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DESIGN AND ANALYSIS OF REINFORCING DISTRESSED BRIDGE ABUTMENTS

FINAL REPORT

VOLUME I

Submitted to
South Dakota Department of Transportation

BY

Sangchul Bang
Associate Professor of Civil Engineering
Principal Investigator

South Dakota School of Mines & Technology
Rapid City, South Dakota 57701

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Sangchul Bang, Ph.D., P.E.
Associate Professor
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1. INTRODUCTION

The main objective of this study is to develop a standardized set of design and analysis procedures for utilizing a tie-rod and drilled-in concrete anchor system that reinforces the distressed sill-type concrete bridge abutments supported by either timber or steel piles, as schematically shown in Figure 1. It is intended to provide the South Dakota Department of Transportation a cost-effective technique for designing and maintaining stable bridge abutments.

The study includes: (1) the development of a design method based on the limiting equilibrium approach, (2) the development of an analysis method using generalized plane strain finite element method capable of analyzing the continuum, the reinforced continuum, and the structural members, (3) the determination and evaluation of soil properties based on either linear elastic or nonlinear inelastic stress-strain relationship, and (4) the comparison of results from the developed method of analysis with those from a truly three dimensional method of analysis when it is applied to skew bridges.

This report consists of two volumes. Volume one describes the detailed development and application of the design and analysis methods. Volume two includes the user's manual for the developed computer program.

2. DESIGN METHODOLOGY

The design method of the tie-rod and drilled-in concrete anchor system reinforcing the distressed sill-type concrete bridge abutment supported by piles is described in this chapter. It is based on the

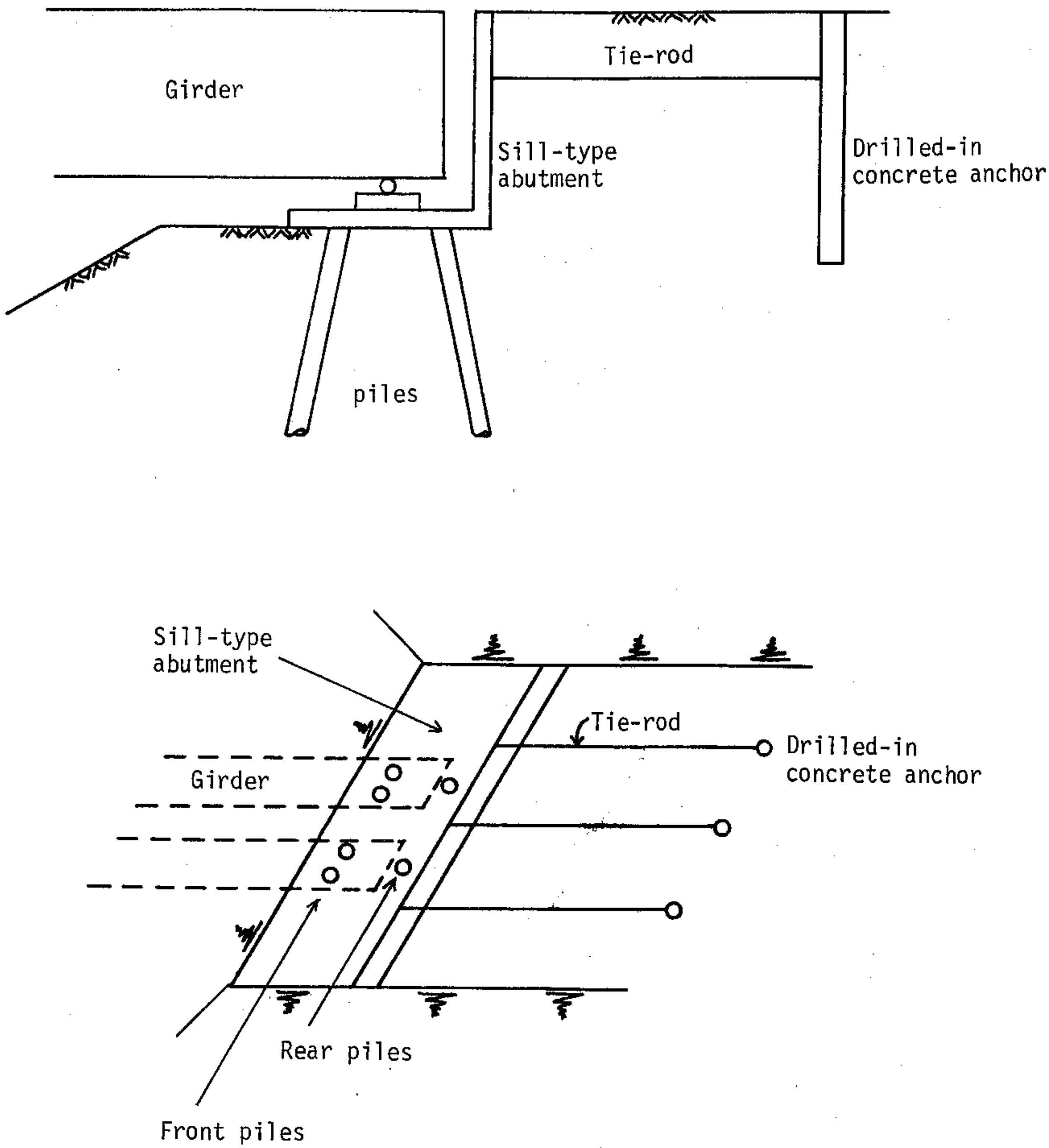


Figure 1. Schematic Diagram of Tie-Rod and Drilled-In Concrete Anchor System.

limit equilibrium approach, i.e., the detailed parameters are determined from the equilibrium condition for adequate safety without considering the anticipated movement. The expected amount of system movement will be considered in the analysis part of the study (Chapter 3). This chapter includes a detailed description of the anticipated lateral earth pressure behind the abutment, the determination of the tie-rod diameter and length, the drilled-in concrete anchor requirement, and the conversion of soil strength parameters.

2.1 Lateral Earth Pressure

For the purpose of determining the magnitude and distribution of anticipated lateral earth pressure behind the abutment wall, several assumptions have been made. They include: (1) The restraint provided by the piles supporting the abutment does not affect the development of lateral earth pressure, (2) a tie-rod of sufficient size is used to minimize the lateral movement of the abutment, and (3) the abutment is relatively rigid. These assumptions lead to the adoption of at-rest lateral earth pressure state behind the abutment for detailed design.

The total lateral thrust expected from the cohesionless backfill material in the at-rest state can be expressed as

$$P_H = (1/2\ \gamma\ H^2 + q\ H)\ K_o \cos\delta \tag{1}$$

where P_H = total lateral thrust

γ = unit weight of backfill material

H = height of the abutment

q = magnitude of surcharge on the ground surface

K_0 = at-rest lateral earth pressure cofficient

δ = friction angle between the abutment and the backfill material

The at-rest lateral earth pressure coefficient can be obtained from either the empirical relationship

$$K_0 = 1 - \sin\phi \tag{2}$$

where ϕ = internal friction angle of the backfill material

or the elasticity relationship

$$K_0 = \frac{\nu}{1-\nu} \tag{3}$$

where ν = Poisson's ratio of the backfill material. Typical values of the wall friction angle, δ, vary from $1/3\phi$ for relatively smooth walls to $2/3\phi$ for relatively rough walls. For detailed values of δ, refer to Table 1 in volume two of this report, the user's manual.

2.2 Tie-Rod Diameter

Assuming conservatively that the supporting piles provide little or negligible lateral resistance, i.e., the entire developed lateral earth pressure is resisted by the tie-rod, one can calculate the design axial force developed within the tie-rod from

$$T = P_H \cdot FS \tag{4}$$

where T = developed axial force per unit width within the tie-rod

FS = factor of safety considered in the design due to several factors, e.g. sag of the tie-rod, change in temperature, and/or possible creep

If a skew bridge is considered, the developed axial force must be

modified as

$$T = P_H \cdot FS \frac{1}{\cos\theta} \tag{5}$$

where θ = bridge skew angle measured from a line perpendicular to the abutment to the tie-rod

Finally, the maximum developed axial force, T_{max}, within a given tie-rod is calculated from

$$T_{max} = \frac{P_H \; FS}{\cos\theta} S_H \tag{6}$$

where S_H = horizontal spacing of the tie-rod.

Note that it is assumed that all tie-rods are installed horizontally.

The minimum required cross-sectional area of the tie-rod can then be determined from

$$A_{min} = \frac{T_{max}}{f_{all}} \tag{7}$$

where f_{all} = allowable tensile stress of the tie-rod material

or $$d_{min} = \sqrt{\frac{4 \; A_{min}}{\pi}} \tag{8}$$

where d_{min} = minimum diameter of the tie-rod.

2.3 Drilled-In Concrete Anchor

The necessary embedded length of the drilled-in concrete anchor must be determined from consideration of both the short term and long term stability. The former considers the stability of the drilled-in concrete anchor immediately after construction and for a short period of

time thereafter. Therefore, the undrained shear strength of the soil must be considered for the detailed calculation. The latter considers the stability of the drilled-in concrete anchor over the design life span.

2.3.1 Short Term Stability

The determination of the drilled-in concrete anchor length based on short term stability consideres only the foundation soil. Note that the undrained shear strength of the soil is needed for this purpose. If the undrained shear strength is not available, one can calculate it approximately from the cohesion and friction angle of the soil as described in Section 2.5.

According to Matlock (7) the ultimate resistance of laterally loaded piles per unit length is expressed as

$$p_{ult} = \left(3 + \frac{\gamma z}{Su} + 0.5 \frac{z}{D} \right) SuD \tag{9}$$

where p_{ult} = ultimate resistance per unit length

γ = unit weight of the soil

Su = undrained shear strength of the soil

z = depth where P_{ult} is desired

D = diameter of the pile.

The total lateral resistance of the pile then becomes

$$P_{ult} = \int_0^L p_{ult} \, dz \tag{10}$$

where L = length of the pile.

Substitution of equation (9) into equation (10) and integration lead to

$$P_{ult} = [3L + \frac{\gamma L^2}{2Su} + \frac{L^2}{4D}]\ SuD \tag{11}$$

This is the total lateral resistance against the maximum developed tie-rod force. Therefore by setting equation (6) and equation (11) equal, one can solve for minimum required length of the drilled-in anchor from the short term stability consideration.

$$L_{min} = \frac{-3SuD + \sqrt{(3SuD)^2 + \frac{4\ FS\ P_H\ S_H}{\cos\theta}\left(\frac{\gamma D}{2} + \frac{Su}{4}\right)}}{\gamma D + \frac{Su}{2}} \tag{12}$$

2.3.2 Long Term Stability

Determination of the drilled-in concrete anchor length based on long term stability is from the consideration of the internal friction of the soil, since the cohesion is likely to disappear over a long period of time. If the friction angle of the soil is not available, it can be approximated from the undrained shear strength, assuming it is normally consolidated, as outlined in Section 2.5. According to Reese, et al. (8),

$$p_{u1} = \frac{A\gamma z^2}{D}\left[\frac{K_o \tan\phi \sin\beta}{\tan(\beta-\phi)\cos\alpha} + \frac{\tan\beta}{\tan(\beta-\phi)}\left(\frac{D}{z} + \tan\beta\tan\alpha\right)\right.$$

$$\left. + K_o \tan\beta\ (\tan\phi \sin\beta - \tan\alpha) - \tan^2(\beta-2\alpha)\frac{D}{z}\right] \tag{13}$$

$$p_{u2} = A\gamma z \left[\tan^2(\beta-2\alpha)(\tan^8 \beta-1) + K_o \tan\phi \tan^4\beta \right] \quad (14)$$

where p_{u1} = ultimate lateral resistance per unit length of short pile

p_{u2} = ultimate lateral resistance per unit length of long pile

$\beta = 45° + \frac{\phi}{2}$

$\alpha = \frac{\phi}{3} \sim \frac{\phi}{2}$ for loose soil and ϕ for dense soil

A = coefficient (Figure 2)

The value of angle α, which is essentially the horizontal inclination of the top of the failure wedge on the ground surface measured from the direction of pile movement, can be taken as $\frac{\phi}{2}$ for general purposes (10). The coefficient A varies depending on the value of z/D, as shown in Figure 2. From a regression analysis of the curve representing the static loading, the following expressions for the coefficient A are obtained:

$$A = 0.035777 \left(5 - \frac{z}{D}\right)^{2.5} + 0.88 \qquad \text{for } 0 \leq \frac{z}{D} \leq 5$$

$$A = 0.88 \qquad \text{for } \frac{z}{D} > 5 \quad (15)$$

The total ultimate resistance of the drilled-in concrete anchor considering short pile behavior, $P_{ult,1}$, and long pile behavior, $P_{ult,2}$, is obtained from the integrations of p_{u1} and p_{u2} over the length of the drilled-in concrete anchor.

$$P_{ult,1} = \int_0^L p_{u1} \, dz \, D$$

$$P_{ult,2} = \int_0^L p_{u2} \, dz \, D \quad (16)$$

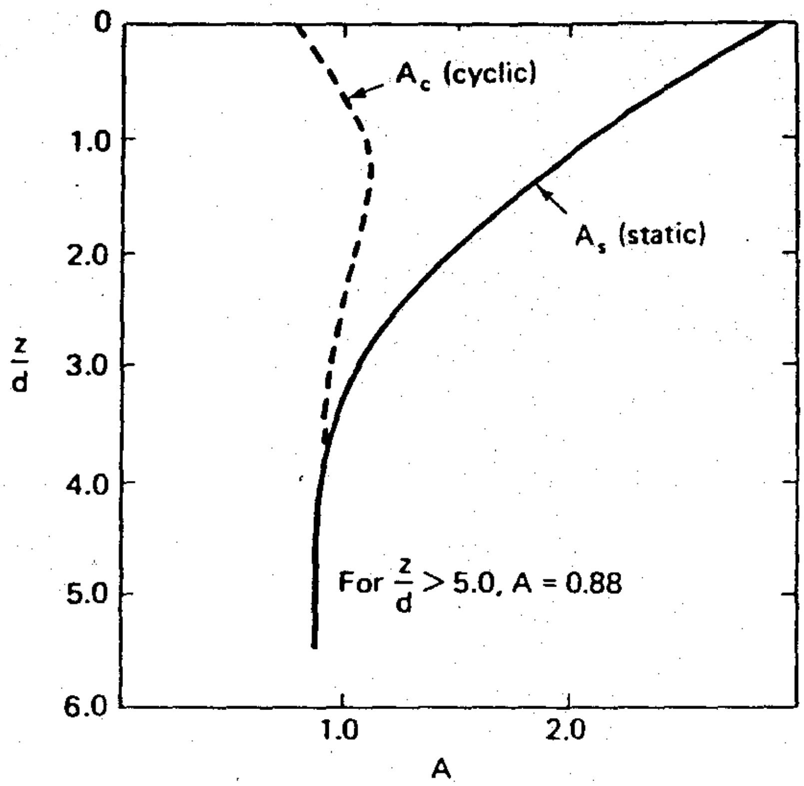


Figure 2. Empirical Coefficient A for Ultimate Soil Resistance Versus Depth

The smaller of $P_{ult,1}$ and $P_{ult,2}$ is used to determine the drilled-in concrete anchor length for long term stability by equating it with the maximum developed axial force within the tie-rod (equation 6).

$$T_{max} = \min(P_{ult,1}, P_{ult,2}) \tag{17}$$

Finally, the required minimum length of the drilled-in concrete anchor is the larger of the values determined from equations (12) and (17).

2.4 Tie-Rod Length

The length of the tie-rod (distance from the abutment to the drilled-in concrete anchor) is determined from the consideration of failure wedges that may develop between the abutment and the drilled-in concrete anchor. It is essential that the failure wedge must not overlap so that no overstressing within the backfill material is induced. Moreover, according to Tschebotarioff (12), the critical failure plane that has an inclination angle of $45° + \frac{\phi}{2}$ to the horizontal at the base of the abutment is only one of many possible failure planes (Figure 3). The mass above the surface of the natural repose line that has an inclination angle of ϕ to the horizontal at the base of the abutment is therefore inherently unstable. For this reason, it is necessary to extend the drilled-in concrete anchor location into a much more stable zone as indicated in Figure 3.

Once the minimum required length of the drilled-in concrete anchor is determined from Section 2.3, the length of the tie-rod can be determined geometrically, e.g. from Figure 3, by appropriately locating

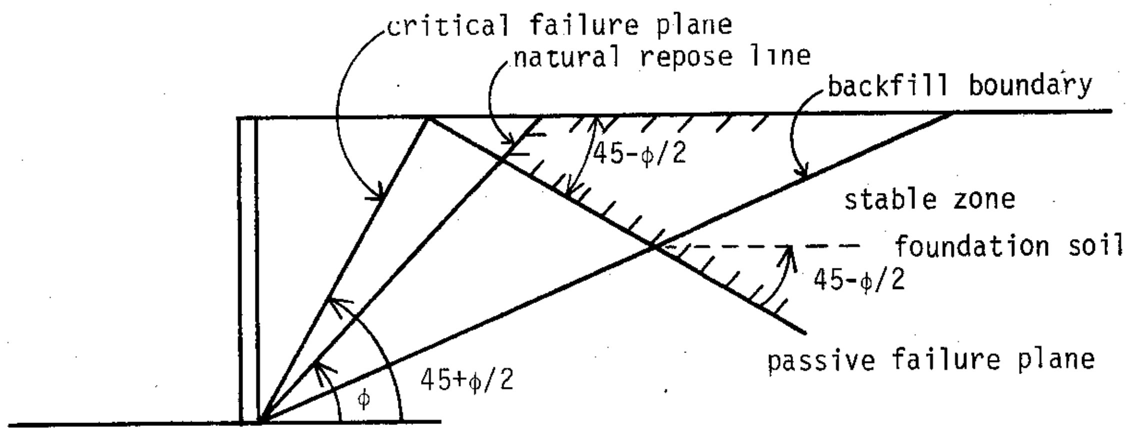


Figure 3. Stable Zone of Drilled-In Concrete Anchor

the drilled-in concrete anchor completely within the stable zone.

2.5 Conversion of Soil Properties

The undrained shear strength of the soil (Su), if not available, can be estimated from cohesion (C) and friction angle (ϕ) as follows.

1. $Su = \frac{\sigma_1 - \sigma_3}{2}$ by definition, where σ_1 and σ_3 are the major and minor principal stresses, respectively.
2. The minor principal stress, σ_3, can be expressed as

$$\sigma_3 = \sigma_1 \tan^2 (45° - \frac{\phi}{2}) - 2\ C \tan(45° - \frac{\phi}{2}) \tag{18}$$

3. Combination of the above two equations yields

$$Su = \frac{\sigma_1}{2} [\ 1 - \tan^2(45° - \frac{\phi}{2})\ ] + C \tan(45° - \frac{\phi}{2}) \tag{19}$$

4. For in-situ stress condition, σ_1 can be calculated from the overburden, i.e.,

   $\sigma_1 = \gamma z$

The conversion from undrained shear strength to soil internal friction angle, ϕ, can be achieved by assuming the soil is normally consolidated, i.e., C = 0, from equation (19). This yields

$$\phi = 90° - 2 \tan^{-1} \sqrt{1 - \frac{2Su}{\gamma z}} \tag{20}$$

where z = depth where Su is measured.

3. ANALYSIS METHODOLOGY

This chapter describes the detailed analysis of the tie-rod and drilled-in concrete anchor system reinforcing the distressed sill-type

concrete bridge abutment supported by piles. The analysis is based on a generalized plane strain finite element method, which assumes that the out-of-plane strain remains zero rather than the out-of-plane displacement being zero as is commonly used in the conventional plane strain approach. It is therefore possible to calculate through the finite element method of analysis the detailed three-dimensional response of the system, including the displacements, the strains and stresses of the continuum, and the axial load, shear forces, and moments in the structural members. This chapter describes how the three-dimensional behaviors of the soil continuum and the structural members are formulated and analyzed. Also included is a description of the reinforced soil continuum element which can be used to model the soil elements reinforced with metal or plastic strips and/or bars. This provision is useful when the abutment construction utilizes a soil reinforcing technique, such as Reinforced Earth, Retained Earth, Soil Nailing, etc. The developed computer program is capable of analyzing the reinforced soil elements with several minor changes in input. The detailed formulation is already included in the program.

3.1 Continuum Elements

A generalized plane strain finite element method of analysis has been developed to investigate the detailed behavior of the tie-rod and drilled-in concrete anchor system. The generalized plane strain condition simply assumes three non-zero displacement components, none of which is dependent on the out-of-plane (z) coordinate. Thus, the out-of-plane strain, ε_z, remains zero, instead of the out-of-plane

displacement, w, being zero as is commonly used in the conventional plane strain approach. This generalized plane strain approach was chosen because the conventional plane strain approach cannot effectively capture the out-of-plane behavior of the skew bridges. Furthermore, fully three-dimensional analysis is prohibitively expensive, tedious and time consuming. The main advantage of the generalized plane strain approach is that it can calculate the three-dimensional displacements, strains and stresses of the continuum while the finite element grid remains in two dimensions. A brief description of the element stiffness matrix formulation of the continuum in the generalized plane strain finite element method of analysis is given below.

To calculate the response of a structural system, it is necessary to establish the governing differential equations of equilibrium, which would need to be solved subject to appropriate boundary and compatibility conditions. In this analysis the differential equations of equilibrium and boundary conditions could be established directly by equilibrium considerations on different elements of the system. An equivalent approach to express the equilibrium of the system is to use the "principle of virtual displacements." This principle states that the equilibrium of the system requires that, for any compatible, small virtual displacements imposed on the system, the total internal virtual work is equal to the total external virtual work.

The total virtual work in the finite element formulation is defined as

$$\delta V = \sum_{e=1}^{N} \delta V_e$$

$$= \sum_{e=1}^{N} [\delta U_e - \delta W_e] = 0 \tag{21}$$

where N = total number of elements

δV_e = virtual work of element

δU_e = element virtual internal energy

δW_e = element virtual external work

The incremental material constitutive relationship is

$$\{\Delta\sigma\} = [C]\,\{\Delta\varepsilon\} \tag{22}$$

where $\{\Delta\sigma\}$ = changes in stress vector

$\{\Delta\varepsilon\}$ = changes in strain vector

$[C]$ = constitutive matrix

Note that the constitutive matrix [C] in incremental analysis depends on current stress state and its history. The element virtual internal energy expression can be written incrementally as

$$\delta\Delta U_e = \int_{V_e} \{\delta\varepsilon\}^T \{\Delta\sigma\}\, dV_e \tag{23}$$

where $\delta\Delta U_e$ = incremental element virtual internal energy

V_e = volume of the element

$\{\delta\varepsilon\}^T$ = incremental strain vector transpose

Substitution of equation (22) into equation (23) yields

$$\delta\Delta U_e = \int_{V_e} \{\delta\varepsilon\}^T [C]\,\{\Delta\varepsilon\}\, dV_e \tag{24}$$

The three-dimensional displacements in the generalized plane strain approach are independent of the out-of-plane z coordinate, i.e.,

$$\begin{aligned} u &= u(x,y) \\ v &= v(x,y) \\ w &= w(x,y) \end{aligned} \tag{25}$$

where u = x directional displacement

v = y directional displacement

w = z directional displacement.

From the definition of strains in three dimensions,

$$\{\varepsilon\} = \{\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{xz}, \gamma_{yz}\}^T = \begin{bmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial v}{\partial y} \\ \frac{\partial w}{\partial z} \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \\ \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \\ \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \end{bmatrix} \tag{26}$$

where ε_x = x-directional normal strain

ε_y = y-directional normal strain

ε_z = z-directional normal strain

γ_{xy} = y-directional shear strain on x-plane

γ_{xz} = z-directional shear strain on x-plane

γ_{yz} = z-directional shear strain on y-plane

it is evident that the strain components in generalized plane strain are

$$\{\varepsilon\} = \begin{bmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial v}{\partial y} \\ 0 \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \\ \frac{\partial w}{\partial x} \\ \frac{\partial w}{\partial y} \end{bmatrix} \tag{27}$$

Using a linear approximation of displacements, the three displacements at each node of the isoparametric quadrilateral continuum element can be approximated as

$$u = \sum_{i=1}^{4} N_i \; u_i$$

$$v = \sum_{i=1}^{4} N_i \; v_i \tag{28}$$

$$w = \sum_{i=1}^{4} N_i \; w_i$$

where u_i, v_i, w_i = approximate i^{th} nodal displacements (Figure 4)

N_i = first order shape function, which transforms any quadrilateral element in global coordinates into a square in local coordinates.

Substituting equation (28) into equation (27) yields

$$\varepsilon_x = \frac{\partial u}{\partial x}$$

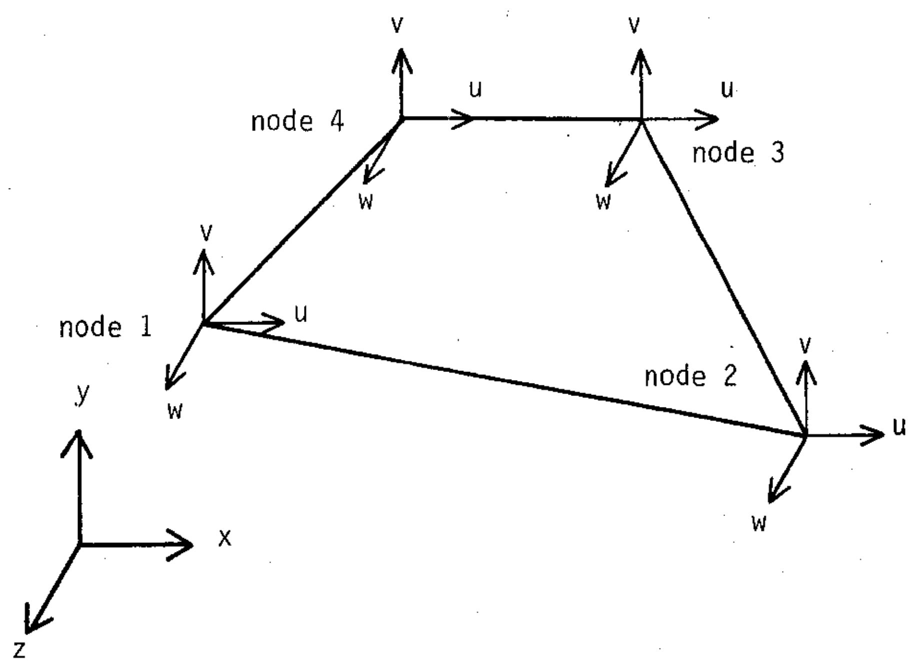


Figure 4. Nodal Displacements of Isoparametric Quadrilateral Element

$$= \frac{\partial}{\partial x} \left[\sum_{i=1}^{4} N_i \; u_i \right] \tag{29}$$

$$= \sum_{i=1}^{4} F_i \; u_i$$

$$\varepsilon_y = \frac{\partial v}{\partial y}$$

$$= \frac{\partial}{\partial y} \left[\sum_{i=1}^{4} N_i \; v_i \right]$$

$$= \sum_{i=1}^{4} G_i \; v_i$$

$$\gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}$$

$$= \frac{\partial}{\partial y} \left[\sum_{i=1}^{4} N_i \; u_i \right] + \frac{\partial}{\partial x} \left[\sum_{i=1}^{4} N_i \; v_i \right]$$

$$= \sum_{i=1}^{4} \left[G_i \; u_i + F_i \; v_i \right]$$

$$\gamma_{xz} = \frac{\partial w}{\partial x}$$

$$= \sum_{i=1}^{4} F_i \; w_i$$

$$\gamma_{yz} = \frac{\partial w}{\partial y}$$

$$= \sum_{i=1}^{4} G_i \; w_i$$

where $F_i = \frac{\partial N_i}{\partial x}$

$$G_i = \frac{\partial N_i}{\partial y}$$

The incremental strain-displacement relationships become

$$\{\Delta\varepsilon\}_e = [B]\ \{\Delta u\}_e \tag{30}$$

where $\{\Delta\varepsilon\}_e$ = element incremental strain vector

$\{\Delta u\}_e$ = element incremental displacement vector

$= \{\Delta u_1, \Delta u_2, \Delta u_3, \Delta u_4, \Delta v_1, \Delta v_2, \Delta v_3, \Delta v_4, \Delta w_1, \Delta w_2, \Delta w_3, \Delta w_4\}^T$

$$[B] = \begin{bmatrix} \{F\}^T & \{0\}^T & \{0\}^T \\ \{0\}^T & \{G\}^T & \{0\}^T \\ \{0\}^T & \{0\}^T & \{0\}^T \\ \{G\}^T & \{F\}^T & \{0\}^T \\ \{0\}^T & \{0\}^T & \{F\}^T \\ \{0\}^T & \{0\}^T & \{G\}^T \end{bmatrix}_{6\times 12}$$

$\{F\}^T = \{F_1, F_2, F_3, F_4\}$

$\{G\}^T = \{G_1, G_2, G_3, G_4\}$

$\{0\}^T$ = null vector transpose

Substitution of equation (30) into equation (24) yields

$$\begin{aligned} \delta\Delta U_e &= \int_{V_e} \{[B]\ \{\delta u\}_e\}^T\ [C]\ \{[B]\ \{\Delta u\}_e\}\ dV_e \\ &= \{\delta u\}_e^T\ [EK]\ \{\Delta u\}_e \end{aligned} \tag{31}$$

where [EK] = element tangent stiffness matrix with a dimension of 12x12

$= \int_{V_e} [B]^T\ [C]\ [B]\ dV_e$

[C] = incremental constitutive matrix

The coefficients of matrix [C] can be obtained from the strain-stress relationship,

$$\{\Delta\varepsilon\} = [D]\,\{\Delta\sigma\} \tag{32}$$

where $[D] = [C]^{-1}$

$$= \begin{bmatrix} d_{11} & d_{12} & d_{12} & 0 & 0 & 0 \\ d_{12} & d_{11} & d_{12} & 0 & 0 & 0 \\ d_{12} & d_{12} & d_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & d_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & d_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & d_{66} \end{bmatrix}$$

$$d_{11} = \frac{1}{E}$$

$$d_{12} = -\frac{\nu}{E}$$

$$d_{44} = \frac{2(1+\nu)}{E}$$

E = tangent modulus

ν = tangent Poisson's ratio

Note that, if a nonlinear soil characterization is used, the tangent modulus, E, depends upon the current stress state and its history. Therefore, the correct value of E as well as the matrices $[C]$ and $[K]$ must be determined from an iteration process.

Once the element tangent stiffness matrices are determined for each element, they are assembled to obtain a global system stiffness matrix based on the element-node arrangement. Meanwhile, the element load vectors, resulting from gravity loading, the horizontal body force, and the tractions along the sides of the element, are assembled separately to produce a global system load vector. Finally, external nodal loads

and moments are added to the global system load vector, and boundary conditions are applied, to obtain a set of simultaneous equations. They are then solved to obtain the global nodal displacements. The obtained nodal displacements are then used to calculate the strains (equation 30) and the stresses (equation 22). When nonlinear soil properties are considered, the calculated stresses are used to estimate a set of new soil tangent modulus values for the next iteration.

It is worthwhile to reiterate the special characteristics of the generalized plane strain finite element analysis. Conventional two-dimensional plane strain finite element analysis - which is incapable of simulating the three-dimensional behavior - requires the size of element stiffness matrix, [EK], to be 8x8, i.e., two displacements along x and y coordinates) at each of four nodes for a linear isoparametric quadrilateral element. Truly three-dimensional finite element analysis, on the other hand, requires an element stiffness matrix, [EK], of 24x24, since there are three displacements along x, y and z coordinates at each of eight nodes for a linear isoparametric brick element. The generalized plane strain finite element analysis requires an element stiffness matrix, [EK], of 12x12, i.e., three displacements at each of four nodes for a linear isoparametric quadrilateral element. It is always desirable to have a smaller size element stiffness matrix, since the majority of computational efforts in solving a finite element formulation comes from the solution of the simultaneous equations.

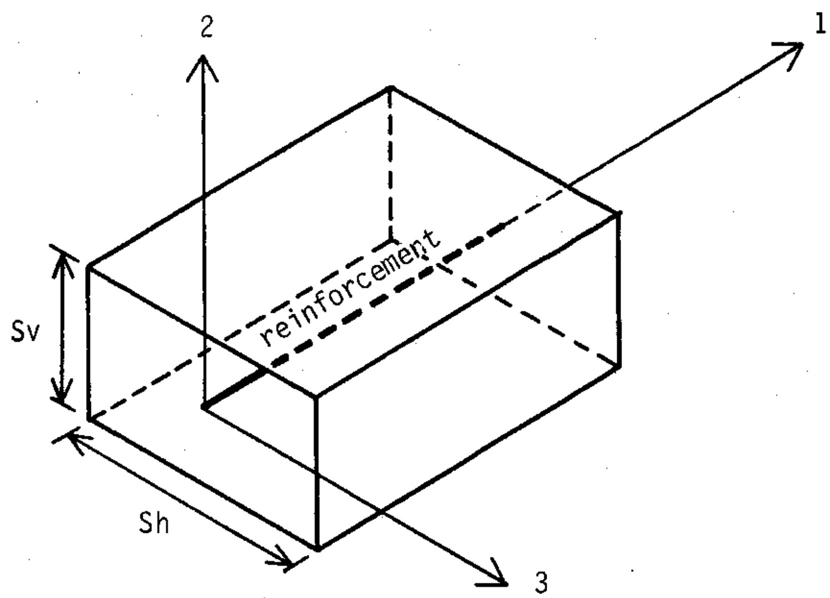
3.2 Reinforced Continuum Elements

The soil elements that are reinforced with strips or bars are

represented in the generalized plane strain finite element method of analysis using the concept of a composite unit cell (9). This concept expresses the orthotropic composite material properties as functions of the properties of each of the constituent materials, i.e., the soil, the reinforcement, and their geometric arrangement.

The unit cell is an isolated small unit of the material that completely exhibits its composite characteristics. Therefore, this approach can be applied only when there are many reinforcements repeated in both horizontal and vertical directions. The schematic diagram of the unit cell is shown in Figure 5. The average values of the stresses distributed over the cell faces, in this approach, are equal to the stresses in the equivalent composite material, and the average values of the strains for the cell are those of the composite. The desired composite properties can therefore be calculated from a detailed consideration of the behavior of the unit cell. These composite properties are then used in the analysis of the reinforced soil elements. Such an analysis yields the composite stress and strain throughout the system. Once the composite stress state is determined at a particular point in the system, the corresponding constituent stress states, e.g. the soil and the reinforcement, may be determined by returning to the analysis of the unit cell. A brief description of these developments is given below.

The strain-stress relationships in local coordinates can be expressed, assuming that the reinforcement has no shear resistance due to its flexible nature, as



Sh: horizontal reinforcement spacing
Sv: vertical reinforcement spacing
1,2,3: local coordinates

Figure 5. Schematic Configuration of Unit Cell

$$\{\varepsilon\} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ & C_{22} & C_{23} & 0 & 0 & 0 \\ & & C_{33} & 0 & 0 & 0 \\ \text{Symmetric} & & & C_{44} & 0 & 0 \\ & & & & C_{55} & 0 \\ & & & & & C_{66} \end{bmatrix} \{\sigma\} \tag{33}$$

where $\{\varepsilon\} = \{\varepsilon_1, \varepsilon_2, \varepsilon_3, \gamma_{12}, \gamma_{13}, \gamma_{23}\}^T$

$\{\sigma\} = \{\sigma_1, \sigma_2, \sigma_3, \tau_{12}, \tau_{13}, \tau_{23}\}^T$

Note that the local coordinate 1 is defined as the axial direction of the reinforcement. If isotropic soil properties are assumed, several coefficients of [C] can be removed, i.e.,

$$C_{12} = C_{13}$$
$$C_{22} = C_{33}$$
$$C_{44} = C_{55} = C_{66} \tag{34}$$

Since the shear resistance of the reinforcement is neglected, the coefficient C_{44} can be obtained directly from the behavior of the soil alone.

$$C_{44} = \frac{2(1+\nu_{so})}{E_{so}} \tag{35}$$

where E_{so} = tangent modulus of the soil

ν_{so} = Poisson's ratio of the soil

To determine the coefficients C_{11} and C_{12}, consider the incremental composite stress state:

$$\sigma_1 = \sigma$$
$$\sigma_2 = \sigma_3 = \tau_{12} = \tau_{13} = \tau_{23} = 0 \tag{36}$$

This indicates that only a uniform normal stress with the magnitude of σ is applied along the coordinate 1 direction on the unit cell shown in Figure 5. From equation (33), one can express

$$C_{11} = \frac{\varepsilon_1}{\sigma}, \; C_{12} = \frac{\varepsilon_2}{\sigma}, \; C_{13} = \frac{\varepsilon_3}{\sigma} \tag{37}$$

The applied composite stress, σ, acting over the composite area, A_c, must be equal to the sum of the reinforcement stress, $\sigma_{1,r}$, acting over the reinforcement area, A_r, and the soil stress along the reinforcement direction, $\sigma_{1,s}$, acting over the soil area, A_s. Assuming that A_c is approximately the same as A_s, it can be written as

$$\sigma A_c = \sigma_{1,s} A_c + \sigma_{1,r} A_r \tag{38}$$

Due to the nature of composite material, the strains of reinforcement and soil along the axial direction, coordinate 1, are the same.

$$\varepsilon_1 = \varepsilon_{1,s} = \varepsilon_{1,r}$$
$$\varepsilon_2 = \varepsilon_{2,s} \tag{39}$$
$$\varepsilon_3 = \varepsilon_{3,s}$$

The constitutive relationships, which define the stress-strain relationships, for the soil and the reinforcement must be satisfied. Therefore,

$$\varepsilon_{1,s} = \frac{\sigma_{1,s}}{E_s}$$

$$\varepsilon_{1,r} = \frac{\sigma_{1,r}}{E_r} \tag{40}$$

where E_s = modulus of soil

E_r = modulus of reinforcement

$\varepsilon_{1,s}$ = strain of soil along 1-coordinate

$\varepsilon_{1,r}$ = strain of reinforcement along 1-coordinate

Substitution of equations (39) into equation (40) yields

$$\sigma_{1,s} = \frac{E_s}{E_r}\,\sigma_{1,r} \tag{41}$$

Equation (41) is substituted into equation (38) to obtain

$$\sigma_{1,r} = \frac{\sigma\, A_c\, E_r}{A_c\, E_s + A_r\, E_r}$$

or

$$\sigma_{1,s} = \frac{\sigma\, A_c\, E_s}{A_c\, E_s + A_r\, E_r} \tag{42}$$

Finally, the coefficients C_{11}, C_{12} and C_{13} are obtained from

$$C_{11} = \frac{\varepsilon_1}{\sigma} = \frac{\varepsilon_{1,s}}{\sigma} = \frac{\sigma_{1,s}}{\sigma\, E_s}$$

$$= \frac{A_c}{A_c\, E_s + A_r\, E_r} \tag{43}$$

$$C_{12} = \frac{\varepsilon_2}{\sigma} = \frac{\varepsilon_{2,s}}{\sigma} = \frac{-\nu_s\, \sigma_{1,s}}{\sigma\, E_s}$$

$$= \frac{-\nu_s A_c}{A_c E_s + A_r E_r} \tag{44}$$

The coefficients C_{22} and C_{23} can be obtained similarly, by considering the incremental composite stress state:

$$\sigma_2 = \sigma$$
$$\sigma_{1,s} = \sigma_3 = \tau_{12} = \tau_{13} = \tau_{23} = 0 \tag{45}$$

From equation (33), then

$$\varepsilon_1 = C_{11}\sigma_1 + C_{12}\sigma$$
$$\varepsilon_2 = C_{21}\sigma_1 + C_{22}\sigma \tag{46}$$
$$\varepsilon_3 = C_{31}\sigma_1 + C_{32}\sigma$$

Along the axial direction of reinforcement, strains are equal, i.e.,

$$\varepsilon_1 = \varepsilon_{1,s} = \varepsilon_{1,r} \tag{47}$$

Also the equilibrium must be satisfied as described in equation (38).

$$\sigma_1 A_c = \sigma_{1,s} A_c + \sigma_{1,r} A_r \tag{48}$$

Since we applied $\sigma_{1,s} = 0$, from equation (48)

$$\sigma_1 = \frac{\sigma_{1,r} A_r}{A_c} \tag{49}$$

The 1-coordinate directional strain can be rewritten as

$$\varepsilon_1 = \varepsilon_{1,r} = \frac{\sigma_{1,r}}{E_r} \tag{50}$$

Also from equation (46) and previously obtained values of C_{11} and C_{12},

$$\varepsilon_1 = C_{11}\ \sigma_1 + C_{12}\ \sigma$$

$$= \frac{\sigma_1\ A_c}{A_c\ E_s + A_r\ E_r} - \frac{\nu_s\ \sigma\ A_c}{A_c\ E_s + A_r\ E_r}$$

$$= \frac{\sigma_1}{E_s(1+\alpha)} - \frac{\nu_s\ \sigma}{E_s(1+\alpha)} \qquad (51)$$

where

$$\alpha = \frac{A_r\ E_r}{A_c\ E_s}$$

Substituting equations (49) and (50) into equation (51) leads to

$$\frac{\sigma_{1,r}}{E_r} = \frac{\sigma_{1,r}\ A_r}{A_c\ E_s(1+\alpha)} - \frac{\nu_s\ \sigma}{E_s(1+\alpha)}$$

or

$$\sigma_{1,r} = -\frac{\nu_s\ E_r}{E_s}\ \sigma \qquad (52)$$

From equation (46)

$$C_{22} = [\ \varepsilon_2 - C_{21}\ \sigma_1]\ \frac{1}{\sigma}$$

$$= [\varepsilon_{2,s} + \frac{\nu_s\ \sigma_1}{E_s(1+\alpha)}\ ]\ \frac{1}{\sigma} \qquad (53)$$

Substitution of equation (52) into equation (49) and then into equation (53) will finally produce an expression for the coefficient C_{22},

$$C_{22} = \frac{1+\alpha(1-\nu_s^2)}{E_s(1+\alpha)} \qquad (54)$$

Similarly, from equation (46),

$$C_{32} = C_{23} = [\ \varepsilon_3 - C_{31}\ \sigma_1\ ]\ \frac{1}{\sigma}$$

$$= [\ \varepsilon_{3,s} + \frac{\nu_s\ \sigma_1}{E_s(1+\alpha)}\ ]\ \frac{1}{\sigma} \qquad (55)$$

Since $\sigma_2 = \sigma$ is applied, without applying $\sigma_{1,s}$ or σ_3, it follows from the definition of isotropic material volume change,

$$\varepsilon_{3,s} = \varepsilon_{1,s} \qquad (56)$$

Due to the nature of composite material, i.e., the strains of the soil and the reinforcement along the coordinate 1 are equal,

$$\varepsilon_{1,s} = \varepsilon_{1,r} = \frac{\sigma_{1,r}}{E_r} \qquad (57)$$

Equation (57) is substituted into equation (56) and then into equation (55) to obtain

$$C_{32} = [\ \frac{\sigma_{1,r}}{E_r} + \frac{\nu_s\ \sigma_1}{E_s(1+\alpha)}\ ]\ \frac{1}{\sigma} \qquad (58)$$

If equation (52) is substituted into equation (49) and then into equation (58), C_{32} is obtained as

$$C_{32} = -\frac{\nu_s\ [1+\alpha(1+\nu_s)]}{E_s(1+\alpha)} \qquad (59)$$

All coefficients in equation (33) are now fully defined.

$$C_{11} = \frac{1}{E_s(1+\alpha)}$$

$$C_{12} = C_{13} = -\frac{\nu_s}{E_s(1+\alpha)}$$

$$C_{22} = C_{33} = \frac{1+\alpha(1-\nu_s^2)}{E_s(1+\alpha)}$$

$$C_{23} = -\frac{\nu_s[1+\alpha(1+\nu_s)]}{E_s(1+\alpha)}$$

$$\alpha = \frac{A_r\ E_r}{A_c\ E_s} \tag{60}$$

To obtain the constitutive relationships in global coordinates, the local coordinates may have to be rotated twice on a two-dimensional plane. First one can rotate the 1-coordinate about the 2-coordinate until the 1-coordinate lies completely on the xy plane as shown in Figure 6. The corresponding transformation matrix [A] can be described in terms of the rotation angle, β.

$$\{\sigma\}_{T2z} = [A]\ \{\sigma\}_{123} \tag{61}$$

where $\{\sigma\}_{T2z} = \{\sigma_T,\ \sigma_2,\ \sigma_z,\ \tau_{T2},\ \tau_{Tz},\ \tau_{2z}\}^T$

$\{\sigma\}_{123} = \{\sigma_1,\ \sigma_2,\ \sigma_3,\ \tau_{12},\ \tau_{13},\ \tau_{23}\}^T$

$$[A] = \begin{bmatrix} \cos^2\beta & 0 & \sin^2\beta & 0 & \sin 2\beta & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ \sin^2\beta & 0 & \cos^2\beta & 0 & -\sin 2\beta & 0 \\ 0 & 0 & 0 & \cos\beta & 0 & \sin\beta \\ -\frac{\sin 2\beta}{2} & 0 & \frac{\sin 2\beta}{2} & 0 & \cos 2\beta & 0 \\ 0 & 0 & 0 & -\sin\beta & 0 & \cos\beta \end{bmatrix}$$

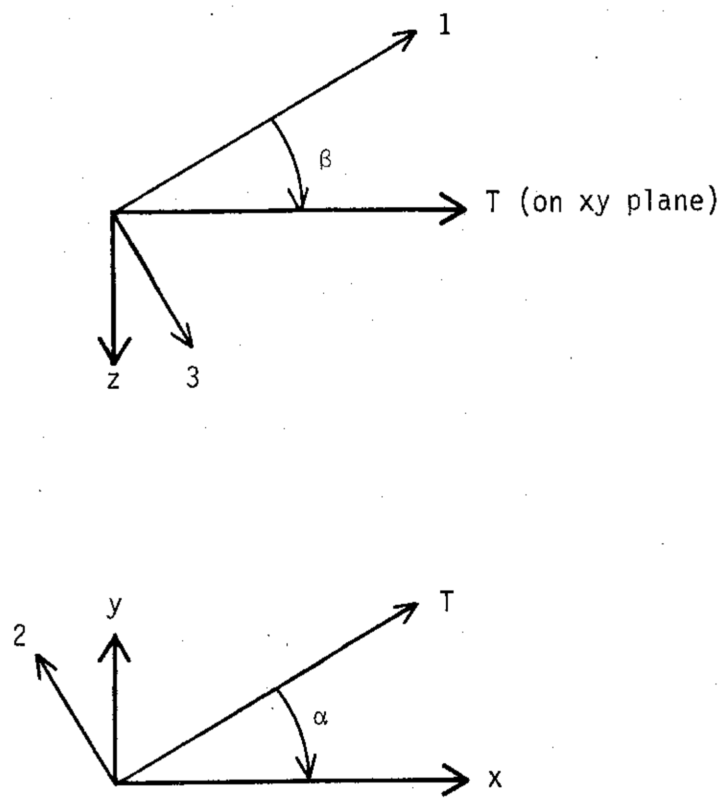


Figure 6. Coordinate Rotation from Local Coordiates to Global Coordinates

β = reinforcement orientation from xy plane along z-coordinate measured counterclockwise positive.

Next, the T-coordinate is rotated about the z-coordinate until the T and x coordinates coincide to complete the transformation as shown in Figure 6. The corresponding transformation matrix [B] is then defined as

$$\{\sigma\}_{xyz} = [B]\ \{\sigma\}_{T2z} \tag{62}$$

where $\{\sigma\}_{xyz} = \{\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{xz}, \tau_{yz}\}^T$

$$[B] = \begin{bmatrix} \cos^2\alpha & \sin^2\alpha & 0 & -\sin 2\alpha & 0 & 0 \\ \sin^2\alpha & \cos^2\alpha & 0 & \sin 2\alpha & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ \frac{\sin 2\alpha}{2} & -\frac{\sin 2\alpha}{2} & 0 & \cos 2\alpha & 0 & 0 \\ 0 & 0 & 0 & 0 & \cos\alpha & -\sin\alpha \\ 0 & 0 & 0 & 0 & \sin\alpha & \cos\alpha \end{bmatrix}$$

α = projection of reinforcement orientation on xy plane from x-coordinate measured counterclockwise positive.

Combining equations (33), (61) and (62) yields

$$\begin{aligned} \{\sigma\}_{xyz} &= [B]\ \{\sigma\}_{T2z} \\ &= [B]\ [A]\ \{\sigma\}_{123} \\ &= [B]\ [A]\ [C]^{-1}\ \{\varepsilon\}_{123} \\ &= [B]\ [A]\ [C]^{-1}\ [A]^T\ \{\varepsilon\}_{T2z} \\ &= [B]\ [A]\ [C]^{-1}\ [A]^T\ [B]^T\ \{\varepsilon\}_{xyz} \end{aligned} \tag{63}$$

Finally the constitutive relationships of composite unit cell in global coordinates are obtained.

$$\{\sigma\}_{xyz} = [K]\ \{\varepsilon\}_{xyz} \tag{64}$$

where $[K] = [BAC^{-1}(BA)^T]_{6x6}$

The detailed steps involved in applying the composite unit cell approach in the generalized finite element analysis are described below.

1. Obtain the element stiffness matrix [EK] from matrix [K].
2. Assemble into a global stiffness matrix.
3. Compute the composite stresses and strains.
4. Recover the reinforcement stress from

$$\sigma_{1,r} = \varepsilon_1 E_r$$

$$\varepsilon_1 = \sum_{j=1}^{6} [BA]_{j,1} \{\varepsilon\}^c_{j,xyz} \tag{65}$$

where $\{\varepsilon\}^c_{xyz}$ = composite strains in global coordinates.

5. Calculate developed axial stress of reinforcement.

$$\sigma_1 = \sum_{j=1}^{6} [B'A']_{j,1} \{\sigma\}^c_{j,xyz} \tag{66}$$

where $[B'] = [B]^{-T}$

$[A'] = [A]^{-T}$

$\{\sigma\}^c_{xyz}$ = composite stresses in global coordinates.

6. Calculate the soil stress along 1-coordinate from

$$\sigma_{1,s} = \sigma_1 - \sigma_{1,r} \frac{A_r}{A_c} \tag{67}$$

7. Compute the remaining local coordinate soil stresses from

$$\sigma_i = \sum_{j=2}^{6} [B'A']_{j,i} \{\sigma\}^c_{j,xyz} \tag{68}$$

where $\sigma_i = \{\sigma_2, \sigma_3, \tau_{12}, \tau_{13}, \tau_{23}\}$

8. Transform the soil stresses into global coordinates

$$\{\sigma\}^s_{xyz} = [BA]\ \{\sigma\}^s_{123} \tag{69}$$

where $\{\sigma\}^s_{xyz} = \{\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{xz}, \tau_{yz}\}^T$ of soil

$\{\sigma\}_{123} = \{\sigma_{1,s}, \sigma_2, \sigma_3, \tau_{12}, \tau_{13}, \tau_{23}\}^T$

9. If hyperbolic nonlinear soil characterizations (5) are used, the minor principal stress, σ_{minor}, must be calculated from $\{\sigma\}^s_{xyz}$. One can use a cubic equation solver for this purpose. A new estimation of instantaneous tangent modulus of the soil is then made possible.

3.3 Structural Members (Beam-Column Elements)

Representation of structural members, i.e., the piles, the abutment, the tie-rod, and the drilled-in concrete anchor, in the analysis is described in this section.

Based on local coordinates 1, 2, and 3 as defined in Figure 7, the force-deformation relationships of general beam-column element in three-dimensional space are described as (2)

$$\{F\} = [K]\ \{\delta\} \tag{70}$$

where $\{F\}$ = element end force vector

$\{\delta\}$ = element end displacement vector

$[K]$ = element stiffness matrix in local coordinates

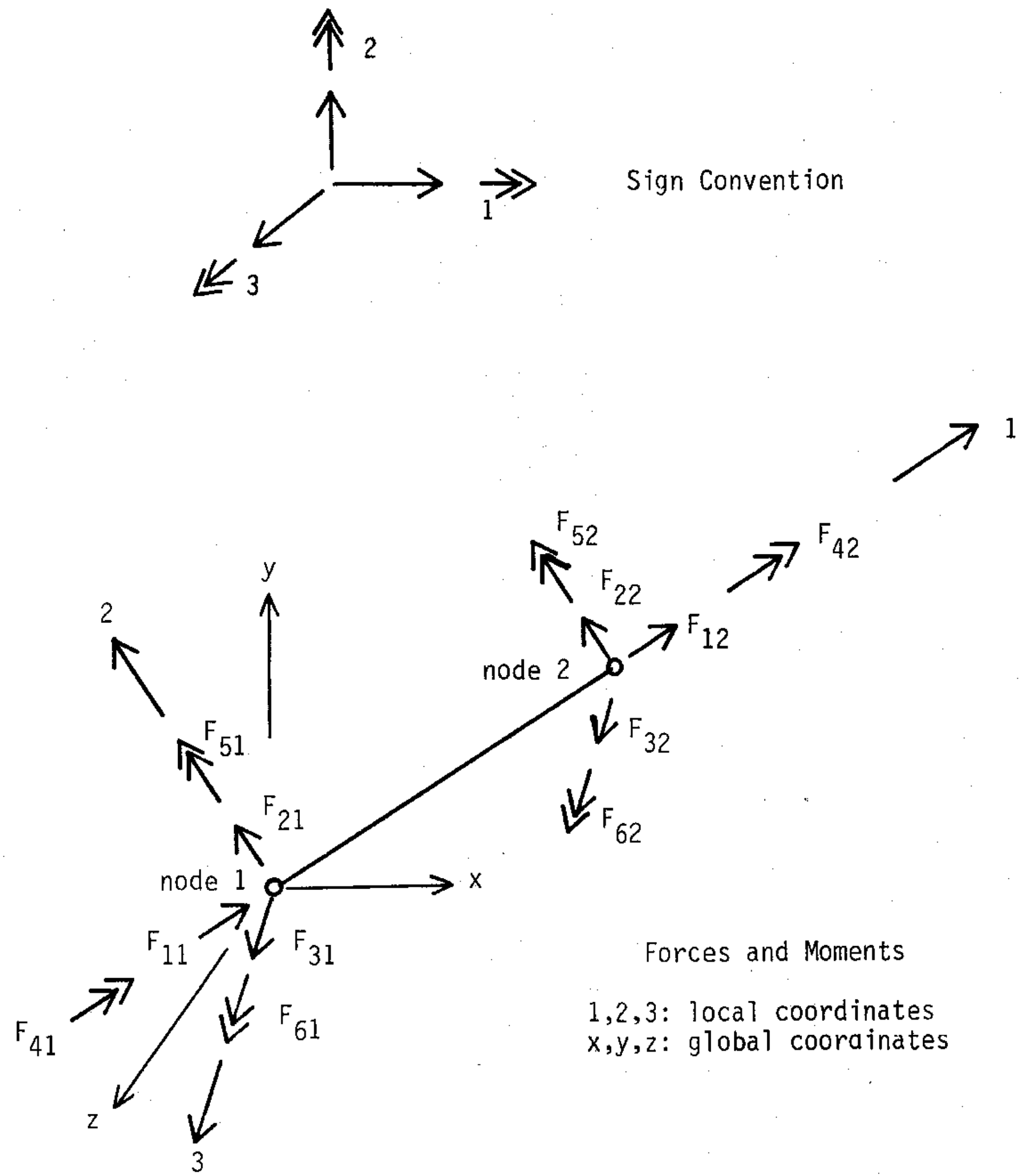


Figure 7. Local Coordinates

The element stiffness matrix [K] is expressed as

$$[K] = \begin{bmatrix} K_{11} & 0 & 0 & 0 & 0 & 0 & -K_{11} & 0 & 0 & 0 & 0 & 0 \\ & K_{22} & 0 & 0 & 0 & K_{26} & 0 & -K_{22} & 0 & 0 & 0 & K_{26} \\ & & K_{33} & 0 & -K_{35} & 0 & 0 & 0 & -K_{33} & 0 & -K_{35} & 0 \\ & & & K_{44} & 0 & 0 & 0 & 0 & 0 & -K_{44} & 0 & 0 \\ & & & & K_{55} & 0 & 0 & 0 & K_{35} & 0 & K_{5,11} & 0 \\ & & & & & K_{66} & 0 & -K_{26} & 0 & 0 & 0 & K_{6,12} \\ & & & & & & K_{11} & 0 & 0 & 0 & 0 & 0 \\ & \text{Symmetric} & & & & & & K_{22} & 0 & 0 & 0 & -K_{26} \\ & & & & & & & & K_{33} & 0 & K_{35} & 0 \\ & & & & & & & & & K_{44} & 0 & 0 \\ & & & & & & & & & & K_{55} & 0 \\ & & & & & & & & & & & K_{66} \end{bmatrix} \tag{71}$$

where $K_{11} = \frac{EA}{L}$

$$K_{22} = \frac{12EI_3}{L^3}$$

$$K_{26} = \frac{6EI_3}{L^2}$$

$$K_{33} = \frac{12EI_2}{L^3}$$

$$K_{35} = \frac{6EI_2}{L^2}$$

$$K_{44} = \frac{GJ_1}{L}$$

$$K_{55} = \frac{4EI_2}{L}$$

$$K_{5,11} = \frac{2EI_2}{L}$$

$$K_{66} = \frac{4EI_3}{L}$$

$$K_{6,12} = \frac{2EI_3}{L}$$

E = Young's modulus

A = cross-sectional area

L = length

G = shear modulus

J_1 = polar moment of inertia about 1-coordinate

I_2 = moment of inertia about 2-coordinate

I_3 = moment of inertia about 3-coordinate

The element end forces are

$$\{F\} = \{F_{11}, F_{21}, F_{31}, F_{41}, F_{51}, F_{61}, F_{12}, F_{22}, F_{32}, F_{42}, F_{52}, F_{62}\}^T \quad (72)$$

where F_{ij} = force component along i coordinate at j^{th} node, for i=1, 2 and 3, and moment component about i coordinate at j^{th} node, for i= 4, 5 and 6. (Refer to Figure 7 for details.)

