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STUDY OF SHEAR BEHAVIOR OF DEEP BEAMS

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Abstract- This paper presents laboratory test results of 7 deep beams in which experimental and analytical investigation are carried out on behavior of reinforced concrete deep beams under cyclic loading. The variables in the study are: the quantity of shear reinforcement. In this investigation the deep beams were tested as simply supported beam having same shear span to effective depth (a / d) ratio. The spacing and area of shear reinforcement of deep beam was changed and the shear behavior of deep beam under loading studied. In this study, load deflection responses, crack pattern, modes of failure and shear strength are studied. The comparison of analytical (ACI 318) and experimental value of shear strength capacity of deep beam is done. From the result of this study, it has been observed that the modes of failure in deep beams are influenced by the quantity of shear reinforcement. The diagonal strains and the diagonal crack widths in shear span increase as the shear reinforcement increase. For low percentage of web steel in deep beams, the flexure mode of failure is likely to occur. Shear failure of deep beam was mainly due to diagonal cracking and it was along the lines joining the loading point and support.
Keywords- Deep beam, shear strength, shear reinforcement, deflection, strain in steel

Introduction

Reinforced concrete deep beams are very useful members widely used in building, bridges and Infrastructures. To consider a beam as a deep beam, depth to span length should be less than certain value. This ratio is the most frequently used parameter by researchers and engineers. In deep beams, plane section before bending remains plane after bending is not valid. Deep Beams are applying as foundation walls or raft slab, shear walls in building. It is also used in Water tank structure. As per IS 13920 (clause), depth to span ratio is restricted due to less experimental data is available on deep beams. The study is limited to same span to depth ratio, with M_{20} grade concrete and longitudinal reinforcement of 2.0 % with varying shear reinforcement. The purpose of this study are limited to the study the structural performance of deep beam by varying spacing and area of shear reinforcement, study the shear behavior of deep beam under cyclic loading and comparison of analytical and experimental shear strength capacity of deep beam.

Review of Literature

There are many researches carried out study on reinforced concrete deep beams. The behavior of deep beams was described in terms of crack pattern, load versus deflection responses, failure modes and strain in steel reinforcement and concrete. Reinforced concrete deep beam may exhibit different types of failures due to shear, anchorage or bearing failures [6, 7, 8, 9 & 10]. It has been observed that the modes of failure in deep beams are influenced by beam depth and the percentage of shear reinforcement. As the depth of beam and quantity of web reinforcement increases, the failure changes from diagonal – tension to shear compression. As beam depth increases, the shear strength decreases due to change of mode of cracking as well as energy dissipation.

I.S. 456-2000 Codal Provisions

The stress distribution along the depth of beam is non-linear, so lever arm between compressive force and tensile force can't be determined so easily as in case of shallow beam having liner stress distribution. So that lever arm shall be determined by using empirical relations are as follows [5]:-
For Simply Supported Deep Beams
The lever arm (z) is given as,

$$Z = 0.2(L+2D)\ ;\ 1 \le \frac{L}{D} \le 2$$

$$Z = 0.6L\ ; \qquad \frac{L}{D} < 1$$

Where L = effective span, D = total depth of beam

Effective Span

The center to center distance between supports or 1.15 times the clear span whichever is less should be taken for effective span.

Methods of design of deep beams

Following are the methods of design of deep beams:

1. Design by using I.S.456-2000 code method
2. Design by using ACI-318 code method
3. Design by using ACI-Appendix A (Strut and Tie) method.

In this experimental study deep beams are designed by using I.S.456-2000 method [2, 3 & 4]. Seven beams are designed and cast for experimental study.

Shear strength of deep beam by ACI 318 method

According to ACI code [1], simply supported deep beams are defined as the beams with shear span to depth ratio less than two or clear span to depth ratio less than four. The shear strength evaluated by the ACI code expression seems to be very conservative for deep beams. The shear strength for deep members is calculated by adding the contributions from the concrete and distributed vertical and horizontal reinforcement.

