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Shear strength prediction of Non Flexural RC Deep Beams using various Approaches.

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ABSTRACT *— In this study, shear behavior of RC non flexural deep beams which are predominant in shear were studied. According to ACI 318-08(1), deep beams are classified as shear span to depth (a/d) ratio less than 2.5, shear capacity of deep beam was worked out by ACI 318 equation 11.30 and 11.31 and results were compared with modified ACI equation by Tan et al(2). Strut and tie approach is also used which are suggested by many codes like ACI 318 (appendix A) and Euro code 2(3). Shear capacity found from STM analysis was compared with ACI 318 equation and modified ACI equation. Parameters considered for the study are a/d ratio ranging from 0.5 to 1 and compressive strength of concrete (25MPa, 50Mpa), shear reinforcement varied between 0 to 0.17%. It is seen from the analysis that both ACI 318-99 and modified ACI equation does not consider the effect of shear span to depth (a/d) ratio and STM approach was found much rational.*

Keywords— Strut and tie method, Deep beams, ACI 318.

1, INTRODUCTION

Reinforced concrete deep beams are commonly used in high rise buildings, offshore structures and complex foundation systems. Deep beams are more predominant in shear rather than flexure. This shear action in the beam leads to complex stresses, compression in a diagonal direction and tension in a perpendicular direction. An arch action is usually seen as the force transferring mechanism of deep beams, failure is seen as web compression failure or shear tension failure Shear strength of deep beams depends on various parameters like compressive strength of concrete, shear reinforcement, shear span to depth ratio. ACI 318-99 Code suggests design criterion for the shear strength of deep beams is known to be conservative with a large safety margin. In ACI Eq. (11-29), it is assumed that diagonal cracking occurs at the same shear strength as for slender beams, but that the shear strength of the concrete is greater than the shear force causing diagonal cracking. This paper also presents a strut and tie approach of determining shear behavior of deep beams, strut and tie method is rational and unified approach which represents complex behavior of beams into simple truss model which is applicable where Bernoulli-Euler beam theory is not valid, generally termed as disturbed region (D-regions) in which non-linear strain variation is observed . STM is very popular in designing of Corbels, complex foundations, beam-column joint. Provisions for the design of deep beams using a strut-and-tie model have been included in several codes and guidelines for practice, including AASHTO LRFD, ACI 318 (APPENDIX A), Euro Code 2 and the Canadian code.

2, SELECTION OF DEEP BEAM SPECIMENS

16 deep beam specimens are studied in the midst of various factors which are influencing the shear behavior of beam are low and high compressive strength of concrete (25 MPa and 50 Mpa), shear span to depth (a/d) ratio (0.5 to 1), and shear reinforcement ratio (0 to 0.017). Four specimens (B1 to B4) with a/d ratio 0.5 and compressive strength 25 MPa and varying shear reinforcement are selected (Table 1). In B1 specimen shear reinforcement is kept nil, on the other hand Specimen B2 is unreinforced in horizontal direction and vertically reinforced and B4 is reinforced in both direction. In addition to its variation in shear reinforcement, a/d ratio is changed keeping compressive strength of concrete ($f_c^{'}$) constant and $f_c^{'}$ is changed maintaining a/d ratio constant. Fig. 1 shows typical deep beam specimen.

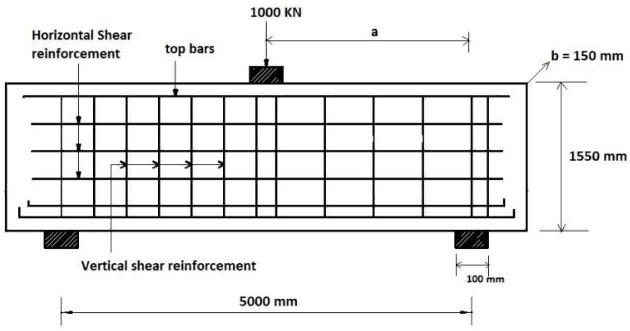

Fig. 1 Typical Deep beam

3, ACI 318-99

ACI 318-99 recommended shear strength prediction of both concrete and steel reinforcement separately. These design equations are applicable to beams with *ln*/*d* less than 5 or a/d less than 2.5, The shear design at the critical section (at distance *a*/2 from the support) is based on:

$$V_c = \left(3.5 - 2.5\frac{M_u}{V_u d}\right)\left(1.9\sqrt{f^{'}_c} + 2500\rho_w \frac{V_u d}{M_u}\right) b_w d \qquad \text{Equation (i)}$$

$$V_s = \left[\frac{A_v}{s}\left(\frac{1 + \frac{l_n}{d}}{12}\right) + \frac{A_{vh}}{s_2}\left(\frac{11 - \frac{l_n}{d}}{12}\right)\right] f_y d \qquad \text{Equation (ii)}$$

