Effect of Aggregate Interlocking and Dowel action of Beams under Flexural Loading- A Literature Review

Joshi Sreenivasa Prasad, P. Polu Raju

Abstract: ***The aim of the present review is to study the influence of aggregate interlocking across cracked surface, reinforcement crossing the shear cracks and dowel action of longitudinal tensile reinforcing bars across the cracks. The aggregate interlocking is uncertain and depends on the shear reinforcement and action of loads under the and dowel action of reinforced concrete beams under flexural loading. In reinforced concrete beams, shear resistance is provided by shear transfer in un cracked compression concrete, supports. Similarly, dowel action is an important component for shear resistance. Due to complexity involved in shear transfer mechanism, the prediction on the effect of both aggregate interlocking and dowel action is a difficult task. Previous research had given focus on both the components separately. The present review is to study the effect of both aggregate interlocking and dowel action as common entity and understand the relationship of the same.***

Keywords : ***Aggregate interlocking, dowel action, flexural loading, shear resistance, shear transfer mechanism.***

I. INTRODUCTION

The great advantages of concrete lies in its compressive strength and ability to be moulded. Primarily, the reinforced concrete beams are designed to with stand flexure and shear. Sudden failure due to low shear strength is not desirable. To determine the size of the section and arrangement of reinforcement, flexure is considered first . The beams are then designed for shear. The shear resistance of reinforced concrete beams is provided by shear transfer in un cracked compression zone, aggregate interlock across crack surface, stirrups crossing through shear crack and dowel action of longitudinal reinforcing bars crossing the cracks in concrete [1].

The two principle mechanisms in transferring shear forces across a reinforced concrete crack are aggregate interlock and dowel action.

The interaction between rough surfaces of the crack is due to aggregate interlock and shear resisted by the reinforcement is referred as dowel action.

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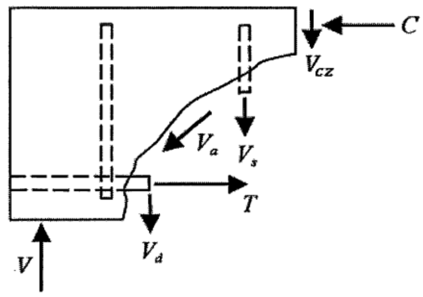

Fig. 1: Mechanism of Shear Transfer in Cracked concrete Beam

Freebody diagram of a segment of reinforced concrete beam (**Fig.1**) separated by a diagonal tension crack.

The components of shear transfer mechanism are

a) Shear resistance by uncracked concrete in compression V_{cz}
b) Vertical component of aggregate interlock across crack surface V_{ay}
c) Dowel force in tension reinforcement V_d
d) Shear resistance by stirrups V_s

The transverse shear force is denoted as V, which is maximum near the support and is equal to the reaction at the supports and resisted by the shear transfer mechanism. Before the flexure cracking occurs, entire shear is resisted by uncracked concrete.

Once the cracking begins, redistribution of stresses takes place and aggregate interlocking force V_a and dowel force V_d begins to develop. As the crack propagates and develops into diagonal tension crack, all the mechanism mentioned above is effective.

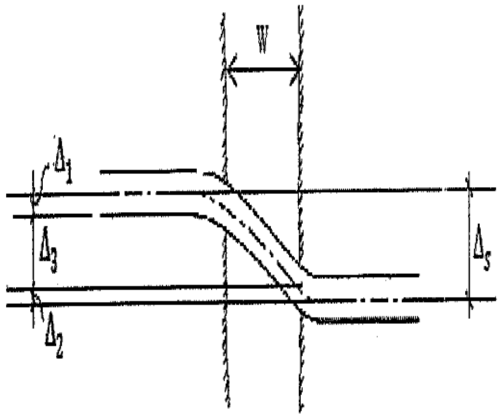

Fig. 2: Deformation of concrete and bar of free length.

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From the **Fig.2**

$\Delta_s = \Delta_1 + \Delta_2 + \Delta_3$

Δ_1, Δ_2 = Deformation of the concrete around it.

Δ_3 = Deformation of the bar over the free length.

In nut shell, shear resistance is calculated as sum of shear carried by un cracked concrete in compression, shear carried by dowel action and shear carried by aggregate interlock.