Following are the procedure of analysis of shear strength of deep beam:

1. Shear carried by concrete and steel $V_n = Vc + V_{st}$
2. Shear taken by concrete $Vc = 0.13\sqrt{f_{ck}}$ .t.d
3. Shear taken by steel

$$Vst = 0.85\left(\frac{Av}{s_1}\times\frac{1+f}{12}+\frac{Ah}{s_2}\times\frac{11-f}{12}\right)fy.d$$

$$f = \frac{l_n}{d}$$

Where ln = clear span

s_1= c/c spacing of vertical web reinforcement

s_2 = c/c spacing of horizontal web reinforcement

4. Hence Total shear = . $V_u = V_n + V_{st}$

Experimental Program

Material

In this experimental program mix design of M_{20} grade concrete was used by using IS code method. The target strength was 26.6 N/mm2 and water-cement ratio 0.50. Sand was natural river sand with specific gravity 2.6 and its water absorption was 2.18 %. The coarse aggregate 20 mm size with specific gravity 2.75 and its water absorption was 2.5 %. The steel reinforcement of high strength deformed bars (Fe 415) and cement of 53 grade were used.

Beam details

Following are the details of deep beam

Length L = 1550 mm Shear span a = 675 mm

Width B = 100 mm Effective depth d = 716 mm

Depth D = 750 mm

The Reinforcement details of Seven Beams as tabulated In Table 1. (See Table 1)

The Beams are to be tested by applying one point loading as shown in figure no.1 and reinforcement details is given in Fig (2, 3 & 4).

Casting work

Before actual casting, various ingredients of concrete such as cement, sand and aggregate were tested in laboratory. Their results were found satisfactory. Reinforcement mesh for every beam was kept ready according to individual designs. Form work for casting beams of required dimensions as mentioned above was kept ready. For M_{20} grade concreting, weigh batching was adopted. Proportions of various ingredients of concrete were taken from I.S. 456 – 2000. Casting was done on casting platform near heavy structural lab. Code numbers or Beam marks were written on each beam. Names to the beams were given like B_1, B_2, B_3, B_4, B_5, B_6, B_7 and designed by I.S. method. (See Fig 5)

Curing work

Beams were covered by wet gunny bags for 24 hours after casting. After 24 hours formwork was removed carefully and curing of beams was started. Wet gunny bags were kept surrounding the beam surface and watered so as keep them moist. Beams were cured for 28 days. (See Fig 6)

Experimental Set Up and Testing

Seven beams were tested up to failure under one point loading, with central concentrated load and two simple supports as shown in Figure 8. Beams were tested on loading frame (1000 KN) in Structural engineering laboratory. The hydraulic jack was used to apply the load on beam. A dial gauge of least count of 0.01 mm was attached below the beam at the centre so as to measure central deflection of the beam. At each load increment, applied load, cracks developed were recorded.

Results and Discussion

(See Table 2)

Comparison of analytical and experimental shear strength of deep beams:

A comparison between the analytical and experimental shear capacities of beams was carried out. The analytical shear strength of all deep beams was calculated by ACI code method. The comparisons of experimental failure load with analytical results are listed in table 3 shows that analytical results are greater than experimental results. The results obtained from both methods are safe. (See Table 3)

Type of failure of deep beams

For beam B1, B2, B3, B6, B7 high percentage (greater 0.33 %) of web reinforcement was provided and they were failed in shear. In this beams crack started in the shear zone and propagated upwards towards the load point. In beam B4, B5 low percentage (less than 0.33 %) of web reinforcement was provided and they were failed in flexure. In this beams first crack was observed in moment region at the bottom of beam. As the load was increased, this vertical crack started to propagate upwards and reached at top. Finally beams failed due to flexure because of crushing of concrete. (See Table 4)

Load- deflection curves

Fig (8 & 9) shows load –deflection curves in beams B_3 and B_4 with varying percentage of web reinforcement. In B_3 and B_4 beams 0.33 % and 0.27 % of vertical reinforcement was provided. The maximum deflection in B_3 and B_4 were 5.28 mm and 5.24 mm respectively. Initially as the load goes on increasing deflection also increased. Finally they were failed in shear. Fig (10) shows load-deflection curves for beam B5 with 0.19 % of vertical web reinforcement. Initially as the load goes on increasing deflection also increased. For 1.04 mm deflection, there was linear loading up to 60 KN. From this point, deflection varies up to 4.36 mm at a maximum load of 90 KN and shows flexural behavior of beam. Similarly beam B_1, B_2, B_6, B_7, exhibit relatively similar behavior of the load – deflection response and failed in shear. Fig (9) shows load-deflection response of beam B_4 under cyclic loading.

