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Experimental Investigation on Safety and Serviceability Conditions of Reinforced Concrete Deep Beams

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Abstract: A Deep beam is defined as a structural member having aspect ratio (L/D) less than 2.0 for simply supported beam, less than 5.0 for continuous beam and dominated by shear deformation. In the experimental investigation six deep beams are casted, out of which two are conventional beams, two are chlorinated and remaining two are added by bolts and nuts. The main objective of this paper is to investigate the behavior of RC deep beams under different exposure conditions. Parameters under consideration are shear behavior of RC deep beams, modes of failure, load deflection response, factors affecting strength, crack pattern. Emphasis is also given to study the behavior of deep beams in resisting deflection and cracking along with serviceability conditions like fatigue, vibration and durability. As the serviceability performance checks are mandatory for structural members exposed to environmental conditions which ultimately effects strength, performance of RC deep beams are quantified and tested to check the width of diagonal spacing cracks that form under the application of service loads.

Index Terms: Deep beam, Serviceability, Crack pattern, Stress-Strain response, Durability.

I. INTRODUCTION

Reinforced concrete deep beams have many applications in bridges, buildings, foundations and offshore structures. There are many structural elements whose behaviour similar to deep beams such as load bearing walls, transfer beams, piles cap, coupling beams in buildings, plate elements in the folded plates and bunker walls. According to the American Association of State Highway and Transportation Officials (AASHTO), both horizontal and vertical reinforcement must contain minimum of 0.3% cross sectional area. According to Literature survey, failure of deep beams is mainly due to diagonal cracking and due to the use of high strength reinforcement. The shear strength of deep beam is six times greater than design load requirement. Under the application of service load the maximum crack width is limited to less than 0.16 inch.Some of the literature summarized as follows. Tested seven simply supported rectangular beams, the present work is the comparison of shear strength of deep beams which is predicted by using models proposed by IS code. Along the lines joining the loading points and supports diagonal cracking was observed which is considered as major failure in deep beams.

Cracking and it was along the lines joining the loading points and supports[1]. A non-linear distribution of stress and strain is shown in this paper, in all beams it is observed that as the energy absorption capacity increases tensile bar capacity is also increasing, this results with increase in cracks number but with less crack width[2]. Three RC deep beams were designed as per three different country codes where, for each shear span to depth ratio was concluded that failure is mainly due to diagonal cracking and use of high strength reinforcement[3]. Concrete strength, shear span to depth ratio and shear reinforcement are considered as three main parameters which could affect the shear capacity of RC deep beams[4]. In this present study it describes about the factor that influence the shear strength of deep beam. From the result it has been found that the shear strength of deep beam increases as the horizontal tensile reinforcement increases[5].The present study describes the theory regarding the shear failure of reinforced concrete deep beam under single point loading or two point loading[6].In this paper deep beams are considered as transfer girder where transfer of loads occurs through loading face to supports in transverse direction. Shear is the main failure mode rather than flexure where beams are characterized by small span to depth ratio[7]. In this study a numerical method of estimating shear capacity is proposed[8]. It was observed that the horizontal and vertical web reinforcement is mainly influenced by shear span to depth ratio and main longitudinal bottom reinforcement[9]. When compared the experimental results to analytical results, the deformation increases with the ductility of the specimen[10].

II. MATERIAL PROPERTIES

The material properties of concrete and the reinforcement details used in the deep beams are shown in Table I and Table II respectively. The casted beams are tested under three-point loading after 28 days of curing. M30 grade of concrete is used.

Table I: Material properties of concrete

Material	Quantity
Cement	368kg/m^3
Fine aggregate	563kg/m^3
Coarse aggregate	951kg/m^3
Water	168lt/m^3

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Table II: Reinforcement details

Zone	Diameter of Bar(mm)
Tension Reinforcement	12
Longitudinal Reinforcement	10
Transverse reinforcement	8

III. EXPERIMENTAL PROGRAM

Cubes of 150mm×150mm×150mm dimension are used for calculating compressive strength of designed concrete grade M30.Slump of 100mm maintained throughout. Materials used in the design are OPC 53 grade specific gravity is 2.65, bulk density, Fine aggregates whose fineness module and specific gravity are 1.52,2.68, and 2.324 respectively. 20mm size coarse aggregate is used. Table III shows the mix proportion of M30 grade of concrete. Shear reinforcement typologies are tested by casting the deep beam specimens of sizes (1200×200×600mm) and (900×200×500mm).

Table III: Mix proportion of concrete

Grade	Cement (%)	Fine aggregate (%)	Coarse aggregate (%)	w/c
M30	1	1.5	2.8	0.45

A. Deep Beam Specimen Details

Six beams are considered out of which two beams are conventional type, two specimens are subjected to chlorination and remaining two beams are added with nuts and bolts. Two different dimensions of beams are considered in the design in order to understand the shape effect on the results. Specimen sizes are 1200×200×600mm and 900×200×500mm. A clear cover of 20mm is maintained on all sides. The specimens are tested through three point loading on a loading frame.

