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Research Article

Behavior of Concrete Deep Beams with High Strength Reinforcement

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Abstract

The high performance reinforcement continues to gain wider acceptance in industry practice, for the mechanical properties of these new materials. For decades, methods of design and analysis of concrete members reinforced with normal strength steel have been developed. Recently, reinforcing steel (550 & 550D) with strength higher than conventional steel has become commercially available. The introduction of high strength reinforcing steel can be useful to reduce the quantity of reinforcement required, thereby lessening reinforcement congestion and improving constructability. The paper presents construction and testing of several high strength reinforced concrete deep beams which includes three beams, designed for three different country codes, for each shear span to depth ratio as described and the test data is presented. The beam consists of simple span subjected to two point loads, each span being 0.7 m in length. The shear span to depth ratios ranged from 0.62 to 0.77. Measurements were made during each test inclusive of applied loads and mid span deflections directly from programmed instrument (K.P.T.L.) through load cell and L.V.D.T's. Cracks were marked and photographed at each initial and final crack. The beams generally failed in shear, exhibiting the behavior of deep beam depending on shear span to depth ratio.

Keywords: *Deep Beam, Two Point Loading, Finite Strip Method*

1. Introduction

A beam is considered as deep, if the depth of beam is in relation to the span of the beam. For simply supported beam it acts as deep beam when the ratio of its effective span (L) to overall depth (D) is less than 2.0 and that for continuous beam when the ratio is less than 2.5. The effective span is defined as the centre to centre distance between the supports or 1.15 times the clear span whichever is less.

Types of deep beams may be classified as Simply Supported Deep Beams, Continuous Deep Beam & Deep Beams with and without opening. Verity of application for Deep beam is found that can be used in situations where other type of beams or structural components cannot be used such as in bridges where long spans are required. In large halls or building where no column is to be used. R. C. C. side walls of water tank may act as deep beams. Pile caps can also act as deep beams in case of smaller spans. Raft foundation may contain deep beams in some cases. Bunkers & Silos of such structures may act as deep beam. R. C. C. shear walls may act as deep beam i.e. where dimensions and span are restricted.

For decades, methods of design and analysis for concrete members reinforced with normal strength steel have been developed. Recently, reinforcing steel with strength higher than conventional steel has become commercially available. The introduction of high strength reinforcing steel can be useful to reduce the quantity of reinforcement required, thereby lessening reinforcement congestion and improving constructability. The strut and tie modeling technique is a widely accepted approach for reinforced concrete deep beams.

However, there are significant differences between various design code implementations for this technique with respect to reinforcement tie, which influences on the capacity of adjacent concrete struts. Furthermore, each design code specifies different limits on the maximum permitted stress in the ties. Since high performance reinforcement continues to gain wider acceptance in industry practices, it is necessary to validate existing design approaches, for the mechanical properties of these new materials.

Considerable increase in load carrying capacity occurs with increasing concrete strength and decreasing shear span to depth ratio (K. N. Smith and A. S. Vantsiotis, 1982). Application of consistent equilibrium and ultimate strength consideration to the designing and detailing of reinforced concrete beam (Peter Marti, 1985). The effect of top & bottom loading simultaneously on reinforced concrete deep beams. Proposals are made for predicting shear strengths of such beams (S. C. Less & W. B. Siao, 1994). Simply supported reinforced concrete deep beams subjected to variables, affecting shear strength of deep beams (A.

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F. Ashour, 2000). Behavior of the deep beams is described in terms of cracking pattern, load vs. deflection, failure mode & strains in steel reinforcement & concrete (Gerardo Aguilar et al, 2002). Study of shear failure of reinforced concrete deep beams under two point or single point loading with a shear span to effective depth ratio between 1.0 & 2.5 is due to a crushing of concrete in a compressive zone with restricted depth above the tip of the critical diagonal crack (Prodromos D. Zararis, 2003). Study of new model to determine the shear strength of reinforced concrete deep beams (Gaetano Russo et al, 2005).

