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Parametric study on the shear strength of concrete deep beam using ANSYS

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Abstract: - This paper deals with the comparison of shear strength of a concrete deep beam predicted using the models proposed by IS code, ACI code and ANSYS software with the corresponding experimental shear strength of the concrete deep beam published in the literature. This paper also deals with the influence of various parameters on the shear strength of concrete deep beams. The parameters considered are shear span to depth ratio, percentage of steel and cube compressive strength of concrete beam. The magnitude of shear span to depth ratio considered is 0.50 to 1.00. The percentage of steel is varied from 1 to 4 percent. The characteristic compressive strength of concrete is varied from 25MPa to 100MPa. The parametric study on the shear strength of concrete deep beams is carried out using the models proposed by IS code and ANSYS software. The results of the study give an insight to the range for the magnitude of the various parameters to be considered for the optimum performance of various structural systems.

Keywords: **-** *Shear, deep beams, concrete, longitudinal reinforcement*

I. INTRODUCTION

Beams having larger depth are known as deep beams. Such beams are used as the wall of the water tanks, bunkers and also used as load distributing structural elements such as transfer girders, pile caps, foundation walls and in offshore structures. According to IS: 456 (2000), a simply supported concrete beam having effective span less than 2.0 times the overall depth is considered as a deep beam. Deep beams are structural elements, in which significant amount of load is transferred to the supports by a compression strut joining the load and the reaction. Due to the small value of span-to-depth ratio, the failure of deep beams is controlled by shear rather than flexure. The basic assumption of the plane section assumed to remain plane after bending is not valid for deep beams. It has a nonlinear stress distribution along the depth of the beam.

The shear strength of concrete deep beams can be predicted by the models proposed by existing codes of practices namely, IS 456(2000), ACI 318 (2008), JSCE (2007), CSA (2004), BS 8110 and by the models proposed by various researchers, namely, Zsutty (1968), Mau and Hsu (1989), Matamoros and Wong (2000) and Park and Kuchma (2007) etc. The shear strength of concrete beams can also be predicted by numerical methods. In this paper, a concrete test beam subjected to two point loading published in literature (Thomas 2010) has been considered. The shear strength of test beam is predicted using the models proposed by IS:456 (2000), ACI 318 (2008) and by the numerical model proposed by ANSYS 12.0 software. The magnitude of predicted shear strength is compared with the corresponding experimental shear strength of the test beam.

The comparison is done to check the degree of accuracy of the application of ANSYS software for further parametric study. In this paper, the influence of various parameters, namely, shear span to depth ratio, percentage of steel, cube compressive strength of concrete beam on the shear strength of concrete deep beams have been reported. The parametric study is carried out using the models proposed by IS:456(2000) and ANSYS 12.0 software.

II. ANALYTICAL MODEL

In general, designers follow models proposed in the code of practices. In Indian standard code of practice IS:456 (2000) , deep beam is distinguished from shallow beam only in terms of flexural design. The design for shear resistance is considered as similar to that of shallow beam.

2.1 IS 456-2000 model

The enhancement in the shear stress for low values of shear span to depth ratio is accounted for the model proposed in IS 456 (2000). The total shear strength of the beam is computed by Eq. (1)

$$V_u = V_{uc} + V_{us} \qquad (1)$$

where, V_{uc} is the shear resistance of concrete and V_{us} is the shear resistance of vertical steel.

$$V_{c,c} = k_1 \; \tau_c bd \qquad (2)$$

where k_1 is the shear enhancement factor accounting for the arch action in beams. τ_c is the average permissible shear stress of concrete beam. b and d are the width and depth of the beam cross section. k_1 in Eq. (2) is given by

$$k_1 = \begin{cases} 2.0\, d/a & \text{when } a/d \le 2.0 \\ 1.0 & \text{when } a/d \ge 2.0 \end{cases} \qquad (3)$$

The factor k_1 accounts for the load sustenance by arch action. τ_c proposed by SP:24 (1983) is given by

$$\tau_c = \frac{0.85\sqrt{0.8 f_{ck}}\left(\sqrt{1+5\beta}-1\right)}{6\beta} \qquad (4)$$

where, f_{ck} is the characteristic compressive strength of concrete and is computed by

$$f_{ck} = \frac{f'_c}{0.8} \qquad (5)$$

where f'_c is the cylinder compressive strength of concrete. β in Eq. (4) is the factor accounting for the influence of the longitudinal reinforcement and is given by

$$\beta = \frac{0.8 f_{ck}}{k_0 \; p_t} > 1.0 \qquad (6)$$

where p_t is the longitudinal steel reinforcement ratio and k_0 is the coefficient of longitudinal reinforcement ratio and is given by 6.89. p_t is given by

$$p_t = \frac{100 A_s}{bd} \qquad (7)$$

where A_s is the area of steel longitudinal reinforcement.

