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EXPERIMENTAL STUDY OF SHEAR STRENGTH OF CONCRETE BEAMS REINFORCED WITH LONGITUDINAL TENSION STEEL

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ABSTRACT

Laterally loaded reinforced concrete beams may fail in shear before their full flexural strengths are attained if they are not adequately designed for shear. Unlike flexural failures, shear failures are very sudden and unexpected. A thorough knowledge of the different modes of shear failure and the mechanisms involved is necessary to prevent them. Shear strength of concrete is an important consideration in the design of RC members. In situations, where use of steel stirrups becomes impractical or difficult to provide such as RC slab, the intrinsic shear strength of the concrete becomes all important. For concrete of low shear strength, quite often the concrete cross-section size needs to be enhanced only to provide for the high shear demand. It is, therefore, pertinent to study the shear strength of concrete. The present describe the experimental investigation on shear strength of concrete beams reinforced with longitudinal tension steel. The primary design variables were the shear span-to-depth ratio in terms of depth of beam and amount of longitudinal reinforcement. The study aims to investigate the effect of increasing percentage of longitudinal reinforcement and depth of beams in terms of shear span-to-depth ratio on shear strength of concrete. Test results show that, the depth of beam in terms of shear span-to-depth ratio is highly influencing parameter of shear strength of concrete in addition to the amount of longitudinal reinforcement and concrete compressive strength. This aspect is not reflected in the Indian Standard [4]

Keywords: Shear; flexural strength; hear strength of concrete; shear span-to-depth ratio; amount of longitudinal reinforcement

1. INTRODUCTION

Concrete is the most widely used construction material all over the world in view of its compressive strength, high mouldabilty, structural stability and economic considerations. Also, it is very strong in compression and very weak in other mechanical properties such as tensile strength and shear strength. The direct compression test on concrete is well established and standardized and is found by casting either cubes or cylinder and testing it in

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direct compression. However, there is no direct way to find out the tensile and/or shear strength concrete. Therefore, attempts have been made to find the indirect split tensile strength of concrete by casting and testing cylinders and prisms

Shear strength of concrete has been found out proposition to experimentally evaluate. This is so primarily due to interlocking of the coarse aggregates among themselves. As a result of particle interlocking, it does not feasible to apply a shearing action (direct shearing force) in a plane, as is customarily done in case of metals. Experiments have to be, therefore, devised to indirectly asses the shear strength of concrete. In one of the popularly adopted devices, a beam of appropriate length is subjected to shearing and bending actions under 4-Point Loading System (2- active and 2-passive forces). The beam segment of subjected to constant shear is refereed to as shear span, which offers itself to be studied for performance under shear, bending being negligible for short shear span. In the present study, such a device has been adopted to study the performance of concrete under direct shearing action. Once steel bars are introduced, generally along a direction perpendicular to shearing force, these bars start coming into action to resist shearing force. Thus, steel bars become intrinsically linked to resisting shearing force along with the inherent concrete resistance. The shear resistance due to these longitudinal steel bars is commonly referred as dowel effect. The primary design variables were the shear span-to-depth ratio in terms of depth of beam and amount of longitudinal reinforcement. The study aims to investigate the effect of increasing percentage of longitudinal reinforcement and depth of beams in terms of shear span-to-depth ratio on shear strength of concrete.

2. EXPERIMENTAL PROGRAM

2.1 Material Properties

The test specimens were Cast using cement; fine aggregate, coarse aggregate, water and supper plasticizer. The materials, in general, confirmed to the specifications laid down in the relevant Indian Standards Codes. For grading of fine and coarse aggregate, sieve analysis was carried out.

Cement: Ordinary Portland cement of 43-grade confirming to IS: 8112:1989 was used throughout the experimental work. All tests were carried out as per IS: 4031-1988. The specific gravity and fineness were 3.14 and 275 m^2/kg, respectively.

Coarse Aggregate: Crushed granite metal obtained from a local source was used as coarse aggregate and the maximum size of used was 20 mm along with the 10mm.

