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An Experimental Study on Steel Fibre Reinforced Concrete Deep Beams with and Without Web Openings

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ABSTRACT

Deep beams are widely used as transfer girders in offshore structures and foundations, walls of bunkers and load bearing walls in buildings. The load transfer in the deep beam get interrupt when the openings are provided, which will decrease the shear carrying capacity and its serviceability. Adequate measures should be taken against the strength of deep beam when such openings are unavoidable. Literature shows there are limited studies reported on deep beam strength with circular openings.

The present experimental study deals with the ultimate strength and behaviour of simply supported steel fibre reinforced concrete deep beams having dimensions 750mm×325mm×75mm (L x D x b) with and without circular openings were tested under gradually increasing two-point loading. The deflection and crack pattern are studied for deep beam with the influence of steel fibre content (i.e. from 0 to 1 percent). The average of six deep beams for each percentage of steel fibres were tested for shear carrying capacity of beam. The experimental results are compared with the theoretical formula for ultimate load carrying capacity. Also, this study indicates the effective location of circular opening in the deep beams.

KEYWORDS: *Deep beam, Web Opening, SFRC*

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INTRODUCTION

According to IS 456:2000 code a beam is said to be deep beam when the effective span to depth ratio of beam is less than 2.0 for simply supported condition. Deep beams are structural elements commonly used in building construction to support heavy loads over large spans. Unlike traditional beams, deep beams have a relatively large depth compared to their span, resulting in higher shear stresses, and often requiring special design considerations. Deep beams transfer loads primarily through flexure and shear, making them suitable for carrying heavy loads while minimizing the need for additional support columns or walls.

Openings in the deep beams are provided for various services in the structure which may in any shape (rectangular, circular, etc.,). Due to the presence of such openings the transfer get interrupt leading to decrease in the strength or load carrying capacity and leads to cracks in the deep beam. To overcome this effect steel fibres with required percentage are added to concrete to enhance the load carrying capacity and to avoid the growth of cracks in the deep beams.

Fig. 1 Deep beam with openings

Steel Fibre has high elasticity, strength and help to prevent creep and improves abrasion resistance. Steel fibres are available in different kinds as mentioned below:

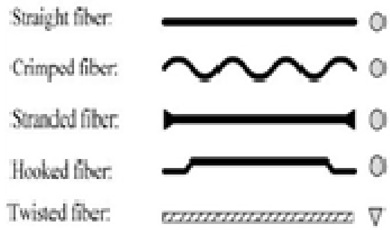


Fig. 2 Types of steel fibres

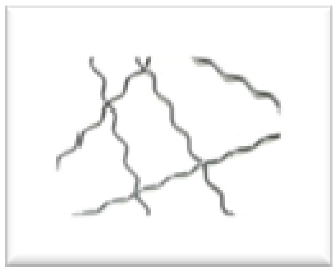


Fig. 3 Crimped Steel Fibre

In the present work crimped type steel fibres with varying percentages (0.25, 0.50, 0.75 and 1%) are used with an aspect ratio of 60.

Literature Review

Studies have been limited in reporting strength of deep beam with web openings.

F K Kong [2003]

Prof. Kong has given important information about deep beams and it is worth mentioning at this stage. The information related to the failure of deep beams with different patterns of web openings are presented in his work.

He observed that the first visible inclined cracks normally appear in the support bearing regions and from the opening corners at load varying levels of about 36–55% of the ultimate loads.

Also, he identified the flexural cracks in both cases of opening (rectangular and circular) flexural cracks are very few and generally occur in the range of ultimate loads of about 60–95%.

Finally, he concluded that web opening in deep beam weakens the shear carrying capacity and compared that circular type of web opening is more effective than rectangular type.

V. Vengatachalapathy and Dr. R. Ilangovan [2012]

They have measured the ultimate strength of reinforced concrete deep beams using steel fibres with and without openings (rectangular) in web subjected to two- point loading, seven concrete deep beams of dimensions 750mm x 350mm x 75 mm thick were tested to destruction by applying gradually increased load.

Finally, they concluded that web openings may be provided away from shear zone area of the beams and fiber content of 0.75% by volume may be added to improve the strength of the structure.

Vinu R. Patel and I. I. Pandya [2012]

They measured the shear strength of Polypropylene Fiber Reinforced Concrete (PPFRC) moderate deep beams without stirrups having span to depth ratio 2.0, 2.4, 3.0, 4.0.

Finally, they concluded that inclusion of steel fibers (Circular Corrugated Type) in the concrete beam improves the shear strength of R.C.C. beams without stirrups. Steel fibers can be used to replace stirrup partially with proper design of concrete.

