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Effect Of Web Reinforcement On Ultimate Strength Of Reinforced Concrete Deep Beam

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ABSTRACT

It is observed that, reinforced concrete beams failed due to flexure but in case of deep beam failure occur due to shear. Deep beams may be defined as the beam where shear span to depth ratio less than 2. A number of researchers already proposed various approach to predict the ultimate strength of deep beams. In this study a newer approach is developed to calculate the ultimate shear strength of deep beams based on strut and tie model. Deep beams of different web reinforcement are used to predict the shear strength. A new effectiveness coefficient has been introduced to understand the contribution of steel during failure of deep beam under concentrated loads.

Keywords **–** deep beam, shear strength, concrete strength.

I. Introduction

Shear strength of reinforced concrete deep beam is composed of two components, nominal shear strength provided by concrete and nominal shear strength due to web reinforcement. Deep beams used in this research composed of different shear span to depth ratio, compressive strength of concrete, longitudinal reinforcement ratio and vertical reinforcement ratio. Though the prediction of ultimate shear strength of different research groups are not the same but some of the characteristics remain same such as with the increase of shear span to depth ratio the deep beam become more and more slender and failure occur at lower load. Tan et al (1998) proposed a shear design equation for deep beams but it was so conservative to use in practical. According to Sing B. et al (2006), continuous deep beams also exhibit the same tendency as simply supported deep beams. Arabzadeh et al. (2009) describe a simple sturt and tie model to predict shear strength. Lu et al (2010) also proposed a new formula based on sturt and tie model to predict the shear strength of deep beams. W.W. kuo et al. (2010) also describes the force transfer mechanism for deep beam based on B and D region (ACI 318-05). Deep beams have no B region and single D region. The diagonal compression flows directly from the point of applied load to the end support at an inclination angle (θ). According to the provision of ACI 318-05 Code, the angle (θ) shall not be taken as less than 25°.

Therefore, the beam having shear span to depth ratio greater than 2.0 are chosen as deep beams for this research.

II. BEAM DATA

Simply supported, single span reinforced concrete deep beam (**Fig.1**) data are used for this research. Beam of different shear span to depth, concrete strength and web reinforcement are summarized to understand the behavior of deep beams. Following notations are used to define different parameters of deep beams:

a = shear span (distance from support to applied load)
b = width of beam
d = effective width of beam
h = height of the beam
Vu = Theoretical ultimate shear strength
Ln = clear span
f'_c = cylinder strength of concrete
f_y = strength of steel
ρ_h = horizontal reinforcement ratio
ρ_v = vertical reinforcement ratio
ξ = softening coefficient of concrete
g = proposed coefficient
Vs = Steel contribution to share strength
Vexp = Experimental shear strength

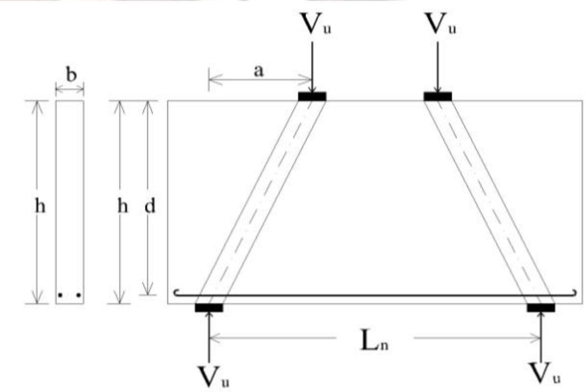


Fig.1 Geometry of concrete deep beam

Material properties, experimental setup and obtained test results are selected from different researchers [9], [11] to prepare a deep beam database. In selecting these data, following screens were applied.

1. The test specimens were reported to have failed because of web compression failure, not shear tension, bearing, or flexural failures;
2. The shear span to depth ratio (a/d) was less than 2.0;
3. The test specimens were simply supported.
4. Loads and reactions were applied through the bearing blocks with reported depth; and
5. Horizontal and vertical web reinforcements, if detailed, were distributed uniformly.

