UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Residual Load Capacity and Modelling of Failure Mechanisms of Alkali-Silica Reaction Affected Concrete Structures

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under the supervision of
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Certificate of Authorship/Originality

I, Atila Sarikaya, declare that this thesis is submitted in fulfilment of the requirements for the award of doctor of philosophy, in the Faculty of Engineering and IT at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

Alkali-silica reaction (ASR) in concrete can impair a structure's essential functions regarding strength and serviceability. Considering the number of structures suffering from ASR, it is of great importance to determine the residual load capacity of ASR-affected concrete structures.

In this study, a phenomenological model is developed to determine the mechanical behaviour of structural elements in the inelastic range. One of the key components of the model is the *coupled elastoplastic-damage constitutive model* (CEPD), which can capture permanent deformations and stiffness degradation that accumulate during inelastic processes. ASR effects, on the other hand, are represented as a combination of ASR-induced residual stresses and eigenstrains. Hence, mechanical stresses associated with the free expansion and ASR-induced internal pressures are considered simultaneously. The model is capable of representing the evolution of plasticity and damage variables under free ASR expansion conditions. In case external stresses are present (at macroscale), they interact with ASR-induced stresses and contribute to the evolution of inelastic variables.

One of the essential contributions in the present work is the *direct-coupling* method in which a prescribed relationship between the strain tensor components is defined. The method allows using a single set of variables. Hence, the number of parameters required for calibration is reduced. Computational efficiency of the method is also shown.

As another contribution, a three-surface composite yield function is developed for concrete. Accordingly, a *transition zone* yield surface defined between compression and tension yield surfaces is proposed. The presence and definition of the transition zone allows one to limit deviatoric stress. Therefore, it provides more accurate results than those obtained from the two-surfaced yield functions based on tension cut-off only. In addition, an explicit return-mapping algorithm is developed for the general multi-surface plasticity, and it is applied to the concrete plasticity computations.

Results obtained from the model are compared with the experimental data. Firstly, stress-strain diagrams for normal concrete (no ASR involved) are compared, and it was shown that results are very close under monotonic and cyclic loads for a large range of concrete strengths. Secondly, load-displacement diagrams of ASR-affected beams are compared. Under significant ASR expansion conditions, the characteristic features such as degradation in stiffness and loss in load-carrying capacity are observed from the beam model results. On the other hand, for moderate degree of ASR expansion, the load-displacement relations of beams showed no significant difference, which is in agreement with physical experiments.

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Atila Sarikaya

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List of Publications

Journal Paper

J-1. **Sarikaya, A.** & Erkmen, R.E. 2019, 'A plastic-damage model for concrete under compression', *International Journal of Mechanical Sciences*, vol. 150, pp. 584-93. https://doi.org/10.1016/j.ijmecsci.2018.10.042

Conference Papers

C-1. **Sarikaya, A.**, Erkmen, R.E., Gowripalan, N., Sirivivatnanon, V. & South, W. 2019, 'A plastic-damage model for concrete under cyclic loads', paper presented to the Concrete 2019, Sydney, Australia, 2019/09/11.

C-2. **Sarikaya, A.**, Erkmen, R.E., Gowripalan, N., Sirivivatnanon, V. 'A plastic-damage model for concrete affected by alkali-silica reaction', 16th International Conference on Alkali-Aggregate Reaction in Concrete (ICAAR), Lisboa, Portugal, 2020-2022.

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Abbreviations

AAR	Alkali-Aggregate Reaction
ASR	Alkali-Silica Reaction
BVP	Boundary Value Problem
CEPD	Coupled Elasto-Plastic-Damage (model)
CP	Complementarity Problem
CPA	Generalised Cutting Plane Algorithm
CPPA	Closest Point Projection Algorithm
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
KKT	Karush-Kuhn-Tucker (conditions)
LCP	Linear complementarity problem
NR	Newton-Raphson (technique)