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BENCHMARK PROBLEMS FOR ASSESSING A COMBINED MICRO-MECHANICAL CONTINUUM BASED MODEL FOR CONCRETE

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Summary.
Two sets of benchmark problems are described. The first is based on a series of notched torsion tests on plain concrete specimens, which were undertaken at Cardiff University in the mid 1990s, but for which many of the results were not published until the tests were used recently by the authors to validate a numerical model for concrete. The second set of benchmarks described is based on a series of tests undertaken recently by the authors on hexagonally shaped specimens loaded in compression, in which some of the specimens were loaded to a point where some damage occurred were then unloaded, rotated and reloaded again until failure. Both sets of tests are considered in a series finite element analyses which employ a plastic-damage-contact model for concrete developed by the authors. This contribution then goes on to describe, in outline, the recent development of the model in which a micro-mechanical solution, based on a two-phase composite, is used to simulate compression induced cracking.

1 INTRODUCTION

A review of papers which address the numerical simulation of concrete fracture in recent years shows that there are certain experimental studies which are considered by many authors for the validation of numerical models[1]. These, for example, include the experimental studies of Arrea & Ingraffea[2], Hassanzadeh[3] and Nooru-Mohammed[4]. The data set used is, in many respects, rather limited when compared with the number of numerical investigations in which it has been employed and, in particular, there are a limited number of examples suitable for the validation of three dimensional models. Furthermore, there are also limited data available on compression induced fracture.

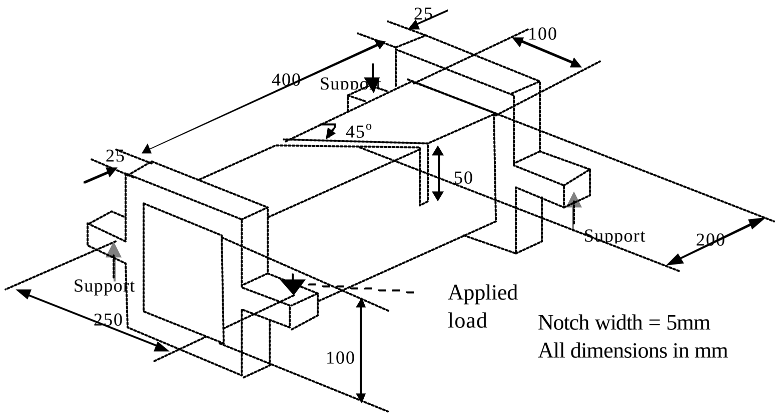
In an attempt to provide more examples suitable for validating three-dimensional modelling approaches, the authors have recently presented results[1], and associated finite element simulations, from a set of notched torsion fracture tests undertaken by Barr and Brokenshire[5,6] in the mid 1990s for which only very limited results were previously published. The present authors have also conducted a series of tests on hexagonally shaped specimens loaded in compression in which some of the specimens were loaded to a point where some damage has occurred, then unloaded, rotated and reloaded to failure across different surfaces. These tests, and the results of some associated finite element analyses, are described in a forthcoming publication[7].

The primary motivation for considering the above experimental studies was to provide validation data for the on going development of a three dimensional plastic-damage-contact model for concrete, named Craft[7,8]. Recent development work on the model has focused on the use of micro-mechanical solutions to simulate cross-cracking, i.e. splitting cracks induced by compression.

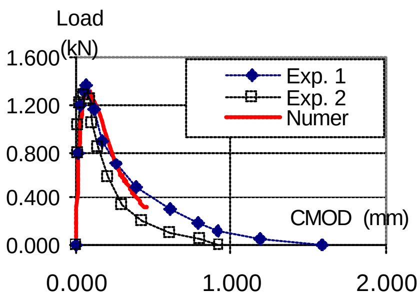
In this contribution outline descriptions of the experimental studies are provided along with a few key results from finite element analyses in which the above model, as implemented in the Finite Element program LUSAS, is used for the simulations. The essential features of the micro-mechanical cross-cracking model are then discussed.

3 THREE DIMENSIONAL TORSION FRACTURE TESTS

A series of torsional fracture tests were undertaken by Barr and Brokenshire[5,6,1] in the mid 1990s for the purpose of developing a test for measuring the fracture energy of plain concrete. Tests were conducted on notched prismatic and cylindrical specimens and the testing arrangement for the former is illustrated in Figure 1. The torsion load is applied via steel collars which were bolted to the ends of the specimens.



Test set up for prismatic tests



Load CMOD response

Figure 1: Notched cylindrical tests of Barr and Brokenshire

The measurements taken in the test series included crack mouth (normal) opening and sliding displacements as well the load and displacement at the point the load was applied to the loading collar. The opening and sliding displacements were measured with clip gauge transducers. Feedback from the crack mouth opening clip gauge transducer was used to control the load.

