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SHEAR STRENGTH OF R.C.C BEAMS WITHOUT WEB REINFORCEMENT

Shear strength in steel reinforced concrete beams has been the subject of many controversies and debates since the beginning of 20th century. The shear strength of reinforced concrete beams has been extensively studied over the last five decades. A large number of experimental and analytical works have been carried out for the case of slender beams (having a shear span to depth ratio $a/d \geq 2.5$) with and without shear reinforcement under two-point loading.

Transversely loaded reinforced concrete beams may fail in shear before attaining their full flexural strengths if they are not adequately designed for shear. Unlike flexural failures, shear failures are very sudden and unexpected, and sometimes violent and catastrophic. A thorough knowledge of the different modes of shear failures and the mechanisms involved is necessary to prevent them.

Existing codes and specifications of different countries for reinforced concrete design with regard to shear differ considerably in important aspects. This only reflects the fact that we know very little about the behavior and strength of reinforced concrete subjected to shearing force in spite of the considerable number of tests and theoretical investigations made during more than half a century.

Despite the great research efforts, however, there is still not a simple, albeit analytically derived formula to predict quickly and accurately the shear strength of slender beams. In addition, many of the factors that influence the determination of the required minimum amount of shear reinforcement are not yet known. As a consequence, the current provisions for shear in standard codes such as ACI code, BIS code, BS code are still based on empirical or semi empirical considerations.

DISCUSSION ON SHEAR

Shear force is present in beams at sections where there is a change in bending moment along the span. It is equal to the rate of change of bending moment. An exact analysis of shear strength in reinforced concrete beam is quite complex. Several experimental studies have been conducted to understand the various modes of failure that could occur due to possible combination of shear and bending moment acting at a given section.

The main obstacle to the shear problem is the large number of parameters involved, some of which may not be known. Therefore, for some time, researchers have concentrated on the internal mechanism of shear failure.

The usual arrangement for investigating shear failure is that of a beam subjected to symmetrically placed two equal concentrated loads 'P' at distance 'a' (shear span) from the supports. It has the advantage of combining two different test conditions, viz, pure bending, that is, no shear force is present between the two loads P, and constant shear force in the two end regions or shear spans.

The failure of beam considered in shear is induced by cracks outside the central section of the beam. Though the bending moment is maximum in the central section, the cause of failure of the beam considered is due to shear force in the end region of the beam where the cracks appeared causing failure. It is to be noted that in the central section there is no shear force present (pure bending). Hence it is felt that the shear force, or the shear stress, must be responsible for such a failure. Thus, the term '*shear failure*' is chosen. Later it was recognized that shear stress at failure is far from being constant.

It is believed that the shear failure of reinforced concrete members without stirrups initiates when the principal tensile stress within the shear span exceeds the tensile strength of concrete. This results in initiation of diagonal crack which later propagates through the beam web. In other words, the diagonal cracking strength of reinforced concrete members depends on the tensile strength of concrete, which in turn is related to its compressive strength.

Studies have shown that shear force is resisted by the combined action of three factors namely, the uncracked concrete in compression region, the aggregate interlocking and the shear acting across the longitudinal steel bars. The shear force across the steel bars is also known as dowel force. The unbalanced shear in excess of the three combined factors is assumed to be resisted by the shear reinforcement. The shear reinforcement is generally provided in the form of vertical stirrups. The stirrups should encircle tension reinforcement and their free ends should be properly anchored in the compression zone of the section so that the vertical legs may resist tension without slipping.

Here the behaviour of reinforced concrete beams in shear can be explained in two stages viz., pre-cracking stage and post cracking stage.

Pre-cracking Stage

Before cracking, the reinforced concrete beam acts more or less like a homogeneous beam. The flexural stress (f) across any section are given by the classical formula

$$f = \frac{My}{I}$$

where M= bending moment

The shear stress (τ) across the same section is given by –

$$\tau = \frac{VA\bar{y}}{Ib}$$

where V = shear force, A = cross sectional area

$\bar{y}$ = the distance of centroid of an element from the neutral axis of the section, I = moment of inertia of the section, b = width of the element

The maximum diagonal tension can be calculated from the classical formula.

$$t = \frac{f}{2} + \sqrt{(\frac{f}{2})^2 + \tau^2}$$

Where t= unit diagonal tension

f = Unit direct stress taken as positive in tension and

τ = the unit shear

The direction of maximum diagonal tension is given by the relation tan $2\theta = \frac{2\tau}{f}$ where 'θ' is the angle made by 't' with respect to stress 'f'.

Post-cracking Behaviour

The mechanism of shear transfer in a cracked concrete beam is illustrated in a free body diagram.

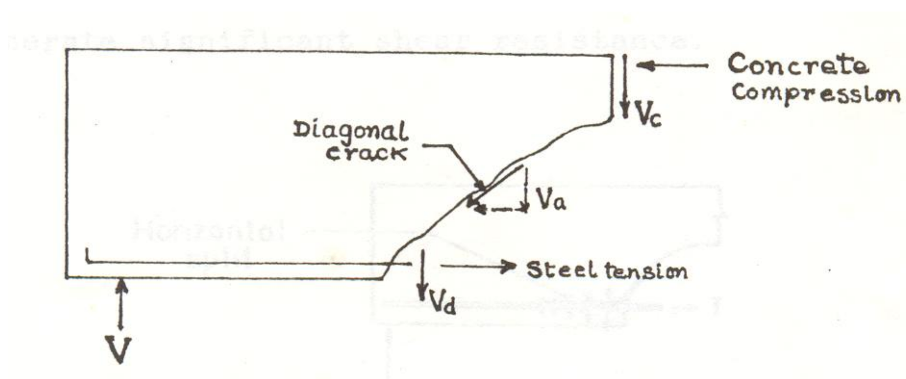

Fig. 1.1 Mechanism of shear transfer

The shear force V is resisted by the combined action of various forces as mentioned below.

$$V = V_c + V_d + V_a$$

where, Shear v_c , from the un-cracked concrete compression zone,

Shear V_d, from the dowel action of longitudinal reinforcement.