$$V_{us} = (0.87 f_y A_{sv} d) / S_v \qquad (8)$$

where f_y is the characteristic strength of the vertical steel, A_{sv} is the total cross-section area of vertical steel with in a distance of S_v and S_v is the spacing of the vertical steel along the length of the member.

2.2 ACI 318 – 2008 Model

The shear strength of the beam is computed based on the strut-and-tie model. The beams with shear span to depth ratio 1.0 or below transfer shear force primarily through formation of the tied arch mechanism, where concrete diagonal struts form between the point of application of load and the supports. The total shear strength of the beam is computed by eq. (4) to (11). The shear strength of the concrete in a beam is the minimum of the following shear forces.

1. Face A_1 of the nodal zone above support plate (point A in fig.1)

$$V_{A1} = (0.80)\,(0.85)\, f'_c \, l_p b \qquad (9)$$

Where l_p is the width of the support plates

2. Face B_1 of the nodal zone under the bearing plate (Point B in fig.1)

$$V_{B1} = (0.85)\, f'_c \, l_b \, b \qquad (10)$$

Where l_b is the width of the bearing plates

3. Tie AD at the bottom

$V_{AD}=A_s f_{ys} tan\theta$ (11)

Where θ, for ACI code, is the angle between the inclined strut and horizontal direction.

4. Face A2 of the C-C-T nodal zone A(fig 1)

V_{A2}= (0.80) (0.85) $f'_c\, w_t b\ tan\theta$ (12)

Where, w_t is the effective tie width and is given by 2(h-d)

5. Strut BC and face B_2 of the C-C-C nodal zoneB

V_{B2} = (0.85)$f'_c\ d_a\ tan\theta$ (13)

Where, d_a is the depth of the top horizontal compression strut BC

6. Strut AB faces A_3 of the C-C-T nodal zone A

V_{A3}= (0.75) (0.85) $f'_c\ (l_p\, sin\theta + w_t\ cos\theta)\ bsin\theta$ (14)

7. Strut AB and face B_3 of the C-C-C nodal zone B(fig.1)

$V_{B3}= (0.75)\ (0.85) f'_c\ (l_b\ sin\theta + d_a cos\theta)\ b\ sin\theta$ (15)

The shear strength of concrete strut is computed as

$V_u = V_{strut/tie} = minimum\ (V_{A1}, V_{B1}, V_{AD}, V_{A2}, V_{B2}, V_{A3}, V_{B3})$ (16)

The model accounts for the influence of longitudinal reinforcements explicitly (Eq.11)

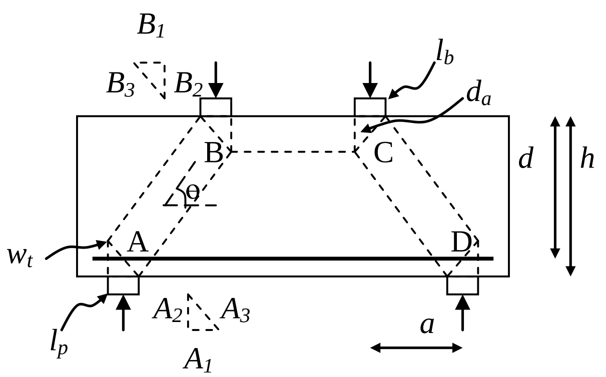

Fig. 1: Strut-and-tie model for deep beam

The influence of cracking and possible presence of transverse reinforcement is accounted for in the model by introducing a nodal stress factor or a member stress factor, whose magnitude varies between 0.75 and 1.0.

2.3 ANSYS software model

ANSYS is a finite element analysis (FEA) code widely used in the computer-aided engineering (CAE) field. ANSYS software allows engineers to construct computer models of structures, machine components or systems; apply operating loads and other design criteria; and study physical responses, such as stress levels, temperature distributions, pressure, etc. It permits an evaluation of a design without having to build and destroy multiple prototypes in testing.

The finite elements used in the modeling of the beam are link 8, solid 45 and solid 65.

