Shear Strength of Deep Beams: A State of Art

G. Sri Harsha, P. Polu Raju

Abstract: ***In this present study a comprehensive literature has been reviewed on shear strength of deep beams. The shear behavior of deep beams must be understood by varying various parameters such as web reinforcement, shear span to depth ratio, size of the beam, depth of the beam, vertical reinforcement, side face reinforcement, percentage of reinforcement, Crack width criteria, Shear span deflection. Comparison of various international codes for the design of reinforced concrete deep beam is reviewed. This study provides preliminary support for proposing a new shear strengthening technique during the design of the member.***

Index Terms: a/d ratio, Deep Beam, Web Reinforcement, Shear strength, Size Effect

I. INTRODUCTION

Any structural member is designed based on the major criteria like safety & serviceability conditions where the ultimate load and its corresponding deflections are the main constraints. Beams are designed to transfer loads from slabs to columns where deep beams appear in the case of longer spans. Theory of simple bending criteria is not applicable in case of deep beams and they must be designed by considering non-linear stress distribution along the depth of the member. Many Researchers in the past had done research on shear strength parameter in deep beams since shear failure is the primary concern.

II. DEEP BEAM

Deep Beams possess two-dimensional action in compared with normal beams and the assumption where the plane section remains plane before and after bending is not applicable as the strain is not distributed linearly. The applied pressure will have more effect on the stress rather than strain, also shear deformation in normal beams can be neglected but in deep beams, the failure is mainly due to shear which cannot be neglected. Due to larger depths, like in traditional method stress is not linear in elastic stage and the parabolic shape at ultimate stress is not achieved which is also a major reason for shear failure in deep beams.

Deep Beams are used for the structure where there are no intermediate columns and for long spans. In bridges, deep beams are used as girders to support the carriageway. Deep Beams are also used in RCC water tanks as side walls and Pile foundation they are used as connections for pile caps.

Deep beams are those whose depth is more when compared to the normally used beams, but they are categorized based on their shear span to depth ratio. Different codes define the deep beams differently

- According to IS: 456-2000 clause-29, A beam shall be deemed to be a deep beam when the ratio of effective span-to-overall depth ($\frac{l}{D}$) is less than 2.0 for simply supported beam and 2.5 for continuous beam
- According to ACI-318 clause 10.7.1 deep beams are members loaded on one face and supported on the opposite face so that compression struts can develop between the loads and the supports, and have either: Clear spans, l_n, equal to or less than four times the overall member depth or Regions with concentrated loads within twice the member depth from the face of the support
- According to BS 8110, Deep Beam is a beam having the length to ratio ranging between 0.5 to 2.0.

III. FAILURES IN DEEP BEAMS

A. Shear Failure

Shear is rubbing or tearing action between the member. Shear forces in beams are caused when the applied momentum changes along its length, thus shear cracks would propagate in the shear span region. Deep beams normally fail in shear [1]. Shear tension failure occurring due to the loss of the bond strength in flexural reinforcement caused by the horizontal cracks and shear compression failure occurring due to crushing of concrete at the point of application of the load. This shear failure is fragile in nature and results in sudden damage or collapse.

B. Shear tension failure

This failure occurs when there is less bond strength at the flexural level reinforcement due to the horizontal cracks (Fig.1), which reduces the bond between the concrete and the reinforcement bars, thus the load transfer mechanism from concrete to steel is disturbed and load will not transfer properly.

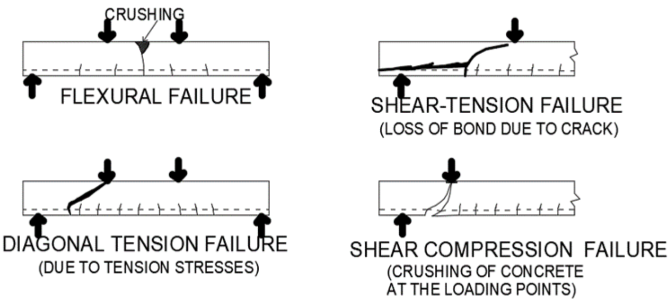

Fig. 1: Failure Points in Deep Beams

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C. Shear compression failure

Shear compression failure occurs due to the crushing of the concrete at the loading points. When the reinforcement is yielded, the load distribution is not possible and the concrete reaches its ultimate capacity which leads to crushing at the loading points [2].

D. Flexural failure

Flexural tension failure occurring due to yielding of the steel and flexural compression failure occurring due to crushing of concrete.

E. Diagonal tension failure

Diagonal tensile stresses with varying magnitude and degree of deviation will result in either shear or bending or both which occurs in most of the areas.

