EFFECT OF SHEAR SPAN-TO-EFFECTIVE DEPTH RATIO ON THE SHEAR STRENGTH OF RC BEAMS

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Abstract - This research studied the effect of shear span-to-effective depth ratio(a/d) on the shear strength of reinforced concrete (RC) beams with stirrups. A total of three beams with shear-span-to-effective depth ratios (a/d) ranging from 2.5 to 4.5 were tested under a concentrated load at mid-span to determine the shear strength. A displacement-controlled loading was conducted and the mid-span deflections of the beams were recorded by means of a data acquisition system until failure. The changes in the strength based on the a/d were determined and compared with each other. It was observed that the strength of the beams decreased as the a/d increased.

Index terms - Reinforced concrete, Beam, Shear strength, Shear span-to-effective depth ratio.

I. INTRODUCTION

The shear strength of reinforced concrete (RC) beams has been studied using analytical and empirical methods by various researchers. Shear-span-to-effective depth ratio (a/d) and stirrup ratio are the significant parameters that influence the shear failure as reported by CEB [1]. The a/d takes into account the ratio between bending moment (M) and shear force (V) occurring simultaneously in the same cross section M/(Vxd). It is calculated as a/d, where a is the distance between the applied force and the support and d is the effective depth of cross section.

RC beams are classified into three types depending on a/d as; (i) deep beams $0 < a/d < 1$, (ii) short beams $1.0 < a/d < 2.5$, (iii) normal beams $a/d > 2.5$ by Bressler and Macgregor[2]. It has been also recognized that, as members become deeper, the ultimate shear strength V_{ult}becomes progressively larger than that in slender beams. In the last five decades, experimental and theoretical studies were performed. Clark [3] reported that the nominal shear strength of an RC beam is a function of the compressive strength of concrete, the longitudinal reinforcement ratio (ρ) and a/d. Leonhardt and Walther [4] investigated the size effect in RC members with a/d ranging from 3 to 8 subjected to shear. Comparisons between short and slender members were made.Kani [5] studied the size effect on the shear strength of RC beams with a/d ranging from 1 to 8 without stirrups. Test results indicated significant influence of a/d on the shear strength. These studies included the influence of a/d on the shear behaviour and shear capacity of RC beams.

In the classical theory of RC; shear failure modes for increasing a/d are classified into; deep beam failure, shear compression failure, shear tension failure, flexural shear failure [6]. In order to predict the shear strength of RC beams more accurately, various studies [7-9] a wide range of a/d; concrete strength and section properties have been made. In this study, the change in the shear strength with respect to the a/d was investigated experimentally. The experimental program consisted of three beams with a/d of 2.5, 3.5 and 4.5. The beams were loaded at the mid-span by applying a displacement-controlled concentrated load. The load-deflection curves of beams with stirrups compared to the studies of Mazhari [10] and Özgen [11] that included RC beams without stirrups.

II. EXPERIMENTAL PROGRAM

A combination of letters and numbers is used for specimen labels: “C” followed by the shear span-to-effective depth ratio to indicate all test specimens in this study and “S” followed by the spacing of stirrups (s). For example, a beam having a shear span-to effective depth ratio of 2.5 and stirrup spacing of 20 cm is labelled as C2.5S20R.

The concrete mix proportions for all beams are given in Table 1. A concrete mix consisting of Portland cement (CEMI 42.5) and a maximum aggregate size of 12 mm in diameter was used.
Three beams with stirrups (C2.5S20R, C3.5S20R, C4.5S20R), were tested under three-point loading to determine their ultimate load capacities using a displacement-controlled loading machine.

Table.1Properties of Concrete

Materials	Mixture Proportions (kg/m^3)
0-1 mm natural sand	350
0-3 mm crushed sand	550
5-12 mm crushed stone	1000
Cement CEMI 42.5R	300
Water	165
Superplasticizer	3

A tensile reinforcement ratio (ρ) of 1.28, a compression reinforcement ratio (ρ') of 0.72, a cross section of 150 mm/240 mm (b/h) and a concrete cover of 22 mm were used in all specimens. Deformed bars with diameters of 16 mm and 12 mm were used as the tensile and compression reinforcement, respectively. The stirrup diameter and spacing were 8 mm and 20 cm, respectively. The geometrical properties of test specimens and reinforcement arrangement are shown in Figure 1.