2.3.1 LINK8

Link 8 is a spar which may be used in a variety of engineering applications. This element can be used to model trusses, sagging cables, links, springs, etc. The 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions. As in a pin-jointed structure, no bending of the element is considered. Plasticity, creep, swelling, stress stiffening, and large deflection capabilities are included. Link 8 element is used for modeling the reinforcement bars.

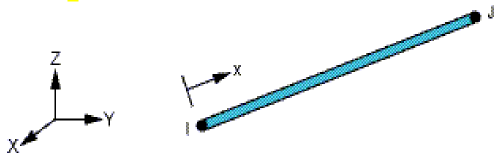

Fig.1. Geometry of LINK 8 element

2.3.2 SOLID 45

SOLID45 is used for the 3-D modeling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. A reduced integration option with hourglass control is available. Solid 45 elements is used for modeling the support blocks and the load blocks.

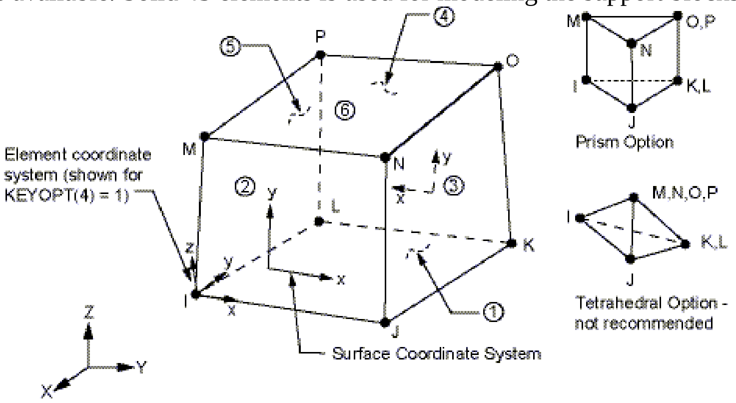

Fig.2. Geometry of SOLID 45 element

2.3.3 SOLID65

SOLID65 is used for the 3-D modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. Other cases for which the element is also applicable would be reinforced composites (such as fiberglass), and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Up to three different rebar specifications may be defined.

The concrete element is similar to the SOLID45 (3-D Structural Solid) element with the addition of special cracking and crushing capabilities. The most important aspect of this element is the treatment of nonlinear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep. The rebar are capable of tension and compression, but not shear. They are also capable of plastic deformation and creep. Solid 65 is used for modeling the concrete beam block.

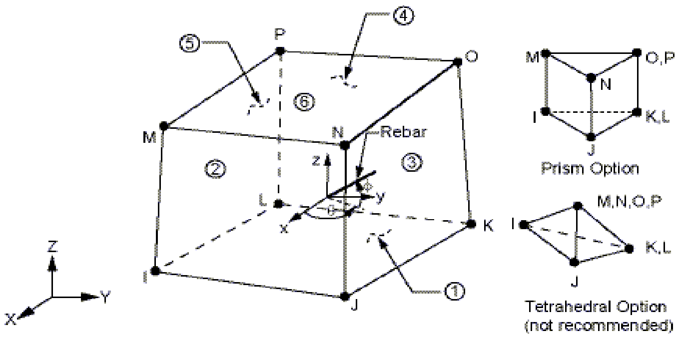

Fig.3. Geometry of SOLID 65 element

III. DETAILS OF BEAM FOR THE ANALYSIS

A concrete test beam of designation S0.3/0.5 published in the literature (Thomas 2010) has been considered in this study. The test beam has 170 mm wide and 500 mm overall depth The concrete cube compressive strength at the time of testing the beam is given by 44.0 MPa. The beam has three numbers of 10 mm diameter longitudinal bars at the tensile face of the beam. The beam has two numbers of 8 mm diameter longitudinal bars at the compression face of the beam. The ultimate tenslie strength of 8 mm diameter and the 10 mm diameter steel bars are given by 728 MPa and 683 MPa respectively. The beam has vertical shear stirrups of 8mm diameter at a spacing of 247 mm c/c. The overall length of the beam is 1590 mm. The span of the beam is given by 990 mm with an overhang of 300mm each on either side of the span. The effective depth of the beam is given by 416 mm. The shear span to depth ratio is 0.5. The schematic of cross section and reinforcement detailing of beams are given in Fig. 4. The experimental shear strength of the test beam reported in the literature is given by 250kN. The shear strength of test beam is predicted using the models proposed by IS:456 (2000), ACI 318 (2008) and by the numerical model proposed by ANSYS 12.0 software. The magnitude of predicted shear strength are compared with the corresponding experimental shear strength of the test beam and is given in Fig 5.