2. Behavior of Deep Beams

The behavior of deep beams is significantly different from that of beams of more normal proportions, requiring special consideration in analysis, design and detailing of reinforcement. Because of their proportions, they are likely to have strength controlled by shear. On the other hand, their strength is likely to be significantly greater than predicated by usual equations. Special design methods account for these differences. Stresses in deep beams can be studied using the methods of two dimensional elasticity, such as finite element analysis or finite strip method. Plane sections before bending remaining plane after bending does not hold good for deep beams. Significantly warping of the cross-sections occurs because of high shear stresses, consequently flexural stresses are not linearly distributed, even in the elastic range, and the usual methods for calculating section properties and stresses cannot be applied.

Shear strength of deep beams may be as much as 2 to 3 times greater than that predicated using conventional equations developed for members of normal proportions. For deep beams, however a significant part of the load is transferred directly from the point of application to the supports by diagonal compression strut as shown in Figure 1.

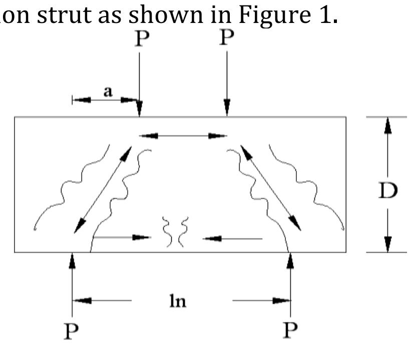

Fig.1 Deep beams carrying concentrated loads

Diagonal cracks that form roughly in a direction parallel to a line from the load to support isolate a compression strut, which acts with the horizontal compression in the concrete and the tension in the main reinforcement to equilibrate the loads. The geometry of this mechanism and the relative importance of each contribution to shear strength clearly depend on the properties of the member as well as the placement of the loads and reactions.

The reinforcement of deep beams differs from that of normal beams. The main flexural steel is placed near the tension edge, as usual, although because of the greater depth of the tension zone it may be advisable to distribute such steel over, the bottom third of the member. As per I. S. 456-2000, flexural steel is placed within a zone of depth equal to (0.25D-0.05L) adjacent to the bottom face of the beam where 'D' is the overall depth and 'L' is the effective span.

3. Analysis of Deep Beams

The strength of deep beams is usually controlled by shear rather than flexure, provided a normal amount of longitudinal reinforcement is used. The shear action in the beam web leads to compression in a diagonal direction and tension in a direction perpendicular thereto.

Numerous classical mathematical procedure of approximation has been developed for the analysis. The methods of approximation used to solve this governing differential equation can be grouped into three approaches

1. Direct Approach,
2. Weighted Residual Method
3. Finite Strip Method

2.1 Failure Modes

Failure modes of deep beam can be divided in following two main categories.

Mode I-Flexural failure mode
Mode II-Shear failure mode

Shear failure mode can be sub divided into following three categories.

Mode II-1: Diagonal tension failure, which in the line of thrust become so eccentric and give rise to flexural failure in compressive zone. It is important however to mention that this kind of failure is a result of tensile crack extension in compressive zone due to flexural load.

Mode II-2: Shear compression failure where RC beam fails due to the development of diagonal crack into the compressive zone and reduces the area of resisting region excessively and beam crushes once generated compressive stress exceeds compressive strength of concrete.

Mode II-3: Shear proper or compressive failure of struts, which is often observed in beams with very small shear span to depth ratio (L/D < 1.5).In this case due to the small L/D ratio, the line of thrust will be so steep and arch action not only reserve flexural capacity in most cases but also efficiently sustains required shear force. Arch is clearly observed in those beams and finally beams fail due to either sudden tensile crack formation parallel to the strut axes or compressive crush in normal direction to the strut axes.

