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USER'S GUIDE FOR COMPUTER PROGRAM HEAVE

by

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The program HEAVE is a one-dimensional computer program for approximate analysis of vertical movements of swelling foundation soils beneath permanent structures caused by changes in vertical loads and/or the moisture profile. The program is applicable to slab, long continuous, and circular shaft foundations. Results of both one-dimensional consolidometer swell tests and soil suction tests may be used in HEAVE.

(Continued)
20. ABSTRACT (Continued).

The program considers effects of soil overburden pressures and structural loads, heterogeneous soils, and saturated or hydrostatic equilibrium moisture profiles on the computed heave. An arbitrary final soil suction profile may also be input if soil suction results are available. Differential heave may be estimated by comparing heaves computed for different soil strata and vertical loads.

HEAVE can estimate the movement of circular drilled shaft foundations, the maximum tension force in circular shafts from heave of surrounding swelling soil, and the restraining force provided by the underream (a bell or enlargement of the shaft base). Upward movement is assumed negligible if restraint exceeds the uplift thrust from surrounding swelling soil. Estimates of shaft movement can be made for moisture migrating down the shaft from the ground surface, moisture migrating from an intermediate zone such as from a relatively thin, pervious sandy stratum, and moisture migrating upward from below the base of the shaft such as from capillary rise of a rising water table.
Preface

This computer program and user's guide were prepared under RDT&E Work Unit AT40/EO/004, "Foundations on Swelling Soils," sponsored by the Office, Chief of Engineers, U. S. Army. The investigation on which this report is based was conducted during FY 81.

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The Commander and Director of WES during preparation of this report was COL Tilford C. Creel, CE. The Technical Director was Mr. Fred R. Brown.
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### Conversion Factors, U. S. Customary to Metric (SI) Units of Measurement

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>feet</td>
<td>0.3048</td>
<td>metres</td>
</tr>
<tr>
<td>pounds (force) per square foot</td>
<td>47.88026</td>
<td>pascals</td>
</tr>
<tr>
<td>square feet</td>
<td>0.09290304</td>
<td>square metres</td>
</tr>
<tr>
<td>tons (force)</td>
<td>8896.444</td>
<td>newtons</td>
</tr>
<tr>
<td>tons (force) per square foot</td>
<td>95.76052</td>
<td>kilopascals</td>
</tr>
<tr>
<td>tons (mass) per cubic foot</td>
<td>320.3692</td>
<td>kilograms per cubic metre</td>
</tr>
</tbody>
</table>
Purpose and Scope

1. The purpose of this user's guide is to document the computer program HEAVE, which was developed to assist the design engineer in determining optimum foundations in expansive soils. This program may be used to estimate vertical foundation movements for the methodology described in TM 5-818-7 (Headquaters, Department of the Army 1982). The program HEAVE approximates potential vertical movements beneath the center or corner of rectangular slab foundations, beneath the central axis or edge of long (or strip) continuous footings, and beneath the center of circular deep shaft foundations. Vertical movement may also be computed for soils beneath these foundations constructed in excavations and for soils adjacent to the foundation not confined by structural loads. Foundation movement estimated by HEAVE has been checked by comparison with field test sections (Johnson 1981) and practical application to existing structures.

2. Structural loads are assumed to be transferred to the supporting soils, and the soil-bearing capacity is assumed not to be exceeded beneath the foundations. Computation of potential heave beneath the circular deep shaft foundation also considers the restraining force of underreams and the uplift force of swelling adjacent soil. Laboratory test data from consolidation swell or soil suction tests are used in the program HEAVE.

Methodology of Computations

Foundation movement

3. The potential total vertical heave at the bottom of the foundation as shown in Figure 1 is determined by
**Figure 1. Schematic for computation of vertical movement by program HEAVE**

\[ \Delta H = N \cdot DX \sum_{i=NBX}^{i=NEL} \text{DELTA}(i) = N \cdot DX \sum_{i=NBX}^{i=NEL} \frac{e_f(i) - e_o(i)}{1 + e_o(i)} \]  

where

- \( \Delta H \) = potential vertical heave at the bottom of the foundation, ft
- \( N \) = fraction of volumetric swell that occurs as heave in the vertical direction
- \( DX \) = increment of depth, ft
- \( NEL \) = total number of elements
- \( NBX \) = number of nodal point at bottom of the foundation
- \( \text{DELTA}(i) \) = potential volumetric swell of soil element \( i \), fraction
- \( e_f(i) \) = final void ratio of element \( i \)
- \( e_o(i) \) = initial void ratio of element \( i \)

The \( \Delta H \) is the potential vertical heave beneath a flexible, unrestrained foundation. The bottom nodal point \( NNP = NEL + 1 \) is often set at the depth of the active zone. The program HEAVE assumes that \( N = 1 \). The fraction \( N \) should be 1 for one-dimensional consolidometer swell test results. The soil suction test results tend to provide an upper bound.

* A table of factors for converting U. S. customary units of measurements to metric (SI) units is presented on page 3.
estimate of the maximum in situ heave for intact soil \((N = 1)\) in part because the soil suction tests are performed without the horizontal restraint on soil swell that exists in the field and during consolidometer tests. Dividing the heave by \(3\) \((N = 1/3)\) will tend toward a lower bound estimate for fissured soil (Richards 1967). Differential heave may be estimated by comparing the computed heaves for different soil strata, vertical loads, and equilibrium moisture profiles.

4. The program HEAVE computes the difference in void ratio \(\Delta e\) (i.e., \(e_f - e_o\)) from consolidometer swell test results of each soil layer by

\[
\Delta e = c_s \log \frac{\sigma_s}{\sigma_v}
\]

where

- \(c_s\) = swell index
- \(\sigma_s\) = swell pressure, tsf
- \(\sigma_v\) = vertical effective pressure, tsf

The compression index \(c_c\) is substituted for \(c_s\) if \(\sigma_v\) exceeds \(\sigma_s\).

5. The program HEAVE computes \(\Delta e\) from soil suction test results of each soil layer by

\[
\Delta e = C_\tau \log \frac{\tau^o_{mo}}{\tau^o_{mf}}
\]

where

- \(C_\tau\) = \(\alpha G_s /100B\), suction index
- \(\alpha\) = compressibility factor
- \(G_s\) = specific gravity
- \(B\) = slope soil suction parameter
- \(\tau^o_{mo}\) = initial matrix suction without surcharge pressure, tsf
- \(\tau^o_{mf}\) = final matrix suction without surcharge pressure, tsf

The compressibility factor \(\alpha\) is the ratio of the change in volume for a corresponding change in water content and can be found by the procedure in TM 5-818-7. The \(B\) parameter is the slope of the matrix soil
suction-water content relationship expressed as

$$\log \frac{t^0}{t_0} = A - Bw$$

(4)

where

$$A = \text{ordinate intercept soil suction parameter, tsf}$$

$$w = \text{water content, percent dry weight}$$

6. The matrix suction $$t^0_m$$ is assumed to be related to the pore water pressure by

$$t^0_m = -u_w + a\sigma_m$$

(5)

where

$$u_w = \text{pore water pressure, tsf}$$

$$\sigma_m = \text{total mean normal confining pressure, tsf}$$

The total mean normal confining pressure $$\sigma_m$$ is given by

$$\sigma_m = \frac{(1 + 2K_T)}{3} \sigma_v$$

(6)

where

$$K_T = \text{ratio of total horizontal to vertical stress in situ}$$

$$\sigma_v = \text{total vertical pressure, tsf}$$

Equilibrium pore water pressure

7. The accuracy of the estimates of the potential vertical heave in simulating the maximum in situ heave depends heavily on the ability to properly estimate the equilibrium pore water pressure profile. Figure 1 indicates examples of extremes that can occur in the seasonal moisture profile. Seasonal heave between extreme wet and dry moisture profiles can be estimated by taking the difference between heaves computed for both extreme wet and dry profiles (Figure 1a), or the sum of the settlement for the wet profile and heave of the dry profile (Figure 1b). The program HEAVE considers the three following profiles illustrated in Figure 1.
8. Saturated profile. The saturated profile, Method 1, assumes that the in situ pore water pressure is zero within the active zone $X_a$ of moisture change and heave

$$u_w = 0$$  \hspace{1cm} (7)

9. Hydrostatic I. The hydrostatic I profile, Method 2, assumes that the pore water pressure at depth $X$ becomes more negative with increasing vertical distance above the groundwater level in proportion to the unit weight of water

$$u_w = \gamma_w (X - X_a)$$  \hspace{1cm} (8)

where $\gamma_w$ is the unit weight of water (0.0312 tcf).