The element end displacements are

$$\{\delta\} = \{\delta_{11}, \delta_{21}, \delta_{31}, \theta_{11}, \theta_{21}, \theta_{31}, \delta_{12}, \delta_{22}, \delta_{32}, \theta_{12}, \theta_{22}, \theta_{32}\}^T \quad (73)$$

where δ_{ij} = displacement along i coordinate at j^{th} node.

θ_{ij} = rotation about i coordinate at j^{th} node.

Transformation of the local displacement vector to the global

displacement vector needs the following coordinate transformation.

$$\{\delta\} = [T]\{\Delta\} \tag{74}$$

where $\{\delta\}$ = local coordinate displacement vector

$\{\Delta\}$ = global coordinate displacement vector

$[T]$ = 12x12 transformation matrix

The transformation matrix can be expressed as

$$[T] = \begin{bmatrix} [C] & [0] & [0] & [0] \\ [0] & [C] & [0] & [0] \\ [0] & [0] & [C] & [0] \\ [0] & [0] & [0] & [C] \end{bmatrix} \tag{75}$$

where $$[C] = \begin{bmatrix} C_x & C_y & C_z \\ -\dfrac{C_x C_z}{C_x^2 + C_y^2} & -\dfrac{C_y C_z}{C_x^2 + C_y^2} & C_x^2 + C_y^2 \\ \dfrac{C_y}{C_x^2 + C_y^2} & -\dfrac{C_x}{C_x^2 + C_y^2} & 0 \end{bmatrix}$$

$$C_x = \frac{x_2 - x_1}{L}$$

$$C_y = \frac{y_2 - y_1}{L}$$

$$C_z = \frac{z_2 - z_1}{L}$$

L = length of the beam-column element

$$= \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

x_i, y_i, z_i = coordinates of i^{th} node defining the beam-column element

Note that this transformation has several restrictions:

1. For beam-column elements located completely on the xy plane, the 2-coordinate must be parallel to the z-coordinate.
2. For inclined beam-column elements, a plane defined by the 1 and 2 coordinates must coincide with the z coordinate.
3. The 1 coordinate must be always along the axial direction of the beam-column element.

Finally, the element stiffness matrix in global coordinates can be obtained as explained below. First, consider the relationships of displacements and forces between local and global coordinates.

$$\{\delta\} = [T]\ \{\Delta\} \qquad (76)$$

$$\{F\} = [T]\ \{P\}$$

where {P} = force vector in global coordinates.

Substituting equations (76) into (70) yields,

$$[T]\{P\} = [K]\ [T]\ \{\Delta\} \qquad (77)$$

Multiply both sides by $[T]^{-1}$ to obtain

$$\{P\} = [T]^{-1}\ [K]\ [T]\ \{\Delta\} \qquad (78)$$

Since the matrix [T] is orthogonal, $[T]^{-1} = [T]^T$

Therefore,

$$\{P\} = [T]^T\ [K]\ [T]\ \{\Delta\} \qquad (79)$$

The element stiffness matrix in global coordinates defines the relationship between {P} and {Δ}, i.e.,

$$\{P\} = [EK]\,\{\Delta\} \tag{80}$$

Therefore one can obtain the element stiffness matrix in global coordinates,

$$[EK]_{12x12} = [T]^T\,[K]\,[T] \tag{81}$$

where [T] = transformation matrix from equation (75)

[K] = element stiffness matrix in local coordinates from equation (71)

The element stiffness matrices are then assembled to obtain the global stiffness matrix. The global stiffness matrix of beam-column elements may then be summed with that of continuum elements, if any continuum elements exist. The final set of simultaneous equations are then solved for nodal or element-end displacements. These can then be used to calculate element end forces in local coordinates from equations (76) and (80).

$$\begin{aligned}\{F\} &= [T]\,\{P\}\\ &= [T]\,[EK]\,\{\Delta\}\end{aligned} \tag{82}$$

The solution vector {F} has 12 components as shown in Figure 7. They represent axial thrusts, shear forces, and bending moments developed on each end of the beam-column element.

4. COMPARISON OF DEVELOPED ANALYSIS METHOD

4.1 Example Problem

To illustrate the effectiveness of the generalized plane strain finite element method of analysis, a comparison has been made with the results obtained from a truly three-dimensional analysis (1). Figure 8 shows the schematic description of the selected example problem. The problem includes a sill-type concrete abutment reinforced with a system of tie-rods and drilled-in concrete anchor. The tie-rods have a diameter of 1.5 inches installed at a skew angle of 11.31° to the plane perpendicular to the abutment. The drilled-in concrete anchors are 2.5 ft. in diameter and made of reinforced concrete with a length of 5 ft. The thicknesses of the abutment stem and base are a uniform 1 ft. It rests on top of linear elastic soil with Poisson's ratio of 0.3, tangent modulus of 3,500 psi, and unit weight of 120 pcf.

The simulation of tie-rods and drilled-in concrete anchors is relatively simple in either of the finite element analyses. The abutment stem and base can be simulated by beam-column elements in the generalized plane strain finite element method of analysis. The same approach is not directly possible in truly three-dimensional finite element analysis. Plate elements, therefore, have been used to model the abutment. The behavior of the plate element is described by

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{bmatrix} = \begin{bmatrix} C_{xx} & C_{xy} & 0 \\ C_{xy} & C_{yy} & 0 \\ 0 & 0 & G_{xy} \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} \qquad (83)$$

where $C_{xx} = C_{yy} = \dfrac{E}{1-\nu^2}$

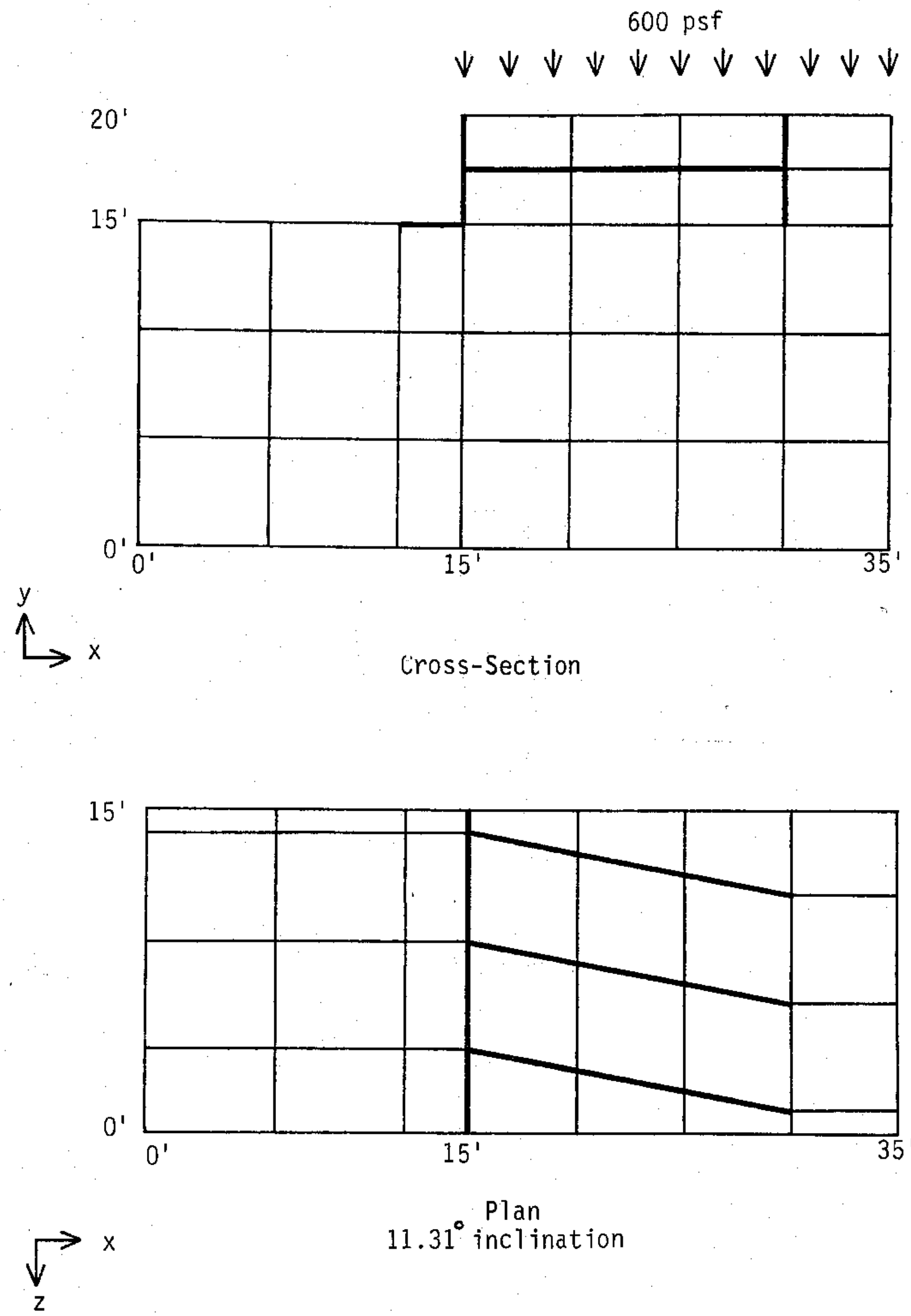


Figure 8. Example Problem

$$C_{xy} = \frac{\nu E}{1-\nu^2}$$

$$G_{xy} = \frac{E}{2(1+\nu)}$$

A tangent modulus value of 3,000 ksi and Poisson's ratio of 0.3 have been used for the analysis.

4.2 Results

It is noted that a total of 42 nodes, 29 isoparametric quadrilateral continuum elements and 8 beam-column elements are used in the generalized plane strain finite element analysis; whereas the truly three-dimensional analysis requires 210 nodes, 116 brick elements to model the soil, 9 beam-column elements for the tie-rods, 6 beam-column elements for the drilled-in concrete anchors, and 12 plate elements for the abutment. It took the CDC Cyber-180 mainframe computer at the South Dakota School of Mines and Technolgoy approximately 8.5 and 182.5 seconds, respectively, of CPU time to complete the analysis for the generalized plane strain finite element analysis and the truly three-dimensional finite element analysis resulting in a ratio of 21.5 in computational time. The calculated results for the two different approaches are described below.

Table 1 shows a comparision of three-dimensional displacements at selected nodes. As can be seen from the table, the difference in displacements is virtually negligible. Shown in Figure 9 is the comparison of out-of-plane directional deformation of the tie-rod. For the purpose of comparison, the middle tie-rod has been selected from the

Table 1. Comparison of Displacements at Selected Nodes.

Node	u		v		w	
GPS(3-D)	GPS	3-D	GPS	3-D	GPS	3-D
4 (88)	0	0	-0.194	-0.192		
8 (92)	-0.016	-0.014	-0.213	-0.211		
12 (96)	-0.048	-0.050	-0.310	-0.310		
16 (100)	-0.048	-0.050	-0.390	-0.391		
17 (101)	0.015	0.014	-0.390	-0.391	-0.0055	-0.000
18 (102)	0.077	0.070	-0.391	-0.391		
23 (107)	0.011	0.010	-0.552	-0.556	0.0032	0.003
24 (108)	0.064	0.067	-0.585	-0.590		
29 (113)	0.012	0.012	-0.617	-0.622	-0.0020	-0.002
30 (114)	0.032	0.029	-0.653	-0.657		
34 (118)	-0.003	-0.004	-0.617	-0.622		
35 (119)	0.008	0.008	-0.618	-0.622	0.0044	0.002
36 (120)	0.020	0.020	-0.618	-0.622		
42 (126)	0	0	-0.692	-0.697		

GPS: Generalized plane strain finite element analysis.

3-D: Truly three-dimensional finite element analysis.

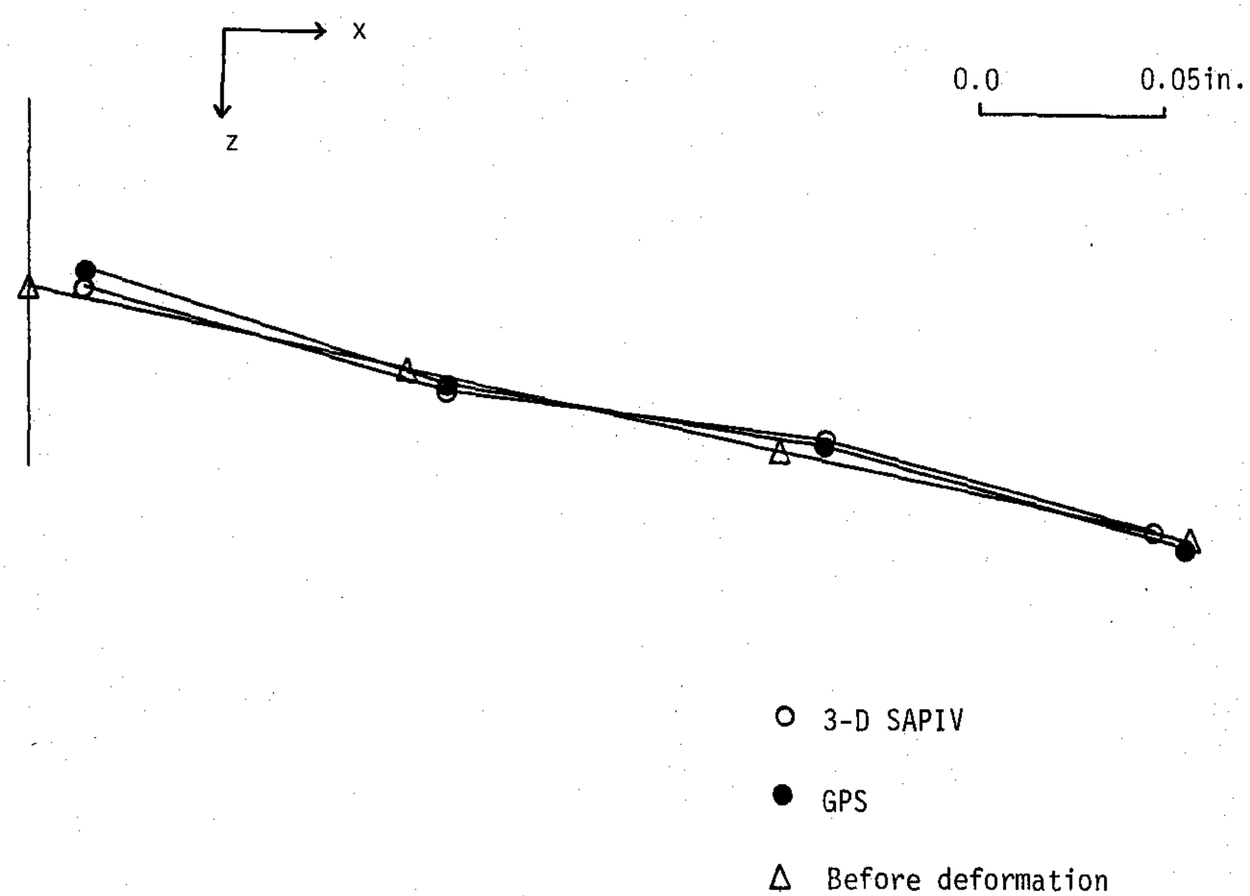


Figure 9. Tie-Rod Deformation on xz Plane

results of the truly three-dimensional analysis. Again, the generalized plane strain finite element method of analysis is shown to be capable of capturing the out-of-plane behavior closely without a significant loss in accuracy.

Figure 10 indicates variations of developed three normal stresses along a vertical line 30 inches away from the abutment calculated from the two finite element approaches. Without any doubt, the results are essentially the same.

Finally, developed axial force, shear force, and bending moment within the drilled-in concrete anchor, and axial force within the tie-rod are compared in Table 2. It shows that the differences range approximately from 2.7% to 12.1%.

Table 2. Comparison of Forces and Moments

	Axial Force		Shear Force		Bending Moment	
	GPS	3-D	GPS	3-D	GPS	3-D
Mid-depth of concrete anchor	lbs 12,360	11,030	lbs 977	952	ft-lbs 29,243	28,544
Mid-length of tie-rod	lbs 390	401				

GPS: Generalized plane strain finite element analysis.

3-D: Truly three-dimensional finite element analysis.

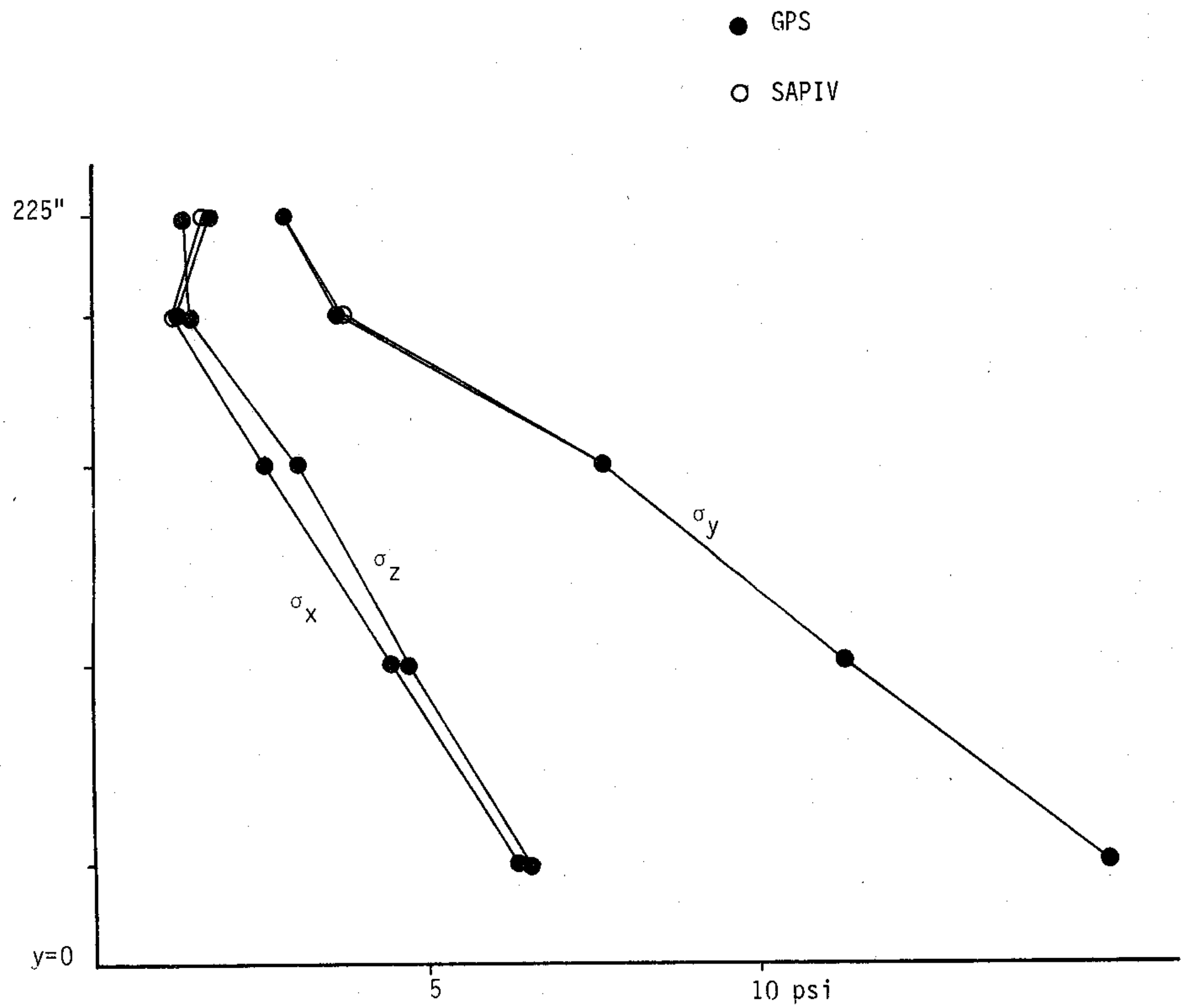


Figure 10. Stress Variation; 30 Inches from the Abutment

Based on the comparisons discussed, it is concluded that the generalized plane strain finite element method of analysis can effectively capture most of the significant three-dimensional response of the skew bridge reinforcing system utilizing tie-rods and drilled-in concrete anchors without significant error, but with a remarkable reduction in computational effort.

5. CONSTITUTIVE RELATIONSHIP

The internal mechanical response of a soil can be expressed in terms of stresses and strains. Two of the most widely used soil constitutive relationships are described here and incorporated in the computer program explained in volume two of the report.

5.1 Linear Elastic Soil Model

The linear elastic soil stress-strain relationship in three dimensions can be expressed by the generalized Hooke's Law (3). The tangent modulus, E, can be obtained from the measurement of stresses and strains by calculating the slope of the linear portion of the curve passing through the origin of the coordinates. The Poisson's ratio, ν, can be estimated by measuring the strains along the axial direction, ε_a, and the lateral direction, ε_l, i.e.,

$$\nu = -\frac{\varepsilon_l}{\varepsilon_a} \tag{84}$$

5.2 Nonlinear Hyperbolic Soil Model

The hyperbolic stress-strain relationships were first developed (4) for use in nonlinear incremental analyses of soil deformations. In each

increment of such analyses the stress-strain behavior of the soil is treated as being incrementally linear, and the relationship between incremental stress and strain is assumed to be governed by the generalized Hooke's Law of elastic deformations. Given below is the description of the development of hyperbolic soil stress-strain relationship parameters and their determination as given by Selig (11).

To help understand the hyperbolic model, consider a compression test on a cylinder initially confined by hydrostatic pressure, σ_3 (Figure 11a). The soil is subjected to an increasing axial stress, called a deviator stress, $\sigma_1 - \sigma_3$ (Figures 11b), until shear failure occurs. A typical resulting stress-strain relationship is shown by the dashed curve in Figure 12. This relationship is assumed to be represented mathematically by a hyperbola of the form

$$\sigma_1 - \sigma_3 = \frac{\varepsilon}{\dfrac{1}{E_i} + \dfrac{\varepsilon}{(\sigma_1 - \sigma_3)_u}} \tag{85}$$

where E_i = initial tangent modulus, and $(\sigma_1 - \sigma_3)_u$ = ultimate deviator stress at large strain as shown by the solid curve in Figure 12. The hyperbola is considered valid up to the actual soil failure point A. Thus, the ultimate deviator stress is defined in terms of the actual failure deviator stress by the failure ratio R_f, as

$$R_f = \frac{(\sigma_1 - \sigma_3)_f}{(\sigma_1 - \sigma_3)_u} \tag{86}$$

The parameters of E_i and $(\sigma_1 - \sigma_3)_u$ may be found by trial curve

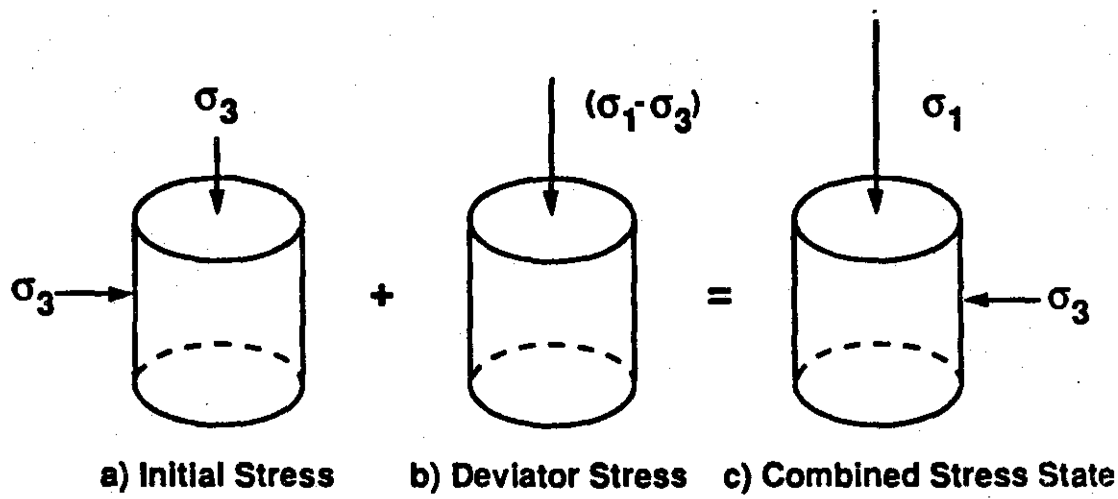


Figure 11. Triaxial Test Stress Conditions

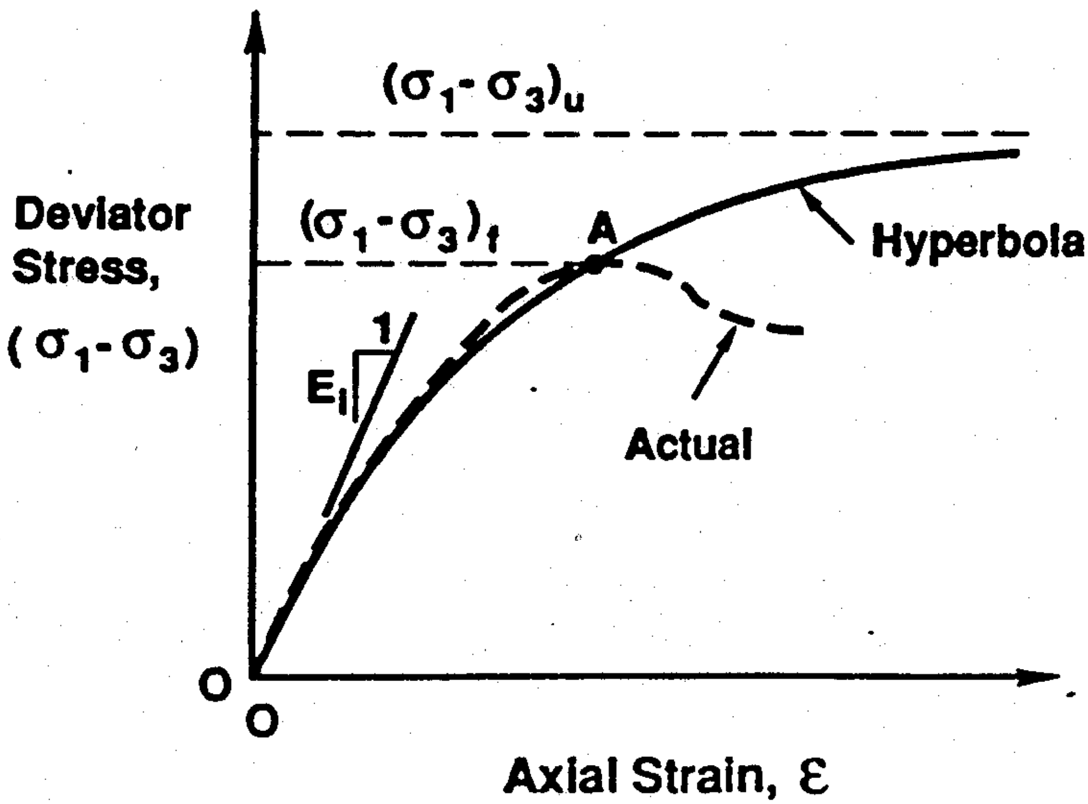


Figure 12. Comparison of Actual Stress-Strain Curve with Hyperbola

fitting. However, it is more convenient to plot the actual test data in the linearized hyperbolic form of Figure 13. Then the most appropriate straight line is used to represent the transformed equation (85). The equation of this line is

$$\frac{\varepsilon}{(\sigma_1 - \sigma_3)} = \frac{1}{E_i} + \frac{\varepsilon}{(\sigma_1 - \sigma_3)_u} \tag{87}$$

The initial tangent modulus is assumed to increase with confining pressure according to the equation

$$E_i = K\, P_a\, (\sigma_3/P_a)^n \tag{88}$$

where P_a is the atmospheric pressure which is used to non-dimensionalize the parameters K and n.

The failure envelope, defined from Mohr circles at failure, is expressed mathematically by

$$(\sigma_1 - \sigma_3)_f = \frac{2C \cos\phi + 2\sigma_3 \sin\phi}{1 - \sin\phi} \tag{89}$$

The actual envelope is often curved. Thus a best fit straight line is used or ϕ may be varied with σ_3. In the latter case ϕ is represented by

$$\phi = \phi_0 - \Delta\phi \log_{10}(\sigma_3/P_a) \tag{90}$$

where ϕ_0 = value of ϕ for $\sigma_3 = P_a$, and

$\Delta\phi$ = reduction in ϕ for a ten-fold increase in σ_3.

The tangent modulus for any stress state may be determined by differentiating equation (85). The resulting equation is

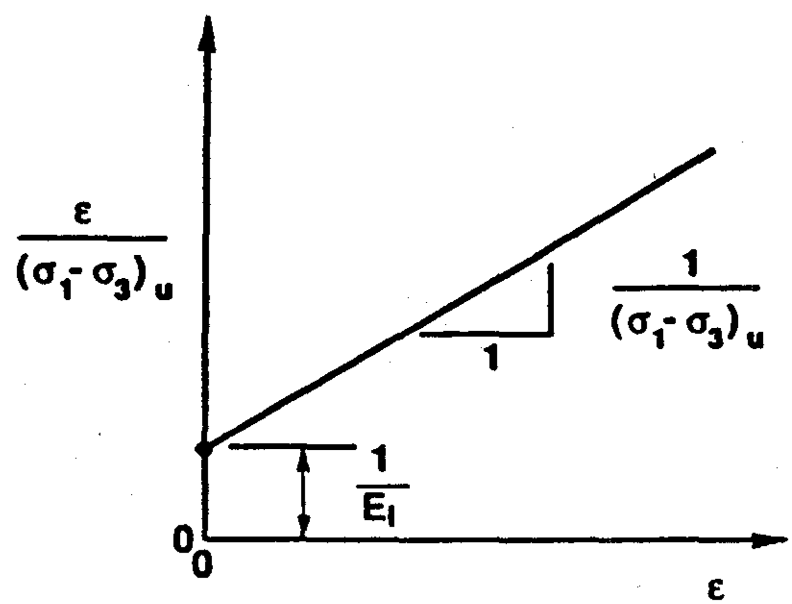


Figure 13. Linear Transformation of Hyperbola for Young's Modulus

$$E_t = \left[1 - \frac{R_f \; (1 - \sin\phi) \; (\sigma_1 - \sigma_3)}{2C \; \cos\phi + 2\sigma_3 \; \sin\phi} \right]^2 K \; P_a \; (\sigma_3/P_a)^n \tag{91}$$

Thus the parameters for defining the tangent modulus are K, n, C, ϕ_0, $\Delta\phi$, and R_f.

The second soil property used in the model is bulk modulus B, defined as

$$B = \frac{\Delta\sigma_m}{\Delta\varepsilon_{vol}} \tag{92}$$

where $\Delta\sigma_m$ = change in mean stress, and

$\Delta\varepsilon_{vol}$ = change in volumetric strain.

The volumetric strain behavior in the triaxial test is illustrated in Figure 14. The modulus B is determined from triaxial data by

$$B = \frac{\sigma_1 - \sigma_3}{3\varepsilon_{vol}} \tag{93}$$

Only one point on the curve can be selected from each test, since B is assumed to be independent of $\sigma_1 - \sigma_3$ and only dependent on σ_3 which is constant for a given test. An example of an appropriate fitting point is P in Figure 14. Duncan, et al. (5) proposed using the volume change and deviator stress corresponding to the point at which the volume change curve has a horizontal tangent or at which 70% of the strength is reached, whichever occurs first.

The variation of B with σ_3 is assumed to be given by

$$B = K_b \; P_a \; (\sigma_3/P_a)^m \tag{94}$$

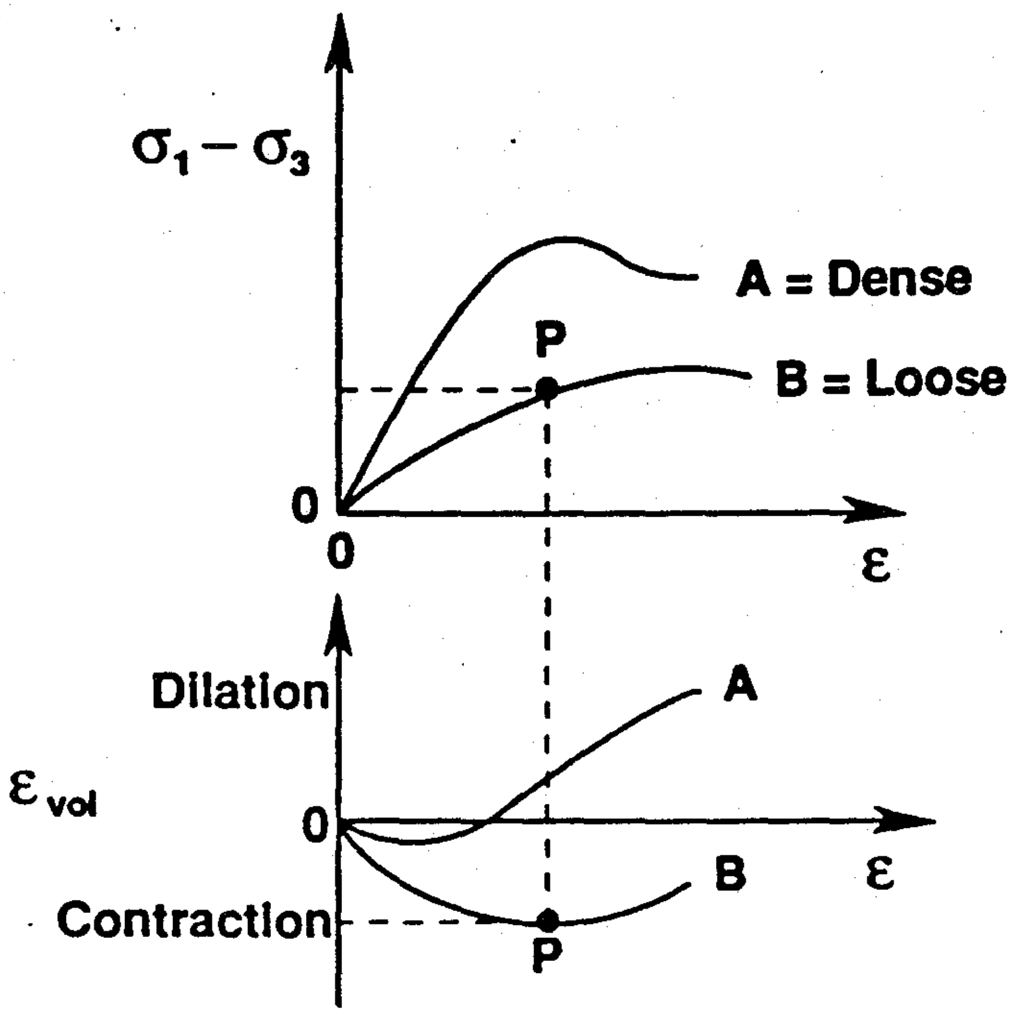


Figure 14. Volumetric Strain Trends from Triaxial Tests

The parameters K_b and m are determined as shown in Figure 15. The line in Figure 15 is the logarithmic form of equation (94).

This highly idealized soil characterization has some significant limitations which should be understood by anyone who uses it in the finite element method of analysis; these limitations are discussed in the following three paragraphs (6).

(1) Being based on the generalized Hooke's Law, the relationships are most suitable for analysis of stresses and movements prior to failure. The relationships are capable of predicting accurately nonlinear relationships between loads and movements, and it is possible to continue the analyses up to the stage where there is local failure in some elements. However, when a stage is reached where the behavior of the soil mass is controlled to a large extent by the properties assigned to elements which have already failed, the results will no longer be reliable, and they may be unrealistic in terms of the behavior of real soils at and after failure. These relationships are not useful, therefore, for analyses extending up to the stage of instability of a soil mass. They are useful for predicting movements in stable earth masses.

(2) The hyperbolic relationships do not include volume changes due to changes in shear stress, or "shear dilatancy." They may, therefore, be limited in the accuracy with which they can be used to predict deformations in dilatant soils, such as dense sands under low confining pressures.

(3) The parameters are not fundamental soil properties, but only values of empirical coefficients which represent the behavior of the soil

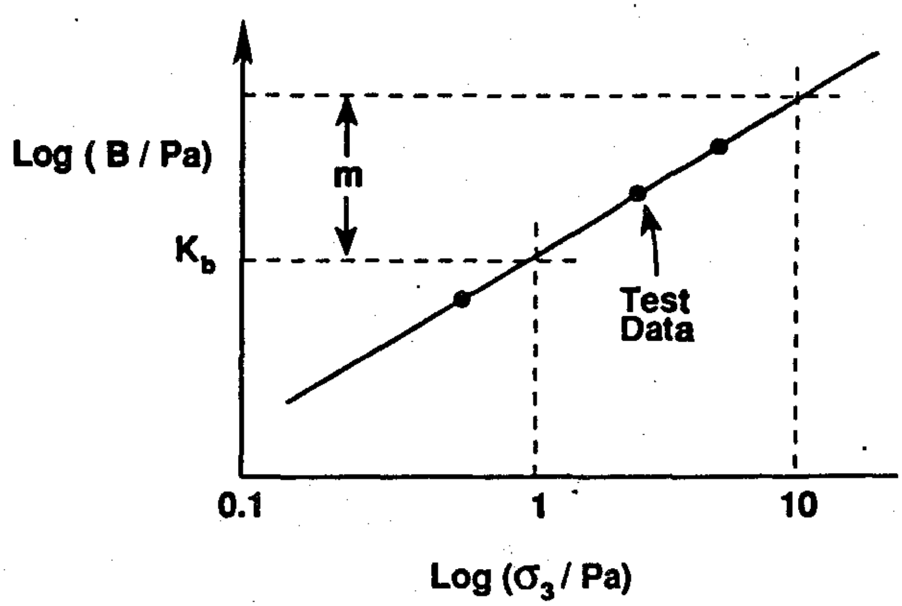


Figure 15. Determination of K_b and m

under a limited range of conditions. The values of the parameters depend on the density of the soil, its water content, the range of pressures used in testing, and the drainage conditions. In order that the parameters will be representative of the behavior of the soil in the field condition, the laboratory test conditions must correspond to the field conditions with regard to these factors.

6. HYPERBOLIC SOIL PARAMETERS

The values of hyperbolic parameters described in Section 5.2, can be determined in a series of simple, straightforward steps using the data from either drained or unconsolidated undrained triaxial tests. The detailed procedures for evaluating these parameters are described below.

6.1 Preliminary

The first step in evaluating the hyperbolic soil parameters is to select data appropriate to the problem being analyzed. In the case of natural soils, the laboratory tests must be performed using undisturbed soil samples. In the case of fill materials, the tests must be performed using specimens compacted to the same density and water content as in the field.

Tests performed with pressures much higher or lower than those that might be expected in the field should not be used in evaluating the hyperbolic parameters, the reason being that the values of the parameters which best fit the results of the tests depend to some extent on the range of pressures used during the tests. The test data should also be inspected closely to eliminate experimental errors and

inconsistencies.

When the stress-strain data points do not describe smooth variations, judgements should be made to draw smooth curves through the data to make the most reasonable interpretation of the test data. Additionally, the stress-strain curves should be shifted, if necessary, so that they pass through the origin.

6.2 Strength Parameters

The values of cohesion (C) and internal friction angle (ϕ) can be evaluated using any conventional procedure, e.g. the Mohr circle approach or the p-q stress diagram approach (6). The Mohr circle approach involves first plotting the stress circles and then determining the values of cohesion and friction angle by drawing the failure envelope and measuring the intercept and the slope of the envelope. The p-q stress diagram approach involves plotting the values of p and q stresses, where $p = 1/2\ (\sigma_1 + \sigma_3)$ and $q = 1/2\ (\sigma_1 - \sigma_3)$ at failure, respectively. Measured intercept and slope angle then can be converted to cohesion and internal friction angle as shown in Figure 16. The advantage of this approach is that it is somewhat simpler to fit the best straight line through a series of points which do not fall in a straight line than it is to draw the best straight envelope for a series of circles which do not have a common tangent.

The Mohr circle envelope for almost all soils is sometimes curved to some extent. The wider the range of pressures involved, the greater the curvature is. In the case of cohesionless soils, e.g. sands, gravels, and rockfills, this curvature - one of such examples is shown

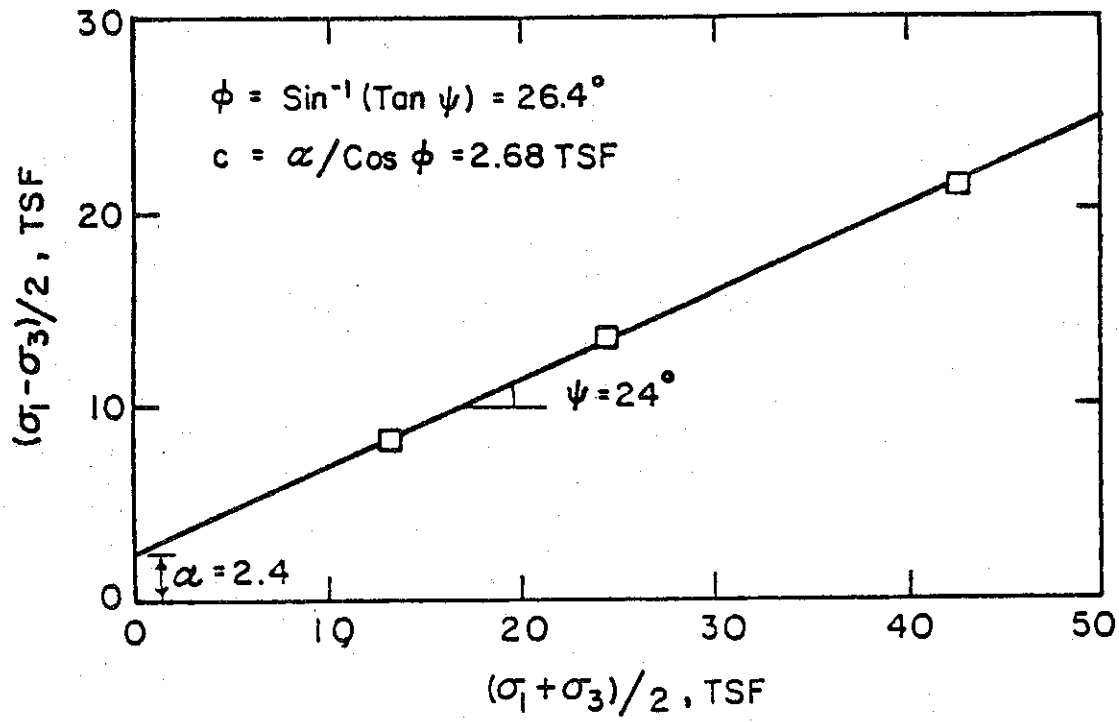


Figure 16. Modified Mohr Envelope

in Figure 17 - can make it difficult to select a single value of ϕ which is representative of the full range of pressures of interest. In such cases, it is usually found (5) that the values of the friction angle decrease in proportion with the logarithm of the confining pressure, i.e.,

$$\phi = \phi_0 - \Delta\phi \log_{10} \left(\frac{\sigma_3}{P_a}\right) \tag{95}$$

where ϕ_0 = value of friction angle for σ_3 equal to P_a

$\Delta\phi$ = reduction in ϕ for a 10-fold increase in σ_3

σ_3 = confining pressure during triaxial test

P_a = atmospheric pressure

The values of ϕ_0 and $\Delta\phi$ can be obtained from the semi-log plot of friction angle vs. normalized confining pressure as shown in Figure 18.

6.3 Tangent Modulus Parameters

In evaluating the loading modulus, K, and the modulus exponent, n, two steps are involved. The first is to determine the values of initial tangent modulus, E_i, for each test, and the second is to plot these values against confining pressure, σ_3, on full-log space.

Consider the stress-strain curves shown in Figure 19. The best hyperbolic fit of the curves is usually achieved by matching the hyperbola to the experimental curve at points corresponding to 70% and 95% of the strength, as indicated by arrows in Figure 19. A set of these two points is then replotted on axial strain, ε_a, vs. $\varepsilon_a/(\sigma_1 - \sigma_3)$. Through each pair of points on this diagram a straight line is drawn, corresponding to the hyperbola which matches the stress-strain

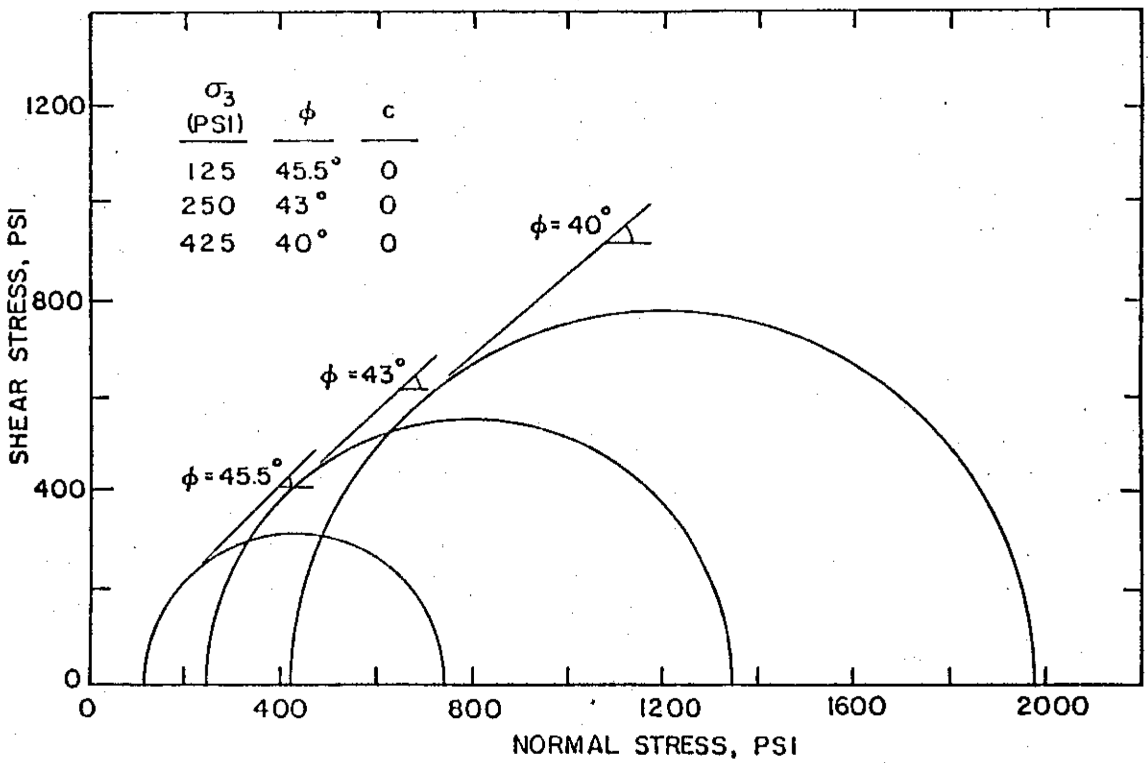


Figure 17. Mohr Envelope

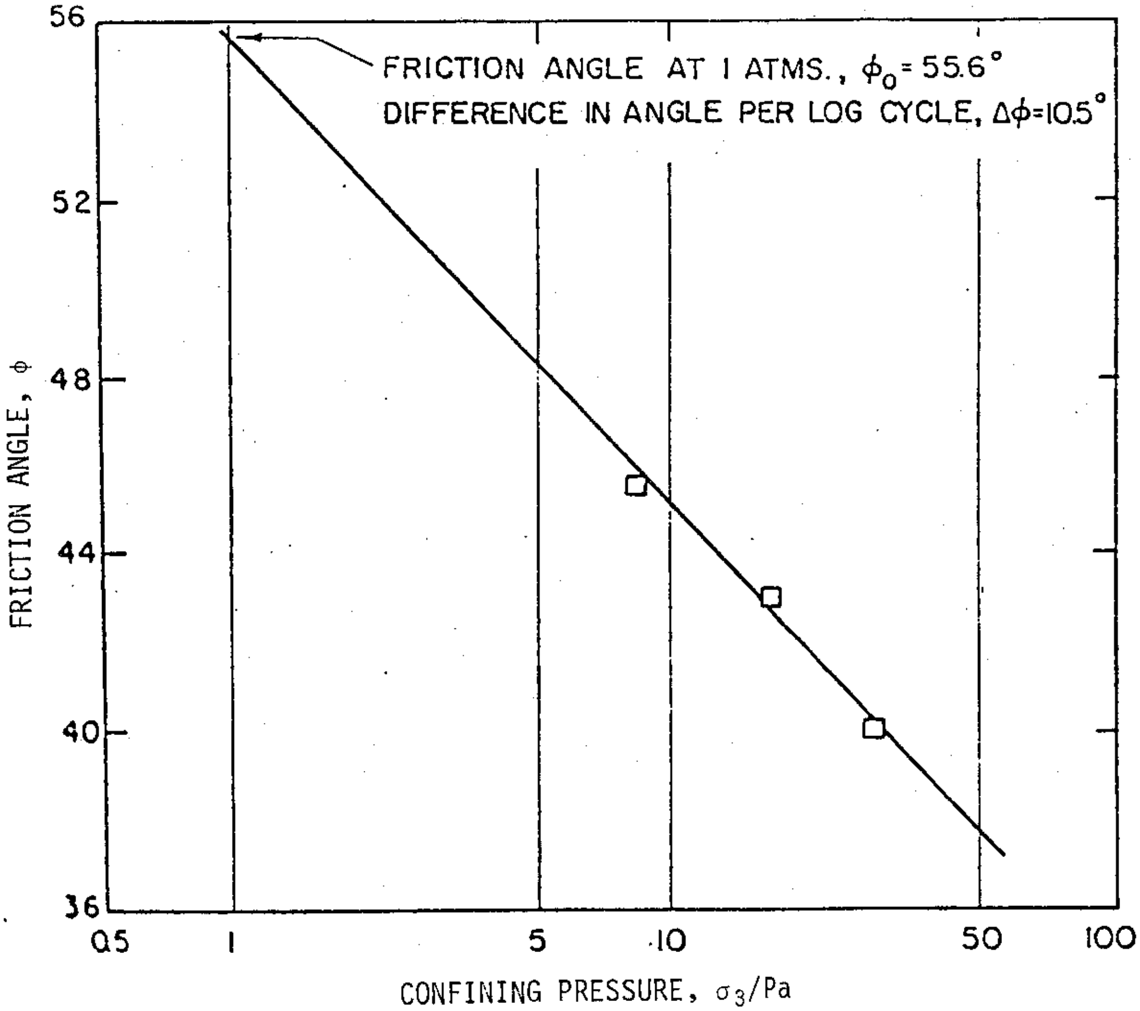


Figure 18. Variation of Friction Angle with Confining Pressure

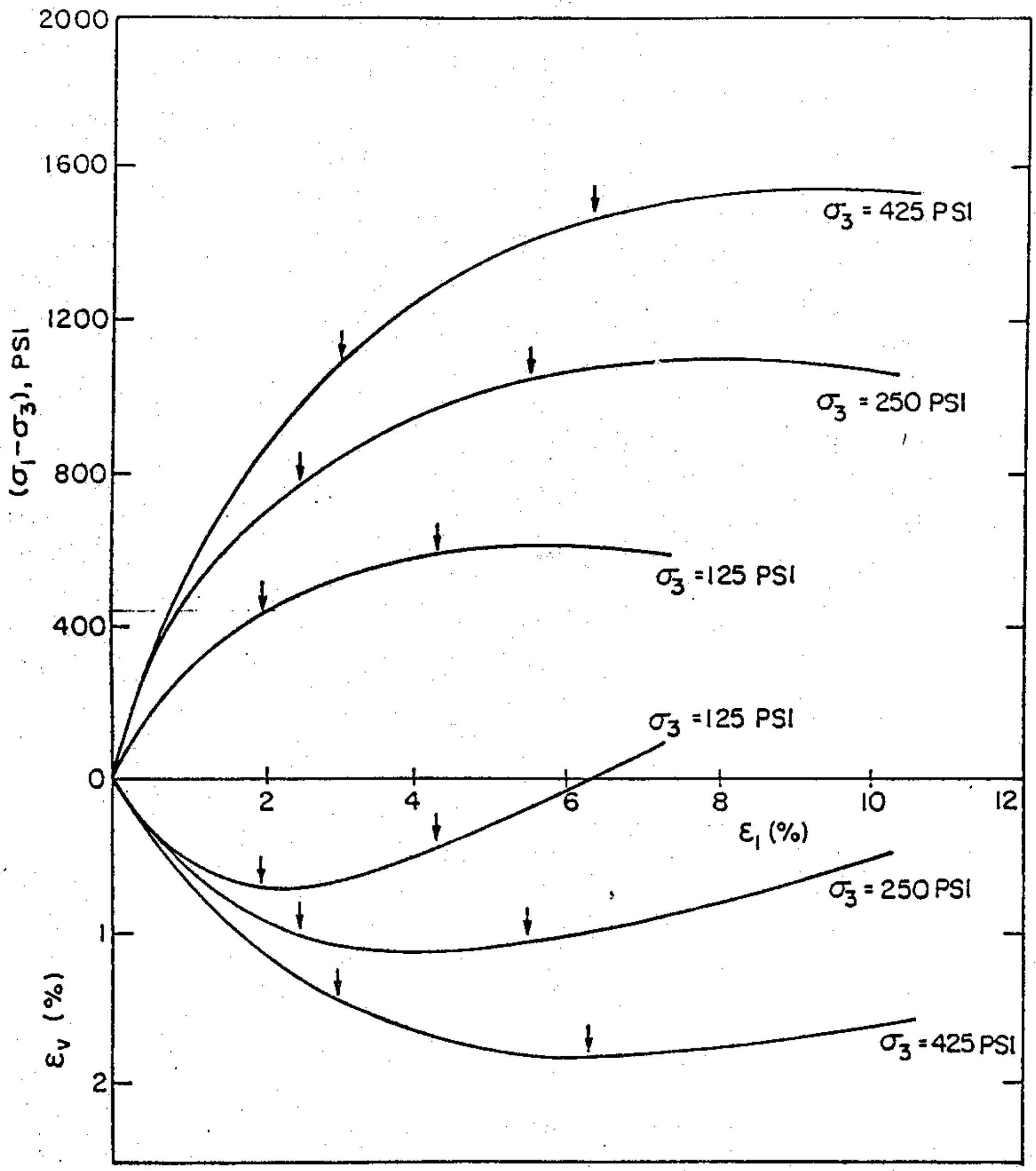


Figure 19. Replotted Stress-Strain and Volume-Change Curves

curve at the 70% and 95% points (Figure 20). The values of E_i and $(\sigma_1 - \sigma_3)_{ult}$ are the reciprocals of the intercepts and the slopes of these lines. Next, the value of E_i/P_a for each of the tests is plotted against the corresponding value of σ_3/P_a on full-log space as shown in Figure 21. The value of K is equal to the value of E_i/P_a at the point where σ_3/P_a is equal to unity. The value of n is the slope of the line on this plot, i.e.,

$$n = \frac{\Delta \log_{10} (\frac{E_i}{P_a})}{\Delta \log_{10} (\frac{\sigma_3}{P_a})} \tag{96}$$

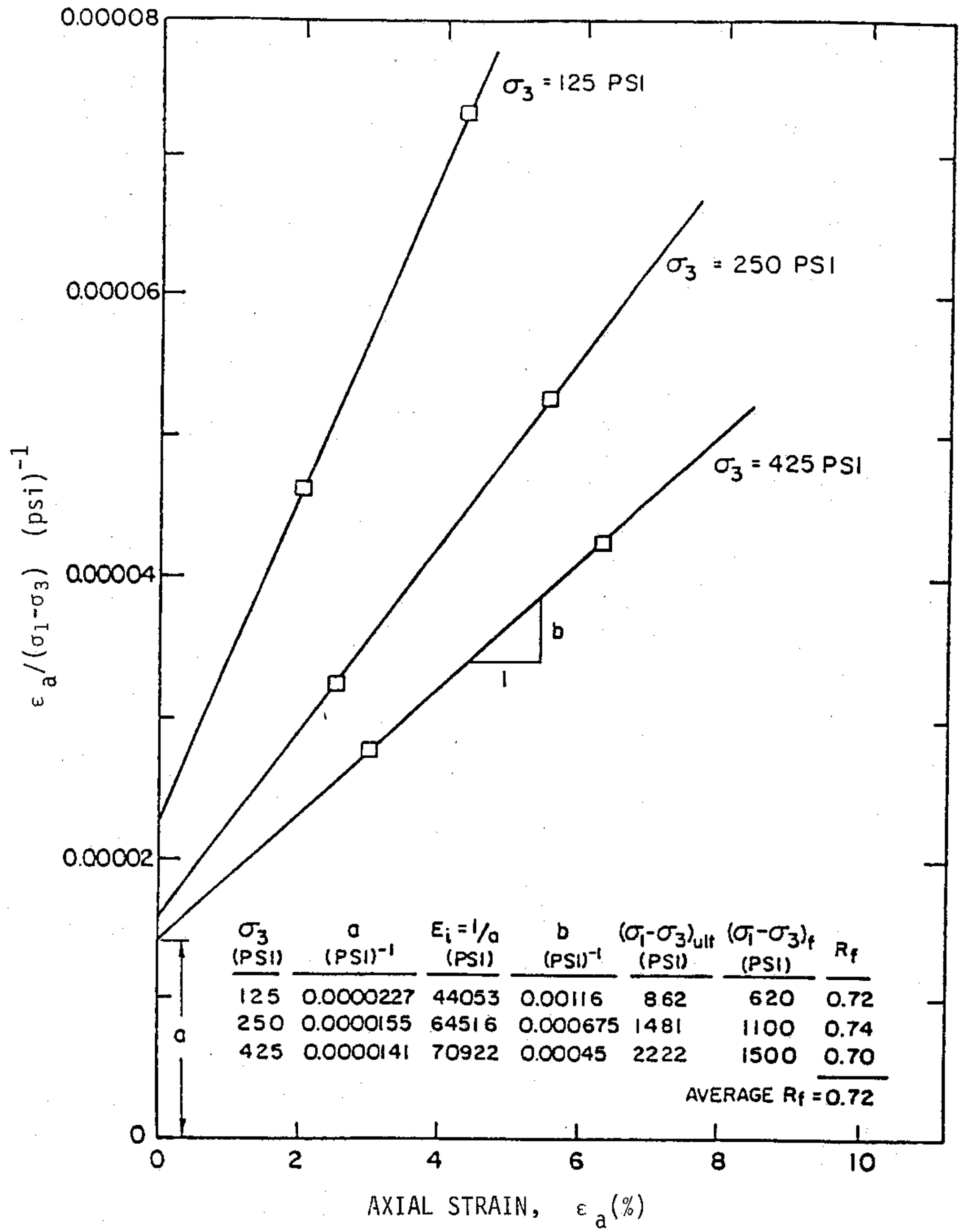
The value of failure ratio, R_f, can be obtained during the steps described above. From the definition of R_f, one can obtain

$$R_f = \frac{(\sigma_1 - \sigma_3)_f}{(\sigma_1 - \sigma_3)_{ult}} \tag{97}$$

where $(\sigma_1 - \sigma_3)_f$ = deviator stress at failure measured from the test. Note that a variation of the values of R_f usually occurs. An average value of R_f can be chosen as a representative one in such cases.

