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Analysis and Design of R.C. Deep Beams Using Code Provisions of Different Countries and Their Comparison

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Abstract : This paper describes analysis and design of deep beams subjected to two equal point loads acting 1/3/rd of span with different L/D ratios and codes referred were INDIAN.STANDERD CODE (I.S.-456-2000), NEWZEALAND (NDS-3101-2006),CANADIAN(CSA-A23.3-2004.),CIRIA GUIDE-2(1977) and APPENDIX-A of ACI -318 {STRUT and TIE METHOD) for design purpose. The parameters obsevered were Lever Arm, Theoretical steel required and strength of deep beam.

Key words: Deep Beam, Finite,strength, code provisions, Design.

I. INTRODUCTION

Beams with large depths in relation to spans are called deep beams. As per IS-456 (2000) Clause 29, a simply supported beam is classified as deep when the ratio of its effective span L to overall depth D is less than 2. Continuous beams are considered as deep when the ratio L/D 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.

As per New Zealand Code, Deep Beams are members loaded on one face & supported on the opposite face, so that compression struts can develop between the loads & supports,& have either; clear span , Ln equal to or less than 3.6 times the effective depth for simply supported or continuous beams ,clear span equal or less than 1.6 times the effective depth for cantilever beams.

The Canadian code (CSA-A23.3-2004.) defines deep beam as a beam in which the ratio of the clear span (l_0) to the overall depth (h) is less than the limits given below.

For Simple spans : $l_0 / h < 1.25$,

For Continuous spans: $l_0 / h < 2.5$

The CIRIA Guide applies to beams having an effective span/ depth ratio (l/h) of less than 2 for single-span beams and less than 2.5 for continuous beams.

As per APPENDIX-A of ACI-318 (Strut and tie Method) code provisions the deep beam is defined as the ratio of effective span to depth is less than or equal to four.

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II. OBJECTIVE OF STUDIES

The main objective of this investigation is to The main objective of this investigation was to conduct an experimental study on strength & behavior of deep beams. To study the variations in the deep beams designed by using codes of different countries such as IS 456:2000, (NDS-3101-2006), CIRIA GUIDE-2, APPENDIX –A of ACI-318-2005(STRUT AND TIE METHOD) and CSA-A23.3-2004.

1. The objectives of the experimental investigation can be listed as follows.
2. To observe & explain the cracking & failure modes of deep beams subjected to two points load.
3. To compare the flexural steel requirement and deflections as per different code provisions.

To arrive at the most realistic code to be used for design of deep beam.

III. EXPERIMENTAL INVESTIGATION

1. The experimental investigation was carried out to find out the strength, cracking pattern and behavior of the deep beam under the two point loads and for various L/D ratios such as 1.71, 1.6 and 1.5. For each L/D ratios three specimen beams were cast and testing of these deep beams was carried out in the Heavy Structure Laboratory. The experimental set up was as shown in Fig.1.
2. The dimensions of the deep beam designed by CIRIA GUIDE-2 was L=700 mm, D=4000 mm. B=150 mm and the two point loading is applied to the given beam. Two point loads of 50 KN were applied on the beam. The initial cracking was observed at 180 KN load at point of support of bearing at top, and the cracking pattern was observed in the middle and diagonal portion of the beam aftert250 KN. After that application of loading was stopped where the maximum cracks were observed at 315 KN. The cracking pattern of the deep beam was observed is as shown in Fig.2

Fig.1 EXPERIMENTAL SET UP

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Fig .2 CIRIA GUIDE -2

The beam was designed by IS-456-2000 code provisions having dimensions L=700 mm, D=4000 mm. B=150 mm and the two point loading were applied to the given beam Two point loads of 50 KN were applied on the beam. The initial cracking was observed at 200 KN load at point of support of bearing at top and the maximum cracking pattern was observed in the middle and diagonal portion of the beam after 250 KN. After that application of loading was stopped at 335KN. The cracking pattern of the deep beam was observed is as shown in Fig.3

The beam was designed by NEWZEALAND CODE having dimensions L=700 mm, D=400 mm. B=150 mm and the two point loading were applied to the given beam. Two point loads of 50 KN were applied on the beam. The initial cracking was observed at 180 KN at the point of support of bearing, and the cracking pattern was observed in the middle and diagonal portion of the beam at 300 KN. After that application of loading was stopped at 440KN where maximum crack pattern was observed. The cracking pattern of the deep beam was observed is as shown in Fig.4.