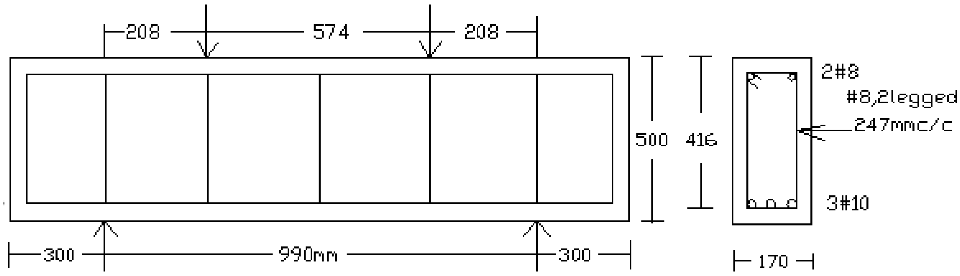

Fig.4. Details of Beam

The shear strength predicted using the model proposed by IS:456(2000) is found to be 90 percent of the corresponding experimental shear strength of the concrete test beam. The shear strength predicted using the model proposed by ACI 318 (2008) is found to be 81.4 percent of the corresponding experimental shear strength. The shear strength predicted using the model proposed by the numerical method using ANSYS 12.0 software is found to be 93.6 percent of the corresponding experimental shear strength of the concrete test beam. This indicates that the application of finite elements Link 8, Solid 45 and Solid 65 in ANSYS 12.0 software are found to be satisfactory in predicting the shear strength of concrete test beam. Hence in this paper, to study the influence of various parameters on the shear strength of concrete deep beams using ANSYS 12.0 software, these finite elements are used.

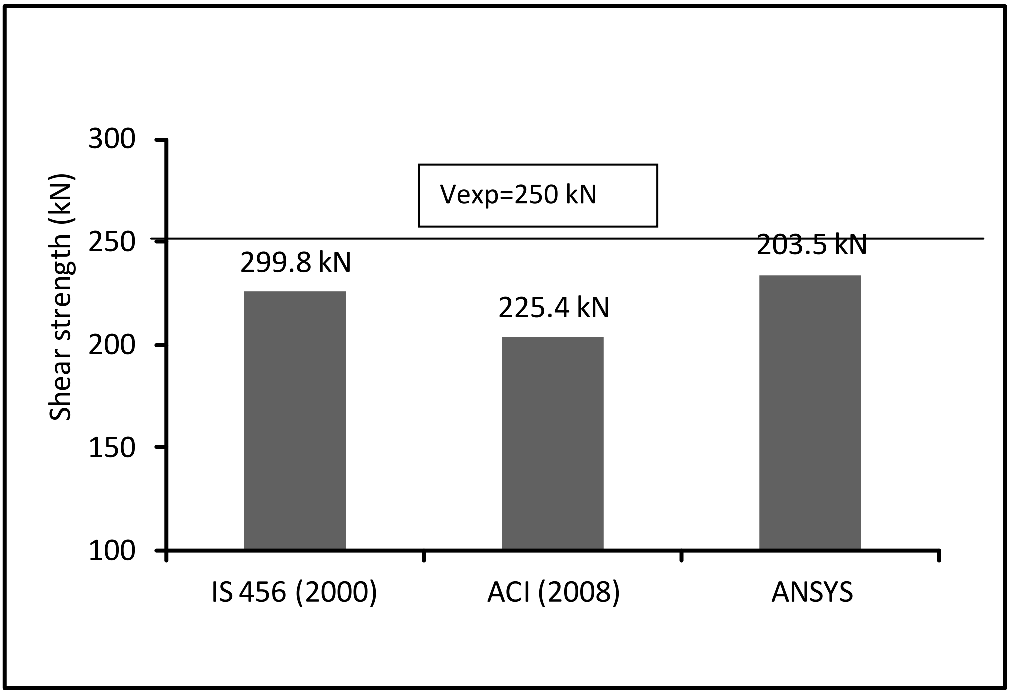

Fig 5.Predicted shear strength of test beam

IV. PARAMETRIC STUDY

The parametric study is carried out by assuming the typical concrete deep beam given in Fig.4. The beam has 170 mm wide and 500 mm overall depth . The beam has two numbers of 8 mm diameter longitudinal bars at the compression face of the beam. The beam has vertical shear stirrups of 8mm diameter at a spacing of 247 mm c/c. The overall length of the beam is 1590 mm. The span of the beam is given by 990 mm with an overhang of 300mm each on either side of the span. The effective depth of the beam is given by 416 mm.

