

Design Considerations for Reinforced Concrete Nuclear Structures Subjected to Simultaneous Pressure and Seismic Shear

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ABSTRACT

This paper includes: (a) a review of experimental results on 50 tests on flat reinforced concrete elements subjected to simultaneous tension and cyclic in-plane membrane shear, and (b) the formulation of preliminary design recommendations for strength and stiffness of the walls of containments and other structures carrying this combination of forces, which can be produced by combined pressurization and seismic loading.

Experiments were conducted with 6 inch thick specimens reinforced with either two-way orthogonal bars or four-way bars, with steel percentages similar to those used in containment structures. Specimens were precracked in tension in most cases, and then loaded in shear. Variables included steel percentage, type of reinforcing pattern, biaxial tension or only uniaxial tension in the orthogonal steel, level of tension during shear (0 to $0.9f_y$), type of shear loading (monotonic or cyclic), sequence of application of tension and shear, and level of stress at which cyclic shear was begun. A lower bound expression for the shear strength of cyclically loaded specimens reinforced with two-way orthogonal steel is given by

$$v_u = [2.7 + 0.6(\rho f_y - \sigma_N)] \sqrt{f'_c} \text{ (psi)}$$

where ρ is the minimum reinforcement ratio, f_y is the yield strength of reinforcing steel, f'_c is the compressive strength of the concrete in psi, and σ_N is the applied normal stress (biaxial tension level). Strength for two-way reinforcing is predicted by a simple equilibrium model that accounts for axial and dowel forces in the reinforcing crossing a potential diagonal failure crack, but specimens with four-way reinforcing were substantially stronger than model predictions.

The shear stiffness for specimens cracked in both directions is very low and relatively independent of level of biaxial tension. A representative value of shear stiffness is about 5% of that of uncracked concrete, with further degradation of the secant stiffness as cyclic shear load is continued. Tangent stiffness after cycling is extremely low for shear stresses less than about 25 psi, but increases rather sharply at high shear stresses. The effects of the low shear stiffness on deformations and forces in the containment liner are discussed.

Comparisons are given between these test results and results on much thicker specimens tested at the Portland Cement Association, and both are compared to experiments conducted on small-scale cylindrical structures in Japan.

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