Specimen details and detailing of deep beams are shown in the Table IV and Table V respectively. Each beam is tested under three point loading. Fig. 1and Fig. 2 shows the layout of deep beams.

Table IV: Specimen details

Specimen	Length (mm)	Width (mm)	Depth (mm)	Type
DB-1	1200	200	600	Conventional
DB-2	900	200	500	
DB-3	1200	200	600	Chlorinated
DB-4	900	200	500	
DB-5	1200	200	600	with nuts and bolts
DB-6	900	200	500	

Table V: Detailing of Deep beam

Specimen	L/D ratio	Main bars A_{st} (mm^2)	Stirrups A_{st} (mm^2)	Horizon-tal bars A_{st} (mm^2)
DB-1	1.91	600	452	472
DB-2	1.61	500	300	440
DB-3	1.91+	600	452	472
DB-4	1.61	500	300	440
DB-5	1.91	600	452	472
DB-6	1.61	500	300	440

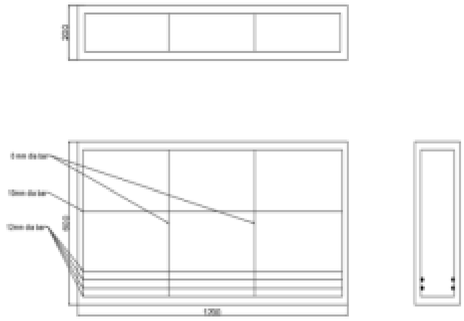

Fig. 1: Layout of a deep beam of size (1200×200×600)

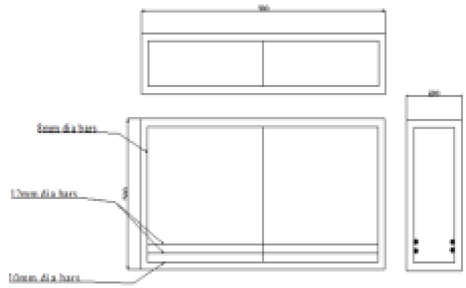

Fig. 2: Layout of a deep beam of size (900×200×500)

B. Casting of Specimens

All the six beams are casted in a steel mould using M30 grade of concrete and the aggregates used is of 20mmsize. The steel reinforcement in the tension zone is of 12mm size, the longitudinal reinforcement is of 10mm size and transverse reinforcement is of 8mm size.

IV. METHODOLOGY

All the specimens were tested on loading frame having capacity of 2000kN. The specimens were tested under simply supported conditions with three point loading. The supported plate also acts like a loading point hence it is called as simply supported condition. The six deep beams are tested under the loading frame equipment shown.

In the present study two of them are conventional beams (DB-1 and DB-2). The conventional beams are regular ordinary beams varying with different sizes.

Another two of them are chlorinated beams (DB-3 & DB-4). Generally On an average, seawater in the world's oceans has a salinity of approximately 35 parts per thousand, or 3.5%. This means 35 grams of salts is present in every 1 liter (1000 ml) of seawater. DB-3 and DB-4 beams are cured for 28days in water, which contains 3.5gms of salt for every 1 liter of water.

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Another two beams (DB-5& DB-6) are casted by adding composite materials i.e. nuts and bolts. Generally a Nut is a type of fastener with a threaded hole; nuts are almost and always used in conjunction with a mating bolt to fasten multiple parts together. The most common shapes used today are hexagonal. The mechanical properties of steel nuts apply with metric ISO thread with nominal thread diameters up to and including 39mm and heights not less than 0.8D made of carbon steel. It does not apply to nuts which have to meet special requirements such as for weld ability, corrosion resistance, and ability to withstand temperatures above + 300°C. The use for nuts above 39mm is only permitted, when nuts meet all the requirements. In beam DB-5 and DB-6 Nuts and Bolts are used as a composite material and is added during the casting.

V. RESULTS AND DISCUSSION

Some of the important parameters observed during the testing in deep beams were crack pattern, stress-strain response, load-deflection response, Flexural failure, Local failure, Shear failure, Serviceability and Compression failure of Deep beams. Details and properties of tested deep beams are shown in Table VI.

