DESIGN CONSIDERATIONS FOR SEISMIC TANGENTIAL SHEAR IN REINFORCED CONCRETE CONTAINMENT STRUCTURES

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SUMMARY

Introduction: An important design condition in reinforced concrete containment structures is that of combined internal pressurization and seismic action. In conventional U.S. cylindrical containments the pressurization produces horizontal and vertical cracks on the order of 0.3 to 0.4 mm wide. The seismic membrane shears must be transmitted across these cracks by a combination of interface shear transfer (IST) on the rough concrete surfaces, by dowel action (DA) in the reinforcing bars crossing the crack, and by axial forces in inclined bars provided to resist membrane shear. This paper presents results of extensive experimental studies on IST and DA in large concrete specimens subjected to combined tension and cyclic shear, the resulting design implications, and the influence of this non-linear shear resistance mode on dynamic response. Research sponsors are NSF and NRC.

Results: Interface shear transfer (IST) degrades with cyclic shear loading. As reversing shear (simulating seismic action) on the order of ± 1.4 MPa progresses, the concrete interfaces degrade slightly. The amount of "free slip" encountered at low shear stresses increases, but after the two surfaces of the crack make contact, the second leg of the shear stiffness relation becomes more stiff with each shear reversal. The area enclosed by the resulting hysteresis loop decreases slightly with increased cycling. Forces in the reinforcing bars normal to the crack, induced as the two concrete surfaces at the crack tend to ride over one another, are about 1/3 the total applied shear load when the crack width is 0.3 mm. This restraining force increases substantially with crack widths of 0.5 mm or more. IST characteristics of cracked concrete sections (areas from 1450 to 1940 cm^2) are specified as functions of crack width, shear stress level, axial stiffness of rebars across the crack, concrete properties, etc.

Dowel action is defined for reinforcing bars (43 mm diam. and smaller) embedded in large precracked concrete blocks, loaded in cyclic shear alone and in combined cyclic shear and constant axial tension. The shape of the dowel force-shear displacement relationship and its degradational characteristics with load cycling are both similar to that of IST, but with tighter hysteresis loops. Tension of about 200 MPa applied to the bar increases dowel flexibility by as much as 50% and also leads to earlier development of combined dowel-bond splitting along the bars. These effects have been studied extensively.

Combined IST and DA for cracked concrete reinforced with large bars (43 mm diam.) is also described in detail. An engineering model to represent this behavior is formulated for use in helping to establish new design criteria. New dynamic response analysis methods for cracked containments are summarized. The reduced nonlinear stiffness, which changes with seismic shear reversals, is used to predict vessel response. The distribution of shear stresses around the containment is given, taking into account the possibility of closed cracks over part of the vessel because of overturning effects.

Closure: Seismic membrane shear transfer by IST and DA in cracked reinforced concrete is feasible at stress levels on the order of 1.5 MPa shear; higher stress levels may be feasible pending the outcome of current experiments on large biaxially tensioned specimens carrying reversing membrane shear. Design implications with regard to (a) potential splitting effects, (b) dynamic response, and (c) multidirectional reinforcing patterns, may now be formulated on a more realistic basis. Tentative design recommendations are compared with existing code requirements.