10. Hydrostatic II. The hydrostatic II profile, Method 3, is similar to the hydrostatic I profile except that a shallow water table does not exist. The negative pore water pressure of this profile also becomes more negative with increasing vertical distance above the bottom of the active zone $X_a$ in proportion to the unit weight of water

$$u_w = u_{wa} + \gamma_w (X - X_a)$$  \hspace{1cm} (9)

where $u_{wa}$ is the negative pore water pressure in tons per square foot at depth $X_a$ in feet.

Depth of the active zone

11. The depth of the active zone $X_a$ is defined as the least soil depth above which changes in water content and heave occur because of climate and environmental changes after construction of the foundation. The depth $X_a$ may be estimated by procedures described in TM 5-818-7. Predictions of shaft movement can be made for the three cases of active depths shown in Table 1. The three cases are differentiated in program HEAVE by denoting the depths $X_a$ and $X_f$ where $X_f$ is the depth of inactive or nonswelling soil overlying the swelling soil.
Effect of uplift forces

12. The program HEAVE ignores uplift thrust of swelling soils adjacent to slab or long continuous footings. The uplift thrust of adjacent swelling soils on deep foundations (Figure 2) is determined for the assumption that interaction of stresses between skin friction and end bearing is negligible and is expressed as

\[
Q_u = \pi D_s \int_0^{L_n} f_s \, dL
\]  

(10)

where

- \(Q_u\) = maximum uplift thrust on perimeter of shaft, tons
- \(D_s\) = diameter of shaft, ft
- \(L_n\) = thickness of the swelling layer moving up relative to the shaft, ft
- \(f_s\) = skin resistance, tsf
- \(dL\) = differential increment of shaft length \(L\), ft

The point \(n\) in Figure 2 is the neutral point. The value of \(L_n\) should be approximately equal to the depth \(X_a\). The maximum tension force \(T\) in the shaft is estimated from

\[
T = Q_w - Q_u
\]  

(11)

where \(Q_w\) is the loading force from the structure and includes the weight of the shaft.

13. The skin friction \(f_s\) is evaluated by

\[
f_s = c_a + K \sigma'_v \tan \phi_a
\]  

(12)

where

- \(c_a\) = adhesion, tsf
- \(K\) = ratio of horizontal to vertical effective stress
- \(\sigma'_v\) = vertical effective stress, tsf
- \(\phi_a\) = angle of friction between the soil and shaft, deg
If drained strength data are available, $c_a$ is often set equal to zero and $\phi_a$ set equal to the effective angle of internal friction $\phi'$ of remolded soil or the strength at large strain. The skin friction based on undrained strength data is given by

$$f_s = \alpha_f c_u$$

where

$\alpha_f$ = reduction coefficient
$c_u$ = undisturbed undrained shear strength, tsf

14. The program HEAVE computes the minimum percent steel $A_s$ required if ASTM A 615 (1976) Grade 60 steel is used by the equation

$$\text{Percent } A_s = -0.03 \frac{T}{D^2}$$
where

\[ T = \text{negative tension force, tons} \]
\[ D_s = \text{shaft diameter, ft} \]

15. The bearing capacity of the soil above the underream is calculated in program HEAVE by the equation

\[ q_b = cN_c + \sigma_v' N_q \]  \hspace{1cm} (15)

where

- \( q_b \): bearing capacity above the underream, tsf
- \( c \): cohesion, tsf
- \( \sigma_v' \): effective vertical overburden pressure, tsf
- \( N_c, N_q \): bearing capacity factors

If undrained strength data are used, then \( N_c = 7 \) and \( N_q = 0 \). The cohesion \( c \) is the undrained shear strength \( c_u \). If drained strength data are used, then the bearing capacity factors are calculated by program HEAVE by the following equations (Vesic 1977):

\[ N_c = \cot \phi'(N_q - 1) \] \hspace{1cm} (16)
\[ N_q = (1 + \tan \phi') \tan \phi' \tan^2 \left( \frac{45 + \phi'}{2} \right) \] \hspace{1cm} (17)

where \( \phi' \) is the effective angle of shearing resistance. The cohesion \( c \) is the effective cohesion in Equation 15. Equation 17 is indicative of failure by the Terzaghi local shear mechanism and tends to represent a lower limit of the bearing capacity factor \( N_q \).

16. The soil suction model described in TM 5-818-7 may also compute the effect of uplift as well as the consolidometer swell model if the swell pressure is input for each soil layer. If the swell pressure is not input, the program assumes that the swell pressure is given by the initial soil matrix suction, an assumption that can greatly exceed the swell pressure. Computed shaft uplift movements will be an upper limit because the shaft stiffness is assumed equal to the soil stiffness.
Bearing capacity

17. The program HEAVE computes the bearing capacity of the foundation soil assuming that Equations 15-17 are applicable. If undrained strength data are used, \( N_c = 9 \). The message

**BEARING CAPACITY OF TSF EXCEEDED FOR ELEMENT**

is printed if loading pressures exceed the computed bearing capacity of the given element.

Computer Program

18. The program consists of a main routine and five subroutines. The main routine feeds in the input data, calculates effective overburden pressure, determines the restraining force \( Q_r \) for a deep shaft foundation, and computes the foundation force beneath the shaft and tension force from uplift of adjacent swelling soils. The subroutine MECH applies the mechanical model for prediction of potential heave using the results of consolidometer swell tests. The subroutines SUCT and HSUCT apply the soil suction model. The subroutine PSAD sets up the proper depths in the soil profile for calculation of heave. The subroutine SLAB sets up the bearing pressure for slab and long continuous footings. The program is set to consider up to 10 different soils and a maximum of 80 soil elements. The capacity of the program may be increased by adjusting the PARAMETER statements.

Input data

19. The program was prepared for time-sharing on the Honeywell series G600 computer. The input data are entered in free field format as illustrated in Table 2. Descriptions of the input data are given in Table 3.

Output data

20. The output data are illustrated in Table 4. Descriptions of the output data are given in Table 5.
Example Applications

21. Three example problems are provided. All use the soil properties given in Table 6.

Slab in excavation

22. Table 7 illustrates the input data for a slab in an excavation 12 ft deep (Figure 3). The groundwater DGWT is 22 ft below ground surface or 10 ft below the slab. The mechanical model was used for a 100- by 100-ft slab. The output data are provided in Table 7 for a loading pressure of 0.072 tsf assuming a saturated final pore pressure profile at the center. Heave beneath the slab is 0.25 ft. Heave adjacent to the slab in soil above 12 ft of depth is 0.18 ft.

Long continuous footing

23. Table 8 illustrates the input data for an infinitely long continuous footing 100 ft wide on the ground surface (Figure 4) using the mechanical model. The groundwater level is 8 ft below the footing. The output data are provided in Table 8 for a loading pressure of 0.072 tsf assuming a saturated final pore pressure profile. The heave beneath this footing is 0.14 ft.

Circular shaft

24. Table 9 illustrates the input data for a circular shaft 30 ft deep and 2 ft in diameter with a 3-ft-diam underream (Figure 5) using the soil suction model with drained strength data. The active zone extends from the ground surface to 10 ft below the base of the shaft. A 10-ton loading force $Q_w$ is placed on the shaft. The output data are provided in Table 9 assuming a saturated profile for the full 40 ft of active depth, $X_a$. The shaft heave of 1.16 ft is the maximum that a cracked shaft could rise excluding subsoil movement, while one-third of this heave or 0.4 ft is more likely in a fissured soil. The actual shaft heave will be less if no fracture results in the shaft. The maximum soil heave adjacent to the shaft is 1.3 ft. A gap could open beneath the bottom of the shaft. The maximum tension force of -166.5 tons will require 1.3 percent steel in the 2-ft-diam shaft.
Figure 3. Slab foundation in excavation with deep water table ($X_a = 22$ ft)
Figure 4. Long continuous footing at ground surface
Figure 5. Shaft foundation 30 ft deep with active zone from ground surface to 40 ft deep
References


Mechanism of Uplift

The shaft is lifted when the uplift force \( Q_u \) given by 
\[
\sigma - \sigma' \times A_{act}
\]
where \( \sigma \) is active, exceeds the restraining force \( Q_r \). The shaft stops lifting when \( Q_u < Q_r \) or the skin friction \( f_s \times A_{act} \) is less than \( Q_r \).

Case 2 converged to Case 1 when \( x_f = 0 \).

Same as Case 1 except that soil from the ground surface to depth \( x_f \) does not swell and does not contribute to uplift.