A. Load vs. Deflection Curve

For all the six deep beams the applied load versus deflection response are shown in Fig. 3. It is observed that the response to load and initial stiffness is different for all the tested specimens. For conventional deep beam-1 (DB-1) the maximum load obtained is 680kN, at first the load is increased until the initial diagonal cracks are obtained and at the same deflection the load is increased to maximum load and starts decreasing at a deflection of 5.76mm. For conventional deep beam-2 (DB-2), the first diagonal crack starts propagating and as the load increases to maximum 560kN, the observed deflection is 5.48mm. The third specimen is chlorinated deepbeam-3(DB-3), here the first diagonal crack starts propagating and as the load increases to maximum 430kN, the observed deflection is 6.11mm. In the case of chlorinated deep beam-4 (DB-4), the maximum load obtained is 430kN, at first the load is increased until the initial diagonal cracks are obtained and at the same deflection the load is increased to the maximum load and starts decreasing at a deflection of 6.11mm. For deep beam-5 (DB-5)the first diagonal crack starts propagating and as the load increases to maximum 756kN, the observed deflection is 5.12mm and the last specimen is deep beam-6 (DB-6), the maximum load obtained is 580kN, where the deflection is 1.26mm. The overall response of the six specimens failed in shear.

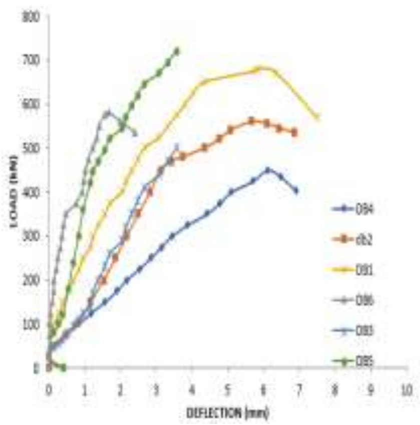

Fig. 3: load Vs deflection for span to depth ratio 1.91

Table VI: Details and properties of tested beams

S.no	Specimen	Length	Depth	Thickness	l/d	First flexural cracking load(kN)	First diagonal cracking load(kN)	Total failure load
1	DB-1	1200	600	200	1.91	372	500	680
2	DB-2	900	500	200	1.61	360	480	560
3	DB-3	1200	600	200	1.91	302	466	532
4	DB-4	900	500	200	1.61	101	260	430
5	DB-5	1200	600	200	1.91	460	620	756
6	DB-6	900	500	200	1.61	380	500	580

B. Crack Pattern and Failure Modes

The specimens under the various loading were obtained from the readings of the LVDT (Linear Variable Differential Transducer) and the load from cell will be recorded automatically. The crack pattern of DB-1 to DB-6 are shown in Fig.4, the cracks propagated (shear cracks) from supports to the loading point at 45°. In DB-1 the initial crack propagated at 372kN with 4.07mm deflection, the peak load observed is 680kN and the maximum crack width of 8mm was occurred. In DB-2 the initial crack was propagated at 360kN with 5.48mm deflection, the peak load observed is 560kN and the maximum crack width of 4mm was occurred. In DB-3 the initial crack propagated at 302kN with 5.11mm deflection, the peak load observed is 532kN and the maximum crack width of mm was occurred. In DB-4 the initial crack was propagated at 101kN with a deflection of 6.11mm, the peak load observed is 430kN and maximum crack width of 8.8mm was occurred. In DB-5 the initial crack propagated at 460kN with 5.12mm deflection, the peak load observed is 756kN and maximum crack width of 2.2mm was occurred. In DB-6 the initial crack propagated at 380kN with 1.26mm deflection, the peak load observed is 580kN and maximum crack width of 2mm was occurred. The cracks were the Shear cracks, which were propagated from the supports to the loading point. (Fig. 4 & Fig. 5)

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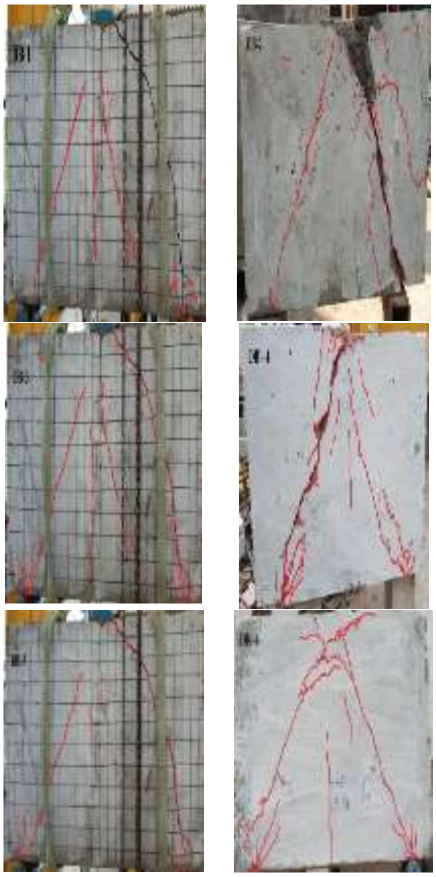

Fig. 4: Crack pattern of DB-1, DB-2, DB-3, DB-4, DB-5, DB-6

C. Flexural Failure in Deep Beams

In the above tested beams flexural cracks are found that occurs at the mid span of the section, and they appear if tension stress exceeds tensile strength of concrete. Due to the effect of horizontal stress in pure bending zone the cracks are vertical. Diagonal cracking load to ultimate load of total six deep beams and the flexural is in Table VI.

