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Effect of Caging and Swimmer Bars on Flexural Response of RC Deep Beams

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ABSTRACT
Beams with shear span to depth ratio (a/d) less than or equal to 2 are considered as deep beams. They have wide applications in pile caps, water tanks, shear walls, corbels etc. Their strength is controlled by shear. Swimmer bars are small inclined bars, whose both ends are bent horizontally and welded to both top and bottom flexural reinforcement. Swimmer bars forming a plane crack interceptor system is effective in carrying shear. Also, a reinforcement caging provided at the centre of a simply supported beam is supposed to enhance its flexural capacity. In this study, an experimental investigation on the flexural response of deep beams reinforced with caging and swimmer bars is done. Various parameters like ultimate load, deflection and failure modes of different reinforcement patterns are studied.
Keywords – caging, pure bending, shear failure, shear span, swimmer bars

I. INTRODUCTION

Reinforced concrete beams are designed with adequate safety margins against bending and shear. The flexural members having shear span to depth ratio (a/d) less than 2 are considered as deep beams. RC deep beams are having wide applications in water tanks, bunkers, silos, shear walls, raft foundation, pile caps, corbels etc. These members are having greater shear strength due to the arch action between concrete and reinforcement forming a strut and tie model. The likely failure behavior of deep beams is due to shear, which is sudden and difficult to predict.

Shear reinforcement is usually provided in the form of stirrups or inclined bent-up bars. A combination of both types is also used. Swimmer bar system is an alternative shear reinforcement system, in which small inclined bars bent horizontally at both ends are used. These bends are either welded or bolted to the top and bottom longitudinal reinforcements. This can be provided in many ways like a single swimmer alone, two swimmers forming a rectangular shaped swimmer, rectangular shaped swimmer with cross bracings etc.

There are various methods to increase the flexural strength of RC beams. But these methods cause change in the geometry of the structure and hence increases the construction cost. Provision of a reinforcement caging at the mid span of simply supported beam is an alternative method for the strengthening of beams without changing its geometry. This caging is provided as an addition to the existing tensile reinforcement. This is provided by ensuring sufficient spacing between different layers of reinforcement.

In this paper, the comparative study on the flexural strength, crack pattern and load-deflection charecteristics of seven reinforced concrete deep beams are done.

II. SIGNIFICANCE OF WORK

2.1 Scope of the Study

From the literature review conducted, it is understood that shear reinforcement in the form of vertical stirrups ensures ductile behavior of deep beams. When horizontal or inclined stirrups are provided, it enhances the flexural strength. But the increase in ultimate load carrying capacity is very small when compared to the control beam. Hence alternatives for considerable increase in the flexural strength need to be explored. Also the effectiveness of swimmer bar system is experimented for ordinary beams. Behavior of deep beams with swimmer bars as shear reinforcement is unknown. Hence the study focuses on the behavior of deep beams under the combination of caging and swimmer bars.

2.2 Objective of the Study

The objective of the study is to increase the ultimate load carrying capacity of the beam by introducing a reinforcement caging at the mid-span. The corresponding shear strength is provided by different patterns of swimmer bars and their combinations are studied under flexural testing.

III. PRELIMINARY INVESTIGATION OF MATERIALS

Portland Pozzolana Cement (PPC), confirming to IS 12269 was used for the experimental work. Various laboratory tests like fineness, initial and final setting times, standard consistency etc were conducted on cement. The results are tabulated in TABLE 1.

Table 1 Test Results of Cement

Test Conducted	Result
Fineness, %	2.3
Standard consistency, %	32
Initial setting time, min	110
Final setting time, min	320
3 day compressive strength	23.84
7 day compressive strength	36.71
28 day compressive strength	46.62

M sand was used as the fine aggregate. Laboratory tests were conducted to determine its physical properties as per IS 2386 (Part III). 20 mm sized coarse aggregates were used in the present study. Various laboratory tests were conducted on coarse aggregates to determine the different physical properties as per IS 2386. Both the aggregates were tested for their gradation. The test results are tabulated in TABLE 2. The mix design is given in TABLE 3

Table 2 Test Results Of Aggregates

Test Conducted	Result
Specific gravity of FA	2.63
Specific gravity of CA	2.65
Fineness modulus of FA	2.959
Fineness modulus of CA	4.833
Water absorption (%) of FA	1.43
Water absorption (%) of CA	0.25

Table 3 M30 Mix Proportioning

Cement (Kg/m^3)	405
Fine aggregate (Kg/m^3)	638
Coarse aggregate (Kg/m^3)	1184
Water (litre/m^3)	159
Water cement ratio	0.39
Mix ratio	1:1.57:2.92

The various tests conducted on hardened concrete were compressive strength, split tensile strength, modulus of elasticity and flexural strength. The test results confirmed as per the specifications of IS 456:2000, IS 5816:1999 and IS 516:1959 are given in TABLE 4.