The shaft is lifted a distance equal to the vertical swelling of the soil beneath the shaft as wetting ascends to the base of the shaft. The shaft is lifted further as soil wetting ascends above the base when uplift force \( Q_u \) exceeds the restraining force \( Q_r \). The shaft stops lifting when \( Q_u < Q_r \) or \( f_s \times A_{act} < Q_r \).

**Table 1**

**Prediction of Shaft Movement**

<table>
<thead>
<tr>
<th>Case</th>
<th>Mechanism of Uplift</th>
<th>Sketch</th>
<th>Equations*</th>
</tr>
</thead>
</table>
| 1    | The shaft is lifted when the uplift force \( Q_u \) given by \( \sigma - \sigma' \times A_{act} \) exceeds the restraining force \( Q_r \). The shaft stops lifting when \( Q_u < Q_r \) or \( f_s \times A_{act} < Q_r \). | ![Sketch 1](image1.png) | 1. \( \Delta \text{shaft} < 0 \) if \( \sigma_s - \sigma'_s \times A_{act} < Q_r \)  
2. \( \Delta \text{shaft} < 0 \) if \( f_s \times A_{act} < Q_r \)  
3. \( \Delta \text{shaft} = (X_s - L)c_s \log \frac{\sigma_s}{\sigma'_v} + (L - X_s)c_s \log \frac{\sigma_s}{\sigma'_{act}} \) if \( \sigma_s > \sigma'_{act} > \sigma'_v \)  
4. \( \Delta \text{shaft} = (X_s - L)c_s \log \frac{\sigma_s}{\sigma'_v} \) if \( \sigma_s > \sigma'_v > \sigma'_{act} \)  
5. \( \Delta \text{soil} = (X_s - L)c_s \log \frac{\sigma_s}{\sigma'_v} \) if \( \sigma_s > \sigma'_v > \sigma'_{act} \)  
6. \( A_{act} = (L - X_f)D_s \)  
7. \( Q_r = Q_u + f_s(L - X_f)D_s + q_b \frac{D^2}{b^2} (D^2 - D_s^2) \) |
| 2    | Same as Case 1 except that soil from the ground surface to depth \( x_f \) does not swell and does not contribute to uplift. | ![Sketch 2](image2.png) | |
| 3    | The shaft is lifted a distance equal to the vertical swelling of the soil beneath the shaft as wetting ascends to the base of the shaft. The shaft is lifted further as soil wetting ascends above the base when uplift force \( Q_u \) exceeds the restraining force \( Q_r \). The shaft stops lifting when \( Q_u < Q_r \) or \( f_s \times A_{act} < Q_r \). | ![Sketch 3](image3.png) | |

**Notation:**

\( A_{act} \) = area over which swell pressure \( \sigma_s \) is active, ft²  
\( c_s \) = swell index or suction index \( C_s \), Equations 2 and 3  
\( D_b \) = diameter of underreamed base, ft  
\( D_s \) = diameter of shaft, ft  
\( f_s \) = skin friction found by Equations 12 and 13, tsf  
\( L \) = length of shaft, ft  
\( q_b \) = bearing capacity of soil above underream, tsf  
\( Q_r \) = force restraining uplift force of swelling soil, tons  
\( Q_u \) = uplift force \( \sigma_s - \sigma'_s \times A_{act} \), tons  
\( Q_v \) = structural load on shaft including shaft weight, tons  
\( X_f \) = depth or thickness of active zone, ft  
\( X_s \) = depth of nonswelling soil from ground surface, ft  
\( \Delta \text{shaft} \) = movement of shaft, ft  
\( \Delta \text{soil} \) = movement of soil surrounding shaft, ft  
\( \sigma_s \) = soil swell pressure, tsf  
\( \sigma'_v \) = effective overburden pressure, tsf
Table 2
Input Data Format

<table>
<thead>
<tr>
<th>Step</th>
<th>Data</th>
</tr>
</thead>
</table>
| 1    | The program will print: 
      | TITLE? 
      | = . Input description of the problem |
| 2    | The program will print after carriage return: 
      | NPROB,NSUCT,NBPRES,NNP,NBX,NMAT,DX 
      | = . Input the above variables (see Table 3 for definitions) |
| 3    | The program will print after carriage return: 
      | M,G,WC,EO,C,PHI,K 
      | = . Input the above variables |
| 4A   | If NSUCT = 0, the program will print after carriage return: 
      | M,SP,CS,CC 
      | = . Input the above variables |
| 4B   | If NSUCT = 1, the program will print after carriage return: 
      | M,A,B,ALPHA,KT,PI,SP 
      | = . Input the above variables. If ALPHA left blank, then 
      | \( a = 0 \) for \( PI \leq 5 \) 
      | \( a = 0.0275PI - 0.125 \) for \( 5 < PI < 40 \) 
      | \( a = 1 \) for \( PI \geq 40 \) 
      | If SP left blank, the swell pressure will be assumed 
      | the initial matrix soil suction |
|      | The program will repeat steps 3 and 4 until all soils from \( M = 1 \) to \( M = NMAT \) are input |
| 5    | The program will print after carriage return: 
      | ELEMENT,NO. OF SOIL 
      | = . Input 1,1 
      | = . Input element,2 for elements in increasing order 
      | for each increase in soil type \( M \) as the last and deepest element 
      | for soil type \( M = NMAT \) |
| 6    | The program will print after carriage return up to NPROB: 
      | XA,XF,DGWT,IOPTION,NOPT 
      | = . Input the above variables |
| 7A   | If NBPRES \( \neq 1 \), the program will print after carriage return: 
      | Q,BLEN,BWID,LOCATION(CENTER=0,EDGE/CORNER=1) 
      | = . Input the above variables |
| 7B   | If NBPRES = 1, the program will print after carriage return: 
      | PLOAD,AF,DP,DB 
      | = . Input the above variables |
Table 1: Description of Input Data

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPROB</td>
<td>2</td>
<td>Number of cases with the same soil profile. Loads and foundation dimensions can be varied</td>
</tr>
<tr>
<td>NSUCT</td>
<td>2</td>
<td>Option for model: 00 for consolidation swell (MECH) model; 1 for soil suction model</td>
</tr>
<tr>
<td>NBPRES</td>
<td>2</td>
<td>Option for foundation: 1 for circular or shaft; 2 for rectangular slab; 3 for long continuous footing</td>
</tr>
<tr>
<td>NX</td>
<td>2</td>
<td>Number of nodal point at the bottom of the foundation</td>
</tr>
<tr>
<td>NMAT</td>
<td>2</td>
<td>Total number of different soil layers</td>
</tr>
<tr>
<td>DX</td>
<td>2</td>
<td>Increment of depth, ft</td>
</tr>
</tbody>
</table>

Physical Properties

| M     | 3    | Number of soil layer |
| WC    | 3    | Initial water content w of soil layer M, percent |
| E0    | 3    | Initial void ratio e0 of soil layer M |
| C     | 3    | Soil effective cohesion c' or undrained shear strength cu, tf |
| PHI   | 3    | Effective angle of internal friction φ' |
| K     | 3    | Ratio of horizontal to vertical effective pressure K.K = 1.0 if left blank |

Swell Characterization by the Consolidation Swell (MECH) Model

| M     | 4A   | Number of soil layer |
| SP    | 4A   | Swell pressure ul of soil layer M, tf |
| CS    | 4A   | Swell index cs of soil layer M |
| CC    | 4A   | Compression index cc of soil layer M |

Swell Characterization by the Soil Suction (SUCT) Model

| M     | 4B   | Number of soil layer |
| A     | 4B   | Intercept of log suction and water content relationship of soil layer M, tsf |
| R     | 4B   | Slope of log suction and water content relationship of soil layer M |
| ALPHA | 4B   | Compressibility factor α of soil layer M |
| KT    | 4B   | Ratio of total horizontal to vertical pressure Kt of soil layer M |
| PI    | 4B   | Plasticity index PI of soil layer M, percent |
| SP    | 4B   | Swell pressure us of soil layer M, tf. u = uo if left blank |

Element Characterization

| ELEMENT | 5    | Number of soil element |
| NO. of Soil | 5    | Number of soil layer M |
| NEL | 5    | Total number of soil elements |
| NMAX | 5    | Total number of soil layers |

