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DEVELOPMENT OF FINITE ELEMENT PROCEDURES FOR THE 2-D SIMULATION OF ALKALI-AGGREGATE REACTION IN CONCRETE

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Introduction

Many concrete structures throughout the world are suffering from deteriorations induced by Alkali Aggregate Reaction (AAR) that impair the durability, serviceability and might also affect, in the long term, the safety of the installation. AAR produces concrete expansion and leads to reduction of strength, stiffness and generates undesirable deformation. The most evident manifestations of deleterious AAR in a concrete structure are map cracking, displacement of structural member due to internal expansion of the concrete, and popouts. (ACI committee 221, 1998). For diagnostic as well as remedial purposes it is important for engineers to be able to simulate the effects of AAR on a structure. This paper presents a finite element procedure to simulate Alkali-Aggregate Reaction in concrete using the general purpose finite element package SAP2000.

AAR causes concrete to undergo expansion with time. The rate of AAR and therefore the rate of straining is controlled by compressive stresses within the concrete. Under high compressive stresses the expansion due to AAR slows down considerably. In some situations AAR can even be self-limiting as a result. In this study, a simple piece-wise linear relation was used to model the dependency of the rate of expansion on the compressive stress. The effect of the expansion of concrete on the structure was estimated in an incremental fashion by mimicking it as a thermal expansion which could be readily accommodated in SAP2000.

In order to verify the results of the simulation an analytical solution for a simple problem was obtained and used as a benchmark solution for testing the finite element procedures. There was good agreement indicating the validity of the proposed procedure.

Methodology

The expansion and damage due to AAR are strongly influenced by applied compressive stress or compression induced by restraint to AAR expansion. Therefore it is modeled as a stress dependent concrete growth function in the analysis. Concrete growth strain varies with the compressive stress. Figure 1 shows the relationship used in the calculations. (Huang and Pietruszczak, 1996). However, it should be emphasized that the proposed simulation method is independent of the particular model used to relate concrete expansion to the stress.

An important assumption used in the simulation is that the expansion due to AAR in the principal stress directions are uncoupled and that, for a given small time increment, the expansion in each principal direction and the corresponding principal stress are related through a relationship like the above independently of the other principal stresses.

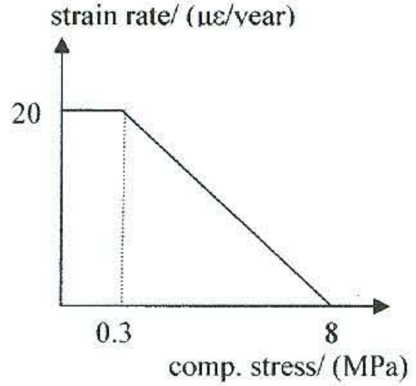

Figure 1. Strain rate vs. comp. stress in concrete

The simulation over a long time period is performed as a series of small time increments. The SAP2000 package is used to analyze strain increments within a given time increment as being due to a temperature increment. Using the stresses at the beginning of the time increment in each finite element the principal directions and the principal stresses are calculated. These values are then used to estimate the strain increment in concrete in each principal direction. The orthotropic material coordinates are set along the principal directions and the coefficient of thermal expansion in each direction is set equal to the strain increment in that direction. The entire structure is then subjected to a unit temperature rise, and the SAP2000 package is used to compute the resulting stress increments which are used to update the total stresses in the concrete. This new state of stress will be the starting point for the next time increment and so on.

The present study was limited to 2-D plane strain cases. A computer program was written to update the stresses and the material coordinate directions and properties in the SAP2000 database after each time increment.

The case of a simple uniform column fixed at either end and subjected to AAR was used as a benchmark problem to test the simulation results. An analytical solution for this problem was obtained and simulation results were compared against this analytical result.

Results

The solution to the benchmark problem of a uniform column under AAR is given by:

$$\sigma = \begin{Bmatrix} E\dot{\varepsilon}_u & \text{for } t \le t_0 = \sigma_L / E\dot{\varepsilon}_u \\ \sigma_U - (\sigma_U - \sigma_L)e^{-\lambda(t-t_0)} & \text{for } t > t_0 \end{Bmatrix}$$

Where

$$\lambda = E\dot{\varepsilon}_u / (\sigma_U - \sigma_L)$$

$\dot{\varepsilon}_u$ = unrestrained concrete growth rate at zero stress

σ_L = stress below which $\dot{\varepsilon} = \dot{\varepsilon}_u$

σ_U = stress above which $\dot{\varepsilon} = 0$

$\dot{\varepsilon}$ = strain rate

t = time

E = modulus of elasticity of concrete.

The result of the comparison of the finite element simulation of the benchmark problem with the above analytical solution is shown in

Figure 2. Further details are given in (Ajith *et al.*, 2009). The good agreement is indicative of the validity of the proposed simulation method.

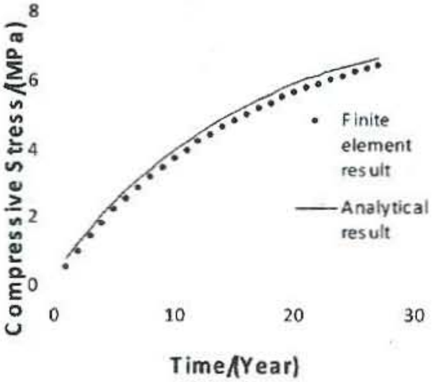

Figure 2. Stress vs. time for benchmark problem

Conclusion

The proposed simulation technique for AAR holds promise for use in 2-D cases. It is independent of the model used to relate the expansion of concrete to the stress. It may be easily extended to 3-D cases as well.

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