III. APPROACH AND METHODOLOGY

Ultimate load carried by the concrete strut and by the web reinforcement as shown in **Fig 2**. Load carried by the concrete strut (C) is estimated as following the formula provided by Lu et al. (2010), which is based on strut and tie model. But in this research, a new equation has been developed to calculate the load carried by the web reinforcement (F).

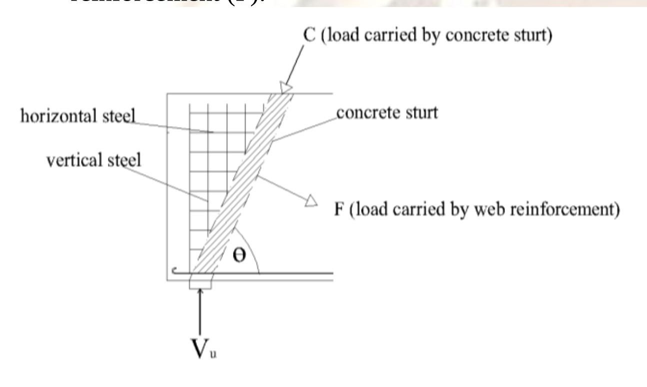


Fig.2 Load Transfer Mechanism of Deep Beams

Following **Fig 2**, it is estimated that, ultimate shear strength,

$$V_u = C \sin\theta + gF \cos\theta \qquad 1$$
$$C = \xi f'_c A_{str} \qquad 2$$
$$F = bdf_y \{\rho_v (a/d)\cos\theta + \rho_h \sin\theta\} \qquad 3$$

Equation 1 represents the basic theory of calculating share strength by adding concrete contribution with steel contribution. Here, g is a proposed coefficient. Equation 2 represents the capacity of concrete strut where, ξ is the softening coefficient of concrete proposed by Lu et al (2010). To calculate the active force provided by the reinforcement during failure, equation 3 has been introduced which represents equilibrium condition.

IV. COEFFICIENT OF EFFECTIVENESS OF WEB REINFORCEMENT

To verify the equation with steel contribution provided by Lu et al (2010) a new coefficient g has been introduced. The coefficient g represents the effectiveness of web reinforcement. The value of g has been calculated as 0.3905. **Fig 3** represents the value of steel contribution provided by Lu et al. vs expected web steel contribution calculated from equation 3. The slope of the straight line represents the value of g, where a good correlation of 0.9433 was observed.

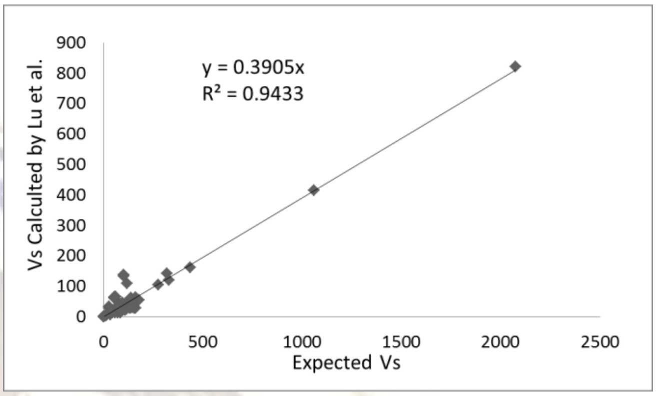


Fig.3 Comparison of steel contribution with predicted value

V. COMPARISON OF PREDICTED VALUE

Experimental data [7],[14] of 97 deep beams are used to compare with theoretical value obtained from Lu et al (2010), Arabzadeh et al. (2011) and proposed formula based on three categories; i) Vexp < 200 kip (**Fig. 4**) ii) 200 < Vexp < 500 kip (**Fig. 5**) and iii) Vexp > 500 kip (**Fig. 6**). It is observed that, shear strength can be predicted from proposed formula with small standard deviation for each of the three categories. For high strength concrete where the ultimate value is higher than 500 kip, the prediction of each of the three formulas are very much similar. When the ultimate shear strength is less than 200 kip prediction of Arabzadeh et al. seems to be inadequate where as for the shear strength greater than 200 kip the prediction is quite conservative.