Dipti R. Sahoo, Carlos A. Flores, etal. [2012]

They conducted experiment on two RC deep beams with large openings under monotonically increased concentric loading. They identified the ultimate strengths and failure modes of these specimens and compared with those predicted by a design STM.

They concluded that design STMs significantly underestimate the ultimate strengths of the test specimens. The crushing of concrete that occurred in the highly stressed region over the supports was primarily due to the lack of confinement of the concrete under high axial stress.

Critical Observations:

The following critical observations are made from the existing literature in reinforced concrete deep beams and deep beams with openings.

- Limited research on deep beam with circular web openings.
- Limited research work on crimped type steel fibres.

Objectives

Following are the objectives of present study:

1. To study the shear behavior of normal reinforced RC deep beam without web opening for the following circumstances:

A. With stirrups
B. Without stirrups
C. Without stirrups but with steel fibre reinforcement.

2. To observe the shear behavior of normal reinforced RC deep beam with rectangular and circular web openings under the following conditions:

A. Beams provided with stirrups
B. Beams provided without any stirrups
C. Beams without stirrups, but with the provision of steel fibre reinforcement

3. To investigate the crack growth with respect to loading and measurement of final crack at failure for objective 1 and 2.

Materials & Methodology

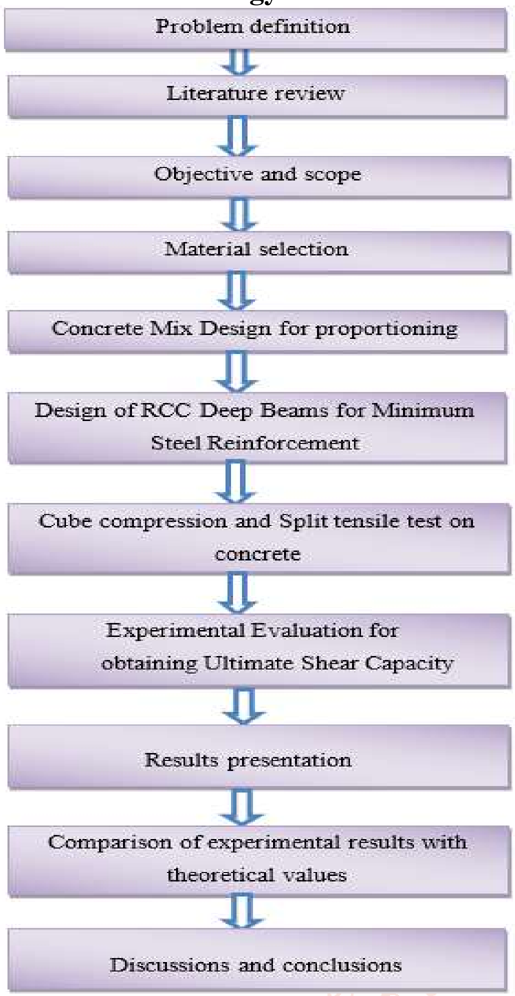


Fig. 4 Methodology flow chart

The materials used for experimental work and their properties are:

1. **Cement:** 53 Grade Ordinary Portland cement conforming to IS 12269 with a specific gravity of 3.11 was used for all the specimens cast.
2. **Fine Aggregates:** The Fine Aggregates used for casting was clean river sand. The specific gravity of fine aggregate was 2.60. The fineness modulus of the fine aggregate was 3.20. The optimum moisture content was found to be 4%.
3. **Coarse Aggregates:** The coarse aggregate used was broken granite stone of size 10 mm. The specific gravity of coarse aggregate was 2.72. The bulk density of coarse aggregate was found to be 1640 kg/m^3.
4. **Water:** Bore well water available in the Structural Engineering laboratory was used for casting all specimens of this investigation. The quality of water was found to satisfy the requirements of IS 456 2000.
5. **Admixture**: Superplastisizer is used as admixture for improve the workability of concrete due to the presence of steel fibres.
6. **HYSD Steel Bars:** Two steel rods of 16mm diameter of 500 N/mm^2 yield strength were used as the main tension reinforcement. Each beam contained web reinforcement consisting of 6 nos. of 6mm diameter in 3 layers having yield strength of 500 N/mm^2.
7. **Steel Fibres:** Crimped Type steel fibres are used as replacement of vertical or shear reinforcement with an aspect ratio (A_r) of 60.

