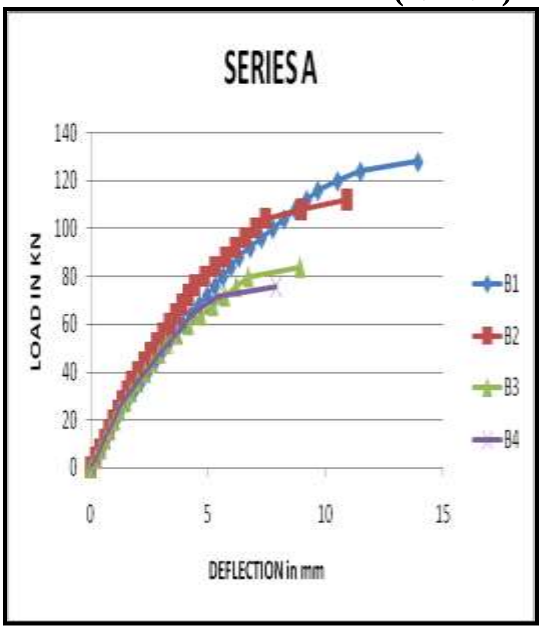
Graph 5.2: Load V/s Deflection for HSC Beam 2 (1.8/2.5/225)



Graph 5.3: Load V/s Deflection for HSC Beam 3(1.8/2.5/300)



Graph 5.4: Load V/s Deflection for HSC Beam 4 (1.8/2.5/)



Graph 5.33: Load V/s Deflection for HSC series A beams

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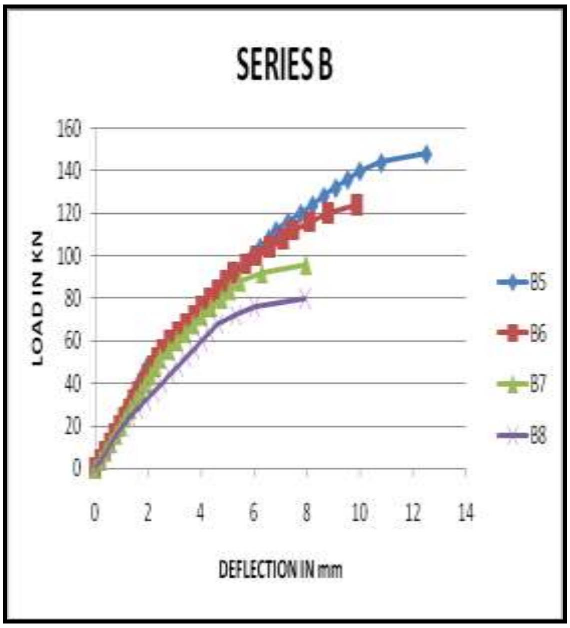
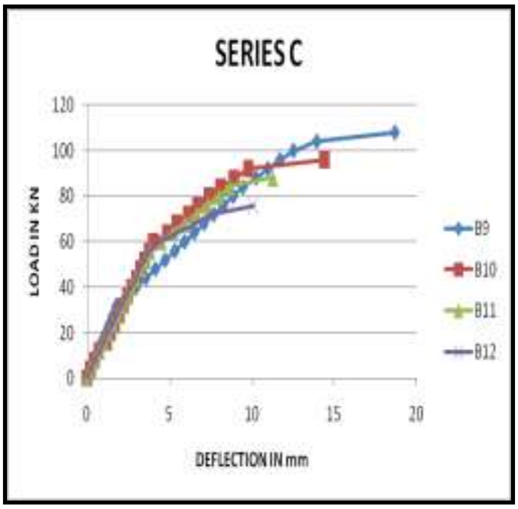
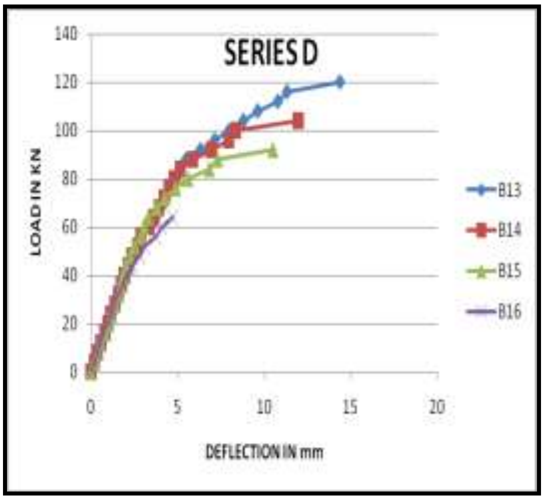


