MIXED MODE FRACTURE IN COMPACT SHEAR SPECIMENS

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A punch through type test geometry which is based on cube specimens has been investigated numerically. A range of variations to this geometry have been studied. The two main parameters investigated are (a) varying the top and bottom notches and (b) varying the bottom support condition. Initial experimental studies are also presented for a selected geometry.

INTRODUCTION

The primary aim of the work reported within is the optimisation of a punch through shear geometry developed by Davies (1). A similar geometry has been previously reported by Luong (2) who developed the geometry particularly for the investigation of the shear behaviour of rocks. Luong's (2) specimen originally used a cylinder into which two symmetric cores, one form the top and the other from the base, were cut.

For any shear (Mode II) specimen the essential features are that it must be of a simple compact geometry and be capable of being loaded in a standard testing machine. The geometry should also produce as near to pure shear as possible, in particular the removal of tensile stresses adjacent to the notch is attempted; this is the most onerous condition and has exercised considerable effort.

NUMERICAL RESULTS

The loading arrangement and support conditions for the six geometries investigated are shown in Fig. 1.

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The geometry is based on a 150mm cube with two 100mm diameter cores in both the top and bottom faces. The notch separations are specified as 30mm, 50mm and 70mm by varying the depth of the 4mm thick coring.

The support conditions are varied from simple full vertical support 1 and 3, full vertical and radial restraint 2 and 4, partial vertical support 5, to partial vertical and radial restraint 6. With only 1 and 2 being adopted for the symmetric top and bottom notches. The detail of the unsymmetrical coring is given in Fig. 2 to be used in conjunction with support conditions 3,4,5 and 6. For types 1 and 2 the notch depths were assumed symmetric about the centre of depth. The loading was assumed to be uniformly distributed on the top face.

Both 3D and 2D axisymmetric approximations to the geometry of Fig. 2 have been analysed using linear elastic finite elements. The area of greatest interest is the region between the two cored notches, the work presented therefore concentrates on the stress distribution between them. The stresses have been predicted between lines joining the inner, centre line and outer faces of the notch. In general tensile stress develop at the inner face at the bottom notch adjacent to the support, these are matched by tensile stress on the outer face of the notch below the loading cylinder. Compressive stresses are apparent at the outer face of the bottom notch and the inner face of the top notch. The tensile stresses, which are more evident in standard 2D analysis, are modified in the axisymmetric analysis by the compressive normal stress generated in the cored specimens. The radial restraint also helps to reduce these tensile stresses.

Fig. 3 shows the variation of the normalised maximum tensile stress with notch separation for the two symmetric cored types, 1 and 2, and for the four specimens with a 10mm notch at the base. The stresses are all normalised with respect to the average shear stress across the section to facilitate direct comparison of the stress localisation.

The results all indicate significant tensile stresses on the inner face of the bottom notch. The results indicate that specimen type 6 provides the smallest tensile stress for both the 30mm and 50mm notch separations. These normalised tensile stresses reduce as the notch depths are increased; this is a standard feature of stress localisation in notched samples.

Fig. 4 shows the variation of normalised normal, hoop and shear stress along a line joining the centre of each notch for specimen type 6. The hoop stress is small in magnitude and approximately constant along the line between the two notches. The normal stress is compressive with respect to the required shear failure surface and is of a similar magnitude to the shear stress.

There are indications of small tensile stresses normal to the shear surface at both notches. These stresses are smaller than indicated from Fig. 3 because the results are based on the centre plane midway between the faces of the notches.

EXPERIMENTAL RESULTS

The numerical investigations have been accompanied by, as yet, limited experimental studies. The present paper provides detail of the loading and monitoring arrangement together with a preliminary result. The tests recorded were undertaken on 150mm cubes of normal weight medium strength concrete.

The loading and monitoring arrangement is shown in Fig. 5. The top vertical movement between the platterns is monitored as the aggregate of the vertical transducers marked as 2 and 3 in Fig. 5. The loading is undertaken with deflection control from the bottom transducer 1. Radial movement is monitored at transducers 4 and 5. Transducer 4 is horizontally mounted to coincides with the vertical position of the bottom of the top notch. Transducer 5 is at the mid point of the notch separation.

