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The triaxial testing of fresh concrete*

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The tests carried out by Mr Ritchie on fresh concrete are interesting records of the resistance to deformation of this material, which appears to be closely allied to that of other materials such as clay, silt and sand which have been extensively examined during the last decade. Considerable knowledge exists as to their behaviour and the effect upon their resistance to deformation of air voids, pore water pressure, drainage conditions and so on. This knowledge may be used to examine the behaviour of fresh concrete. The techniques of soil testing have in fact been used in concrete technology from time to time but there have been difficulties, not the least of which is the interpretation of the results. For example, a test on various cements gave the following values of liquid limit:

ordinary Portland cement	18
high alumina cement	15
super-sulphated cement	17

These might be of interest, if they were of any practical use, but at present no such use exists.

In examining the development of the triaxial test for the measurement of the rheological properties of concrete, it is important to know the factors which influence the results. Undoubtedly these *include* the fineness of the cement, the amount of water, the shape and surface texture of the aggregates, and the relative proportions of the cement and the fine and coarse aggregates. For concretes made with the same cement and aggregates, it is clear that these factors will reduce the amount of water, and the relative proportions of the cement and aggregates. Mr Ritchie has shown that the angle of shearing resistance ø is affected by these factors and therefore it would be convenient to assume that ø is a direct measure of the rheological properties of wet concrete, but this is not so for the undrained triaxial test.

When the shear strength of a saturated material is determined by the undrained triaxial compression test, the result, for a saturated specimen, will be controlled by the value of the pore water pressure which develops. For cohesive materials fully saturated, the developed pore pressure, u, is equal to σ in the Coulomb equation $s = c + (\sigma - u) \tan ø$ so that $ø = 0$. For silts and fine sands, it is found that, below a certain value of cell pressure, the value of ø is not zero. This is associated with a dilatant structure and negative pore water pressures. Above the critical cell pressure, the pore pressure is positive and equal to σ so that $ø = 0$ again. We might assume that a rich mix (say 1:3) would approximate in behaviour to a saturated silt or fine sand, in which case we would expect it to behave as a c, ø material to start with and, after a sufficiently high cell pressure had been reached, to give a $ø = 0$ result. This may, indeed, be what Mr Ritchie obtained: see Figure I in which the Mohr circles are reproduced from his paper. From this it appears the critical cell pressure is about 45 lb/in^2 which compares with the value of 45 lb/in^2 obtained by Bishop and Eldin[(1)] for sand and of 65 lb/in^2 obtained by Penman[(2)] for silt.

This argument assumes, of course, that fully compacted fresh concrete has a dilatant structure, but since by definition a fully compacted concrete has been subject to large shearing forces to overcome its immobility, if it does not possess a dilatant structure then it is not fully compacted ! From tests on sands, silts and clays, it is known that an unsaturated specimen containing air, when tested under undrained conditions, will give an angle ø. It might follow, therefore, that the angles of ø measured by Mr Ritchie are a measure of

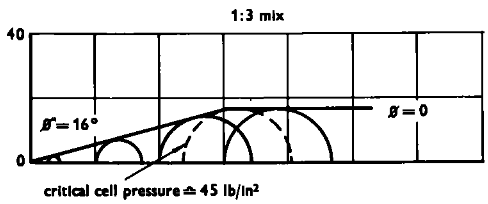

Figure I

*Pages 37 to 42 of *Magazine* No. 40.

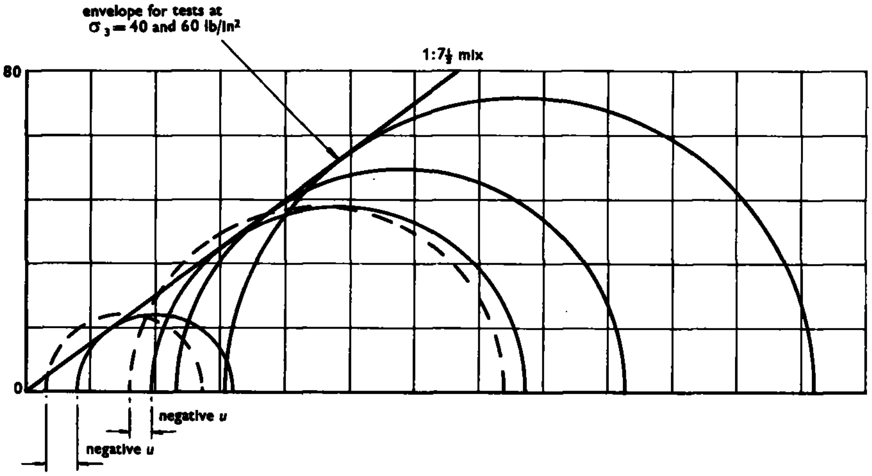

Figure II

the air voids content of his mixes. It is, of course, common experience that fully compacted concrete contains some air, but this is usually only about ½ to 1½%. Since this would not be sufficient to alter the results significantly from those expected from saturated specimens, we are back, therefore, to the conclusion that the results are affected by negative pore pressures.