The shear strength of concrete is calculated by equation (i), a factor $\left(3.5 - 2.5 M_u / V_u d\right)$ is multiplied for consideration of shear-strength reserve of deep beams after diagonal cracking has occurred, this factor shall not exceed 2.5. ACI code restricts V_c value to $6\sqrt{f_c^{'}}bd$. In ACI Eq. (11-31), the coefficients in parenthesis are weighting factors for the relative effectiveness of the vertical and horizontal web steel. At *ln* /*d* = 5, vertical and horizontal web steel are taken to be equally effective, i.e. the vertical web steel contribution V_{sv} is equal to the horizontal web steel contribution V_{sh} provided A_v/s is equal to A_{vh}/s_2 (2).

4, MODIFIED ACI 318-99 EQUATION (2)

ACI predictions are conservative for a/d = 0.75; the conservatism disappears for higher a/d Thus, it is realized that the favorable effect of horizontal web steel is overestimated by the current ACI Code. The reason for the inconsistency is that in ACI 318-99 Eq. (11-31) for web steel contribution, the threshold for ln/d at which both horizontal and vertical web steel are equally effective, is probably unrealistic. By modifying the threshold ln/d from 5 to 2.50 (thereby reducing the weighting factor from 11 to 6 for V_{sh}), a more consistent result is obtained. The proposed revision for Eq. (11-31) is as follows

$$V_s = \left[\frac{A_v}{s}\left(\frac{1+l_n/d}{12}\right)+\frac{A_{vh}}{s_2}\left(\frac{6-l_n/d}{12}\right)\right] f_y d \qquad \text{Equation (iii)}$$

5, STRUT AND TIE APPROACH

5.1 ACI 318-08

Strut and tie method is a geometrical approach. American Concrete Institute (ACI) Committee 318 introduced the strut-and-tie modelling (STM) method in its Building Code for structural concrete, ACI 318, in the year 2002 as Appendix-A, which subsequently underwent minor revisions in the 2005 and 2008 versions.. In Appendix-A of ACI 318-08, the nominal compressive strength of a strut is expressed as the product of the effective concrete strength (i.e., the crushing strength of concrete in the strut) and the least cross-sectional area of the strut.

$$F_{ns} = f_{ce} A_{cs} \qquad \text{[Eq. (A-2), ACI 318-08 Appendix-A]}$$

Where

F_{ns} : Nominal compressive strength of a strut without longitudinal reinforcement, A_{cs} : lesser of the cross-sectional areas at the two ends of a strut, f_{ce} : Least value of the effective strength of concrete from among the effective compressive strength of concrete within the strut proper and those within the two bounding nodes. The effective compressive strength of concrete within the strut proper is calculated in terms of the specified cylinder compressive strength of concrete, $f_c^{'}$, as per Sec. A.3.2 of the ACI Code as

$$f_{ce} = 0.85 \beta_s f_c^{'} \qquad \text{[Eq. (A-3), ACI 318-08 Appendix-A]}$$

Where β_s is the efficiency factor of the strut and $f_c^{'}$ is the cylinder compressive strength of concrete. The effective compressive strength of concrete within any of the two nodal zones bounding the strut is calculated in terms of the specified cylinder compressive strength of concrete, $f_c^{'}$, as per Sec. A.5.2 of the ACI Code. Fig.2 shows typical strut and tie geometry of deep beam. Ws is the width of strut is calculated by $Ws = l_b \sin\alpha + t_w \cos\alpha$, l_b is length of bearing plate, t_w is tie width and s_w is top strut width.

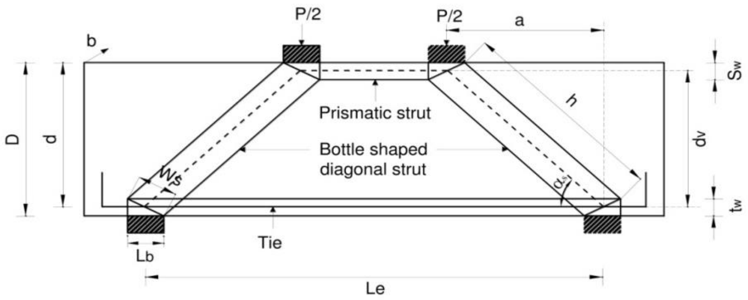

Fig.2. Typical Strut and Tie model of a deep Beam.

