The behavior of Single Span Concrete Deep Beam: A Review

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ABSTRACT

The reinforced concrete deep beam is widely used in a tall building, pile cap, foundation walls, and offshore gravity structures. From many years Reinforced concrete deep beams have been investigated by several researchers. The main objective of this paper was to review the behavior of the reinforced concrete deep beams under bending, shear, and torsion.Many factors that effected to the shear force behavior of deep beams are studied such as slenderness (shear span/depth ratio), concrete compressive strength, the loading and supporting conditions and main and web reinforcement. In the current paper, studied the works that carried out in this field to date.

Keywords: Reinforced concrete, deep beam, shear behavior.

1. INTRODUCTION

The ACI Building Code 318-14[1] consider the beam as deep if the slenderness (shear span/ depth) ratio less than five, supported on the opposite face and loaded on one face so that compression struts can develop between the supports and the loads. The deep beam response differs from the response of the most flexural members, this difference in response is mainly due to the influence of shear deformations and vertical normal stresses in these members [2]. Figure (1) shows the nonlinearity in stress distribution in mid-span at the elastic stage. The concrete deep beam strength is governed by shear rather than flexure, the shear strength is a function of main and web reinforcement, concrete strength, loading and supporting conditions and slenderness (span/depth) ratio.

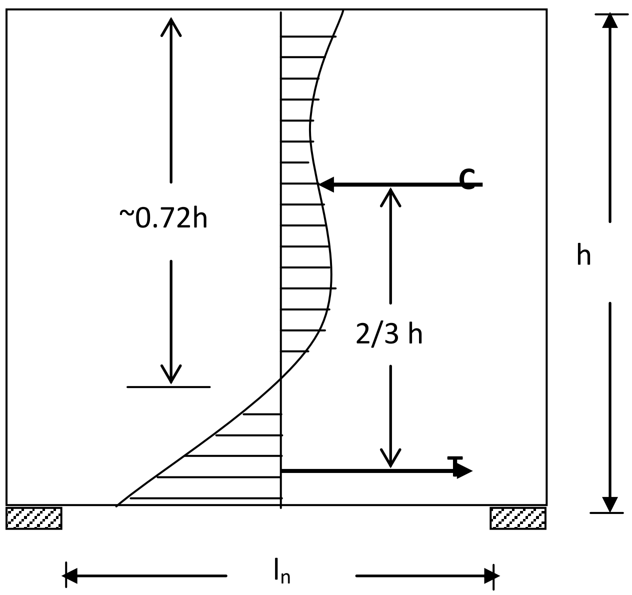

Figure (1): Elastic Stress Distribution in Deep Beams [2].

2. BEHAVIOR OF DEEP BEAMS

2.1.Mechanisms of Shear Transfer

the shear in cracked reinforcement concrete deep beam is transferred with various mechanisms depends on the applied load and support condition, the reinforcement distribution, extent and width of the crack, and other variables. The ACI-ASCE Committee [3], defined the types of shear transfer mechanisms are:

a. Shear stresses in un-cracked concrete.
b. Interface shear transfer (Aggregate interlock).
c. Dowel action of longitudinal reinforcement.
d. Tied-arch action.
e. Shear Reinforcement

2.2.Modes of Failure

Three models of failure can happen in single-span deep beams these are shown in Figure. (2) [4]:

a. Flexure: This happened in a beam of minimum tension reinforcement.
b. Flexural shear: The major cracks extend upwards from the support towards the load.
c. Diagonal splitting: The crack extends between the load and the support and grows outwards from mid-depth.

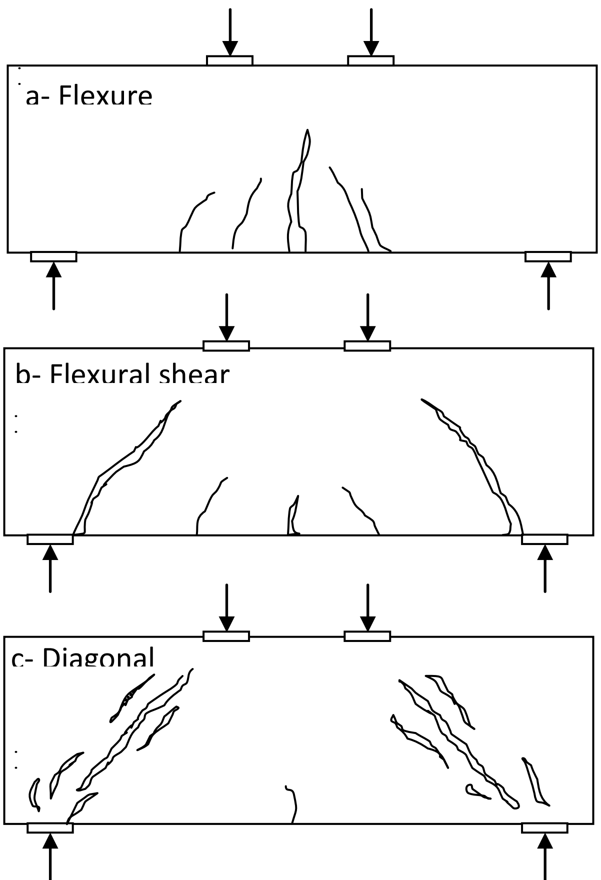

Figure (2): Modes of Failure of Single-Span Reinforced Concrete Deep Beams [4].