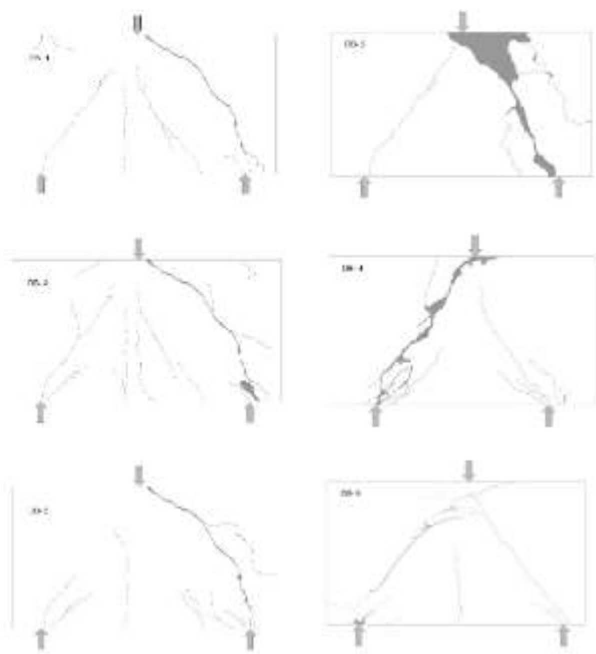

Fig. 5: Digitalized crack pattern

D. Shear Failure in Deep Beams

In deep beams the mechanism of transferring load leads to the type of shear failure that is most common in deep beams. The deep beams fail by widening of diagonal shear cracks and crushing of concrete. From the Table VI it has been found that the diagonal and shear cracks appear between 680kN and 700kN of failure load which are observed at supports and load points. Shear cracks depends on concrete compressive strength.

E. Local Failure of Deep Beams

In Fig. 5 it has been observed that local failure is at supports and load points, which happened due to occurrence of high compressive strength at the area around the supports and loading face. DB3 and DB4 beams failure happens at 480kN. Two diagonal cracks and crushing of concrete by widening at support point as shown in fig: 5.Same type of failure is also observed in DB1 and DB3. By using bearing plates, where the high compressive strength is distributed over an area i.e. at supports and load points this failure mode could be overcome. The occurred failure is desirable where stress exceeds allowable compression stress of concrete and can be called as premature failure.

F. Compression Failure of Deep Beams

In deep beams the failure mode is expanded in compression zone, as the compression zone strain exceeds the ultimate strain. This phenomenon is due to the occurrence of yield of all steel reinforcement before the compression failure which is according to plastic theory. Tensile reinforcement failure capacity is higher when compared to compression area. After the formation of critical diagonal crack, as the load increases crack opening is also increasing. This is in the case of shear compression failure.

G. Serviceability of Deep Beams

In this present study serviceability of deep beams are studied only in terms of deflections. Section depth of beam is directly proportional to the stiffness of the beam which results in brittle failure. The variation of load and deflection of tested deep beams are shown in Fig. 3. The brittle failure decreases ductility of elements and the structural elements strength decreases below the flexural capacity. Serviceability criteria for minimum web reinforcement ensures ductile failure under the reference of IS 456-2000. The behavior of deep beams is mainly affected by the strength of tensile reinforcement. Generally under reinforced beams fail due to flexural cracks rather than diagonal cracks. In the case of under reinforced section, beam fails due to flexural cracks only there are no diagonal cracks. In DB1until the failure point only four cracks appeared, but where as in DB3 the cracks appeared were more than 16.Diagonal cracks are wider than flexural cracks which concludes that shear failure is the important parameter that majorly effect the performance of deep beams.

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VI. CONCLUSION

The following conclusions were drawn based on the experimental results.

- The load carrying capacity of DB-5&DB-6 is higher than conventional deep beams (DB-1&DB-2).
- The failure crack pattern is not similar for DB-1&DB-2 to those of DB-3&DB-4.
- The use of adding Nuts & bolts to the provided reinforcement shear strength increases when compared to conventional deep beams.
- The Stresses developed in DB-5&DB-6 is higher which indicates the load bearing capacity is high and strains developed at maximum stress in DB-5&DB-6 is lesser i.e. deflection is less.
- The Shear strength of DB-5&DB-6 is higher i.e. the ability to withstand the effect of imposed load is higher for DB-5&DB-6.

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