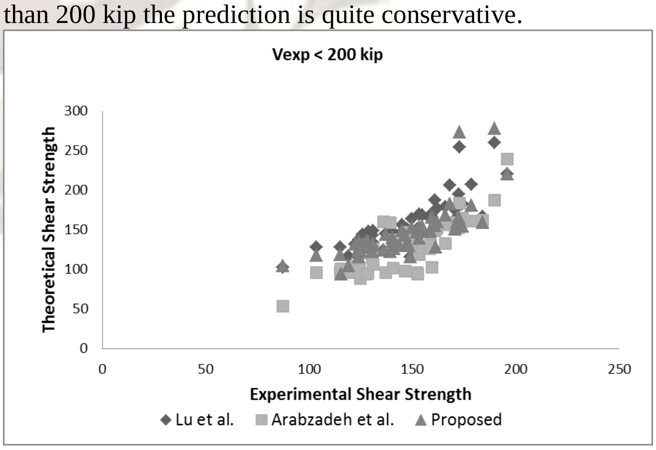


Fig.4 Vcal vs Vexp (Vu < 200 kip)

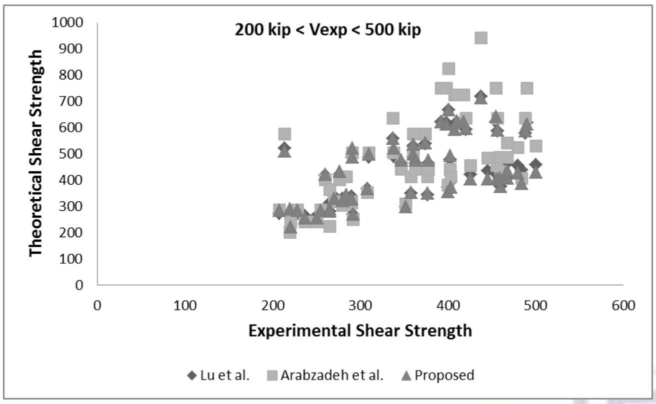
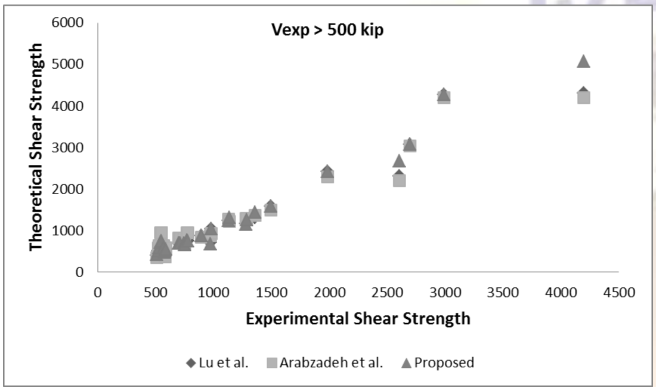


Fig.5: Vcal vs Vexp (200 kip < Vu < 500 kip)



ξ = $\sqrt{f'_c}$ $\leq$ 0.52

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Value of this coefficient decreases with the increase of concrete cylinder strength. As a result it is observed that, rate of increase of shear stress decreases with the increase of concrete cylinder strength as shown in **Fig 7**.

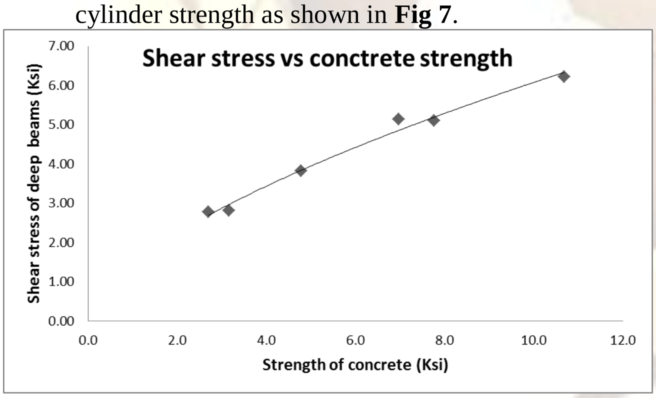

Fig.7: Effect of concrete strength on shear stress.