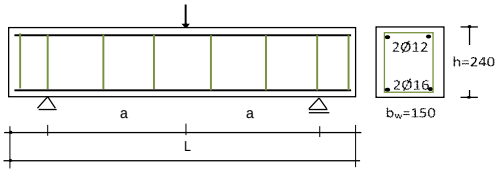


Figure 1: Geometry of beams and reinforcement arrangement (unit: mm)

The yield strength of tensile and compression reinforcements were 679 and 566 MPa, respectively. The yield strength of stirrups was 814 MPa. The properties of beams are shown in Table 2, where fc is the concrete compressive cylinder strength, ρ is the tensile reinforcement ratio, ρ' is the compressive reinforcement ratio and Ø/s is the stirrup diameter-spacing ratio.

Table.2 Properties of Beams

Beams	f_c (MPa)	a/d	a (mm)	l	ρ (%)	ρ' (%)	Ø/s
C2.5R[&]	24.85	2.5	525	1400	1.28	---	---
C3.5R[#]	24.85	3.5	735	2200	1.28	------	
C4.5R[#]	21.37	4.5	945	2200	1.28	---	---
C6.0R[#]	23.83	6.0	1260	3000	1.28	------	
C2.5S20	24.85	2.5	525	1400	1.28	0.72	Ø8/20
C3.5S20	23.83	3.5	735	2200	1.28	0.72	Ø8/20
C4.5S20	23.83	4.5	945	2200	1.28	0.72	Ø8/20

[&]Mazhari (2018), [#] Özgen (2018)

III. TESTING AND INSTRUMENTATION

The beams were loaded at mid-span with a static loading rate of 30 μm/s by using a displacement-controlled loading machine. The applied load and the deflections at various locations were recorded at predetermined time intervals via a computer-aided data acquisition system. The net deflections of the beams were recorded by using potentiometric displacement transducers. The beams were loaded until either failure or the load dropped below approximately 80% of its peak value.

IV. RESULTS AND FINDINGS

The crack patterns of tested beams are shown in Figure 2-4. At the early stages of loading, fine vertical cracks were observed around the mid-span of all beams as expected.As the load was increased, new flexural cracks appeared away from the mid-span area. Some of these cracks were gradually inclined towards the loading point with further increases in theapplied loads and the applied load reached its maximum value with the formation of first diagonal crack. The loads carried by the beams decreased rapidly and the C2.5S20R and C3.5S20R beams failed in shear. It can be inferred from load-deflection curve and crack shape that C4.5S20R beam exhibited flexural-shear failure.

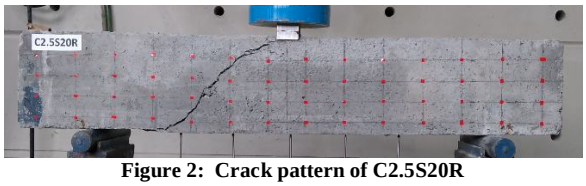


Figure 2: Crack pattern of C2.5S20R

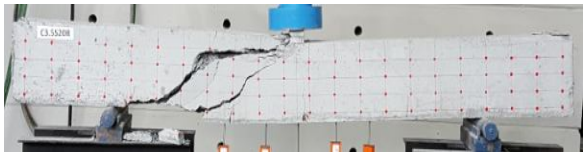


Figure 3: Crack pattern of C3.5S20R

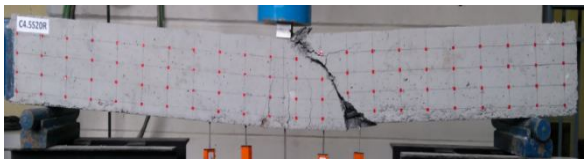


Figure 4: Crack pattern of C4.5S20R

Mazharireported that C2.5R beam failed in shear. Özgenreported that C3.5R and C4.5R beams failed in shear while C6.0R beam exhibited flexural failure as expected. Experimental results are summarized in Table 3, where P_{co} and δ_{co} are the maximum load and the mid-span deflection at the maximum load, respectively, P_u and δ_u are the ultimate load and mid-span deflection at the ultimate load respectively.

