INTERNATIONAL JOURNAL FOR NUMERICAL AND ANALYTICAL METHODS IN GEOMECHANICS, VOL. 3, 301–302 (1979)

LETTERS TO THE EDITOR

DISCUSSION OF 'CONSOLIDATION DUE TO SHEAR LOADS DISTRIBUTED OVER A RECTANGULAR AREA'

N. B. Shanker, K. S. Sarma and M. V. Ratnam, *Int. J. Numer. Anal. Methods Geomech.*, **2**, 329–342 (1978).

The authors have noted that the Mandel–Cryer effect appears in the solution to the problem solved in this paper. Their reiteration of previously published information concerning this effect does not fully reiterate the physical processes involved (Gibson *et al.*,[1] Josselin De Jong,[2] Schiffman *et al.*,[3] Verruijt[6]). It is insufficient to pass this phenomenon off as '... some internal redistribution of stresses ...'.

Consider a sequence of points (1), (2) and (3) taken in the direction of drainage. We will use as our example this sequence of points with increasing depth, under the loaded area, moving away from a free-draining surface. This example in no way detracts from the generality of the explanation. We will further concentrate our attention on the middle point (2).

Point (1) will drain before point (2), and the strains at point (1) will develop prior to strains at (2). In order for compatibility of strain to be maintained, a portion of the total stress at (1) will transfer to (2). This will be reflected in an increase in total stress at (2) at early stages of consolidation. Furthermore, during this early time the effective stresses will not have developed. By the effective stress principle the excess pore pressure will then also increase along with the total stresses. The dissipation of excess pore pressure at (2) will commence only after the effective stresses start to develop at a rate which is greater than the total stress transfer from (1) to (2), compensated for by the rate of change of total stress in going from an undrained to a drained state.

We now consider the relationship between points (2) and (3). As time progresses, the process described above relating total stresses between (1) and (2) is repeated between (2) and (3). That is, there will be a total stress transfer from (2) to (3), with (2) losing total stress.

Thus a characteristic of the Mandel–Cryer effect is an oscillation of total stress as a function of the progress of consolidation. This oscillation has been found in all cases, to this writer's knowledge, where the Mandel–Cryer effect has been theoretically calculated.

The processes relating to the Mandel–Cryer effect have been experimentally verified (Gibson *et al.*,[1] Verruijt[5]). As has been reported previously the experimental verification noted that the process is equivalent to a 'shrinkage' phenomenon in which a 'crust' forms at the drainage surfaces causing additional total stresses to develop in the consolidating mass (Schiffman *et al.*[3]).

The Mandel–Cryer effect, aside from its physical implications, is a clear indication of the differences between coupled and uncoupled theories of consolidation. Coupled theory inexorably ties the governing equations of equilibrium and continuity together. They are bound by the effective stress principle, and cannot be decoupled without *a priori* knowledge of the total stress behaviour during the consolidation process (Sills[4]).

Historically the Mandel–Cryer effect has been regarded almost exclusively in terms of excess pore pressure behaviour. While this relationship is of considerable importance and, as has been discussed, can affect a variety of field conditions, not the least of which is the stability of embankments, there are other important implications. One, for example, relates to the dilatancy phenomenon which occurs when cyclic loads are applied to a soil. It is plausible to speculate that imposed cyclic loading will reinforce the cyclic nature of the Mandel–Cryer effect. This could well have influences on soil behaviour which bear further investigation.

Previous work in this area (Schiffman *et al.*[3]) has defined the region of the Mandel–Cryer effect for a particular geometry and loading condition. This region for a normally loaded half-plane (and axially symmetric half-space) is interior to a hyperbolic surface which starts at the edge of the load. It would be enlightening if the authors would explicitly define the region of Mandel–Cryer effect for a tangentially loaded rectangular area.

ROBERT L. SCHIFFMAN
University of Colorado
Boulder, Colorado, U.S.A.

REFERENCES

1. R. E. Gibson, K. Knight and P. W. Taylor, 'A critical experiment to examine theories of three-dimensional consolidation', *Proc. European Conf. on Soil Mechanics and Foundation Engineering*, Weisbaden, **1**, 69–76 (1963).
2. G. De. Josselin De Jong, *Discussion, Proc. European Conf. on Soil Mechanics and Foundation Engineering*, Weisbaden, **2**, 35 (1963).
3. R. L. Schiffman, A. T-F. Chen and J. C. Jordan, 'An analysis of consolidation theories', *J. Soil Mech. Found. Div. ASCE*, **95**, 285–312 (1969).
4. G. C. Sills, 'Some conditions under which Biot's equations of consolidation reduce to Terzaghi's equation', *Géotechnique*, **25**, 129–132 (1975).
5. A. Verruijt, *Discussion, Proc. Sixth Int. Conf. on Soil Mechanics and Foundation Engineering*, **3**, 401–402 (1965).
6. A. Verruijt, 'Elastic storage of aquifers', in *Flow Through Porous Media*, Ed. R. J. M. De Wiest, Academic Press, New York, 1969, pp. 331–376.

AUTHORS' RESPONSE TO SCHIFFMAN'S DISCUSSION*

The authors thank Prof. Schiffman for his valuable comments on their paper. They are quite aware of Prof. Schiffman's own contributions on the subject matter of the paper. The physical and mathematical implications of the Mandel–Cryer effect as brought out by him are too well known to be reemphasized. The authors (Shanker *et al.*[2]) have proved that the rate of mobilization of settlements is faster than the rate of pore pressure dissipation in soils subjected to (plane strain) consolidation, which also explains the possibility of manifestation of the Mandel–Cryer effect in certain regions of the consolidating medium.

The region of the Mandel–Cryer effect for the case of a strip footing resting on the surface of a semi-infinite medium and subjected to normal load is interior to a hyperbolic surface (Schiffman *et al.*[1]). A similar region for a strip footing subjected to (unidirectional) shear load over a half-plane can be proved to be the entire quarter-plane $xz > 0$ (see Figure 1 of the paper for the x–z coordinate system).

N. B. SHANKER
K. S. SARMA
M. V. RATNAM
Regional Engineering College
Warangal, India

* Preceding Letter.

REFERENCES

1. R. L. Schiffman, A. T.-F. Chen and J. C. Jordan, 'An analysis of consolidation theories', *Soil Mech. Found. Div., ASCE*, **95**, 285–312 (1969).
2. N. B. Shanker, K. S. Sarma and M. V. Ratnam, 'Plane strain consolidation under shear loads', *Indian Geotech. J.*, **6**, 207–219 (1976).