Shear V_a, from vertical component of the force due to aggregate interlock or interface shear transfer.

The approximate proportion of contribution of the above three forces are

- Shear in compression zone V_c 20 to 40%
- Shear from dowel action V_d 15 to 25%
- Shear from aggregate interlock V_a 35 to 50%

When shear displacement occurs along an inclined crack, dowel action in reinforcements gets mobilized. When the two faces of a flexural crack of moderate width are given a shear displacement relative to each other, a number of coarse aggregate particles projecting across the crack interlock with each other generate significant shear resistance.

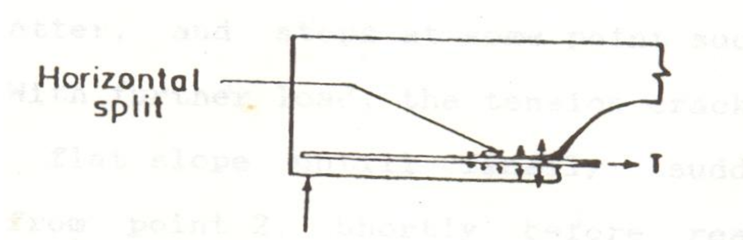

Fig 1.2 Horizontal splitting along reinforcement due to dowel action

As the applied shear force is increased the dowel action is the first to reach to capacity after which a proportionally large shear is transferred to aggregate interlock. The aggregate interlock mechanism is probably the next to fail, necessitating a rapid transfer of a large shear force to the concrete compression zone, which as a result of this sudden shear transfer, the beam often fails abruptly and explosively.

Failure Modes in Shear (Without Web Reinforcement)

The various failure modes in shear without web reinforcement are-

a) Diagonal Tension failure: The shear failure always in the shear span (a) when the a/d ratio is above 2. The diagonal crack starts from the last flexural crack and turns gradually into a crack more and more inclined under the shear loading as noted in Fig. 1.3. Such a crack comes not proceed immediately to failure, although in some of the longer shear spans this either seems almost to be the case or an entirely new and flatter diagonal crack suddenly causes failure. More typically, the diagonal crack encounters resistance as it moves up into the zone of compression becomes flatter and stops at some point such as that marked 1 in Fig.1.3. With further load, the tension crack extends gradually at a very flat slope until finally sudden failure occurs, possibly from point 2. Shortly before reaching the critical failure point at 2 the more inclined lower crack 3 will open back, at least to the steel level and usually cracks marked 4 will develop.

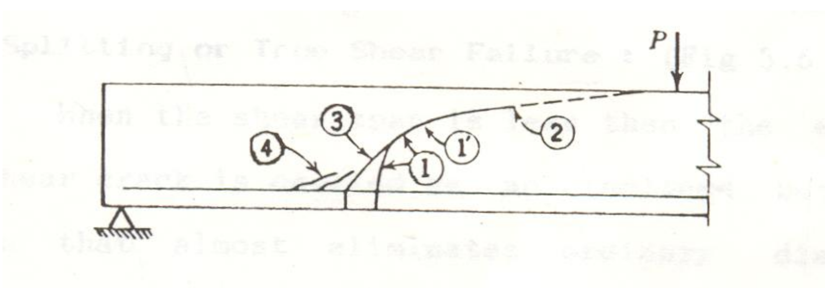

Fig. 1.3 Diagonal tension failure

b) Shear compression failure: A large shear in short shear spans may initiate approximately a 45 degree crack, called a web shear crack, across the neutral axis before a flexural crack appears. Such a crack crowds the shear resistance into a smaller depth and thereby increasing the stresses, tends to be self-propagating until stopped by the load or reaction. A compression failure finally occurs adjacent to the load. This type of failure has been designated as a shear compression failure because the shaded area in Fig.1.4 also carries most of the shear and the failure is caused by the combination. This failure occurs at a range of a/d between 1.0 and 2.5. The ultimate load is sometimes more than twice at diagonal cracking.

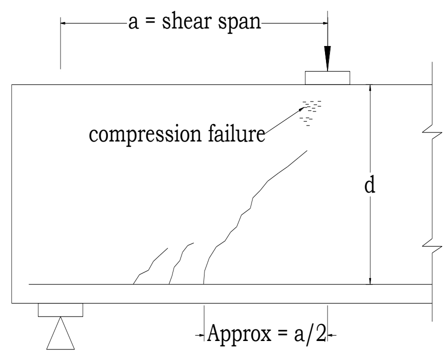

Fig. 1.4 Shear compression failure

c) ***Splitting or true shear failure:*** When the shear span is less than the effective depth d, the shear crack is carried as an inclined between load and reaction that almost eliminates ordinary diagonal tension concepts. Shear strength is much higher in such cases. The final failure, as shown in Fig.1.5, becomes a splitting failure or it may fail in compression at the reaction. The analysis of such an end section is closely related to the analysis of a deep beam. This failure occurs when a/d is less than unity.

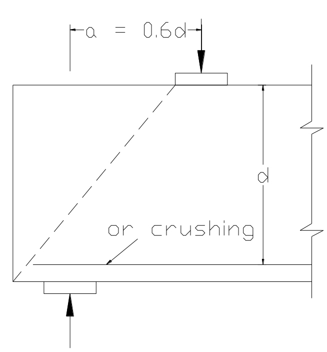

Fig. 1.5 Splitting shear failure