PREDICTION OF SWELLING IN EXPANSIVE CLAYS

By

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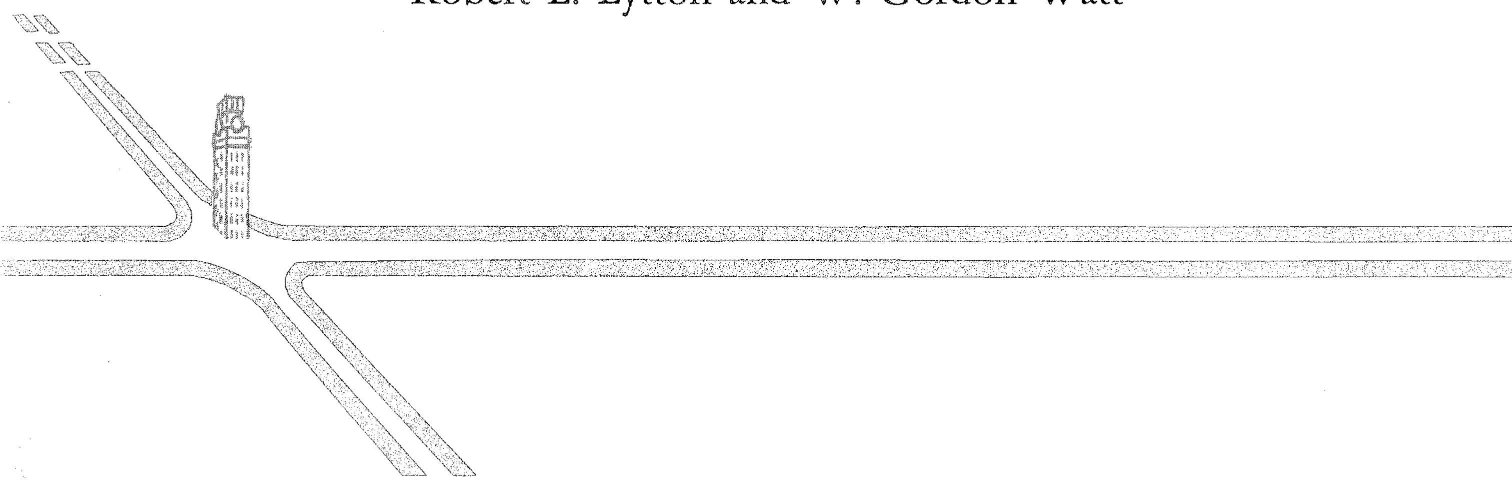

SUMMARY REPORT 118-4 (S)

SUMMARY OF
RESEARCH REPORT 118-4

PROJECT 3-8-68-118

COOPERATIVE HIGHWAY RESEARCH PROGRAM
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Foreword

Research Report 118-4 is the fourth in a series of reports resulting from Research Project 3-8-68-118, entitled "Study of Expansive Clays in Roadway Structural Systems." The concepts of water seepage through partially saturated soils as well as numerical solutions of the fluid mechanics were presented in Research Report 118-3 (Ref 1). Research Report 118-4 covers volume changes in clay as a consequence of changes in water content and soil suction at points throughout the soil.

Introduction

The amount of swell to be expected at any point on the soil surface is calculated by algebraically summing the axial movements of short segments of the column of soil which lies beneath that point. The volume change that takes place in a short segment of clay results from increases in water content which are coincident with decreases in soil suction. The vertical changes in length of the columnar segments are considered to be constant fractions of the volume change. The volume changes are reduced at depth by the overburden pressure.

This method of calculation does not take into account compensating linear shrinkages at points within the soil which are drying, nor does it allow for the shearing resistance and variable lateral pressures between elements of soil expanding at different rates. Furthermore, for purposes of computation the expansion of the soil volume has been uncoupled from the water volume and soil suction changes within the soil, although in reality the processes take place at the same time. However, when small changes are considered, fairly accurate predictions can be achieved.

Pressure and Volume Relationships

Specific volumes based on the dry weight of soil are used throughout the report in order that specific water volume and water content can be numerically equal. The swelling curve of total specific volume versus specific water volume has a low slope at small water contents and becomes tangent to lines of constant saturation at higher values. The application of overburden pressure or surcharge causes a smaller increase in total specific volume than is possible under free-swell conditions for the same increment of additional water. In the field, soils swell to the maximum possible value only when they have unlimited access to phreatic water.

Soil swell can be described by Eq 1:

$$V_T = V_{TI} + (V_{TP} - V_{TI})\left(\frac{V_W - V_{WI}}{V_{WP} - V_{WI}}\right)^Q \qquad (1)$$

where

V_{WI} = initial water content,
V_{TI} = initial total specific volume,
V_T = total specific volume resulting from the additional increment of water $(V_W - V_{WI})$,
V_{TP} = total specific volume that would result if the water content was V_{WP},
$(V_{WP} - V_{WI})$ = amount of water that the soil could absorb under the overburden pressure if water supply were unlimited, and
Q = an exponent.