Equilibrium Moisture Profile

| XA    | 6    | Depth of the active zone Xa, ft. Movement beneath the foundation assumes the equilibrium moisture profile extends down to the bottom nodal point NNP |
| XF    | 6    | Depth from ground surface to the depth that the active zone begins Xf, ft |
| DGWT  | 6    | Depth to the groundwater table, ft. DGWT is set internally to the depth of nodal point NNP if IOPTION = 1 |
| IOPTION | 6    | Equilibrium moisture profile: =0 for saturation (Equation 7); =1 for hydrostatic I (Equation 8); to simulate Equation (9), set IOPTION = 1 and DGWT = Xa - uo/k, or IOPTION = 2 if NSUCT = 1; if IOPTION = 3 and NSUCT = 1, the final total soil suction without surcharge pressure u' is input for each soil layer |
| NOFT  | 6    | Option for amount of output: =0 for forces (if NBPRES = 1) and total heave; =1 for forces, total heave, and the friction and excess pore pressure at each depth interval |

Loading and Dimensions of Foundation

| Q     | 7A   | Foundation and superstructure pressure, tsf |
| RLEN  | 7A   | Radius of circular foundation (NBPRES = 1); length of slab (NBPRES = 2), 0.0 for long continuous (NBPRES = 3), ft |
| RDID  | 7A   | 0.0 for circular foundation; width of slab; width of long continuous footing, ft |
| LOCATION | 7A  | =0 for center of rectangular slab or long continuous footing; = 1 for corner of slab or edge of long continuous footing. Not used for circular foundation where only center results printed |
| LOAD  | 7B   | Loading force on circular shaft including weight of shaft q, tons |
| AF    | 7B   | Reduction factor of skin friction term u (Equation 13) |
| DP    | 7B   | Diameter of shaft Dp, ft |
| DB    | 7B   | Diameter of base or underream Db, ft |
Table 4

Output Data Format

<table>
<thead>
<tr>
<th>Line</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NBPRES ≠ 1</td>
</tr>
<tr>
<td>1</td>
<td>(If NOPT = 1)</td>
</tr>
<tr>
<td></td>
<td>ELEMENT DEPTH, FT DELTA HEAVE, FT EXCESS PORE PRESSURE, TSF</td>
</tr>
<tr>
<td>2</td>
<td>SOIL HEAVE NEXT TO FOUNDATION EXCLUDING SUBSOIL = FEET</td>
</tr>
<tr>
<td>3</td>
<td>SUBSOIL MOVEMENT = FEET</td>
</tr>
<tr>
<td>4</td>
<td>TOTAL SOIL MOVEMENT = FEET</td>
</tr>
<tr>
<td></td>
<td>NBPRES = 1</td>
</tr>
<tr>
<td>1</td>
<td>FORCE Restraining UPLIFT = EXCESS = TONS</td>
</tr>
<tr>
<td>2</td>
<td>SHAFT HEAVE (EXCLUDING SUBSOIL MOVEMENT) = FEET</td>
</tr>
<tr>
<td>3</td>
<td>FORCE AT BOTTOM OF SHAFT = TENSION = TONS</td>
</tr>
<tr>
<td></td>
<td>AREA STEEL = PERCENT</td>
</tr>
<tr>
<td>4</td>
<td>(If NOPT = 1)</td>
</tr>
<tr>
<td></td>
<td>ELEMENT DEPTH, FT DELTA HEAVE, FT EXCESS PORE PRESSURE, TSF</td>
</tr>
<tr>
<td>5</td>
<td>SOIL HEAVE NEXT TO FOUNDATION EXCLUDING SUBSOIL = FEET</td>
</tr>
<tr>
<td>6</td>
<td>SUBSOIL MOVEMENT = FEET</td>
</tr>
<tr>
<td>7</td>
<td>TOTAL SOIL MOVEMENT = FEET</td>
</tr>
<tr>
<td>8</td>
<td>TOTAL SHAFT MOVEMENT = FEET</td>
</tr>
</tbody>
</table>
Table 5
Description of Output Data

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEMENT</td>
<td>Number of element</td>
</tr>
<tr>
<td>DEPTH, FT</td>
<td>Depth of center of element, ft</td>
</tr>
<tr>
<td>DELTA HEAVE, FT</td>
<td>Heave of increment (element) (\Delta H), ft</td>
</tr>
<tr>
<td>EXCESS PORE PRESSURE, TSF</td>
<td>Initial negative pore pressure exceeding equilibrium pressure, tsf</td>
</tr>
<tr>
<td>SOIL HEAVE NEXT TO FOUNDATION EXCLUDING SUBSOIL</td>
<td>Movement of adjacent soil above bottom of foundation, ft</td>
</tr>
<tr>
<td>SUBSOIL MOVEMENT</td>
<td>Movement of soil beneath foundation, ft</td>
</tr>
<tr>
<td>TOTAL SOIL MOVEMENT</td>
<td>Total heave of soil adjacent to foundation, ft</td>
</tr>
<tr>
<td>FORCE RESTRAINING UPLIFT</td>
<td>Force restraining uplift (Q_r), tons</td>
</tr>
<tr>
<td>EXCESS</td>
<td>(Q_r = Q_u) where (Q_u) = uplift force, tons</td>
</tr>
<tr>
<td>SHAFT HEAVE (EXCLUDING SUBSOIL MOVEMENT)</td>
<td>Movement of shaft excluding soil movement beneath shaft, ft</td>
</tr>
<tr>
<td>FORCE AT BOTTOM OF SHAFT</td>
<td>Force exerted on soil beneath the shaft (positive quantity), tons</td>
</tr>
<tr>
<td>TENSION</td>
<td>Maximum tension in shaft (negative quantity), tons</td>
</tr>
<tr>
<td>AREA STEEL</td>
<td>Percent steel from Equation 14 assuming ASTM A615 Grade 60 steel is used. The minimum steel should be 1 percent although the computed steel may be less.</td>
</tr>
<tr>
<td>TOTAL SHAFT MOVEMENT</td>
<td>Total movement of shaft, ft</td>
</tr>
</tbody>
</table>

Note: Positive values represent upward movement or compression force while negative values represent downward movement or tension force.
<table>
<thead>
<tr>
<th>Depth, ft</th>
<th>$G_s$, ft</th>
<th>$w_o$, %</th>
<th>$e_o$</th>
<th>$c_u$</th>
<th>$c_s$, tsf</th>
<th>$\phi$, deg</th>
<th>$K$</th>
<th>$\sigma_s$, tsf</th>
<th>$c_s$</th>
<th>$c_c$</th>
<th>Suction Parameters</th>
<th>Atterberg Limits</th>
<th>LL</th>
<th>PI</th>
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</thead>
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<td>0-4</td>
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<td>23.0</td>
<td>0.800</td>
<td>0.5</td>
<td>2.20</td>
<td>20</td>
<td>1.0</td>
<td>0.045</td>
<td>0.27</td>
<td>6.75</td>
<td>0.25</td>
<td>1.00</td>
<td>1.0</td>
<td>57</td>
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<tr>
<td>4-8</td>
<td>2.70</td>
<td>25.0</td>
<td>0.745</td>
<td>0.5</td>
<td>0.66</td>
<td>20</td>
<td>1.0</td>
<td>0.045</td>
<td>0.27</td>
<td>6.75</td>
<td>0.25</td>
<td>1.00</td>
<td>1.0</td>
<td>60</td>
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<tr>
<td>8-12</td>
<td>2.75</td>
<td>30.0</td>
<td>0.825</td>
<td>1.0</td>
<td>0.70</td>
<td>30</td>
<td>1.0</td>
<td>0.030</td>
<td>0.27</td>
<td>5.04</td>
<td>0.17</td>
<td>0.26</td>
<td>1.0</td>
<td>49</td>
</tr>
<tr>
<td>12-30</td>
<td>2.76</td>
<td>29.0</td>
<td>0.828</td>
<td>2.0</td>
<td>2.40</td>
<td>10</td>
<td>2.0</td>
<td>0.052</td>
<td>0.20</td>
<td>5.86</td>
<td>0.18</td>
<td>1.00</td>
<td>2.0</td>
<td>75</td>
</tr>
<tr>
<td>30-</td>
<td>2.76</td>
<td>29.0</td>
<td>0.828</td>
<td>2.0</td>
<td>2.85</td>
<td>10</td>
<td>2.0</td>
<td>0.048</td>
<td>0.13</td>
<td>6.14</td>
<td>0.19</td>
<td>1.00</td>
<td>2.0</td>
<td>80</td>
</tr>
</tbody>
</table>
Table 7
Input and Output Data for Slab in Excavation