It is quite uncertain regarding the contribution of aggregate interlock, as it depends on amount of shear reinforcement and contribution of loads close to the support and influences the cracking pattern and relative crack displacement. Similarly, the interaction between the reinforcement and surrounding concrete near the crack is governed by dowel action and stresses induced are difficult to measure. The effect of aggregate interlock may vary depending on the amount of shear reinforcement provided, shear span to effective depth ratio, concrete strength or the type of aggregate used.

Early study on shear transfer mechanism was first adopted by Ritter and Morsch at the beginning of Twenth century. Subsequently many attempts have been adopted to improve the truss anolgy.

Four methods are commonly used to calculate shear strength

a) Classical Method: Based on truss analogy
b) Variable strut angle method: Based on theory of plasticity
c) Smeared truss model: Compression field theories
d) Discrete crack approach

Near the supports or applied loads, the stress distribution is not uniform and these are referred as 'Discontinuity regions' where the shear often becomes critical. Strut and Tie models are widely recommended for design and analysis of D-regions.

Still significant uncertainties and questionable assumptions implicit in this method.

Shear resistance is given by the equation

$V = V_C + V_S$ ($\theta = 45°$)

V_C = Shear resisted by beam without stirrups

V_S= Contribution of stirrups

In reality, shear failure is likely to be governed by equilibrium at the shear crack.

In practice, lowest possible angle of inclination is usually adopted to minimise the area of stirrups.

Discrete crack approaches provide rational description of shear behaviour , but too complex for practical purposes as they require the solution of complicated analytical solutions.

A. DOWEL FORCE CONTRIBUTION TO SHEAR STRENGTH OF RC BEAMS

Until 1958, there was usual assumption that dowel action of longitudinal reinforcement does not exist and the maximum compressive strain would occur at the extreme fibre in the compression fibre of the shear span and most critical span would be the flexure span of the beam. It is assumed that plane section remain plane after the progressive diagonal crack.

Watstein and Mathey[2] ,conducted experiments on beams failing in shear as shown in the **Figure3** below.

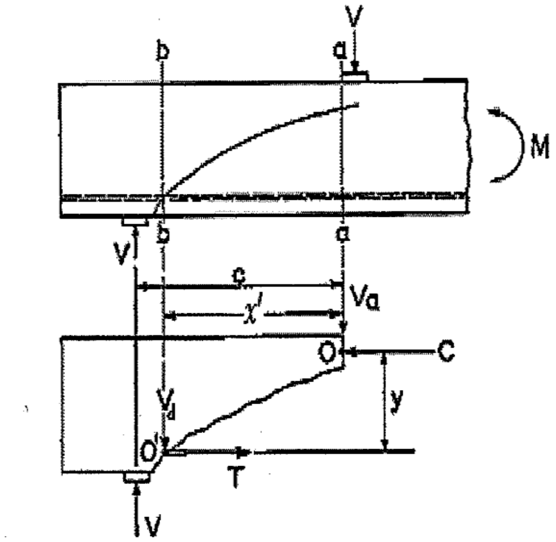

Fig. 3: Reinforced Concrete Beam Tested by Watstein and Mathey.

They concluded that

a) Dowel force is maximum at the section a-a, after which it decreases rapidly.
b) Dowel force ranges from 0.38-0.74 and found to be high for the beam containing large diameter bar and high percentage of longitudinal reinforcement.
c) In the shear span plane section remain plane before the formation of the diagonal tension crack, beyond this maximum compressive strain occurs at some distance below the compressive face of the beam. The strain at the maximum compressive fibre begins to decrease and changes to tension with small magnitude.
d) After the formation of the diagonal crack, upper portion of the beam with in the shear span develops curved surface concave towards the mid plane.

Dowel force would become zero at the failure of the beam, but the validity is questioned due to lack of experimental evidence as discussed above.

Sarkar et.al [8] conducted similar experiment on high strength by beam end test and concluded that,

In the absence aggregate interlocking, dowel force is the predominant factor, but its contribution decreases with strength of the concrete.

Beams having range of 40-110Mpa , the shear contributions of the various components would be

a) V_a in the range of 34-40%
b) V_{cz} in the range of 13-17%
c) V_d in the range 43-53%

B. AGGREGATE INTERLOCKING CONTRIBUTION TO SHEAR STRENGTH OF RC BEAMS

The effect of aggregate interlock may vary depending on the amount of shear reinforcement provided, shear span to effective depth ratio, concrete strength or type of aggregate used.

