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LARGE SCALE DIRECT TENSION TEST OF CONCRETE

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ABSTRACT

A pilot large scale direct tension test is reported. Two independently controlled actuators were used to ensure a homogeneous tensile field and to avoid secondary flexural stresses. Fracture energy and tensile strength are reported. From this pilot test, it was determined that the fracture energy obtained from large scale direct tension tests is significantly higher than the one obtained in wedge splitting tests on laboratory sized specimens.

Introduction

Whereas it is widely acknowledged that ideally tensile strength and fracture properties of concrete should be determined from direct tension tests, the complexity of such a task has precluded the widespread use of such test. Instead, those important material properties are commonly obtained from tests on notched flexural specimens (notched beams, or wedge splitting tests). As such, there are doubts as to whether strength and fracture properties indirectly obtained from such tests are truly material properties, or whether they are also significantly influenced by the specimen geometry.

It should be noted that relatively few direct tension tests (as compared to fracture of flexural specimens) have been performed, for reference we cite, [1, 2, 3]. In most cases a single actuator was used, and an elaborate mechanical system ensured the uniformity of the load. The complexity of such a test stems from the fact that once a crack starts at one end (due to the heterogeneity of concrete), redistribution occur resulting in secondary flexural stresses.

In the proposed experimental setup, based on two separate actuators, a constant crack opening along the ligament is maintained throughout the fracture test. To the best of the authors knowledge, Carpinteri and Ferro were the first, and only, researchers to perform multiple actuator tension tests, albeit on much smaller specimens, [3].

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Hence, this communication reports on what the authors believe to be the largest servo-controlled direct tension test ever performed on concrete specimens. This basic and fundamental pilot test yielded some interesting results which should be interpreted within the context of the Size Effect Law, [4].

It should be noted that only one test was performed at a time when financial support was available for only one such experiment. Clearly, no definite conclusions could be drawn from it; however given the size of the specimen, the complexity of the setup, and the uncertainly associated with the likelihood of others in the near future, prelimiary results are hereby presented.

Test Setup

As part of an ongoing research project, investigating the mixed mode response of concrete/rock interfaces, [5], a unique large scale biaxial testing apparatus was designed, assembled and tested in the Structural Engineering Laboratory of the University of Colorado, see Fig. 1.

Starting with an existing 4,400 kN (milion pounds) servo-controlled testing machine, two additional horizontal actuators, each with a capacity 530 kN (120 kips) in tension and 660 kN (150 kips) in compression were installed. Each of the three actuators is in turn separately controlled by an analogue controller, providing the experimentalist with endless possibilities. Two horizontal actuators were selected instead of a single one to provide better (independent) control for uniform stress fields, or to facilitate the application of a stress gradient.

The setup was designed to accommodate specimens with cross sectional dimensions of 750 by 250 mm (30 by 10 inches). Thus, normal stresses of 5.5 MPa (800 psi) and 7.0 MPa (1,000 psi) could be applied in tension and compression respectively through the two horizontal actuators.

Hence, this unique setup was used to perform a single large scale direct tension pilot test.

Specimen Preparation and Properties

The specimen was monlothically cast, and its gross dimensions were 1,016 by 762 by 254 mm (40 by 30 by 10 inches). A 25 mm (one inch) deep and 16.5 mm (0.65 in.) wide side groove was preformed, and in addition two opposite notches, 99 mm (3.9 inch) deep where placed. Thus the net dimensions of the section were tensile failure was induced were 203 by 564 mm (8 by 22.2 inches), and a cross sectional area of 1,145 cm^2 (to be compared with Carpinteri's 400 cm^2). Fig. 2 shows the specimen dimensions.

In order to connect the specimen to the actuators, two parallel aluminum plates were anchored to the concrete specimen. Great care was exercised in ensuring that those plates were exactly parallel to each other, and numerous 76 mm (3 inch) long anchors were used to connect the plate to the concrete.

Concrete mix consisted of 14.6% cement, 7.3% water, 23.4% sand, 54.7% gravel (maximum aggregate size 20 mm, 3/4 inch) by weight.