MIX DESIGN

1. 0% Steel fibre:

Trial mix = cement: sand: jelly: w/c ratio
= 1: 1.86: 3.05: 0.45

2. 0.5% Steel fibre:

Trial mix = cement: sand: jelly: w/c ratio
= 1: 1.85: 3.02: 0.45

3. 0.75% Steel fibre:

Trial mix = cement: sand: jelly: w/c ratio
= 1: 1.844: 3.017: 0.45

4. 1% Steel fibre:

Trial mix = cement: sand: jelly: w/c ratio
= 1: 1.837: 3.005: 0.45

Design of Deep Beam

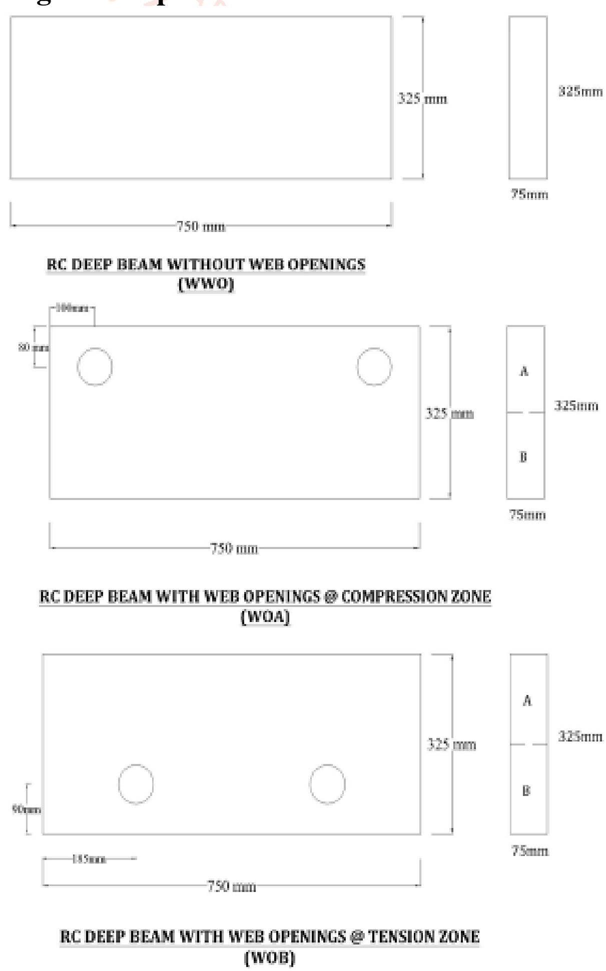


Fig. 5 Deep beam with openings

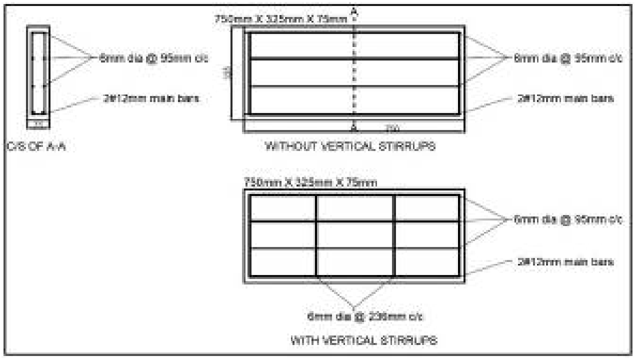


Fig. 6 Reinforcement details

Experimental Study and Result discussion

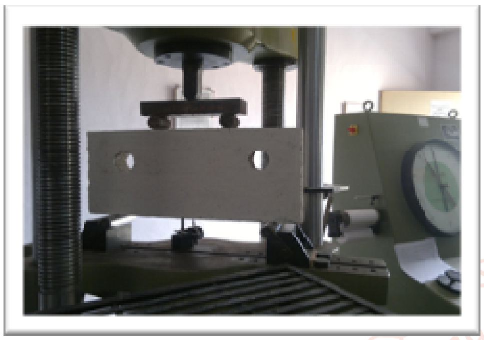


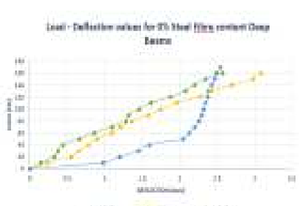
Fig. 7 Experimental set up

UTM of 2000kN capacity with dial gauge is used for testing. The average of three specimen readings is recorded during the test with different percentage of steel fibre (0%, 0.5%, 0.75% and 1%) for the following types of deep beams:

- Deep beam without web opening (WWO)
- Deep beam with web opening at position A or opening in compression zone or opening above the centroidal axis (WWA)
- Deep beam with web opening at position A or opening in compression zone or opening above the centroidal axis (WWA)

For 0% Steel Fibre:

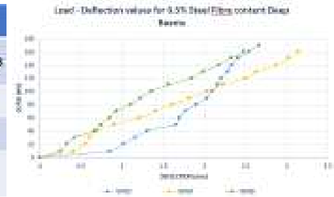
%age of Steel Fibre	0%		
	Without opening	With opening @ A	With opening @ B
First Crack Load (kN)	74	68	62
Ultimate Load (kN)	164	160	152
Max. Deflection (mm)	2.50	3.08	2.58



- The deep beam without web opening deflects significantly in comparison to the deep beam with web opening.
- In other words, deep beams without web opening appear to be weaker in resisting deflection for loads varying from 0 – 80 kN.
- In contract to this the deflection are observed to be constant even though considerable amount of load was applied beyond 80 kN.