Load – web strain curves

The observations on web strain in steel as " load versus micro strain "curves are shown in figure 7 and 8 with varying percentage of web strains. The maximum web strains observed in beams B~~1~~ and B_2 are 13824 and 07122 micro strain respectively. When the load was given up to 48 KN, there was no any micro strain found in beams. As the percentage of web reinforcement increases, strain in steel decreased for same load. The load carrying capacity increases as the percentage of web reinforcement increased for the same strain.

Behavior of beams

Fig (9, 10 &11) shows behavior of beams B_2, B_7, B_4 with varying percentage of web reinforcement. The vertical web reinforcement 0.50 %, 0.40 %, 0.75 % was provided in beams B_2, B_7, B_4 respectively. During loading it was observed that minor cracks have been formed in shear span in the direction of line joining the support and loading point. Also minor flexural cracks in moment region at bottom of beam were also observed. As the load increases, large diagonal cracks were formed from support to the loading point in beams B_2 and B_7. The beams were failed in shear-compression. Beam B_1, B_3, B_6 shows similar behavior as above. Fig 15 showed flexural behavior of beams B_4. During loading it was observed that flexural cracks have been formed in moment region at bottom of beam and then increases towards the loading point.

Conclusions

From experimental investigation following conclusions have been drawn:

1. Failure mode changes from flexure to shear at 0.33 % web reinforcement.
2. The ultimate shear strength of deep beams decreases by 50 % with decrease in percentage of web reinforcement by 0.16 %.
3. The ultimate shear strength of deep beams increase by 24 % for increase in percentage of web reinforcement by 0.44 %.
4. As the percentage of web reinforcement increases by 0.1 %, load carrying capacity increased by 78% and strain in steel decreased by 87% for same strain and same load respectively.
5. Shear failure of deep beams was mainly due to diagonal cracking and it was along the lines joining the loading point and support.
6. In shear failure, the deformation at first crack is 41 % of total deformation at failure. The factor of safety in shear is 2.5.
7. In flexural failure, the deformation at first crack is 23 % of total deformation at failure. The factor of safety in flexure is 4.0.
8. In shear failure, the load taken at the first crack is 63 % of the total collapse load. The factor of safety in shear is 1.5.
9. In flexure failure, the load taken at first crack is 57 % of total collapse load. The factor of safety in flexure is 1.5.

Notations

a = shear span
d = effective depth in mm
a / d ratio = shear span to effective depth ratio
ACI = American concrete institute
As = area of tension steel
As min = area of minimum steel
U.D.L. = uniformly distributed load
W = loading on beam
Vu = shear strength of beam
τ_v = nominal shear stress
Mu = factored bending moment
RA, RB = reactions at support

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Table No. 1: Details of Reinforcement of Deep Beams

Beam	A_{st} mm²	Vertical steel (stirrups)			Nominal horizontal steel		
		Av mm²	Pt %	Dia.and spacing c/c	Ah mm²	P_t %	Dia. and spacing c/c
B1	100.5	376.9	0.50	4mmØ@100mmc/c	50.26	0.067	4mmØ@230mmc/c
B2		301.5	0.40	4mmØ@125mmc/c	50.26	0.067	4mmØ@230mmc/c
B3		251.3	0.33	4mmØ@150mmc/c	50.26	0.067	4mmØ@230mmc/c
B4		201	0.27	4mmØ@175mmc/c	50.26	0.067	4mmØ@230mmc/c
B5		141.2	0.19	3mmØ@150mmc/c	28.24	0.037	3mmØ@230mmc/c
B6		392	0.52	5mmØ@150mmc/c	78.4	0.10	5mmØ@230mmc/c
B7		565.4	0.75	6mmØ@150mmc/c	113	0.15	6mmØ@230mmc/c

Table 2: Geometric Details and Test Results of Deep Beams

Beam	Geometry Size (mm)									
	L mm	l mm	b mm	D mm	a mm	d mm	l/D	a/d	Exp. Pu KN	δ peak mm
B_1	1550	1450	100	750	675	716	1.93	0.94	192	8.45
B_2									102	6.93
B_3									94	5.28
B_4									92	5.24
B_5									90	4.36
B_6									102	5.30
B_7									120	5.98