Graph 5.34: Load V/s Deflection for HSC series B beams



Graph 5.35: Load V/s Deflection for HSC series C beams



Graph 5.36: Load V/s Deflection for HSC series D beams

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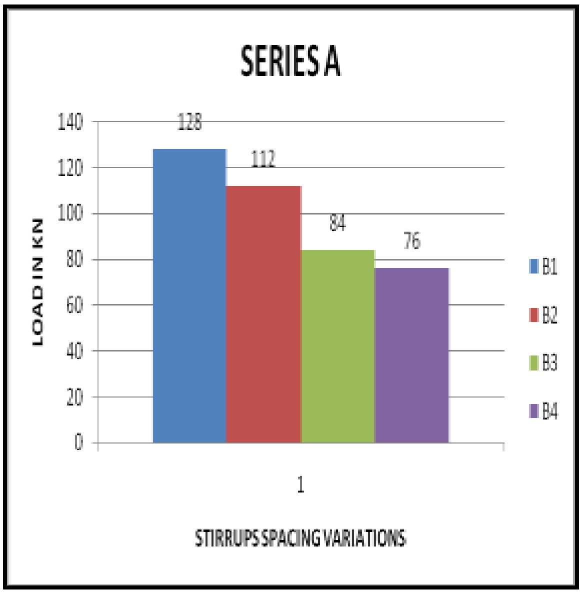
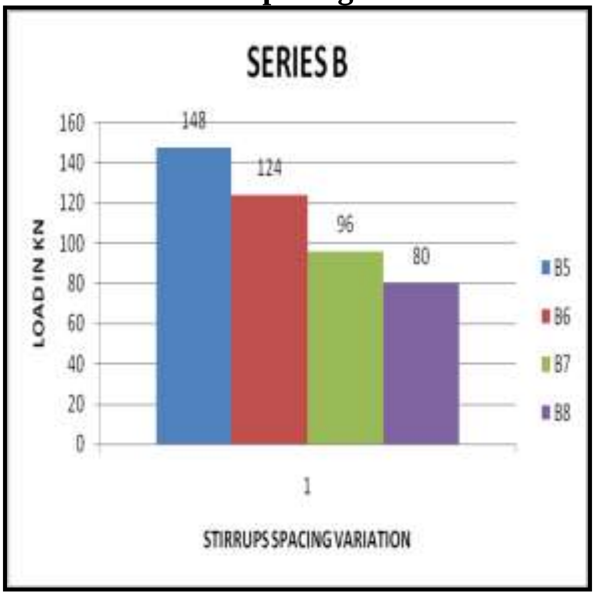
Bar Chart for Load V/S Variation of Shear Reinforcement:



Graph 5.41: Load V/s Shear reinforcement spacing variation for HSC beam series A



Graph 5.42: Load V/s Shear reinforcement spacing variation for HSC beam series B

II- CONCLUSION:

The following conclusions were made from the experimental investigation

1. Mix proportion for HSC M70 was obtained using chemical admixture and without using mineral admixture and the average 28-day strength was found to be 80 Mpa.
2. As the percentage of longitudinal reinforcement increased from 1.8% to 3.2%, the shear strength of HSC beams also increased (dowel shear contribution increased), it was significant for small spacing of shear steel (150,225mm), but this was not significant for beams without web reinforcement and large spacing of stirrups (300mm) Failure becomes more sudden and explosive as the longitudinal steel ratio increases from 1.8% to 3.2%.
3. As the depth of the HSC beams increased, the deflection decreased and the load carrying capacity (shear capacity) increased but load carrying capacity was insignificant for beams without shear reinforcement.

4. As the length of the beam increased, keeping all other parameters constant than the load carrying capacity decreased and bending moment in the beam increased.

5. The shear span to depth ratio was very significant in the shear capacity and shear behavior of HSC slender beams, keeping all other parameters constant and as the a/d ratio decreased the load carrying capacity increased and vice-versa. Lower a/d ratio showed shear tension or diagonal tension mode of failure and higher a/d ratio showed shear flexure mode of failure. For the beams with a/d = 2.5 shows a shear compression failure for less stirrup spacing and for large stirrup spacing shear-tension failure was observed and in some case bond splitting due to inadequate anchorage was observed. For large stirrup spacing, for a/d = 3.25 and a/d = 4.25 the failure of the beam mechanism occurred soon after diagonal crack i.e. diagonal tension failure and for a/d =5.5 showed shear-flexure failure for less stirrup spacing, diagonal tension failure in case of large stirrup spacing.

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