The tests were considered in a series of finite element analyses which used the plastic-damage-contact model implemented in the finite element program LUSAS. Results from a recent simulation are shown in Figure 1, which shows that the peak load and initial softening behaviour is captured well. It is noted that the match between experimental and numerical results is closer than that presented in Jefferson *et al.* [1]

4 ROTATED HEXAGONAL COMPRESSION TESTS

A new series of tests has been undertaken by the authors on hexagonally shaped specimens, which are loaded in compression until some damage has occurred and then unloaded and rotated before being reloaded again until failure[9]. The test set up is illustrated in Figure 2. The results show that the diffuse cracking accumulated during the initial loading direction has the effect of lowering the peak load carrying capacity of the rotated specimen relative to the peak load obtained under monotonic loading, as illustrated in the response curves shown in Figure 2 in which Set 1 tests are loaded monotonically and Set 3 loaded, unloaded and rotated.

Numerical simulations of the experiments were performed here using the Craft model. The numerical results manage to capture the essential features of the experimental behaviour, in particular, a reduction of the peak load attained as a result of damage initiated in the original loading direction, however the post-peak responses were not always captured accurately. The result of the simulation of a test, without a twist, is shown in Figure 3.

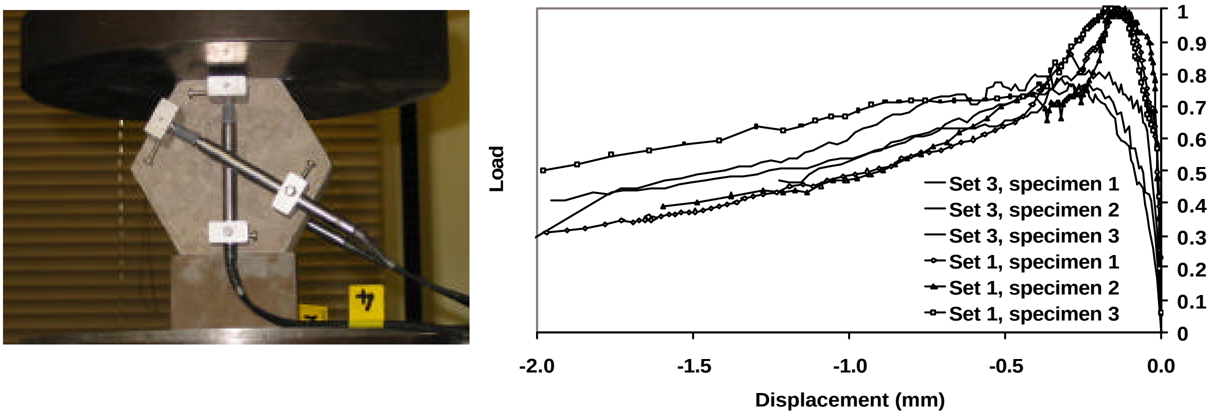


Figure 2. Hexagonal specimen testing arrangement and response curves

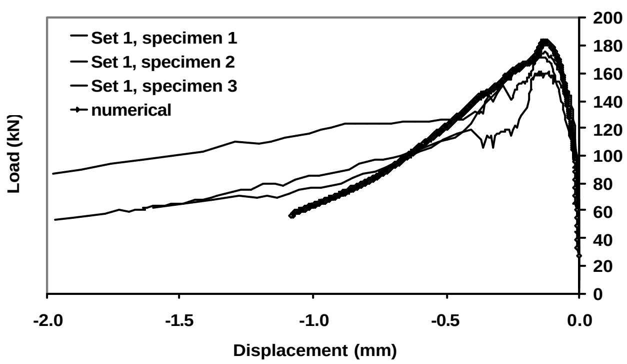


Figure 3. Experimental and numerical response curves for monotonic loading case

5 COMBINED MICRO-MECHANICAL, CONTINUUM BASED MODEL

The model is a development of the Craft model referred to above, but uses a micro-mechanics based damage component. In this model it is assumed that concrete comprises a matrix and an inclusion phase, each with different elastic properties. Eshelby tensors are employed to derive the strain in each phase and a Mori-Tanaka averaging scheme used to derive the overall constitutive relationships. The chief advantage of this approach is that under uniaxial compression tensile stresses develop in the matrix phase which can be assumed to develop micro cracks, thus even when there is no overall tensile stress, the model predicts the experimentally observed cracking that occurs in uniaxial compression tests . The development of the model is on-going but the essential ideas are provided in Jefferson and Bennett[10]

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