Fine aggregate: Locally available Yamuna river sand was used as fine aggregate. The specific gravity was 2.60 and fineness modulus was 2.29.

Sperplasticizer: A modified melamine base highly effective high range water reducing concrete admixture was used throughout the investigation. It was dark brown in color having 1.22 specific gravity.

Reinforcing Steel rebars: Thermo-mechanically treated (TMT) rebar of F_e 415 grade used was

2.2 Concrete Mix Design

The concrete mixes were designed in accordance with the Indian standard recommended method of concrete mix design (IS 10262 – 1982). The concrete mix was prepared for 400 kg/m^3 cement content. The proportions of cement, fine aggregate, coarse aggregate is given in the Table 1.

Table 1. Mix proportions

Sl. No.	Description	Test result
1	Cube compressive strength (MPa)	43
2	Cement (kg)	24.50
3	Fine aggregate (sand) (kg)	44.50
4	Coarse aggregates (kg)	81.00
5	Water – cement Ratio	0.32
6	Water (liters)	7.800
7	Plasticizer as % of wt. of cement	0.85
	Mix proportion	1:1.82:3.31

2.3 Test specimens

Twelve specimens were designed and fabricated to study the behavior of reinforced concrete (RC) beams. The span of the beam has been kept constant at 1m with 0.1m overhangs on either side of the supports. The spacing between the top two point-loads has been kept at 200mm as shown in Figure 1.The depth of the beam has been varied at 150, 200,250, 300, 350 and 400 mm to achieve desired six shear span-to-depth ratios (a/d-ratios). All beams were rectangular in cross section, 100 mm wide. Standard cubes (150 mm x 150 mm x 150 mm), cylinders (150 mm x 300 mm) and prisms (100 mm x 100 mm x 500 mm) were cast with each mix to know the various mechanical properties of concrete.

2.4 Test Procedure

After 28-days curing period, the beam specimens were removed from the curing tank and both sides of the beam were white-washed to aid observations of the crack development during testing. Load was applied gradually with the help of jack and deflection of proving ring was recorded to find the failure load. All the beams were tested to failure under four-point loading test set-up (2-active, 2-passive) as shown in Figure 1. The cube specimens were tested for compressive strength, the cylinder specimens for split tensile strength and prism specimens for flexural strength as per IS: 516-1975.

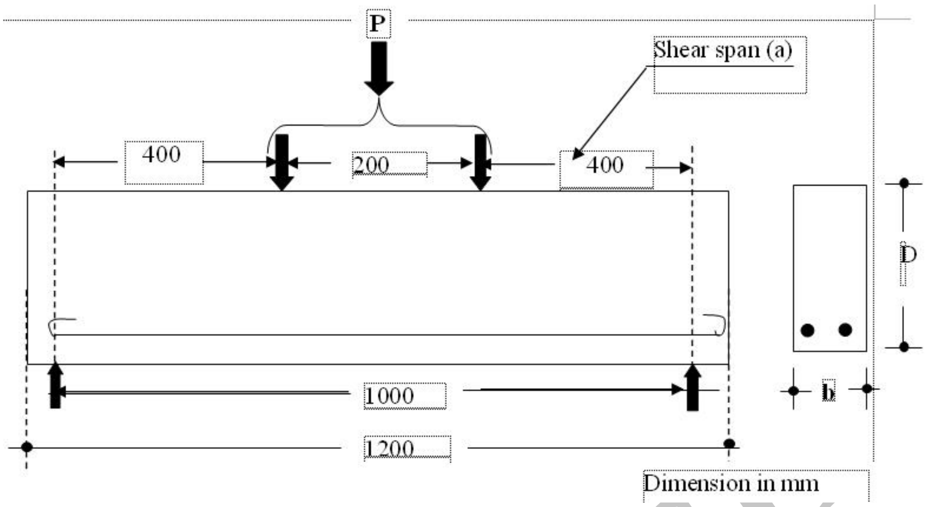

Figure 1. Four point loading test set-up

2.5 Test Results and Discussion

The results obtained from the experimental investigation are tabulated in Tables 2 and 3. From the results obtained, the effect of various parameters on shear strength of concrete are analyzed and discussed as follows.