If, during a test on a mixture of sand and gravel, a value of apparent cohesion c_u were obtained, we would know that this was due to the development of such a negative pore water pressure. An approximation to the angle ϕ' (in terms of effective stress) could be obtained by shifting the Mohr circles for the lower cell pressures to the right an amount u (= negative pore water pressure) to give $c' = 0$. For lean mixes, c' will be asymptotic to 0 and for a 1:7½ mix it is probably nearly equal to 0 for the higher cell pressures where the c_1' component is a small percentage of the total deviator stress and the negative pore pressures will be small. It is not surprising, therefore, that for the 1:6 and 1:7½ mixes a Mohr envelope (a straight line) for the cell pressures above 40 lb/in² passes close to the zero, with a smaller value of ϕ than the mean line shown. See Figure II also based on one from Mr Ritchie's paper.

In all this, however, the complete analysis of Mr Ritchie's results is impeded by lack of information as to the pore water pressure generated, so that an effective stress analysis cannot be carried out. I consider that the rheological properties of fresh concrete can be studied only by means of tests in which the pore water pressures are measured and, as a result of work in soil mechanics, consider it axiomatic that, since the rheological properties of materials such as silts, sands, gravels and clays are examined in terms of effective stress, this analysis would be best suited to work on concrete.

So far Mr Ritchie's results have been discussed without any reference to mobility, workability or any of the usual terms in concrete, but rather as a general problem in the analysis of triaxial test results and with reference only to known results of tests on silts, sands and gravels. But this problem is a far cry from the practical problems of mix design and workability and here the term workability is used in the wide sense in which I have used it elsewhere,(3) namely the ease with which the concrete can be handled from the mixer to its final fully compacted position. In this sense I find difficulty in appreciating what bearing undrained triaxial tests on concrete have on such practical problems.

Reply by the author

I thank Mr Akroyd for his observations on the analysis of the triaxial test results for fresh concrete in the light of similar tests on saturated samples of silt, sand and gravel.

I agree that a knowledge of the actual pore pressures developed would be of interest. However, in order to record this, the material under test would require to be saturated, which of course is not suitable for fresh concrete samples. Further, I am not fully convinced that the cement paste matrix, which has a gel structure of its own, can be considered to act in exactly the same manner as pore water. The comparison may be true for rich mixes with a high water/cement ratio, but this is certainly not the case with lean mixes of low water/cement ratio where the matrix does not form a continuous medium.

I do not consider that the lack of information on possible pore pressures should prevent the use of the undrained triaxial test as a laboratory means of comparing the internal resistance of various concrete mixes and relating these results to that aspect of workability which I have termed mobility.

With reference to Mr Akroyd's closing remarks, he implies that the rheological study of the results of the triaxial test is too remote from practice and he has difficulty in relating this study to practical problems. I would maintain that the measurement of the flow properties of fresh concrete has for too long been left to a succession of empirical tests with little or no thought of the rheological problems involved. My own work in this field has emphasized that it is not sufficient to specify workability in terms of one arbitrary test and also that the contributing property of mobility can be visualized and expressed in terms of internal resistance to deformation.

In conclusion, I must add that I have found this concept of flow very helpful in the study of the practical problem of the build-up of concrete pressure on formwork. Internal resistance is closely related to the effect of such significant variables as rate of placing, mode of compaction and mix characteristics on the maximum pressure and total load developed.[4,5]

REFERENCES

1. BISHOP, A. W. and ELDIN, G. Undrained triaxial tests on saturated sands and their significance in the general theory of shear strength. *Géotechnique*. 1950. Vol. 3, No. 2. pp. 13–32.
2. PENMAN, A. D. M. Shear characteristics of a saturated silt, measured in triaxial compression. *Géotechnique*. 1953. Vol. 6, No. 3. pp. 312–328.
3. AKROYD, T. N. W. *Concrete properties and manufacture*. Oxford, Pergamon Press, 1962. p. 3.
4. RITCHIE, A. G. B. The pressure developed by concrete on formwork. *Civil Engineering and Public Works Review*. Vol. 57. No. 672. July 1962. pp. 885–888. No. 673. August 1963. pp. 1027–1030.
5. RITCHIE, A. G. B. Research on the pressures developed by concrete on formwork. *Structural Concrete*. Vol. 1, No. 10. July/August 1963. pp. 454–463.