FE-FFT multiscale model of damage in hydroelectric dams under alkali-silica reaction

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Abstract

Hydroelectric dams are susceptible to Alkali-Silica Reaction (ASR), a concrete degradation mechanism that leads to structural expansion and cracking. ASR spans multiple length and time scales, from chemical reactions at the atomic level to the deterioration of structures over 200 meters tall. The Swiss Committee on Dams (1) emphasizes the critical need for representative numerical models to understand and predict dam deterioration. Current multiscale numerical models of dams under ASR are limited to 2D due to the computational cost of conventional methods such as Finite Elements (FE) (2, 3). However, 3D modeling is crucial, since dams are almost systematically composed of 3D features such as arches and corners.

This study proposes a 3D multiscale approach that integrates Fast Fourier Transform (FFT)-based solvers at the mesoscopic scale with FE method at the dam scale. The mesostructure of concrete is represented by three phases including aggregates, cement paste, and expanding ASR gel pockets. A non-local damage model is employed to simulate crack initiation and propagation within periodic Representative Volume Elements (RVEs). These RVEs are loaded with macroscopic strains derived from dam-scale loading conditions, such as structural weight and hydraulic pressures. This 3D FE-FFT approach allows to derive key structural parameters, including homogenized stiffness and displacements at the dam crest. These outputs are compared with those from the existing 2D FE^2 model (3) and validated against field data from the Illsee dam in Switzerland.

(1) Swiss Committee on Dams. Concrete Swelling of Dams in Switzerland. 2017.

(2) A. I. Cuba-Ramos. Multi-Scale Modeling of the Alkali-Silica Reaction in Concrete. EPFL, 2017.

(3) E. R. Gallyamov, A. I. Cuba Ramos, M. Corrado, R. Rezakhani, and J. -F. Molinari. Multi-Scale Modelling of Concrete Structures Affected by Alkali-Silica Reaction: Coupling the Mesoscopic Damage Evolution and the Macroscopic Concrete Deterioration. International Journal of Solids and Structures 207: 262–78, 2020.

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