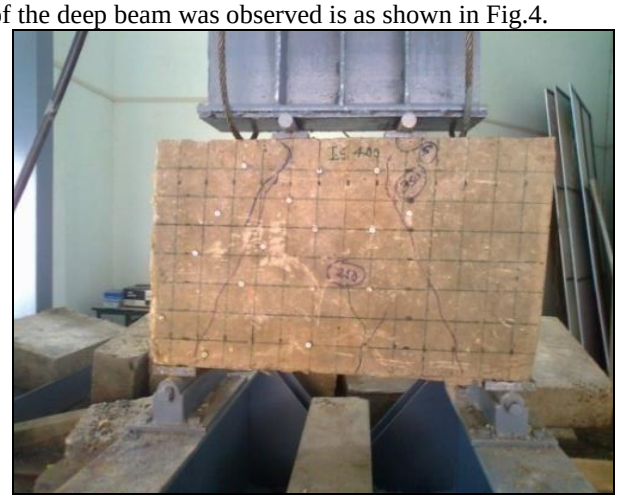

Fig. 3 IS-456-2000

Fig.4 NEWZEALAND CODE

The beam was designed by Appendix A of ACI-318 (STRUT AND TIE METHOD) having dimensions L=700 mm, D=400 mm. B=150 mm and the two point loading was applied to the given beam. Two point loads of 50 KN were applied on the beam. The initial cracking was observed at 230 KN at the point of support of bearing, and the cracking pattern was observed in the middle and diagonal portion of the beam at 300 KN. After that application of loading was stopped at 430 KN where maximum crack pattern was observed. The cracking pattern of the deep beam was observed is as shown in Fig.5.

The beam was designed by CANADIAN CODE having dimensions L=700 mm, D=400 mm. B=150 mm and the two point loading was applied to the given beam. Two point loads of 50 KN were applied on the beam. The initial cracking was observed at 170 KN at the point of support of bearing, and the cracking pattern was observed in the middle and diagonal portion of the beam at 300 KN. After that application of loading was stopped at 360 KN where maximum crack pattern was observed. The cracking pattern of the deep beam was observed is as shown in Fig.6.

Fig.5 STRUT AND TIE METHOD

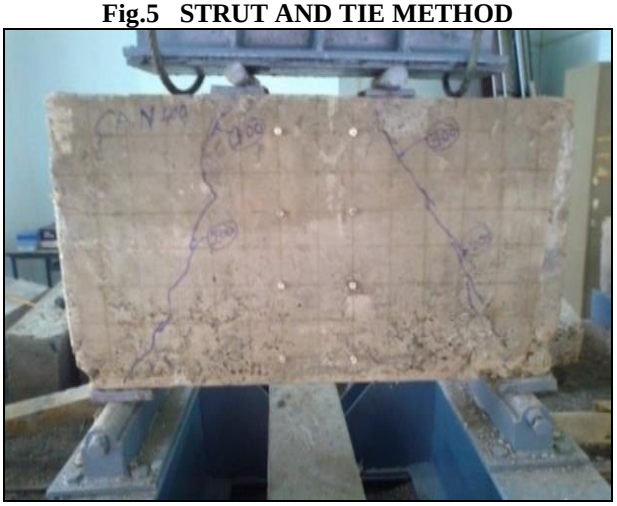

Fig.6 CANADIAN CODE

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1.4.5 PERCENTAGE INCREASE IN STRENGTH AT MAXIMUM CRACKS:

DESIGN METHOD / L/D RATIO	STM	NDS	CSA	CIRIA	IS 456	PERCENTAGE INCREASE IN STRENGTH OF STM WITH RESPECT TO			
						NDS	CSA	CIRIA	IS 456
1.71	385	350	320	330	250	9.90	20.31	16.66	35.06
1.71	365	335	315	310	275	8.90	15.87	17.75	32.72
1.71	375	330	320	325	250	13.63	17.18	15.38	33.34
1.6	410	370	330	315	300	10.81	19.51	24.15	26.83
1.6	390	360	340	315	320	8.34	14.70	23.80	21.87
1.6	400	370	335	320	325	8.10	19.40	25.00	23.07
1.5	440	380	350	300	400	15.78	20.72	35.66	9.09
1.5	420	350	360	310	380	12.00	21.66	35.48	10.52
1.5	430	375	355	305	380	14.66	21.12	38.98	13.15

1.4.2 CODE COMPARISION IN CASE OF EACH COUNTRY CODE:

DESIGN METHOD	L/D RATIO	IS	NDS'	CSA	CIRIA GUIDE-2	ACI-318 (STM)
FLEXURAL STEEL (MM^2)	1.71	129.52	140	139.86	85.14	140
	1.6	124.93	132	131.28	82.10	132
	1.5	120.64	121	120.00	79.27	121
REINFORCRMENT HORIZONTAL (MM^2) VERTICAL (MM^2)	1.71	105 63	67.5 112.5	90 90	131.25	68 113
HORIZONTAL (MM^2) VERTICAL (MM^2)	1.6	112.50 67.5	67.5 112.5	90 \90	131.25	68 113
HORIZONTAL (MM^2) VERTICAL (MM^2)	1.5	108 64.8	67.5 112.5	90 90	131.25	68 113
LOAD AT FIRST CRACK (KN)	1.71	225	130	130	160	180
	1.6	200	140	145	170	190
	1.5	175	180	170	190	230
LOAD AT MAX CRACK(KN)	1.71	290	390	320	325	380
	1.6	335	400	340	315	400
	1.5	350	440	360	300	430

1.4.3 PERCENTAGE INCREASE IN FLEXURAL STEEL

L/D RATIO	PERCENTAGE INCREASE IN FLEXURAL STEEL OF STRUT & TIE METHOD WITH RESPECT TO OTHER			
	CSA	NDS	CIRIA	IS-456
1.71	0.10	0.10	39.18	8.09
1.6	0.55	0.55	37.80	5.65
1.5	0.85	0.85	34.48	2.98

From the experimental investigation the percentage increase in strength of the beam at first crack load and at the load of maximum cracks were observed this variation of the strength is shown in the table below.

1.4.4 PERCENTAGEINCREASE IN STRENGTH AT FIRST CRACK:

DESIGN METHOD → / L/D RATIO	STM	NDS	CSA	CIRIA	IS 456	PERCENTAGE INCREASE IN STRENGTH OF STM WITH RESPECT TO			
						NDS	CSA	CIRIA	IS 456
1.71	180	120	130	170	175	33.33	27.77	9.55	2.77
1.71	160	110	110	145	150	31.25	31.25	9.37	6.25
1.71	190	130	130	160	180	31.57	27.77	11.11	5.26
1.6	210	140	125	190	200	33.33	27.47	9.52	4.76
1.6	190	130	140	170	180	31.57	26.31	10.52	5.26
1.6	180	125	145	155	170	30.55	25.44	13.88	5.55
1.5	230	180	170	170	225	21.74	26.08	11.08	2.17
1.5	200	150	145	180	190	25.00	27.50	10.00	5.00
1.5	235	160	155	220	225	31.92	27.04	9.38	4.25

1.4.5 PERCENTAGE INCREASE IN STRENGTH AT MAXIMUM CRACKS:

DESIGN METHOD / L/D RATIO	STM	NDS	CSA	CIRIA	IS 456	PERCENTAGE INCREASE IN STRENGTH OF STM WITH RESPECT TO			
						NDS	CSA	CIRIA	IS 456
1.71	385	350	320	330	250	9.90	20.31	16.66	35.06
1.71	365	335	315	310	275	8.90	15.87	17.75	32.72
1.71	375	330	320	325	250	13.63	17.18	15.38	33.34
1.6	410	370	330	315	300	10.81	19.51	24.15	26.83
1.6	390	360	340	315	320	8.34	14.70	23.80	21.87
1.6	400	370	335	320	325	8.10	19.40	25.00	23.07
1.5	440	380	350	300	400	15.78	20.72	35.66	9.09
1.5	420	350	360	310	380	12.00	21.66	35.48	10.52
1.5	430	375	355	305	380	14.66	21.12	38.98	13.15

