Modeling the Nonlinear Behavior of ASR-Affected Concrete Structures

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Abstract

The long operating lives and the license renewal process of nuclear power plants require an assessment of structural integrity against internal and external hazards. The structural integrity of concrete structures can be affected by degradations caused by Alkali-Silica Reaction (ASR) that takes place in concrete over an extended period of time. ASR in concrete is a chemical reaction that produces an expansive gel inside the concrete when it encounters water. The gel expansion leads to degradation in the mechanical properties of concrete. Throughout the world, many nuclear power plants are affected by ASR-induced degradation. Hence, it is necessary to predict the behavior of ASR-affected concrete structures and determine the impact of ASR on safety. This study proposes an approach that simulates the non-linear behavior of ASR-affected reinforced concrete structures.

This study uses large-scale experimental data from the literature that consists of reinforced concrete (RC) panel specimens. The RC specimens are conditioned in an environmental chamber to encounter ASR and tested under pure shear loading. A previously proposed method for modeling ASR expansion and concrete degradation has been incorporated into finite element analysis using the Concrete Damaged Plasticity (CDP) model. This approach is then used to capture the shear behavior of reinforced concrete panels after ASR has occurred. Firstly, the residual ASR-induced strains and the ASR-induced expansion behavior are simulated using an orthotropic thermal expansion. Subsequently, loading conditions in the experimental study are replicated to investigate the response of ASR-affected specimens subjected to shear stresses. The sensitivity of the proposed approach to different modeling and material parameters is investigated. The four CDP model parameters found to have the most significant impact are tension damage, strain hardening, tension stiffening, and dilation angle. Recommendations are provided for evaluating and estimating each of these parameters in finite element-based simulations. The behavior of the ASR-affected panels is predicted with high accuracy in both low and high strain regions.

The main contributions of this research are as follows: (1) it incorporates the evolution of ASR strains in a finite element analysis by using an orthotropic thermal expansion model, (2) it accounts for ASR-induced damage and its impact on behavior using a concrete damage plasticity model and (3) it accurately simulates the nonlinear shear stress-strain behavior of shear panels and examines how uncertainties in modeling and material properties affect the behavior of ASR-affected shear panels.