Table 4 Test Results of Hardened Concrete

Test Conducted	Result (N/mm^2)
Compressive strength of concrete cube	36
Compressive strength of concrete cylinder	29
Splitting tensile strength of concrete cylinder	4.1
Flexural strength of PCC beam	4.2

IV. EXPERIMENTAL PROGRAM

4.1 Details of Specimen

A total of seven specimens were casted and tested. All the specimens had dimensions of 200mm x 200mm x 700mm with an effective span of 600mm. The beams were provided with same longitudinal reinforcement of 2 no of 12 mm dia bars at tension region and 2 hanger bars of 12 mm dia at top.

The beam was divided into three zones of 200 mm span. The middle span was considered to be undergoing pure bending under two point loading. Hence, this span is kept free of shear reinforcement. When caging was provided, the horizontal and vertical distance between different layers of longitudinal reinforcement was kept 50 mm as per IS 456 specification. Thus two additional layers of 12 mm dia bars were provided at the two faces of the beam in the pure bending region, which was welded around the vertical stirrups at the boundary of the shear span forming a caging.

The control beam had vertical stirrups at both the shear spans. Specimens with single swimmer, rectangular shaped swimmer, rectangular shaped swimmer having cross bracings, combinations of caging and swimmers were also tested. The details of the specimens used are given in TABLE 5

Table 5 Details of Specimens

Beam	a/d	Reinforcement Pattern Used
CB	1.15	Vertical stirrups at shear span at 100 mm spacing
SSB	1.15	4 no of single swimmer at shear span at 50 mm spacing
RSB	1.15	2 no of rectangle shaped swimmer at shear span at 100 mm spacing
RSXB	1.15	2 no of rectangle shaped swimmer with cross bracings at shear span at 100 mm spacing
CBG	1.15	Caging at midspan with vertical stirrups at shear span
SSBG	1.15	Caging at midspan with single swimmers at shear span
RSBG	1.15	Caging at midspan with rectangle shaped swimmers at shear span

Fig 1 to 3 shows the various patterns used. Swimmer bars and caging were integrated with the longitudinal reinforcement by welding.

Fig.1 Reinforcement of Beam RSB

Fig.2 Reinforcement of Beam RSXB

Fig.3 Reinforcement of Beam RSBG

The prepared mix was poured in the mould in three layers and well compacted. The de-molded specimens were left for curing and tested after 28 days.

4.2 Testing of Specimens

The specimens were tested using a 100t loading frame under two point loading. LVDT was used to determine the deflection at the center of the beam. Prior to testing, the positions of two point loads, supports and mid-point were deflection is to be noted were marked.

After marking the positions, the specimen was placed on a 100 t UTM. The bed of the testing machine was provided with two rollers of 100 mm diameter on which the specimen was supported. These were positioned at distance of 600 mm centre to centre making the effective span of the deep beam to be tested. The load was applied through two rollers of 50 mm diameter mounted at the third points of supporting span, and was spaced at 200 mm. The load was applied equally between the two loading rollers with the help of another roller of 50 mm diameter. The test set-up is shown in Fig.4.

Fig 4 Test Setup

To study the deep beam behavior, the shear span to depth ratio was kept less than 2 for all the specimens. The load was increased uniformly and corresponding change in deflection were noted. Cracking behavior was carefully observed. The specimens were loaded up to the failure loads.

V. EXPERIMENTAL RESULTS

5.1 Ultimate Load

The flexural strength of the specimens was inferred from its failure load. The specimen designated SSBG which is a combination of caging and single swimmer bars showed an increase of around 35% than the reference beam. When rectangular swimmer bars were provided as shear reinforcement (i.e., RSB) the increase was 20.83%. This value increased only a 2% when provided along with caging (beam designated as RSBG). When a combination of vertical stirrups and caging were provided (i.e., CBG) the percentage increase in strength was only 4.33%. The only specimen which showed a decrease in flexural strength was RSXB which is having rectangular swimmer bars with cross bracings as shear reinforcement. The flexural strength of the beam was decreased by 8.33% in this case. The comparison of flexural strength of all specimens is shown in TABLE 6 and Fig.5

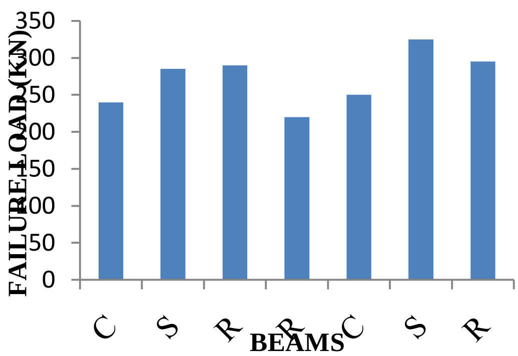

Fig.5. Comparison of Ultimate Loads

Table 6 Comparison of Flexural Strengths of Different Specimens

Designation of the Specimen	Flexural Strength (kN)	%Increase in Flexural Strength
CB	240	0
SSB	295	22.916
RSB	290	20.83
RSXB	220	-8.33
CBG	250	4.166
SSBG	325	35.4
RSBG	295	22.916

5.2 Crack Pattern

The flexural strength of the control beam was found to be around 240 kN For this beam, some mid span bending cracks were formed at the early stages of loading. The first shear crack was formed in the lower part of the shear span. Failure occurred due to the propagation of a shear crack from the support towards the loading point.