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IV. CONCLUSIONS

1. STEEL:

As per the code provisions of different countries it was observed that, As L/D ratio decreases there is an increase in the flexural steel of the deep beams has been observed, L/D ratio is inversely proportional to flexural steel of the beam.

For L/D ratio 1.71 there is an average 0.10 % increase in steel in STRUT AND TIE method with respect to CANADIAN code, 0.10% increase in NEWZELAND code, 39.18%increase in steel with respect to CIRIA GUIDE -2 (1977) code, 8.09%increase in steel with respect to IS 456-2000 code.

For L/D ratio 1.6 there is an average 0.55%increase in steel in STRUT AND TIE method of ACI-318 code with respect to CANADIAN code, O.55% increase in NEWZELAND code, 37.80%increase in steel with respect to CIRIA GUIDE -2(1977) code, 5.65%increase in steel with respect to IS 456-2000 code.

For L/D ratio 1.5 there is an average 0.85% increase in steel in STRUT AND TIE method of ACI-318 code with respect to NEWZEALAND code,0.85%increase in steel with respect to CANADIAN code, 34.48%increase in steel with respect to CIRIA GUIDE -2(1977) code, 2.98%increase in steel with respect to IS 456-2000 code.

Strut-and-tie model is a good approach to design. It is a simple approach but provisions against web cracking are not clearly given in this method. Though it is a conservative method, the area of steel calculated using the STRUT AND TIE method of the NEWZEALAND code provisions is nearly equal to that required as per IS456:2000, but it is more for CANADIAN and CIRIA GUIDE-2 (1977) code recommendations.

2. STRENGTH:

The load observed at maximum cracks:

As L/D ratio decreases there is an increase in the strength of the deep beams has been observed, the L/D ratio is inversely proportional to strength of the beam For L/D ratio 1.71 there is an average 10.81% increase in strength of the Deep beam designed as per the provisions given and the method used is Strut and Tie in ACI-318 code with respect to NEWZEALAND code, 17.78%increase in strength with respect to CANADIAN code, 16.60 % increase in strength with respect to CIRIA GUIDE -2 (1977) code, 33.70 % increase in strength.

For L/D ratio 1.6 there is an average 9.08 % increase in strength of the Deep Beam designed as per the provisions given and the method used is Strut and Tie of ACI-318 code with respect to NEWZEALAND code, 17.87 % increase in strength with respect to CANADIAN code, 24.32% increase in strength with respect to CIRIA GUIDE -2 (1977) code, 23.93 % increase in strength with respect to IS 456-2000 code at the point of maximum crack load.

For L/D ratio 1.5 there is an average 14.12 % increase in strength of the Deep Beam designed as per the provisions given and the method used is Strut and Tie of ACI-318 code with respect to NEWZEALAND code, 21.16 % increase in strength with respect to CANADIAN code, 36.70 % increase in strength with respect to CIRIA GUIDE -2 (1977) code, 10.92 % increase in strength with respect to IS 456-2000 code at the point of maximum crack load.

3. VERTICAL STEEL:

It was observed that the vertical steel required in the deep beam as per the provisions given in APPENDIX-A OF ACI-318 (Strut and Tie method) is more by 50 % in the NEWZEALAND code, 62.5 % more in the CANADIAN, 62.5 % in the CIRIA GUIDE-2 (1977) and 50 % in the IS 456-2000 code provisions.

4. LEVER ARM:

From the study of the different codes it was observed that as the L/D ratio increases the lever arm decreases.

From the code provisions and the study of the various codes the Strut and Tie method given by the ACI-318 code is suitable for the design of Reinforced Concrete Deep beam.

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