The value of V_{TP} can be calculated from a relationship between swelling pressure and total specific volume:

$$V_{TP} = V_{TF} - \left(\frac{P}{P_O}\right)^{\frac{1}{m}}(V_{TF} - V_{TO}) \qquad (2)$$

where

V_{TO} = total specific volume when swell pressure is the maximum value p_o,
V_{TF} = total specific volume at zero swell pressure,

V_{TP} = total specific volume at swell pressure p , and

m = an exponent.

The total specific volume versus swell pressure curve with the values of V_{TF} , p_o , V_{TO} , and m can be determined experimentally. The value of Q is determined from a free-swell test, as are the values of V_{TI} that correspond to possible initial water contents V_{WI}. Therefore, given any initial water content, the increase in volume can be calculated for any known increase in water content and under any external pressure.

The change in total specific volume divided by the initial total specific volume is the volumetric strain in the swelling soil. The vertical strain is obtained by multiplying the volumetric strain by a factor which has been reasonably estimated by computer simulation as one hundred percent. The vertical strain at a point is then applied over a soil column segment to obtain the incremental change in length. The summation of the increments is the estimate of heave of the ground surface.

The limitations of this method include the inability to deal with the following peculiarities: (1) hysteresis in shrink-swell activity and (2) double-valued functions of total specific volume. Although these limitations should be recognized, they probably will not be serious in most practical situations.

The Two-Dimensional Computer Program

The computer program GCHPIP7 (Grid-Cylindrical-Heavy soil PIPe) was developed to predict transient moisture movement and uses the moisture changes to estimate total volume changes. An austere version of FORTRAN has been maintained to permit easy conversion from the CDC 6600 computer to other types of machines.

Data are input into nine tables laid out to conform to 80-column computer input cards. The region is simulated by a series of pipes laid out in a rectangular pattern in a vertical plane or in a cylindrical configuration. Soil and water properties such as suction and permeability are concentrated at the intersections of the vertical and horizontal pipes. Subroutines readily convert from suction to water content. Unsaturated permeabilities dependent on suction are set at each intersection.

Boundary or internal conditions are varied for calculating new suctions, permeabilities, and water contents throughout the region by an iterative process. Water content changes are used to calculate heaves at surface stations. Output can be printed at any intermediate time step before the region reaches equilibrium, and new boundary conditions can be input at any time step in order to simulate the natural fluctuations in the field environment.

An option is available to allow for the effect of overburden on the suction values obtained from laboratory tests. If the suction values have been obtained under field conditions, the option can be bypassed.

The One-Dimensional Computer Program

The computer program SWELL1 yields a coarser solution by a simpler method than GCHPIP7. Suction can vary in either the vertical or horizontal direction but not in both directions in the same problem. The horizontal and vertical distances between pipe intersections must be equal. Apart from these two restrictions, SWELL1 is as capable as GCHPIP7 and the solution process is faster.

Example Problems

There is no known set of field and laboratory data sufficient to provide information for free-swell curves and swell pressure versus total specific volume curves or to give field measurements with which to validate the results. Therefore, typical curves were assumed and swelling predictions were compared with field measurements made by personnel of the Natural Resources Research Institute at the University of Wyoming (Ref 2). The computer prediction of the swell profile gives results which, in the light of the many assumptions made, are much closer to measured results than would reasonably be expected.

Conclusions

The computer programs of this report are analytical tools with broad ranges of capabilities for studying problems in swelling clays. On one hand, the soil properties required for input are largely unknown for many soils, and experimental determination of these simple properties is indicated. On the other hand, the computer can now be used to study the effect of changes of soil properties on the accuracy of prediction of swell. These computer studies will be valuable as indications of the range of precision required of instruments which are intended to measure the soil properties.

KEY WORDS: moisture movement, expansive clays, discrete-element analysis, computers, permeability, suction, ponding, Crank-Nicholson method, unsaturated permeability, compressibility, swelling.

References

1. Lytton, Robert L., and Ramesh K. Kher, "Prediction of Moisture Movement in Expansive Clays," Research Report 118-3, Center for Highway Research, The University of Texas at Austin, May 1970.
2. Lamb, Donald R., William G. Scott, Robert H. Gietz, and Joe D. Armijo, "Roadway Failure Study No. II. Behavior and Stabilization of Expansive Clay Soils," Research Publication H-18, Natural Resources Research Institute, University of Wyoming, Laramie, August 1967.

The full text of Research Report 118-4 can be obtained from R. L. Lewis, Chairman, Research and Development Committee, Texas Highway Department, File D-8 Research, 11th and Brazos Streets, Austin, Texas 78701 (512/475-2971).