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Editorial

The problem of shear has important, deep, and sometimes unrecognizable, ramifications on the structural behaviour of reinforced concrete (RC) beams and slabs. And this complexity often extends also to RC beams and slabs that are strengthened by externally bonded fibre reinforced polymer (FRP) composite materials. It is therefore not surprising that the mechanics and mechanisms of shear failure, and the basis of design for shear in reinforced concrete structural elements have exercised the minds of researchers and designers for over a hundred years. Indeed a critical review of research publications in this area confirms the enormous amount of research that is yet to be done to clarify the influence of shear on flexural behaviour.

It is therefore inevitable, and indeed again unsurprising, that shear design has been based on experimental data because of the large number of interactive and interdependent parameters that influence shear failure. In beams as well as in slabs, shear failures are a complex interaction of bending and shear, and the propagation of the diagonal tension crack at failure is, as a result, extremely rapid. In beams, such failures may therefore occur in the tension zone, in the compression zone or in the web of the beam, or as often happens, in any combination of these three modes. The internal force system at collapse under these conditions is statically indeterminate, and simplifying assumptions regarding force distribution then become a necessity. If there is a major message and implication from these studies, it is that, in reality, we should be considering an integrated approach for the design of flexure and shear. This need becomes very critical when designing beams strengthened for flexure and shear with externally bonded steel or FRP plates and laminates.

One of the major difficulties facing rigorous mathematical analysis and rational design against shear is the evaluation of the slope of the shear crack. Because of the complex moment–shear interaction, and equally importantly, of the heterogeneous nature of concrete, the evaluation of the slope of the shear crack has again necessarily to be based on test data. However, it is possible to establish the limiting bounds for the angle of the shear crack if a sufficiently large number of tests involving the major parameters are carried out. In RC slabs, for example, published test data show that the angle of the failure surface in punching shear failures varies from 25 to 30° in normal density concrete whereas with high strength concrete, slopes of the failure shear crack may vary from 30° to 40°. The assumption of a rational value for the failure surface can then lead to sound engineering models.

The problem of shear failure in RC beams can be completely solved only when the internal mechanics of load distribution at collapse is clearly understood. Various investigators have suggested that a cracked reinforced member behaves like a two-hinged tied arch, and have put forward theoretical analyses based on arch action. Extensive test results, on the other hand, show that a normally bonded reinforced beam failing in shear behaves like a beam right up to the failure stage, in spite of extensive cracking and deformation. In ordinary beams, when the loads are applied close to the support, it is possible to develop, beyond diagonal cracking, some form of tie-rod action, indicative of the progressive disruption of bond which invariably accompanies shear failure; but even then, a neutral plane exists right up to the failure stage. As the shear span increases, bending action predominates. The term "arch action" in relation to a beam failing in shear is thus misleading, and has connotations inconsistent with the physical behaviour of a normal RC beam.

Extensive tests also show that the phenomena of aggregate interlock and dowel action are interdependent, and are not easy to separate. In the initial stages of diagonal crack formation, the aggregate interlock action predominates while the influence of dowel action becomes significant in the later stages of the diagonal crack development. The net shear carried by this interface phenomena depends on the amount of tension steel, the web reinforcement, the moment-shear ratio and the concrete strength. The shear transfer through aggregate interlock and dowel action is maximum for beams without web reinforcement. The provision of shear reinforcement results in the transfer of shear forces to stirrups,

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and in substantial reductions in the shear carried per se by aggregate interlock and dowel action. As the diagonal crack becomes wider towards failure, and as the break of bond develops progressively in the failure region, the shear transfer through aggregate interlock and dowel action both reduces to negligible proportions. To utilize fully the dowel action and aggregate interlock in resisting shear in RC beams, the web reinforcement needs to be designed so as to yield simultaneously with the longitudinal steel, which, of course, is very difficult to achieve in practice.

Unlike RC beams, the resistance offered by dowel action in two-way slabs is much higher, of the order of 25–35% of the ultimate resistance. This contribution cannot therefore be ignored in the analysis and design of the punching shear strength of slab-column connections. However, there is a simple way of quantifying the contribution of dowel action to shear resistance. Many tests show that both concrete compression zone and dowel action contributions depend on the same parameters; it is then possible and justifiable to unify these two actions as a single entity, particularly because the estimation of the dowel action effect, on its own, is difficult, especially in the case of a slab where yielding of the tension reinforcement occurs.

Many tests also show that the shear behaviour of lightweight aggregate concrete beams is similar to that of dense concrete beams, and that no significant differences in the mechanism of shear failure exist between dense and lightweight aggregate concretes beams. There are, however, differences relating mainly to the magnitude of diagonal tension resistance. These arise from differences in bond stress, strength under combined stresses, and more particularly, from the shear contribution through aggregate interlock. In most types of lightweight aggregate concrete beams, the diagonal crack fractures a much higher percentage of aggregate particles compared to gravel and crushed rock aggregates, resulting in a reduction in aggregate interface shear transfer.

Published literature rightly emphasizes the complex and complicated nature of shear cracking, and the importance of avoiding sudden, brittle failures. The ability for beams and slabs to develop ductile failures in our designs, and preserve structural integrity under all load conditions has always been fundamental to structural design. But this requirement has now become much more critical in the light of our experience of structural failures all over the world. It is here that fibre reinforcement can bring significant engineering benefits.

Tensile cracking in plain concrete is inherently unstable and uncontrolled, and the incorporation of a small volume of steel fibres can totally transform such cracking into a slow, controlled crack growth, especially in the dowel zone. Many tests on RC beams and slab—column connections show that this unique property of fibre concrete can prevent spalling and disintegration of the concrete cover resulting in enhanced ductility and energy absorption characteristics, and preserve the unity and structural integrity of the members after failure. The incorporation of fibre reinforcement in concrete is particularly attractive and beneficial in slab-column connections where it can significantly enhance ductility and energy absorption properties, and transform brittle punching shear failures into gradual and ductile shear failures, and preserve the continuity and integrity of the structural element after failure.