IV. LOADING CONDITIONS

The ACI code had given the difference between the deep and slender beam. In deep beam, the 3-point loading or 4-point loading is applicable on some conditions based on the ratio of shear span and depth of beam

- a/d ≤ 2 three-point loading is considered
- a/d = 2 four-point loading is considered and
- a/d > 2 it is no more a deep beam and is referred as slender beam (Fig. 2)

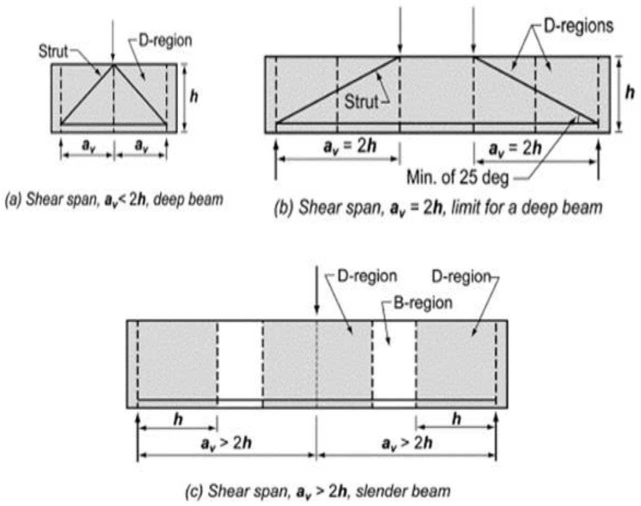

Fig. 2: Loading Conditions from ACI Code

V. REVIEW ON DEEP BEAMS

Salamy *et al.* [3] did an investigation on RC Deep Beams by Analytical and Experimental methods. A fracture type analysis is employed to simulate RC members through smeared rotating crack approach. The Underground structures such as Box Culverts come under Deep Beams, as per the Classification conducted on three sets of nineteen RC Deep Beams. The Results of Experiments are used to evaluate the Results of the Finite Element Simulation. He concluded that due to the size and aspect ratio of each individual member of such structures which most of them are attributed to RC deep beam category, investigation of deep beams behavior was inevitable.

Pandurang *et al.* [4] proposed a relation between theoretical and experimental results by studying the Shear and Bending Strength of RC Deep Beams. He evaluated the Stress in Deep Beams by using the method of two-dimensional analysis and observed that flexural stresses are not linearly distributed in RC Deep Beams, and load transferred directly from point of a load of application to support by diagonal Compression. Applied the analytical formula derived by Albeit to predict the quickly and accurately shear strength in Slender beams.

Patil *et al.* [5] Studied behavior of Deep Beams with high-performance reinforcement. There are significant differences between various design code implementations for this technique with respect to reinforcement tie, which influences on the capacity of adjacent concrete struts. Each design code specifies different limits on the maximum permitted stress in the ties. He Concluded that Failure of deep beams was mainly due to diagonal cracking and it was along the lines joining the loading points and supports.

Arabzadeh *et al.* [6] Conducted an investigation on Sixteen RC Deep Beams. He considered Compressive Strength as the main parameter and tested the specimens under two-point top loading. Observations were made on mid-span and loading point deflections, crack formations, failure modes, and shear strengths. The test results indicated that both vertical and horizontal web reinforcement are efficient in the shear capacity of deep beams, also the orthogonal shear reinforcement was the most efficient when placed perpendicular to major axis of diagonal crack.

VI. EFFECT OF VARIOUS PARAMETERS ON DEEP BEAMS

A. Shear strength vs a/d Ratio:

The study of shear performance on concrete structures started long ago. In 1995 the first shear failure in the beam came into view, which appeared at the storehouse of walkinair force depot. Many researchers started examining the shear behavior of beams and noticed that they cannot design as normal as traditionally done so far.

Salamy *et al.* [3] analyzed on deep beams by comparing the experimental analysis of strut and tie model on shear strength and a/d ratio with the finite element analysis using general FE code [DIANA 8.1.2]. The main intention in comparing the experimental and finite element analysis is to know how far the FEA can analyze the behavior of deep beam so that the experimental analysis which is expensive can be replaced with the software analysis. The analysis showed that the ultimate load carrying capacity of analysis is approximately equal to 0.8 times the experimental which can be considered as satisfactory.

Kamaran *et al.* [7] conducted the experimental analysis of 24 beams to know the parameters affecting the shear capacity and a/d ratio. The compressive strength and the shear span to depth ratio have more impact on the shear stress. ACI code is satisfactory for the normal strength concrete than the high strength, AASHTO LFRD is less efficient for the shear span to depth ratio less than 1, EC2 and Model code 2010 are stable overall but it decreases with the increase of the concrete strength.

Firoz *et al.* [8] conducted experiment analysis of deep beams using various codes such as American Concrete Institution(ACI) code, Construction Industry Research and Information Association (CIRIA) code and Indian standard (IS) code. The specimens of length 4.5m, 5m and 5.5m are designed using three codes and graphs are drawn for tension reinforcement vs clear span to depth ratio, shear reinforcement vs clear span to depth ratio and total reinforcement vs clear span to depth ratio, Shear strength vs a/d ratio (Fig.3) by keeping moment and shear constant and later varying them.