The influence of various parameters, namely, shear span to depth ratio, percentage of steel and cube compressive strength of concrete beam on the shear strength of concrete deep beams have been reported. The magnitude of shear span to depth ratio considered is 0.50 to 1.00. The percentage of steel is varied from 1 to 4 percent. The characteristic compressive strength of concrete is varied from 25MPa to 100MPa. The parametric study on the shear strength of concrete deep beams is carried out using the models proposed by IS:456(2000) and ANSYS software.

4.1 Influence of grade of concrete on the shear strength of beam predicted using ANSYS 12.0 software

The shear strength of concrete beam is predicted using ANSYS 12.0 software .The shear strength of concrete beam corresponding to shear span to effective depth (a/d) ratio ranging from from 0.5 to 1.0 has been predicted. The shear strength of concrete beams with amount of steel reinforcement 1, 2, 3 and 4 percent has been computed. The strength grades of the concrete considered in this study are 25, 50, 75 and 100MPa.The grade of longitudinal steel bars is assumed constant and is equal to 250 MPa. The influence of grade of concrete on the shear strength of concrete beam predicted using ANSYS 12.0 software is given in Fig.6. The predicted shear strength of the concrete beam decreases with increase in a/d ratio. For smaller values of a/d ratio, the mechanism of failure in beam is controlled by compression strut failure, for which higher magnitude of shear capacity is predicted. The shear strength of the beam increases with increase in longitudinal shear reinforcement ratio.

The influence of the a/d ratio and longitudinal steel reinforcement ratio on the shear strength of the beam made up of normal strength concrete (f_{ck}=25MPa) and mild steel (Fe250 grade) is given in Fig.6(a).The predicted results indicate that use of large amount of longitudinal steel of Fe 250 grade is not effective in enhancing the shear strength of beam of normal strength concrete.

The predicted shear strength of reinforced beam of moderate strength concrete (f_{ck} = 50MPa) and mild steel (Fe 250 grade) as longitudinal reinforcement is given in fig.6 (b). The shear strength of the beam increases with increase in longitudinal steel reinforcement ratio. The predicted shear capacity of moderate strength concrete beam of longitudinal steel reinforcement ratio of 3 percent is found to be equal in magnitude when compared to the shear strength of normal strength concrete beam with longitudinal reinforcement ratio of 4 percent