4. Design of Deep Beams

Deep beams are designed and cast for two points loading and for two shear spans viz. 200 mm and 250 mm. Point loads of 50 kN are applied on deep beams for design purpose. Dimensions of deep beams chosen for design purpose are, Length = 700 mm, Depth = 325 mm, Thickness = 150 mm.
M20 and Fe 550

Design of deep beams is done by following methods.

1. Design by using I.S.456-2000 method
2. Design by using B.S.8112 method
3. Design by using ACI-318 method

Simply supported deep beams
For each method mentioned above, several beams with 200 mm and 250 mm shear spans are designed and cast. Total six deep beams are designed and cast for this study. The Reinforcement Schedule is shown in Table 1.

Table 1 Reinforcement Schedule

Code used for Design of Deep Beam		**I. S. 456:2000**		**B. S. 8112-02**		**A. C. I. (318)-05**	
Identification Mark		**a-1**	**a-2**	**b-1**	**b-2**	**c-1**	**c-2**
Shear Span (mm)		**200**	**250**	**200**	**250**	**200**	**250**
Shear span to depth ratio		0.62	0.77	0.62	0.77	0.62	0.77
S No.	**Type of reinforcement**	**Spacing and No. of bars.**	**Spacing and No. of bars.**	**Spacing and No. of bars.**	**Spacing and No. of bars.**	**Spacing and No. of bars.**	**Spacing and No. of bars.**
1	Horizontal Main steel	3-8 mm Φ	1- 10 mm Φ & 2-8 mm Φ	3-8 mm Φ	1- 10 mm Φ & 2-8 mm Φ	3-8 mm Φ	1- 10 mm Φ & 2-8 mm Φ
2	Side Face Reinforcement a) Vertical Steel	5-Two legged 6 mm dia. stirrups @ 165 mm c/c	5-Two legged 6 mm dia. stirrups @ 165 mm c/c	4-Two legged 6 mm dia. stirrups @ 220 mm c/c	4-Two legged 6 mm dia. stirrups @ 220 mm c/c	6-Two legged 6 mm dia. stirrups @ 130 mm c/c	6-Two legged 6 mm dia. stirrups @ 130 mm c/c
	b) Horizontal Steel (in central zone)	3-Two legged 6 mm dia. stirrups @ 70 mm c/c	3-Two legged 6 mm dia. stirrups @ 70 mm c/c	3-Two legged 6 mm dia. stirrups @ 70 mm c/c	3-Two legged 6 mm dia. stirrups @ 70 mm c/c	2-Two legged 6 mm dia. stirrups @ 90 mm c/c	2-Two legged 6 mm dia. stirrups @ 90 mm c/c

5. Experimental Work

After analysis and design is over, casting of the deep beams was done. In all several deep beams were cast (for 200 mm shear span and 250 mm shear span) for each of the three design methods viz. IS 456-2000, B. S. 8112 and ACI-318. Three beams for each shear span were cast.

Case I: includes three beams of each IS 456-2000, B. S. 8112 and ACI-318 of shear span 200 mm.
Case II: includes three beams of each IS 456-2000, B. S. 8112 and ACI-318 of shear span 250 mm.

Before actual casting, various ingredients of concrete such as cement, sand and aggregate were tested in Laboratory. Reinforcement mesh for every beam was kept ready according to individual designs.

Formwork for casting beams of required dimensions as mentioned above was kept ready. For M 20 grade concreting, weigh batching was adopted. In all eighteen beams are cast. After casting curing has been done for next 28 days. The concrete cubes and steel bars are tested to assure material quality.

6. Results and Discussions

Before actual testing was started, testing set up such as span adjustment, Two point loading arrangement etc. was done. Span of 600 mm was fixed on the testing platform. Positions of shear spans, loading points were marked on beams. Bearing plates were kept first on the support and then beams were kept on these bearing plates.

Above beams, again bearing were kept at loading points and two transverse bars were kept on these plates for point loadings. Above these bars I section was kept so as to transfer the load to two points as required as shown in Figure 1. Initial creaking load, failure pattern and failure load of every beam was recorded.