5.2 Euro Code 2

The nominal strength of strut as per Euro code 2 can be written as

$$F_{ns} = \sigma_{Rd,\max 3} A_{cs} = 0.6 \nu^{'} f_{cd} A_{cs} = 0.6\left(1 - \frac{f_{ck}}{250}\right) f_{cd} A_{cs}$$ Equation(iv)

VI. RESULTS AND DISCUSSION

Comparative results of shear capacity of deep beams found from various approaches are shown in table 1. A study on shear capacity of deep beams was conducted. It was shown that shear capacity calculated by ACI 318 equation 11.30 and 11.31 overestimates as ACI 318 equation considers equal effect of both horizontal and vertical shear reinforcement, modified equation is derived by considering the effect of shear reinforcement as individual entity. Fig. 3 shows the shear strength values predicted by various approaches for all 16 deep beams specimens. Strut and tie suggested by ACI 318 (Appendix A) was found rational as it considers effect of shear span to depth (a/d) ratio, shear reinforcement, compressive strength of concrete. Strut efficiency factor in ACI 318 Appendix A are merely numerical values (0.6 and 0.75) which depends only on transverse reinforcement. Strut efficiency factor suggested by EC2 is depends on compressive strength. Strut efficiency factor is foremost factor which influences the strut behaviour in STM approach which is direct indicator of behaviour of beam.

Transverse reinforcement

Effect of transverse reinforcement on shear capacity beam is shown in fig.4, ACI 318 and modified ACI equation does not allow zero shear reinforcement. It was clearly seen that shear capacity increases with increase in shear reinforcement, whereas STM approach predicts shear strength of beam with no shear reinforcement but value remains constant for same a/d ratio and same compressive strength of concrete up to minimum shear reinforcement is provided as suggested by codes. Vu found from STM are constant (fig.4) for given a/d ratio and compressive strength of concrete which indicates further research is obligatory with considering effect of various other factors which influences the shear behaviour of non flexural deep beams.

Table 1. Properties of Beam specimens and summary of test results

Beam ID	a/d	f'c(Mpa)	ρ_v	ρ_h	ρ_T	Vu,(ACI 318)	Modified ACI 318 Eq.	Vu, ACI (Appendix A)	Vu,EC2
B1	0.50	25.00	0.0000	0.0000	0.0000	-*	-*	605	565
B2	0.50	25.00	0.0017	0.0000	0.0017	911	911	605	565
B3	0.50	25.00	0.0000	0.0017	0.0017	698	515	605	565
B5	0.50	25.00	0.0017	0.0017	0.0034	1130	947	605	565
B6	0.50	50.00	0.0000	0.0000	0.0000	-	-	1211	1050
B7	0.50	50.00	0.0017	0.0000	0.0017	1024	1024	1211	1050
B8	0.50	50.00	0.0000	0.0017	0.0017	811	628	1211	1050
B9	0.50	50.00	0.0017	0.0017	0.0034	1243	1060	1211	1050
B11	1.00	25.00	0.0000	0.0000	0.0000	-	-	404	377
B12	1.00	25.00	0.0017	0.0000	0.0017	911	911	404	377
B13	1.00	25.00	0.0000	0.0017	0.0017	698	515	404	377
B14	1.00	25.00	0.0017	0.0017	0.0034	1130	947	404	377
B17	1.00	50.00	0.0000	0.0000	0.0000	-	-	807	700
B18	1.00	50.00	0.0017	0.0000	0.0017	1024	1024	807	700
B19	1.00	50.00	0.0000	0.0017	0.0017	811	628	807	700
B20	1.00	50.00	0.0017	0.0034	0.0051	1243	1060	1009	700

* out of scope of ACI 318

Shear span depth (a/d) ratio

Fig.5 shows the effect of shear span depth (a/d) ratio, it was proved that shear capacity of beam decreases as a/d ratio increases. ACI Appendix A predicts higher value than EC2 whereas both give similar trend line.

Influence of compressive strength of concrete

Compressive strength of concrete have greater influence on capacity of beam, it is evident that higher the compressive strength higher the capacity of beam. Fig.6 shows relation between compressive strength of concrete and shear strength of beam. All four approaches demonstrate an increase in shear capacity with increase in compressive strength of concrete.