6.4 Bulk Modulus Parameters

The determination of volume change parameters, K_b and m, requires measurements of axial strains and volumetric strains during the tests. The procedures are similar to that of obtaining K and n, and therefore it is not repeated here. It can be found in reference 5.



σ_3 (PSI)	a (PSI)$^{-1}$	$E_i = 1/a$ (PSI)	b (PSI)$^{-1}$	$(\sigma_1-\sigma_3)_{ult}$ (PSI)	$(\sigma_1-\sigma_3)_f$ (PSI)	R_f
125	0.0000227	44053	0.00116	862	620	0.72
250	0.0000155	64516	0.000675	1481	1100	0.74
425	0.0000141	70922	0.00045	2222	1500	0.70
					AVERAGE R_f =	0.72

Figure 20. Transformed Stress-Strain Plot

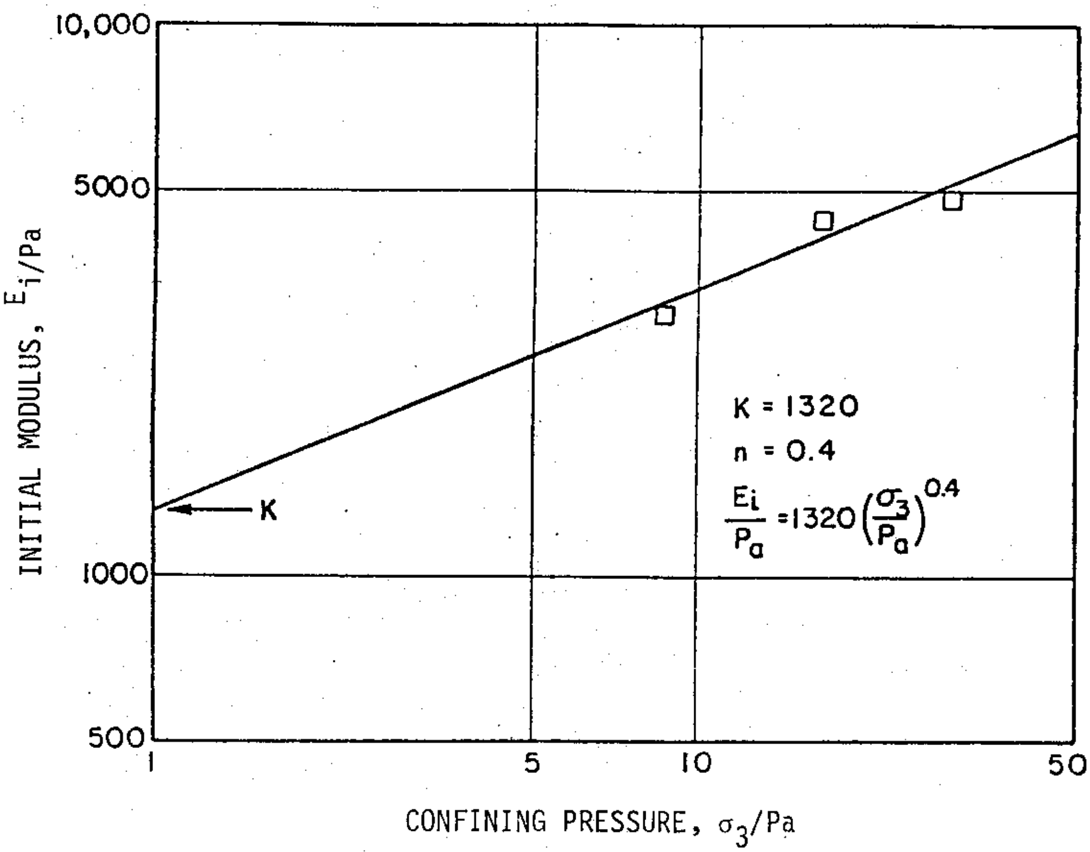


Figure 21. Variation of Initial Tangent Modulus with Confining Pressure

6.5 Laboratory Test Results

A total of 20 soils have been tested to obtain the hyperbolic soil parameters to describe their stress-strain relationships. Table 3 shows the resulting hyperbolic parameters of these soils. Note that the values of K_b and m were not measured, since the soil samples were not saturated. These hyperbolic properties have been included in the computer program, so that the detailed hyperbolic parameters can be described by simply designating the soil number, KCODE, as indicated in Table 3. The actual test data, stress-strain curves, Mohr circles, and calculation of hyperbolic parameters of these soils are included in the Appendix.

7. CONCLUSIONS

Results from a comprehensive study of a tie-rod and drilled-in concrete anchor system that reinforces distressed sill-type bridge abutments are presented in detail. Included are the development of design and analysis methods, the detailed soil properties evaluation and determination, and the comparison with a truly three-dimensional method of analysis. A computer program that has been developed based on the results of this study and its user's manual are included separately in volumn two of this report.

The method of analysis based on the generalized plane strain finite element method has been proven very effective and efficient in calculating the three-dimensional response of the sytem, though it is not truly three-dimensional in nature. It can, therefore, be expanded to analyze other types of skew or non-skew bridge abutment

Table 3. Nonlinear Material Properties of Selected Soils

KCODE	Soil	Description	K	n	R_f	C (psf)	ϕ	γ (pcf)
1	Crushed Limestone		700	0.85	0.74	0	50	103.5
2	Crushed Quartzite		525	0.95	0.76	0	50	103.5
3	Reddish Brown Silty Clay	Meade Co. 8-10 ft.	140	0.34	0.59	2,400	17	137.5
4	Reddish Brown Silty Clay	Meade Co. 13-15 ft.	150	0.23	0.43	1,700	30	137.5
5	Reddish Brown Silty Clay	Meade Co. 18-20 ft.	215	0.41	0.60	1,100	35	136.0
6	Gray Silty Clay w/Pebbles	Pennington 8.5-10.5 ft.	290	0.32	0.65	0	50	125.3
7	Gray Shale	Pennington 14-16 ft.	70	1.57	0.73	1,550	15	124.8
8	Light Brown Silty Clay	Pennington 8-9 ft.	90	0.26	0.63	1,850	25	125.0
9	Light Brown Silty Clay	Pennington 13-15 ft.	235	0.10	0.79	1,650	30	126.6
10	Brown Silty Clay w/Pebbles	Pennington 18-20 ft.	220	0.36	0.82	0	36	125.5
11	Brown Silty Clay w/Pebbles	Minnehaha Co. 13-14 ft.	125	0.26	0.76	0	32	134.3
12	Brown Silty Clay w/Pebbles	Minnehaha Co. 16-17 ft.	140	0.53	0.67	0	42	127.8
13	Gray Brown Shale	Jones Co. 32-56 ft.	470	0.21	0.37	0	40	121.5
14	Gray Silty Clay	Lawrence Co. 7.5-9 ft.	170	0.38	0.53	1,200	24	124.0
15	Gray Silty Clay	Lawrence Co. 14-15 ft.	245	0.25	0.65	1,500	35	125.6
16	Gray Silty Clay	Lawrence Co. 19-20 ft.	105	0.36	0.57	0	40	125.0
17	Brown Silty Clay	Brule Co. 3-16 ft.	195	0.20	0.80	1,300	40	128.7
18	Brown Silty Clay	Brule Co. 32-42 ft.	255	0.34	0.70	2,950	10	122.0
19	Brown Silty Clay	Brule Co. 51-55 ft.	305	0.42	0.65	2,100	32	122.0
20	Gray Shale	Buffalo Co. 38-41.5 ft.	115	0.92	0.20	0	50	116.0

K = loading modulus

n = modulus exponent

R_f = failure ratio

C = cohesion

ϕ = internal friction angle

γ = unit weight

configurations, e.g. bulkhead abutments with either soldier piles or sheet piles, without much difficulty.

8. REFERENCES

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APPENDICES

I. Triaxial Test Results

II. Stress-Strain Curves

III. Mohr Circles

IV. Hyperbolic Parameters Determination

APPENDIX - I Triaxial Test Results (Typical)

TABLE 1. IDENTIFICATION OF SOILS

LOCATION (COUNTY)	BORING NUMBER	DEPTH (FEET)	SOIL DESCRIPTION	DESIGNATION NO. (KCODE)
PENNINGTON	----	----	CRUSHED LIMESTONE	1
MINNEHAHA	----	----	CRUSHED QUARZITE	2
MEADE	17	8-10	REDDISH BROWN SILTY CLAY	3
MEADE	17-1	13-15	REDDISH BROWN SILTY CLAY	4
MEADE	17-2	18-2	REDDISH BROWN SILTY CLAY	5
PENNINGTON	18	8-10	GRAY SILTY CLAY WITH PEBBLES	6
PENNINGTON	18-1	14-16	GRAY CLAY (SHALE)	7
PENNINGTON	67	8-9	LIGHT BROWN SILTY CLAY	8
PENNINGTON	67-1	13-15	LIGHT BROWN SILTY CLAY	9
PENNINGTON	67-2	18-20	BROWN SILTY CLAY WITH PEBBLES	10
MINNEHAHA	20-1	13-14	LIGHT BROWN SAND WITH PEBBLES AND SILT	11
MINNEHAHA	57-1	16-17	BROWN SILTY CLAY WITH SAND	12
JONES	43-1	32-56	GRAY AND BROWN CLAY (SHALE)	13
LAWRENCE	64	7-9	GRAY SILTY CLAY	14
LAWRENCE	64-1	14-15	GRAY SILTY CLAY	15
LAWRENCE	64-2	19-20	GRAY SILTY CLAY	16
BRULE	65	3-16	BROWN SILTY CLAY	17
BRULE	65-1	32-42	BROWN SILTY CLAY	18
BRULE	65-2	51-55	BROWN SILTY CLAY	19
BUFFALO	79	38-45	GRAY CLAY (SHALE)	20

TRIAXIAL TEST CALCULATIONS

Boring Number: 17 ,Sample Number: M12
Depth (ft.) = 9.5 ,Sigma 3 Value (psf) = 1150
Sample Description: Reddish brown silty clay (CL-ML)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	7.0	8.8	0.25	430
20.0	14.0	18.6	0.51	914
30.0	20.0	27.2	0.76	1331
40.0	25.0	34.0	1.01	1660
50.0	31.0	42.8	1.26	2083
60.0	36.0	49.7	1.52	2413
70.0	40.0	55.6	1.77	2693
80.0	45.0	62.5	2.02	3022
90.0	50.0	69.5	2.27	3350
100.0	55.0	76.4	2.53	3675
110.0	60.0	83.4	2.78	3999
120.0	65.0	90.3	3.03	4321
130.0	69.0	95.9	3.28	4575
140.0	73.0	101.5	3.54	4827
150.0	77.0	107.0	3.79	5078
160.0	81.0	112.6	4.04	5328
170.0	84.0	116.8	4.29	5511
180.0	86.0	119.5	4.55	5627
190.0	90.0	125.1	4.80	5873
200.0	90.0	125.1	5.05	5858
210.0	92.0	127.9	5.30	5972
220.0	95.0	132.1	5.56	6150
230.0	95.0	132.1	5.81	6134
240.0	97.0	134.8	6.06	6246
250.0	98.0	136.2	6.31	6294
260.0	98.0	136.2	6.57	6277
270.0	98.5	136.9	6.82	6292
280.0	99.0	137.6	7.07	6306
290.0	100.0	139.0	7.32	6353
300.0	100.0	139.0	7.58	6335
325.0	102.5	142.5	8.21	6450
350.0	104.0	144.6	8.84	6499
375.0	106.0	147.3	9.47	6578
400.0	109.0	151.5	10.10	6717
450.0	111.0	154.3	11.36	6744
500.0	113.0	157.1	12.63	6768
550.0	116.0	161.2	13.89	6847
600.0	120.0	166.8	15.15	6979
650.0	126.0	175.1	16.41	7219
700.0	130.0	180.7	17.68	7336
750.0	134.0	186.3	18.94	7446
800.0	137.0	190.4	20.20	7494

TRIAXIAL TEST CALCULATIONS

Boring Number: 17 ,Sample Number: M1-1-II
Depth (ft.) = 14.8 ,Sigma 3 Value (psf) = 2020
Sample Description: Reddish Brown Silty Clay (CL-ML)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	19.0	25.3	0.26	1226
20.0	35.0	48.3	0.52	2338
30.0	49.0	68.1	0.78	3288
40.0	60.0	83.4	1.04	4015
50.0	77.5	107.7	1.30	5173
60.0	90.0	125.1	1.55	5991
70.0	105.0	145.9	1.81	6972
80.0	118.0	164.0	2.07	7814
85.0	125.0	173.8	2.20	8267
95.0	136.0	189.0	2.46	8970
100.0	142.0	197.4	2.59	9354
110.0	154.0	214.1	2.85	10117
120.0	162.0	225.2	3.11	10614
130.0	172.0	239.1	3.37	11239
145.0	181.0	251.6	3.76	11780
150.0	184.0	255.8	3.89	11959
160.0	190.0	264.1	4.15	12316
175.0	196.0	272.4	4.53	12653
185.0	199.0	276.6	4.79	12812
200.0	203.0	282.2	5.18	13016
225.0	205.0	285.0	5.83	13054
250.0	206.0	286.3	6.48	13028
275.0	206.5	287.0	7.12	12969
300.0	207.5	288.4	7.77	12941
325.0	208.0	289.1	8.42	12881
360.0	208.0	289.1	9.33	12754
410.0	204.0	283.6	10.62	12330
450.0	201.0	279.4	11.66	12007
530.0	195.0	271.0	13.73	11376

TRIAXIAL TEST CALCULATIONS

Boring Number: 17 ,Sample Number: M1-2-III
Depth (ft.) = 19.4 ,Sigma 3 Value (psf) = 2740
Sample Description: Reddish Brown Silty Clay (ML-CL)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	15.0	20.0	0.27	978
20.0	32.0	44.2	0.53	2159
30.0	44.5	61.9	0.80	3016
40.0	58.0	80.6	1.07	3920
50.0	72.0	100.1	1.34	4853
60.0	91.0	126.5	1.60	6117
70.0	105.0	145.9	1.87	7039
80.0	125.0	173.8	2.14	8357
90.0	136.0	189.0	2.41	9067
100.0	150.0	208.5	2.67	9973
110.0	165.0	229.3	2.94	10940
120.0	178.0	247.4	3.21	11770
130.0	186.0	258.5	3.48	12265
140.0	194.0	269.7	3.74	12757
150.0	201.0	279.4	4.01	13180
160.0	209.0	290.5	4.28	13667
170.0	214.0	297.5	4.55	13955
180.0	218.0	303.0	4.81	14176
190.0	220.0	305.8	5.08	14266
200.0	222.0	308.6	5.35	14355
225.0	118.0	164.0	6.02	7576
250.0	112.0	155.7	6.68	7140
320.0	102.5	142.5	8.56	6403
360.0	102.5	142.5	9.63	6328
408.0	103.0	143.2	10.91	6269

TRIAXIAL TEST CALCULATIONS

Boring Number: 18 ,Sample Number: I
Depth (ft.) = 16 ,Sigma 3 Value (psf) = 3930
Sample Description: Grey Silty Clay With Pebbles (MH)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	7.5	9.4	0.23	471
20.0	15.0	20.0	0.47	1000
30.0	22.5	30.6	0.70	1530
40.0	31.0	42.8	0.93	2134
50.0	39.0	53.8	1.17	2678
60.0	46.0	63.9	1.40	3174
70.0	52.0	72.3	1.64	3580
80.0	58.0	80.6	1.87	3983
90.0	63.0	87.6	2.10	4316
100.0	68.0	94.5	2.34	4648
110.0	72.5	100.8	2.57	4944
125.0	78.0	108.4	2.92	5299
130.0	81.0	112.6	3.04	5497
140.0	83.5	116.1	3.27	5653
150.0	87.0	120.9	3.50	5875
160.0	90.0	125.1	3.74	6063
170.0	93.5	130.0	3.97	6284
185.0	97.0	134.8	4.32	6495
200.0	100.0	139.0	4.67	6672
225.0	104.0	144.6	5.26	6896
250.0	110.5	153.6	5.84	7282
275.0	112.0	155.7	6.43	7335
300.0	115.0	159.8	7.01	7484
325.0	115.5	160.5	7.59	7470
350.0	115.5	160.5	8.18	7422
375.0	114.5	159.2	8.76	7311
400.0	112.0	155.7	9.35	7106
425.0	112.0	155.7	9.93	7060
450.0	112.0	155.7	10.51	7014

TRIAXIAL TEST CALCULATIONS

Boring Number: 20-1 ,Sample Number: M2-1-1V
Depth (ft.) = 13 ,Sigma 3 Value (psf) = 1150
Sample Description: Light Brown Sand With Pebbles and Silt (SP-SM)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	8.0	10.0	0.28	500
20.0	16.0	21.3	0.55	1062
30.0	20.0	27.2	0.83	1353
45.0	25.0	34.0	1.24	1685
50.0	27.0	36.7	1.38	1817
65.0	30.0	41.4	1.79	2040
70.0	30.5	42.1	1.93	2071
80.0	32.0	44.2	2.21	2167
90.0	33.0	45.5	2.48	2228
100.0	34.0	46.9	2.76	2289
110.0	35.0	48.3	3.03	2350
120.0	36.0	49.7	3.31	2410
130.0	36.5	50.4	3.59	2437
140.0	37.0	51.1	3.86	2463
150.0	37.0	51.1	4.14	2456
160.0	38.0	52.4	4.41	2515
175.0	38.5	53.1	4.83	2537
190.0	39.0	53.8	5.24	2559
200.0	39.0	53.8	5.52	2551
210.0	39.5	54.5	5.79	2577
225.0	39.5	54.5	6.21	2565
255.0	40.0	55.6	7.03	2593
275.0	40.0	55.6	7.59	2578
300.0	40.5	56.3	8.28	2591
350.0	41.0	57.0	9.66	2583
375.0	41.5	57.7	10.34	2595

TRIAXIAL TEST CALCULATIONS

Boring Number: 43 ,Sample Number: S12
Depth (ft.) = 8 ,Sigma 3 Value (psf) = 1730
Sample Description: Grey and Brown Clay (Shale) (CH)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	10.0	13.3	0.26	654
20.0	10.0	13.3	0.53	652
30.0	19.0	25.3	0.79	1236
40.0	21.0	28.6	1.05	1394
50.0	26.0	35.4	1.32	1721
60.0	32.0	44.2	1.58	2143
70.0	37.0	51.1	1.84	2472
80.0	43.0	59.8	2.11	2886
90.0	49.0	68.1	2.37	3279
100.0	54.0	75.1	2.63	3604
110.0	60.0	83.4	2.89	3994
120.0	68.0	94.5	3.16	4514
130.0	75.0	104.3	3.42	4965
140.0	82.0	114.0	3.68	5414
150.0	89.0	123.7	3.95	5860
160.0	95.0	132.1	4.21	6238
170.0	103.0	143.2	4.47	6745
180.0	108.0	150.1	4.74	7053
190.0	114.0	158.5	5.00	7424
200.0	119.0	165.4	5.26	7728
210.0	125.0	173.8	5.53	8095
220.0	129.0	179.3	5.79	8331
230.0	131.0	182.1	6.05	8436
240.0	121.0	168.2	6.32	7770
250.0	110.0	152.9	6.58	7044
260.0	105.0	145.9	6.84	6705
270.0	100.0	139.0	7.11	6368
280.0	99.0	137.6	7.37	6286

TRIAXIAL TEST CALCULATIONS

Boring Number: 57 ,Sample Number: M1-1-2
Depth (ft.) = 3.5 ,Sigma 3 Value (psf) = 580
Sample Description: Brown Silty Clay With Sand (ML)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	11.0	14.6	0.25	720
20.0	14.0	18.6	0.50	914
30.0	16.0	21.3	0.75	1042
40.0	20.0	27.2	1.00	1328
50.0	20.0	27.2	1.25	1325
60.0	20.0	27.2	1.50	1321
70.0	23.0	31.3	1.75	1516
80.0	24.0	32.6	2.01	1577
90.0	25.0	34.0	2.26	1639
100.0	25.0	34.0	2.51	1635
110.0	29.0	39.4	2.76	1891
120.0	30.0	41.4	3.01	1980
130.0	30.0	41.4	3.26	1975
140.0	31.0	42.8	3.51	2036
150.0	33.0	45.5	3.76	2161
160.0	34.0	46.9	4.01	2221
170.0	34.0	46.9	4.26	2215
180.0	34.0	46.9	4.51	2209
190.0	34.0	46.9	4.76	2204
200.0	34.0	46.9	5.01	2198

TRIAXIAL TEST CALCULATIONS

Boring Number: 64 ,Sample Number: L12
Depth (ft.) = 8.5 ,Sigma 3 Value (psf) = 1300
Sample Description: Grey Silty Clay (CL)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	3.0	3.8	0.26	184
20.0	3.0	3.8	0.52	184
30.0	13.0	17.3	0.78	846
40.0	20.0	27.2	1.04	1327
50.0	29.0	39.4	1.30	1920
60.0	38.0	52.4	1.55	2546
70.0	44.0	61.2	1.81	2961
80.0	50.0	69.5	2.07	3356
90.0	57.0	79.2	2.33	3816
100.0	63.0	87.6	2.59	4207
110.0	69.0	95.9	2.85	4595
120.0	72.0	100.1	3.11	4782
130.0	75.0	104.3	3.37	4968
140.0	79.0	109.8	3.63	5219
150.0	82.0	114.0	3.89	5403
160.0	83.0	115.4	4.15	5454
170.0	83.0	115.4	4.40	5439
180.0	83.0	115.4	4.66	5424
190.0	83.0	115.4	4.92	5409
200.0	85.0	118.2	5.18	5525
210.0	85.0	118.2	5.44	5510
220.0	85.0	118.2	5.70	5494
230.0	85.0	118.2	5.96	5479

TRIAXIAL TEST CALCULATIONS

Boring Number: 64 ,Sample Number: L1-1-I
Depth (ft.) = 95 ,Sigma 3 Value (psf) = 2305
Sample Description: Grey Silty Clay (CL)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	11.0	14.6	0.25	722
20.0	30.0	41.4	0.51	2038
30.0	45.0	62.5	0.76	3072
40.0	60.0	83.4	1.01	4085
50.0	75.0	104.3	1.26	5094
60.0	99.5	138.3	1.52	6740
70.0	99.0	137.6	1.77	6689
80.0	108.0	150.1	2.02	7279
90.0	116.0	161.2	2.27	7798
100.0	122.0	169.6	2.53	8180
110.0	128.0	177.9	2.78	8560
120.0	132.0	183.5	3.03	8804
130.0	135.0	187.6	3.28	8981
140.0	137.0	190.4	3.54	9090
150.0	138.5	192.5	3.79	9166
160.0	139.5	193.9	4.04	9208
170.0	140.0	194.6	4.29	9216
180.0	140.5	195.3	4.55	9225
190.0	140.5	195.3	4.80	9200
205.0	140.0	194.6	5.18	9131
220.0	139.5	193.9	5.56	9062
230.0	139.0	193.2	5.81	9006
240.0	138.0	191.8	6.06	8917
250.0	137.5	191.1	6.31	8861
275.0	137.5	191.1	6.94	8801
310.0	136.5	189.7	7.83	8654
330.0	135.5	188.3	8.33	8543
350.0	134.0	186.3	8.84	8402
390.0	133.0	184.9	9.85	8247
425.0	131.0	182.1	10.73	8044

TRIAXIAL TEST CALCULATIONS

Boring Number: 64 ,Sample Number: Li-2-I
Depth (ft.) = 20 ,Sigma 3 Value (psf) = 2740
Sample Description: Grey Silty Clay (CL)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	4.0	5.0	0.25	249
20.0	11.0	14.6	0.51	725
30.0	16.0	21.3	0.76	1052
45.0	21.0	28.6	1.14	1407
50.0	24.0	32.6	1.26	1606
60.0	30.0	41.4	1.52	2032
70.0	33.0	45.5	1.77	2229
80.0	36.5	50.4	2.02	2459
100.0	40.0	55.6	2.53	2700
110.0	41.5	57.7	2.78	2794
120.0	43.0	59.8	3.03	2888
130.0	43.0	59.8	3.28	2880
140.0	43.0	59.8	3.54	2873
150.0	42.0	58.4	3.79	2799
160.0	41.0	57.0	4.04	2725
170.0	41.0	57.0	4.29	2718
190.0	40.0	55.6	4.80	2637
200.0	40.0	55.6	5.05	2630

TRIAXIAL TEST CALCULATIONS

Boring Number: 65 , Sample Number: R14
Depth (ft.) = 8.0-8.5 , Sigma 3 Value (psf) = 1080
Sample Description: Brown Silty Clay (CL)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	5.0	6.3	0.25	307
20.0	20.0	27.2	0.50	1335
30.0	27.0	36.7	0.75	1797
40.0	40.0	55.6	1.01	2714
50.0	60.0	83.4	1.26	4061
60.0	72.0	100.1	1.51	4861
70.0	84.0	116.8	1.76	5657
80.0	90.0	125.1	2.01	6045
90.0	95.0	132.1	2.26	6365
100.0	100.0	139.0	2.51	6683
110.0	109.0	151.5	2.76	7265
120.0	111.0	154.3	3.02	7379
130.0	115.0	159.8	3.27	7628
140.0	120.0	166.8	3.52	7936
150.0	125.0	173.8	3.77	8246
160.0	130.0	180.7	4.02	8553
170.0	133.0	184.9	4.27	8727
180.0	136.0	189.0	4.52	8901
190.0	140.0	194.6	4.77	9139
200.0	140.0	194.6	5.03	9114
210.0	145.0	201.6	5.28	9415
220.0	149.0	207.1	5.53	9649
230.0	151.0	209.9	5.78	9753
240.0	152.0	211.3	6.03	9791
250.0	152.0	211.3	6.28	9765
260.0	156.0	216.8	6.53	9995
270.0	159.0	221.0	6.78	10160
280.0	160.0	222.4	7.04	10196
290.0	160.0	222.4	7.29	10189
300.0	162.0	225.2	7.54	10268
325.0	166.0	230.7	8.17	10450
350.0	169.0	234.9	8.79	10566
375.0	172.0	239.1	9.42	10679
400.0	176.0	244.6	10.05	10852
425.0	179.0	248.8	10.68	10960
450.0	181.0	251.6	11.31	11004
500.0	183.0	254.4	12.56	10968
550.0	185.0	257.1	13.82	10929
600.0	185.0	257.1	15.08	10770
650.0	185.0	257.1	16.33	10610
700.0	183.0	254.4	17.59	10338
750.0	180.0	250.2	18.84	10014

TRIAXIAL TEST CALCULATIONS

Boring Number: 65 ,Sample Number: 7
Depth (ft.) = 40 ,Sigma 3 Value (psf) = 4450
Sample Description: Brown Silty Clay (CL)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	15.5	20.6	0.25	1026
20.0	28.0	38.1	0.50	1890
30.0	37.0	51.1	0.75	2528
40.0	44.0	61.2	1.01	3020
50.0	49.5	68.8	1.26	3389
60.0	54.5	75.8	1.51	3722
70.0	58.0	80.6	1.76	3951
80.0	62.0	86.2	2.01	4212
90.0	65.0	90.3	2.26	4405
100.0	68.0	94.5	2.51	4596
110.0	70.5	98.0	2.76	4753
120.0	73.0	101.5	3.02	4909
130.0	74.5	103.6	3.27	4996
140.0	76.0	105.6	3.52	5084
150.0	77.5	107.7	3.77	5171
160.0	79.0	109.8	4.02	5257
170.0	79.5	110.5	4.27	5276
180.0	80.0	111.2	4.52	5296
190.0	81.0	112.6	4.77	5348
200.0	81.5	113.3	5.03	5367
210.0	82.0	114.0	5.28	5385
220.0	82.5	114.7	5.53	5404
230.0	82.5	114.7	5.78	5389
240.0	83.0	115.4	6.03	5408
250.0	83.0	115.4	6.28	5393
260.0	83.0	115.4	6.53	5379
270.0	83.5	116.1	6.78	5396
280.0	84.0	116.8	7.04	5414
290.0	85.0	118.2	7.29	5464
300.0	85.0	118.2	7.54	5449
310.0	84.5	117.5	7.79	5402

TRIAXIAL TEST CALCULATIONS

Boring Number: 65 ,Sample Number: 3
Depth (ft.) = 54.3 ,Sigma 3 Value (psf) = 6520
Sample Description: Brown Silty Clay (CL)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	10.5	14.0	0.27	699
20.0	2.0	2.5	0.54	125
30.0	8.0	10.0	0.81	498
40.0	14.5	19.3	1.08	957
50.0	21.5	29.2	1.35	1447
60.0	29.0	39.4	1.62	1947
70.0	35.0	48.3	1.89	2378
80.0	39.0	53.8	2.16	2642
90.0	43.0	59.8	2.43	2926
100.0	48.0	66.7	2.70	3257
110.0	51.0	70.9	2.97	3451
120.0	54.5	75.8	3.24	3678
130.0	57.0	79.2	3.51	3836
145.0	60.0	83.4	3.92	4021
150.0	61.5	85.5	4.05	4115
160.0	63.0	87.6	4.32	4204
170.0	65.0	90.3	4.59	4325
180.0	66.0	91.7	4.86	4379
190.0	66.5	92.4	5.14	4400
200.0	67.0	93.1	5.41	4420
225.0	67.5	93.8	6.08	4421
250.0	67.5	93.8	6.76	4390
275.0	67.5	93.8	7.43	4358
300.0	67.0	93.1	8.11	4294
325.0	67.0	93.1	8.78	4262
350.0	67.0	93.1	9.46	4231

TRIAXIAL TEST CALCULATIONS

Boring Number: 67 ,Sample Number: P1-1-I
Depth (ft.) = 15 ,Sigma 3 Value (psf) = 1845
Sample Description: Light Brown Silty Clay (CH)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	9.0	11.3	0.25	561
20.0	13.5	18.0	0.49	893
30.0	18.0	23.9	0.74	1188
40.0	22.0	29.9	0.99	1481
50.0	25.5	34.7	1.23	1713
60.0	29.0	39.4	1.48	1943
70.0	32.0	44.2	1.72	2170
80.0	34.5	47.6	1.97	2334
90.0	37.0	51.1	2.22	2496
100.0	39.5	54.5	2.46	2658
110.0	42.0	58.4	2.71	2840
120.0	44.0	61.2	2.96	2968
130.0	46.0	63.9	3.20	3095
140.0	48.5	67.4	3.45	3255
150.0	50.0	69.5	3.69	3347
160.0	52.0	72.3	3.94	3472
170.0	54.5	75.8	4.19	3629
185.0	55.5	77.1	4.56	3681
190.0	56.5	78.5	4.68	3743
200.0	58.0	80.6	4.93	3832
210.0	59.5	82.7	5.17	3921
225.0	61.0	84.8	5.54	4005
250.0	64.0	89.0	6.16	4174
320.0	70.0	97.3	7.88	4482
360.0	72.0	100.1	8.87	4560
400.0	75.0	104.3	9.85	4699
450.0	77.5	107.7	11.08	4789
475.0	78.5	109.1	11.70	4817
500.0	79.5	110.5	12.32	4845
550.0	81.5	113.3	13.55	4897
600.0	83.0	115.4	14.78	4916
700.0	89.0	123.7	17.24	5119
800.0	90.0	125.1	19.70	5022
850.0	90.5	125.8	20.94	4973
900.0	92.5	128.6	22.17	5004
950.0	94.0	130.7	23.40	5004
1000.0	96.0	133.4	24.63	5029

TRIAXIAL TEST CALCULATIONS

Boring Number: 67-2 ,Sample Number: P1-2-II
Depth (ft.) = 19.7 ,Sigma 3 Value (psf) = 4000
Sample Description: Brown Silty Clay With Pebbles (MH)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	7.0	8.8	0.25	429
20.0	10.0	13.3	0.51	650
30.0	25.5	34.7	0.76	1691
40.0	37.0	51.1	1.01	2484
50.0	44.0	61.2	1.26	2968
60.0	50.0	69.5	1.52	3364
70.0	55.0	76.4	1.77	3691
80.0	60.0	83.4	2.02	4016
90.0	64.0	89.0	2.27	4273
100.0	68.0	94.5	2.53	4528
110.0	72.0	100.1	2.78	4782
120.0	75.5	104.9	3.03	5001
130.0	79.0	109.8	3.28	5220
140.0	82.0	114.0	3.54	5404
150.0	84.5	117.5	3.79	5554
160.0	87.0	120.9	4.04	5703
170.0	89.0	123.7	4.29	5819
180.0	92.0	127.9	4.55	5999
190.0	94.0	130.7	4.80	6113
200.0	96.0	133.4	5.05	6227
210.0	97.5	135.5	5.30	6307
220.0	100.0	139.0	5.56	6452
230.0	101.0	140.4	5.81	6499
240.0	103.0	143.2	6.06	6610
250.0	104.0	144.6	6.31	6656
260.0	106.0	147.3	6.57	6766
270.0	107.0	148.7	6.82	6811
280.0	109.0	151.5	7.07	6920
290.0	110.0	152.9	7.32	6964
300.0	112.0	155.7	7.58	7072
325.0	116.5	161.9	8.21	7305
350.0	120.0	166.8	8.84	7473
375.0	123.0	171.0	9.47	7607
400.0	125.0	173.8	10.10	7677
425.0	127.5	177.2	10.73	7775
450.0	129.5	180.0	11.36	7841
475.0	131.0	182.1	11.99	7876
500.0	133.5	185.6	12.63	7968
525.0	135.0	187.6	13.26	8000
550.0	136.0	189.0	13.89	8000
575.0	137.0	190.4	14.52	8000
600.0	138.0	191.8	15.15	7999
625.0	139.0	193.2	15.78	7997
650.0	140.0	194.6	16.41	7994
675.0	141.5	196.7	17.05	8019
700.0	143.0	198.8	17.68	8042
725.0	144.5	200.9	18.31	8064
750.0	145.0	201.6	18.94	8029
775.0	147.0	204.3	19.57	8077

TRIAXIAL TEST CALCULATIONS

Boring Number: 79 ,Sample Number: 1
Depth (ft.) = 41 ,Sigma 3 Value (psf) = 3745
Sample Description: Grey Clay (Shale) (MH)

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	7.0	8.8	0.26	432
20.0	21.0	28.6	0.51	1406
30.0	45.0	62.5	0.77	3071
40.0	76.0	105.6	1.03	5174
50.0	109.0	151.5	1.29	7401
60.0	139.0	193.2	1.54	9413
70.0	169.0	234.9	1.80	11415
80.0	205.0	285.0	2.06	13811
90.0	234.0	325.3	2.31	15723
100.0	270.0	375.3	2.57	18094
110.0	304.0	422.6	2.83	20319
120.0	335.0	465.6	3.08	22332
130.0	372.0	517.1	3.34	24732
140.0	406.0	564.3	3.60	26921
150.0	440.0	611.6	3.86	29098
165.0	501.0	696.4	4.24	32999
175.0	529.0	735.3	4.50	34750
180.0	553.0	768.7	4.63	36277
190.0	580.0	806.2	4.88	37946
200.0	613.0	852.1	5.14	39996
210.0	650.0	903.5	5.40	42296
220.0	679.0	943.8	5.66	44063
230.0	710.0	986.9	5.91	45949
240.0	739.0	%1027.2	6.17	47695
250.0	764.0	%1062.0	6.43	49173
260.0	793.0	%1102.3	6.68	50900
270.0	818.0	%1137.0	6.94	52360
280.0	841.0	%1169.0	7.20	53683
290.0	863.0	%1199.6	7.46	54935
300.0	882.0	%1226.0	7.71	55988
310.0	898.0	%1248.2	7.97	56845
320.0	918.0	%1276.0	8.23	57949
320.0	920.0	%1278.8	8.23	58075

TRIAXIAL TEST CALCULATIONS

Boring Number: BACK-FILL A ,Sample Number: 9
Depth (ft.) = -- ,Sigma 3 value (psf) = 1400
Sample Description: Limestone Gravel

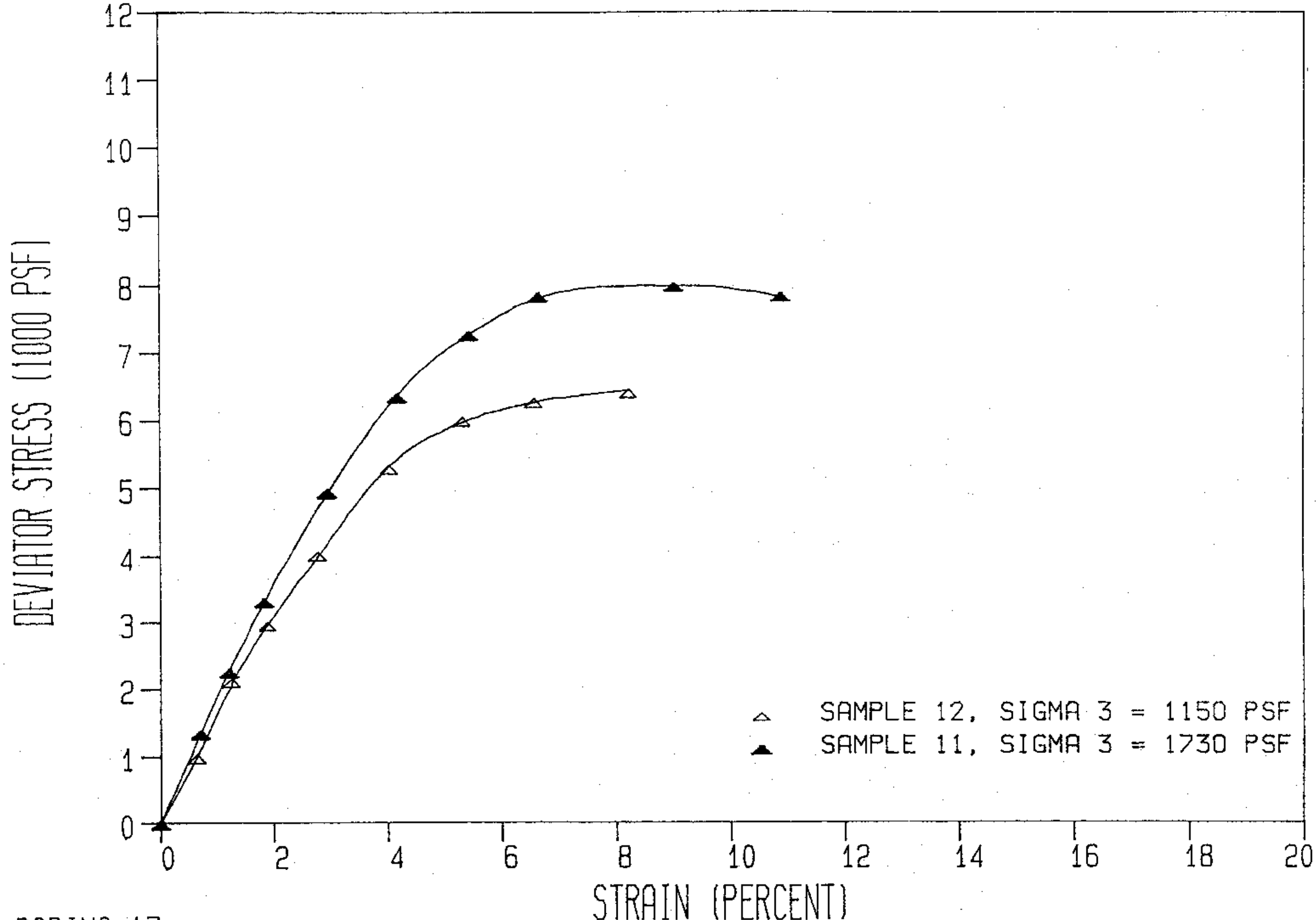
DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	8.0	25.0	0.11	287
20.0	13.0	40.7	0.22	465
30.0	18.0	56.3	0.32	643
40.0	25.0	78.3	0.43	893
50.0	32.0	100.2	0.54	1141
60.0	39.0	122.1	0.65	1389
70.0	47.0	147.1	0.76	1673
80.0	54.0	163.6	0.86	1858
90.0	62.0	187.9	0.97	2131
100.0	70.0	212.1	1.08	2404
110.0	89.0	269.7	1.19	3053
120.0	107.0	324.2	1.30	3666
130.0	123.0	372.7	1.41	4209
140.0	135.0	409.0	1.51	4615
150.0	148.0	448.4	1.62	5054
160.0	156.0	472.7	1.73	5321
170.0	165.0	499.9	1.84	5622
180.0	173.0	524.2	1.95	5888
190.0	180.0	545.4	2.05	6120
200.0	188.0	569.6	2.16	6385
220.0	196.0	593.9	2.38	6642
240.0	205.0	621.2	2.59	6931
260.0	220.0	666.6	2.81	7422
280.0	228.0	690.8	3.03	7675
300.0	232.0	703.0	3.24	7792
325.0	240.0	727.2	3.51	8038
350.0	249.0	754.5	3.78	8316
375.0	254.0	769.6	4.05	8459
400.0	259.0	784.8	4.32	8601
425.0	269.0	815.1	4.59	8908
450.0	274.0	830.2	4.86	9048
475.0	277.0	839.3	5.14	9121
500.0	278.0	842.3	5.41	9128
525.0	279.0	845.4	5.68	9135
550.0	280.0	848.4	5.95	9141
575.0	282.0	854.5	6.22	9180
600.0	283.0	857.5	6.49	9186
625.0	285.0	863.5	6.76	9224
650.0	285.0	863.5	7.03	9198
675.0	280.0	848.4	7.30	9010

TRIAXIAL TEST CALCULATIONS

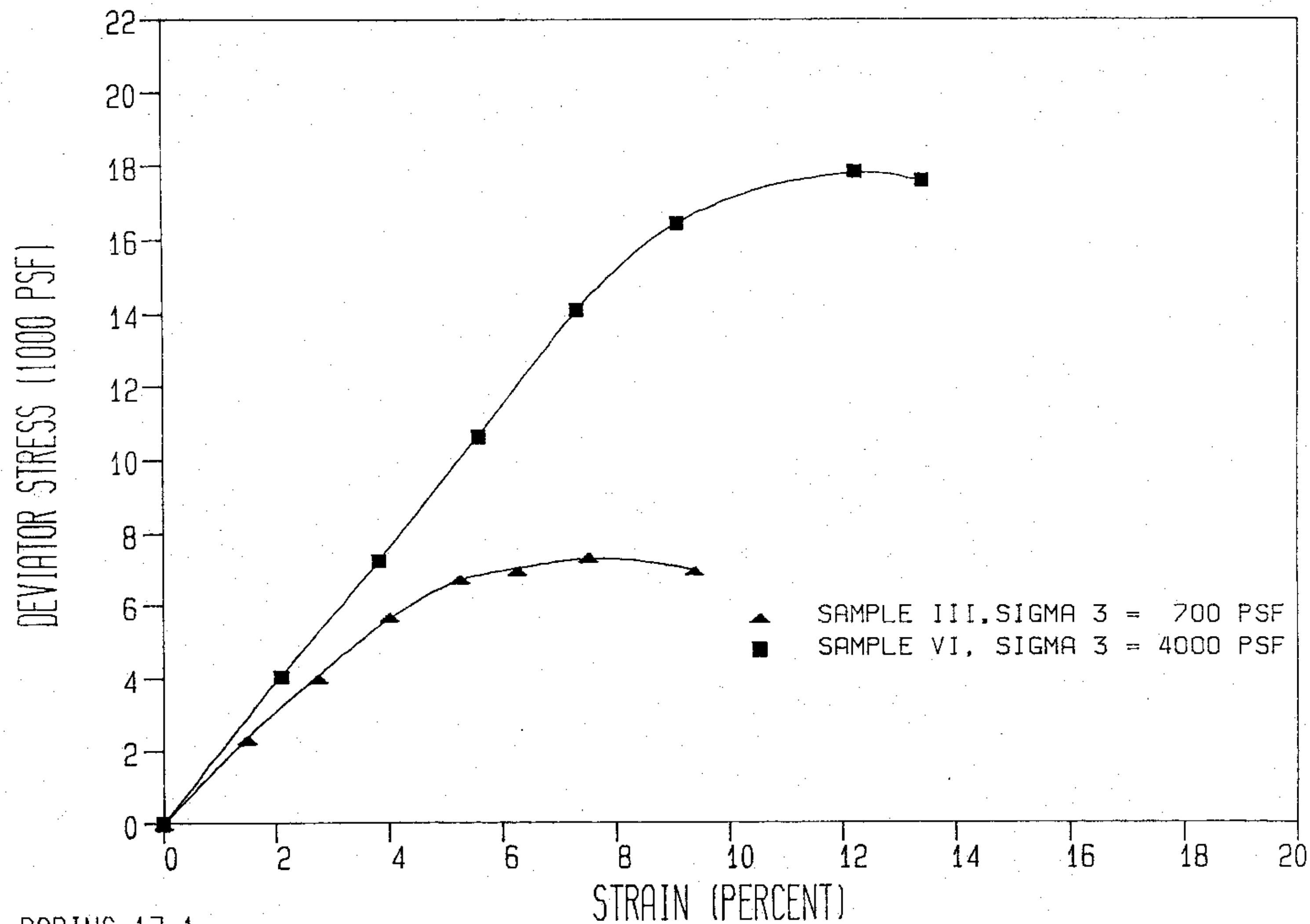
Boring Number: BACK-FILL B ,Sample Number: 1
Depth (ft.) = -- ,Sigma 3 Value (psf) = 350
Sample Description: Quartzite Gravel

DEFORMATION READING IN. X 0.001	LOAD RING READING X 0.0001	AXIAL LOAD LBS	AXIAL STRAIN (PERCENT)	DEVIATOR STRESS (PSF)
10.0	6.0	18.8	0.11	215
20.0	11.0	34.4	0.22	394
30.0	14.0	43.8	0.33	500
40.0	17.0	53.2	0.44	607
50.0	21.0	65.7	0.55	749
60.0	25.0	78.3	0.66	891
70.0	30.0	93.9	0.77	1067
80.0	33.0	103.3	0.87	1173
90.0	36.0	112.7	0.98	1278
100.0	37.0	115.8	1.09	1312
110.0	41.0	128.3	1.20	1452
120.0	44.0	137.7	1.31	1557
130.0	46.0	144.0	1.42	1626
140.0	47.0	147.1	1.53	1659
150.0	50.0	156.5	1.64	1763
160.0	52.0	157.6	1.75	1773
170.0	55.0	166.6	1.86	1874
180.0	57.0	172.7	1.97	1940
190.0	59.0	178.8	2.08	2005
200.0	60.0	181.8	2.19	2037
210.0	61.0	184.8	2.30	2069
220.0	63.0	190.9	2.40	2134
230.0	64.0	193.9	2.51	2166
240.0	65.0	196.9	2.62	2197
250.0	66.0	200.0	2.73	2228
260.0	66.0	200.0	2.84	2226
270.0	66.5	201.5	2.95	2240
280.0	67.0	203.0	3.06	2254
290.0	68.0	206.0	3.17	2286
300.0	70.0	212.1	3.28	2350
325.0	72.0	218.2	3.55	2410
350.0	72.0	218.2	3.83	2404
375.0	77.5	234.8	4.10	2580
400.0	75.0	227.3	4.37	2490
425.0	70.0	212.1	4.64	2317

APPENDIX - II Stress - Strain Curves

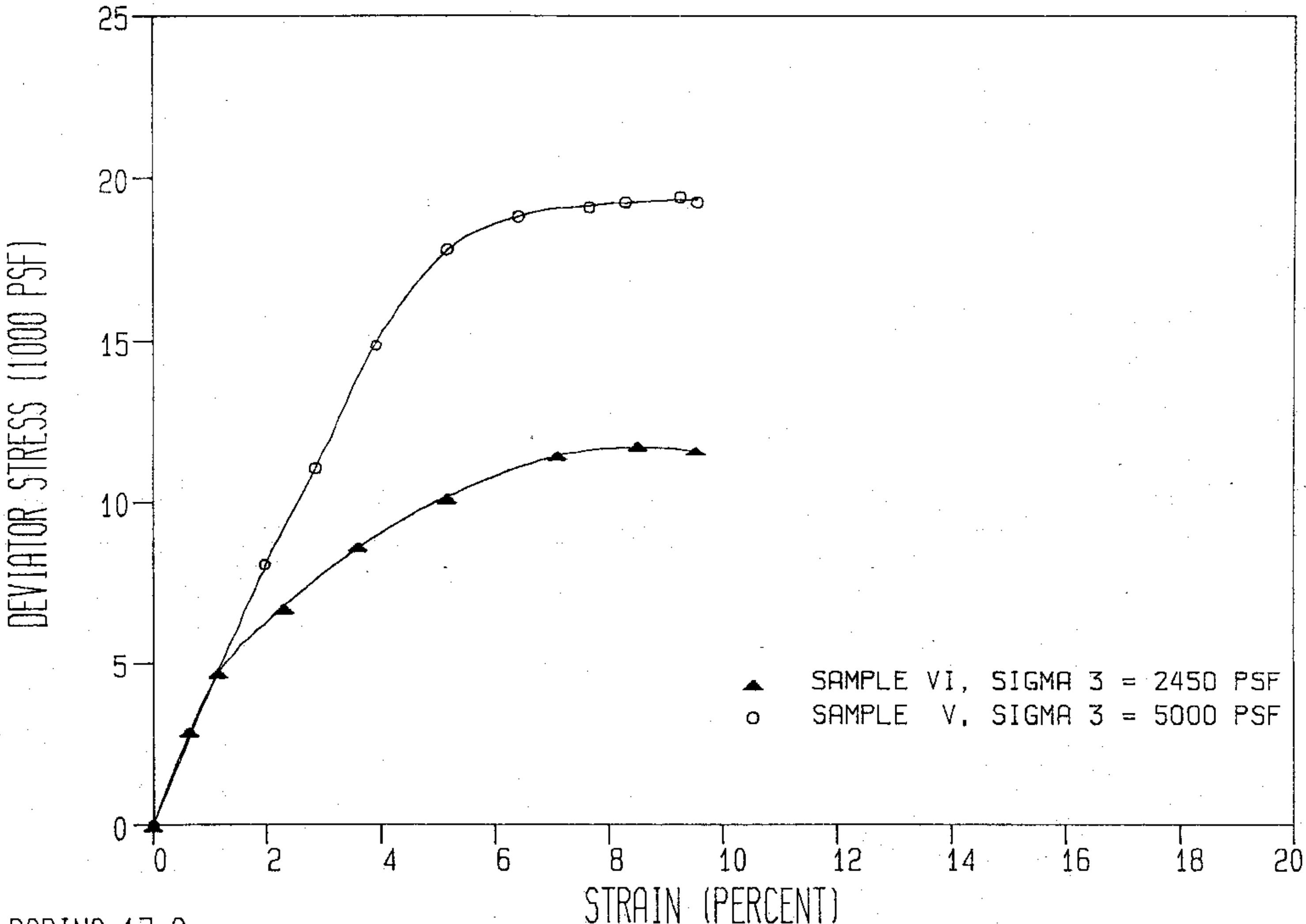

DEVIATOR STRESS (1000 PSF)
0
1
2
3
4
5
6
7
8
9
10
11
12
STRAIN (PERCENT)
0
2
4
6
8
10
12
14
16
18
20
SAMPLE 12, SIGMA 3 = 1150 PSF
SAMPLE 11, SIGMA 3 = 1730 PSF

BORING 17

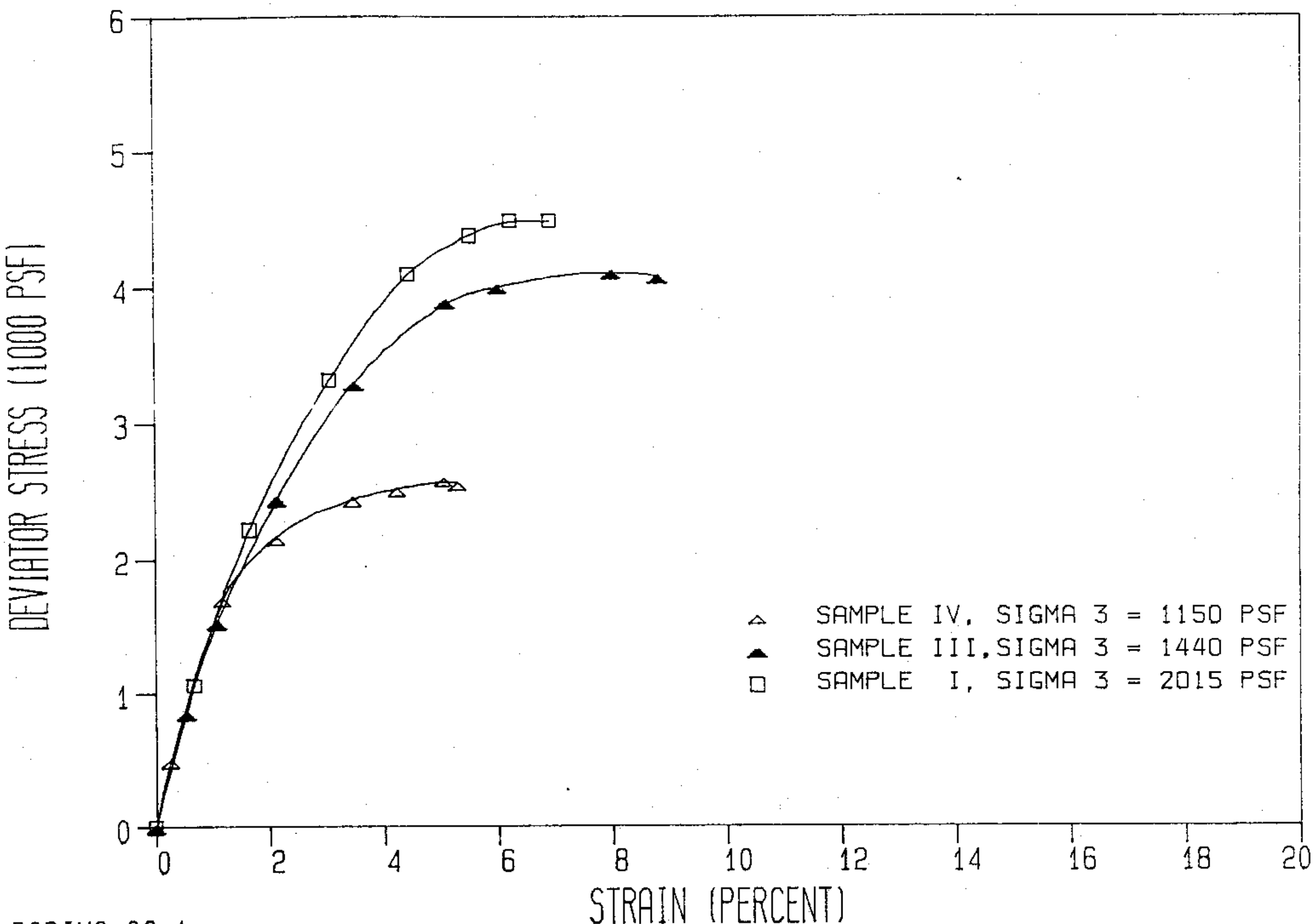


DEVIATOR STRESS (1000 PSF)
STRAIN (PERCENT)
0
2
4
6
8
10
12
14
16
18
20
22
SAMPLE III, SIGMA 3 = 700 PSF
SAMPLE VI, SIGMA 3 = 4000 PSF