Two Point Loading with each point load of 50 kN was applied at the beginning. Manually operated hydraulic pump was used to transfer load. Deflection at various loads is measured by L. V. D. T. The average initial cracking load, average load at failure, average deflection at centre and mode of failure is studied for each beams. The average test result is given in Table 2 below.

Table 2 Average Test Results

Case No.		Case 1			Case 2		
Design Method		**I.S.456**	**B.S.8112**	**ACI 318**	**I.S.456**	**B.S.8112**	**ACI 318**
Shear span (mm)		200	200	200	250	250	250
Shear span to depth ratio		0.62	0.62	0.62	0.77	0.77	0.77
Reinforcement Provided (No. of bars)	Flexural Steel Required in mm^{2}`	126.14	146.25	126.14	157.41	157.42	157.95
	Flexural Steel						
	i) 10 mm Φ				1	1	1
	ii) 08 mm Φ	3	3	3	2	2	2
	iii) Area (mm^2)	150.73	150.73	150.73	179.02	179.02	179.02
	Shear Required (mm^2)` Vertical	110.625	113.04	110.625	73.125	113.04	110.625
	Horizontal	66.375	84.78	66.375	121.875	84.78	66.375
	6 mm dia.						
	Vertical	6	4	6	5	4	6
	Horizontal	2	3	2	3	3	2
Average Load at first crack	Total	390 kN	370 kN	430 kN	370 kN	360 kN	420 kN
	Each Point load	195 kN	195 kN	215 kN	185 kN	180 kN	210 kN
Average Failure Load	**Total**	**1000 kN**	**970 kN**	**1000 kN**	**950 kN**	**960 kN**	**970 kN**
	Each Point load	500 kN	485 kN	500 kN	475 kN	480 kN	500 kN
Average Deflection at failure	**Total**	**3.43 mm**	**3.32 mm**	**3.56 mm**	**3.49 mm**	**3.75 mm**	**3.65 mm**
	Permissible deflection	2.4 mm	2.4 mm	2.4 mm	2.4 mm	2.4 mm	2.4 mm
	Deflection at 500 kN load	2.19 mm	2.59 mm	2.19 mm	2.13 mm	2.22 mm	2.16 mm
Observed mode of failure		**ModeII3**	**Mode II3**	**Mode II3**	**Mode II3**	**Mode II3**	**Mode II3**

Conclusions

1) Failure of deep beams was mainly due to diagonal cracking and it was along the lines joining the loading points and supports.
2) The cracks pattern and failure mechanisms for deep beams reinforced with high strength reinforcement were similar to those deep beams with normal strength reinforcing steel.
3) Minimum flexural steel requirement of B.S.8112 as well as A.C.I-318 is more than I.S.456-2000. (The lever arm of A.C.I-318 is more by 6% that of B.S.8112 & I.S.456) The flexural steel required of all 3 cases is nearly same.
4) The flexural steel required by Finite strip method is approximately 10% less than all 3 cases.
5) The vertical web reinforcement required by A.C.I-318 code is approximately 40 % more than I.S.456-2000.
6) The horizontal web reinforcement required by A.C.I-318 code is approximately 40 % less than I.S.456-2000.
7) The strength of beams with 250 mm shear span is less than that of 200 mm shear span. It is clear from these results that the strength of deep beam is inversely proportional to the shear span for the constant depth of the beam.
8) The average failure load of A.C.I-318 code is approximately 10 % more than B.S.8112 as well as I.S.456.
9) No separate checking for shear is specified in I.S.456. It is assumed that the arching action of the
10) main tension steel & the web steel together with concrete will carry the shear.
11) All the beams had low deflection at failure as there was no flexural failure.
12) As reported by F. K. Kong the shear strength of deep beams is 2 to 3 times greater than that given by usual equations. But in our case due to use of high strength reinforcement the shear strength of deep is found 6 times greater than design loads.

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