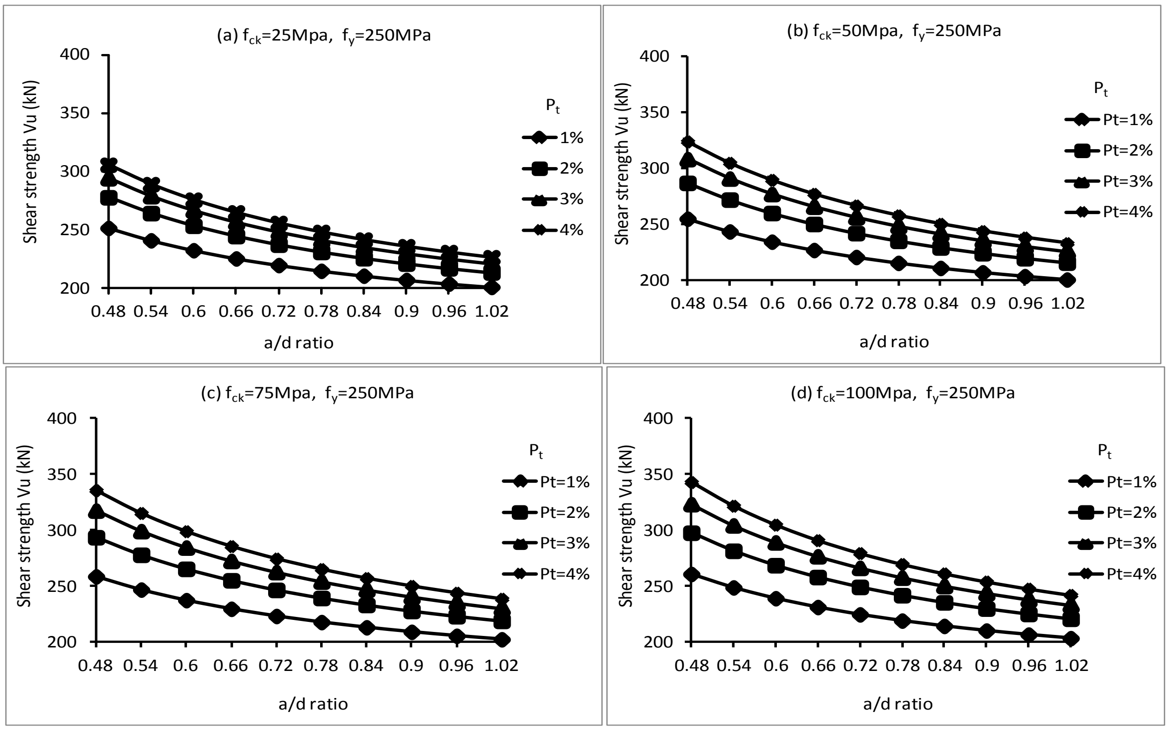

Fig. 6. Influence of grade of concrete on the shear strength of beam based on ANSYS.

(a) Beam with concrete of normal strength grade (f_{ck}=25MPa)
(b) Beam with concrete of moderate strength grade (f_{ck}=50MPa)
(c) Beam with concrete of high strength grade (f_{ck}=75MPa)
(d) Beam with concrete of very high strength grade (f_{ck}=100MPa)

The variation of predicted shear strength of beam with high strength concrete (f_{ck} = 75MPa) and very high strength concrete (f_{ck} = 100MPa) is given in fig. 6(c) and 6(d) respectively. The shear strength of the beam increases with increase in longitudinal steel reinforcement ratio. For all values of shear span to overall depth ratio (a/d) and longitudinal shear reinforcement ratio (p_t), the magnitude of predicted shear strength of high strength concrete beam is found to be equal in magnitude when compared to the corresponding beam with very high strength concrete beam. This indicates that the increase in strength of concrete greater than f_{ck} equal to 75 MPa does not improve the shear capacity of concrete deep beams containing mild steel as longitudinal reinforcement.