3. BRIEF LITERATURE REVIEW

Till now many types of research have been done by investigators on reinforced concrete deep beams. Research works highlighting the principle, assumptions, equations used and modeling techniques involved along with conclusions and results are discussed here. Both analytical and experimental work done in this field to date has been discussed in detail.

Leonhardt and Walther [5] in 1962 tested Nine single-span concrete deep beams with span/depth ratio equal to 1.0. load condition and steel distribution are discussed. It was concluded that the concrete deep beam behaves as tied arches, the bending stress is deviating from the line distribution at mid-span, the main web reinforced is useful against the propagation of inclined cracks and shear capacity cannot improve by main reinforced.

Ramakrishnan and Ananthanarayana [6] in 1968 tested 26 single-span concrete deep beams with different slenderness ratios and load. The test concluded that the diagonal tension failure model is dominant. It was Developed a new expression for shear strength based on the splitting strength of concrete, the expression has the form:

$$P_c = \beta.K.f_t.b.H \qquad (1)$$

where:

P_c = ultimate applied load

f_t = splitting strength of concrete

b = width of beam

H = beam height

β = shear span coefficient, (2 for a central concentrated load and uniformly distributed load)

K = splitting coefficient (1.12 could be used as a lower bound)

Kong et al. [7] in 1970 tested thirty-five simply supported concrete deep beams with slenderness ratios from 0.23 to 0.70, and study the effects of web reinforcement on the response of the beam. It was showed that the suitable distribution of web reinforced depends on slenderness ratios.

Kalyanarman et al. [8] in 1979 carried out a test with two single-span concrete deep T-beams. The beams had slenderness ratios of 1.0 and 1.35. and indirectly load applied. The concluded results show the deep T-beams have a 70% increase in shear strength than deep rectangular beams under indirectly loaded.

Smith and Vantsiotis [9] in 1982 tested fifty-two reinforced concrete deep beams. Test results concluded that inclined cracking happens at 40 to 50 percent of the ultimate load, and the presence of shear reinforced increases the ultimate shear strength. the main reinforced has little effect on the ultimate shear strength. Its effect is more noticeable in beams with slenderness ratios less than one.

Subedi [10] in 1988 tested 19 concrete deep beams and proposed a method of analysis. The method is depended on the equilibrium of forces across the failure surface as shown in Figure (3). The ultimate load capacity is given by:

$$P_u = \frac{1}{a}\left[\left(h_w{}^2 + c^2 + h_w.t_c\right)b.f_{tc} + \left(2h_w + t_c\right).P_{st} + \left(h_w + t_c\right).P_h + c.P_v\right] \quad (2)$$

Where

P_v and P_h are the vertical and horizontal force components of the web reinforcement.

P_{st} is the force in the main longitudinal reinforcement.

f_{tc} is the tensile strength of concrete.

a, c, h_w , t_c, and b are dimensional properties shown in Figure. (3).

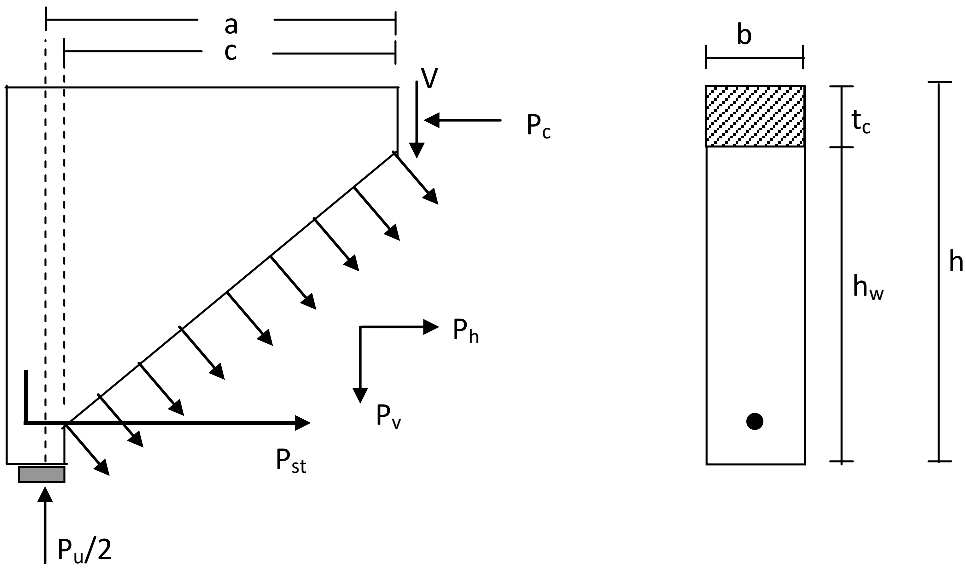

Figure. (3): Equilibrium of Forces Across the Potential Failure Surface

Mau and Hsu [11] in 1989 suggested the following formula for the shear strength of deep beams:

$$\frac{V}{bdf'_c} = \frac{1}{2}\left[K\left(w_h + 0.03\right) + \sqrt{K^2\left(w_h + 0.03\right)^2 + 4\left(w_h + 0.03\right)\left(w_v + 0.03\right)}\right] \quad (3)$$

where:

K= a coefficient representing the shear span effect.

$$w_v = \rho_v f_y / f'_c$$

$w_h = \rho_h f_y / f_c^{'}$

ρ_v = reinforced ratio of vertical steel

ρ_h = reinforced ratio of horizontal steel

Tan et al. [12] in 1995 studied the shear strength of nineteen concrete deep beams with variable concrete compressive strengths from 41 to 59 MPa. The study concluded that the slenderness ratios have more effected on the ultimate strength and small effect on the diagonal cracking strength. The good result getting when comparing the results with the ACI 318-89 Building Code.

Prodromos D. Zararis [13] in 2003 carried out many experiments for the deep beam with different slenderness ratios. The experiment shows that the shear failure of the concrete deep beam was happening under a single-point or two-point loading, with slenderness ratios between 1.0 and 2.5 Because the concrete in a compression zone is crushing. A simple formula was derived for depth in the compression zone, also the shear strength of deep concrete beams without and with web reinforced.

R.S. Londhe [14] in (2010) investigate experimentally of shear strength for twenty-seven deep concrete beams with many variables are the percent of longitudinal steel, horizontal web steel, vertical steel, orthogonal web steel, shear span/depth ratio, and cube concrete strength. The results showed that the capacity of load transfer of the transfer beam (deep) with arrangement longitudinal reinforce increased significantly. Also, the shear reinforced is more influence than the main reinforced in increasing the shear strength.

B.R. Niranjana, S.S.Patil [15] in (2012) tested several deep beams under two-point load with different L/D ratios and analyzed by FORTRAN Program. the change in flexural stress, shear stress and strain in deep concrete beam were plotted. The study concluded that the Failure of deep concrete beams was happened by diagonal cracking and extend between loading points and supports, and observed that the arching action of the major tension reinforced and the web reinforced together with concrete that carried the shear.

B.R. Niranjan, A.N. Shaik, S.S. Patil, [16] in (2013) carried out many experimental for deep beams with three L/D ratios (1.5, 1.6, 1.71) and investigate the change in strain pattern at mid-span of the beam. The test was plotted the flexural strains at misspent and obtained the failure crack patterns, Also, the deviation of strain pattern is more visible at small slenderness ratios.

Pandurang S Patil, Girish V Joshi [17] in (2014), five concrete deep beams with different span/depth ratio were tested and study the response of deep beams under bending and shear loads. The result shows that the diagonal cracking Failure is mainly model failure in beams, the cracksinclination decreases with increases span/depth ratio and the load taken at first crack in shear failure is larger than flexural.

G.S. Suresh, Sh. Kulkarni [18] in 2016 eighteen rectangular deep beams of size (150x350)mm and 700mm long were cast and three different span/depth ratio (0.43, 0.64 and 0.86) and different concrete strength are tested and analyzed by NSYS 14.5 software to compared the results. the result shows that the increase in main reinforced increased the flexural strength, the experimental test is found that the deflection and flexuralsteel are more experimentally than the non-linear FEA.

The ACI Building Code 318-18 [1] suggest the equation for shear strength of concrete deep beams:

$$V_c = \left(3.5 - 2.5\frac{M_u}{V_u d}\right)\left(0.16\sqrt{f'_c} + 17.2\rho\frac{V_u d}{M_u}\right)b_w d \quad (4)$$

Shear strength of web reinforced is given by:

$$V_s = \left[\frac{A_v}{s}\left(\frac{1+\frac{l_n}{d}}{12}\right) + \frac{A_{vh}}{s_2}\left(\frac{11-\frac{l_n}{d}}{12}\right)\right].f_y d \quad (5)$$

Where

M_u and V_u are the ultimate moment and shear at the section under consideration,

ρ is the longitudinal reinforcement ratio ($A_s/b_w d$),

d and b_w are the effective depth and beamwidth respectively,

A_v is the area of vertical shear reinforcement at spacing s,

A_{vh} is the area of horizontal web reinforcement at spacing s_2.

4. CONCLUSIONAND FUTURE SCOPES

From the above description,the investigations and experimental of reinforced concrete deep beams begin from 50 years past and the response was studied. it was developed Many empirical equations for analysis and design for these beams. All these investigations are restricted to a limited concrete compressive strength, supporting and loading conditions and shear span to depth ratios. There is still more scope for study the response of reinforced concrete deep beams.

The further work can be carried out for many cases of investigation the response of concrete deep beams such as

1- Review Finite element analysis and design of deep beams.

2- Review of study the behavior of multi-span concrete deep beams.

3- Review of study the behavior of concrete deep beams strengthens by FRP

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