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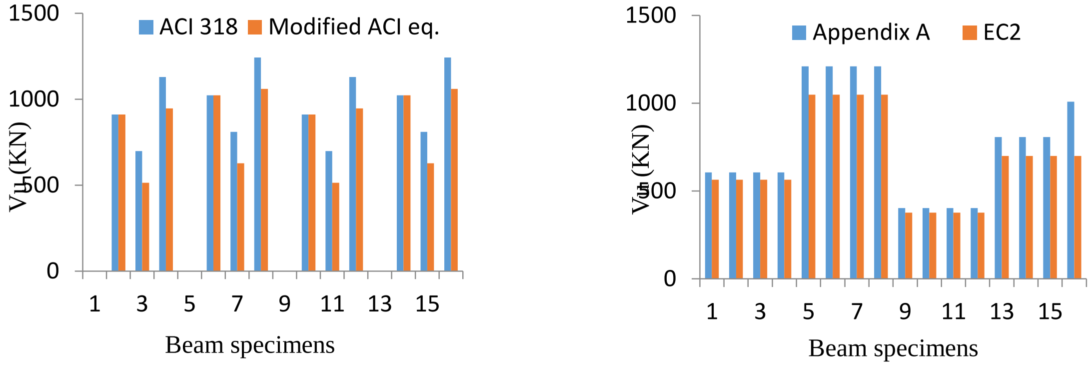

Fig.3 Bar chart of shear strength of deep beams

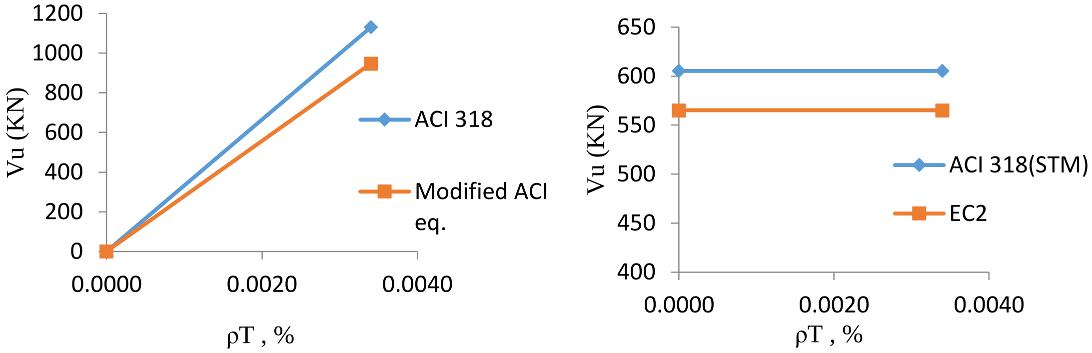

Fig.4 Effect of transverse reinforcement ratio on shear capacity beams.

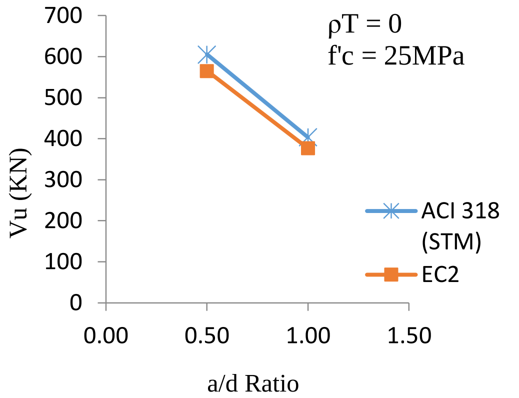

Fig.5

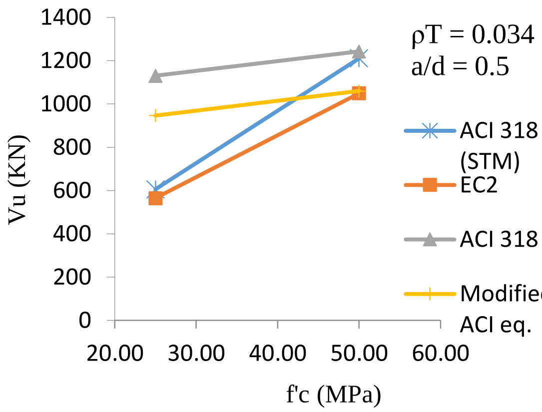

Fig.6

VII. CONCLUSIONS

1) It is evident from this research; web reinforcement (shear reinforcement) plays a significant role in non flexural deep beams. The ACI 318 code overestimates the contribution of web reinforcement, with appropriate revision to the ACI 318 equation; the conservatism of the predictions is maintained.

2) Compressive strength of concrete increases the shear capacity of beam but surely may not be increases the efficiency.

3) STM approach is rational method found from past various researches though it takes in to consideration influencing factors diversely, more research need to be done since STM gives freedom to designer to choose their own strut and tie model geometry as there is no unanimity in the selection of STM.

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BIOGRAPHIES

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