Table 3: Comparison of Shear Strength of Deep Beams

Beam	A_{st} mm²	Av mm²	Pt %	Ah mm²	Pt %	Theoretical V_u KN	Experimental V_u KN
B_1	100.5	376.9	0.50	50.26	0.067	212	192
B_2		301.5	0.40	50.26	0.067	200	102
B_3		251.3	0.33	50.26	0.067	193	94
B_4		201	0.27	50.26	0.067	188	92
B_5		141.2	0.19	28.24	0.037	193	90
B_6		392	0.52	78.4	0.10	193	102
B_7		565.4	0.75	113	0.15	193	120

Table 4: Type of Failure of Deep Beams

Beam	Ast mm²	Av mm²	Ah mm²	Ptv %	Pth %	Experimental Vu KN	Type of failure
B_1	100.5	376.9	50.26	0.50	0.067	192	Shear
B_2		301.5	50.26	0.40	0.067	102	Shear
B_3		251.3	50.26	0.33	0.067	94	Shear
B_4		201	50.26	0.27	0.067	92	flexure
B_5		141.2	28.24	0.19	0.037	90	flexure
B_6		392	78.4	0.52	0.10	102	Shear
B_7		565.4	113	0.75	0.15	120	Shear

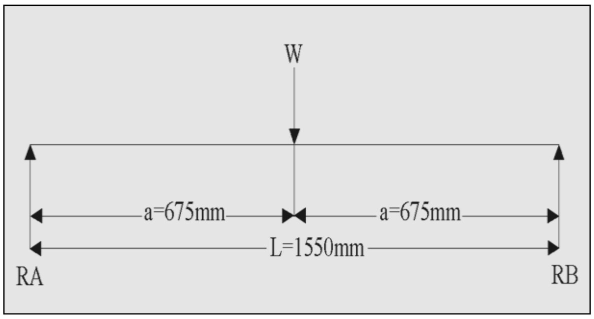

Fig. 1: central point loading for deep beam

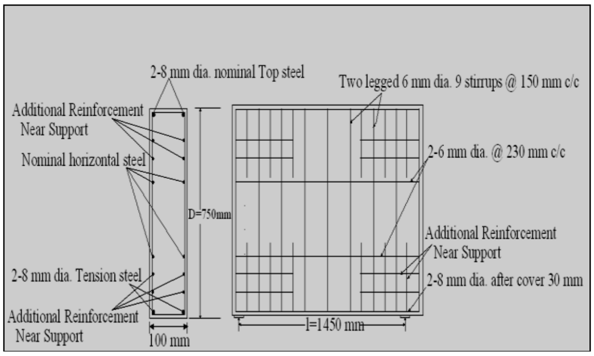

Fig. 2: Details of reinforcement of deep beams