Input Data

```plaintext
SYSTEM ?FORT
OLD OR NEW-OLD HEAVE
READY
*RUN
=SLAB IN EXCAVATION, DGWT = 22 FT MECH
NPROB, NSUCT, NBPRES, NNP, NBX, NMAT, DX
=3, 0, 2, 45, 25, 4, 5
M*G, WC, EO, C, PHI, K
=1, 2, 7, 23, 0, 8, 0
M*ALL, SP, CS, CC
=1, 57, 2, 27, 0, 45, 0
M*G, WC, EO, C, PHI, K
=2, 2, 7, 25, 0, 745, 0
M*ALL, SP, CS, CC
=2, 60, 0, 66, 0, 45, 0
M*G, WC, EO, C, PHI, K
=3, 2, 75, 30, 0, 825, 0
M*ALL, SP, CS, CC
=3, 49, 0, 7, 0, 03, 0
M*G, WC, EO, C, PHI, K
=4, 2, 76, 29, 0, 828, 0
M*ALL, SP, CS, CC
=4, 75, 2, 4, 0, 052, 2
ELEMENT, NO. OF SOIL
=1, 1
=7, 2
=17, 3
=25, 4
=44, 4
XA, XE, DGWT, IOPTION, NOPT
=22, 0, 0, 0, 0, 1
Q*BLEM, BWID, LOCATION (CENTER=0, EDGE/CORNER=1)
=. 072, 100, 0, 100, 0
```

(Continued)
<table>
<thead>
<tr>
<th>Element Depth (ft)</th>
<th>Delta Heave (ft)</th>
<th>Excess Pore Pressure (sf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.7313</td>
<td>0.0150</td>
<td>0.45</td>
</tr>
<tr>
<td>1.7320</td>
<td>0.0153</td>
<td>0.43</td>
</tr>
<tr>
<td>1.7329</td>
<td>0.0158</td>
<td>0.42</td>
</tr>
<tr>
<td>1.7335</td>
<td>0.0163</td>
<td>0.41</td>
</tr>
<tr>
<td>1.7349</td>
<td>0.0168</td>
<td>0.40</td>
</tr>
<tr>
<td>1.7360</td>
<td>0.0173</td>
<td>0.39</td>
</tr>
<tr>
<td>1.7379</td>
<td>0.0178</td>
<td>0.38</td>
</tr>
<tr>
<td>1.7397</td>
<td>0.0183</td>
<td>0.37</td>
</tr>
<tr>
<td>1.7414</td>
<td>0.0188</td>
<td>0.36</td>
</tr>
<tr>
<td>1.7430</td>
<td>0.0193</td>
<td>0.35</td>
</tr>
<tr>
<td>1.7445</td>
<td>0.0198</td>
<td>0.34</td>
</tr>
<tr>
<td>1.7460</td>
<td>0.0203</td>
<td>0.33</td>
</tr>
<tr>
<td>1.7475</td>
<td>0.0208</td>
<td>0.32</td>
</tr>
<tr>
<td>1.7489</td>
<td>0.0213</td>
<td>0.31</td>
</tr>
<tr>
<td>1.7502</td>
<td>0.0218</td>
<td>0.30</td>
</tr>
<tr>
<td>1.7515</td>
<td>0.0223</td>
<td>0.29</td>
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<tr>
<td>1.7527</td>
<td>0.0228</td>
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<td>1.7535</td>
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<td>1.7540</td>
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<tr>
<td>1.7545</td>
<td>0.0240</td>
<td>0.25</td>
</tr>
<tr>
<td>1.7549</td>
<td>0.0244</td>
<td>0.24</td>
</tr>
<tr>
<td>1.7553</td>
<td>0.0248</td>
<td>0.23</td>
</tr>
<tr>
<td>1.7557</td>
<td>0.0252</td>
<td>0.22</td>
</tr>
<tr>
<td>1.7559</td>
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<td>0.21</td>
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</tbody>
</table>

Table 7 (continued)
Table 8

Input and Output Data for Long Continuous Footing on Ground Surface

Input Data

Input Data

=LONG CONTINUOUS ON GROUND SURFACE, DGWT = 8 FT MECH
NFROB,NSUCT,NBPRES,NF,P,NBX,NMAT,DX
=2,0,3,17,1,2,5
Mr,Gr,WC,E0,C,PHI,K
=1,2,7,23,8,8,8
Mr,ALL,SP,CS,CC
=1,57,2,2,0,457,27
Mr,Gr,WC,E0,C,PHI,K
=2,2,7,25,7,745,27
Mr,ALL,SP,CS,CC
=2,60,7,66,0,457,27
ELEMENT, NO. OF SOIL
=1,1
=9,2
=16,2
Xa,XF DGWT, IOPTION, NOFT
=8,0,8,0,1
Q, BLEN, BWID, LOCATION (CENTER=0, EDGE/ CORNER=1)
=0,72,0,100,1

Output Data

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>DEPTH, FT</th>
<th>DELTA HEAVE, FT</th>
<th>EXCESS PORE PRESSURE, TSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
<td>0.03832</td>
<td>2.13549</td>
</tr>
<tr>
<td>2</td>
<td>0.75</td>
<td>0.03432</td>
<td>2.10679</td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>0.03141</td>
<td>2.07809</td>
</tr>
<tr>
<td>4</td>
<td>1.75</td>
<td>0.02911</td>
<td>2.04939</td>
</tr>
<tr>
<td>5</td>
<td>2.25</td>
<td>0.02722</td>
<td>2.02068</td>
</tr>
<tr>
<td>6</td>
<td>2.75</td>
<td>0.02561</td>
<td>1.99198</td>
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<tr>
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<td>3.25</td>
<td>0.02420</td>
<td>1.96328</td>
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<td>8</td>
<td>3.75</td>
<td>0.02296</td>
<td>1.93458</td>
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<td>9</td>
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<td>0.36518</td>
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<tr>
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<td>4.75</td>
<td>0.02093</td>
<td>0.33508</td>
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<td>0.30498</td>
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<td>12</td>
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<td>0.01893</td>
<td>0.27489</td>
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<tr>
<td>13</td>
<td>6.25</td>
<td>0.01792</td>
<td>0.24479</td>
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<td>6.75</td>
<td>0.01691</td>
<td>0.21469</td>
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<td>15</td>
<td>7.25</td>
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<td>0.18459</td>
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<td>16</td>
<td>7.75</td>
<td>0.01489</td>
<td>0.15450</td>
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</tbody>
</table>

SOIL HEAVE, FT: ADJACENT TO FOUNDATION= 0. SUBSOIL= 0.13968

*BYE
**resources used $ 2.83, used to date $ 589.92= 29%
**time sharing off at 10.481 on 06/04/80
Table 9
Shaft Foundation 30 Feet Deep

**Input Data**

<table>
<thead>
<tr>
<th>RUN</th>
<th>SHAFT FOUNDATION, DGWT = 40 FT</th>
<th>SUCT</th>
<th>DRAINED DATA</th>
<th>NPROB, ASUCT, NBPRES, NNPF, NBX, NMAT, DX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>=1, 1, 1, 41, 31, 1, 1.</td>
<td>M, G, WC, E0, C, PHI, K</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>=1, 2, 3, 23, 8, 0, 20, 1.</td>
<td>M, A, B, ALPHA, AK0, PI</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>=1, 5, 1, 25, 1, 1, 1, 39.</td>
<td>M, G, WC, E0, C, PHI, K</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>=2, 2, 7, 25, 0, 745, 0, 20, 1.</td>
<td>M, A, B, ALPHA, AK0, PI</td>
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<td></td>
</tr>
<tr>
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<td>=2, 6, 75, 25, 1, 1, 1, 40.</td>
<td>M, G, WC, E0, C, PHI, K</td>
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<tr>
<td></td>
<td>=3, 2, 75, 30, 825, 0, 30, 1.</td>
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<tr>
<td></td>
<td>=3, 5, 04, 17, 261, 1, 1, 14.</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>=4, 2, 76, 29, 828, 1, 1, 10, 2.</td>
<td>M, A, B, ALPHA, AK0, PI</td>
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</tr>
<tr>
<td></td>
<td>=4, 5, 04, 51, 18, 1, 1, 2, 55.</td>
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<tr>
<td></td>
<td>=5, 2, 76, 29, 828, 1, 1, 10, 2.</td>
<td>M, A, B, ALPHA, AK0, PI</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>=5, 6, 14, 19, 1, 2, 1, 55.</td>
<td>ELEMENT, NO. OF SOIL</td>
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<td></td>
</tr>
<tr>
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<td>=1, 1</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>=9, 3</td>
<td>=9, 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>=13, 4</td>
<td>=13, 4</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>=31, 5</td>
<td>=31, 5</td>
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<tr>
<td></td>
<td>=40, 5</td>
<td>=40, 5</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>XA, XF, DGWT, IOPTION, NOPT</td>
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<td>FLOAD, AF, D, DB</td>
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</table>