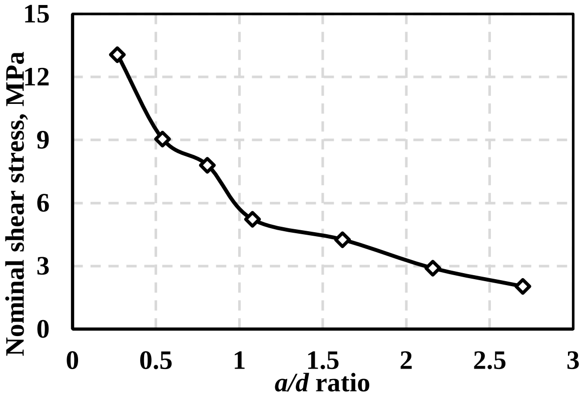

Fig. 3: Effect of *a/d* ratio [9]

A. Shear Strength vs ln/d Ratio:

Shear strength decreases with the increase of length to depth ratio as there is a chance of keeping more shear reinforcement in the web [9].

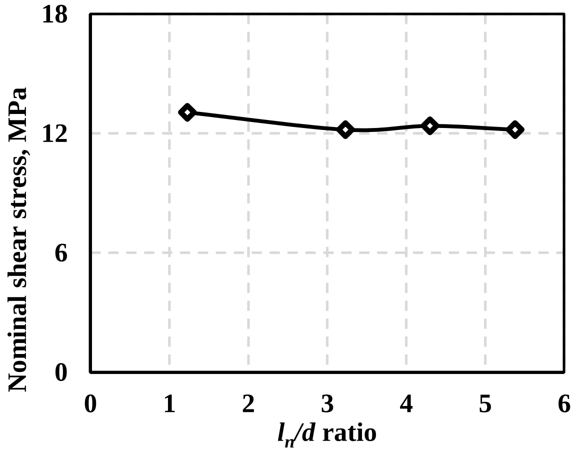

Fig. 4: Shear Strength vs l_n/d Ratio [9]

B. Web Reinforcement Effect:

Crack propagation was very high in beams with horizontal web reinforcement and the performance of beams with orthogonal reinforcement was most effective [10].

C. Tension Reinforcement Effect on Shear Strength:

The nominal shear stress increases with the increase of tension reinforcement up to certain stage and decreased at 0.8% and gradually increased later on [11].

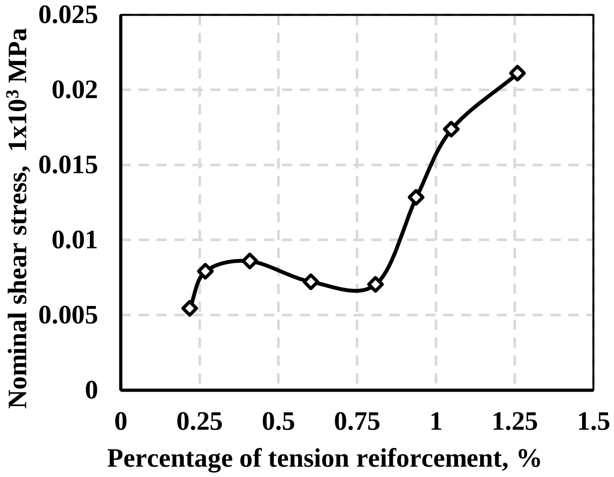

Fig. 5: Effect of Tensile Reinforcement [11]

D. Size effect in RC Deep Beams:

The failure of deep beams occurs when there is an improper adopting of shear transfer and Spacing, Diameter of web reinforcement, Geometry is the secondary cause.

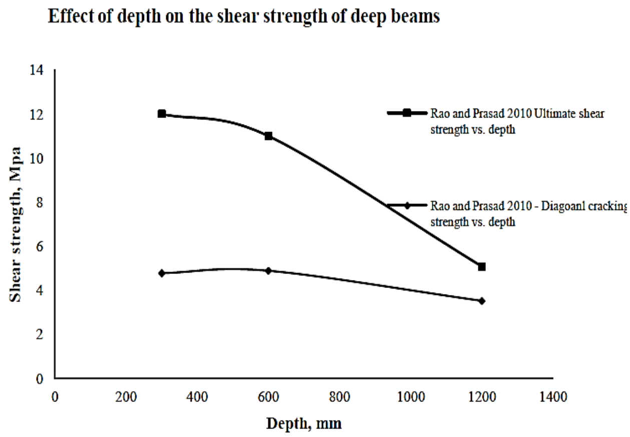

Fig. 6: Depth effect on diagonal cracking of shear strength of deep beams [12]

VII. CONCLUSION

The following conclusion were drawn after the detailed study on shear strength of deep beams

- Diagonal Tensile Stresses will increase rapidly if proper care is not taken for the stresses criteria while designing the beam.
- Major Failure is diagonal cracking in Deep Beams, with the increase in span to depth ratio, the inclination of cracks increases.
- The portions of uncracked concrete depth resist the shear stress and the transfer of shear at cracked portion is negligible
- Concentrating of shear reinforcement within middle region of shear span can improve the ultimate shear strength of deep beam
- Shear strength decreases with the increase in the depth of the beam.

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The Influencing parameters like Horizontal web reinforcement, shear span to depth ratio, Distribution of web reinforcement along depth, compressive strength of concrete, effect of depth on shear strength of deep beams, cover is to be studied in depth by conducting experimental investigation.

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