The specimen was tested after 31 days, and had a tensile strength (measured from three Brazilian tests) of 3.3 MPa (486 psi), and a compressive strength (average of three tests) of 28.2 MPa (4,095 psi).

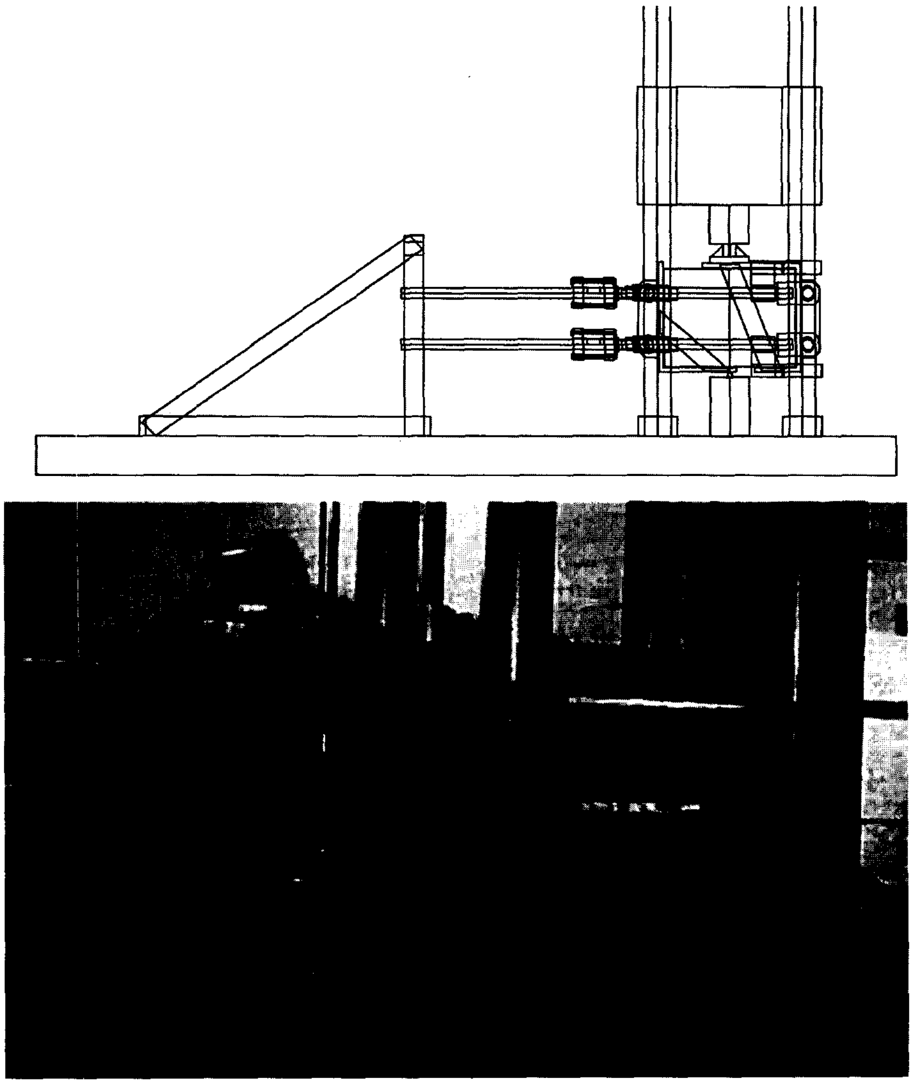

FIG. 1.
Large scale biaxial testing apparatus of the University of Colorado.

Instrumentation and Testing Procedure

The specimen was instrumented with two proximity probes (each having a resolution of 10^{-3} mm, $3.9*10^{-5}$ inch), one on the top and the other on the bottom side over the notches. The proximity probes had an effective gage length of 88.9 mm (3.5 inches) and were centered over the notch. Those proximity probes not only measured the crack opening displacements (COD) but also provided the feedback signal to the corresponding of the two controllers. In addition, the load applied by each individual actuator was recorded, as well as the acoustic emission detected from a single sensor.