VI. Effect of Vertical Web Reinforcement

In case of normal beam where shear strength to depth ratio is greater than 2.0, stirrup is designed to carry the excess shear force that could not be carried by the effective concrete section. In case of deep beam, both vertical and horizontal reinforcement is used. Deep beams were tested keeping same compressive strength, f'_c, tensile reinforcement ratio ρ_t, shear span to depth ratio a/d and horizontal reinforcement ratio ρ_h but the vertical reinforcement ratio ρ_v were varied to understand the behavior. It is observed that, (see **Fig. 8**) with the increase of vertical reinforcement shear strength also increases.

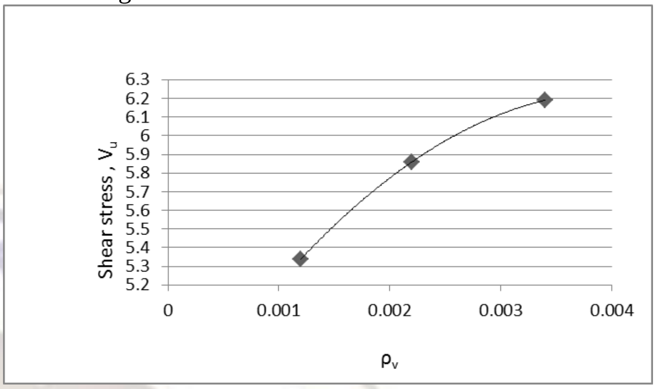

Fig.8: Effect of vertical web reinforcement on shear stress.

VII. Effect of Horizontal Web Reinforcement

The contribution of horizontal reinforcement cannot be ignored. According to **Fig. 9** shown below it is obvious that at constant shear span to depth ratio (1.25), compressive strength of concrete, (50.67 Mpa), constant vertical reinforcement ratio (0.0013), and ultimate shear stress of the deep beam increases with the increase of horizontal shear reinforcement. According to Park J. W. and Kuchma D. (2007), if the web of a deep beam is heavily reinforced, the failure will controlled by strut crushing; however, without sufficient reinforcement, failure can be occur suddenly due to the splitting of concrete struts. Park J. W. and Kuchma D. (2007) also observed that horizontal web reinforcement is more effective than vertical web reinforcement when a/d is less than 0.75, and vertical web reinforcement is more effective than horizontal web reinforcement when a/d ratios are greater than or approximately equal to 1.0.

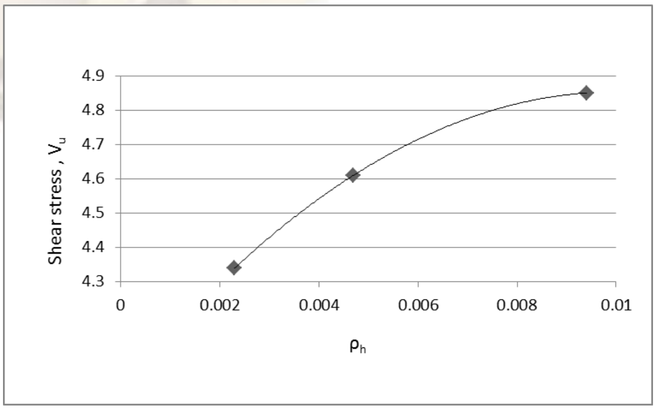

Fig.9: Effect of horizontal web reinforcement on shear stress.

VIII. Conclusion

Behavior of deep beams is quite difficult to understand and most of the researchers predict the value of ultimate shear strength with method of iteration. In this study simplified force transfer mechanism is used to understand the beam behavior. According to the proposed formula, it is found that, 39% of the force acting perpendicular to the diagonal cracks contributes to the shear strength of deep beams. Softened coefficient for concrete of medium strength does not vary and the value of the softened coefficient of concrete having compressive strength between 20Mpa to 40Mpa is 0.52. But for concrete of higher compressive strength greater than 40Mpa the value of softened coefficient decreases with the increase of compressive strength of concrete. Further research may be done to understand the deep beam behavior with different end conditions. The value of mid span deflection may be calculated which will not be similar as normal beams

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