The specimen installed within the loading frame of Fig. 5 coincides with that shown inset in Fig. 4 and is clearly of the geometry and restraint of type 6 as per Fig. 1.

Fig. 6 shows the variation of vertical displacement against load for a notch separation of 50mm. Based on a nominal diameter of 100mm for the cores, a load of 100 kN coincides with an average shear stress of 6.4 N/mm^2. The graph therefore extends up to a shear stress of the order of 16 N/mm^2 and the specimen has not visibly failed at that load. During the testing an audible crack was detected at approximately 100 kN.

Careful examination of both the top and bottom transducer traces indicate a bedding in path up to about 25 kN this is followed by a clearly stiff linear response which terminates at approximately 75 kN. At this load a quite rapid reduction in stiffness occurs, over a short load interval. This is followed by a more or less linear response, at a lower stiffness, up to full load at 250 kN. Total collapse occurred at a slightly larger load but is not recorded.

The variation of radial displacement with applied axial load is shown in Fig. 7. Both the upper transducer, 4, and the lower transducer, 5, plots are reproduced. The outward radial movements are conventionally assigned positive.

Following an initial bedding in, indicating a positive outward radial movement, the displacement progressively reduces inwards being more pronounced at the upper transducer. There are no other clear linear distinguishing features to these displacement plots, although there is evidence of a dogleg in both plots at about 80 to 100 kN.

It is considered that the initial failure occurred at approximately 75 kN load this coincides with an ave rage shear stress of 9.6 N/mm^2. This coincides both with the clear reduction in the vertical stiffness and a less apparent step in the radial response. Following this further tests were carried out and the loading was halted at 150 kN, prior to total collapse, and the specimen investigated. The specimen was broken up progressively from one side and it became apparent that failure between the two cored notches had already taken place.

DISCUSSION

It appears likely that the tensile fracture, as predicted by the numerical modelling, develops between the inner surface at the bottom notch and the outer surface at the top notch. This failure surface forms in the standard 'S' pattern. The initial tensile failure is likely to be proceeded by a mixed mode failure along the required plane.

Because the initial failure is from the inside at the bottom to the outside at the top a total collapse does not readily occur. The radial restraint, coupled to the hoop effect, compresses the failure surface. This coupled with the larger diameter of the failure surface at the top, than the bottom, results in large frictional resistance. This is considered to be the response between 75 kn and final failure when the outer disc bursts under the action of the inner truncated cone.

In conclusion, the investigation of the push through geometry has failed to remove the influence of the peak tensile stress. The normal stress generated in the selected geometry also appears to be so large as to almost mask the failure process.

ACKNOWLEDGEMENT

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(2) Luong,M.P.,"Tensile and Shear Strengths of Concrete and Rock",Int. Conf. on Fracture and Damage of Concrete and Rock, Vienna, 1988.