2.6 Effect of depth of beams in terms of shear span-to-depth ratio (a/d-ratio)

The shear strength of concrete beams for different depths at 28 days curing age is given in Table 2 and the variation of shear strength with different shear span-to-depth ratio is shown in Figure 2.it is evident from the plots that high shear strength is developed at lower value of span-to-depth ratio and the shear strength decreases at higher value of span-to-depth ratio.

Figure 2 shows the effect of shear span-to-depth ratio (or moment-shear ratio) on nominal shear stress at diagonal cracking, which is obtained by dividing measured failure load to the nominal cross sectional area (b x d). As the shear span-to-depth (a/d) ratio decreases, the shear strength increases. The increase in shear strength is significant in RC beam specimens with a/d ratio less than about 1.78(AI-0.80 /1.10 AII-0.80 /1.23 AIII-0.80 /1.45), because a significant portion of the shear is transmitted directly to the support by an inclined strut. This mechanism is frequently referred to as arch action and the magnitude of the direct load transfer increases with decreasing a/d-ratio. The shear strength of RC beams with a/d-ratio less than 1.78 is higher than those of the RC beams with a/d-ratio more than 1.78. This result is due to the beneficial effect of direct load transfer to the support by arch action or so called strut-and-tie load transfer mechanism. The transition point between the arch action and beam action (or transfer beams and normal beams) lies between a/d-ratio of 1.45 to 1.78. Either side of this a/d ratio, behavior RC beams, in terms of load resisting mechanism, failure pattern and the noise at failure, were entirely different.

2.7 Modes of Failure

All beam specimens failed in shear i.e. a sudden failure without warning, loud noise at failure with the appearance of single shear crack in the shear span and fine flexural cracks in the middle portion of the beam. The shear crack crosses the compression zone of the beam. Figure 4 shows a typical crack patterns for RC beam specimens of different a/d ratio.

Table 2. Shear strength of the concrete beams: Effect of depth of the beams in terms of the shear span-to-depth ratio

Test Beam Designation	**Beam Size (bxD) mm**	**Effective depth (d) mm**	**a/d ratio**	**Stress values in MPa**				**ρ (%)**	**Shear stress (MPa)**
				f_{cu}	**f_t**	**f_r**	**f_y**		
AI-0.80 /1.10	100x400	375	1.10	43.00	3.30	6.40		0.80	2.62
AII-0.80 /1.23	100x350	325	1.23	42.50	3.35	6.42		0.80	2.00
AIII-0.80 /1.45	100x300	275	1.45	43.25	3.40	6.45	435	0.80	1.60
AIV-0.80 /1.78	100x250	225	1.78	43.50	3.42	6.40		0.80	1.30
AV-0.80 /2.28	100x200	175	2.28	42.50	3.41	6.42		0.80	1.20
AVI-0.80 /3.20	100x150	125	3.20	42.75	3.30	6.41		0.80	1.12

f_{cu} : Cube compressive strength of concrete, f_t : Split cylinder tensile strength of concrete
f_r : Tensile strength of concrete in bending f_y : Tensile strength of reinforcing steel
Beam notation: Series number is given before hyphen; this is followed by longitudinal steel (%) and then by the a/d-ratio.