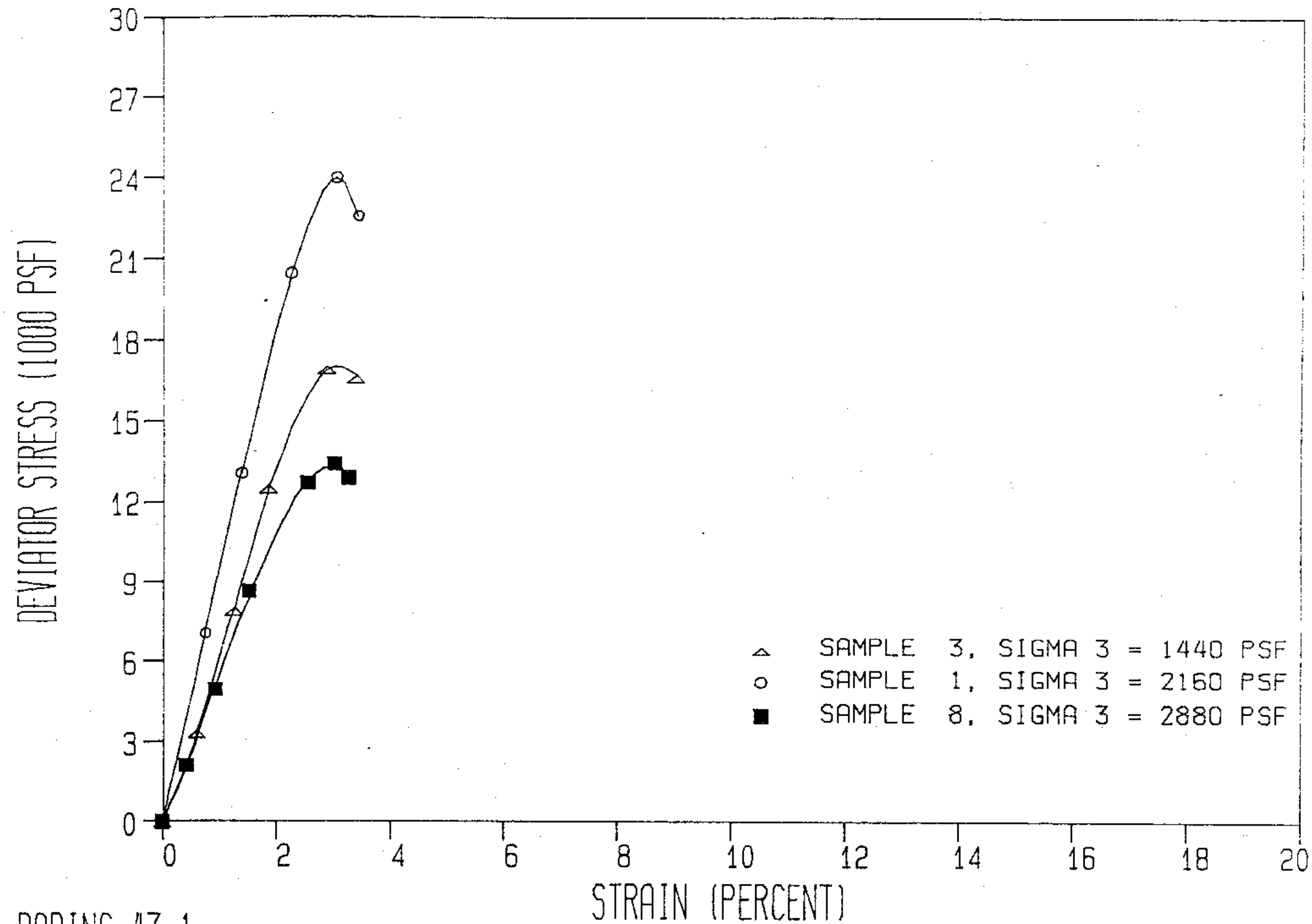
BORING 17-1


DEVIATOR STRESS (1000 PSF)
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18
20
STRAIN (PERCENT)
SAMPLE VI, SIGMA 3 = 2450 PSF
SAMPLE V, SIGMA 3 = 5000 PSF

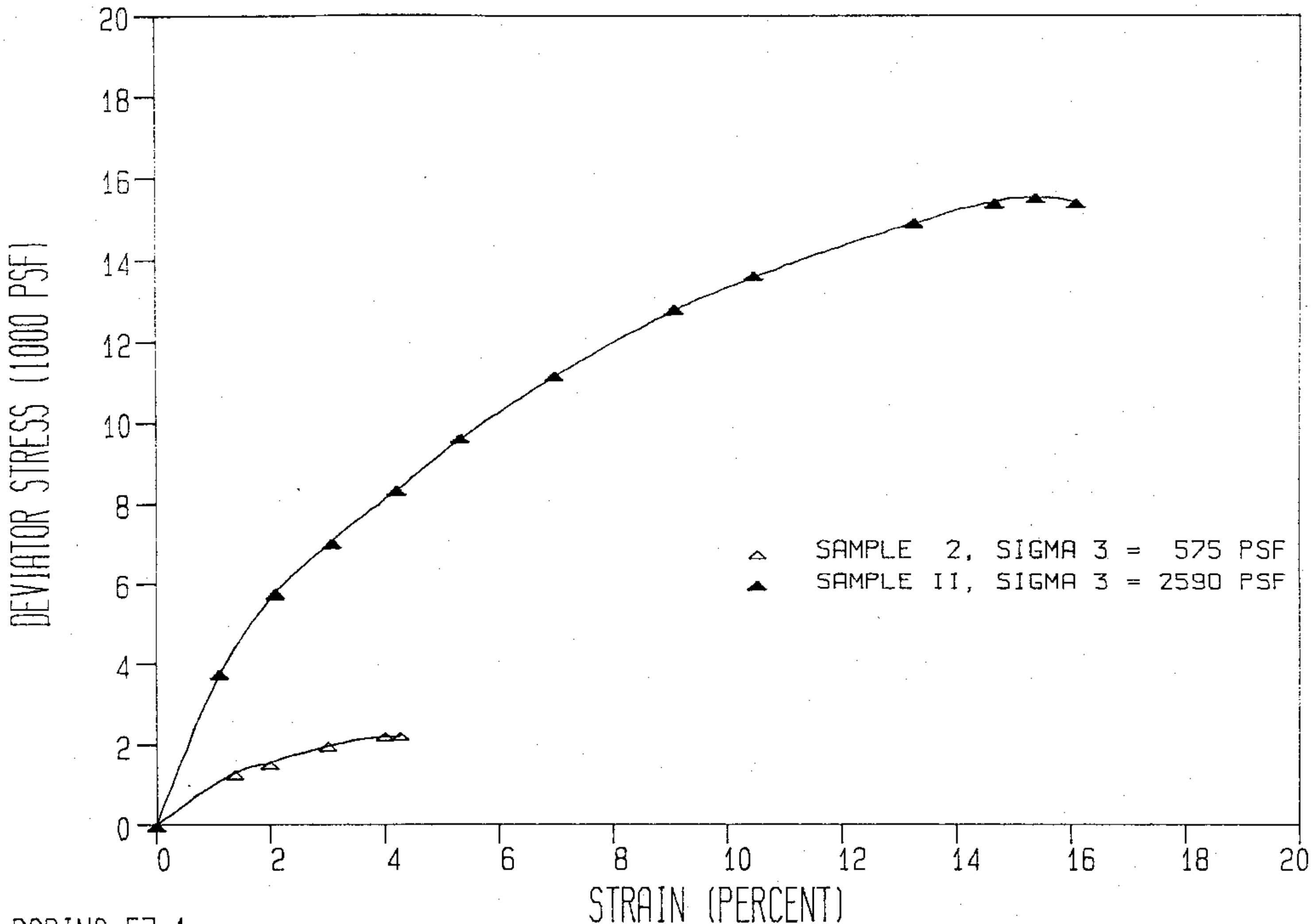
BORING 17-2


DEVIATOR STRESS (1000 PSF)
STRAIN (PERCENT)
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
20
SAMPLE IV, SIGMA 3 = 1150 PSF
SAMPLE III, SIGMA 3 = 1440 PSF
SAMPLE I, SIGMA 3 = 2015 PSF

BORING 20-1

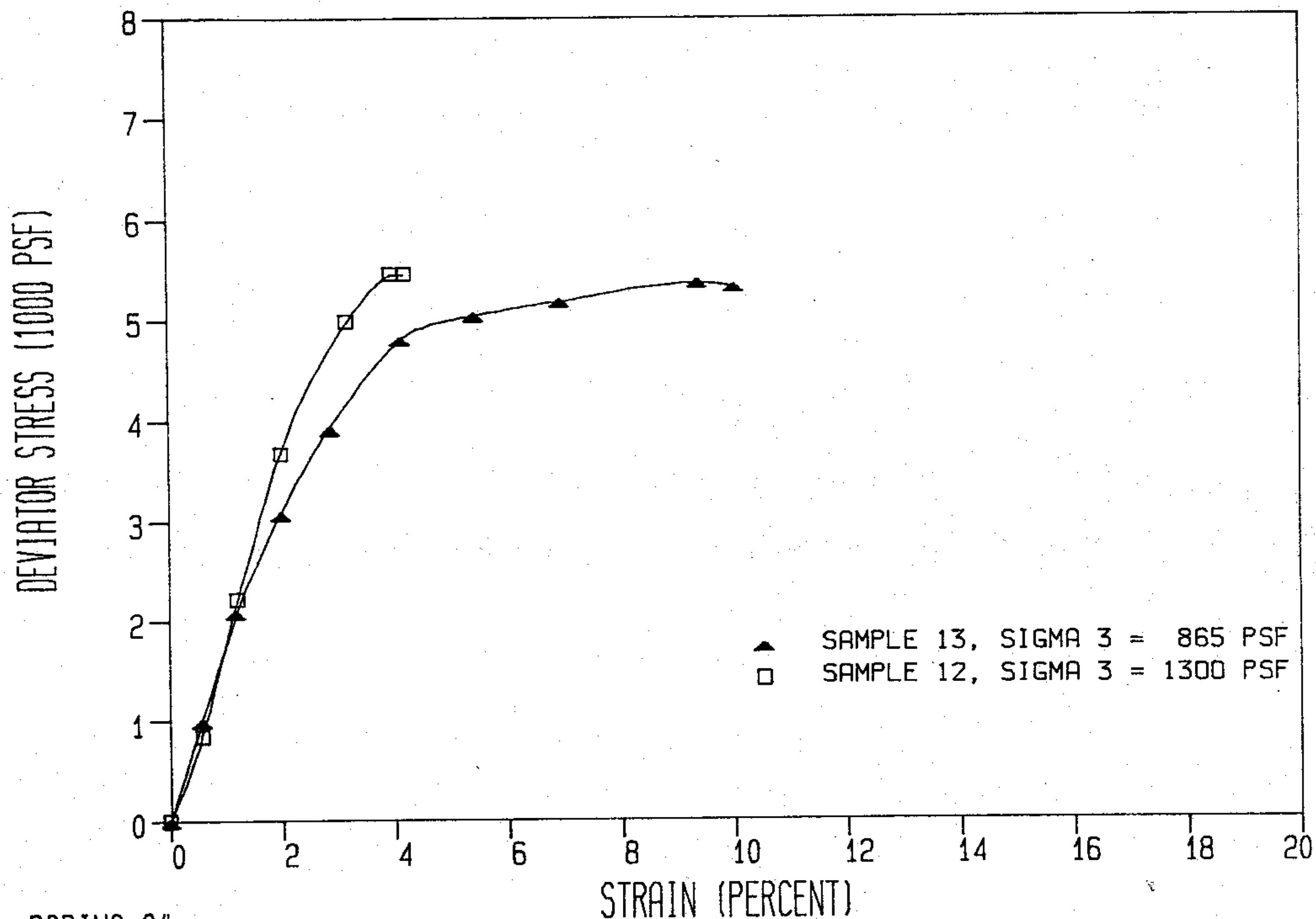

DEVIATOR STRESS (1000 PSF)
30
27
24
21
18
15
12
9
6
3
0
0
2
4
6
8
10
12
14
16
18
20
STRAIN (PERCENT)
SAMPLE 3, SIGMA 3 = 1440 PSF
SAMPLE 1, SIGMA 3 = 2160 PSF
SAMPLE 8, SIGMA 3 = 2880 PSF

BORING 43-1

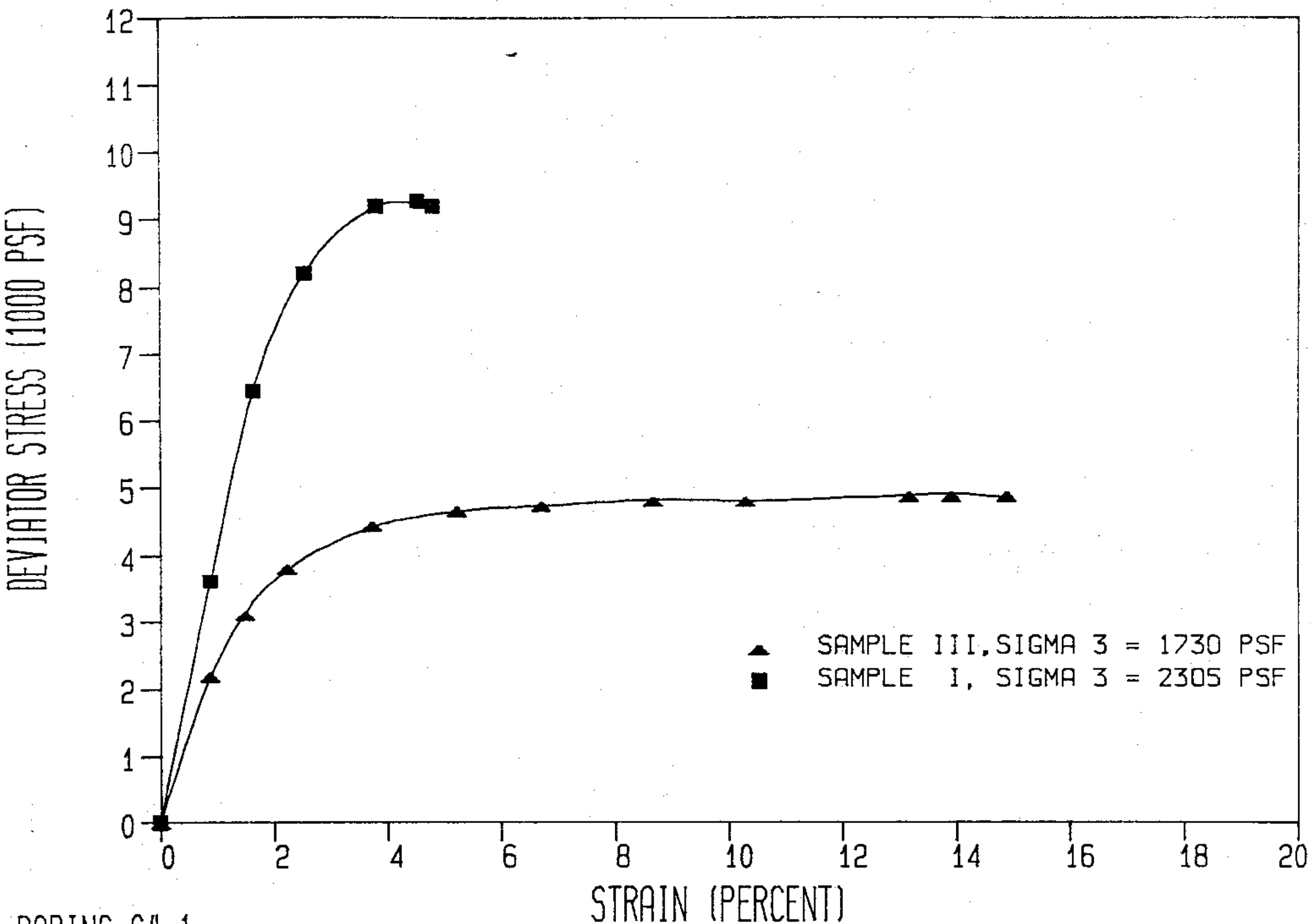


DEVIATOR STRESS (1000 PSF)
0
2
4
6
8
10
12
14
16
18
20
STRAIN (PERCENT)
SAMPLE 2, SIGMA 3 = 575 PSF
SAMPLE II, SIGMA 3 = 2590 PSF

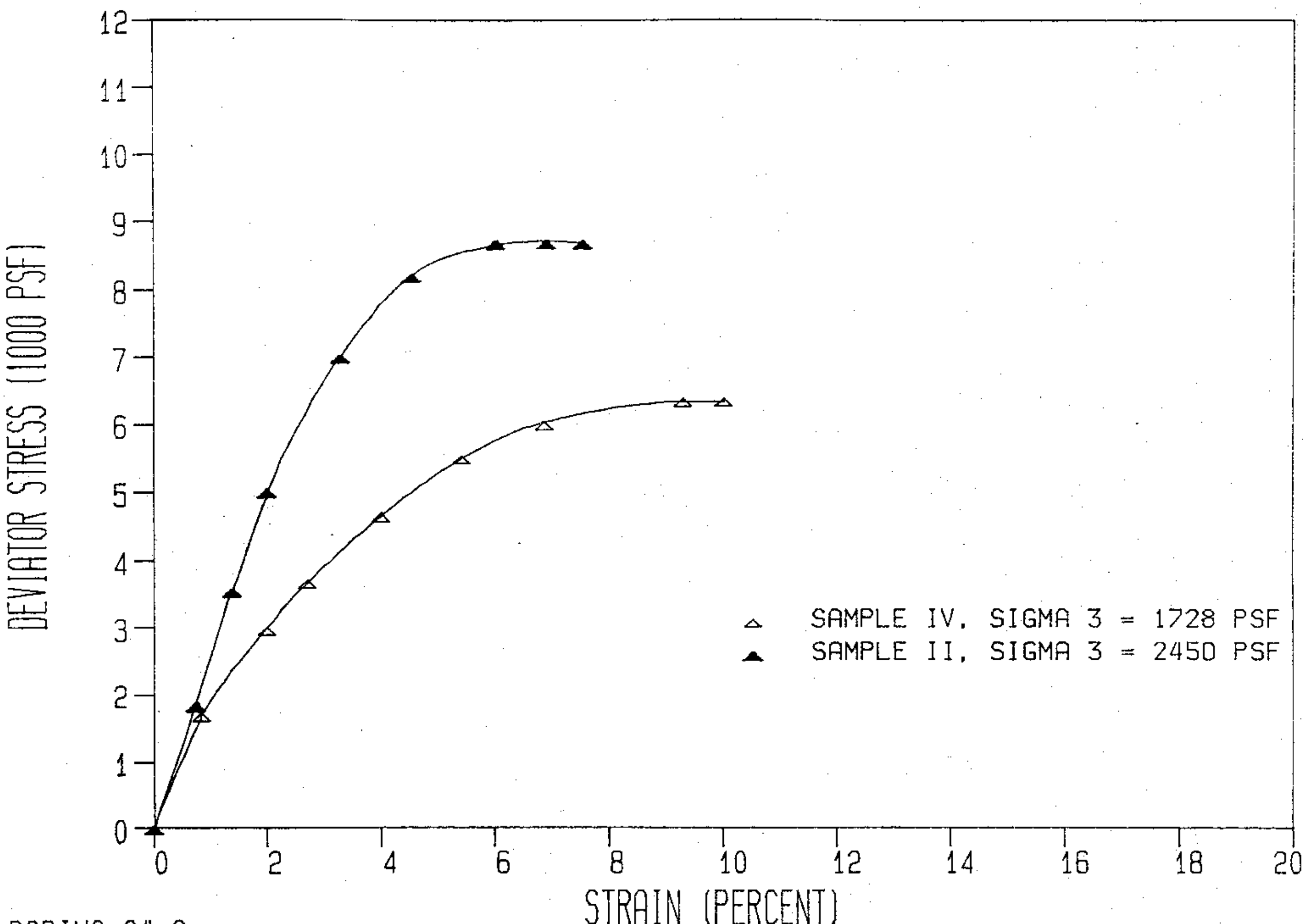
BORING 57-1


DEVIATOR STRESS (1000 PSF)
STRAIN (PERCENT)
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
SAMPLE 13, SIGMA 3 = 865 PSF
SAMPLE 12, SIGMA 3 = 1300 PSF

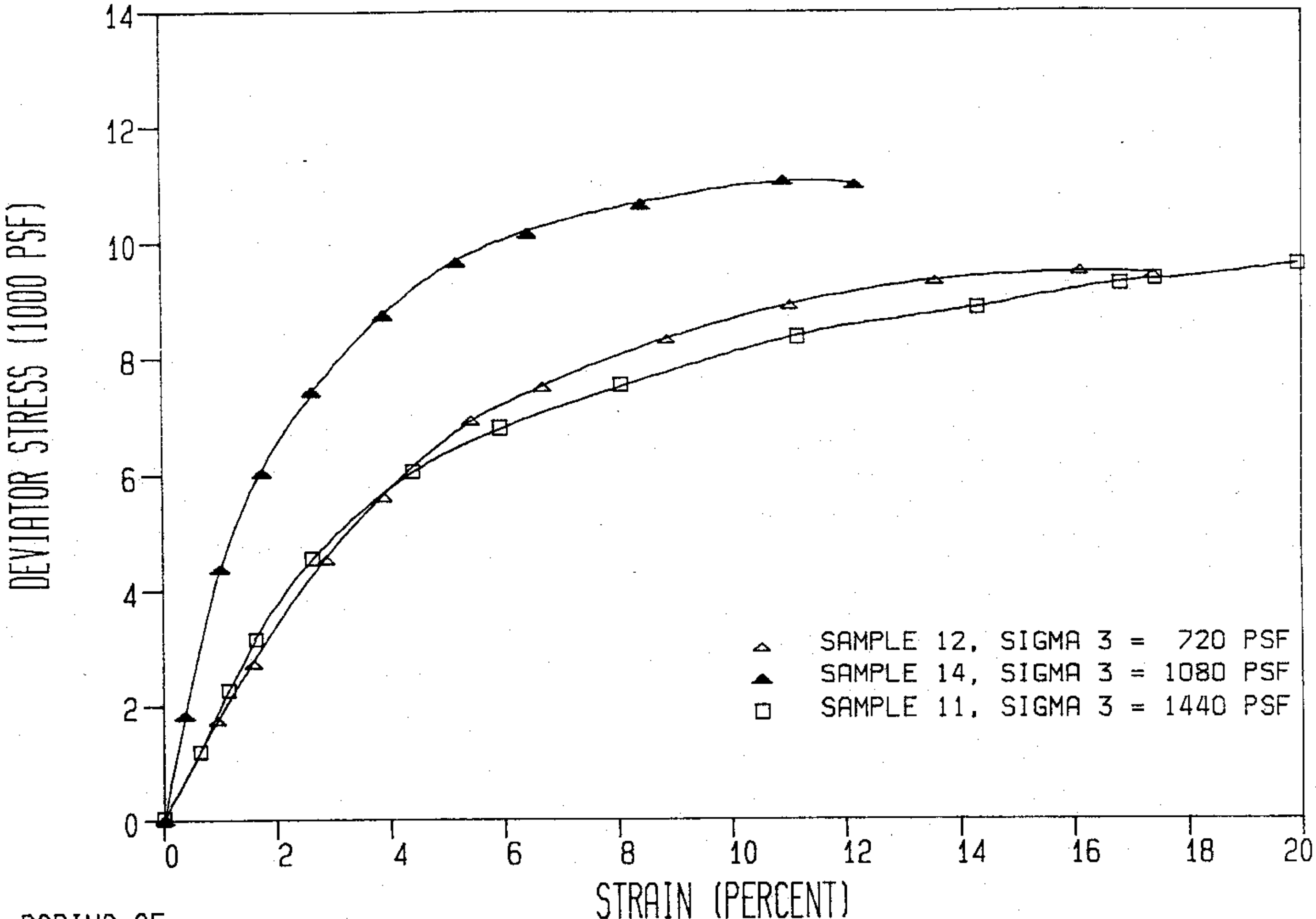
BORING 64


DEVIATOR STRESS (1000 PSF)
STRAIN (PERCENT)
SAMPLE III, SIGMA 3 = 1730 PSF
SAMPLE I, SIGMA 3 = 2305 PSF
0
1
2
3
4
5
6
7
8
9
10
11
12
0
2
4
6
8
10
12
14
16
18
20

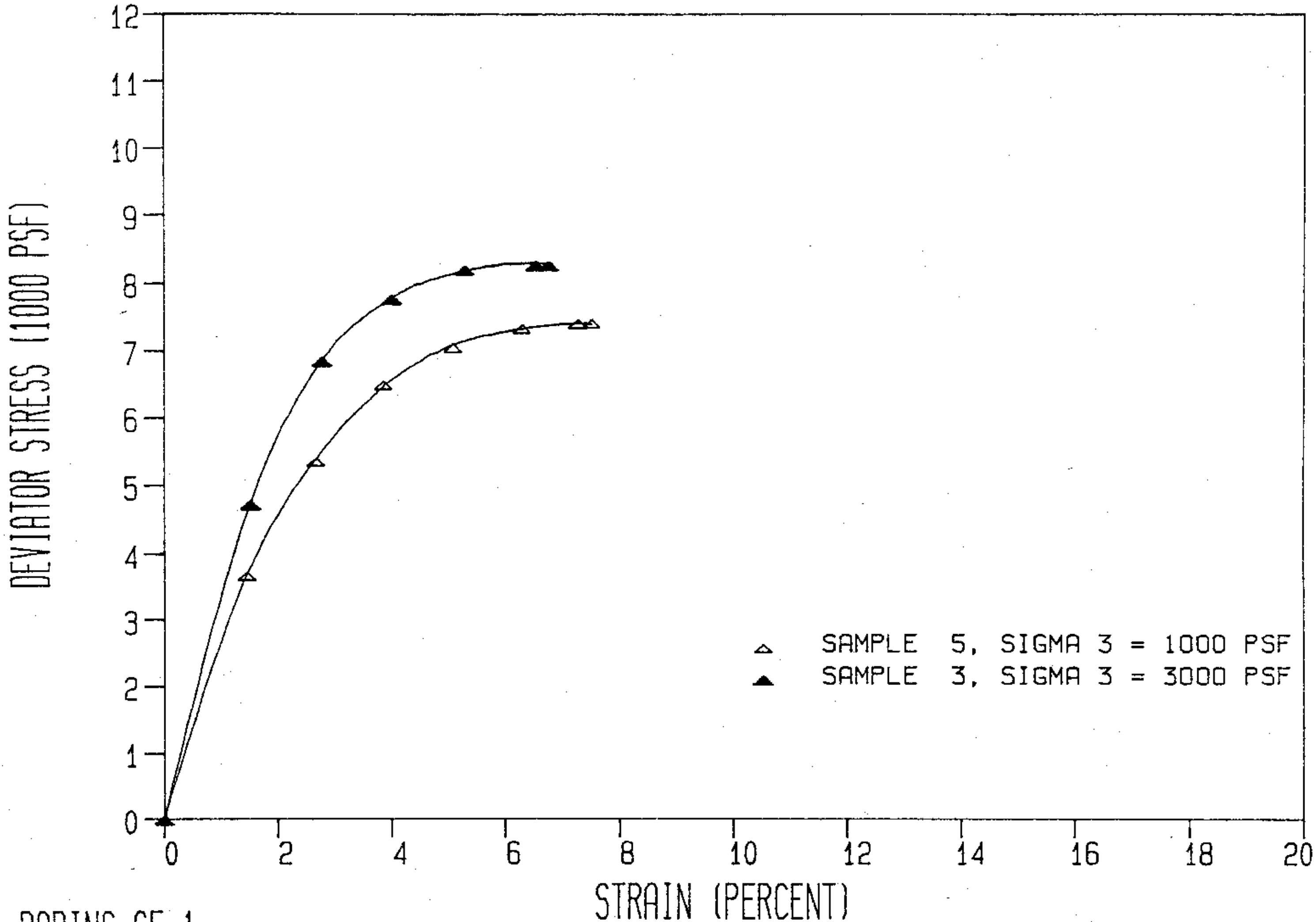
BORING 64-1


DEVIATOR STRESS (1000 PSF)
STRAIN (PERCENT)
0
1
2
3
4
5
6
7
8
9
10
11
12
0
2
4
6
8
10
12
14
16
18
20
SAMPLE IV, SIGMA 3 = 1728 PSF
SAMPLE II, SIGMA 3 = 2450 PSF

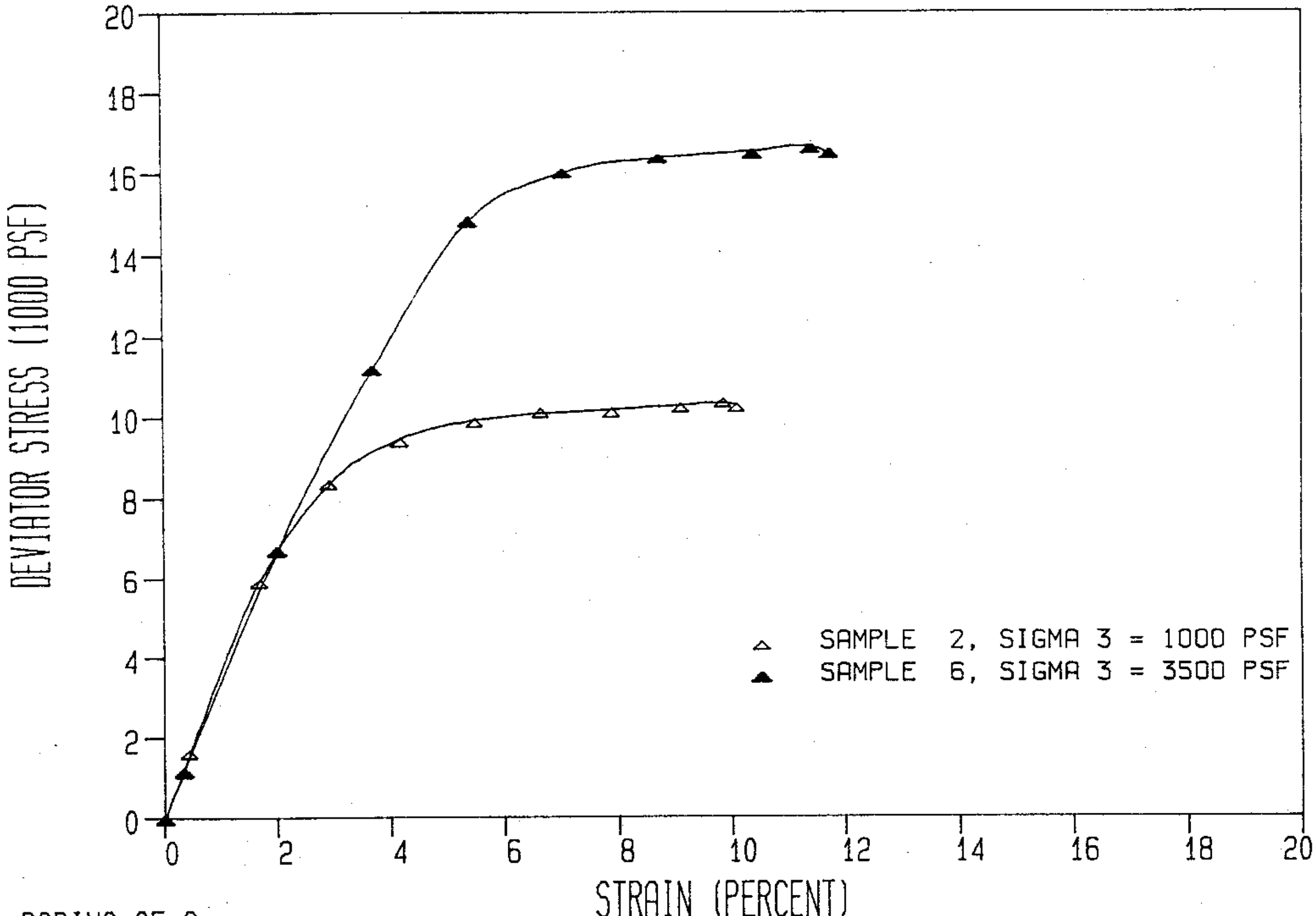
BORING 64-2


DEVIATOR STRESS (1000 PSF)
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
STRAIN (PERCENT)
SAMPLE 12, SIGMA 3 = 720 PSF
SAMPLE 14, SIGMA 3 = 1080 PSF
SAMPLE 11, SIGMA 3 = 1440 PSF

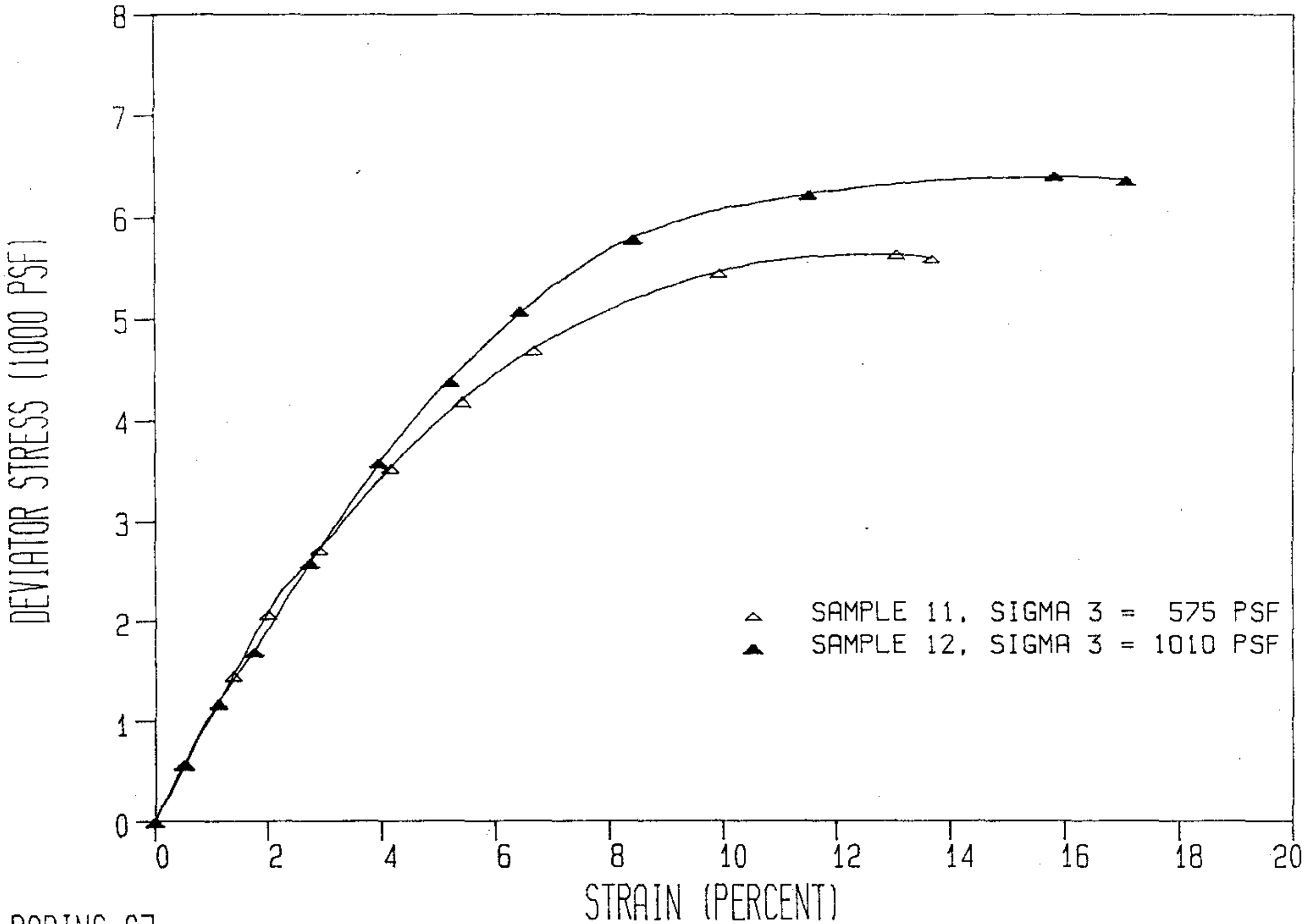
BORING 65


12
11
10
9
8
7
6
5
4
3
2
1
0
DEVIATOR STRESS (1000 PSF)
0
2
4
6
8
10
12
14
16
18
20
STRAIN (PERCENT)
SAMPLE 5, SIGMA 3 = 1000 PSF
SAMPLE 3, SIGMA 3 = 3000 PSF

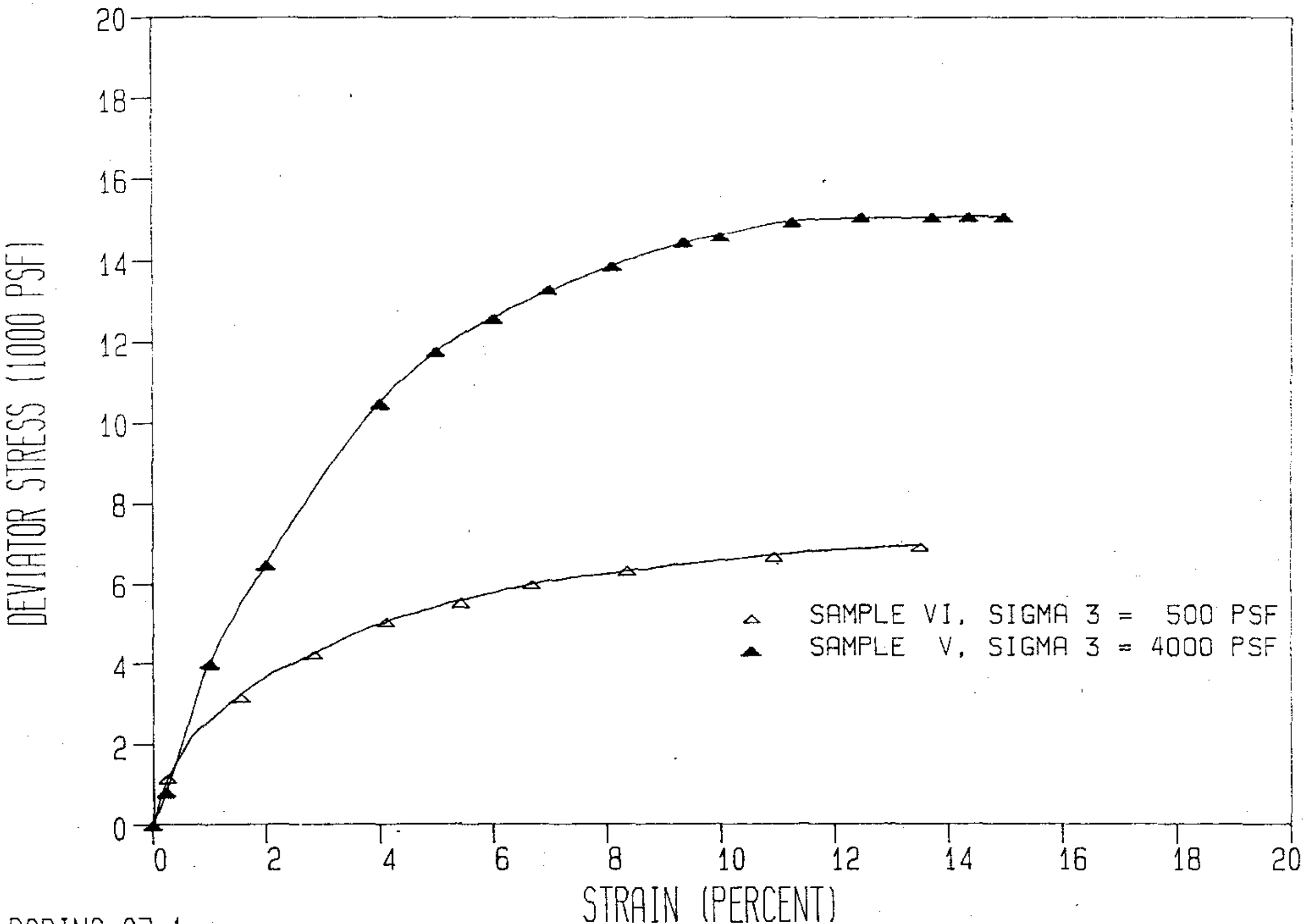
BORING 65-1


DEVIATOR STRESS (1000 PSF)
STRAIN (PERCENT)
0
2
4
6
8
10
12
14
16
18
20
SAMPLE 2, SIGMA 3 = 1000 PSF
SAMPLE 6, SIGMA 3 = 3500 PSF

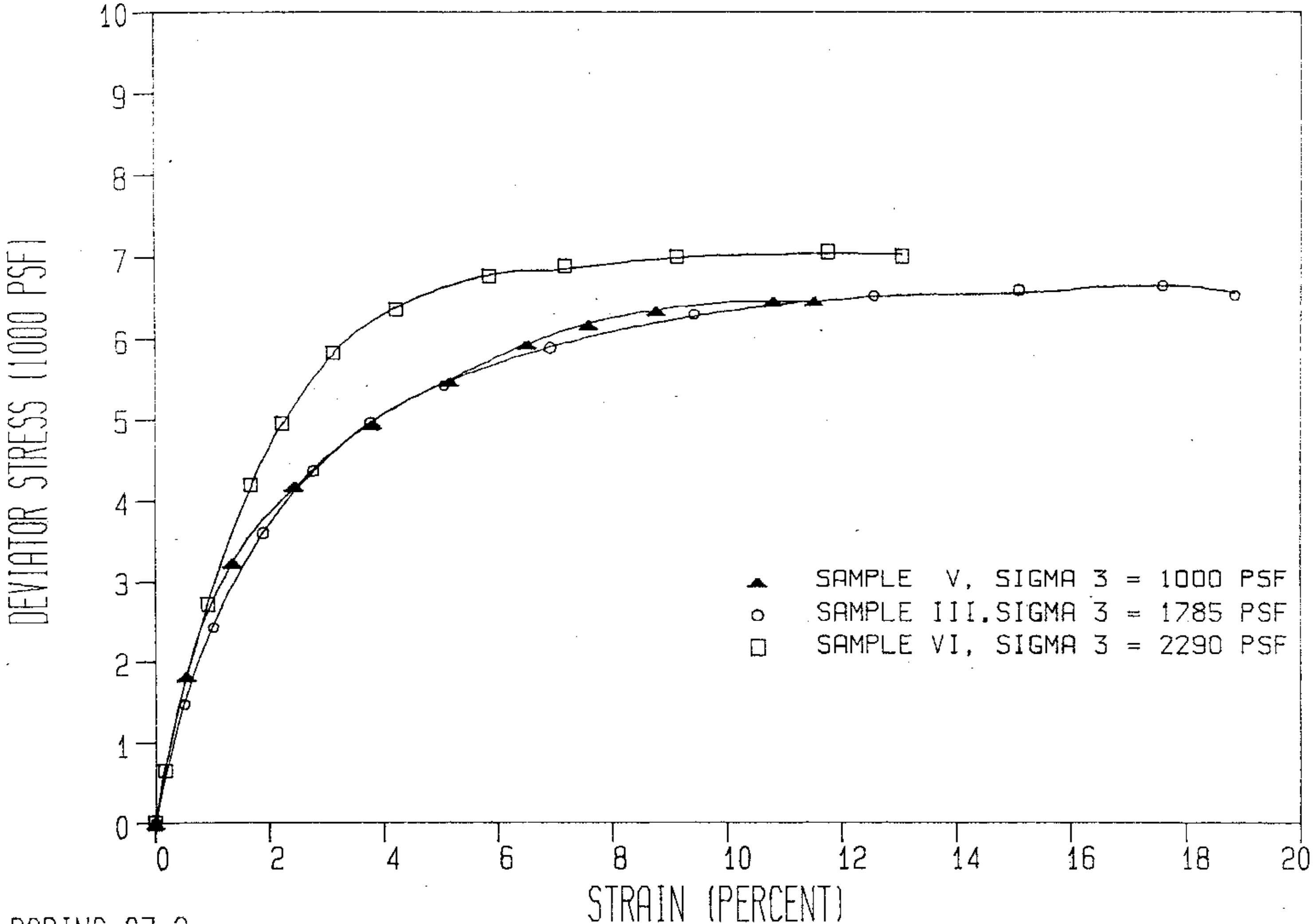
BORING 65-2


DEVIATOR STRESS (1000 PSF)
0
1
2
3
4
5
6
7
8
STRAIN (PERCENT)
0
2
4
6
8
10
12
14
16
18
20
SAMPLE 11, SIGMA 3 = 575 PSF
SAMPLE 12, SIGMA 3 = 1010 PSF

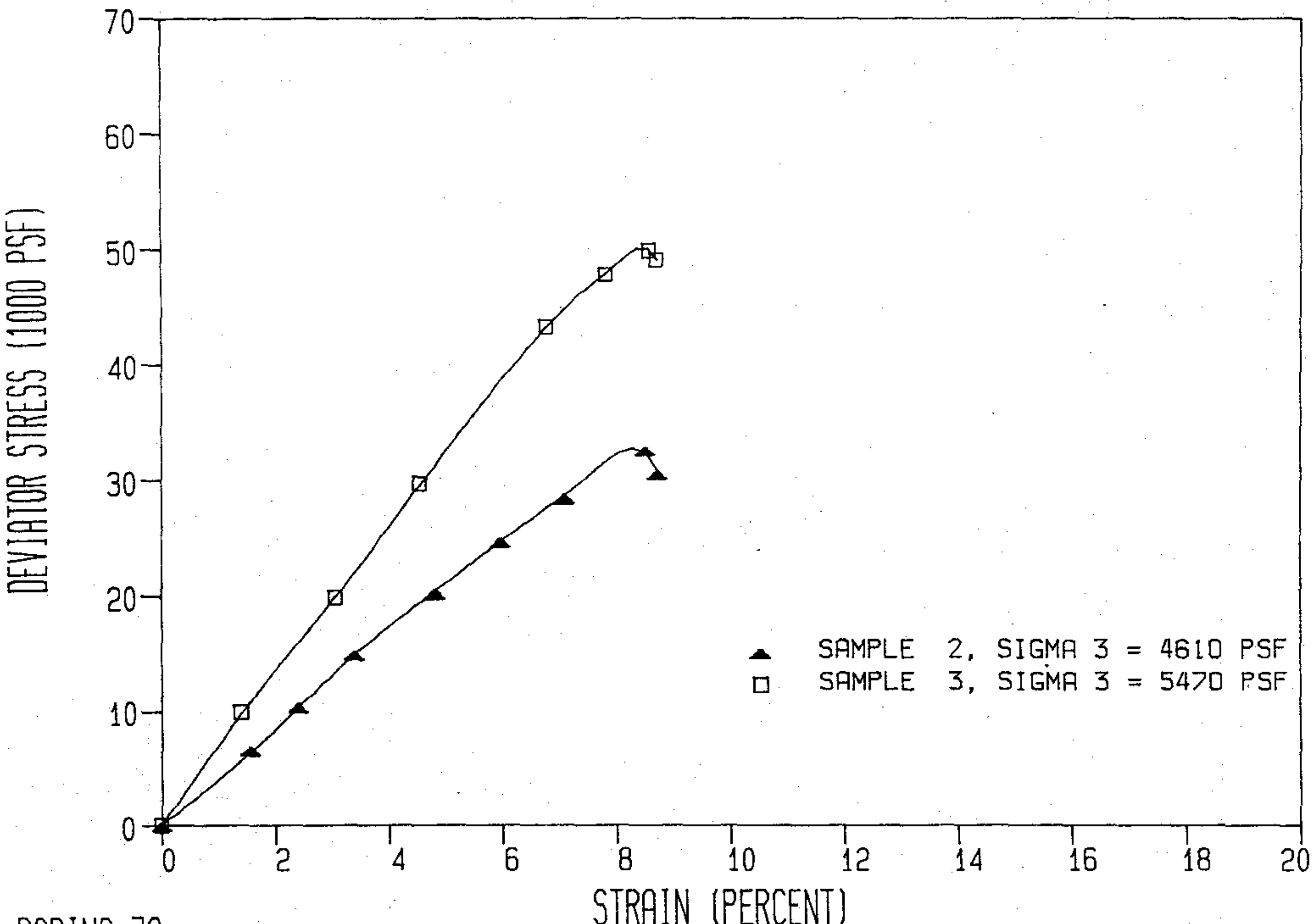
BORING 67


DEVIATOR STRESS (1000 PSF)
STRAIN (PERCENT)
SAMPLE VI, SIGMA 3 = 500 PSF
SAMPLE V, SIGMA 3 = 4000 PSF
0
2
4
6
8
10
12
14
16
18
20

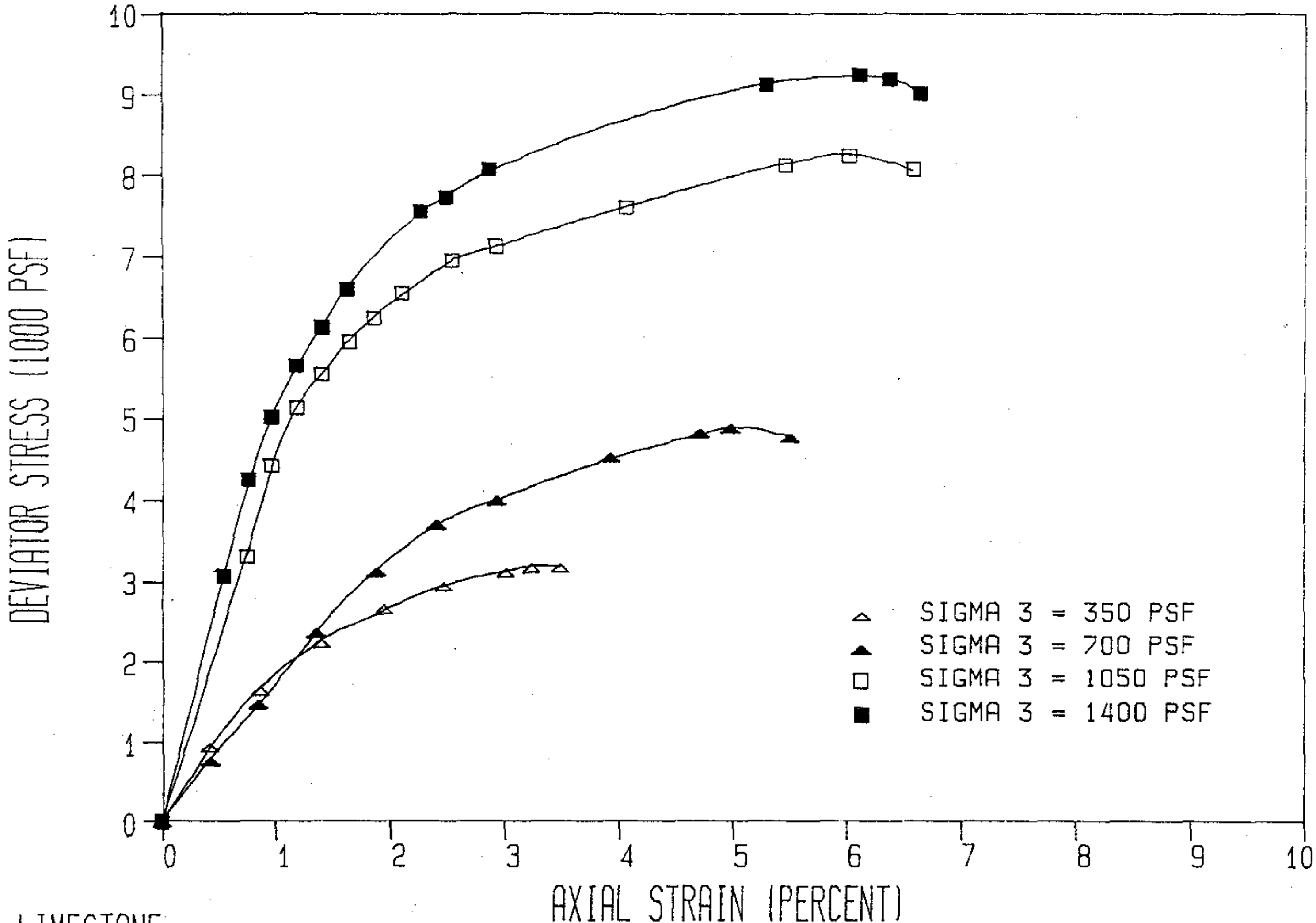
BORING 67-1


DEVIATOR STRESS (1000 PSF)
STRAIN (PERCENT)
0
2
4
6
8
10
12
14
16
18
20
1
3
5
7
9
SAMPLE V, SIGMA 3 = 1000 PSF
SAMPLE III. SIGMA 3 = 1785 PSF
SAMPLE VI, SIGMA 3 = 2290 PSF

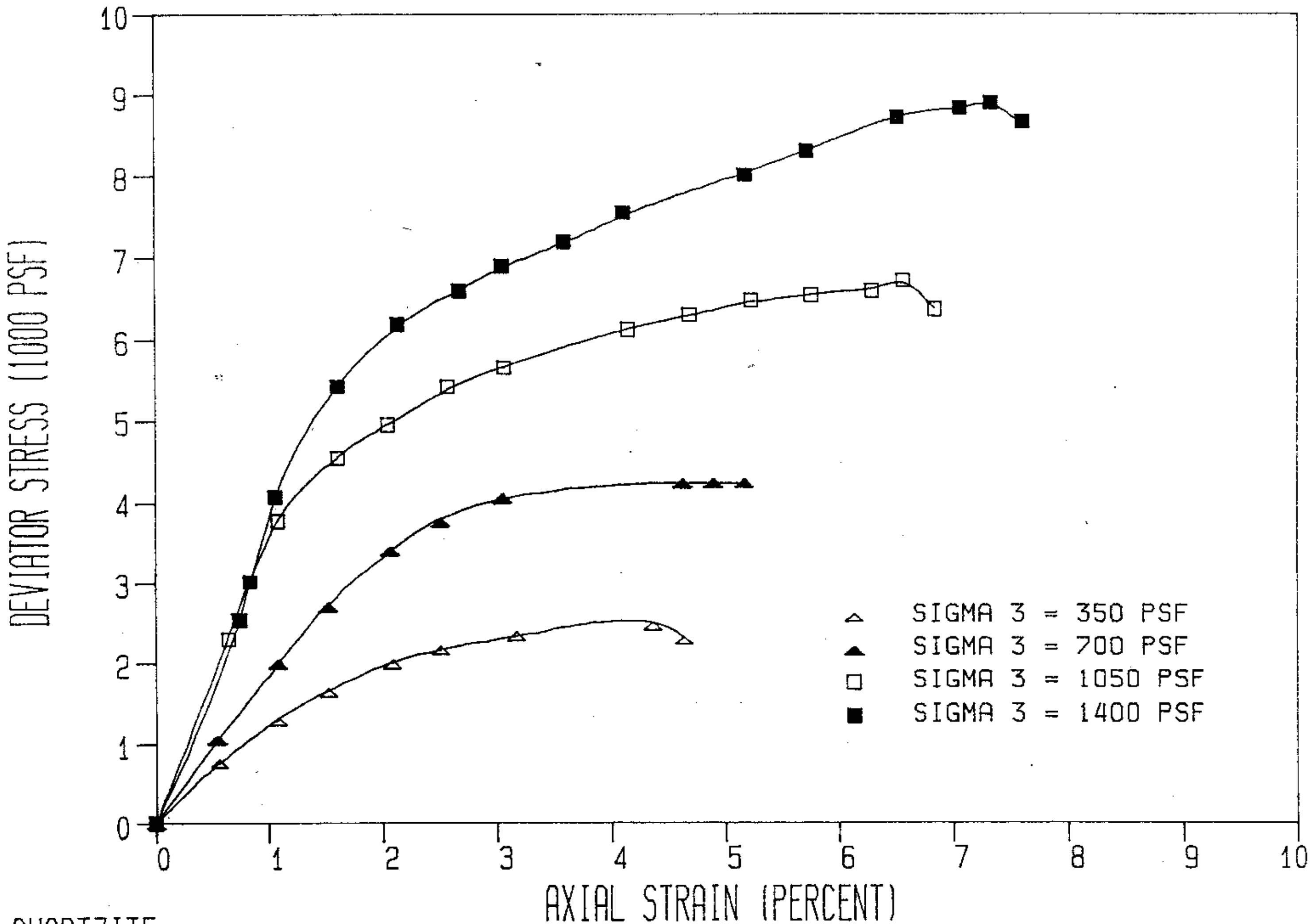
BORING 67-2


DEVIATOR STRESS (1000 PSF)
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
20
STRAIN (PERCENT)
SAMPLE 2, SIGMA 3 = 4610 PSF
SAMPLE 3, SIGMA 3 = 5470 PSF