(Continued)
Table 9 (Concluded)

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>DEPTH, FT</th>
<th>DELTA HEAVE, FT</th>
<th>EXCESS</th>
<th>FORCE PRESSURE, TSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>0.15241</td>
<td>9.97117</td>
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SOIL HEAVE, FT: ADJACENT TO FOUNDATION = 1.30535  SUBSOIL = 0.06666
APPENDIX A: PROGRAM LISTING

1000C PREDICTION OF HEAVE - HEAVE
1010C BASED ON CONSTANT VOLUME SWELL/SWELL OVERBURDEN/SUCTION
1020C DEVELOPED BY L. D. JOHNSON
1030 PARAMETER NL=10, NQ=81
1040 COMMON A(NL), B(NL), G(NL), WC(NL), ED(NL), SP(NL), AK(NL), CS(NL),
1050& CC(NL), ALPHA(NL), AK0(NL), P(NQ), IE(NQ+1), N1, N2, NBX, NEL, IOPTION,
1060& NOPT, DX, DXX, DGWT, PI, XA, XF, DELH, DELH1, DELH2
1080 DIMENSION PP(NQ), PI(NL), C(NL), PHI(NL)
1085 PRINT 1
1086  1 FORMAT(6HTITLE?)
1090 READ 3
1100  3 FORMAT(30H)
1110 GAW=0.03125
1120 PI=3.14159265
1130 NP=1
1140 PRINT 5
1150  5 FORMAT(34HNPORB, NSUCT, NBPRES, NNP, NBX, NMAT, DX)
1160 READ, NPROB, NSUCT, NBPRES, NNP, NBX, NMAT, DX
1170 NEL=NNP-1
1180 PRINT 10
1190  10 FORMAT(17HM, G, WC, ED, C, PHI, K)
1200 READ, M, G(M), WC(M), ED(M), C(M), PHI(M), AK(M)
1210 PHI(M)=PHI(M)*PI/180.
1215 IF(AK(M).LT.0.01)AK(M)=1.0
1220 IF(NSUCT.EQ.1)GO TO 25
1230 PRINT 12
1240  12 FORMAT(10HM, SP, CS, CC)
1250 READ, M, SP(M), CS(M), CC(M)
1260 GO TO 20
1270 PRINT 8
1280  8 FORMAT(20HM, A, B, ALPHA, KT, PI, SP)
1290 READ, M, A(M), B(M), ALPHA(M), AK0(M), PI(M), SP(M)
1300 IF(ALPHA(M).LE.0.)GO TO 16
1310 GO TO 20
1320  16 ALPHA(M)=0.0275*PI(M)-.125
1330 IF(PI(M).LE.5.)ALPHA(M)=0.0
1340 IF(PI(M).GE.40.)ALPHA(M)=1.
1350  20 IF(NMAT-M)26, 27, 14
1360  26 PRINT 17*H
1370  17 FORMAT(20H ERROR IN MATERIAL, I5)
1380 STOP
1390  27 L=0
1400 PRINT 30
1410  30 FORMAT(19HELEMENT, NO. OF SOIL)
1420  40 READ, N, IE(N+1)
1430  50 L=L+1
1440 IF(N-L).GT.60, 60, 70
1450  70 IE(L,1)=IE(L-1,1)
1460 GO TO 50
1470  60 IF(NEL-L).GT.80, 80, 40
1480  80 CONTINUE
1490  81
1500 81 FORMAT(1,23HXA, XF, DGWT, IOPTION, NOPT)
1510 READ, XA, XF, DGWT, IOPTION, NOPT
1515 IF(NSUCT.EQ.0, AND, IOPTION.GT.1)PRINT 85
1517 85 FORMAT(30HIOPTION TOO LARGE; IOPTION = ?)
1518 IF(NSUCT.EQ.0, AND, IOPTION.GT.1)READ, IOPTION
1519 IF(IOPTION.GT.1)DGWT=FLOAT(NEL)*DX
1520 IF(NBPRES.EQ.1)GO TO 89
1530 PRINT 86
1540 86 FORMAT(1, 44HO, BLEN, BWID, LOCATION(CENTER=0, EDGE/CORNER=1))
1550 READ, G, BLEN, BWID, MRECT
1560 GO TO 91
1570 89 PRINT 90
1580 90 FORMAT(1, 14HLOAD, AF, DP, DB)
1590 READ, PLOAD, AF, DP, DB
1592 IF(DP.GT.DB)PRINT 88
1593 88 FORMAT(31HDIAM SHAFT TOO LARGE; DIAM SHAFT = ?, DIAM BASE = ?)
1594 IF(DP.GT.DB)READ, DP, DB
1600 91 IF(IOPTION.LT.3)GO TO 92
1610 PRINT 101
1620 101 FORMAT(31HMATERIAL NO, FINAL TOTAL SUCTION)
1630 102 READ, H, CC(M)
1640 IF(NMAT-M).GT.103, 92, 102
1650 103 PRINT 105, H
1660 105 FORMAT(20H ERROR IN MATERIAL ,I5)
1670 GO TO 102
1690C CALCULATION OF EFFECTIVE OVERBURDEN PRESSURE
1700 92 P(I)=0.0
1710 PP(I)=0.0
1720 DXX=DX
1730 DO 100 I=2, NNP
1740 MTYPE=IE(I-1, I)
1750 WCC=WCC(MTYPE)/100,
1760 GAMM=G(MTYPE)*GAW/(1.+WCC)/(1.+ED(MTYPE))
1770 IF(DXX.GT.DGWT)GAMM=GAMM-GAW
1780 P(I)=P(I-1)+DX*GAMM
1790 PP(I)=P(I)
1800 DXX=DXX+DX
1810 100 CONTINUE
1820 IF(NSUCT.GT.0, AND, IOPTION.EQ.2)GO TO 111
1830 GO TO 112
1840 111 MATNEL=IE(NEL, I)
1850 IF(AKO(MATNEL).LT.0.01)AKO(MATNEL)=AK(MATNEL)
1855 F=(1.+2.*AKO(MATNEL))/3,
1860 TFI=A(MATNEL)-B(MATNEL)*WCC(MATNEL)
1870 TFI=10.**TFI
1872 ALP=ALPHA(MATNEL)
1874 IF(DGWT.LT.FLOAT(NEL)*DX)ALP=1.0
1880 TFI=TFI-P(NNP)*F*ALPHA(MATNEL)
1890 112 DXX=0.0
1900 DO 114 I=1, NNP
1910 AI=I-1
1920 BN=DGWT/DX-AI
1930 IF(NSUCT.EQ.0.AND.DXX.LT.DGWT.AND.IOPTION.EQ.1)P(I)=P(I)+
1940& BN*DX*GAW
1950 IF(NSUCT.EQ.0)GO TO 113
1955 IF(I.EQ.1)MTYP=IE(I,1)
1957 IF(I.GT.1)MTYP=IE(I-1,1)
1970 ALP=ALPHA(MTYP)
1975 IF(DXX.GT.DGWT)ALP=1.0
1980 TF=0.0
1990 IF(IOPTION.EQ.1.AND.DXX.LT.DGWT)TF=BN*DX*GAW
2000 IF(IOPTION.EQ.2)TF=TF+FLOAT(NEL)*DX-DXX)*GAW
2005 IF(AKD(MTYP).LT.0.01)AKD(MTYP)=AKD(MTYP)
2010 F=(1.+2.*AKD(MTYP))/3.
2020 IF(IOPTION.EQ.3)TF=CC(MTYP)-P(I)*F*ALP
2040 P(I)=TF+P(I)*F*ALP
2050 IF(P(I).LT.0.0)PRINT 116,P(I),1
2060 116 FORMAT(3I1,HNEGATIVE FINAL EFFECTIVE STRESS,F10.5,
2070& 12H IN ELEMENT,I5)
2080 113 DXX=DXX+DX
2090 114 CONTINUE
2100 IF(NBPRES.GT.1)CALL SLAB(Q,NSUCT,BLEN,BWID,MRECT,NBPRES,PP(NBX))
2110 IF(NBPRES.GT.1)GO TO 210
2120C CALCULATION OF RESTRAINING FORCE
2130 CON=DX*PII*DP*AF
2140 P1=0.0
2150 PR1=0.0
2160 PS1=0.0
2170 AN1=XA/ DX
2180 N1=IFIX(AN1)+1
2190 N2=NBX-1
2200 IF(N1.GE.N2)GO TO 122
2210 DO 120 I=N1,N2
2220 MTYP=IE(NBX-1,1)
2230 PH=PHI(MTYP)
2240 TA=SIN(PH)/COS(PH)
2250 IF(NSUCT.EQ.0.OR.SP(MTYP).GT.0.01)GO TO 115
2260 TAU=TA(MTYP)-B(MTYP)*WC(MTYP)
2270 SP(MTYP)=10.**TAU
2280 115 PS1=PS1+SP(MTYP)*CON
2290 PR=(PP(I)+PP(I+1))/2.
2300 PR1=PR1+PR*CON
2310 P1=P1+(PR*TA*AK(MTYP)+C(MTYP))*CON
2320 120 CONTINUE
2330 122 MAT=IE(NBX-1,1)
2340 QBU=7.*C(MAT)
2350 IF(PHI(MAT).LT.0.001)GO TO 125
2360 PH=PHI(MAT)
2370 TA=SIN(PH)/COS(PH)
2380 XNQ=(PH/2.)**45.*PII/180.
2390 XNQ=(1.+TA)*EXP(TA)**(SIN(XNQ)/COS(XNQ))*2.
2400 XNC=(XNQ-1.)/TA
2410 QBU=C(MAT)**XNC+P(NBX)*XNQ
2420 125 PRE=PLOAD+P1+QBU*PII*(DB**2.-DP**2.)/4.