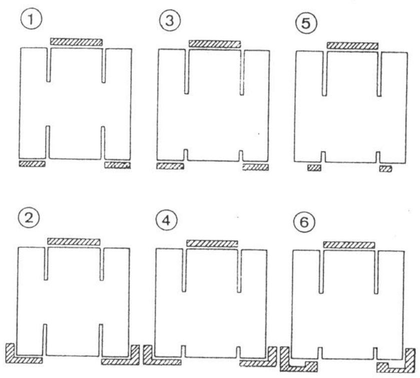

Fig. 1 Punch-through test specimen geometries

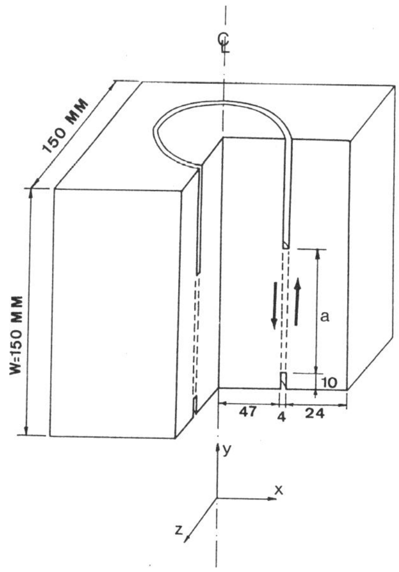

Fig. 2 Proposed shear test specimen geometry

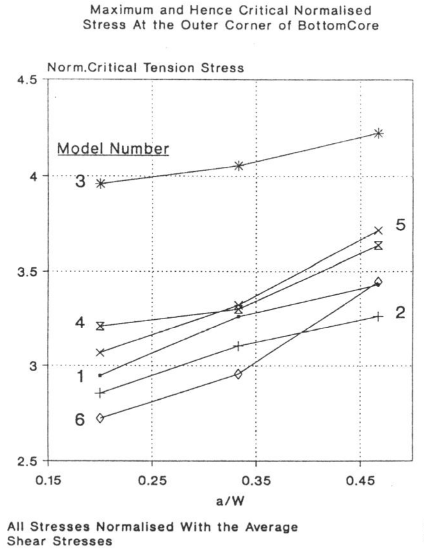

Fig. 3 Comparison of the proposed geometries

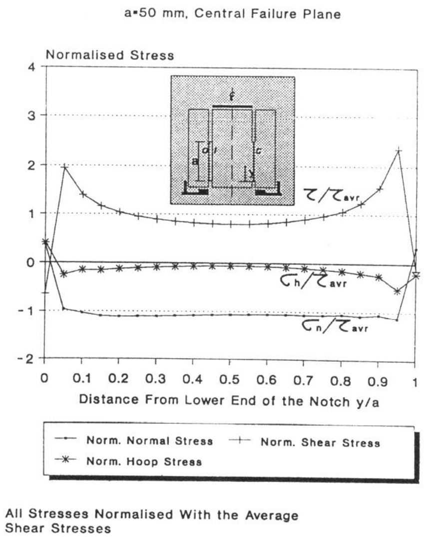

Fig. 4 Stress distributions along the proposed shear plane

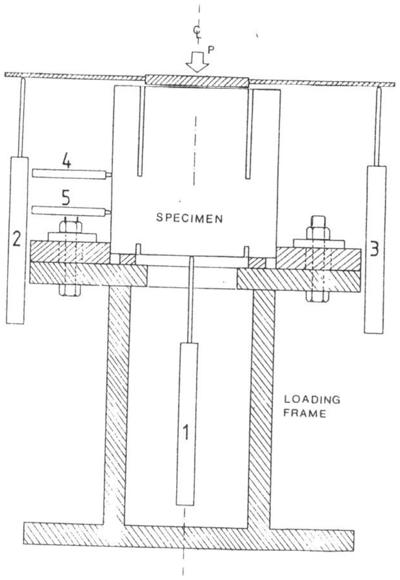

Fig. 5 Loading and instrumentation configuration

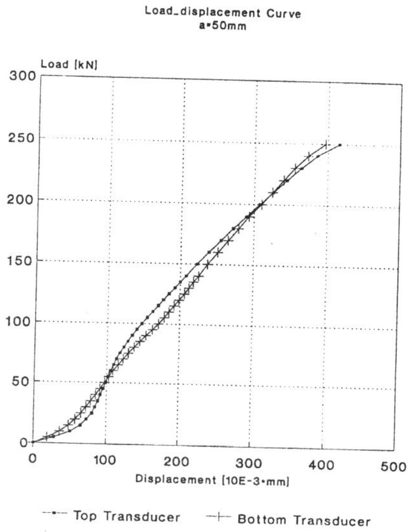

Fig. 6 Load-vertical deflection curve (Transducers 1, 2 and 3)

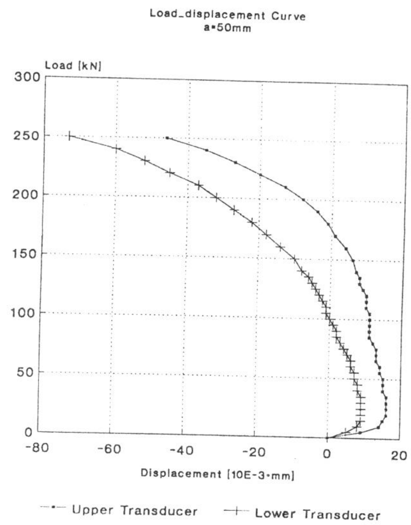

Fig. 7 Load-horizontal deflection curve (Transducers 4 and 5)