BORING 79

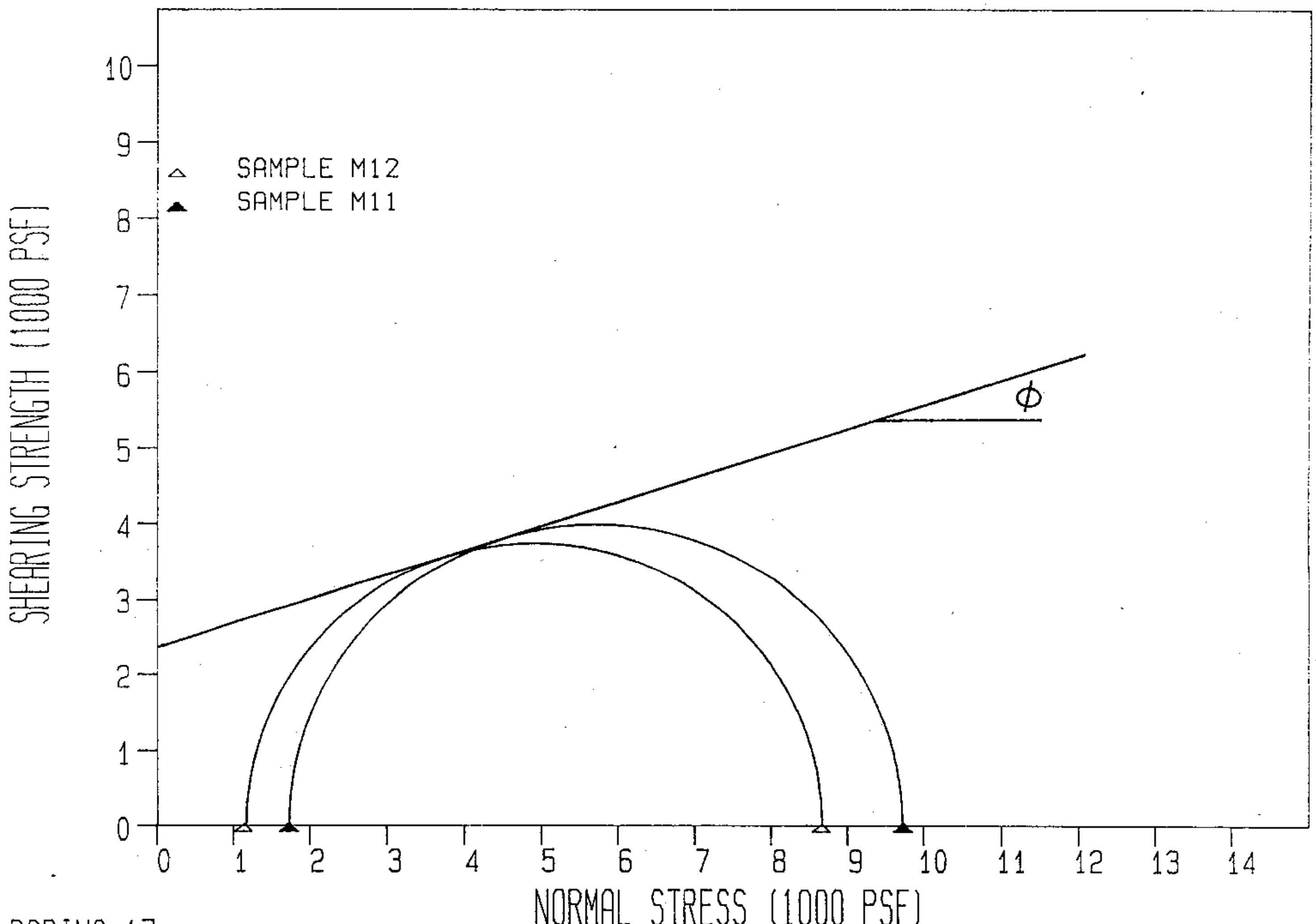

DEVIATOR STRESS (1000 PSF)
AXIAL STRAIN (PERCENT)
0
1
2
3
4
5
6
7
8
9
10
SIGMA 3 = 350 PSF
SIGMA 3 = 700 PSF
SIGMA 3 = 1050 PSF
SIGMA 3 = 1400 PSF

LIMESTONE

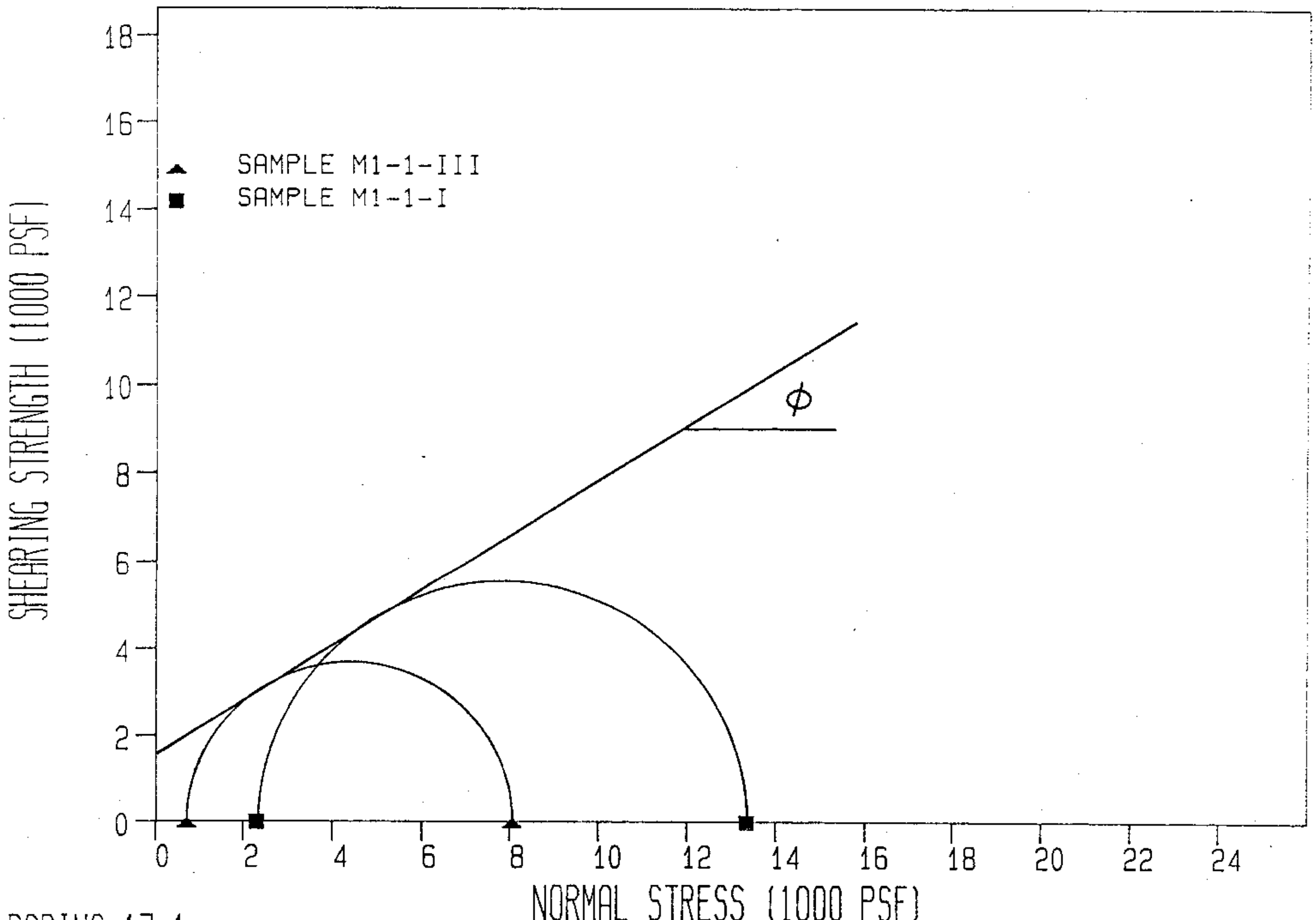

DEVIATOR STRESS (1000 PSF)
AXIAL STRAIN (PERCENT)
0
1
2
3
4
5
6
7
8
9
10
SIGMA 3 = 350 PSF
SIGMA 3 = 700 PSF
SIGMA 3 = 1050 PSF
SIGMA 3 = 1400 PSF

QUARTZITE

APPENDIX - III Mohr Circles

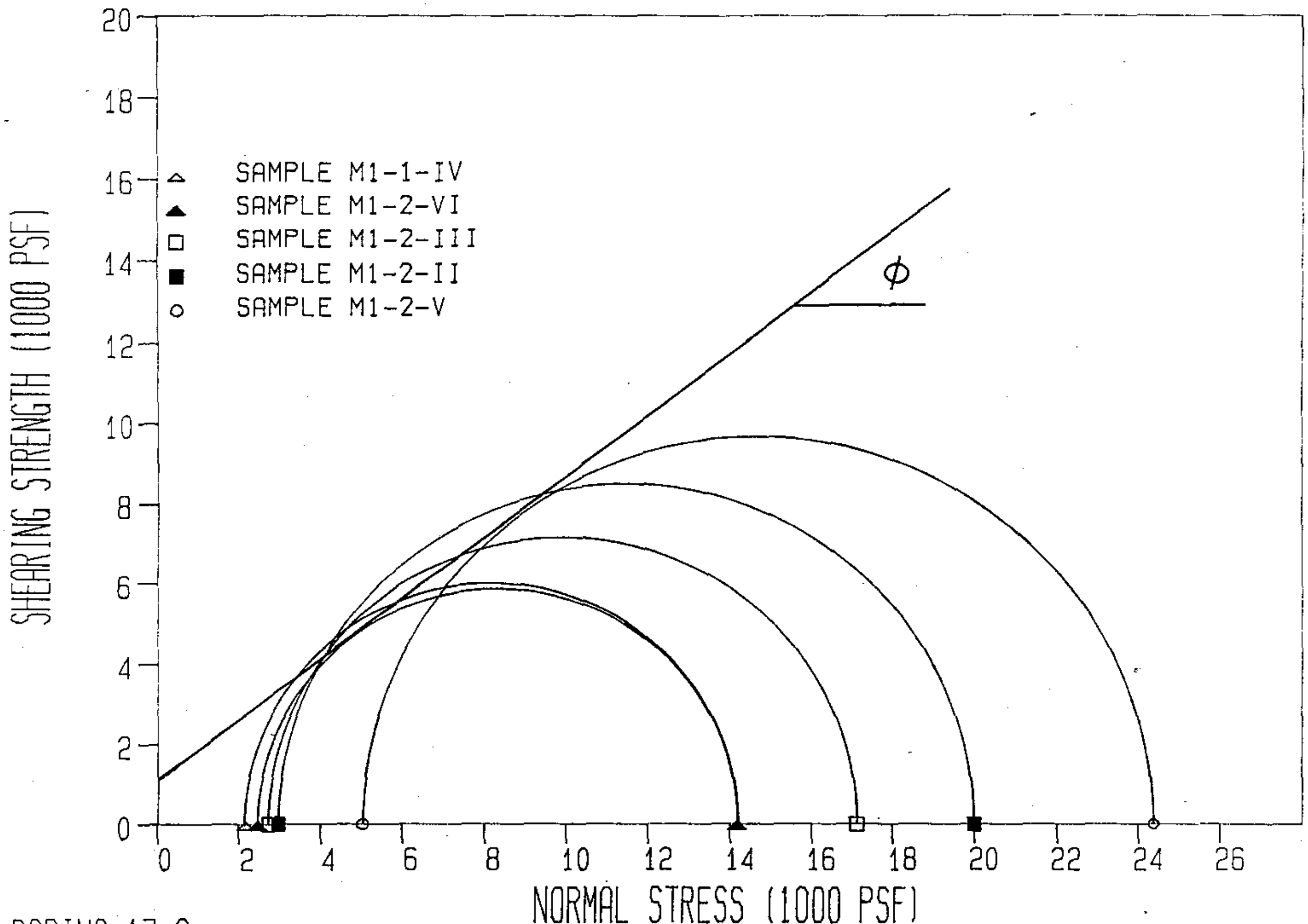

SAMPLE M12
SAMPLE M11
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
φ
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

BORING 17

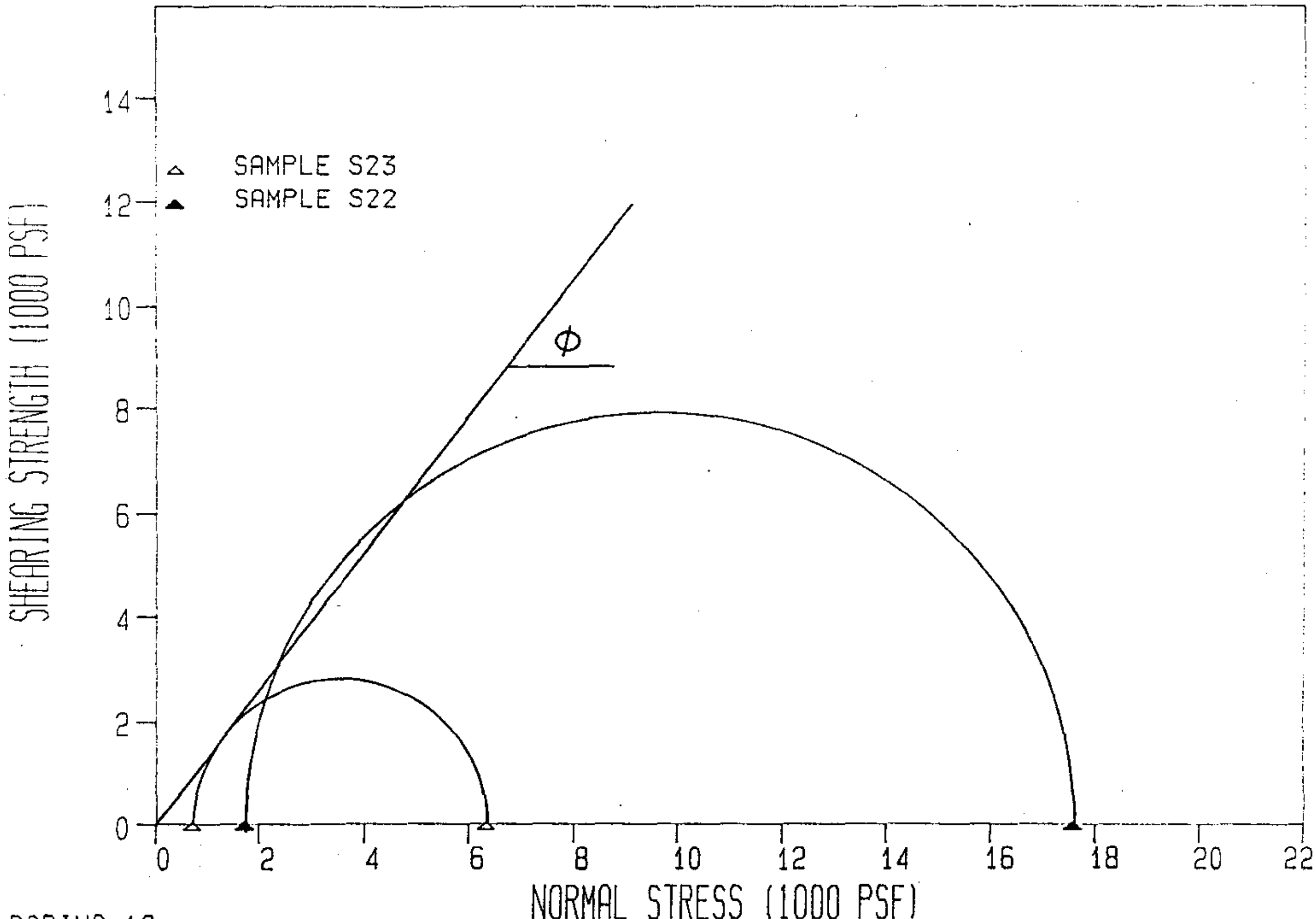


SAMPLE M1-1-III
SAMPLE M1-1-I
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
φ
0
2
4
6
8
10
12
14
16
18
20
22
24

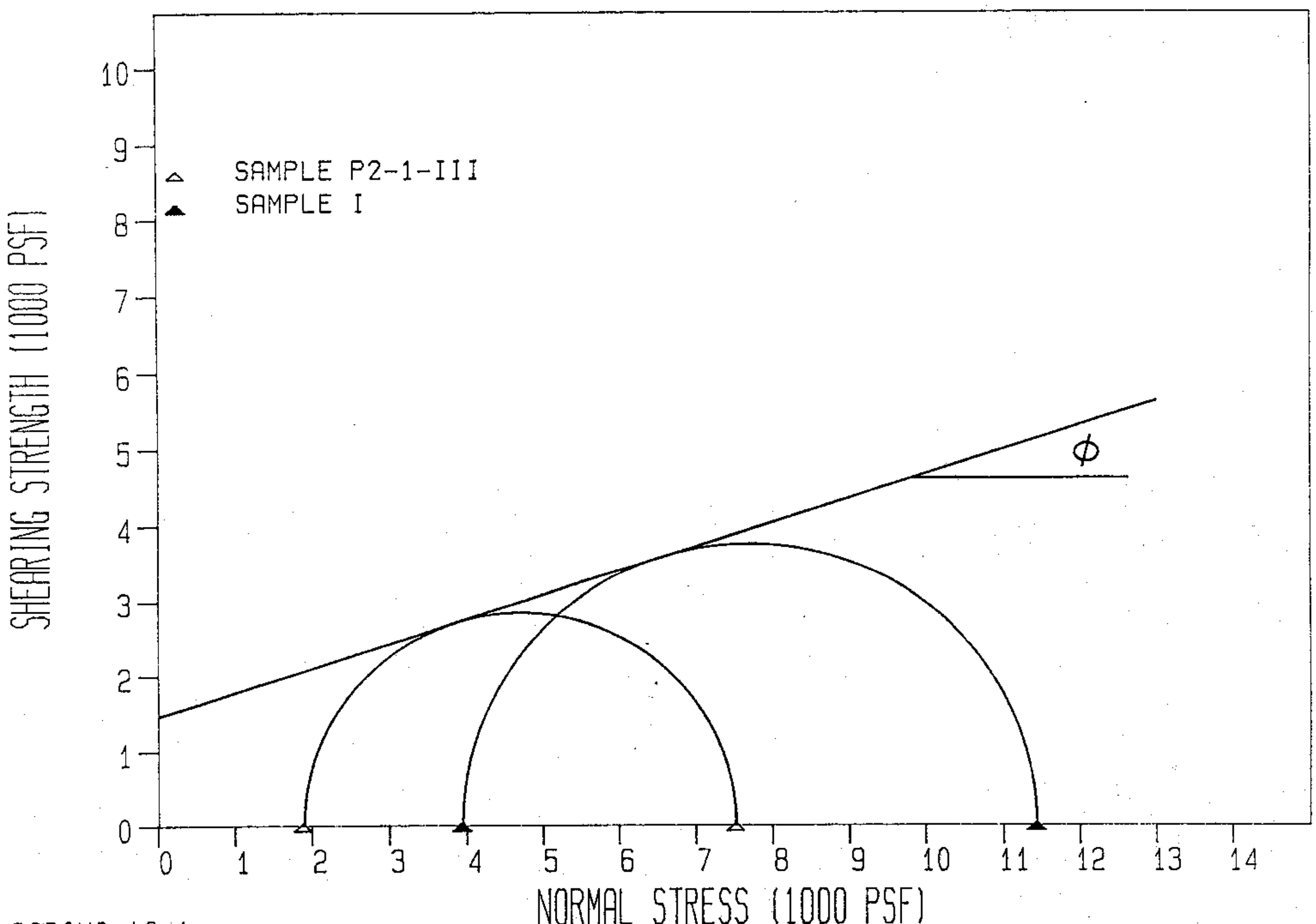
BORING 17-1


SAMPLE M1-1-IV
SAMPLE M1-2-VI
SAMPLE M1-2-III
SAMPLE M1-2-II
SAMPLE M1-2-V
φ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
2
4
6
8
10
12
14
16
18
20
22
24
26

BORING 17-2

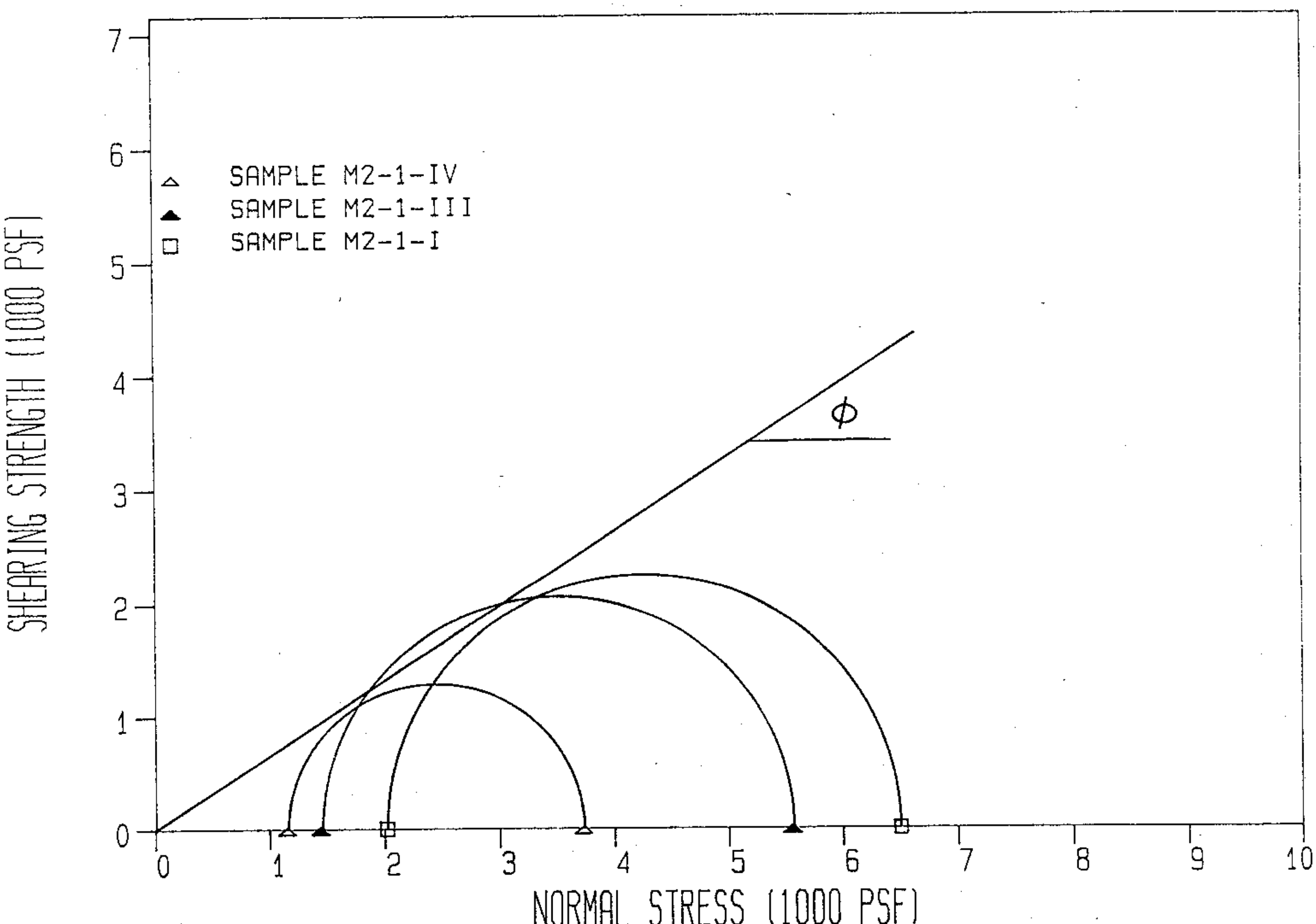

SAMPLE S23
SAMPLE S22
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
φ
0
2
4
6
8
10
12
14
16
18
20
22

BORING 18

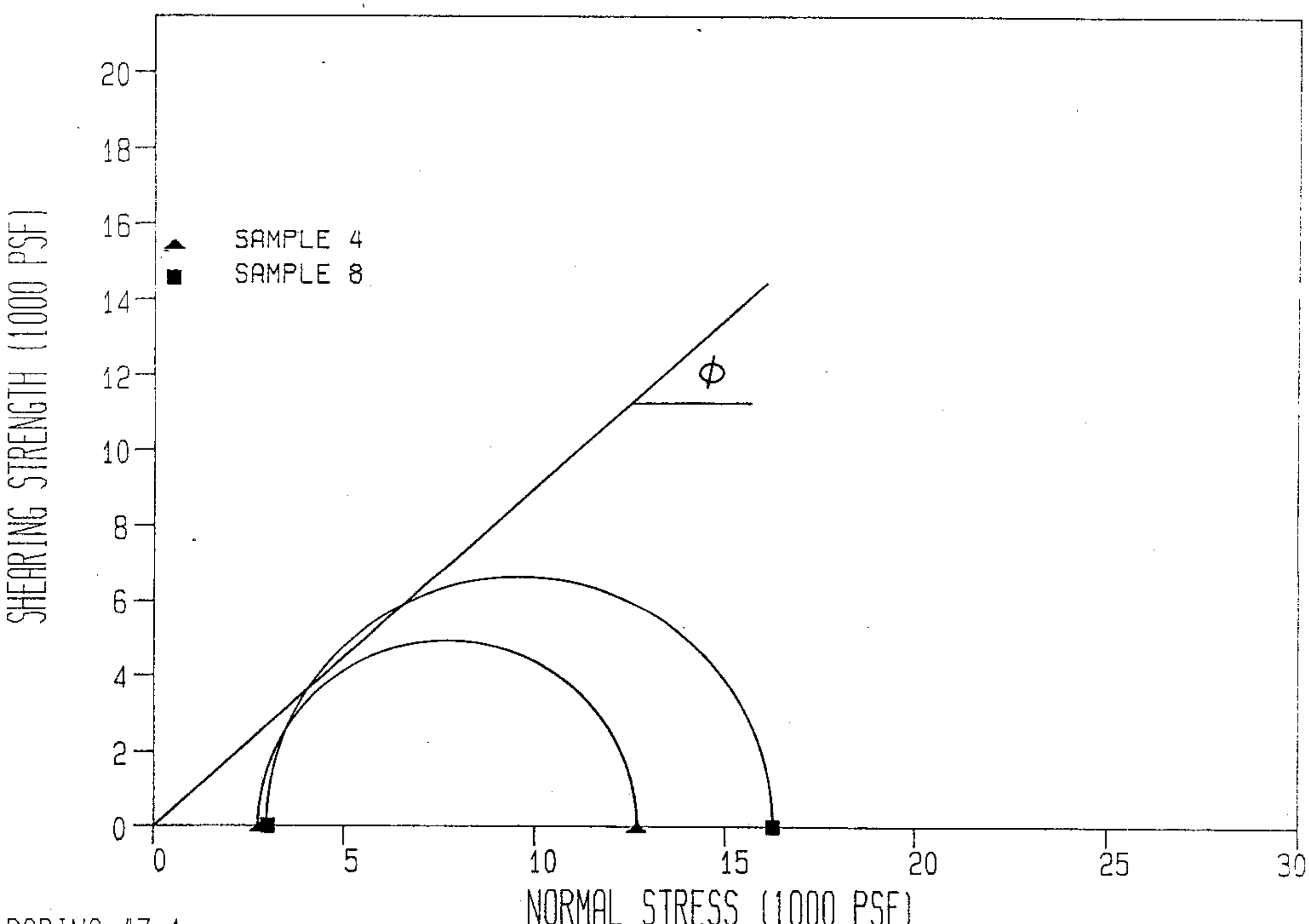


SAMPLE P2-1-III
SAMPLE I
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
φ
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

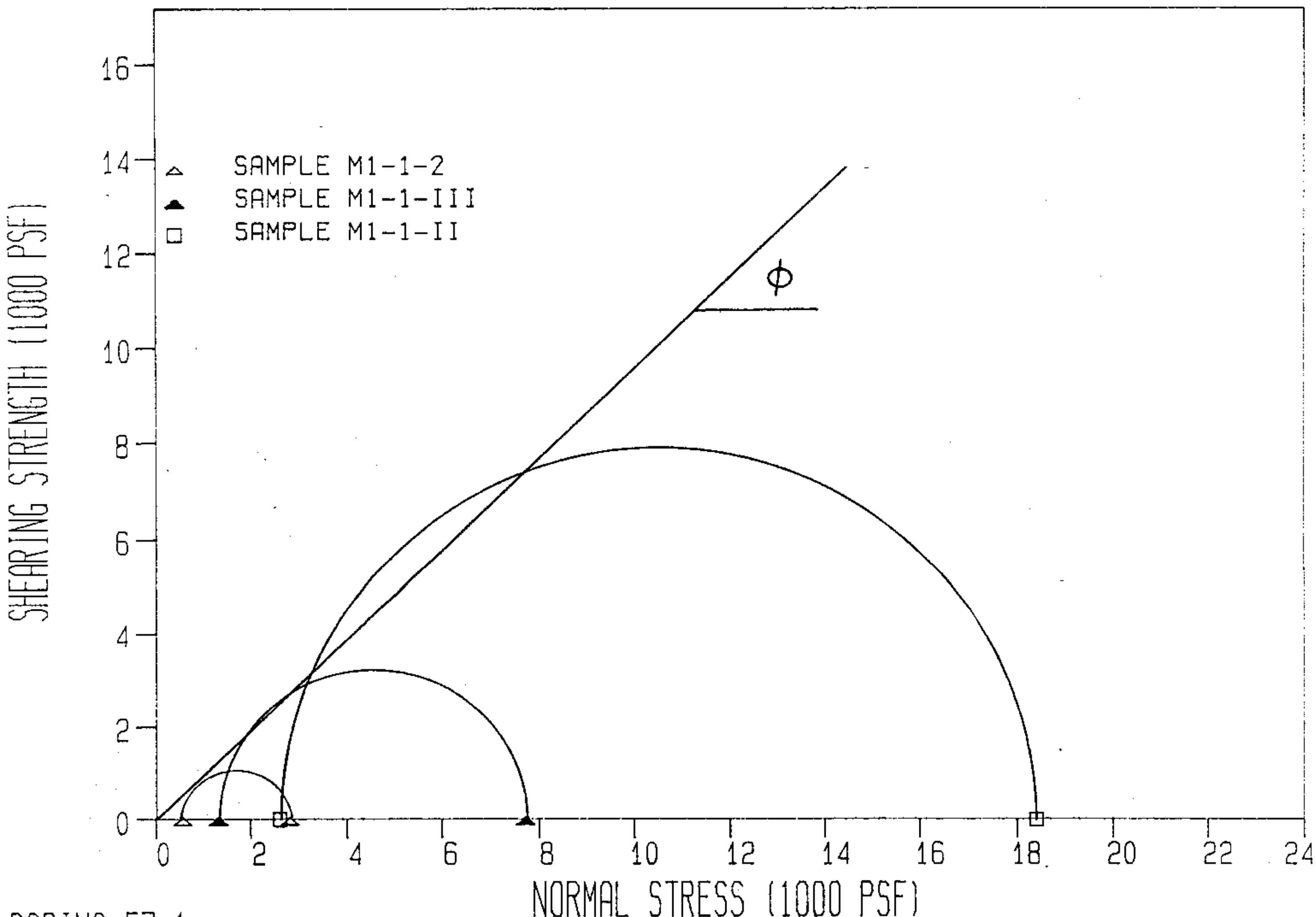
BORING 18-1


SAMPLE M2-1-IV
SAMPLE M2-1-III
SAMPLE M2-1-I
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
φ
0
1
2
3
4
5
6
7
8
9
10

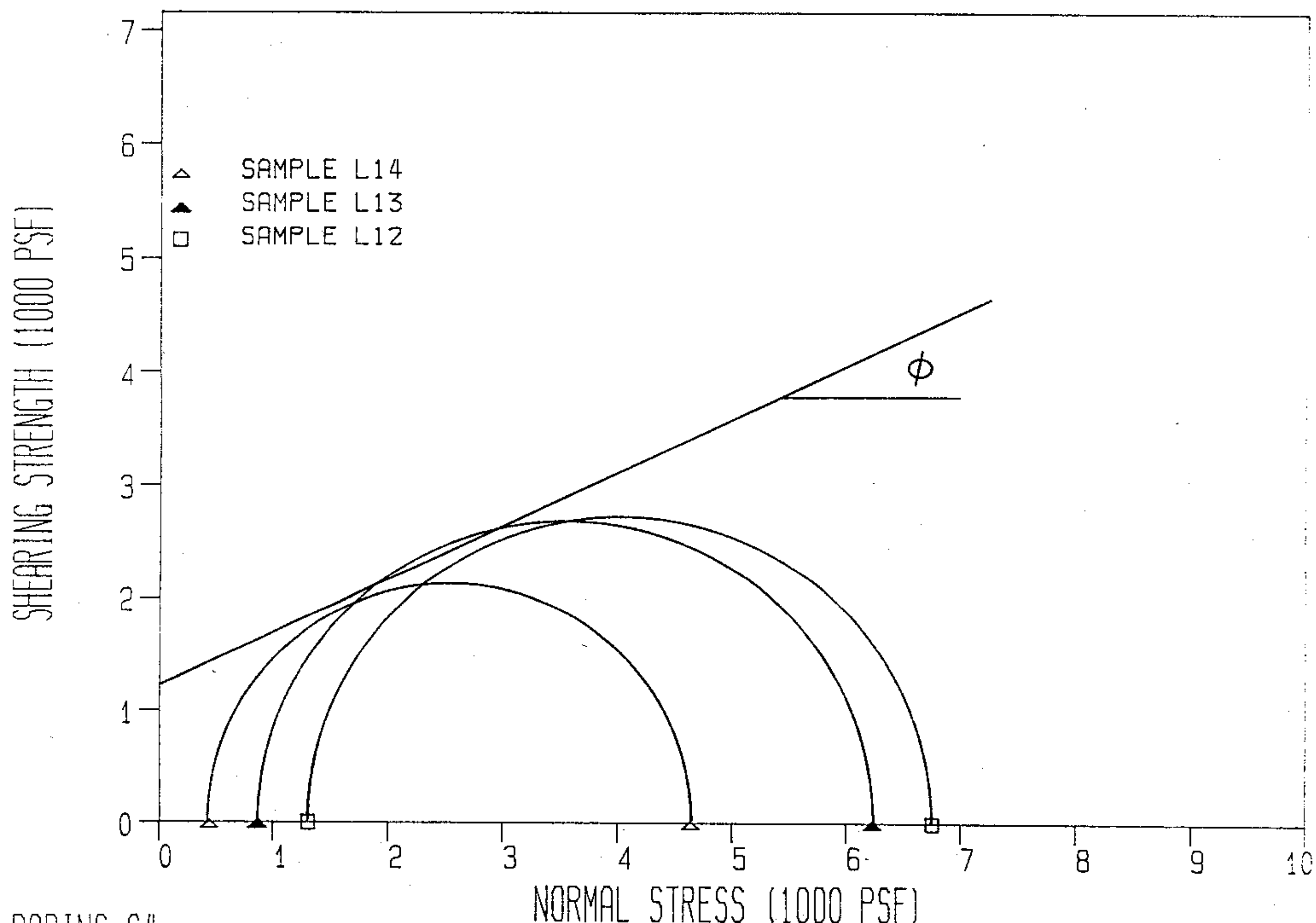
BORING 20-1


SAMPLE 4
SAMPLE 8
φ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30

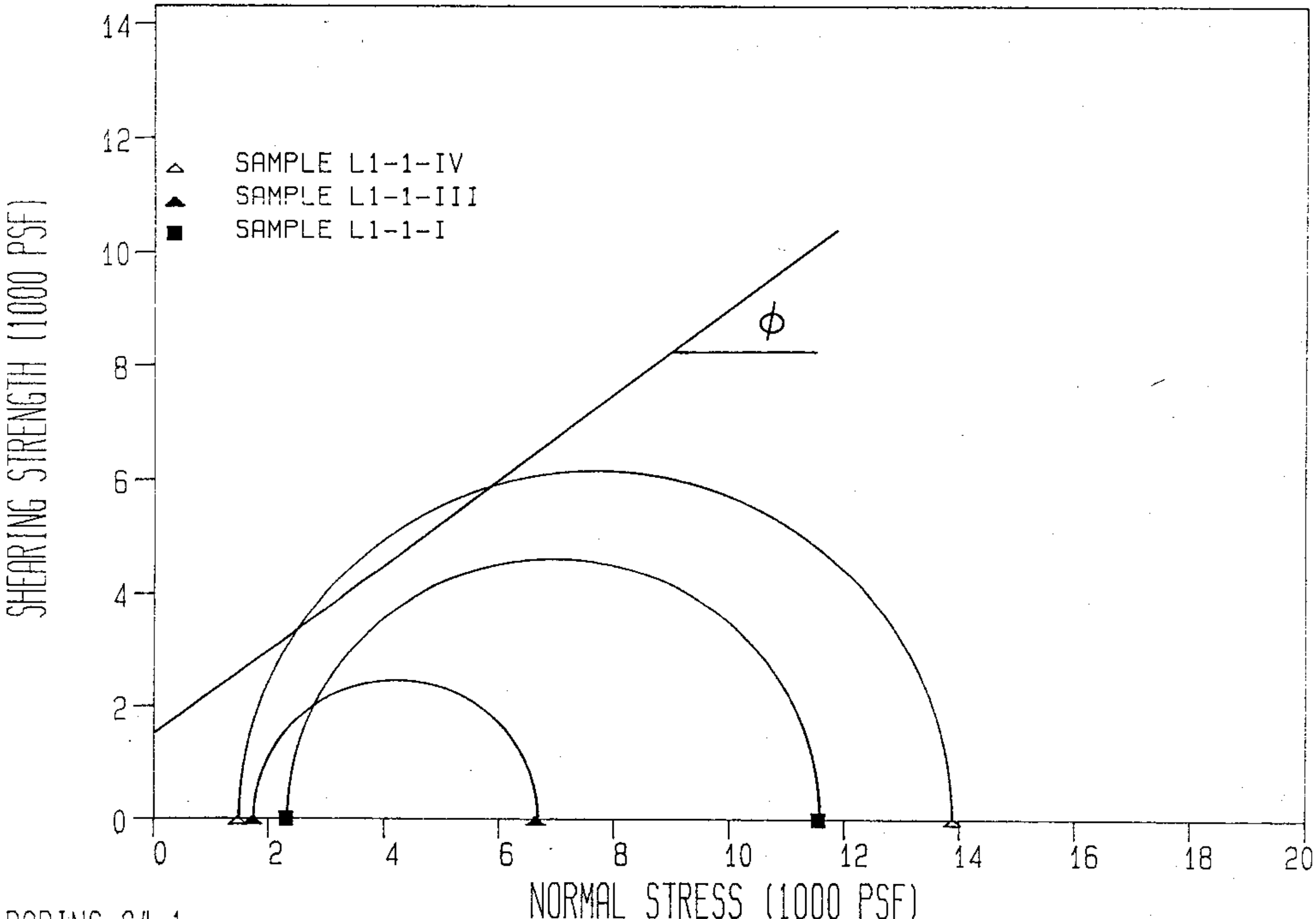
BORING 43-1


SAMPLE M1-1-2
SAMPLE M1-1-III
SAMPLE M1-1-II
ϕ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
2
4
6
8
10
12
14
16
18
20
22
24

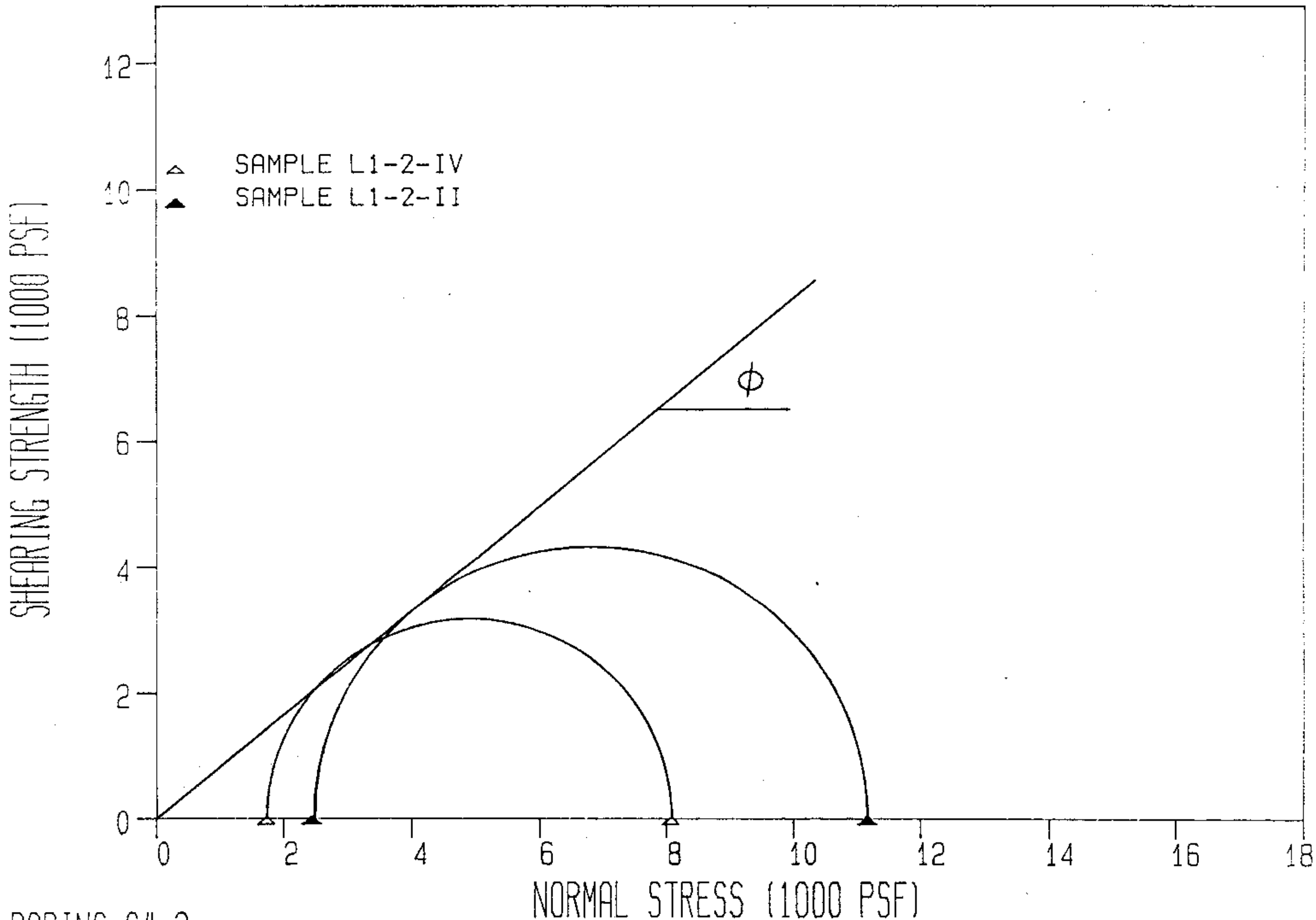
BORING 57-1


SAMPLE L14
SAMPLE L13
SAMPLE L12
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
φ
0
1
2
3
4
5
6
7
8
9
10

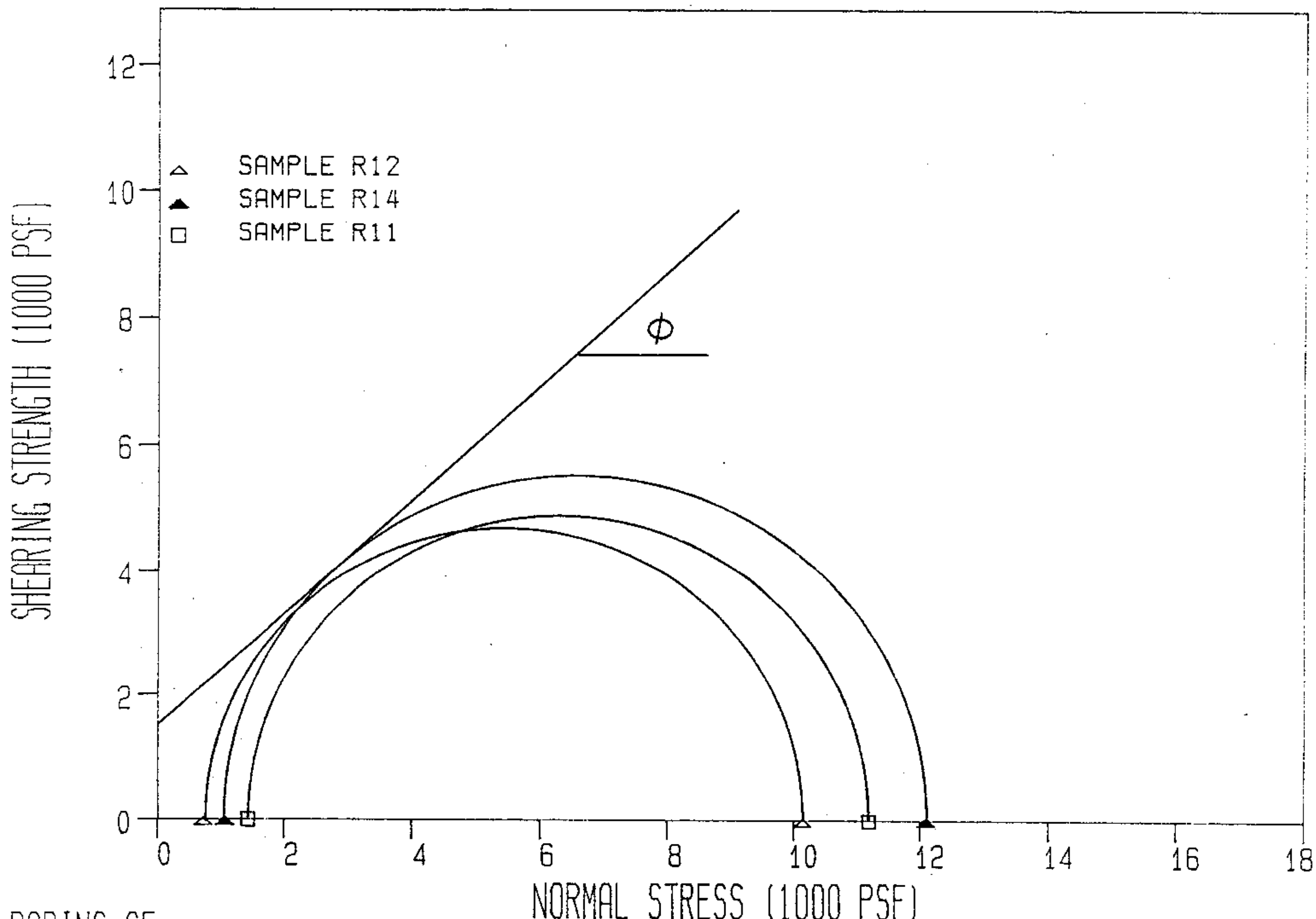
BORING 64


SAMPLE L1-1-IV
SAMPLE L1-1-III
SAMPLE L1-1-I
φ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
2
4
6
8
10
12
14
16
18
20

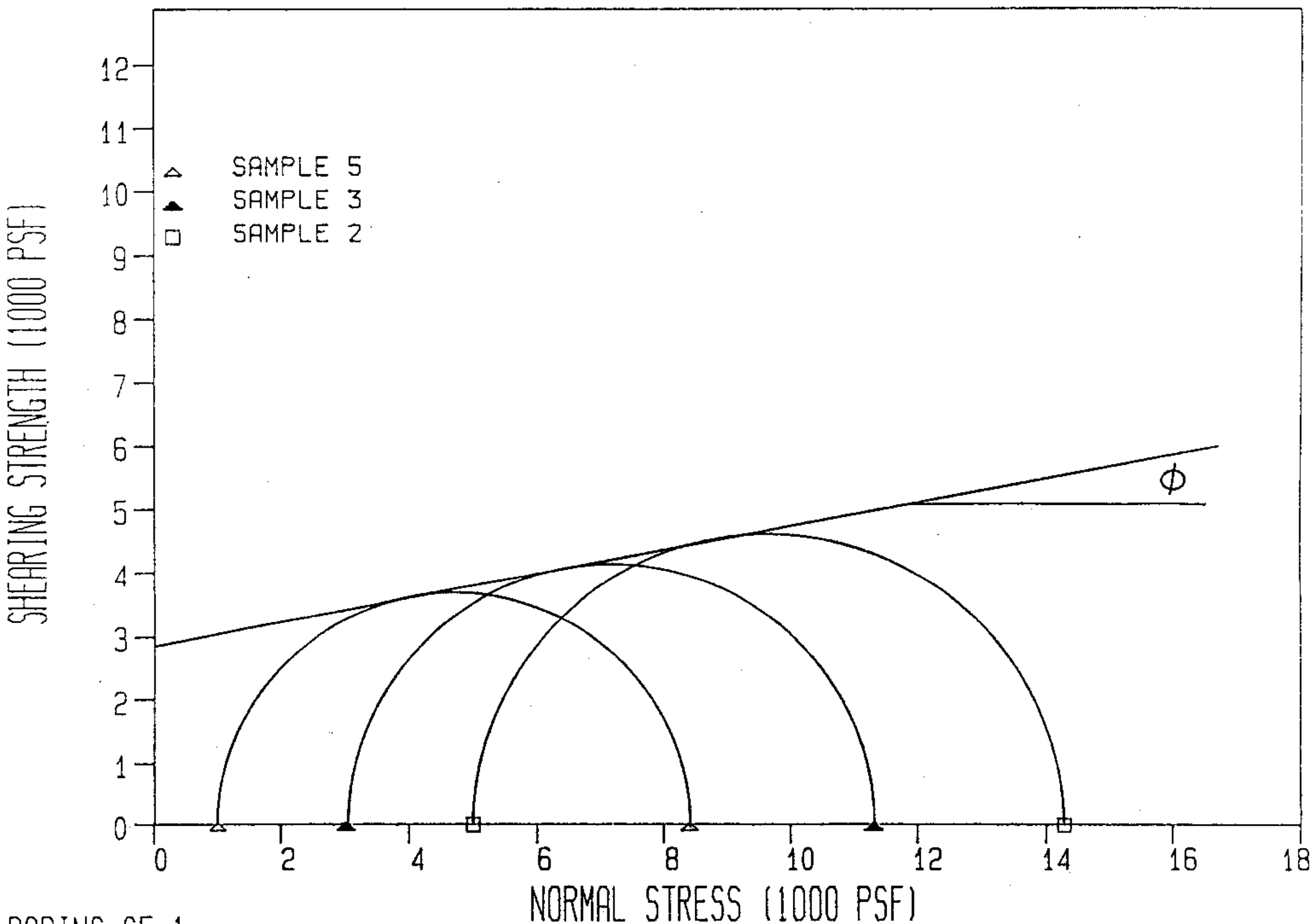
BORING 64-1


SAMPLE L1-2-IV
SAMPLE L1-2-II
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
φ
0
2
4
6
8
10
12
14
16
18

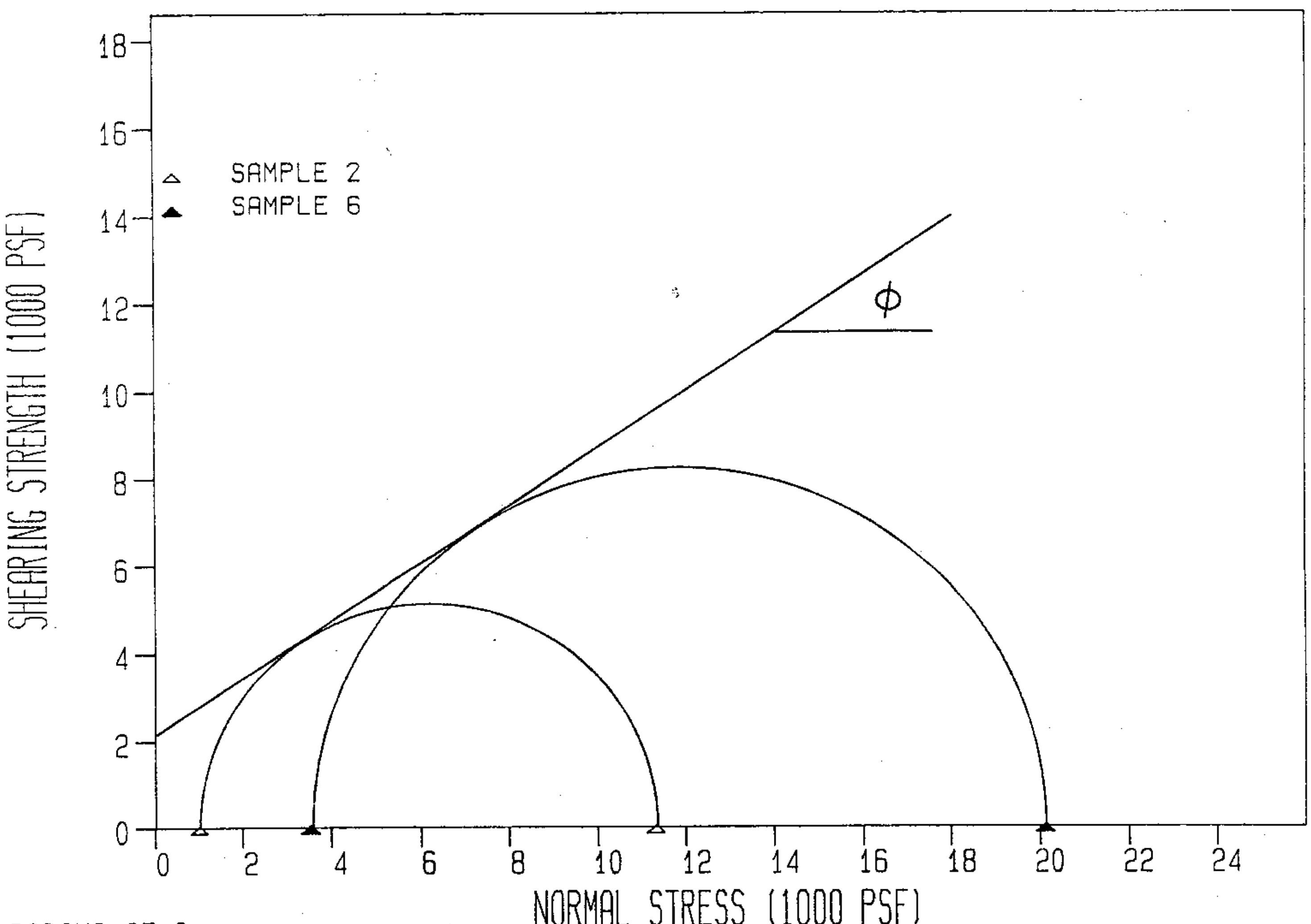
BORING 64-2


SAMPLE R12
SAMPLE R14
SAMPLE R11
φ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
2
4
6
8
10
12
14
16
18