4.2 Influence of grade of steel on the shear strength of beam predicted based on ANSYS.

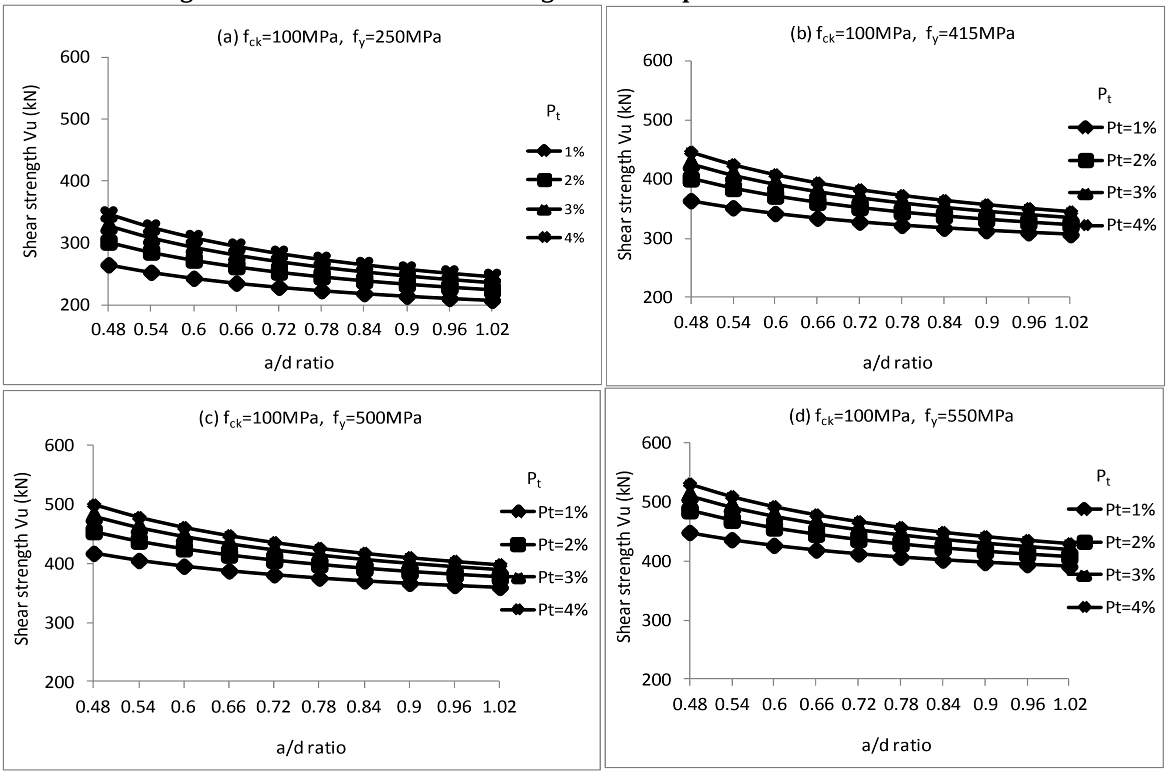

Fig. 7. Influence of grade of steel on the shear strength of beam predicted based on ANSYS.

(a) Beam with grade of steel Fe 250
(b) Beam with grade of steel Fe 415
(c) Beam with grade of steel Fe 500
(d) Beam with grade of steel Fe 550

The predicted shear capacity of very high strength concrete deep beam based on ANSYS corresponding to various values of shear span to overall depth ratio (a/d), longitudinal steel reinforcement ratio (p_t) and grade of steel is given in Fig.7. The predicted shear strength of concrete deep beam increases with increase in grade of steel. The variation of the predicted shear strength of concrete deep beam reinforced with Fe250 grade steel and Fe415 grade steel is given in Fig. 7(a) and 7(b) respectively. The increase in the predicted shear strength of beam reinforced with Fe415 grade steel is found to be 66 percent when compared to the shear strength of corresponding to beam reinforced with Fe 250 grade steel. The predicted shear strength of beams reinforced with Fe 500 grade steel and Fe 550 grade steel is given in Fig.7(c) and 7(d) respectively. The magnitude of the predicted shear strength of beam reinforced with Fe 500 grade steel is found to be 20 percent greater when compared to the shear strength of corresponding beam reinforced with Fe 415. The predicted results indicated that use of 4 percent of very high grade steel of Fe 550 in very high strength concrete beam with a/d ratio equal to 0.5 is not effective.

4.3 Influence of grade of concrete on the shear strength of beam predicted by IS 456-2000.

The shear strength of reinforced concrete beams made up of different grades of concrete predicted using IS 456 is given in Fig 8. The predicted shear strength of the concrete beams longitudinally reinforced with all grades of steel is equal in magnitude. The variation of shear strength of beam corresponding to a/d ratio and longitudinal steel reinforcement ratio for normal strength concrete (25 MPa) is given in Fig. 8(a). The variation of shear strength of beam corresponding to a/d ratio and longitudinal steel reinforcement ratio for medium strength concrete (40 MPa) is given in Fig. 8(b).

The predicted shear strength for concrete deep beams of normal strength concrete with longitudinal steel reinforcement ratio 1 percent is found to be equal in magnitude when compared to the corresponding beam of medium strength concrete having 1 percent of longitudinal steel reinforcement. This indicates that the shear strength of beams are found to be same for both normal strength and medium strength concrete when the longitudinal steel reinforcements is maintained 1 percent and hence increasing the grade of concrete from the normal strength concrete to medium strength concrete with 1 percent of longitudinal steel reinforcement is not effective.

