ABSTRACT

Raoufi, Kambiz. PhD, Purdue University, May 2010. Restrained Shrinkage Cracking of Concrete: The Influence of Damage Localization. Major Professor: Jason Weiss.

Tensile stresses are generated in concrete when volume changes caused by moisture loss, temperature reductions, and chemical reactions are restrained. When these tensile stresses are high enough, they may result in cracking. Cracks can accelerate the deterioration of concrete and reduce the service life of structures. While numerous efforts have been made to evaluate the cracking performance of concrete using small scale laboratory geometries, further work is still needed to link the cracking behavior of small laboratory geometries to that of full scale concrete elements. Small scale laboratory geometries such as the ASTM C-1581 restrained ring or dual ring test geometries corresponds to a slab of approximately one meter long, however most concrete members of interest in the field are 3-5 meters long. In addition to the dissimilarity in the size, the degree of restraint, boundary conditions, and rate of stress development of the laboratory geometries can be different from those of in-situ concrete members. This research sought to quantify the influence of some of these factors.

This study used finite element analysis to investigate the influence of the size of the concrete elements, boundary conditions, degree of restraint, fiber reinforcement, material properties, and rate of shrinkage on the stress development and cracking behavior of concrete elements.

The study begins by examining the influence of damage localization on the size of the crack that develops. It is shown that localization results in the width of the crack that forms being dependent on the length/size of concrete element tested. Further, the crack appears to occur at a slightly earlier age as the length/size of concrete element increases. It is shown that the width of cracks that form in laboratory specimens cannot

directly be used to estimate the cracking performance of larger in-situ elements as is being commonly done in the industry.

The second phase of this study examined the influence of specimen size on the restrained ring test. Restrained rings of various sizes were simulated to investigate the effect of ring size, degree of restraint and fiber reinforcement (i.e., cohesive fracture properties) on the cracking performance of concrete materials. The cracking behavior of the restrained ring test is size dependent and smaller rings tend to have a smaller crack as expected. As the degree of restraint is reduced, stress develops at a slower rate, concrete cracks at a later age and the width of crack is reduced. When cracking occurs at a later age, more stress relaxation has the chance to occur, which would further reduce the width of cracks that form.

Many researchers and specifiers refer to the age of cracking as a material property. This work however shows that the age of cracking is not a material property and is dependent on the geometry of the sample being tested. The third phase of this research examined the role of base restraint on the cracking of linear concrete elements. A series of base-restrained concrete specimens were studied. As the bond between concrete and base decreases, less interfacial de-bonding occurs, fewer cracks are formed, and the maximum size of crack is increased. In cases where a large de-bonded region exists, one major wide crack forms. This crack in the specimen with a large debonded region occurs at an earlier age than in specimens that have a small debonded region.

The final component of this work consists of performing a parametric investigation of the dual ring test. The dual ring, which has been studied by a series of researchers at Purdue since 2002, has recently becoming more widely used to provide a method to quantify the performance of mixtures with a low cracking potential. A series of simulations was performed to quantify the influence of a variety of parameters that influence the results of the dual ring test. The stress development in dual ring is influenced by the elastic modulus of concrete and restraining rings, coefficients of thermal expansion of concrete and restraining rings, magnitude of shrinkage, stress relaxation and rate of cooling. Stresses develop at a slower rate and stress relaxation increases when the elastic modulus of concrete, degree of restraint, or rate of thermal or autogenous shrinkage is reduced. A higher stress relaxation can result in significant stress redistribution during crack propagation, a lower failure stress, and a reduction in cracking potential for restrained concrete elements.

The results of this study were used to design a large scale concrete geometry to assess the in-situ cracking performance of concrete members. Influence of the size of concrete, fracture properties, and degree of restraint on stress development and cracking behavior of concrete specimens were considered in designing the large scale testing geometries.