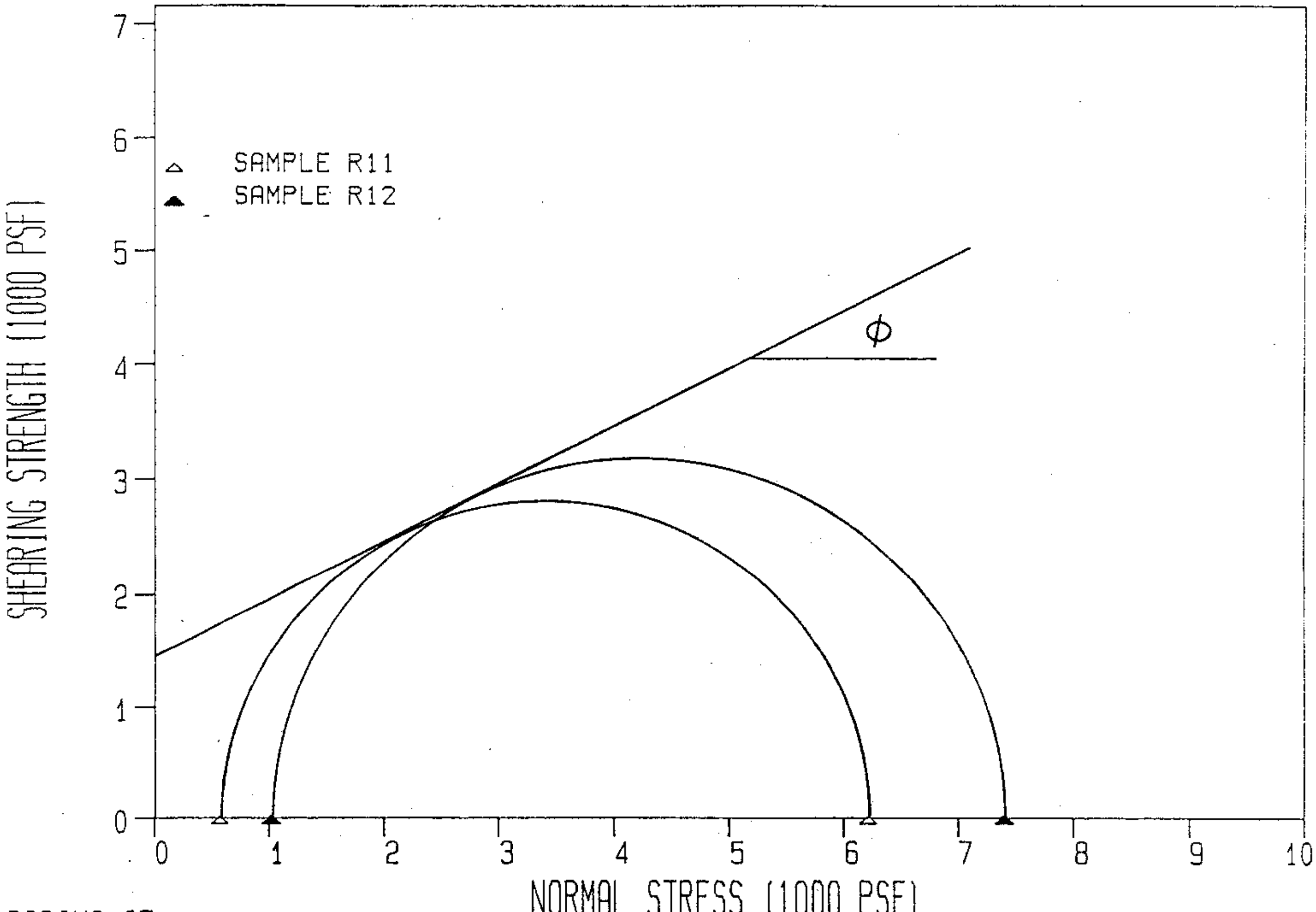
BORING 65


SAMPLE 5
SAMPLE 3
SAMPLE 2
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
φ
0
1
2
3
4
5
6
7
8
9
10
11
12
0
2
4
6
8
10
12
14
16
18

BORING 65-1

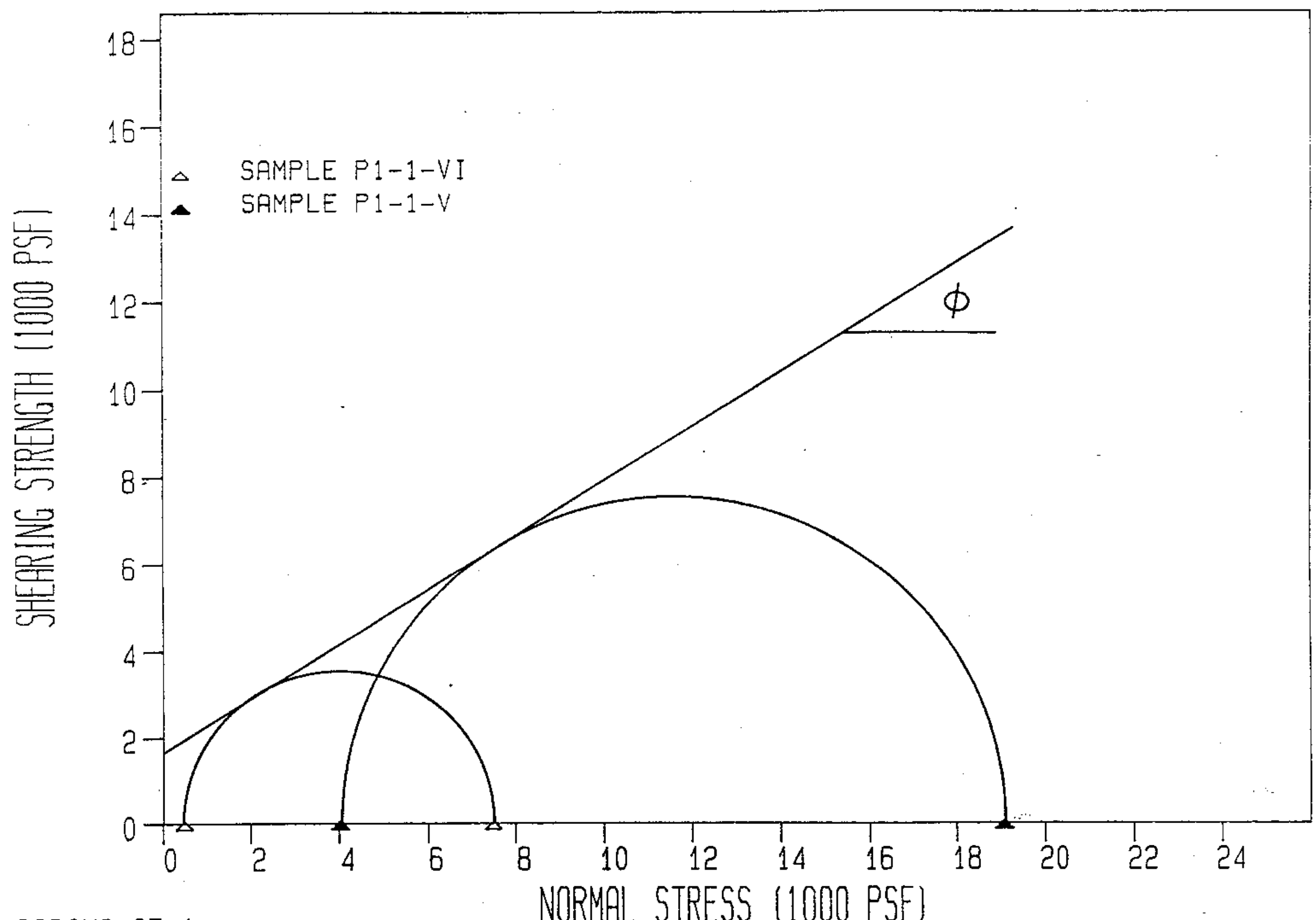

SAMPLE 2
SAMPLE 6
φ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
2
4
6
8
10
12
14
16
18
20
22
24

BORING 65-2



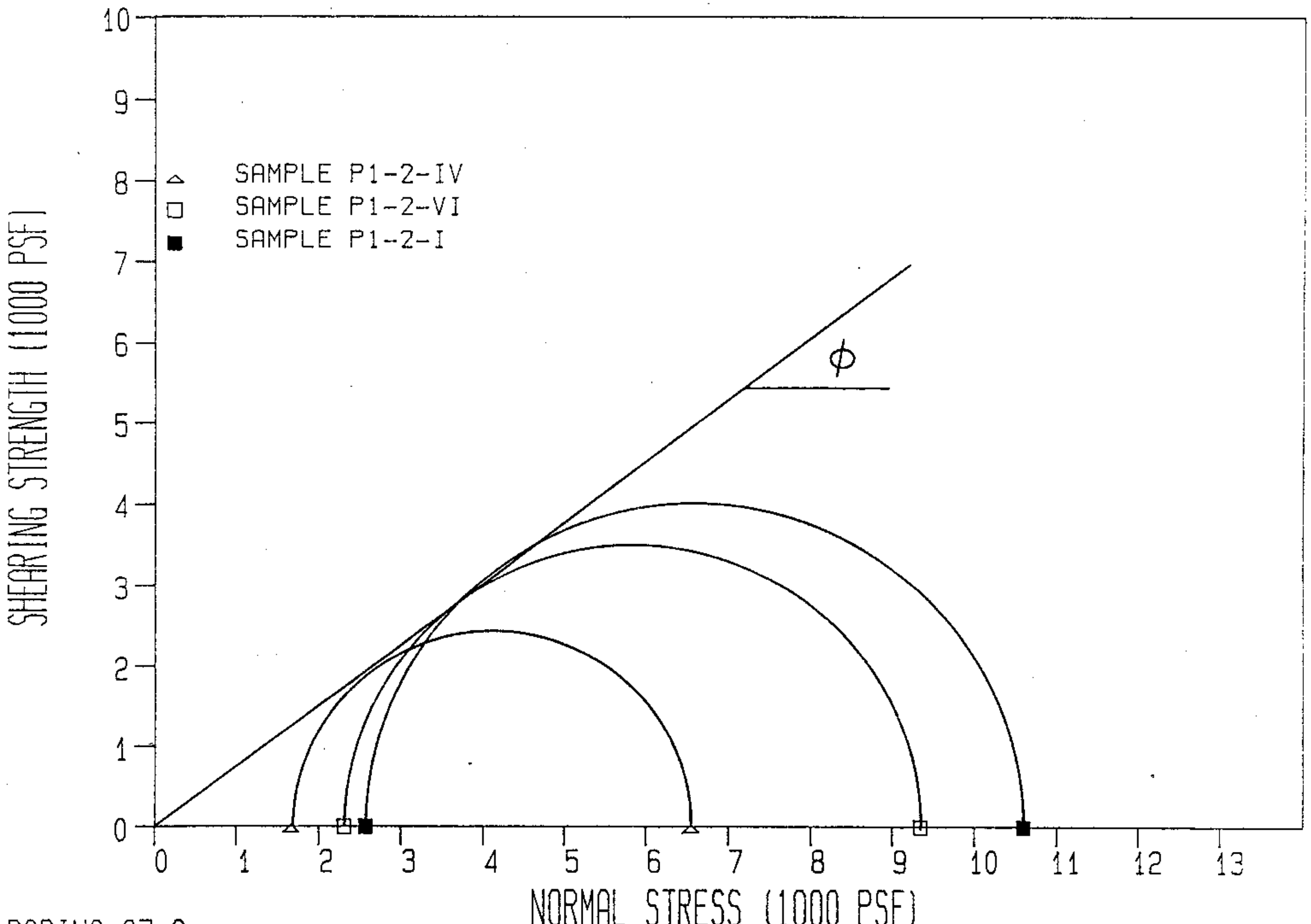
SAMPLE R11
SAMPLE R12
φ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
1
2
3
4
5
6
7
8
9
10

BORING 67

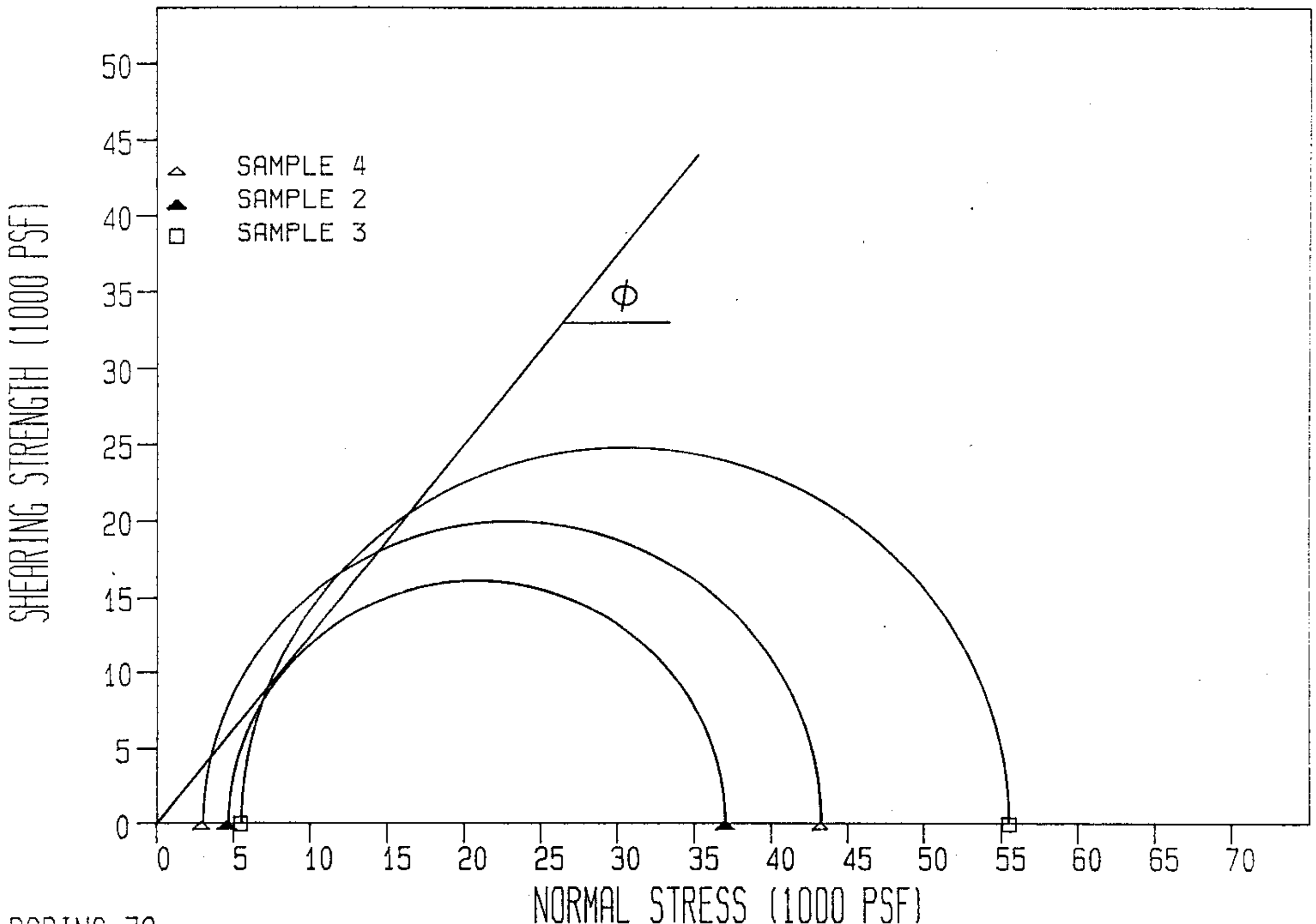


SAMPLE P1-1-VI
SAMPLE P1-1-V
φ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
2
4
6
8
10
12
14
16
18
20
22
24

BORING 67-1

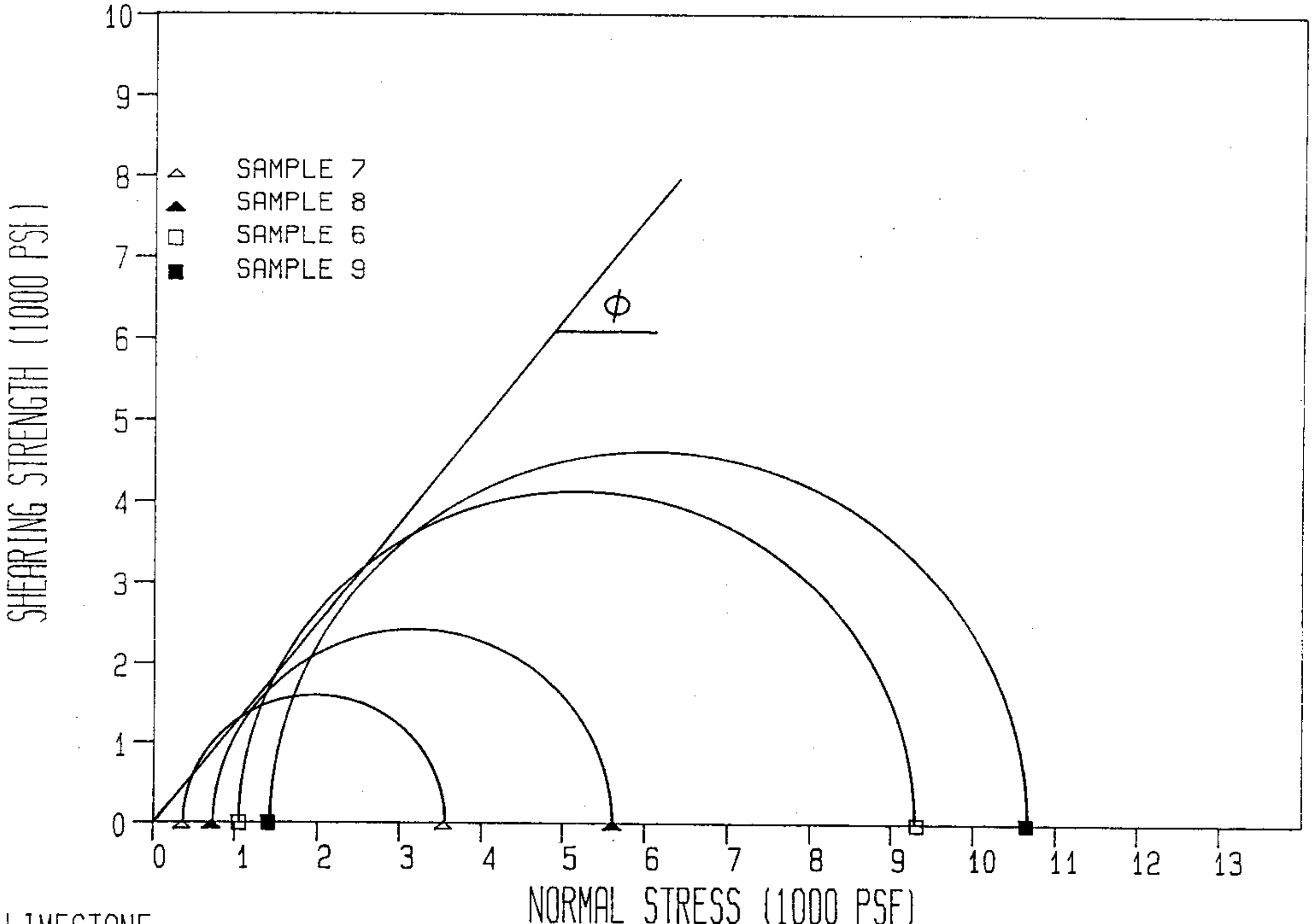

SAMPLE P1-2-IV
SAMPLE P1-2-VI
SAMPLE P1-2-I
φ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
1
2
3
4
5
6
7
8
9
10
11
12
13

BORING 67-2

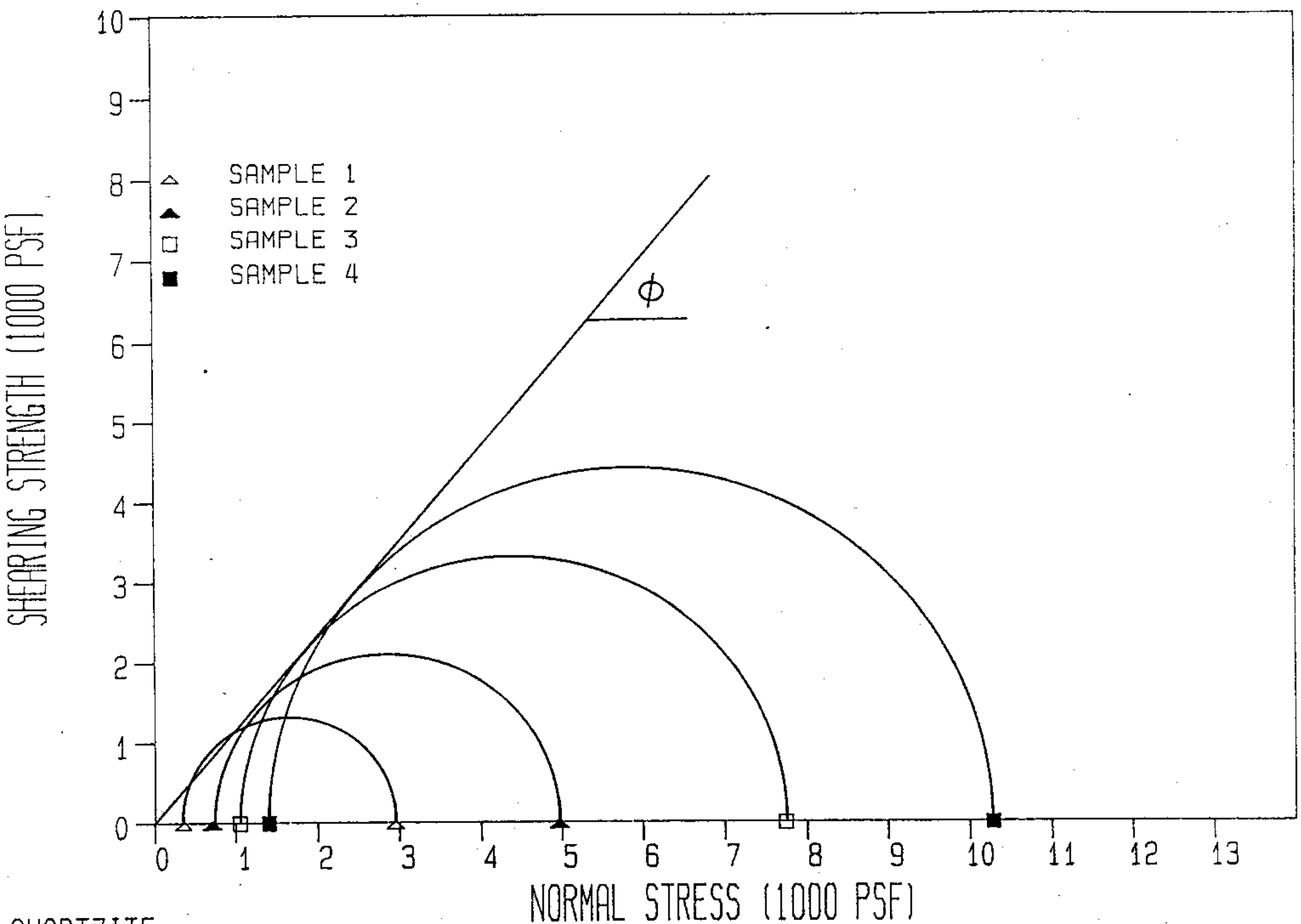


SAMPLE 4
SAMPLE 2
SAMPLE 3
Φ
SHEARING STRENGTH (1000 PSF)
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
NORMAL STRESS (1000 PSF)

BORING 79


SAMPLE 7
SAMPLE 8
SAMPLE 6
SAMPLE 9
φ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
1
2
3
4
5
6
7
8
9
10
11
12
13

LIMESTONE


SAMPLE 1
SAMPLE 2
SAMPLE 3
SAMPLE 4
φ
SHEARING STRENGTH (1000 PSF)
NORMAL STRESS (1000 PSF)
0
1
2
3
4
5
6
7
8
9
10
11
12
13

QUARTZITE

APPENDIX - IV Hyperbolic Parameters Determination

Boring Number: 17

Soil: red-brwn silty clay (CL)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3 1	$(\sigma_1-\sigma_3)_f$ 2	$(\sigma_1-\sigma_3)$ 3	ϵ_a 4	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 5	$(\sigma_1-\sigma_3)$ 6	ϵ_a 7	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 8
1150	6500	4550	0.033	7.3E-06	6175	0.061	9.7E-06
1730	7985	5590	0.034	6.1E-06	7586	0.061	8.0E-06

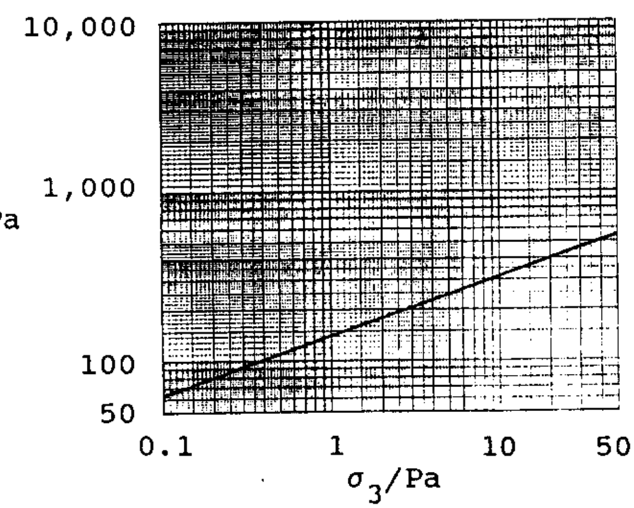
$\frac{\sigma_3}{Pa}$ 9	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$ 10	R_f 11	$\frac{E_i}{Pa}$ 12
0.543	9.38E-05	0.610	114
0.818	7.25E-05	0.579	130

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8 - 5}{7 - 4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 140, n = 0.34, Average R_f = 0.59

Boring Number: 17-1
Soil: red-brwn silty clay (CL)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3 1	$(\sigma_1-\sigma_3)_f$ 2	$(\sigma_1-\sigma_3)$ 3	ϵ_a 4	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 5	$(\sigma_1-\sigma_3)$ 6	ϵ_a 7	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 8
700	7330	5131	0.036	7.0E-06	6964	0.066	9.5E-06
2300	11515	8061	0.030	3.7E-06	10939	0.044	4.0E-06

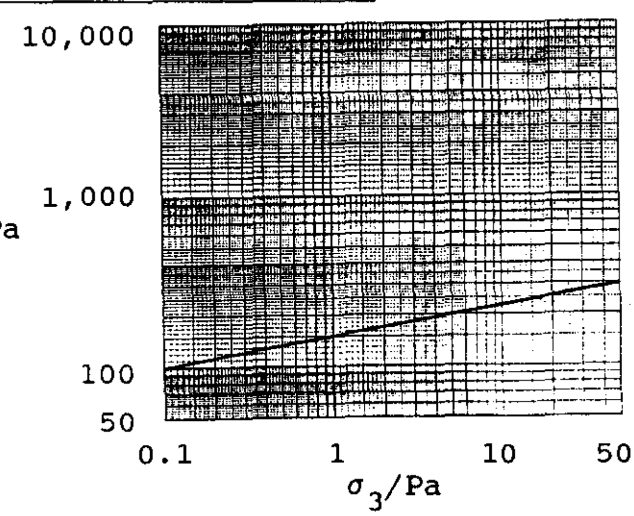
$\frac{\sigma_3}{Pa}$ 9	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$ 10	R_f 11	$\frac{E_i}{Pa}$ 12
0.331	8.21E-05	0.602	116
1.087	2.15E-05	0.247	154

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8 - 5}{7 - 4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 150, n = 0.23, Average R_f = 0.43

Boring Number: 17-2

Soil: red-brwn silty clay (ML)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
2450	11708	8196	0.032	3.9E-06	11123	0.063	5.7E-06
5000	19345	13542	0.034	2.5E-06	18378	0.059	3.2E-06

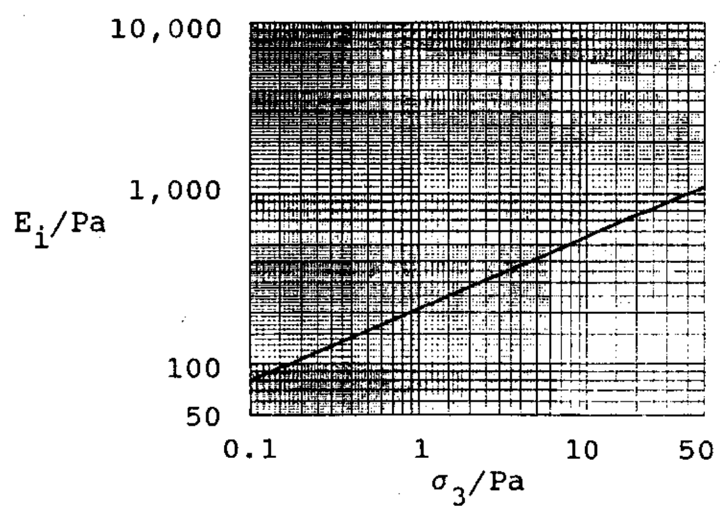
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
1.158	5.68E-05	0.665	226
2.363	2.80E-05	0.541	303

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8 - 5}{7 - 4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 215, n = 0.41, Average R_f = 0.60

Boring Number: 18

Soil: gry silty clay w/peb (MH)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
720	5600	3920	0.019	4.9E-06	5320	0.043	8.1E-06
1730	15848	11090	0.031	2.8E-06	15051	0.054	3.6E-06

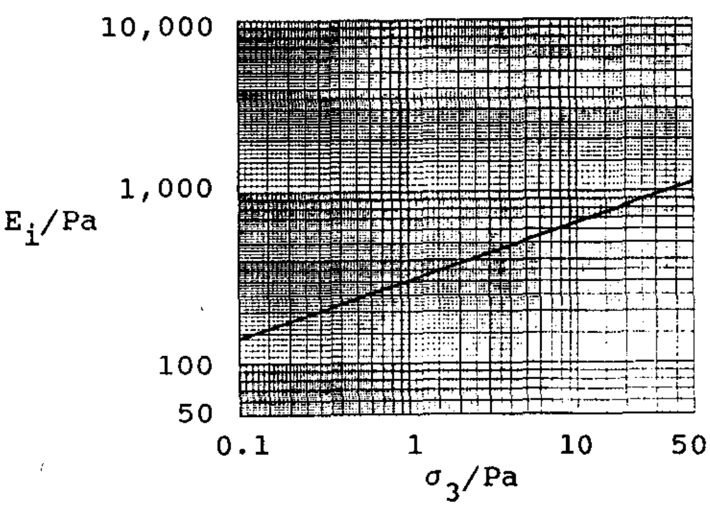
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
0.340	1.35E-04	0.755	207
0.818	3.45E-05	0.546	274

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 290, n = 0.32, Average R_f = 0.65

Boring Number: 18-1
Soil: gray clay (shale) (MH)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
1885	5627	3940	0.069	1.8E-05	5346	0.156	2.9E-05
3930	7484	5239	0.027	5.2E-06	7110	0.056	7.9E-06

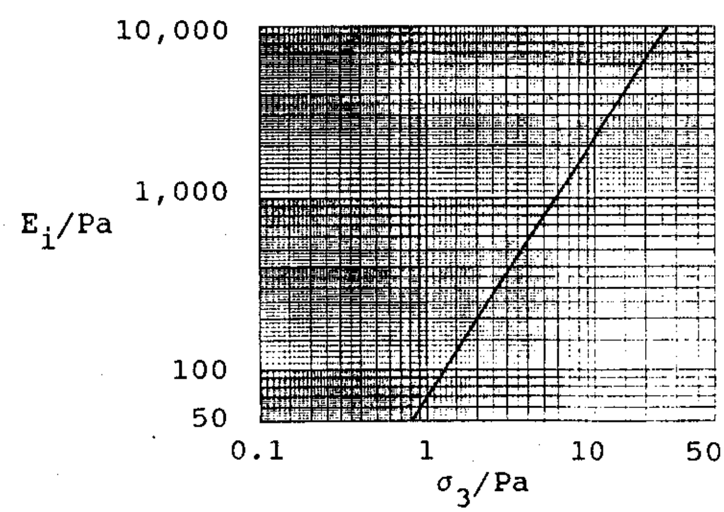
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
0.891	1.34E-04	0.754	57
1.857	9.39E-05	0.703	180

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 70, n = 1.57, Average R_f = 0.73

Boring Number: 20-1
Soil: brwn sand w/peb&silt (SP)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
1440	4106	2874	0.024	8.4E-06	3901	0.051	1.3E-05
2015	4477	3134	0.024	7.7E-06	4253	0.051	1.2E-05

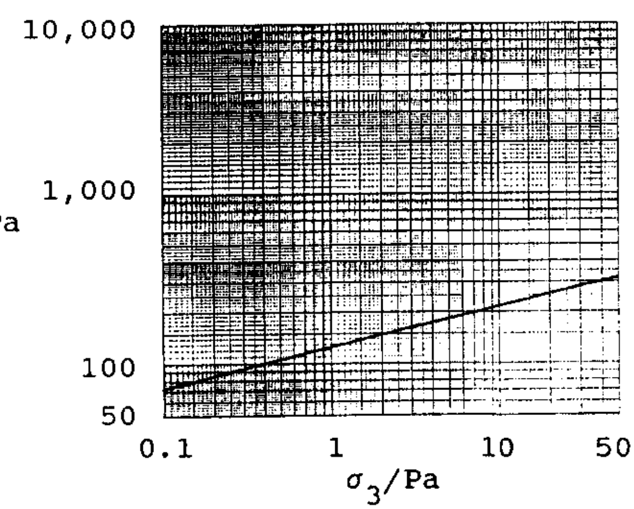
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
0.681	1.75E-04	0.718	114
0.952	1.61E-04	0.718	124

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8 - 5}{7 - 4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 125, n = 0.26, Average R_f = 0.76

Boring Number: 43-1 Soil: gry&brwn clay(shale)(CH)	DATA FOR DEVIATORIC MODULUS PARAMETERS						
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3 1	$(\sigma_1-\sigma_3)_f$ 2	$(\sigma_1-\sigma_3)$ 3	ϵ_a 4	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 5	$(\sigma_1-\sigma_3)$ 6	ϵ_a 7	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 8
1440	16889	11822	0.017	1.4E-06	16045	0.025	1.6E-06
2160	23996	16797	0.017	1.0E-06	22796	0.025	1.1E-06
2880	13345	9342	0.015	1.6E-06	12678	0.025	2.0E-06

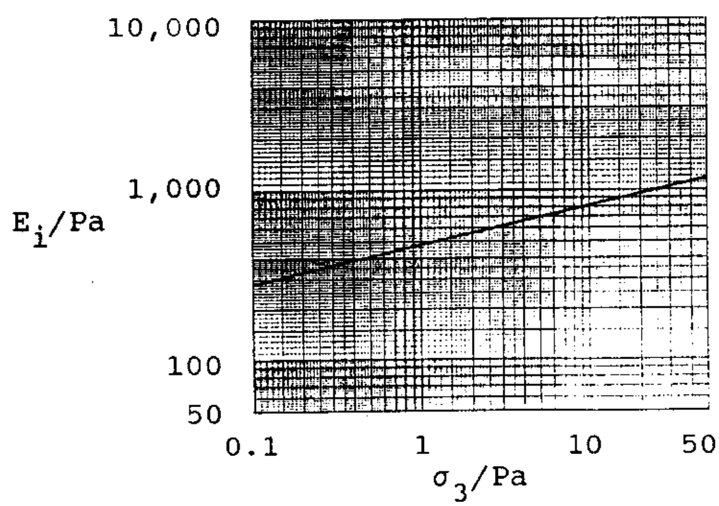
$\frac{\sigma_3}{Pa}$ 9	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$ 10	R_f 11	$\frac{E_i}{Pa}$ 12
0.681	1.50E-05	0.254	400
1.021	1.06E-05	0.254	568
1.361	3.66E-05	0.489	447

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 470, n = 0.21, Average R_f = .037

Boring Number: 57-1

Soil: brwn silty clay w/sand(ML)

		DATA FOR DEVIATORIC MODULUS PARAMETERS					
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
575	2220	1554	0.019	1.2E-05	2109	0.036	1.7E-05
2590	15820	11074	0.067	6.1E-06	15029	0.140	9.3E-06

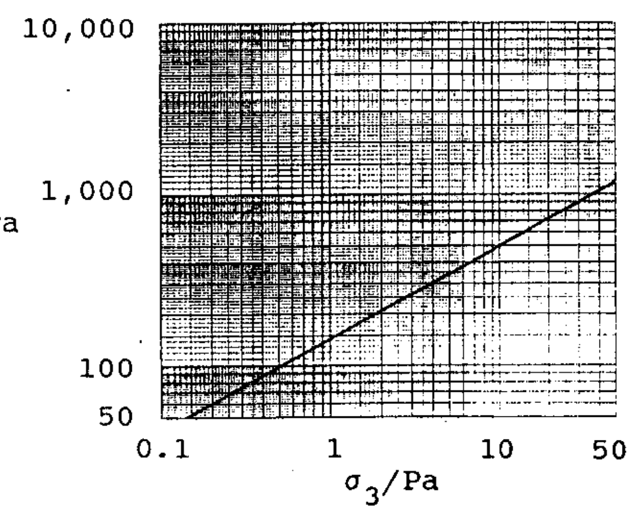
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
0.272	2.85E-04	0.632	69
1.224	4.47E-05	0.708	154

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 140, n = 0.53, Average R_f = 0.67

Boring Number: 64 Soil: gry silty clay (CL)	DATA FOR DEVIATORIC MODULUS PARAMETERS						
	70% STRESS LEVEL			95% STRESS LEVEL			
σ_3 1	$(\sigma_1-\sigma_3)_f$ 2	$(\sigma_1-\sigma_3)$ 3	ϵ_a 4	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 5	$(\sigma_1-\sigma_3)$ 6	ϵ_a 7	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 8
865	5360	3752	0.026	6.9E-06	5092	0.047	9.2E-06
1300	5455	3819	0.020	5.2E-06	5182	0.033	6.3E-06

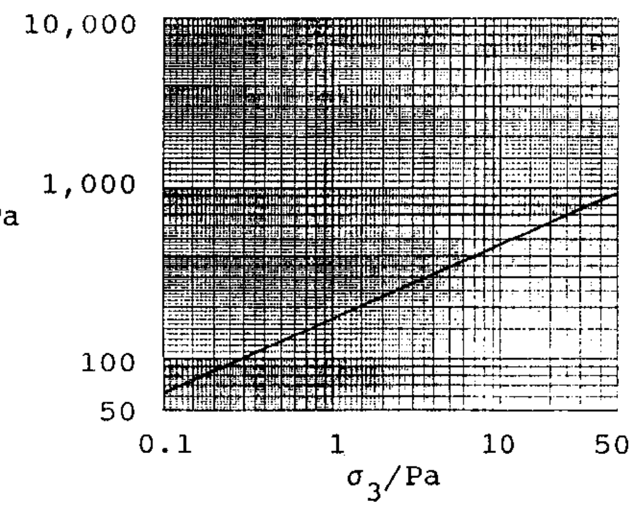
$\frac{\sigma_3}{Pa}$ 9	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$ 10	R_f 11	$\frac{E_i}{Pa}$ 12
0.409	1.10E-04	0.587	116
0.614	8.69E-05	0.474	135

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 170, n = 0.38, Average R_f = 0.53

Boring Number: 64-1

Soil: gry silty clay (CL)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
1730	4900	3430	0.017	5.0E-06	4655	0.047	1.0E-05
2305	9225	6458	0.016	2.5E-06	8764	0.028	3.2E-06

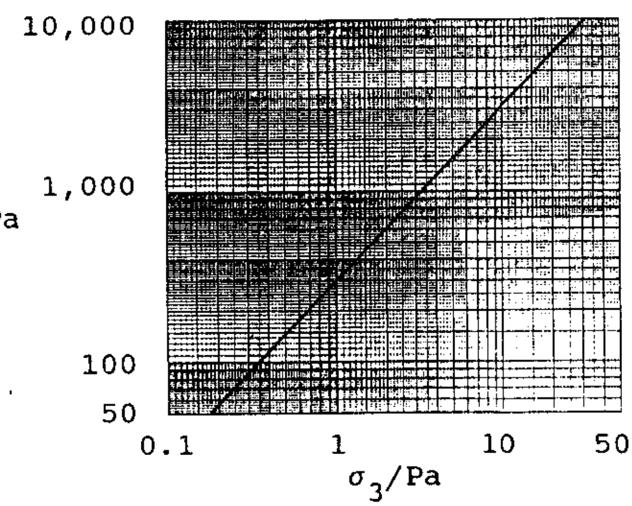
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
0.818	1.71E-04	0.840	231
1.089	5.98E-05	0.551	311

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8 - 5}{7 - 4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 245, n = 0.25, Average R_f = 0.65

Boring Number: 64-2 Soil: gray silty clay (MH)	DATA FOR DEVIATORIC MODULUS PARAMETERS						
	70% STRESS LEVEL			95% STRESS LEVEL			
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
1730	6345	4442	0.037	8.3E-06	6028	0.067	1.1E-05
2450	8710	6097	0.026	4.3E-06	8275	0.045	5.4E-06

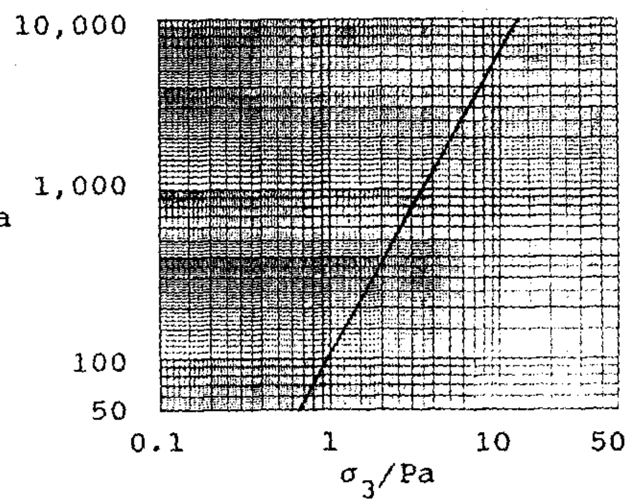
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
0.818	9.28E-05	0.589	97
1.158	6.18E-05	0.538	178

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 105, n = 0.36, Average R_f = 0.57

Boring Number: 65
Soil: brown silty clay (CL)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
720	9430	6601	0.050	7.6E-06	8959	0.110	1.2E-05
1080	11005	7704	0.030	3.9E-06	10455	0.075	7.2E-06
1440	9555	6689	0.058	8.7E-06	9077	0.170	1.9E-05

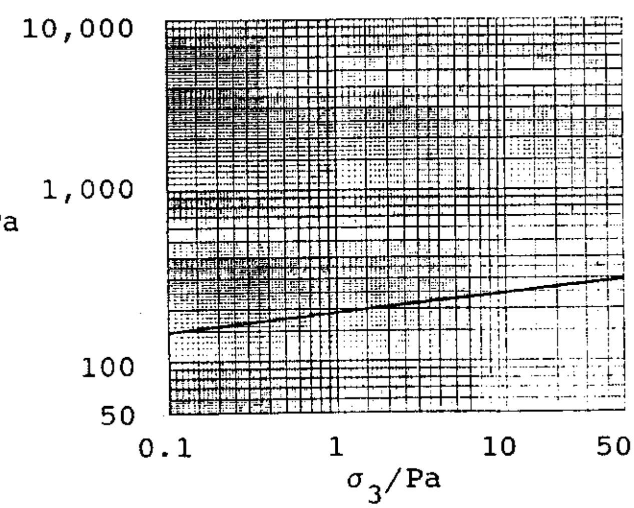
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
0.340	7.84E-05	0.739	129
0.510	7.29E-05	0.802	277
0.681	8.98E-05	0.858	136

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 195, n = 0.20, Average R_f = 0.80

Boring Number: 65-1
Soil: brown silty clay (CH)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3 1	$(\sigma_1-\sigma_3)_f$ 2	$(\sigma_1-\sigma_3)$ 3	ϵ_a 4	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 5	$(\sigma_1-\sigma_3)$ 6	ϵ_a 7	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 8
1000	7405	5184	0.024	4.6E-06	7035	0.049	7.0E-06
3000	8290	5803	0.019	3.3E-06	7876	0.040	5.1E-06

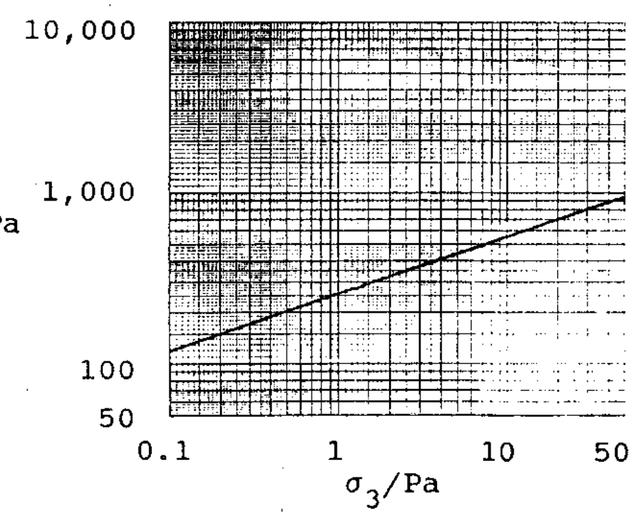
$\frac{\sigma_3}{Pa}$ 9	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$ 10	R_f 11	$\frac{E_i}{Pa}$ 12
0.473	9.34E-05	0.692	198
1.418	8.60E-05	0.715	288

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8 - 5}{7 - 4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 255, n = 0.34, Average R_f = 0.70

Boring Number: 65-2
Soil: brown silty clay (CH)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3 1	$(\sigma_1-\sigma_3)_f$ 2	$(\sigma_1-\sigma_3)$ 3	ϵ_a 4	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 5	$(\sigma_1-\sigma_3)$ 6	ϵ_a 7	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 8
1000	10320	7224	0.026	3.6E-06	9804	0.047	4.8E-06
3500	16615	11631	0.029	2.5E-06	15784	0.061	3.9E-06

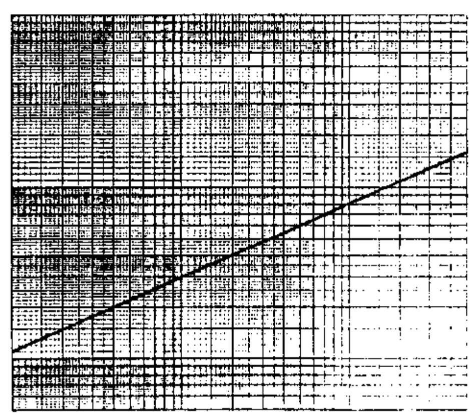
$\frac{\sigma_3}{Pa}$ 9	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$ 10	R_f 11	$\frac{E_i}{Pa}$ 12
0.473	5.69E-05	0.587	223
1.654	4.29E-05	0.712	378

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8 - 5}{7 - 4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 305, n = 0.42, Average R_f = 0.65

Boring Number: 67
Soil: brown silty clay (MH)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
575	5635	3945	0.049	1.2E-05	5353	0.090	1.7E-05
1010	6390	4473	0.052	1.2E-05	6071	0.102	1.7E-05

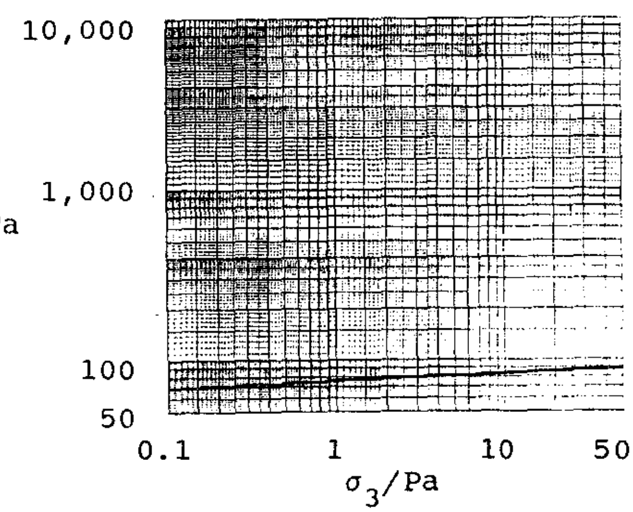
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
0.272	1.07E-04	0.603	66
0.477	1.04E-04	0.662	76

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 90, n = 0.26, Average R_f = 0.63

Boring Number: 67-1
Soil: brown silty clay (MH)

		DATA FOR DEVIATORIC MODULUS PARAMETERS					
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3 1	$(\sigma_1-\sigma_3)_f$ 2	$(\sigma_1-\sigma_3)$ 3	ϵ_a 4	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 5	$(\sigma_1-\sigma_3)$ 6	ϵ_a 7	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 8
500	6975	4883	0.029	5.9E-06	6626	0.088	1.3E-05
4000	15070	10549	0.040	3.8E-06	14317	0.084	5.9E-06

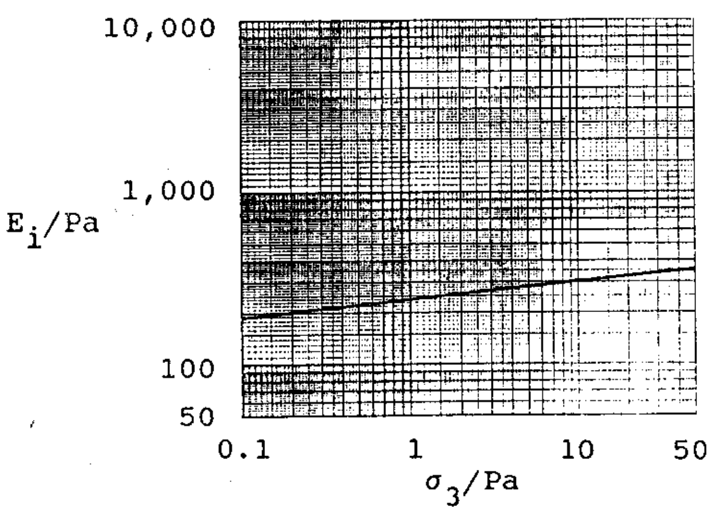
$\frac{\sigma_3}{Pa}$ 9	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$ 10	R_f 11	$\frac{E_i}{Pa}$ 12
0.236	1.24E-04	0.868	203
1.890	4.72E-05	0.711	248

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8 - 5}{7 - 4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 235 , n = 0.10 , Average R_f = 0.79

Boring Number: 67-2 Soil: brwn silty clay w/peb (MH)	DATA FOR DEVIATORIC MODULUS PARAMETERS						
	70% STRESS LEVEL			95% STRESS LEVEL			
σ_3 1	$(\sigma_1-\sigma_3)_f$ 2	$(\sigma_1-\sigma_3)$ 3	ϵ_a 4	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 5	$(\sigma_1-\sigma_3)$ 6	ϵ_a 7	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$ 8
1000	6470	4529	0.028	6.2E-06	6147	0.070	1.1E-05
1785	6655	4659	0.031	6.7E-06	6322	0.095	1.5E-05
2290	7040	4928	0.021	4.3E-06	6688	0.051	7.6E-06

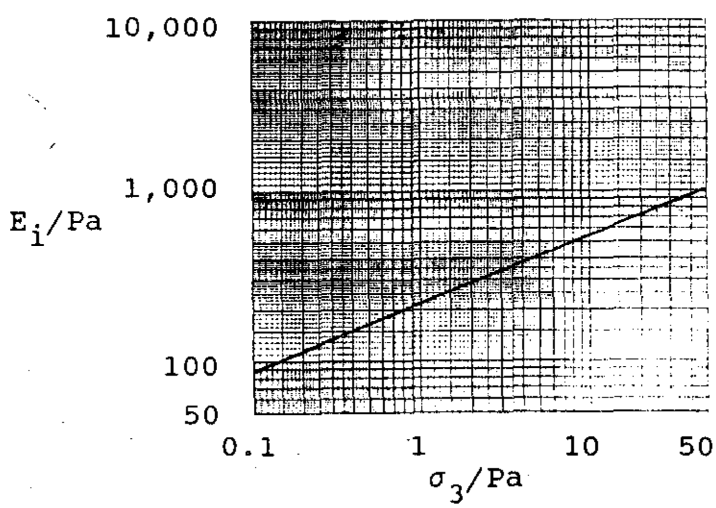
$\frac{\sigma_3}{Pa}$ 9	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$ 10	R_f 11	$\frac{E_i}{Pa}$ 12
0.473	9.66E-05	0.773	152
0.844	1.31E-04	0.871	182
1.082	1.12E-04	0.789	248

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 220, n = 0.36, Average R_f = 0.82

Boring Number: 79

Soil: gray clay (shale) (MH)

DATA FOR DEVIATORIC MODULUS PARAMETERS							
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
4610	32340	22638	0.052	2.3E-06	30723	0.075	2.4E-06
5470	49935	34955	0.060	1.7E-06	47438	0.082	1.7E-06

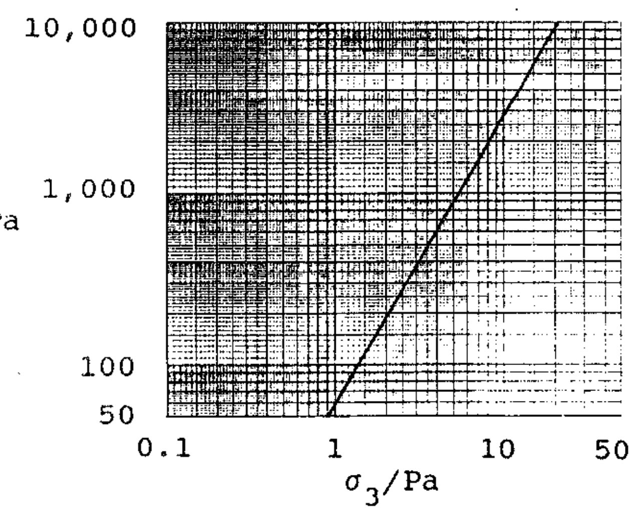
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
2.179	6.27E-06	0.203	240
2.585	5.48E-07	0.027	281

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

E_i/Pa=2.0/(5+8-(10X(4+7)))



K = 115, n = 0.92, Average R_f = 0.20

Boring Number: ----

Soil: limestone gravel (GP)

		DATA FOR DEVIATORIC MODULUS PARAMETERS					
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
350	3190	2233	0.014	6.3E-06	3031	0.027	8.9E-06
700	4880	3416	0.021	6.2E-06	4636	0.041	8.8E-06
1050	8255	5779	0.015	2.6E-06	7842	0.044	5.6E-06
1400	9225	6458	0.015	2.3E-06	8764	0.038	4.3E-06

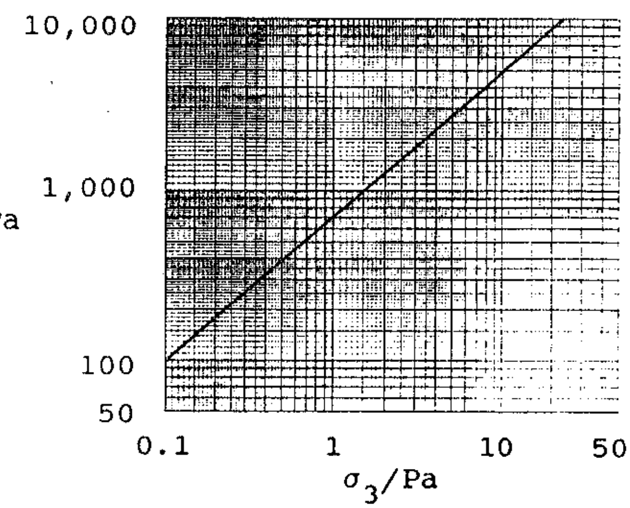
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
0.165	2.03E-04	0.648	138
0.331	1.35E-04	0.658	143
0.496	1.04E-04	0.858	456
0.662	8.75E-05	0.807	468

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

$E_i/Pa=2.0/(5+8-(10X(4+7)))$



K = 700, n = 0.85, Average R_f = 0.74

Boring Number: ----

Soil: quartzite gravel (GP)

		DATA FOR DEVIATORIC MODULUS PARAMETERS					
		70% STRESS LEVEL			95% STRESS LEVEL		
σ_3	$(\sigma_1-\sigma_3)_f$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$	$(\sigma_1-\sigma_3)$	ϵ_a	$\frac{\epsilon_a}{(\sigma_1-\sigma_3)}$
1	2	3	4	5	6	7	8
350	2580	1806	0.017	9.4E-06	2451	0.036	1.5E-05
700	4240	2968	0.016	5.4E-06	4028	0.030	7.5E-06
1050	6685	4680	0.017	3.6E-06	6351	0.048	7.6E-06
1400	8870	6209	0.021	3.4E-06	8427	0.059	7.0E-06

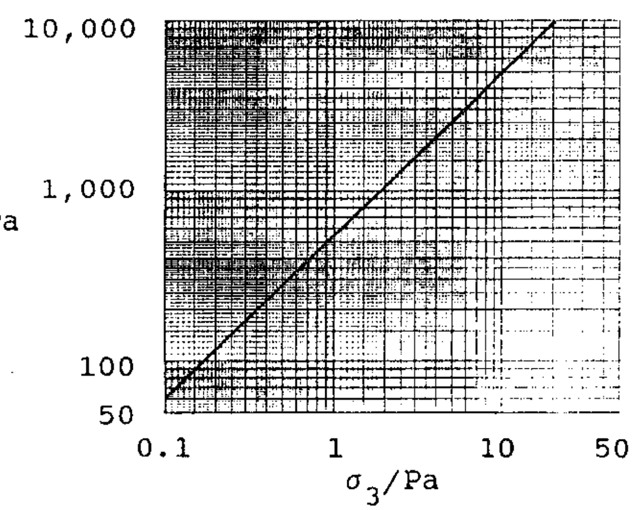
$\frac{\sigma_3}{Pa}$	$\frac{1}{(\sigma_1-\sigma_3)_{ult}}$	R_f	$\frac{E_i}{Pa}$
9	10	11	12
0.165	2.78E-04	0.716	101
0.331	1.47E-04	0.623	155
0.496	1.27E-04	0.846	319
0.662	9.53E-05	0.845	342

Pa = 2116 PSF

$$\frac{1}{(\sigma_1-\sigma_3)_{ult}} = \frac{8-5}{7-4}$$

Rf = 2 X 10

$E_i/Pa = 2.0/(5+8-(10X(4+7)))$



K = 525, n = 0.95, Average R_f = 0.76

DESIGN AND ANALYSIS OF REINFORCING DISTRESSED BRIDGE ABUTMENTS

FINAL REPORT

VOLUME II

USER'S MANUAL

Submitted to
South Dakota Department of Transportation

BY

Sangchul Bang
Associate Professor of Civil Engineering
Principal Investigator

South Dakota School of Mines & Technology
Rapid City, South Dakota 57701

OCTOBER 1988

The contents of this report reflect the view of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the South Dakota Department of Transportation, the State Transportation Commission, or the U.S. Federal Highway Administration. The report does not constitute a standard specification, or regulation.