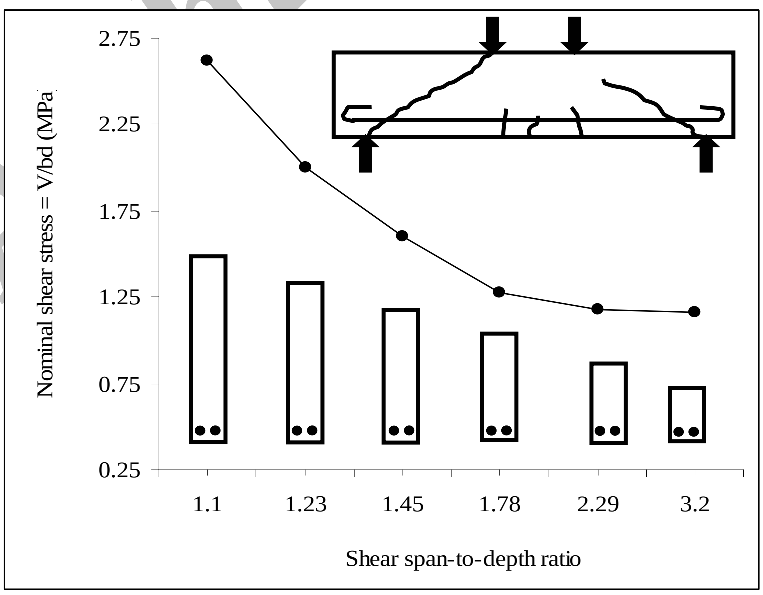

Figure 2. Effect of the shear span-to-depth ratio on the shear strength of concrete

Table 3. Shear strength of the concrete beams: Effect of the longitudinal steel percentage

Test Beam Designation	Beam Size (b x D)	Effective depth (d)	a/d ratio	Stress values in MPa				ρ (%)	Shear stress (MPa)
				f_{cu}	f_t	f_r	f_y		
BI-1.10/0.28	100 x 400	375	1.10	43.50	3.35	6.35	445	0.28	1.60
BII-1.10 /0.42				42.50	3.35	6.48		0.42	2.00
BIII-1.10/0.60				42.75	3.42	6.45		0.60	2.40
BIV-1.10/0.80				43.50	3.42	6.40		0.80	2.50
BV-1.10/1.0				42.25	3.51	6.71		1.00	2.58
BVI-1.10/1.20				42.80	3.35	6.40		1.20	2.61

f_{cu} : Cube compressive strength of concrete, f_t : Split cylinder tensile strength of concrete
f_r : Tensile strength of concrete in bending f_y : Tensile strength of reinforcing steel
ρ : Percentage longitudinal steel
Beam notation: Series number is given before hyphen; this is followed by the a/d-ratio and then longitudinal steel (%)

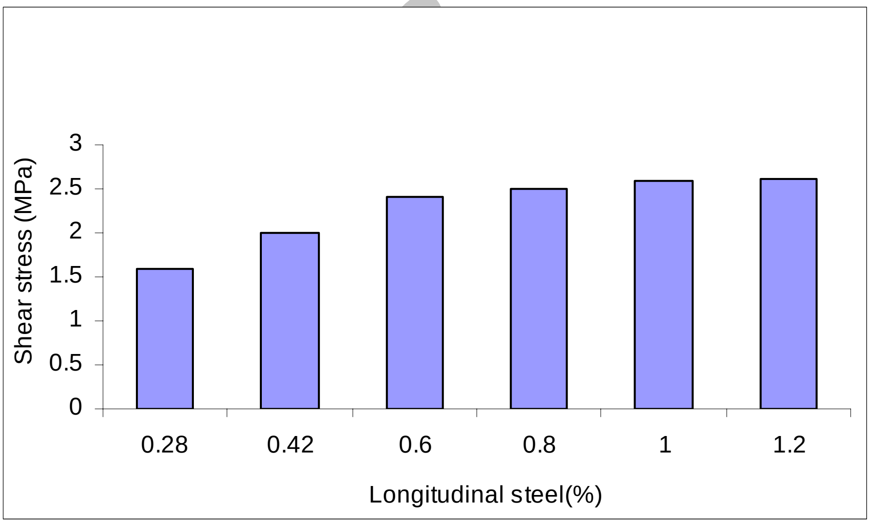

Figure 3. Effect of the longitudinal tension steel (%) on the shear strength of concrete