Fig. 3: Reinforcement Mesh of Simply Supported Deep Beam

Fig. 7: One Point Loading Test Setup for Deep Beam

Fig.4: Reinforcement Mesh with Strain Gauges

Fig.5: Casting Work of Simply Supported Deep Beam

Fig.6: Curing Work of Simply Supported Deep Beam

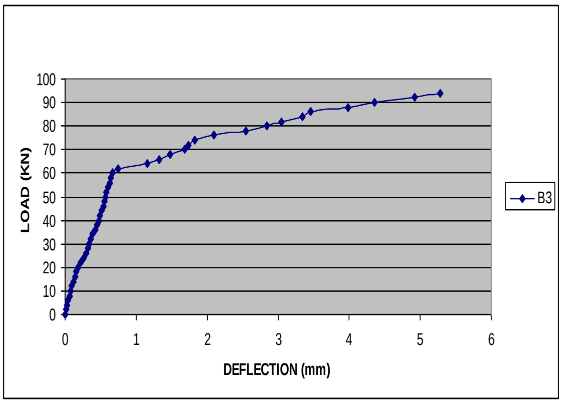

Fig. 8: Variation of load with deflection for beam B_3

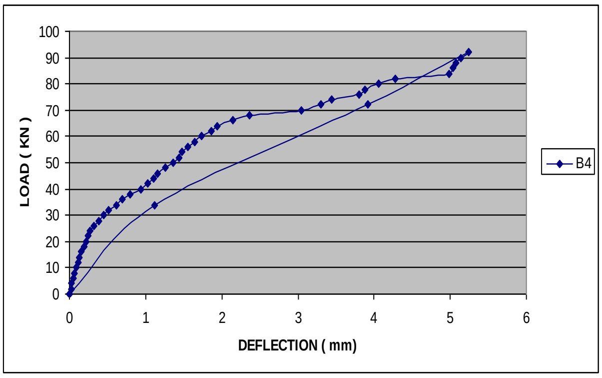

Fig. 9: Variation of load with deflection for loading unloading condition

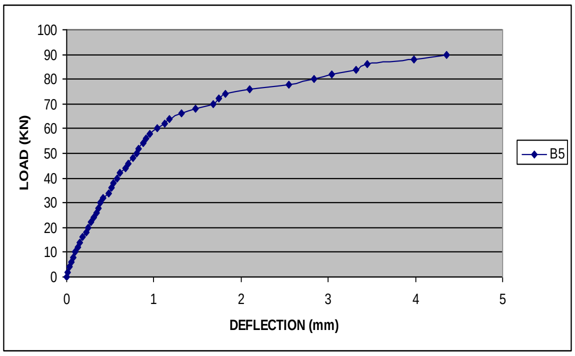

Fig. 10: Variation of load with deflection for beam B_5

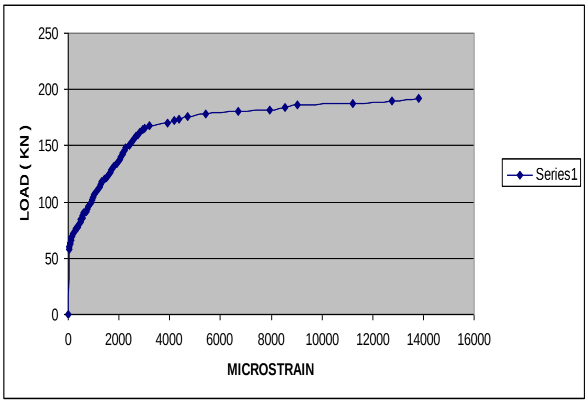

Fig. 11: Variation of load with strain in the steel for beam B_1

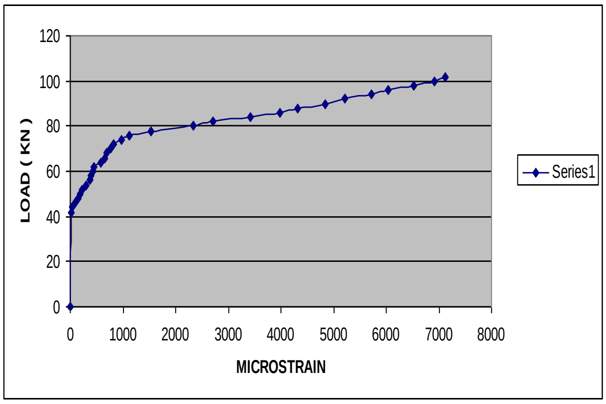

Fig. 12: Variation of load with strain in the steel for beam B_2

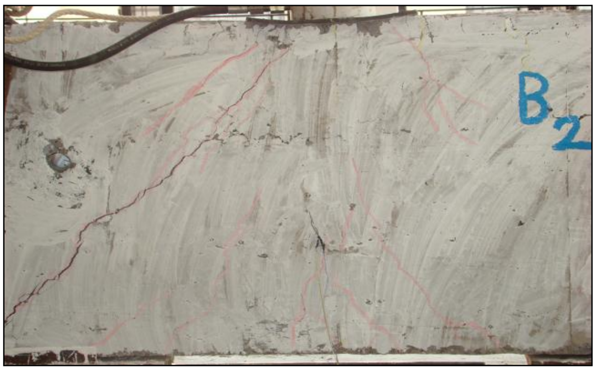

Fig. 13: Behavior of beam B_2

Fig. 14: Behavior of beam B7

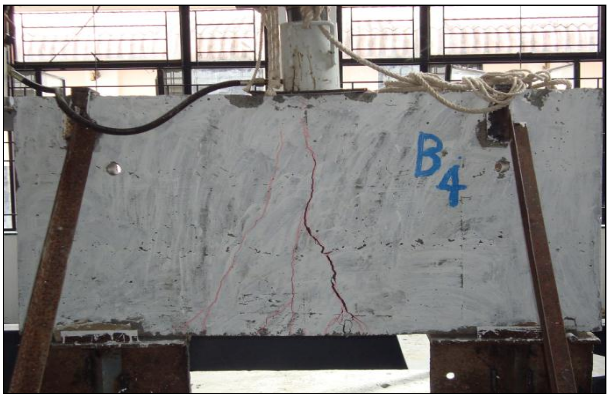

Fig. 15: Behavior of beam B4