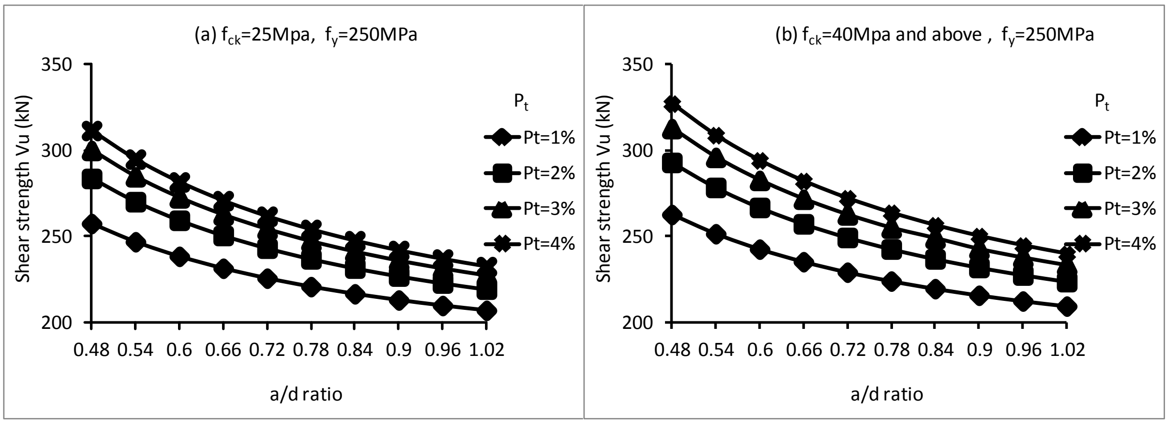

Fig.8 Influence of grade of concrete on the shear strength of beam predicted by IS 456-2000.

(a) Beam with concrete of normal strength grade (f_{ck} = 25MPa)
(b) Beam with concrete of moderate, high and very high strength grade.

The shear strength of beam computed based on IS 456(2000) is equal in magnitude in the case of moderate strength (50 MPa), high strength (75 MPa) and very high strength (100 MPa) concrete beams. The predicted shear strength of beams higher grade concrete (50, 75 or 100 MPa) is found to be greater in magnitude when compared with the shear strength of corresponding beam with normal strength concrete (25 MPa). The increase in the shear strength of beam made up of 40 MPa and above grade concrete and 1 percent of longitudinal steel reinforcement is found to be 2 to 3 percent when compared to the corresponding beams of 25 MPa grade concrete. In beams made up of 40 MPa and above grade concrete and 3 percent of longitudinal steel reinforcement, the increase in shear strength is found to be 5 to 4 percent when compared to the corresponding beams of 25 MPa grade concrete.

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V. COMPARISON OF PREDICTED SHEAR STRENGTH

The model proposed in ACI 318 accounts for possible seven mechanisms of failure of struts and ties. The failure due to diagonal cracking of the member and increase in strength due to arch mechanism is accounted for in IS 456.

The shear strength of concrete deep beams predicted based on the model proposed by ANSYS 12.0 is given in Fig 6 and 7. The shear strength of beam predicted based on the model proposed by IS 456 is given in Fig 8.

Comparison of the details presented in Fig 6 and 7 indicates that the shear strength of beam longitudinally reinforced with 1 percent of mild steel (Fe 250) predicted based on ANSYS 12.0 is found to be almost equal in magnitude when compared to the shear strength of corresponding beam predicted using IS 456(2000).

However, in the case of beams containing longitudinal reinforcement of 2, 3 and 4 percent, the predicted shear strength based on model proposed by ANSYS 12.0 is found to be greater in magnitude when compared the shear strength of the corresponding beam predicted based on IS 456.

The details given in Fig 6 and 7 indicates that beams reinforced with 1 percent of steel of Fe 415, 500 or 550 grade, the shear strength computed based on ANSYS 12.0 is found to be greater in magnitude when compared to the shear strength of corresponding beam predicted based on IS 456(2000). The influence of various grades of longitudinal reinforcement is not accounted for in model proposed by IS 456(2000)

VI. CONCLUSIONS

Based on the theoretical study, following conclusions are arrived at.

1. The longitudinal reinforcement ratio less than 2 percent is recommended for beam with normal strength concrete and mild steel.
2. Unlike in normal strength concrete beam, inclusion of longitudinal steel as high as 4 percent is effective in increasing the shear capacity of the moderate strength concrete beam.
3. Use of high strength concrete is recommended for achieving the maximum shear capacity of concrete deep beam with certain percentage of mild steel.
4. Based on ANSYS 12.0 software, the predicted shear strength of concrete deep beam increase with increase in grade of steel and grade of concrete.
5. In very high strength concrete beams with a/d ratio 0.5 and p_t equal to 4 percent, longitudinal steel of Fe 415 grade is recommended to avoid nodal zone failure.
6. Based on IS 456-2000, the grade of concrete influences the shear strength of RC beam. However, the grade of longitudinal steel reinforcement does not influence the shear strength of beam.
7. The concrete beams reinforced with steel only up to 3 percent are accounted for in model proposed by IS 456.

A detailed experimental study is to be conducted for identifying the appropriate ranges for which model proposed by ANSYS 12.0 and IS 456 are recommended.

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