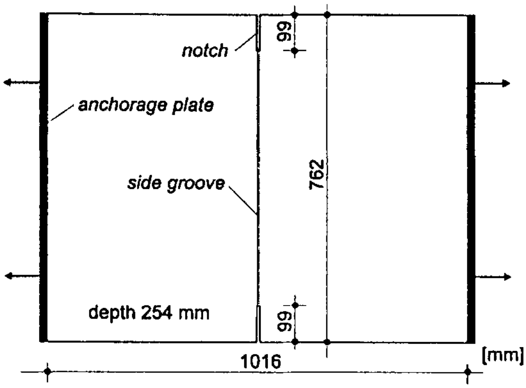

FIG. 2.
Specimen dimensions.

Test Results

Test results are graphically illustrated in Fig. 3.

Examination of the preceding figures, yielded the following observations

1. The load-CMOD recorded for the two actuators are almost identical, until the tailing end of the post-peak. This is a good indicator that indeed identical displacements were applied, and hence a nearly uniform stress field was obtained.
2. We note that whereas the two actuators had diverging loads with respect to time, the COD of both cracks were almost identical throughout the test.
3. Summing up the loads, and taking the average CMOD, we obtain the specimen load-CMOD curve. This, in turn, yielded an unexpectantly high G_F of 280 N/m. This value is to be compared with ≈160 N/m obtained on similar concrete mix, but using the wedge splitting tests by Slowik, Saouma and Plizzari [6].
4. Similar trends were observed by Carpinteri, decrease in tensile strength, and increase in fracture energy with respect to specimen sizes.
5. By preventing secondary flexural stresses, no strain gradient induced limitations of the fracture process zone size (length and width) occur. It is therefore assumed that the largest possible fracture process zone for the given specimen size is obtained. All stress transferring mechanisms, as are aggregate pullout, bridging, crack branching, are activated, resulting in a longer tail of the softening curve and consequently in a higher specific fracture energy.
6. Alternatively, the tensile strength of the specimen, was determined to be 1.61 MPa, which is about half the value of 3.3 MPa determined from the Brazilian tests. Even though completely different geometries were used, the respective nominal strengths appear to be in accordance with the Size Effect Law. However, it should be noted that the specimen had notches leading to stress concentrations and thus possibly a lower apparent tensile strength.
7. This preliminary result seem to indicate that a direct tension test can provide better experimental value for the fracture energy than tests on notched flexural specimens.

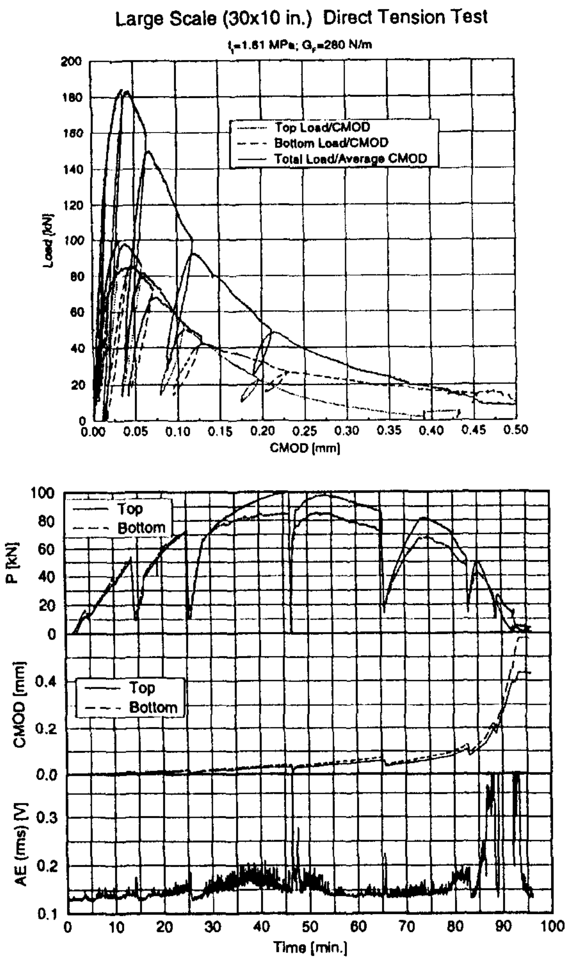

FIG. 3.
Results of pilot test.

Acknowledgments

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