Table.3 Experimental Load and Deflection Values of Beams

Beams	P_{co} (kN)	P_{cu} (kN)	δ_{co} (mm)	δ_u (mm)	δ_u/δ_{co}
C2.5R[&]	84.93	67.95	5.12	6.76	1.32
C3.5R[#]	74.49	59.59	5.42	5.62	1.04
C4.5R[#]	66.19	52.95	7.92	8.02	1.01
C6.0R[#]	55.58	44.46	26.94	51.08	1.89
C2.5S20R	131.06	104.85	7.38	8.52	1.15
C3.5S20R	90.19	72.15	11.60	14.72	1.27
C4.5S20R	74.58	59.66	24.70	36.70	1.4

[&]Mazhari (2018), [#] Özgen (2018)

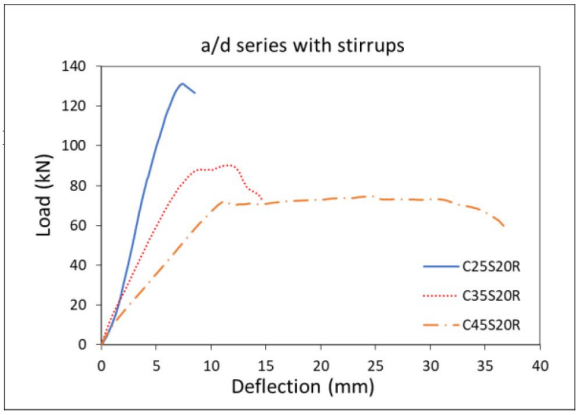


Figure 5: Load-Deflection Curves of RC beams with stirrups

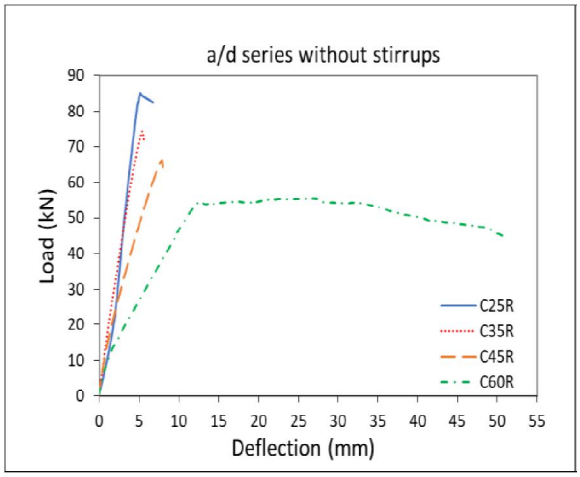


Figure 6: Load-deflection curves of beams without stirrups

Increasing a/d reduced the load carrying capacities of test specimens. The load carrying capacities of RC beams without stirrups decreased14%, 13%, and 20% when a/d was increased to 3.5, 4.5 and 6.0, respectively. The load carrying capacities of RC beams with stirrups decreased 45% and 21%, when a/d was increased to 3.5 and 4.5, respectively. The existence of transverse reinforcement improved the load carrying capacities of RC beams. The load carrying capacities increased 54%, 21% and 13%, respectively, in case of a/d equal to 2.5, 3.5 and 4.5.

CONCLUSION

The following conclusions are drawn based on the experiments of RC beams. Increasing a/d reduced the shear capacities of RC beams both with and without stirrups significantly. The values of P_{co} were significantly affected by a/d. More specifically, P_{co} decreased sharply in case of beams with stirrups as a/d increased. The existence of transverse reinforcement increased the shear capacities of RC beams considerably.The values of $P_{co}$for the beams with and without stirrups were significantly different. This difference got smaller as a/d increased. Increasing a/d had a considerable affect on the failure mode, which was changed from shear to flexure. On the other hand, it was observed that the existence of transverse reinforcement was not able to change the failure mode from shear to flexure.

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