In the case of SSB, no cracks were formed at the early stages of loading. Due to further loading a diagonal shear crack originated from the support. As the loading was increased, the crack widened. This crack propagated from the support towards the loading point causing failure. Similar crack pattern was observed for RSB. When the load was increasing, diagonal shear cracks propagated from the supports towards the compression zone. The diagonal shear cracks occurred in both the shear spans. For the beam RSXB, the beam failed at a load of 220kN. The diagonal crack formed at one of the support point widens upon further loading causing spalling of concrete along the line of propagation of cracks.

When caging was provided, for CBG, cracks started as minor flexural cracks. Then newer inclined cracks were formed in the shear span. Failure was accompanied by crushing of concrete in the compression zone at the tip of the inclined crack. For the beams reinforced with swimmers and caging combination, crack propagation was slow. For SSBG and RSBG, at the early stages less visible hair cracks appeared at the bottom face in the moment region. As the load increased, shear cracks formed at the supports propagates towards loading points. Cracks increased in length and width with load increment and showed a tendency of spalling along the crack. The crack patterns of CB, RSXB and SSBG are shown in the Figures 6 to 8

Fig.6 Crack Pattern of CB

Fig.7 Crack Pattern of RSXB

Fig.8 Crack Pattern of SSBG

5.3 Load Vs Deflection Graph

The corresponding deflection for each load increment was noted and the load deflection graph was plotted. The consolidated Load Vs Deflection graph of the seven RC deep beams is shown in the Fig.9.

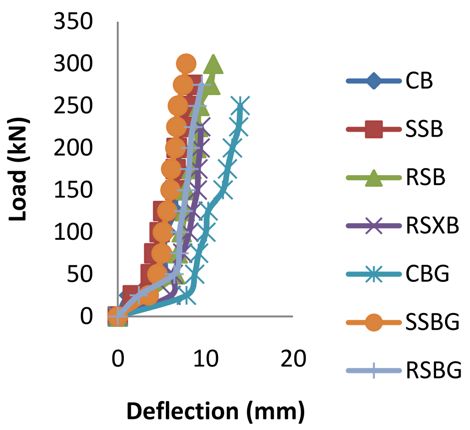

Fig.9. Load Vs Deflection Graph

5.4 Deflection

There was no considerable change in deflection observed at the initial stages of loading. The beams then deflected upon load increment. The maximum deflection observed for each specimen is plotted in the Fig.10.

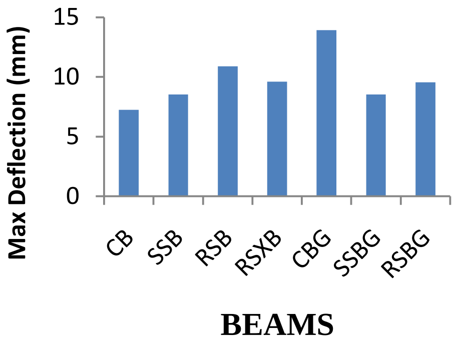

Fig.10 Comparison of Deflection

VI. EVALUATION AND DISCUSSION

6.1 Crack Pattern

From the crack pattern of all the specimens, it is observed that all the beams failed by shear. Diagonal shear cracking leads to failure of the beams in all the cases.

6.2 Ultimate Load

The ultimate load value is increased for all the cases except for the beam RSXB. Maximum increase in flexural strength is observed for the beam SSBG. Same ultimate load is noted for SSB and RSBG.

6.3 Load deflection relationship

From Fig.9, the load deflection relationship of CB, SSB and SSBG are similar. Also similar behavior is observed for beams RSB, RSXB and RSBG. Unique load deflection behavior is observed in the case of CBG.

6.4 Deflection

Each specimens shows different behaviour of deflection due to the different shear reinforcements provided. SSBG shows higher resistance to deflection. Hence it is the stiffer pattern. Beam SSB shows almost similar behaviour as that of SSBG. Maximum deflection was observed for CBG. Hence it has least resistance to deflection.

VII. CONCLUSION

The main objective of this study was to find out the best reinforcement pattern out of different arrangements. The following conclusions were drawn from the study

- Flexural strength of deep beams increased around 35% under the combination of caging and single swimmer bars.
- a/d ratio less than 2 ensures deep beam behaviour.
- New swimmer bar system offered better performance than vertical stirrups.
- A caging provided at the middle zone of deep beam reinforced with vertical stirrups offer increase in flexural strength by only 4%.
- Single swimmer bars showed more strength than rectangular shaped swimmer system.
- The combination of caging and rectangular swimmers offers same strength as that of single swimmers provided alone. This strength was 22% higher than that of the reference beam.
- Maximum deflection was observed for the combination of caging and vertical stirrups.
- All the specimens exhibited diagonal shear failure.
- Diagonal crack propagation was observed in the shear span of all the specimens on load increment.
- Beam with caging at the centre and single swimmers provided as shear reinforcement comes out to be the best pattern in terms of carrying higher flexural strength and resistance to deflection.

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