DESIGN AND ANALYSIS OF REINFORCING DISTRESSED BRIDGE ABUTMENTS - VOLUME II USER'S MANUAL FOR PROGRAM BART

A Report Prepared
for the
South Dakota Department of Transportation

by

Sangchul Bang, Ph.D., P.E.
Associate Professor
Department of Civil Engineering
South Dakota School of Mines and Technology

October, 1988

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PROGRAM ABSTRACT

TITLE: Bridge Abutment Reinforcement with Tie-rods (BART)

AUTHOR: Sangchul Bang
Associate Professor of Civil Engineering
South Dakota School of Mines and Technology
Rapid City, SD 57701
Tel) 605-394-2440

DESCRIPTION: This program performs the design and analysis of a tie-rod and drilled-in concrete anchor system that reinforces the distressed sill-type concrete bridge abutments supported by piles. It calculates the minimum required dimensions of tie-rods and drilled-in concrete anchors, as well as the detailed response of the system including the displacements, strains, stresses, axial forces, shear forces, and bending moments of the continuum and the structural members.

FORMULATION: The design method is based on the limit equilibrium approach in which the detailed parameters are determined from the equilibrium condition for adequate safety. The analysis method is based on the generalized plane strain finite element approach. The finite element grid remains in two dimensions. However, the response of the system is in three dimensions. The soil continuum can be either linear elastic or nonlinear inelastic. The nonlinear inelastic soil characterization follows the hyperbolic soil model. The structural elements are however linear elastic.

PROGRAM STRUCTURE: The program is written in FORTRAN 5 with an IBM-XT compatible personal computer. It is compiled in such a way that the program can be run with or without a math coprocessor. The core storage

requirements are approximately 290,000 bytes for the executable program and 50,000 bytes for the output. Running time varies from 5 to 30 minutes, depending upon how the material characterization and the incremental analysis are specified. Input is from either the keyboard or the data file. Output is written to the file specified.

RESTRICTIONS: The program contains a subroutine which converts relatively simple input into the necessary parameters for a detailed finite element anaylysis. It therefore includes certain geometric restrictions. If any of the restrictions are violated, the program terminates with a description of the reason displayed. If the FORTRAN 5 language rule is violated in input, it prints error message(s) that are provided by the compiler (Microsoft FORTRAN Compiler 4.1) with detailed explanation.

Introduction

This manual is divided into five sections. The first section includes a brief description of the input parameters. The second section contains a detailed explanation of the input parameters. The third section describes the output of the program. The fourth section illustrates an example problem and the fifth section contains a listing of the complete program.

It is anticipated that, initially, the user will need to consult frequently the second, third, and fourth sections. As users become familiar with the program, they will probably need to use only the first section.

In order to facilitate the consultation of the explanatory information contained in the second section, subsections are numbered the same as in Section I.

The program utilizes either four or six files, depending upon whether the input data file exists or not. In both cases, file 5 refers to keyboard input, file 6 to monitor output, and file 7 to the output file that will be generated. When a new set of input data is entered, i.e., when the designated input data file name does not exist, file 8 will be used to create the duplicate input data file. When the existing input data file (file 9) is recalled, the user can run the problem either without or with changes in data. In the latter case, the program will create a new data file that is edited using file 10, while the original data file is still retained. It is important, therefore, to record all input and output file names for future use. The detailed instruction of how these files are used will be displayed at the beginning of execution of the program. The file names can be as long as 12 characters.

Section I - Input

The program itself is virtually self-explanatory. As the calculation proceeds, the program will continuously ask for input of information with detailed instruction. Please make sure that correct units of input parameters are used. Since a significant amount of output may be generated, the program will ask the user whether specific portions of the output are desired or not. They can be stored in a file or skipped by entering appropriate input according to the instruction.

Note that the program is written mostly with free format, unless otherwise specified. When inputting parameters in free format, the data, if more than one, must be separated by blank spaces. The input parameters that have an asterisk (*) are integer variables, i.e., they should not have any decimal. Enter all data starting from column 1.

Following is a complete list, in order, of the input parameters. Refer to Figure 1 for schematic sketch of geometric input parameters.

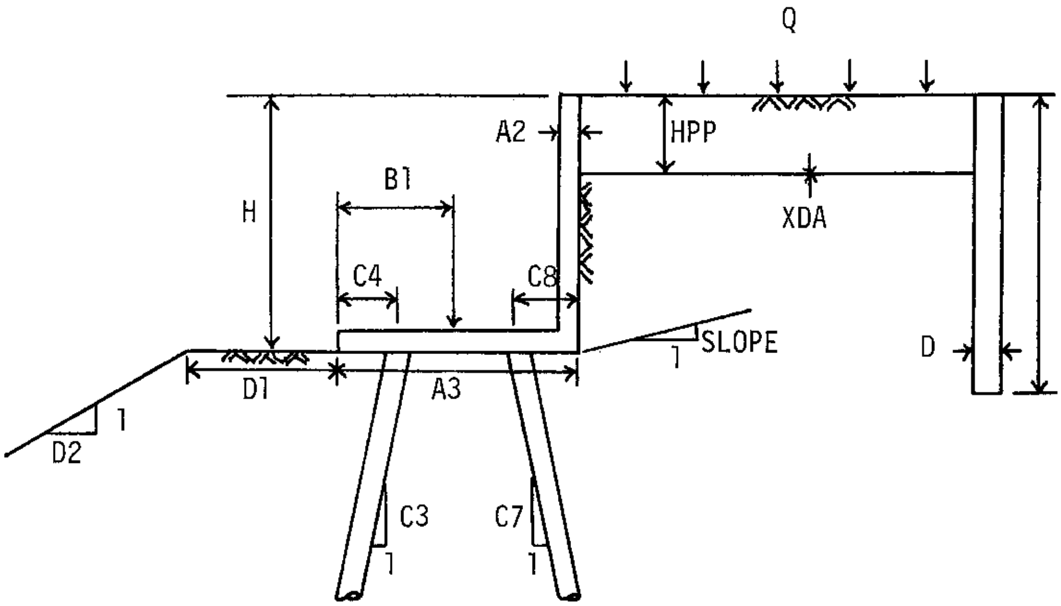


Figure 1a. Geometric Input Parameters

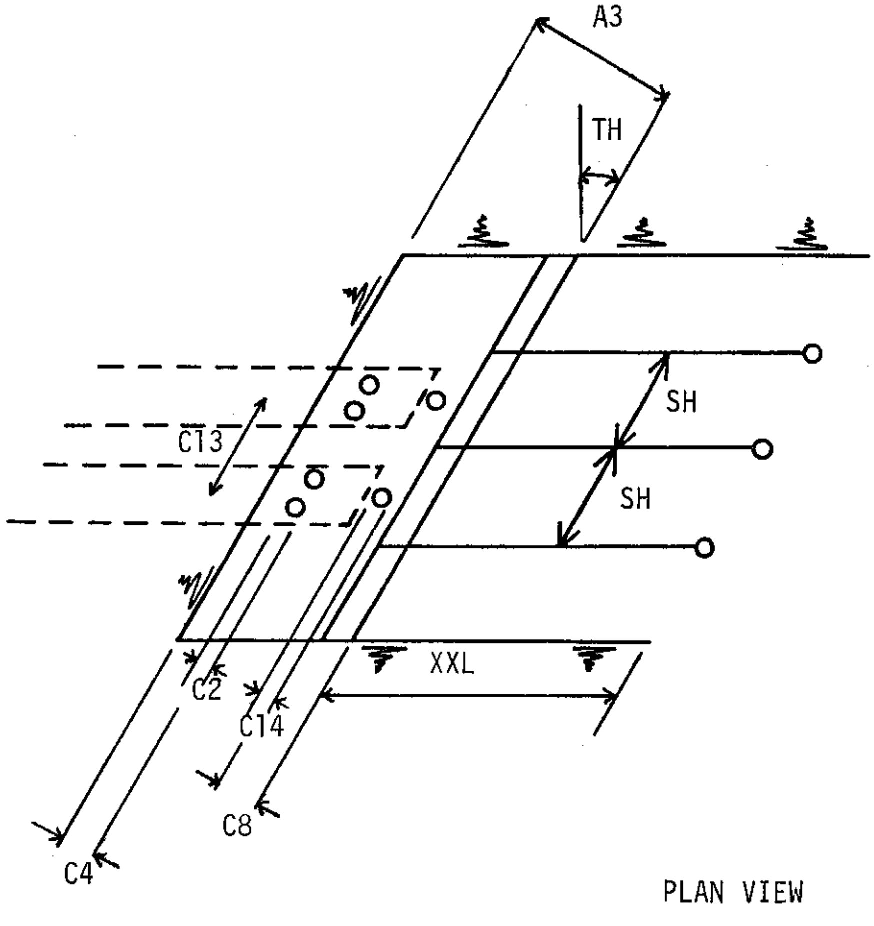


Figure 1b. Geometric Input Parameters (Continued)

1. FILEIN : Input data file name. If this name already exists, the program assumes that you are going to use the existing file. If not, a new file will be created.

   FILEOUT : Output file name. The results will not appear on the monitor. They will be written to this file.

2. TITLE : Heading information to be printed in the output as a title for the problem. It can be up to 80 characters.

3. FNEW : Edited input data file name. Only needed when changes in existing data file (FILEIN) are desired.

4. H : Height of abutment in feet.

   HPP : Depth from ground surface to tie-rod in ft.

   SLOPE : Backfill material slope in V/H

   Q : Amount of surcharge on the ground in psf.

5. DEL : Friction angle between the abutment and the backfill material in degrees.

   TH : Bridge skew angle in degrees.

   SH : Tie-rod spacing in ft.

   FA : Allowable strength of tie-rod material in psi.

   FS : Factor of safety to be considered for the selection of tie-rod diameter.

6. D : Diameter of drilled-in concrete anchor in ft. RETURN results in D = 2.5 ft.

7. Soil Properties: Either reference numbers or direct input as follows:

   To use reference numbers, enter the appropriate number, KCODE, from Tables - 3 and 4.

   GAM1 : Unit weight of backfill material in pcf.

   PH1 : Internal friction angle of backfill material in degrees.

8. GAM2 : Unit weight of soil below the abutment in pcf.

C2 : Cohesion of soil below the abutment in psf.

PH2 : Friction angle of soil below the abutment in degrees.

SU : Undrained shear strength of soil below the abutment in psf.

ZT : Depth in ft. from the ground surface at which SU is measured.

9. The program will calculate and print the design selection of tie-rod and drilled-in concrete anchor at this step. Note that for the finite element analysis, it is necessary to have the tip of drilled-in concrete anchor located below the bottom elevation of the abutment. If the calculated depth of drilled-in concrete anchor does not satisfy this requirement, the program will ask the user to increase the depth of drilled-in concrete anchor.

HP : Desired new length of drilled-in concrete anchor in ft. Input HP to increase the length of drilled-in concrete anchor. New output will be generated. You can change HP as many times as you wish. This process will be terminatd when RETURN is hit.

This step ends the design part of the program. Note that all the results are minimum required ones based on limiting equilibrium at failure.

10. The program will ask for new values of tie-rod diameter, length, and/or surcharge loading to be used in analysis part of the program. The changes may be necessary, since the minimum required diameter of the tie-rod calculated from limiting equilibrium does not usually match with the commercially available sizes. To predict the correct response of the system, the actual size of tie-rod to be used in the field must be inputted.

XDA : New value of tie-rod diameter in inches.

XXL : New value of tie-rod length in ft.

XQ : New value of surcharge magnitude in psf.

11\. ITMAX* : Maximum number of iterations between 1 and 9 allowed for nonlinear analysis.
Default is ITMAX = 9. Use any number for linear analysis.

RELAX : Relaxation factor to be used in nonlinear analysis. Default is RELAX = 0.8. Use any number for linear analysis.

ERMAX : Maximum error permitted during iteration for nonlinear analysis. Defaults is ERMAX = 0.05. Use any number for linear analysis.

INR* : 1 for two increment analysis.
0 for one increment analysis.

12\. A3 : Width of abutment base in ft.

B1 : Distance from abutment toe to bridge girder support in ft. Note that the bridge girder support must be located between the supporting piles.

D1 : Horizontal extension of berm in front of the abutment in ft. Must be greater than zero.

D2 : Slope of soil embankment beyond the berm in front of the abutment in H/V. Must be greater than zero.

13\. C3 : Front row pile batter toward the berm in V/H.

C7 : Rear row pile batter toward the backfill in V/H.

C9 : Length of front row piles in ft.

C10 : Length of rear row piles in ft.

IPILE* : 1 for friction piles.
0 for point bearing piles.

14\. C4 : Distance from toe of abutment base to front row piles in ft.

C8 : Distance from heel of abutment base to rear row piles in ft.

15\. PN2 : Bridge girder support reaction load per unit thickness in lbs/ft.

16. The following set of data is needed to define the backfill material properties.

KEL* : 1 for linear elastic material parameters.

0 for nonlinear inelastic material parameters.

KCODE* : 0 if material properties are inputted directly.

N for an integer number designating the predetermined material properties. Refer Tables-3 and 4 for appropriate selection.

If KEL = 1 and KCODE = 0, input the following:

ESO : Young's modulus in psf

POIS : Poisson's ratio

GY : Unit weight in pcf. Must be negative

If KEL = 0 and KCODE = 0, input the following:

K : Loading modulus

KUR : Unloading - reloading modulus

N : Modulus exponent

RF : Failure ratio

C : Cohesion in psf

PHI : Internal friction angle in degrees

DPHI : Change in PHI over 10-fold increase in confining pressure in degrees

KB : Bulk modulus parameter

M : Bulk modulus exponent

POIS : Constant poisson's ratio, if desired.

GX : Horizontal body force in pcf

GY : Unit weight in pcf. Must be negative.

Section II - Explanatory Information

The program designs a tie-rod system utilizing a cylindrical drilled-in concrete anchor for reinforcing a distressed sill-type bridge abutment based on limit equilibrium method. It also analyzes the system by a generalized plane strain finite element method of analysis.

The design section of the program calculates the minimum required dimensions of tie-rod and drilled-in concrete anchor for adequate safety. This information is then passed on to the analysis section of the program to calculate the two dimensional (three dimensional for a skew bridge) responses of the system. They include the displacements, strains, and stresses of the soil as well as the displacements, thrusts, shear forces, and bending moments of the structural elements (piles, abutment, tie-rod and drilled-in concrete anchor). The detailed description of the development of design and analysis methods is included in volume one of the report.

There are several noticeable features included in the program. It allows the user to perform either one increment or two increment analysis. If one increment analysis is used, all elements, including the continuum, the abutment, the piles, the tie-rods, and the drilled-in concrete anchors are considered simultaneously for the detailed analysis of the system. If two increment analysis is used, the foundation soil below the abutment is first analyzed in increment one to calculate the developed in-situ stresses without any displacements. Remaining elements, i.e., the backfill and the structural elements, are then added in the second increment to calculate the incrementally developed response of the system.

The choice of whether one or two increment analysis should be used depends primarily upon the age of foundation soil below the abutment. If the foundation

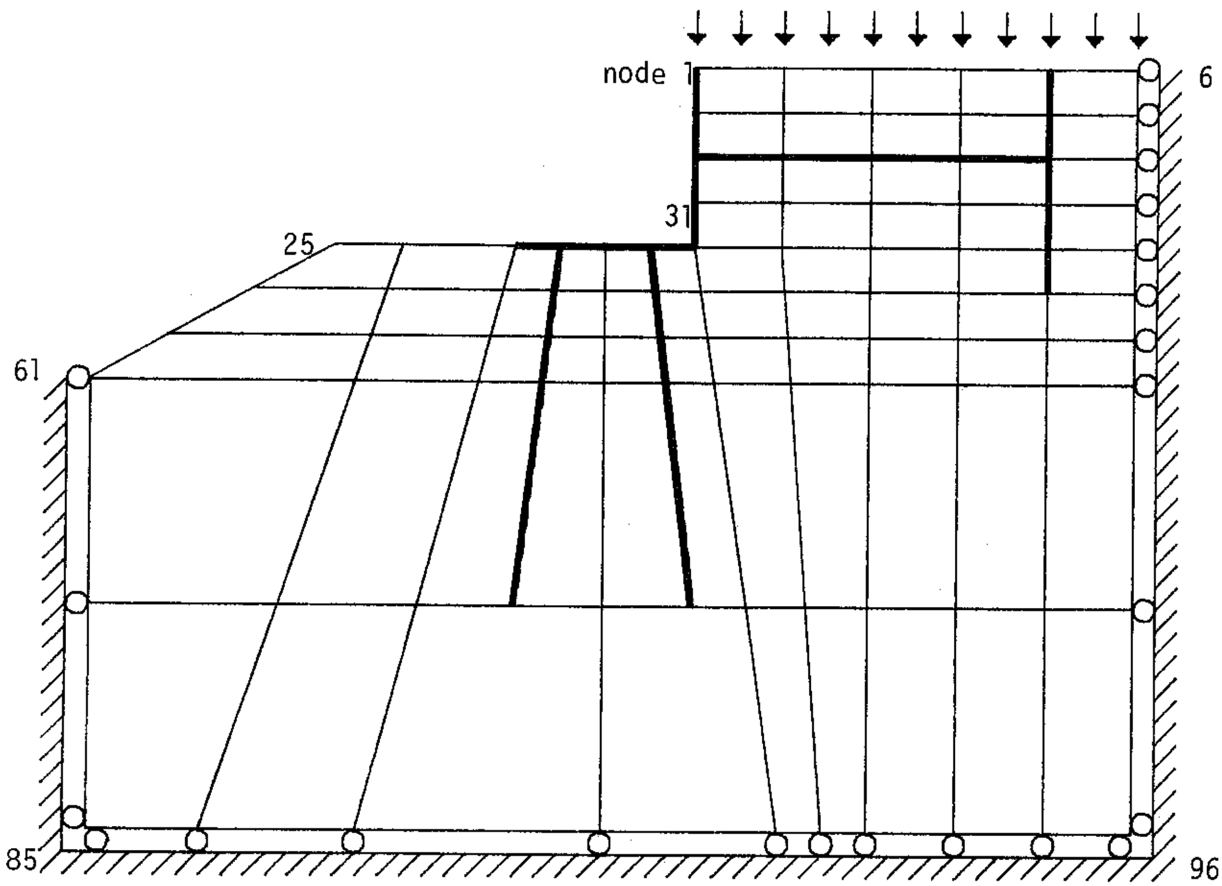
soil is a relatively recent fill, one increment analysis is appropriate, since additional settlement of foundation soil due to its own weight is surely expected. On the other hand, if the foundation soil has been placed for a relatively long period of time, two increment analysis is more appropriate due to the fact that the expected settlement of the foundation soil induced by its own weight might have already taken place.

The program also allows the user to select either linear elastic soil properties or nonlinear inelastic hyperbolic soil properties (1). The former can be expressed by a set of values of constant Young's modulus and Poisson's ratio, while the latter requires input of several parameters describing the nonlinear behavior of the soil. Please refer to step 16 for the detailed nonlinear material property description. For the user's convenience, different ways of defining the nonlinear soil properties are also included.

Unlike the conventional finite element analysis that requires the input of nodal coordinates, boundary conditions, element information, material properties, etc., the program contains a subroutine which converts relatively simple input into the necessary parameters for a detailed finite element analysis. In other words, the program asks the user to input a sequence of geometric, material and loading parameters to define the problem to be solved. A brief description of how they are generated is explained below.

The necessary information regarding the nodes, elements, material properties, and boundary conditions are automatically generated based on input described in steps 1 through 23. Figure 2 shows schematic nodal and element conditions after the generation. The total horizontal extent of the solution domain is defined as

$$H = 4(L_1 + L_2) + 1.5 L_3$$



Element numbering for structural elements are

Tie-rod	:	80 - 83 from left to right
Concrete anchor	:	84 - 88 from top to bottom
Abutment stem	:	76 - 79 from top to bottom
Abutment base	:	89 - 92 from left to right
Front row pile	:	93, 95, 97, 99 and 101 from top to bottom
Rear row pile	:	94, 96, 98, 100 and 102 from top to bottom

Figure 2. Schematics of Generated Finite Element Grid

where L_1 = width of the abutment base

L_2 = width of the berm in front of the abutment base

L_3 = projected length of the tie-rod on the plane perpendicular to the abutment.

The vertical dimension of the solution domain is

$$V = L_4 + L_5 \cos\theta \quad \text{for point bearing piles}$$

and

$$V = L_4 + 1.5\, L_5 \cos\theta \quad \text{for friction piles}$$

where L_4 = height of the abutment

L_5 = length of the piles

θ = pile batter angle to the vertical

The interior nodes are then generated by equally dividing the coordinates of the nodes that define the boundary or locations of significant structural elements.

The element numbering and material number designations are as follows:

1. Elements 1 - 22 (material number 3):

   Soils below the middepth of the piles.

2. Elements 23 - 55 (material number 2):

   Soils between the abutment base and the middepth of the piles.

3. Elements 56 - 75 (material numbers 1 or 2):

   Backfill material. Elements located above the diagonal defined by connecting the lower left corner (node 31) and the upper right corner (node 6) have material number 1. Elements located diagonally below have material number 2.

4. Elements 76 - 79 (material number 6):

   Concrete abutment stem

5. Elements 80 - 83 (material number 7):

   Tie-rod

6. Elements 84 - 88 (material number 8):

   Drilled-in concrete anchor

7. Elements 89 - 92 (material number 9):

   Abutment base

8. Elements 93, 95, 97, 99 (material number 4):

   Front row friction piles. If the piles are end-bearing type, element 101 is added below element 99.

9. Elements 94, 96, 98, 100 (material number 5):

   Rear row friction piles. If the piles are end-bearing type, element 102 is added below element 100.

The specified boundary conditions are: the three sides of the solution domain, i.e., left, right and below, are supported by rollers without allowing out-of-plane directional (^{z}) movements; the tips of the point bearing piles are restricted against any movement or rotation; and all the interior nodes are free to move and/or rotate.

Described below is the explanatory information regarding the input contained in Section I. The capabilities of the program can be best realized by reading the following information and the references cited therein. Please note that the numbering is the same as in Section I for facilitating the consultation of the explanatory information.

2. Title:

   The data set for each problem must begin with a title. There are no restrictions or requirements regarding the contents of title. It can be up to 80 characters.

4. H:

   The height of abutment is measured from the top of the abutment to the bottom elevation of the abutment base.

HPP:

The tie-rods are assumed to be horizontal.

Q:

The amount of surcharge includes the traffic load, the pavement, and the impact load. If a typical HS20 trailer truck (36 Tons) occupying an area of 10' x 30' is considered (4),

(1) uniform load = 0.016 x 36 Tons/10 ft = 115 psf

(2) concentrated load = (0.45 + 0.65) x 36 Tons/300 ft^2 = 264 psf

(3) impact load = 0.3 x [(1) + (2)] = 114 psf

(4) pavement load = 150 pcf x 1 ft thickness = 150 psf

Therefore Q = (1) + (2) + (3) + (4) = 643 psf.

5. DEL:

The friction angle between the abutment and the backfill material can be determined from direct shear tests in the laboratory. If the test results are not available, values in Table-1 can be used for estimation (5).

TH:

The bridge skew angle is measured from the line perpendicular to the bridge girders to the alignment of the abutment. Therefore, when the abutment is placed perpendicular to the bridge girders, the skew angle is zero.

FA:

The allowable tensile strength of tie-rod material can be found from the manufacturer's brochure.

FS:

Typically, a factor of safety near 1.5 is recommended under usual circumstances. A higher factor of safety may be needed if a high probability of

Table-1 Friction Factors for Dissimilar Materials

Interface Materials	Friction angle, δ degrees
Mass concrete on the following materials:	
Clean sound rock	35
Clean gravel, gravel-sand mixtures, coarse sand	29 to 31
Clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel	24 to 29
Clean fine sand, silty or clayey fine to medium sand	19 to 24
Fine sandy silt, nonplastic silt	17 to 19
Very stiff and hard residual or preconsolidated clay	22 to 26
Medium stiff and stiff clay and silty clay	17 to 19
(Masonry on foundation materials has same friction factors)	
Steel sheet piles against the following soils:	
Clean gravel, gravel-sand mixtures, well-graded rock fill with spalls	22
Clean sand, silty sand-gravel mixture, single size hard rock fill	17
Silty sand, gravel or sand mixed with silt or clay	14
Fine sandy silt, nonplastic silt	11
Formed concrete or concrete sheet piling against the following soils:	
Clean gravel, gravel-sand mixture, well-graded rock fill with spalls	22 to 26
Clean sand, silty sand-gravel mixture, single size hard rock fill	17 to 22
Silty sand, gravel or sand mixed with silt or clay	17
Fine sandy silt, nonplastic silt	14
Various structural materials:	
Masonry on masonry, igneous and metamorphic rocks:	
Dressed soft rock on dressed soft rock	35
Dressed hard rock on dressed soft rock	33
Dressed hard rock on dressed hard rock	29
Masonry on wood (cross grain)	26
Steel on steel at sheet pile interlocks	17

uncertainty exists. Note that FS is used only for the selection of tie-rod diameter.

6. D:

   The necessary diameter of the drilled-in concrete anchor must follow the drilling standard (usually in even inches). Please refer to a drilled shaft manual or handbook for details.

7. GAM1, PH1:

   Table-3 shows the measured properties of two backfill materials; crushed Minnekahta Limestone and Sioux Quartzite. The former is typically used in West Rever localities, whereas the latter is mostly used in East River localities.

8. GAM2, C2, PH2:

   The foundation soil material properties can be determined in the laboratory or from Tables-3 and 4.

   SU, ZT:

   The undrained shear strength of the foundation soil, SU, measured at a depth of, ZT, will be used for determining the length of drilled-in concrete anchor based on short-term stability. Therefore, SU needs to be determined at a depth between the ground surface and the bottom elevation of the abutment base. The cohesion, C2, and the friction angle, PH2, are used to determine the length of drilled-in concrete anchor for long-term stability. The program automatically calculates C2 and PH2, if SU is not given, or vice versa.

11. ITMAX:

   The analysis is carried out with incremental steps with iteration conducted in each increment (for linear analysis, the number of iterations is specified as 1). Iteration is necessary when nonlinear soil properties which depend

upon the current stress state are used. ITMAX specifies the maximum number of iterations allowed.

RELAX:

For many problems the rate of convergence of the iteration process can be improved by using a modified estimate of the soil modulus for n^{th} iteration (E^*). This improved estimate is expressed in terms of the calculated modulus (E^n) and the value from the previous iteration (E^{n-1}), i.e., $E^* = E^{n-1} + RELAX(E^n - E^{n-1})$. When the convergence is oscillatory, a relaxation factor (RELAX) less than 1.0 should be used, while for asymptotic convergence, a value greater than 1.0 is indicated. Obviously, a value of RELAX too close to zero will prevent convergence from occurring at all. If no evidence is available as to the nature of convergence, it is recommended to use 1.0, i.e., no relaxation. For typical problems, RELAX of 0.6 - 0.8 is used.

ERMAX:

During iteration, the resulting error is calculated based on the second vector norm of displacements between two consecutive iterations.

$$\text{error} = \frac{|U(n) - U(n-1)|}{|U(n)|}$$

$$U(n) = \sqrt{\Sigma\, u_i(n)^2}$$

where $u_i(n)$ = array of displacements and rotations of node i at n^{th} iteration.

At any stage during iteration, when resulting error is less than or equal to ERMAX, the convergency is assumed to be obtained. If the solution fails to converge, a message is printed indicating the magnitude

of the error, and the solution process continues as if convergence had been obtained.

INR:

Use 1 if two increment analysis is desired. Otherwise use zero for one increment analysis. If INR = 1, only foundation soil is considered in increment one and resulting stresses are calculated without any displacements being added in increment 2.

12. Please refer to Section IV, Example Problem, for the determination of geometric parameters.

A3:

Use total extent of the abutment base from the toe to the backface of the abutment stem.

13. IPILE:

Use 0 if pile tips sit on top of rock or hardpan to describe point-bearing piles. Use 1 if piles are designed as friction piles.

16
17 ESO:
18

Initial tangent modulus of the soil measured from stress-strain curve. If KCODE = N is used, ESO is estimated from K times the atmospheric pressure, where K is the loading modulus described below. Refer to Table-2 for typical values of tangent modulus of several soils.

POIS:

Poisson's ratio of soil describing the volume change behavior. POIS = 0.5 represents an incompressible material, e.g., saturated soil, and POIS = 0. is for fully compressible materials. Note that POIS of 0.0 or 0.5 may cause numerical instability during computation. Refer to Table-2 for several typical values of POIS.

Table-2 Recommended Values of Tangent Modulus (E) and Poisson's Ratio (ν)

Type of Soil	Properties of soil	Void ratio e		
		0.41 to 0.5	0.51 to 0.6	0.61 to 0.70
Sand (course)	ϕ (degrees)	43	40	38
ν = 0.15	E (lb/in^2)	6,550	5,700	4,700
	E (kN/m^2)	45,200	39,300	32,400
Sand (medium coarse)	ϕ (degrees)	40	38	35
ν = 0.2	E (lb/in^2)	6,550	5,700	4,700
	E (kN/m^2)	45,200	39,300	32,400
Sand (fine grained)	ϕ (degrees)	38	36	32
	E (lb/in^2)	5,300	4,000	3,400
ν = 0.25	E (kN/m^2)	36,600	27,600	23,500
Sandy silt	ϕ (degrees)	36	34	30
ν = 0.3 to 0.35	E (lb/in^2)	2,000	1,700	1,450
	E (kN/m^2)	13,800	11,700	10,000
Soft clay	E = (100 - 5000) Su			
Stiff clay	E = (500 - 1,500) Su			
Over Consolidated clay	$E = E_{NCC} \sqrt{OCR}$			

GY:

Gravity induced unit weight of soil. The value of GY must be negative, since the coordinate is defined as positive upward.

K, KUR, N, RF,
C, PHI, DPHI, KB, M:

These are the parameters that define the hyperbolic nonlinear inelastic material behavior during the loading. The instantaneous tangent modulus is calculated from

$$Et = K\,Pa\left(\frac{\sigma_3}{Pa}\right)^n \left[1 - \frac{R_f(1-\sin\phi)(\sigma_1 - \sigma_3)}{2C\cos\phi + 2\,\sigma_3\sin\phi}\right]^2$$

where σ_1 = major principal stress at mid-increment

σ_3 = minor principal stress at mid-increment

K = loading modulus (K)

Pa = atmospheric pressure

n = modulus exponent (N)

Rf = failure ratio (RF)

C = Cohesion (C)

ϕ = friction angle

The detailed derivation of these parameters from laboratory soil testing is explained in Volume I of the report.

The friction angle is defined as $\phi = \phi_0 - \Delta\phi \log_{10}\left(\frac{\sigma_3}{Pa}\right)$

where ϕ_0 = friction angle at zero confining pressure (PHI)

$\Delta\phi$ = change in friction angle over 10 fold increase in confining pressure (DPHI)

Table-3 Nonlinear Material properties of Selected Soils

KCODE	Soil	Description	K	N	RF	C (psf)	ϕ PHI	γ (pcf)
1	Crushed Limestone		700	0.85	0.74	0	50	103.5
2	Crushed Quartzite		525	0.95	0.76	0	50	103.5
3	Reddish brown silty clay	Meade Co. 8 - 10 ft.	140	0.34	0.59	2,400	17	137.5
4	Reddish brown silty clay	Meade Co. 13 - 15 ft.	150	0.23	0.43	1,700	30	137.5
5	Reddish brown silty clay	Meade Co. 18 - 20 ft.	215	0.41	0.60	1,100	35	136.0
6	Gray silty clay w/pebbles	Pennington Co. 8.5 - 10.5 ft.	290	0.32	0.65	0	50	125.3
7	Gray shale	Pennington Co 14 - 16 ft.	70	1.57	0.73	1,550	15	124.8
8	Light brown silty clay	Pennington Co. 8 - 9 ft.	90	0.26	0.63	1,850	25	125.0
9	Light brown silty clay	Pennington Co. 13 - 15 ft.	235	0.10	0.79	1,650	30	126.6
10	Brown silty clay w/ pebbles	Pennington Co. 18 - 20 ft.	220	0.36	0.82	0	36	125.5
11	Brown silty clay w/pebbles	Minnehaha Co. 13 - 14 ft.	125	0.26	0.76	0	32	134.3
12	Brown silty clay w/pebbles	Minnehaha Co. 16 - 17 ft.	140	0.53	0.67	0	42	127.8
13	Gray brown shale	Jones Co. 32 - 56 ft.	470	0.21	0.37	0	40	121.5
14	Gray silty clay	Lawrence Co. 7.5 - 9 ft.	170	0.38	0.53	1,200	24	124.0
15	Gray silty clay	Lawrence Co. 14 - 15 ft.	245	0.25	0.65	1,500	35	125.6
16	Gray silty clay	Lawrence Co. 19 - 20 ft.	105	0.36	0.57	0	40	125.0
17	Brown silty clay	Brule Co. 3 - 16 ft.	195	0.20	0.80	1,300	40	128.7
18	Brown silty clay	Brule Co. 32 - 42 ft.	255	0.34	0.70	2,950	10	122.0
19	Brown silty clay	Brule Co. 51 - 55 ft.	305	0.42	0.65	2,100	32	122.0
20	Gray shale	Buffalo Co. 38 - 41.5 ft.	115	0.92	0.20	0	50	116.0

*Depth is measured from the ground surface.
K = Loading Modulus
N = Modulus Exponent
RF = Failure Ratio

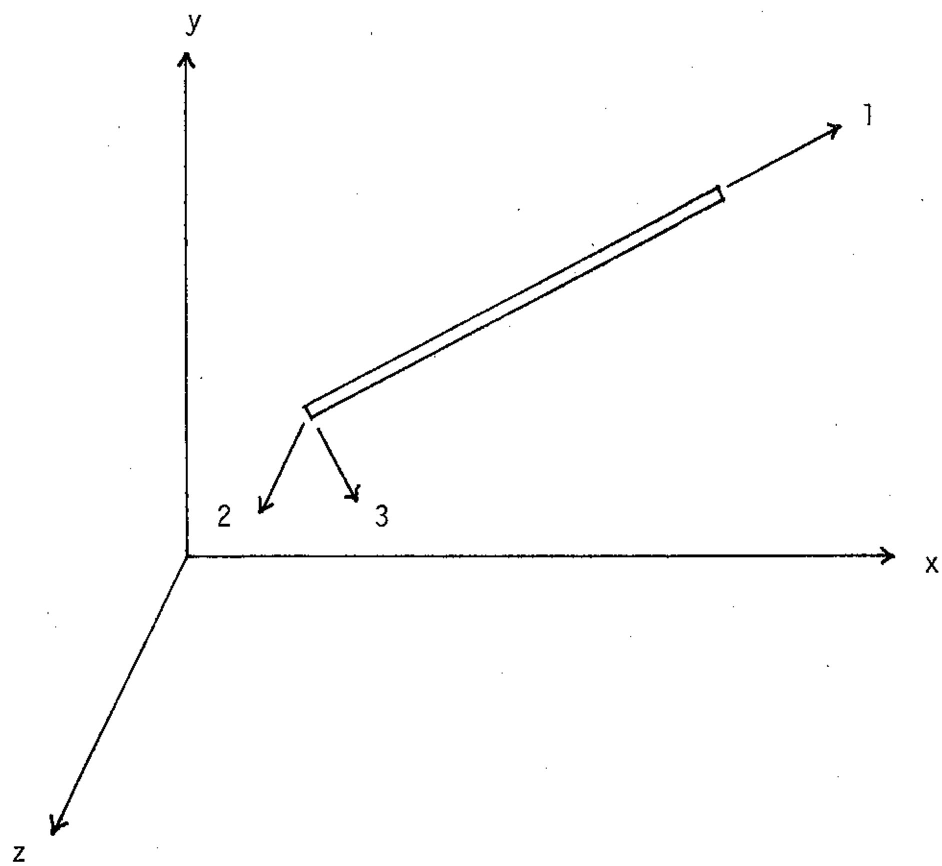
backfill material and 18 soils from various locations (and depths) in South Dakota. Also shown in Table-4 are typical nonlinear hyperbolic parameters of several compacted soils available from literature (1).

19. If there exists only one row of piles, one can analyze the problem by specifying the material and geometric properties of either the front row piles (if the piles are installed between the toe of the abutment base and the girder support) or the rear row piles (if the piles are installed between the heel of the abutment base and the girder support), while using very small values for the other row piles. For instance, a pile diameter of 0.01 ft., pile material modulus of 0.01 psi, etc., can be used. Assuming that the piles lie on x - y plane, the coordinates 2 and z are identical (Figure 3). YI is the moment of inertia about the z or 2 axis, whereas ZI is that about the 3 axis. Typically YI is the moment of inertia about the major axis, and ZI is that about the minor axis.

Table-4 Nonlinear Material properties of Compacted Soils

KCODE	Soil	Description	K	N	RF	C (psf)	ϕ PHI	$\Delta\phi$ DPHI	KB	M	γ (pcf)
21	GW, GP SW, SP	105% of STD. AASHTO	600	0.4	0.7	0	42	9	175	0.2	150
22	GW, GP SW, SP	100	450	0.4	0.7	0	39	7	125	0.2	145
23	GW, GP SW, SP	95	300	0.4	0.7	0	36	5	75	0.2	140
24	GW, GP SW, SP	90	200	0.4	0.7	0	33	3	50	0.2	135
25	SM	100	600	0.25	0.7	0	36	8	450	0.	135
26	SM	95	450	0.25	0.7	0	34	6	350	0.	130
27	SM	90	300	0.25	0.7	0	32	4	250	0.	125
28	SM	85	150	0.25	0.7	0	30	2	150	0.	120
29	SM, SC	100	400	0.6	0.7	500	33	0	200	0.5	135
30	SM, SC	95	200	0.6	0.7	400	33	0	100	0.5	130
31	SM, SC	90	150	0.6	0.7	300	33	0	75	0.5	125
32	SM, SC	85	100	0.6	0.7	200	33	0	50	0.5	120
33	CL	100	150	0.45	0.7	400	30	0	140	0.2	135
34	CL	95	120	0.45	0.7	300	30	0	110	0.2	130
35	CL	90	90	0.45	0.7	200	30	0	80	0.2	125
36	CL	85	60	0.45	0.7	100	30	0	50	0.2	120

*Soil designation is based on Unified Classification System.



1, 2, 3 = local

x, y, z = global coordinates

coordinate 1 is along the axis.

Figure 3. Local and Global Coordinates

Section III - Output

Once the program is successfully executed, a series of outputs will be provided. The first part of the output describes the results of limit equilibrium design of the system. It includes:

1. minimum required diameter of the tie-rod
2. depths of drilled-in concrete anchor considering both long term and short term stability.
3. required length of tie-rod.

Following the design output, results from the generalized plane strain finite element analysis are printed. In most cases, the program asks the user whether the detailed output is desired or not. Described below are the output results, assuming that the user requests the complete output.

1. Nodal Point Data

This prints nodal coordinates, boundary conditions, and equation numbers. The nodal coordinate origin is located at the bottom of abutment (Figure 2), with x being measured positive toward the backfill and y being measured positive upward. Boundary conditions are specified as being either 0 or 1 for each of the 6 degrees of freedom, i.e., x-translation (D-X), y-translation (D-Y), z-translation (D-Z), x-rotation (TH-X), y-rotation (TH-Y), and z-rotation (TH-Z). 0 specifies free and 1 specifies a fixed condition. Note that nodes associated with the continuum only must have TH-X, TH-Y and TH-Z of 1. Global equation numbers indicate the position of non-trivial displacements and rotations.

2. Nodal Point Load

This prints concentrated loads and moments acting on the nodes. Sign convention follows the x, y and z coordinate of global system. Therefore, nodal load acting as a girder support loading usually has a negative sign.

3. Material Properties

The first three materials (numbers 1 - 3) represent soils: the first for backfill material properties behind the abutment, the second for those between the abutment and mid-depth of the piles, and the third for those below the mid-depth of the piles. They will have either linear elastic or nonlinear inelastic soil characterization parameters. The details of these parameters are described in Section II.

The next 6 materials (numbers 4 - 9) give the properties of structural elements. In the output,

AE indicates a product of area and Young's modulus.

GJ1 indicates a product of polar moment of inertia along 1-axis and shear modulus.

EI2 indicates a product of moment of inertia along 2-axis and Young's modulus.

EI3 indicates a product of moment of inertia along 3-axis and Young's modulus.

E indicates Young's modulus.

POIS indicates Poisson's ratio.

FX indicates horizontal body force.

FY indicates vertical body force.

4. Element data

This prints the element information, including the element number, the nodes defining the element, the nature of soil reinforcement, the material number, the skew angle, and the tractions. The nodes associated with an element are numbered counterclockwise. Note that all soil elements have 4 nodes, while structural elements have only 2 nodes. REINF of 1 indicates

that the element is a reinforced soil element. The bridge skew angle is shown, if any, in elements 80 - 83 which define the tie-rods. If ground surcharge loading is considered, it will be shown in the y directional traction (TY) of elements 71 - 75.

5. Convergency

The calculation terminates when either the maximum number of iteration specified (ITMAX) is reached or the resulting error is less than or equal to the specified value (ERMAX). The resulting number of iterations and error are printed. Note that if all materials are linear elastic, only 1 iteration is performed.

6. Nodal Displacements

This prints the node numbers, and the associated 6 global coordinate displacements and rotations. It is important to note that if two increment analysis is used, the displacements and rotations in increment 1 are only for user's reference; they will not be added in increment 2. Also printed at the final increment are the maximum inward and outward horizontal movements of the abutment.

7. Element Output

First, the element number, location, strains, and stresses of continuum are printed. Depending upon the user's request, results are printed at the center and/or along the sides of the elements. CEN indicates that the strains and stresses are those at the center of the element. I-J indicates that the strains and stresses are along the side defined by the first two nodes associated with the element as shown in element data output. Similarly J-K indicates those between second and third nodes, etc.

After the location, 5 strain values are printed; EXX for normal strain along x coordinate, EYY for normal strain along y coordinate, GXY for shear

strain on yz plane along y coordinate, GXZ for shear strain on yz plane along z coordinate, and GYZ for shear strain on xz plane along z coordinate. Normal strains along z coordinate are not printed due to the nature of plane strain. It is noted that all strain designations have the letter D in the front, indicating that all the strain values are incremental - not cumulative.

Next, 6 components of the three dimensional stresses are printed. They are cumulative - not incremental - values, i.e., previous increment stresses are added in. S indicates the normal stress and T indicates the shear stress. Mechanical sign convention and subscript designation are used, i.e., stresses and strains are positive in tension. For example, SXX indicates the normal stress along x-coordinate and TXY indicates the shear stress on yz plane along y direction.

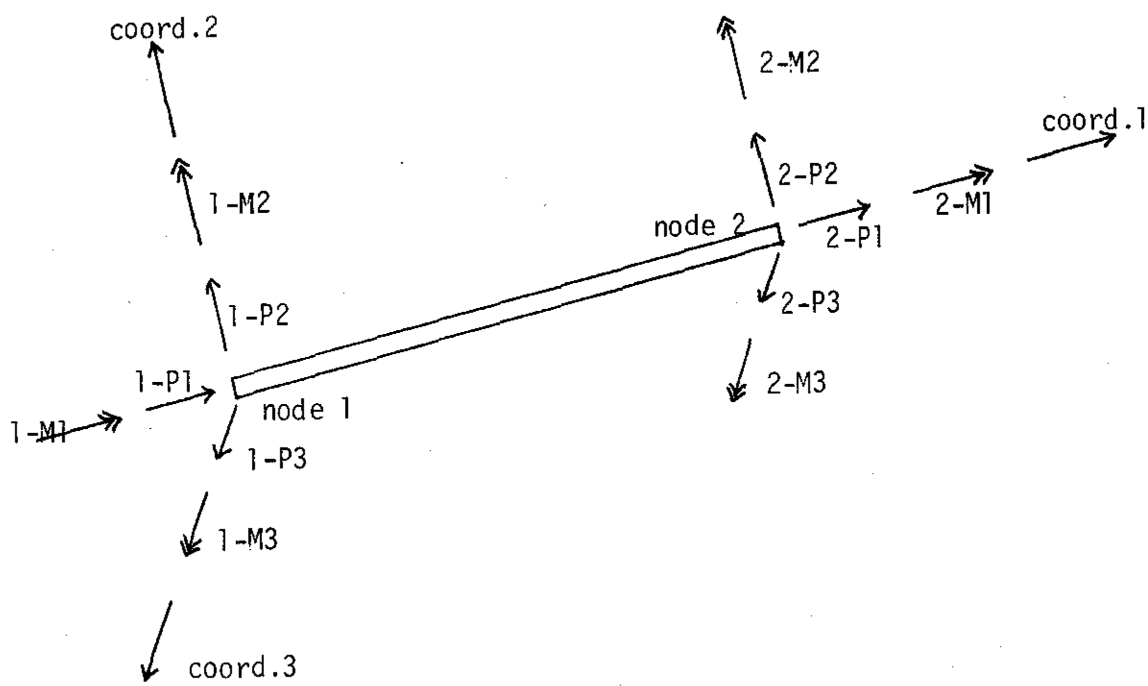


Figure 4. Element End Forces

The second part of the element output contains the response of structural elements. Therefore, this part of the output is not provided for the first increment of two increment analysis. All the detailed developed forces and moments are printed. The first designation (number 1 or 2) indicates the position of the node defining the element. The second designation (letter P or M) indicates whether the result is force (P) or moment (M). The third designation (number 1, 2, or 3) indicates the direction of force or moment along the local coordinate as shown in Figure 4.

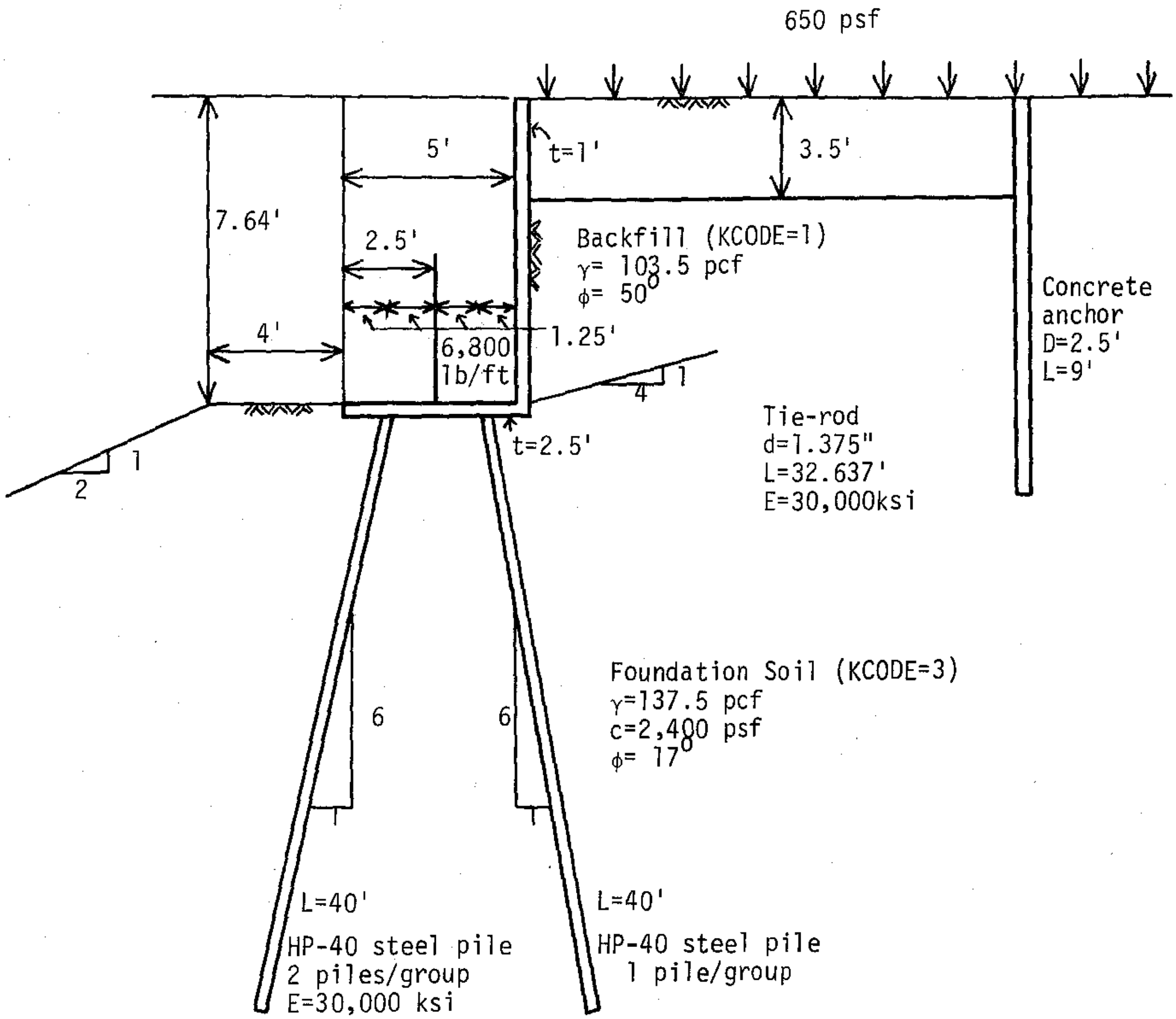
Therefore, 1-P1 indicates the axial thrust, 1-P2 and 1-P3 indicate the shear forces along 2 and 3 directions, 1-M1 represents the torsion about the axial direction, and 1-M2 and 1-M3 indicate the bending moments about 2 and 3 axes at the first node defining the element. Finally, maximum developed axial thrusts, bending moments and shear forces at the tie-rod level and base of the abutment stem are calculated and printed. The maximum shear force and bending moment at a given node, if desired, can be calculated from

$$V_{max} = \sqrt{(1\text{-}P2)^2 + (1\text{-}P3)^2}$$

$$M_{max} = \sqrt{(1\text{-}M2)^2 + (1\text{-}M3)^2}$$

Note that the developed forces and moments are per linear foot along the direction of plane strain. To calculate the total developed forces and moment within the structural elements, one needs to convert the values as shown on the following page.

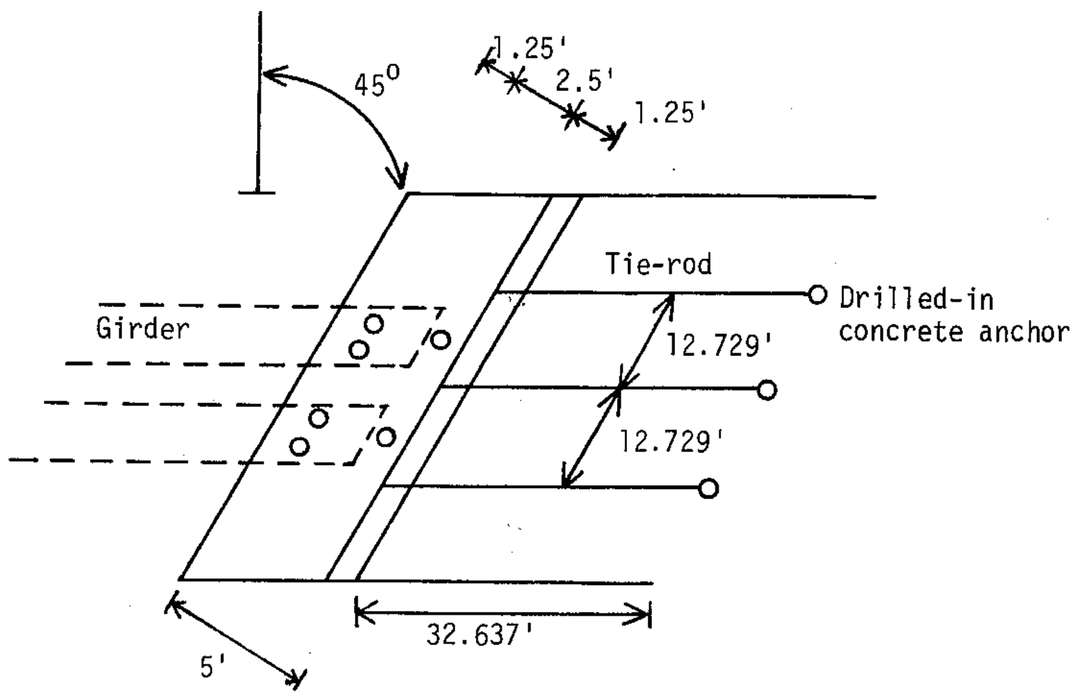
1. Tie rod:	Multiply by the tie-rod spacing.
2. Drilled-in concrete anchor:	Multiply by the drilled-in concrete anchor spacing (same as tie-rod spacing)
3. Abutment stem:	Answers are directly per linear foot.
4. Abutment base:	Answers are directly per linear foot.
5. Piles:	Multiply by the pile group spacing and then divided by the number of piles in the group to obtain force and moments within each pile.