A3
2430  PRF=PRE/((FLOAT(N2)*DX-XF)*PII*DP)
2440  **CALCULATION OF EXCESS RESTRAINING FORCE AT BOTTOM OF PIER**
2450  P2=0.0
2460  DELAV=0.0
2470  PR2=0.0
2480  PR3=0.0
2490  PS2=0.0
2500  CALL PSAU
2510  DO 150 I=N1,N2
2520   MTYP=IE(I+1)
2530  PH=PHI(MTYP)
2540  TA=SIN(PH)/COS(PH)
2550  IF(NSUCT.EQ.0)GO TO 145
2560  CS(MTYP)=ALPHA(MTYP)*B(MTYP)/(100.*B(MTYP))
2570  TAU=A(MTYP)-B(MTYP)*WC(MTYP)
2575  IF(SP(MTYP).GT.0.01)GO TO 145
2580  PS2=PS2+SP(MTYP)*CON
2590  PR=(PP(I)+PP(I+1))/2.
2600  PRR=(PR(I)+PR(I+1))/2.
2610  PR2=PR2+PR*CON
2620  CT=CS(MTYP)
2630  CT=CT/(1.0+EO(MTYP))
2640  IF(PRR.LT.PRF)PRR=PRF
2650  CA=SP(MTYP)/PRR
2660  DEL=CT*ALOG10(CA)*DX
2670  CAT=F'B(F',MTYP,.AND.,NSUCT.EQ.0)CT=CC(MTYP)
2680  IF(<PRR.LT.PRF>)PRR=PRF
2690  IF(DEL.LT.0.0.AND.DXX.GT.DGWT.AND.NSUCT.GT.0)DEL=DEL/ALPHA(MTYP)
2700  IF(DEL.LT.0.0.AND.IOption.LT.2.AND.NSUCT.GT.0)DEL=DEL/ALPHA(MTYP)
2710  P2=P2+(PR*TA*AK(MTYP)+C(MTYP))*CON
2720  DELAV=DELAV+DEL
2730  150 CONTINUE
2740  PST=PS1+PS2
2750  PR1=PR1+PR2
2760  CAT=P1+P2
2770  DPSR=PS2-PR2
2780  Q=PRE-DPSR
2790  IF(DPSR.GT.P2)Q=PRE-P2
2800  PRINT 160,PRE+Q
2810  160 FORMAT(/,25HFORCE RESTRAINING UPLIFT=rF10.3,9H EXCESS=,)
2820  FI0.3,H TONS)
2830  IF(Q.GT.0.0)DELAV=0.0
2840  PRINT 162,DELAV
2850  162 FORMAT(41HSHAFT HEAVE (EXCLUDING SUBSOIL MOVEMENT)=,)
2852  F13.5,H FEET)
2860  **CALCULATION OF FOUNDATION PRESSURE BENEATH FOOTING**
2870  PSTPR=PST-PR
2880  Q0=LOAD-PSTPR
2890  IF(PSTPR.GT.CAT)Q0=LOAD-CAT
2895  IF(Q0.LT.0.0)Q0=0.0000
2900  T=LOAD-DPSR
2910  IF(DPSR.GT.P2)Q=PLOAD-P2
2915 IF(T,GT,0.0)T=0.00000
2920 PRINT 170,Q*T
2930 170 FORMAT(25HFORCE AT BOTTOM OF SHAFT=,F10.3,F9.9 TENSION= ,
2940 & F10.3,F6.9 TONS)
2942 IF(T,LT,-0.0001)ASTEEL=-0.03*T/DP**2.
2944 IF(T,LT,-0.0001)PRINT 180,ASTEEL
2946 180 FORMAT(34X,1HAREA STEEL=,F10.3,F9.9 PERCENT)
2950 IF(QQ,LE,0.01)GO TO 290
2960 BPRES=QQ+PP(NBX)*.7854*(DB**2.-TP**2.)
2970 BPRES=BPRES/.(7854*DB**2.)-PP(NBX)
2975 BPRES1=BPRES
2980 DXX=0.0
2990 DO 200 I=NBX,NXP
3000 IF(I.EQ.NBX)GO TO 201
3005 MTYP=IE(I-1,1)
3006 IF(NSUCT,EQ,1)ALP=ALPHA(MTYP)
3007 IF(NSUCT,EQ,1.AND.DXX.GT.DGWT)ALP=1.0
3008 IF(NSUCT,EQ,1)BPRES=BPRES1*ALP*(1.+2.*AKO(MTYP))/3.
3010 TP=1.+(DB/(2.*DXX))**2.
3015 TP=TP**1.5
3020 IF(CP*MTYP,EQ,1.LT.0.001)GO TO 270
3025 PH=PHICMTYP
3030 TA=SIN(PH)/COS(PH)
3035 XNQ=(PH/2.)+45.*PI/180.
3040 XNQ=(1.+TA)*EXP(TA)*((SIN(XNQ)/COS(XNQ))**2.,
3045 XNC=(XNQ-1.)/TA
3050 QBU=C(MTYP)*XNC+((PP(I)+PP(I+1))/2.)*XNQ
3055 QBUI=QBU
3060 DO 250 I=NBX,NEL
3065 MTYP=IE(I+1,1)
3066 IF(PHI(MTYP),LT,0.001)GO TO 270
3067 PH=PH(MTYP)
3068 TA=SIN(PH)/COS(PH)
3069 XNQ=(PH/2.)+45.*PI/180.
3070 XNQ=(1.+TA)*EXP(TA)*((SIN(XNQ)/COS(XNQ))**2.,
3075 XNC=(XNQ-1.)/TA
3080 QBU=C(MTYP)*XNC+((PP(I)+PP(I+1))/2.)*XNQ
3085 QBUI=QBU
3090 IF(QBUI+QBUI,GT,QBU,1)PRINT 280,QBU,1
3095 280 FORMAT(19HBEARING CAPACITY OF,F10.3,F18H TSF EXCEEDED FOR,
3090 & 8H ELEMENT,I5)
3095 290 FORMAT(19HBEARING CAPACITY OF,F10.3,F18H TSF EXCEEDED FOR,
3100 & 8H ELEMENT,I5)
3100 290 FORMAT(19HBEARING CAPACITY OF,F10.3,F18H TSF EXCEEDED FOR,
3105 & 8H ELEMENT,I5)
3110 290 FORMAT(19HBEARING CAPACITY OF,F10.3,F18H TSF EXCEEDED FOR,
3115 & 8H ELEMENT,I5)
3120 & 33HELEMENT DEPTH,FT DELTA HEAVE,FT,
3125 & 26H EXCESS PORE PRESSURE,TSF)
3130 IF(NSUCT,EQ,0)CALL MECH
3135 IF(NSUCT,EQ,1)CALL SUCT
3140 IF(NQF+QF,GT,DELH1+DELH2
3141 IF1=DELH1+DELH2+DEL1
3142 PRINT 305,DELH1+DELH2+DEL1
3147 306 FORMAT(14HSOIL HEAVE NEXT TO FOUNDATION EXCLUDING SUBSOIL=,
3147 & F8.5,F6.9 FEET,/17HSOIL MOVEMENT=,31X,F8.5,F6.9 FEET,
3147 & /20HTOTAL SOIL MOVEMENT=,28X,F8.5,F6.9 FEET)
3147 IF(NBPRES.EQ.1)DEL2=DELAV+DELH2
3148 IF(NBPRES.EQ.1)PRINT 308,DEL2
3149 308 FORMAT(21HTOTAL SHAFT MOVEMENT=,27X,F8.5,6H FEET)
3150 NP=NP+1
3150 IF(NP,ST,NPROB)GO TO 310
3157 310 STOP
3180 END