2.8 Influence of amount of longitudinal tension reinforcement

The longitudinal percent tension steel affects the amount of longitudinal strain and thereby affects crack width, interface shear transfer, dowel action, and thus the shear strength. Thus, for the same magnitude of loading, as the percent longitudinal tension reinforcement decreases, flexural stresses and strains increase. Thus, crack width increases and the shear strength lowers. The influence of longitudinal reinforcement is accounted for in most major codes but in different ways. A significant increase in the shear strength was observed as the percent longitudinal tension steel. The variation of shear strength with the percent longitudinal tension steel is shown in Figure 3

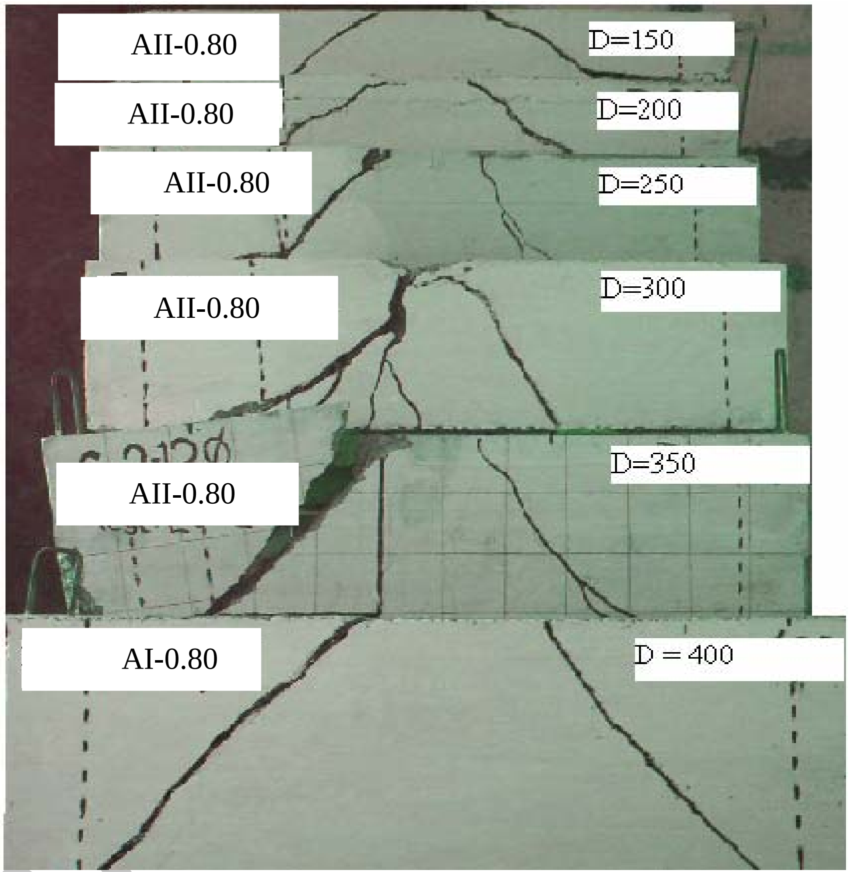

Figure 4. Typical crack patterns for the RC beams

CONCLUSIONS

Based on the present research work, the following conclusions, and inferences arrived at:

1. It is evident that the shear span-to-depth (a/d-ratio) ratio is a significant influencing parameter of the shear strength.
2. For shear span-to-depth (a/d- ratio) ratio < 1.8, the load transfer mechanism of beams is observed to be altogether different primarily because of the tied arch action/truss action, than the shear span-to-depth (a / d- ratio) ratio > 1.8.Thus a/d-ratio of 1.8 is a differentiating line between the normal and transfer (deep) beams.

3. The failure of concrete is not in true shear but in tensile stresses generated by the shear. This happens because of very low tensile strength of concrete.
4. Apparently, the percentage longitudinal tension has significant effect on the shear strength of concrete and the mode of failure.

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