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Experimental data regarding the aggregate interlocking mainly focused on members without shear reinforcement.

Early estimates of percentage of vertical shear carried across the flexural cracks were carried out by Fenwick and Paulay [3]. According to them, an approximate figure of 70% of the shear was taken by aggregate interlock, while the remaining 30% was carried by compression zone and dowel action.

Later work carried out by Taylor [4], confirmed that contribution of aggregate interlock was predominant. The percentage provided by him were aggregate interlock (35%-50%), dowel force (15%-25%) and shear contribution of the compression zone (20%-40%). According to Taylor, crack roughness is the ratio between the aggregate and matrix strengths. This shows, the influence of the type of coarse aggregate used can be critical. Although the contribution of aggregate interlock is more or less understood for members without stirrups, there was lack of experimental data regarding contribution of members with stirrups.

Based on the above statement, Sagaseta [5] in his study concluded that aggregate type has larger impact on the crack roughness than the concrete strength. In gravel specimens, crack went round the aggregate and it was true even for beams up to 80 MPa in which small portion of aggregate fractured at cracks (30%).

Secondly in the push off tests conducted on short span beams, the entire shear force is transferred through the pre crack surface of which both geometry and normal stresses are known. He concluded that for normal size stirrups and concrete strengths used, the contribution of dowel action to shear strength was negligible.

Sagaseta [5] also concluded that critical shear cracks formed at service loads remained stable until the failure, except in slender beams (a/d=3.5) without shear reinforcement, where failure occurred immediately after the diagonal crack had formed.

As far dowel action is considered, Paulay et al. [3], concluded that dowel force depends on bar diameter and Jimez et al. [6] concluded that dowel action is independent of bar diameter, but to compute dowel strength bar diameter is essential.

Jelic et al. [7] based on his experiments keeping the beam dimensions same as in **Fig 4** and with different bar diameters and without shear reinforcement, concluded that as long as reinforcement area is constant, ultimate shear capacity is identical, irrespective of bar size and yield strength of steel. Hence dowel action cannot be considered as viable component in shear transfer mechanism and major factor contributing is the shear resistance of un cracked concrete, due to large shear displacement across the cracked member.

Contradictory to the statement above, Sushree Sangeeta Panda [1], concluded that neglecting aggregate interlock, average of dowel force is 56% of the total shear which is in agreement with Sarkar et al. [8]. According to her, dowel action of flexural tensile reinforcing bars has not been explicitly represented, despite the implicit belief that dowel action is an important component of shear reinforcement.

Dowel force is found to increase with increase in percentage tensile reinforcement, bar diameter, strength of concrete and concrete cover.

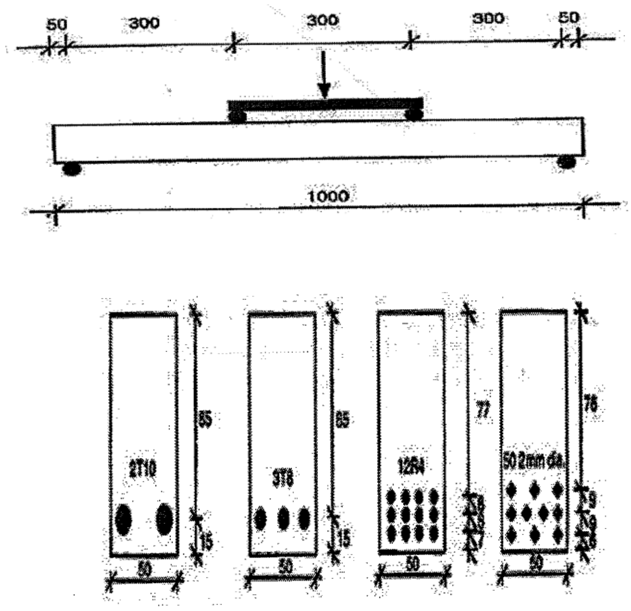

Fig. 4: Reinforced concrete beam tested in the programme by Jelic et.al

II. CONCLUSION

From the above literature review, it is understood that, both aggregate interlocking and dowel force are the major components for shear resistance of reinforced concrete beam. But both the components had been studied independently due to complexity involved. It is recommended ,to prepare a suitable mathematical model for establishing the relationship and to study crack width and displacement with shear reinforcement provided.

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