For 0.5% Steel Fibre:

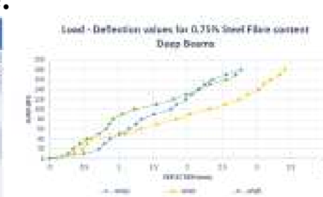
%age of Steel Fibre	0.5%		
	Without opening	With opening @ A	With opening @ B
First Crack Load (kN)	85	77	72
Ultimate Load (kN)	170	164	158
Max. Deflection (mm)	2.54	3.14	2.48



- The deep beam without web opening deflects significantly in comparison to the deep beam with web opening.
- In other words, deep beams without web opening appear to be weaker in resisting deflection for loads varying from 0 – 100 kN.
- In contract to this the deflection are observed to be constant even though considerable amount of load was applied beyond 100 kN.

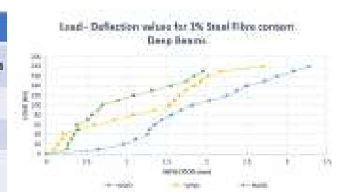
For 0.75% Steel Fibre:

%age of Steel Fibre	0.75%		
	Without opening	With opening @ A	With opening @ B
First Crack Load (kN)	98	89	82
Ultimate Load (kN)	178	174	166
Max. Deflection (mm)	2.78	3.42	2.70



For 1% Steel Fibre:

%age of Steel Fibre	1%		
	Without opening	With opening @ A	With opening @ B
First Crack Load (kN)	100	96	88
Ultimate Load (kN)	180	174	168
Max. Deflection (mm)	5.28	2.70	1.96



Fibre content of 0.75% and 1% by volume provides almost the same ultimate shear strength values of beam improve the strength of the structure with much close values.

Fig. 8 Failure of deep beam with web opening at position A

Fig. 8 Failure of deep beam with web opening at position B

Theoretical Expression for Ultimate Shear Strength of The Deep Beams

Prof. F. K. Kong [10] provided the following expression for determination of ultimate shear strength of deep beam as shown below:

$$Q_u/bD = (P_u 2bD) = 0.1\, f_c\, (\lambda_1)\, (\lambda_2)\, (\lambda_3) + 0.0085\, \Psi_1\, p_t\, f_{ty} + 0.01\, \Psi_w\, K_w\, r_w\, f_{wy}$$

Where:

- Q_u = *ultimate shear strength for single point load* = $P_u/2$ *for 2-point load*
- *B = Overall Thickness of beam*
- f_c = *cylinder (150 mm dia.×300 mm height) compressive strength of concrete*
- f_{cu} = *cube (150 mm) compressive strength of concrete.*
- $\lambda_1, \lambda_2, \lambda_3$ = *empirical co-efficient*

Table I Comparison of Ultimate Shear Capacity b/w experimental & theoretical values

Opening position	Ultimate Shear Load (kN)									
	Fibre – 0%		Fibre – 0.25%		Fibre – 0.5%		Fibre – 075%		Fibre – 1%	
	Exp. value	The. value	Exp. value	The. value	Exp. value	The. value	Exp. value	The. value	Exp. value	The. value
Without web opening (WWO)	164	183.87	167	188.10	170	192.32	178	205	180	206.41
Web opening at position A (WWA)	160	159.42	162	166.22	164	165.11	174	173.64	174	174.59
Web opening position at B (WWB)	152	145.20	155	147.24	158	140.28	166	155.40	168	156.07

Conclusions

The following conclusions are drawn from the experimental investigation:

1. The presence of web opening in the Deep Beam decreases the shear carrying capacity of beam under two point loading.
2. From result analysis it is clear that web openings provided in the compression zone i.e. web opening provided at position - A of the beam improve the Shear Carrying Capacity of Beam when compared with web opening provided at tension zone.
3. The opening in the tension zone of the deep beam reduces the strength of beam about 10 % compared with opening provided at compression zone.
4. Fibre content of 0.75% and 1% by volume provides almost the same ultimate shear strength values of beam improve the strength of the structure with much close values.
5. Fiber content of 0.75% and 1% by volume of the beam reduces the formation of cracks.
6. It has been observed that the Experimental agree with the corresponding values for ultimate shear strength of the deep beam obtained from available published materials.

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