3200 SUBROUTINE MECH
3210 PARAMETER NL=10,NQ=81
3220 COMMON A(NL),B(NL),G(NL),WC(NL),ED(NL),SP(NL),AK(NL),CS(NL),
3230 CC(NL),ALPHA(NL),AKO(NL),P(NQ),IE(NQ),1,N1,N2,NBX,NEL,IOPTION,
3240 NOPT,DX,DXX,DXX,PII,XA,XF,DELH,DELH1,DELH2
3250 DELH1=0.0
3290 CALL PSAD
3300 IF(N1.GE.N2)GO TO 50
3310 DO 10 I=N1,N2
3320 MTYP=IE(I,1)
3330 PR=(P(I)+P(I+1))/2.
3340 CA=SP(MTYP)/PR
3350 E=EO(MTYP)+CC(MTYP)*ALOG10(CA)
3360 IF(PR.LT.SP(MTYP))E=EO(MTYP)+CS(MTYP)*ALOG10(CA)
3370 DEL=(E-EO(MTYP))/(1.+EO(MTYP))
3380 IF(NOPT.EQ.0)GO TO 40
3390 DELP=SP(MTYP)-PR
3400 PRINT 200,I,DX,DEL,DELP
3410 40 DELH1=DELH1+DX*DEL
3420 DXX=DXX+DX
3430 10 CONTINUE
3450 50 DELH2=0.0
3470 IF(NBX.GT.N Nel)GO TO 175
3480 DXX=FLOAT(NBX)*DX-DX/2.
3490 DO 100 I=NBX,NEL
3500 MTYP=IE(I,1)
3510 PR=(P(I)+P(I+1))/2.
3520 CA=SP(MTYP)/PR
3530 E=EO(MTYP)+CC(MTYP)*ALOG10(CA)
3540 IF(PR.LE.SP(MTYP))E=EO(MTYP)+CS(MTYP)*ALOG10(CA)
3550 DEL=(E-EO(MTYP))/(1.+EO(MTYP))
3560 IF(NOPT.EQ.0)GO TO 125
3570 DELP=SP(MTYP)-PR
3580 PRINT 200,I,DX,DEL,DELP
3590 125 DELH2=DELH2+DX*DEL
3600 DXX=DXX+DX
3610 100 CONTINUE
3630 200 FORMAT(I5,F10.2,F15.5,5X,F15.5)
3660 175 RETURN
3670 END
SUBROUTINE SUCT
PARAMETER NL=10,NO=81
COMMON A(NL),B(NL),G(NL),WC(NL),EQ(NL),SP(NL),AK(NL),CS(NL),
CC(NL),ALPHA(NL),AKO(NL),PI(NQ),IE(NQ,1),N1,N2,NBX,NEL,IOPTION,
NOPT,DX,DXX,DGWT,PII,XA,XF,DELH,DELH1,DELH2

DELH1=0.0
CALL PSD
IF(N1.GE.N2)GO TO 50
CALL HSUCT
DELH1=DELH
50 DELH2=0.0
IF(NBX.GT.NEL)GO TO 175
DXX=FLOAT(NBX)*DX-DX/2.
N1=NBX
N2=NEL
CALL HSUCT
DELH2=DELH
175 RETURN
.
END

SUBROUTINE HSUCT
PARAMETER NL=10,NO=81
COMMON A(NL),B(NL),G(NL),WC(NL),EQ(NL),SP(NL),AK(NL),CS(NL),
CC(NL),ALPHA(NL),AKO(NL),PI(NQ),IE(NQ,1),N1,N2,NBX,NEL,IOPTION,
NOPT,DX,DXX,DGWT,PII,XA,XF,DELH,DELH1,DELH2

DELH=0.0
I=N1,N2
MTYP=IE(I,1)
IF(AKO(MTYP).LT.0.01)AKO(MTYP)=AK(MTYP)
F=(1.+2.*AKO(MTYP))/3.
PR=(F(I)+F(I+1))/2.
TAUI=A(MTYP)-B(MTYP)*WC(MTYP)
UINIT=TAUI-PR
CT=ALPHA(MTYP)*G(MTYP)/(100.*B(MTYP))
RTAU=TAUI/PR
DEL=CT*ALOG10(RTAUI)*DX
IF(DL,L.T.0.0,.AND.,DXX,.GT.,.DGWT)DEL=DEL/ALPHA(MTYP)
IF(DL,L.T.0.0,.AND.,IOPTION.LT.2)DEL=DEL/ALPHA(MTYP)
IF(NOPT,.EQ.,0)GO TO 33
PRINT 30,I,DXX,DEL,UINIT
30 FORMAT(15,F10.2,F15.5,5X,F15.5)
33 DELH=DELH+DEL
10 CONTINUE
RETURN
END
SUBROUTINE FSAD
PARAMETER NL=10, NO=81
COMMON A(NL), B(NL), G(NL), WC(NL), ED(NL), SP(NL), AK(NL), CS(NL),
CC(NL), ALPHA(NL), AKO(NL), P(NO), IE(NO), N1, N2, NX, NEL, IOPTION,
MOPT, DXX, DGWT, PII, XA, XF, DELH, DELH1, DELH2
4320 AN1=XF/DX
4330 AN2=XA/DX
4340 N1=IFIX(AN1)+1
4350 N2=AN2
4360 DXX=XF+DX/2.
4380 N3=NX-1
4390 IF(N2.GT.N3)N2=N3
4400 CONTINUE
4410 RETURN
4420 END

SUBROUTINE SLAB(Q, NSUCT, BLEN, BWID, MRECT, NBRES, WT)
PARAMETER NL=10, NO=81
COMMON A(NL), B(NL), G(NL), WC(NL), ED(NL), SP(NL), AK(NL), CS(NL),
CC(NL), ALPHA(NL), AKO(NL), P(NO), IE(NO), N1, N2, NX, NEL, IOPTION,
MOPT, DXX, DGWT, PII, XA, XF, DELH, DELH1, DELH2
5100 CALCULATION OF SURCHARGE PRESSURE FROM STRUCTURE
5200 NNP=NEL+1
5300 ANBX=FLOAT(NBX)*DX
5400 DXX=0,0
5500 BPRES=BPRES1
5600 DO 10 I=NBX, NNP
5700 IF(DXX.LT.0.01)GO TO 30
5800 MTPY=IE(I-1,1)
5900 IF(NSUCT.EQ.1)ALP=ALPHA(MTPY)
6000 IF(NSUCT.EQ.1, AN, DXX.GT.DGWT)ALP=1,0
6100 IF(NSUCT.EQ.1)BPRES=BPRES1*ALP*(1.0+2.0*AKO(MTPY))/3.
6200 IF(NBRES.EQ.3)GO TO 20
6300 IF(DXX.LT.0.01)GO TO 30
6400 IF(DXX.LT.0.01)GO TO 30
6500 BL=BLEN
6600 BW=BWID
6700 BP=BPRES
6800 IF(MRECT.EQ.1)GO TO 40
6900 BL=BLEN/2.
7000 BW=BWID/2.
7100 40 VE2=(BL**2+BW**2+DXX**2)/(DXX**2)
7200 VE=VE2**0.5
7300 AN=BL*BW/(DXX**2).
7400 AN2=AN**2.
7500 ENM=(2.0*AN*VE/(VE2+AN2))*(VE2+1,0)/VE2
7600 FN=2.0*AN*VE/(VE2-AN2)
7700 IF(MRECT.EQ.1)BP=BPRES/4.
7800 AB=ATAN(FNM)
7900 IF(FNM.LT.0.)AB=PII+AB
8000 P(I)=P(I)+BP*(ENM+AB)/PII
8100
GO TO 70
20 DB=DXX/BWID
PS=-.157-.22*DB
IF(MRECT.EQ.0.AND.DB.LT.2.5)PS=-.28*DB
PS=10.*PS
P(I)=P(I)+BPRES*PS
GO TO 70
30 P(I)=P(I)+BPRES
70 DXX=DXX+DX
10 CONTINUE
RETURN
END