Pile group spacing = 12.729'

Wall friction angle = 30°
Bridge skew angle = 45°
Tie-rod spacing = 12.729'
Tie-rod strength = 90 ksi
Factor of safety = 1.5

Figure 5a. Example Problem



PLAN VIEW

Figure 5 b. Example Problem (Continued)

Table 5. Input Data

INPUT

```
      7.640000
      3.500000
   2.500000E-01
    650.000000
     30.000000
     45.000000
     12.729000
   90000.000000
      1.500000
       2.500000000
 1
 3
       9.000000000
        .000000000
       1.375000000
      32.637000000
     650.000000000
9
        .800000000
        .050000000
0
     5.000000
     2.500000
     4.000000
     2.000000
       6.000000000
       6.000000000
      40.000000000
      40.000000000
1
     1.250000
     1.250000
Y
   6800.000000
Y
Y
       0       1
       0       3
       0      -1
0
2
     12.400000
    210.000000
     71.700000
   3.000000E+07
     12.729000
0
1
     12.400000
    210.000000
     71.700000
```

```
   3.000000E+07
     12.729000
      1.000000
   3.000000E+07
      2.500000
Y
Y
Y
N
```

Table 6. Output

```
                    TEST


**INPUT DATA AS FOLLOWS**

  HEIGHT OF ABUTMENT WALL          =      7.640 FT
  DEPTH TO TIE ROD                 =      3.500 FT
  BACKFILL SLOPE (V/H)             =       .250
  SURCHARGE LOADING                =    650.000 PSF
  WALL FRICTION ANGLE              =     30.000 DEG
  BRIDGE SKEW ANGLE                =     45.000 DEG
  TIE ROD SPACING                  =     12.729 FT
  ALLOWABLE STRESS OF TIE ROD      =   .900E+05 PSI

BACKFILL SOIL PROPERTIES

  UNIT WEIGHT                      =    103.500 PCF
  FRICTION ANGLE                   =     50.000 DEG

FOUNDATION SOIL PROPERTIES
  UNIT WEIGHT                      =    137.500 PCF
  COHESION                         =   2400.000 PSF
  FRICTION ANGLE                   =     17.000 DEG
  UNDRAINED SHEAR STRENGTH         =   2013.560 PSF AT    .0 FT

CONCRETE ANCHOR DIAMETER           =      2.500 FT
FACTOR OF SAFETY                   =      1.500


**OUTPUT DATA AS FOLLOWS**

  MINIMUM DIAMETER OF TIE ROD    =       .786 IN


  DEPTH OF CONCRETE ANCHOR FOR SHORT TERM STABILITY=     2.593 FT
  DEPTH OF CONCRETE ANCHOR FOR LONG  TERM STABILITY=     4.000 FT


  SOLUTION CONVERGED AFTER    4 ITERATIONS
  ERROR                         =  .000E+00
  LENGTH OF TIE ROD             =    19.475 FT
  DEPTH OF CONCRETE ANCHOR      =     4.000 FT


MODIFIED RESULTS ARE

  LENGTH OF TIE ROD         =     29.262 FT
  DEPTH OF CONCRETE ANCHOR  =      9.000 FT

******* FINAL DESIGN SELECTION *******
TIE ROD DIAMETER              =      1.375 IN
TIE ROD LENGTH                =     32.637 FT
CONCRETE ANCHOR LENGTH        =      9.000 FT
CONCRETE ANCHOR DIAMETER      =      2.500 FT
```

GENERALIZED PLANE STRAIN FINITE ELEMENT ANALYSIS

RELAXATION = .80
MAXIMUM ERROR FOR ITERATION = .05
MAXIMUM NO. OF ITERATION = 9

**SOLUTION HAS ONE INCREMENT

NODAL POINT DATA

NODAL POINT COORDINATES — BOUNDARY CONDITION CODES — GLOBAL EQUATION NUMBER

IN INCREMENT 1

NODE	X(N)	Y(N)	D-X	D-Y	D-Z	TH-X	TH-Y	TH-Z	D-X	D-Y	D-Z	TH-X	TH-Y	TH-Z
1	.000	7.640	0	0	0	0	0	0	1	2	3	4	5	6
2	5.769	7.640	0	0	0	1	1	1	7	8	9	0	0	0
3	11.539	7.640	0	0	0	1	1	1	10	11	12	0	0	0
4	17.308	7.640	0	0	0	1	1	1	13	14	15	0	0	0
5	23.078	7.640	0	0	0	0	0	0	16	17	18	19	20	21
6	34.617	7.640	1	0	1	1	1	1	0	22	0	0	0	0
7	.000	5.890	0	0	0	0	0	0	23	24	25	26	27	28
8	5.769	5.890	0	0	0	1	1	1	29	30	31	0	0	0
9	11.539	5.890	0	0	0	1	1	1	32	33	34	0	0	0
10	17.308	5.890	0	0	0	1	1	1	35	36	37	0	0	0
11	23.078	5.890	0	0	0	0	0	0	38	39	40	41	42	43
12	34.617	5.890	1	0	1	1	1	1	0	44	0	0	0	0
13	.000	4.140	0	0	0	0	0	0	45	46	47	48	49	50
14	5.769	4.140	0	0	0	0	0	0	51	52	53	54	55	56
15	11.539	4.140	0	0	0	0	0	0	57	58	59	60	61	62
16	17.308	4.140	0	0	0	0	0	0	63	64	65	66	67	68
17	23.078	4.140	0	0	0	0	0	0	69	70	71	72	73	74
18	34.617	4.140	1	0	1	1	1	1	0	75	0	0	0	0
19	.000	2.070	0	0	0	0	0	0	76	77	78	79	80	81
20	5.769	2.070	0	0	0	1	1	1	82	83	84	0	0	0
21	11.539	2.070	0	0	0	1	1	1	85	86	87	0	0	0
22	17.308	2.070	0	0	0	1	1	1	88	89	90	0	0	0
23	23.078	2.070	0	0	0	0	0	0	91	92	93	94	95	96
24	34.617	2.070	1	0	1	1	1	1	0	97	0	0	0	0
25	-9.000	.000	0	0	0	1	1	1	98	99	100	0	0	0
26	-7.000	.000	0	0	0	1	1	1	101	102	103	0	0	0
27	-5.000	.000	0	0	0	0	0	0	104	105	106	107	108	109
28	-3.750	.000	0	0	0	0	0	0	110	111	112	113	114	115
29	-2.500	.000	0	0	0	0	0	0	116	117	118	119	120	121
30	-1.250	.000	0	0	0	0	0	0	122	123	124	125	126	127
31	.000	.000	0	0	0	0	0	0	128	129	130	131	132	133
32	5.769	.000	0	0	0	1	1	1	134	135	136	0	0	0
33	11.539	.000	0	0	0	1	1	1	137	138	139	0	0	0
34	17.308	.000	0	0	0	1	1	1	140	141	142	0	0	0
35	23.078	.000	0	0	0	0	0	0	143	144	145	146	147	148

36	34.617	.000	1	0	1	1	1	1	0	149	0	0	0	0
37	-18.000	-4.500	0	0	0	1	1	1	150	151	152	0	0	0
38	-13.798	-6.288	0	0	0	1	1	1	153	154	155	0	0	0
39	9.596	-8.076	0	0	0	1	1	1	156	157	158	0	0	0
40	-5.394	-9.864	0	0	0	0	0	0	159	160	161	162	163	164
41	-2.500	-9.864	0	0	0	1	1	1	165	166	167	0	0	0
42	.394	-9.864	0	0	0	0	0	0	168	169	170	171	172	173
43	2.158	-9.864	0	0	0	1	1	1	174	175	176	0	0	0
44	7.688	-9.864	0	0	0	1	1	1	177	178	179	0	0	0
45	13.218	-9.864	0	0	0	1	1	1	180	181	182	0	0	0
46	18.749	-9.864	0	0	0	1	1	1	183	184	185	0	0	0
47	23.078	-1.360	0	0	0	0	0	0	186	187	188	189	190	191
48	34.617	-9.864	1	0	1	1	1	1	0	192	0	0	0	0
49	-27.000	-9.000	0	0	0	1	1	1	193	194	195	0	0	0
50	-20.346	-12.576	0	0	0	1	1	1	196	197	198	0	0	0
51	-13.692	-16.152	0	0	0	1	1	1	199	200	201	0	0	0
52	-7.038	-19.728	0	0	0	0	0	0	202	203	204	205	206	207
53	-2.500	-19.728	0	0	0	1	1	1	208	209	210	0	0	0
54	2.038	-19.728	0	0	0	0	0	0	211	212	213	214	215	216
55	4.316	-19.728	0	0	0	1	1	1	217	218	219	0	0	0
56	9.607	-19.728	0	0	0	1	1	1	220	221	222	0	0	0
57	14.898	-19.728	0	0	0	1	1	1	223	224	225	0	0	0
58	20.189	-19.728	0	0	0	1	1	1	226	227	228	0	0	0
59	25.480	-15.476	0	0	0	1	1	1	229	230	231	0	0	0
60	34.617	-19.728	1	0	1	1	1	1	0	232	0	0	0	0
61	-36.000	-13.500	1	0	1	1	1	1	0	233	0	0	0	0
62	-26.894	-18.864	0	0	0	1	1	1	234	235	236	0	0	0
63	-17.788	-24.228	0	0	0	1	1	1	237	238	239	0	0	0
64	-8.682	-29.592	0	0	0	0	0	0	240	241	242	243	244	245
65	-2.500	-29.592	0	0	0	1	1	1	246	247	248	0	0	0
66	3.682	-29.592	0	0	0	0	0	0	249	250	251	252	253	254
67	6.474	-29.592	0	0	0	1	1	1	255	256	257	0	0	0
68	11.526	-29.592	0	0	0	1	1	1	258	259	260	0	0	0
69	16.577	-29.592	0	0	0	1	1	1	261	262	263	0	0	0
70	21.629	-29.592	0	0	0	1	1	1	264	265	266	0	0	0
71	26.680	-29.592	0	0	0	1	1	1	267	268	269	0	0	0
72	34.617	-29.592	1	0	1	1	1	1	0	270	0	0	0	0
73	-36.000	-36.342	1	0	1	1	1	1	0	271	0	0	0	0
74	-27.442	-37.380	0	0	0	1	1	1	272	273	274	0	0	0
75	-18.884	-38.418	0	0	0	1	1	1	275	276	277	0	0	0
76	-10.326	-39.456	0	0	0	0	0	0	278	279	280	281	282	283
77	-2.500	-44.388	0	0	0	1	1	1	284	285	286	0	0	0
78	5.326	-39.456	0	0	0	0	0	0	287	288	289	290	291	292
79	9.711	-39.456	0	0	0	1	1	1	293	294	295	0	0	0
80	14.404	-44.388	0	0	0	1	1	1	296	297	298	0	0	0
81	19.096	-44.388	0	0	0	1	1	1	299	300	301	0	0	0
82	23.789	-44.388	0	0	0	1	1	1	302	303	304	0	0	0
83	28.482	-44.388	0	0	0	1	1	1	305	306	307	0	0	0
84	34.617	-44.388	1	0	1	1	1	1	0	308	0	0	0	0
85	-36.000	-59.184	1	1	1	1	1	1	0	0	0	0	0	0
86	-28.538	-59.184	0	1	1	1	1	1	309	0	0	0	0	0
87	-21.076	-59.184	0	1	1	1	1	1	310	0	0	0	0	0
88	-13.614	-59.184	0	1	1	1	1	1	311	0	0	0	0	0
89	-2.500	-59.184	0	1	1	1	1	1	312	0	0	0	0	0

90	8.614	-59.184	0	1	1	1	1	1	313	0	0	0	0	0
91	12.948	-59.184	0	1	1	1	1	1	314	0	0	0	0	0
92	17.282	-59.184	0	1	1	1	1	1	315	0	0	0	0	0
93	21.615	-59.184	0	1	1	1	1	1	316	0	0	0	0	0
94	25.949	-59.184	0	1	1	1	1	1	317	0	0	0	0	0
95	30.283	-59.184	0	1	1	1	1	1	318	0	0	0	0	0
96	34.617	-59.184	1	1	1	1	1	1	0	0	0	0	0	0

**TOTAL NUMBER OF EQUATIONS = 318 IN INCR= 1

NODAL POINT LOAD TO BE INCLUDED IN INCREMENT 2

NODE	PN(X)	PN(Y)	PN(Z)	M(X)	M(Y)	M(Z)
29	.00000E+00	-.68000E+04	.00000E+00	.00000E+00	.00000E+00	.00000E+00

MATERIAL PROPERTIES

MAT.	K	KUR	N	RF	C	PHI	DPHI	KB	M	PA	FX	FY
1	700.00	1400.00	.85	.74	.00	50.00	.00	.00	.00	2116.80	.0000	-103.5000
***MAT 1 HAS CONSTANT POISSON RATIO OF .300												
2	140.00	280.00	.34	.59	2400.00	17.00	.00	.00	.00	2116.80	.0000	-137.5000
***MAT 2 HAS CONSTANT POISSON RATIO OF .300												
3	140.00	280.00	.34	.59	2400.00	17.00	.00	.00	.00	2116.80	.0000	-137.5000
***MAT 3 HAS CONSTANT POISSON RATIO OF .300												

MAT.	AE	GJ1	EI2	EI3	E	POIS	FX	FY
4	.58E+08	.37E+07	.69E+07	.23E+07	.43E+10	.25	.0000	.0000
5	.29E+08	.18E+07	.34E+07	.12E+07	.43E+10	.25	.0000	.0000
6	.58E+09	.38E+08	.48E+08	.48E+08	.58E+09	.25	.0000	.0000
7	.35E+07	.23E+00	.29E+00	.29E+00	.43E+10	.25	.0000	.0000
8	.22E+09	.69E+08	.87E+08	.87E+08	.58E+09	.25	.0000	.0000
9	.14E+10	.35E+09	.75E+09	.12E+09	.58E+09	.25	.0000	.0000

ELEMENT DATA

IN INCR=1 ONLY ELEMENT 1 THRU 55 ARE CONSIDERED

ELEM	NODE1	NODE2	NODE3	NODE4	REINF	MAT	ANGLE	TX	TY
1	85	86	74	73	0	3	.00	.00	.00
2	86	87	75	74	0	3	.00	.00	.00
3	87	88	76	75	0	3	.00	.00	.00
4	88	89	77	76	0	3	.00	.00	.00
5	89	90	78	77	0	3	.00	.00	.00
6	90	91	79	78	0	3	.00	.00	.00
7	91	92	80	79	0	3	.00	.00	.00
8	92	93	81	80	0	3	.00	.00	.00
9	93	94	82	81	0	3	.00	.00	.00
10	94	95	83	82	0	3	.00	.00	.00
11	95	96	84	83	0	3	.00	.00	.00

12	73	74	62	61	0	3	.00	.00	.00
13	74	75	63	62	0	3	.00	.00	.00
14	75	76	64	63	0	3	.00	.00	.00
15	76	77	65	64	0	3	.00	.00	.00
16	77	78	66	65	0	3	.00	.00	.00
17	78	79	67	66	0	3	.00	.00	.00
18	79	80	68	67	0	3	.00	.00	.00
19	80	81	69	68	0	3	.00	.00	.00
20	81	82	70	69	0	3	.00	.00	.00
21	82	83	71	70	0	3	.00	.00	.00
22	83	84	72	71	0	3	.00	.00	.00
23	61	62	50	49	0	2	.00	.00	.00
24	62	63	51	50	0	2	.00	.00	.00
25	63	64	52	51	0	2	.00	.00	.00
26	64	65	53	52	0	2	.00	.00	.00
27	65	66	54	53	0	2	.00	.00	.00
28	66	67	55	54	0	2	.00	.00	.00
29	67	68	56	55	0	2	.00	.00	.00
30	68	69	57	56	0	2	.00	.00	.00
31	69	70	58	57	0	2	.00	.00	.00
32	70	71	59	58	0	2	.00	.00	.00
33	71	72	60	59	0	2	.00	.00	.00
34	49	50	38	37	0	2	.00	.00	.00
35	50	51	39	38	0	2	.00	.00	.00
36	51	52	40	39	0	2	.00	.00	.00
37	52	53	41	40	0	2	.00	.00	.00
38	53	54	42	41	0	2	.00	.00	.00
39	54	55	43	42	0	2	.00	.00	.00
40	55	56	44	43	0	2	.00	.00	.00
41	56	57	45	44	0	2	.00	.00	.00
42	57	58	46	45	0	2	.00	.00	.00
43	58	59	47	46	0	2	.00	.00	.00
44	59	60	48	47	0	2	.00	.00	.00
45	37	38	26	25	0	2	.00	.00	.00
46	38	39	27	26	0	2	.00	.00	.00
47	39	40	28	27	0	2	.00	.00	.00
48	40	41	29	28	0	2	.00	.00	.00
49	41	42	30	29	0	2	.00	.00	.00
50	42	43	31	30	0	2	.00	.00	.00
51	43	44	32	31	0	2	.00	.00	.00
52	44	45	33	32	0	2	.00	.00	.00
53	45	46	34	33	0	2	.00	.00	.00
54	46	47	35	34	0	2	.00	.00	.00
55	47	48	36	35	0	2	.00	.00	.00
56	31	32	20	19	0	1	.00	.00	.00
57	32	33	21	20	0	2	.00	.00	.00
58	33	34	22	21	0	2	.00	.00	.00
59	34	35	23	22	0	2	.00	.00	.00
60	35	36	24	23	0	2	.00	.00	.00
61	19	20	14	13	0	1	.00	.00	.00
62	20	21	15	14	0	1	.00	.00	.00
63	21	22	16	15	0	2	.00	.00	.00
64	22	23	17	16	0	2	.00	.00	.00
65	23	24	18	17	0	2	.00	.00	.00

66	13	14	8	7	0	1	.00	.00	.00
67	14	15	9	8	0	1	.00	.00	.00
68	15	16	10	9	0	1	.00	.00	.00
69	16	17	11	10	0	2	.00	.00	.00
70	17	18	12	11	0	2	.00	.00	.00
71	7	8	2	1	0	1	.00	.00	-650.00
72	8	9	3	2	0	1	.00	.00	-650.00
73	9	10	4	3	0	1	.00	.00	-650.00
74	10	11	5	4	0	1	.00	.00	-650.00
75	11	12	6	5	0	2	.00	.00	-650.00
76	1	7	0	0	0	6	.00	.00	.00
77	7	13	0	0	0	6	.00	.00	.00
78	13	19	0	0	0	6	.00	.00	.00
79	19	31	0	0	0	6	.00	.00	.00
80	13	14	0	0	0	7	45.00	.00	.00
81	14	15	0	0	0	7	45.00	.00	.00
82	15	16	0	0	0	7	45.00	.00	.00
83	16	17	0	0	0	7	45.00	.00	.00
84	5	11	0	0	0	8	.00	.00	.00
85	11	17	0	0	0	8	.00	.00	.00
86	17	23	0	0	0	8	.00	.00	.00
87	23	35	0	0	0	8	.00	.00	.00
88	35	47	0	0	0	8	.00	.00	.00
89	27	28	0	0	0	9	.00	.00	.00
90	28	29	0	0	0	9	.00	.00	.00
91	29	30	0	0	0	9	.00	.00	.00
92	30	31	0	0	0	9	.00	.00	.00
93	28	40	0	0	0	4	.00	.00	.00
94	30	42	0	0	0	5	.00	.00	.00
95	40	52	0	0	0	4	.00	.00	.00
96	42	54	0	0	0	5	.00	.00	.00
97	52	64	0	0	0	4	.00	.00	.00
98	54	66	0	0	0	5	.00	.00	.00
99	64	76	0	0	0	4	.00	.00	.00
100	66	78	0	0	0	5	.00	.00	.00

**BANDWIDTH OF MATRIX = 61 IN INCR= 1

SOLUTION CONVERGED AFTER 3 ITERATIONS
RESULTING ERROR IS .29477E-01

DISPLACEMENTS AT NODES

NODE	X-TRAN	Y-TRAN	Z-TRAN	X-ROT	Y-ROT	Z-ROT
1	.26126E+00	-.86710E+00	-.83020E-01	-.60492E-02	.28048E-02	-.24001E-01
2	.18381E+00	-.13438E+01	-.77985E-02	.00000E+00	.00000E+00	.00000E+00
3	.17102E+00	-.14605E+01	-.55453E-02	.00000E+00	.00000E+00	.00000E+00
4	.13905E+00	-.15567E+01	-.75167E-03	.00000E+00	.00000E+00	.00000E+00
5	.10683E+00	-.16202E+01	.12288E-01	.77059E-03	.13528E+00	-.98456E-02
6	.00000E+00	-.16749E+01	.00000E+00	.00000E+00	.00000E+00	.00000E+00

7	.21927E+00	-.86710E+00	-.72432E-01	-.60533E-02	.28048E-02	-.23977E-01
8	.14722E+00	-.13407E+01	-.79987E-02	.00000E+00	.00000E+00	.00000E+00
9	.13720E+00	-.14607E+01	-.54788E-02	.00000E+00	.00000E+00	.00000E+00
10	.11837E+00	-.15580E+01	-.10813E-02	.00000E+00	.00000E+00	.00000E+00
11	.89603E-01	-.16202E+01	.10931E-01	.78441E-03	.13528E+00	-.98434E-02
12	.00000E+00	-.16756E+01	.00000E+00	.00000E+00	.00000E+00	.00000E+00
13	.17737E+00	-.86709E+00	-.61826E-01	-.60714E-02	.28048E-02	-.23907E-01
14	.11579E+00	-.13329E+01	-.82306E-02	.23059E-01	-.11822E-01	-.47795E-01
15	.10584E+00	-.14603E+01	-.52903E-02	-.61352E-02	.11190E-01	-.13359E-01
16	.95283E-01	-.15561E+01	-.25225E-02	.10269E-02	-.39756E-01	-.15279E-01
17	.72383E-01	-.16202E+01	.95218E-02	.83297E-03	.13528E+00	-.98426E-02
18	.00000E+00	-.16723E+01	.00000E+00	.00000E+00	.00000E+00	.00000E+00
19	.12795E+00	-.86707E+00	-.49261E-01	-.60499E-02	.28048E-02	-.23865E-01
20	.88872E-01	-.13029E+01	-.11651E-01	.00000E+00	.00000E+00	.00000E+00
21	.84583E-01	-.14497E+01	-.51250E-02	.00000E+00	.00000E+00	.00000E+00
22	.69815E-01	-.15484E+01	-.82695E-03	.00000E+00	.00000E+00	.00000E+00
23	.52022E-01	-.16202E+01	.77272E-02	.89388E-03	.13528E+00	-.98278E-02
24	.00000E+00	-.16633E+01	.00000E+00	.00000E+00	.00000E+00	.00000E+00
25	.36793E-01	-.78913E+00	-.15504E-01	.00000E+00	.00000E+00	.00000E+00
26	.47177E-01	-.78118E+00	-.17911E-01	.00000E+00	.00000E+00	.00000E+00
27	.78439E-01	-.74709E+00	-.22853E-01	-.58876E-02	.27962E-02	-.23960E-01
28	.78442E-01	-.77704E+00	-.26348E-01	-.58876E-02	.27951E-02	-.23965E-01
29	.78441E-01	-.80702E+00	-.29844E-01	-.58988E-02	.27990E-02	-.24000E-01
30	.78441E-01	-.83703E+00	-.33345E-01	-.59101E-02	.28035E-02	-.24010E-01
31	.78439E-01	-.86704E+00	-.36851E-01	-.59246E-02	.28048E-02	-.24012E-01
32	.74350E-01	-.12715E+01	-.13042E-01	.00000E+00	.00000E+00	.00000E+00
33	.55596E-01	-.14427E+01	-.50301E-02	.00000E+00	.00000E+00	.00000E+00
34	.42236E-01	-.15367E+01	.23298E-04	.00000E+00	.00000E+00	.00000E+00
35	.31708E-01	-.16201E+01	.58446E-02	.92076E-03	.13528E+00	-.98088E-02
36	.00000E+00	-.16483E+01	.00000E+00	.00000E+00	.00000E+00	.00000E+00
37	.23274E-01	-.78316E+00	-.70580E-02	.00000E+00	.00000E+00	.00000E+00
38	.13277E-01	-.79078E+00	-.85195E-02	.00000E+00	.00000E+00	.00000E+00
39	-.69115E-02	-.78500E+00	-.87072E-02	.00000E+00	.00000E+00	.00000E+00
40	-.27087E-01	-.75524E+00	-.71254E-02	.31244E-03	.17621E-02	-.20885E-02
41	-.48444E-01	-.82023E+00	-.87582E-02	.00000E+00	.00000E+00	.00000E+00
42	-.66327E-01	-.85870E+00	-.81040E-02	-.14225E-02	.35517E-02	-.75316E-02
43	-.70056E-01	-.97491E+00	-.64940E-02	.00000E+00	.00000E+00	.00000E+00
44	-.69907E-01	-.12242E+01	-.63850E-02	.00000E+00	.00000E+00	.00000E+00
45	-.52836E-01	-.13737E+01	-.31480E-02	.00000E+00	.00000E+00	.00000E+00
46	-.37502E-01	-.14666E+01	-.68537E-03	.00000E+00	.00000E+00	.00000E+00
47	.18373E-01	-.16201E+01	.45882E-02	.92540E-03	.13528E+00	-.98072E-02
48	.00000E+00	-.15623E+01	.00000E+00	.00000E+00	.00000E+00	.00000E+00
49	.18371E-01	-.73303E+00	-.32698E-02	.00000E+00	.00000E+00	.00000E+00
50	.49085E-02	-.76243E+00	-.44001E-02	.00000E+00	.00000E+00	.00000E+00
51	-.73772E-02	-.77083E+00	-.47276E-02	.00000E+00	.00000E+00	.00000E+00
52	-.28815E-01	-.74843E+00	-.46458E-02	-.19045E-04	.18174E-02	-.83105E-03
53	-.83352E-01	-.83377E+00	-.41344E-02	.00000E+00	.00000E+00	.00000E+00
54	-.11019E+00	-.85825E+00	-.38440E-02	-.81653E-03	.36528E-02	-.27284E-02
55	-.11618E+00	-.96131E+00	-.37623E-02	.00000E+00	.00000E+00	.00000E+00
56	-.11724E+00	-.11071E+01	-.27028E-02	.00000E+00	.00000E+00	.00000E+00
57	-.10078E+00	-.12103E+01	-.19980E-02	.00000E+00	.00000E+00	.00000E+00
58	-.74733E-01	-.12836E+01	-.12975E-02	.00000E+00	.00000E+00	.00000E+00
59	-.38941E-01	-.14306E+01	-.51672E-03	.00000E+00	.00000E+00	.00000E+00
60	.00000E+00	-.13763E+01	.00000E+00	.00000E+00	.00000E+00	.00000E+00

61	.00000E+00	-.68877E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
62	.12277E-01	-.69010E+00	-.18867E-02	.00000E+00	.00000E+00	.00000E+00
63	.62501E-02	-.71336E+00	-.27676E-02	.00000E+00	.00000E+00	.00000E+00
64	-.53065E-01	-.73525E+00	-.24729E-02	.15210E-03	.17888E-02	-.32607E-02
65	-.84967E-01	-.81009E+00	-.24549E-02	.00000E+00	.00000E+00	.00000E+00
66	-.12414E+00	-.84764E+00	-.22343E-02	-.73496E-03	.36665E-02	.18809E-02
67	-.14303E+00	-.90044E+00	-.19680E-02	.00000E+00	.00000E+00	.00000E+00
68	-.13369E+00	-.94283E+00	-.16908E-02	.00000E+00	.00000E+00	.00000E+00
69	-.11125E+00	-.98449E+00	-.13152E-02	.00000E+00	.00000E+00	.00000E+00
70	-.82742E-01	-.10234E+01	-.92462E-03	.00000E+00	.00000E+00	.00000E+00
71	-.52695E-01	-.10581E+01	-.58547E-03	.00000E+00	.00000E+00	.00000E+00
72	.00000E+00	-.10794E+01	.00000E+00	.00000E+00	.00000E+00	.00000E+00
73	.00000E+00	-.46738E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
74	-.22922E-01	-.46440E+00	-.59630E-03	.00000E+00	.00000E+00	.00000E+00
75	-.43474E-01	-.51654E+00	-.10493E-02	.00000E+00	.00000E+00	.00000E+00
76	-.80564E-01	-.72111E+00	-.13409E-02	.19772E-03	.17812E-02	-.27874E-02
77	-.78093E-01	-.52169E+00	-.10030E-02	.00000E+00	.00000E+00	.00000E+00
78	-.77619E-01	-.82417E+00	-.12373E-02	-.70173E-03	.36721E-02	.65221E-02
79	-.79434E-01	-.74481E+00	-.11380E-02	.00000E+00	.00000E+00	.00000E+00
80	-.56355E-01	-.56557E+00	-.70167E-03	.00000E+00	.00000E+00	.00000E+00
81	-.50590E-01	-.55095E+00	-.54389E-03	.00000E+00	.00000E+00	.00000E+00
82	-.38998E-01	-.55034E+00	-.38241E-03	.00000E+00	.00000E+00	.00000E+00
83	-.22757E-01	-.55310E+00	-.20946E-03	.00000E+00	.00000E+00	.00000E+00
84	.00000E+00	-.55537E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
85	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
86	-.50840E-01	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
87	-.95696E-01	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
88	-.10129E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
89	-.85812E-01	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
90	-.47334E-01	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
91	-.32521E-01	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
92	-.28150E-01	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
93	-.18186E-01	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
94	-.11060E-01	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
95	-.52539E-02	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
96	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00

HORIZONTAL WALL MOVEMENT

AT THE TOP = .26126 FT.
AT THE TIE-ROD = .17737 FT.
AT THE BASE = .07844 FT.

ELEMENT STRAINS AND STRESSES

EL.NO.	LOC	DEXX	DEYY	DGXY	DGXZ	DGYZ	SXX	SYY	SZZ	TXY	TXZ	TYZ
1	CEN	-.456E-02	-.208E-01	-.427E-03	-.380E-04	-.124E-04	-.371E+04	-.627E+04	-.300E+04	-.336E+02	-.299E+01	-.977E+00
2	CEN	-.394E-02	-.227E-01	-.254E-02	-.306E-04	-.363E-04	-.366E+04	-.654E+04	-.306E+04	-.194E+03	-.235E+01	-.278E+01
3	CEN	-.253E-02	-.286E-01	-.125E-01	-.218E-04	-.561E-04	-.362E+04	-.726E+04	-.326E+04	-.873E+03	-.153E+01	-.392E+01
4	CEN	.113E-02	-.361E-01	.184E-02	.160E-06	-.679E-04	-.316E+04	-.784E+04	-.330E+04	.116E+03	.100E-01	-.427E+01
5	CEN	.217E-02	-.395E-01	-.612E-02	.441E-05	-.645E-04	-.308E+04	-.805E+04	-.334E+04	-.365E+03	.263E+00	-.384E+01
6	CEN	.149E-02	-.383E-01	.739E-02	.114E-04	-.583E-04	-.310E+04	-.781E+04	-.327E+04	.439E+03	.676E+00	-.346E+01
7	CEN	.205E-02	-.381E-01	-.279E-02	.213E-04	-.495E-04	-.295E+04	-.768E+04	-.319E+04	-.164E+03	.125E+01	-.292E+01
8	CEN	.174E-02	-.374E-01	-.112E-03	.175E-04	-.389E-04	-.304E+04	-.780E+04	-.325E+04	-.679E+01	.106E+01	-.236E+01

9	CEN	.207E-02	-.372E-01	-.164E-02	.179E-04	-.285E-04	-.294E+04	-.769E+04	-.319E+04	-.994E+02	.108E+01	-.172E+01
10	CEN	.244E-02	-.373E-01	-.151E-02	.192E-04	-.174E-04	-.284E+04	-.759E+04	-.313E+04	-.905E+02	.115E+01	-.104E+01
11	CEN	.268E-02	-.375E-01	-.646E-03	.200E-04	-.586E-05	-.278E+04	-.755E+04	-.310E+04	-.383E+02	.119E+01	-.348E+00
12	CEN	-.293E-03	-.108E-01	-.295E-02	-.151E-03	-.292E-04	-.123E+04	-.274E+04	-.119E+04	-.212E+03	-.109E+02	-.210E+01
13	CEN	-.554E-03	-.125E-01	-.617E-02	-.107E-03	-.866E-04	-.148E+04	-.319E+04	-.140E+04	-.442E+03	-.766E+01	-.620E+01
14	CEN	-.412E-02	-.702E-02	-.117E-01	-.411E-04	-.114E-03	-.171E+04	-.210E+04	-.114E+04	-.798E+03	-.281E+01	-.778E+01
15	CEN	-.177E-02	-.126E-01	.542E-02	-.112E-04	-.104E-03	-.187E+04	-.349E+04	-.161E+04	.406E+03	-.839E+00	-.778E+01
16	CEN	-.195E-02	-.139E-01	-.217E-01	.332E-04	-.971E-04	-.141E+04	-.263E+04	-.121E+04	-.110E+04	.169E+01	-.494E+01
17	CEN	-.288E-02	-.816E-02	-.259E-02	.509E-04	-.800E-04	-.171E+04	-.253E+04	-.127E+04	-.199E+03	.391E+01	-.614E+01
18	CEN	.498E-03	-.207E-01	-.204E-02	.410E-04	-.636E-04	-.204E+04	-.500E+04	-.211E+04	-.142E+03	.286E+01	-.443E+01
19	CEN	.289E-02	-.279E-01	-.691E-02	.547E-04	-.495E-04	-.182E+04	-.535E+04	-.215E+04	-.396E+03	.314E+01	-.284E+01
20	CEN	.412E-02	-.313E-01	-.680E-02	.567E-04	-.354E-04	-.174E+04	-.554E+04	-.219E+04	-.365E+03	.304E+01	-.190E+01
21	CEN	.475E-02	-.336E-01	-.570E-02	.526E-04	-.240E-04	-.176E+04	-.577E+04	-.226E+04	-.298E+03	.275E+01	-.125E+01
22	CEN	.536E-02	-.349E-01	-.236E-02	.565E-04	-.927E-05	-.171E+04	-.581E+04	-.226E+04	-.120E+03	.288E+01	-.472E+00
23	CEN	.277E-03	-.440E-02	-.383E-02	-.273E-03	-.143E-03	-.270E+03	-.718E+03	-.297E+03	-.183E+03	-.131E+02	-.686E+01
24	CEN	-.140E-02	-.531E-02	-.545E-02	-.178E-03	-.179E-03	-.851E+03	-.137E+04	-.666E+03	-.360E+03	-.118E+02	-.118E+02
25	CEN	-.405E-02	-.334E-02	.257E-04	-.904E-04	-.201E-03	-.142E+04	-.132E+04	-.822E+03	.191E+01	-.669E+01	-.149E+02
26	CEN	-.806E-02	-.623E-03	-.130E-01	.494E-04	-.199E-03	-.135E+04	-.660E+03	-.602E+03	-.599E+03	.228E+01	-.922E+01
27	CEN	-.616E-02	-.222E-02	-.551E-02	.477E-04	-.163E-03	-.175E+04	-.119E+04	-.881E+03	-.386E+03	.334E+01	-.114E+02
28	CEN	-.491E-02	-.955E-02	-.296E-01	.687E-04	-.159E-03	-.125E+04	-.161E+04	-.859E+03	-.117E+04	.272E+01	-.631E+01
29	CEN	.800E-03	-.152E-01	-.158E-01	.129E-03	-.116E-03	-.106E+04	-.277E+04	-.115E+04	-.845E+03	.690E+01	-.617E+01
30	CEN	.376E-02	-.223E-01	-.120E-01	.104E-03	-.669E-04	-.103E+04	-.366E+04	-.141E+04	-.604E+03	.528E+01	-.338E+01
31	CEN	.527E-02	-.264E-01	-.907E-02	.105E-03	-.368E-04	-.101E+04	-.403E+04	-.151E+04	-.434E+03	.504E+01	-.176E+01
32	CEN	.573E-02	-.271E-01	-.490E-02	.109E-03	-.724E-06	-.975E+03	-.409E+04	-.152E+04	-.232E+03	.515E+01	-.343E-01
33	CEN	.558E-02	-.282E-01	-.423E-02	.661E-04	.618E-05	-.111E+04	-.439E+04	-.165E+04	-.206E+03	.322E+01	.300E+00
34	CEN	-.907E-03	-.138E-02	-.155E-02	-.351E-03	-.227E-03	-.263E+03	-.311E+03	-.172E+03	-.781E+02	-.176E+02	-.114E+02
35	CEN	-.197E-02	-.204E-02	.825E-03	-.239E-03	-.387E-03	-.579E+03	-.587E+03	-.350E+03	.481E+02	-.139E+02	-.226E+02
36	CEN	-.326E-02	-.234E-02	.481E-02	-.213E-04	-.353E-03	-.913E+03	-.800E+03	-.514E+03	.295E+03	-.130E+01	-.216E+02
37	CEN	-.102E-01	.203E-02	-.175E-01	-.151E-03	-.347E-03	-.126E+04	-.317E+03	-.473E+03	-.676E+03	-.582E+01	-.134E+02
38	CEN	-.602E-02	-.421E-04	-.498E-02	.127E-03	-.440E-03	-.122E+04	-.529E+03	-.524E+03	-.287E+03	.733E+01	-.253E+02
39	CEN	-.240E-02	-.112E-01	-.502E-01	.419E-03	-.274E-03	-.741E+03	-.126E+04	-.600E+03	-.148E+04	.123E+02	-.806E+01
40	CEN	-.849E-04	-.142E-01	-.318E-01	.108E-03	-.303E-03	-.731E+03	-.169E+04	-.725E+03	-.108E+04	.366E+01	-.103E+02
41	CEN	.310E-02	-.185E-01	-.180E-01	.364E-03	-.179E-03	-.716E+03	-.255E+04	-.978E+03	-.762E+03	.155E+02	-.757E+01
42	CEN	.382E-02	-.200E-01	-.104E-01	.292E-03	.190E-04	-.787E+03	-.305E+04	-.115E+04	-.495E+03	.139E+02	.899E+00
43	CEN	.355E-02	-.169E-01	-.427E-02	.258E-03	.280E-03	-.649E+03	-.269E+04	-.100E+04	-.213E+03	.129E+02	.140E+02
44	CEN	.263E-02	-.161E-01	-.186E-02	-.699E-04	.206E-03	-.840E+03	-.295E+04	-.114E+04	-.105E+03	-.393E+01	.116E+02
45	CEN	.935E-03	.181E-03	.313E-02	-.774E-03	-.520E-03	.175E+03	.100E+03	.825E+02	.154E+03	-.382E+02	-.257E+02
46	CEN	.340E-02	-.146E-02	.116E-01	-.106E-02	-.800E-03	.416E+03	.112E-01	.125E+03	.497E+03	-.453E+02	-.342E+02
47	CEN	-.189E-03	.818E-03	.109E-01	-.862E-03	-.156E-02	.246E+02	.112E+03	.411E+02	.477E+03	-.376E+02	-.680E+02
48	CEN	-.515E-02	.147E-02	-.107E-01	-.124E-02	-.194E-02	-.683E+03	-.111E+03	-.238E+03	-.462E+03	-.534E+02	-.837E+02
49	CEN	-.432E-02	.391E-03	-.312E-02	-.687E-03	-.241E-02	-.685E+03	-.241E+03	-.278E+03	-.147E+03	-.324E+02	-.114E+03
50	CEN	-.124E-02	-.278E-02	-.339E-01	-.629E-03	-.294E-02	-.293E+03	-.399E+03	-.208E+03	-.117E+04	-.216E+02	-.101E+03
51	CEN	-.349E-03	-.889E-02	-.431E-01	.212E-02	-.144E-02	-.459E+03	-.998E+03	-.437E+03	-.136E+04	.668E+02	-.454E+02
52	CEN	-.149E-03	-.111E-01	-.156E-01	.996E-03	-.251E-03	-.702E+03	-.160E+04	-.690E+03	-.639E+03	.408E+02	-.103E+02
53	CEN	.175E-03	-.967E-02	-.697E-02	.665E-03	.457E-04	-.801E+03	-.194E+04	-.821E+03	-.402E+03	.383E+02	.263E+01
54	CEN	-.225E-02	-.836E-02	-.841E-02	.858E-03	.285E-03	-.141E+04	-.225E+04	-.110E+04	-.581E+03	.593E+02	.197E+02
55	CEN	-.173E-02	-.766E-02	-.355E-03	-.411E-03	.112E-03	-.129E+04	-.217E+04	-.104E+04	-.262E+02	-.303E+02	.825E+01
56	CEN	-.374E-02	-.759E-02	-.574E-01	.532E-02	-.266E-02	-.206E+03	-.271E+03	-.143E+03	-.483E+03	.448E+02	-.224E+02
57	CEN	-.200E-02	-.926E-02	-.171E-01	.126E-02	.313E-03	-.976E+03	-.166E+04	-.790E+03	-.797E+03	.589E+02	.146E+02
58	CEN	-.244E-02	-.449E-02	-.303E-02	.810E-03	-.228E-03	-.101E+04	-.129E+04	-.690E+03	-.201E+03	.538E+02	-.152E+02
59	CEN	-.245E-02	-.282E-02	-.188E-02	.125E-02	.249E-03	-.820E+03	-.867E+03	-.506E+03	-.120E+03	.797E+02	.159E+02
60	CEN	-.363E-02	-.362E-02	.181E-02	-.588E-03	.455E-03	-.131E+04	-.130E+04	-.783E+03	.131E+03	-.423E+02	.327E+02
61	CEN	-.872E-02	-.726E-02	-.597E-01	.790E-02	-.221E-02	-.468E+03	-.435E+03	-.271E+03	-.674E+03	.893E+02	-.249E+02
62	CEN	-.123E-02	-.983E-02	-.121E-01	.820E-03	.786E-03	-.605E+03	-.115E+04	-.526E+03	-.385E+03	.260E+02	.249E+02

63	CEN	-.220E-02	-.444E-02	-.557E-02	.612E-03	-.449E-03	-.905E+03	-.119E+04	-.628E+03	-.351E+03	.386E+02	-.284E+02
64	CEN	-.353E-02	-.188E-02	-.702E-03	.179E-02	.239E-04	-.963E+03	-.754E+03	-.515E+03	-.446E+02	.113E+03	.152E+01
65	CEN	-.539E-02	-.219E-02	.790E-03	-.747E-03	.433E-03	-.156E+04	-.111E+04	-.803E+03	.558E+02	-.528E+02	.306E+02
66	CEN	-.116E-01	-.222E-02	-.605E-01	.102E-01	-.296E-02	-.386E+03	-.221E+03	-.182E+03	-.532E+03	.900E+02	-.261E+02
67	CEN	-.173E-02	-.232E-02	-.350E-02	.473E-03	.124E-04	-.992E+03	-.112E+04	-.632E+03	-.364E+03	.492E+02	.129E+01
68	CEN	-.255E-02	-.648E-03	-.118E-02	.621E-03	.358E-03	-.176E+04	-.108E+04	-.851E+03	-.210E+03	.110E+03	.636E+02
69	CEN	-.448E-02	-.551E-03	.578E-03	.208E-02	.814E-03	-.966E+03	-.506E+03	-.442E+03	.338E+02	.122E+03	.477E+02
70	CEN	-.702E-02	-.932E-03	.263E-03	-.886E-03	.403E-03	-.177E+04	-.943E+03	-.815E+03	.180E+02	-.606E+02	.275E+02
71	CEN	-.130E-01	-.891E-03	-.599E-01	.121E-01	-.297E-02	-.272E+03	-.131E+03	-.121E+03	-.349E+03	.706E+02	-.173E+02
72	CEN	-.198E-02	-.846E-03	-.396E-03	.414E-03	.382E-04	-.146E+04	-.106E+04	-.757E+03	-.707E+02	.739E+02	.683E+01
73	CEN	-.440E-02	.437E-03	-.120E-02	.797E-03	.752E-04	-.173E+04	-.593E+03	-.696E+03	-.140E+03	.932E+02	.879E+01
74	CEN	-.529E-02	.396E-03	-.643E-04	.217E-02	.482E-03	-.264E+04	-.966E+03	-.108E+04	-.949E+01	.321E+03	.712E+02
75	CEN	-.851E-02	.190E-03	.152E-03	-.101E-02	.388E-03	-.192E+04	-.786E+03	-.811E+03	.990E+01	-.653E+02	.252E+02

BENDING ELEMENT FORCES AND MOMENTS

EL.NO.	1-P1	1-P2	1-P3	1-M1	1-M2	1-M3	2-P1	2-P2	2-P3	2-M1	2-M2	2-M3
76	.204E+04	.130E+03	-.758E+03	-.191E-02	.143E+01	.808E-01	-.204E+04	-.130E+03	.758E+03	.191E-02	.133E+04	.228E+
77	.313E+04	.306E+03	-.684E+03	-.321E-02	-.132E+04	-.228E+03	-.313E+04	-.306E+03	.684E+03	.321E-02	.252E+04	.762E+0
78	.450E+04	-.122E+04	.149E+04	-.441E-02	-.252E+04	-.762E+03	-.450E+04	.122E+04	-.149E+04	.441E-02	-.566E+03	-.176E+
79	.671E+04	-.110E+04	.276E+04	-.302E-03	.564E+03	.176E+04	-.671E+04	.110E+04	-.276E+04	.302E-03	-.627E+04	-.405E+0
80	.242E+04	-.283E-03	-.133E-02	-.104E-03	.675E-02	-.167E-02	-.242E+04	.283E-03	.133E-02	.104E-03	.412E-02	-.641E-0
81	.213E+04	-.415E-04	.621E-03	-.104E-03	-.412E-02	.641E-03	-.213E+04	.415E-04	-.621E-03	.104E-03	-.949E-03	-.979E-
82	.236E+04	.680E-03	-.177E-03	-.104E-03	.949E-03	.979E-03	-.236E+04	-.680E-03	.177E-03	.104E-03	.497E-03	.457E-
83	.329E+04	-.263E-02	.874E-04	-.104E-03	-.497E-03	-.457E-02	-.329E+04	.263E-02	-.874E-04	.104E-03	-.216E-03	-.169E-
84	-.104E+04	-.784E+03	-.128E+03	-.101E+01	-.180E+01	-.108E+00	.104E+04	.784E+03	.128E+03	.101E+01	.223E+03	-.137E+
85	.217E+04	-.118E+04	.210E+03	-.597E+00	-.222E+03	.137E+04	-.217E+04	.118E+04	-.210E+03	.597E+00	-.145E+03	-.344E+
86	.358E+04	.861E+03	-.737E+03	.569E+00	.144E+03	.344E+04	-.358E+04	-.861E+03	.737E+03	-.569E+00	.138E+04	-.166E+
87	.519E+04	.517E+03	.565E+03	.577E-01	-.138E+04	.166E+04	-.519E+04	-.517E+03	-.565E+03	-.577E-01	.212E+03	-.592E+0
88	.860E+03	.434E+03	.154E+03	.310E+00	-.209E+03	.591E+03	-.860E+03	-.434E+03	-.154E+03	-.310E+00	-.395E+00	-.106E+
89	-.269E+04	.175E+03	.503E+04	.170E+00	-.218E+03	-.100E+01	.269E+04	-.175E+03	-.503E+04	-.170E+00	-.606E+04	.219E+
90	.632E+03	-.123E+03	-.147E+05	.313E+04	.301E+05	.303E+03	-.632E+03	.123E+03	.147E+05	-.313E+04	-.116E+05	-.458E+0
91	.775E+03	.535E+02	-.859E+04	.313E+04	.116E+05	.460E+03	-.775E+03	-.535E+02	.859E+04	-.313E+04	-.690E+03	-.395E+0
92	.194E+04	.191E+03	-.120E+05	.405E+04	.877E+04	.239E+03	-.194E+04	-.191E+03	.120E+05	-.405E+04	.634E+04	-.106E+
93	.243E+05	.339E+03	.186E+04	.385E-03	-.244E+05	.317E+04	-.243E+05	-.339E+03	-.186E+04	-.385E-03	.572E+04	.217E+
94	.708E+04	.802E+02	.468E+03	.163E-02	-.800E+04	.935E+03	-.708E+04	-.802E+02	-.468E+03	-.163E-02	.332E+04	-.133E+0
95	.376E+05	-.277E+02	.971E+03	-.109E-02	-.572E+04	-.217E+03	-.376E+05	.277E+02	-.971E+03	.109E-02	-.399E+04	-.597E+
96	.224E+05	.121E+02	.335E+03	.689E-03	-.332E+04	.133E+03	-.224E+05	-.121E+02	-.335E+03	-.689E-03	-.220E+02	-.115E+
97	.526E+05	.380E+01	-.464E+03	.160E-03	.399E+04	.597E+02	-.526E+05	-.380E+01	.464E+03	-.160E-03	.651E+03	-.217E+
98	.373E+05	.360E+00	-.321E+03	-.357E-03	.220E+02	.115E+02	-.373E+05	-.360E+00	.321E+03	.357E-03	.319E+04	-.791E+
99	.551E+05	.217E+01	.651E+02	-.760E-04	-.651E+03	.217E+02	-.551E+05	-.217E+01	-.651E+02	.760E-04	-.390E-01	.518E-0
100	.453E+05	.791E+00	.319E+03	-.211E-03	-.319E+04	.791E+01	-.453E+05	-.791E+00	-.319E+03	.211E-03	-.368E-02	-.891E-

DEVELOPED FORCES AND MOMENTS PER FOOT OF ABUTMENT

FOR AXIAL THRUST TENSION IS POSITIVE

FOR BENDING MOMENT TENSION ON THE BACKFILL SIDE IS POSITIVE

AXIAL THRUST OF ABUT STEM RIGHT ABOVE TIE-ROD LEVEL -.313E+04 LB/FT
AXIAL THRUST OF ABUT STEM RIGHT BELOW TIE-ROD LEVEL -.450E+04 LB/FT
SHEAR FORCE .149E+04 LB/FT
BENDING MOMENT -.252E+04 FT-LB/FT
AXIAL THRUST OF ABUT STEM AT THE BASE -.671E+04 LB/FT
SHEAR FORCE .276E+04 LB/FT
BENDING MOMENT .627E+04 FT-LB/FT

Section V - Listing of Program

A complete listing of the program is given in this section. The program is written in FORTRAN 5 for IBM-XT compatible personal computer. The compilation is done with Microsoft Fortran Compiler 4.1.

The program requires approximately the following memory space.

Input file	:	1,000 bytes
Output file	:	50,000 bytes
.FOR program	:	100,000 bytes
.EXE program	:	290,000 bytes

It is therefore necessary to store/run the program from the hard disk.

```
C
C    THIS PROGRAM DESIGNS THE TIE-ROD ANCHOR SYSTEM WITH DRILLED-IN
C    CONCRETE ANCHOR FOR REINFORCING DISTRESSED BRIDGE ABUTMENT BASED
C    ON LIMITING EQUILIBRIUM METHOD AND ANALYZES THE SYSTEM BY A
C    GENERALIZED 3-DIMENSIONAL PLANE STRAIN INCREMENTAL AND ITERATIVE
C    FINITE ELEMENT METHOD DEVELOPED BY S.BANG, SDSM&T, AUG. 1988
C
C
C INPUT: IF DATA FILE EXISTS, PROGRAM WILL READ DATA FROM EXISTING FILE
C      AND ANY CHANGE CAN BE MADE. A NEW DATA FILE IS THEN CREATED
C      IF DATA FILE DOES NOT EXIST, PROGRAM WILL CREATE ONE
C OUTPUT:IF OUTPUT FILE EXISTS, NEW RESULTS WILL OVERWRITE IT
C      IF OUTPUT FILE DOES NOT EXIST, PROGRAM WILL CREATE ONE
C
C
C    FILE  5: KEYBOARD INPUT
C    FILE  6: MONITOR OUTPUT
C    FILE  7: OUTPUT FILE
C    FILE  8: NEW INPUT DATA FILE
C    FILE  9: EXISTING INPUT DATA FILE
C    FILE 10: EDITTED INPUT DATA FILE
C
C
      COMMON /BLK1/AE(10),EIY(10),E(10),POIS(10),EX(102),GX(102),INR
      COMMON /BLK17/EIZ(10),GJX(10),IPILE,XPILE,INCR,XXS(102,5),
     +          YYS(102,5),IFILE
      COMMON /BLK12/ZZS(102,5),XYT(102,5),XZT(102,5),YZT(102,5)
      COMMON /BLK7/DUN(10,9),PA
      COMMON /BLK10/ID(100,6),PN(6),FFX(10),FFY(10),TTX(102),TTY(102)
      COMMON/BLK11/AX,GAM,T1,T2,T3
      COMMON/BLK13/CD
      CHARACTER TITLE*80
      CHARACTER*12 FILEOUT,FILEIN,FNEW
      CHARACTER  CD*1
      CHARACTER*1 YES/'Y'/
C
C
C     FORMAT STATEMENTS
C
    6 FORMAT(A1)
   10 FORMAT(A80)
   11 FORMAT(A12)
   18 FORMAT(F20.9)
   19 FORMAT(I2)
   20 FORMAT(//1X,A80)
   30 FORMAT(//1X,'**INPUT DATA AS FOLLOWS**',//,
     +            3X,'HEIGHT OF ABUTMENT WALL        =',F10.3,' FT',/,
     +            3X,'DEPTH TO TIE ROD               =',F10.3,' FT',/,
     +      3X,'BACKFILL SLOPE (V/H)           =',F10.3,/,
     +      3X,'SURCHARGE LOADING              =',F10.3,' PSF',/,
     +      3X,'WALL FRICTION ANGLE            =',F10.3,' DEG',/,
     +      3X,'BRIDGE SKEW ANGLE              =',F10.3,' DEG',/,
```

```
     +              3X,'TIE ROD SPACING                =',F10.3,' FT',/,
     +              3X,'ALLOWABLE STRESS OF TIE ROD     =',E10.3,'
PSI',//,
     +        1X,'BACKFILL SOIL PROPERTIES')
   31 FORMAT(/ 3X,'UNIT WEIGHT                  =',F10.3,' PCF',/,
     +        3X,'FRICTION ANGLE               =',F10.3,' DEG',//,
     +        1X,'FOUNDATION SOIL PROPERTIES',/,
     +        3X,'UNIT WEIGHT                  =',F10.3,' PCF',/,
     +        3X,'COHESION                     =',F10.3,' PSF',/,
     +        3X,'FRICTION ANGLE               =',F10.3,' DEG',/,
     +        3X,'UNDRAINED SHEAR STRENGTH      =',F10.3,' PSF',
     +        1X,'AT',F5.1,' FT',//,
     +              1X,'CONCRETE ANCHOR DIAMETER        =',F10.3,'
FT',/,
     +        1X,'FACTOR OF SAFETY             =',F10.3)
   40 FORMAT(//1X,'**OUTPUT DATA AS FOLLOWS**',//,
     +              3X,'MINIMUM DIAMETER OF TIE ROD   =',F10.3,' IN')
   50 FORMAT(//3X,'DEPTH OF CONCRETE ANCHOR FOR SHORT TERM STABILITY=',
     +           F10.3,' FT')
   80 FORMAT(//3X,'**FRICTION ANGLE OF FOUNDATION SOIL CAN NOT BE',
     +          ' ESTIMATED FROM SU',/,3X,'REENTER FOUNDATION SOIL',
     +          ' PROPERTIES')
   90 FORMAT(//3X,'**ESTIMATED FRICTION ANGLE OF FOUNDATION SOIL IS',
     +           F10.3,/3X,'PROBABLY TOO HIGH -- USE CAUTION')
  100 FORMAT(/1X,'HEIGHT OF ABUTMENT WALL IN FT?',\)
  101 FORMAT(/1X,'DEPTH TO TIE ROD FROM GROUND SURFACE IN FT?',\)
  102 FORMAT(/1X,'BACKFILL SLOPE V/H?',\)
  103 FORMAT(/1X,'SURCHARGE LOADING IN PSF?',\)
  110 FORMAT(/1X,'WALL FRICTION ANGLE IN DEG?',\)
  111 FORMAT(/1X,'BRIDGE SKEW ANGLE IN DEG?',\)
  112 FORMAT(/1X,'TIE ROD SPACING IN FT?',\)
  113 FORMAT(/1X,'ALLOWABLE STRESS OF TIE ROD IN PSI?',\)
  114 FORMAT(/1X,'FACTOR OF SAFETY?',\)
  120 FORMAT(/1X,'BACKFILL SOIL PROPERTIES')
  121 FORMAT(/1X,'UNIT WEIGHT IN PCF?',\)
  122 FORMAT(/1X,'SOIL DESIGNATION NUMBER TO USE REFERENCE',/1X,
     +   'IN TWO DIGIT INTEGER BETWEEN 01 AND 36',/1X,
     +        'OR HIT RETURN TO INPUT PARAMETERS
DIRECTLY',/1X,'NUMBER=?',\)
  130 FORMAT(/1X,'FOUNDATION SOIL PROPERTIES')
  131 FORMAT(/1X, 'UNIT WEIGHT IN PCF?',\)
  230 FORMAT(//3X,'SOLUTION DID NOT CONVERGE AFTER', I5,1X,
     +             'ITERATIONS',/,
     +           3X,'ERROR                    =',E10.3,/,
     +                3X,'LENGTH OF TIE ROD          =',F10.3,' FT',/,
     +                3X,'DEPTH OF CONCRETE ANCHOR    =',F10.3,' FT')
  250 FORMAT(//3X,'SOLUTION CONVERGED AFTER',I5,1X,'ITERATIONS',/,
     +           3X,'ERROR                    =',E10.3,/,
     +                3X,'LENGTH OF TIE ROD          =',F10.3,' FT',/,
     +                3X,'DEPTH OF CONCRETE ANCHOR    =',F10.3,' FT')
  260 FORMAT(//3X,'SHORT TERM STABILITY DOES NOT APPLY FOR DEPTH ',
     +                'OF CONCRETE ANCHOR CALCULATION')
  270 FORMAT(3X,'DEPTH OF CONCRETE ANCHOR FOR LONG  TERM STABILITY=',
```

```
   +       F10.3, ' FT')
 290 FORMAT( /1X,'DO YOU LIKE TO INCREASE THE DEPTH OF CONC. ANCHOR',
   + /,1X,'IF SO INPUT NEW DEPTH IN FT OTHERWISE HIT RETURN',
   + /1X,'NEW DEPTH=?',\)
 330 FORMAT(//1X,'MODIFIED RESULTS ARE',//,
   +                3X,'LENGTH OF TIE ROD       =',F10.3,' FT',/,
   +                3X,'DEPTH OF CONCRETE ANCHOR =',F10.3,' FT')
 340 FORMAT( /1X,'ENTER TITLE OF PROBLEM?',\)
 350 FORMAT(/1X,'**DEPTH OF CONCRETE ANCHOR IS LESS THAN HEIGHT OF ',
   +                 'ABUTMENT. INCREASE THE DEPTH AS FOLLOWS')
 360 FORMAT(/1X,'**THE FOLLOWING WILL BE USED IN FINITE ELEMENT ',
   +             'ANALYSIS',//,
   +                4X,'DIAMETER OF TIE ROD   =',F10.3,' IN',/,
   +                4X,'LENGTH OF TIE ROD     =',F10.3,' FT',/,
   +            4X,'SURCHARGE LOADING     =',F10.3,' PSF',/)
 370 FORMAT(/1X,      'DIAMETER OF CONCRETE ANCHOR IN FT',/,
   +              1X,'HIT RETURN IF 2.5 FT IS USED',/1X,'DIAMETER=?',\)
 380 FORMAT(/1X,'NAME OF OUTPUT FILE',/1X,'IF THIS NAME ALREADY ',
   + 'EXISTS RESULTS WILL OVERWRITE ON THE EXISTING FILE',/1X,
   + 'OTHERWISE A NEW OUTPUT FILE WILL BE CREATED',/1X,'NAME=?',\)
 381 FORMAT(/1X,'NEW VALUE OF TIE ROD DIAMETER',
   +           /1X,'OR HIT RETURN TO KEEP SAME
VALUE',/1X,'DIAMETER=?',\)
 382 FORMAT(/1X,'NEW VALUE OF TIE ROD LENGTH',
   +           /1X,'OR HIT RETURN TO KEEP SAME VALUE',/1X,'LENGTH=?',\)
 383 FORMAT(/1X,'NEW VALUE OF SURCHARGE LOADING',
   +           /1X,'OR HIT RETURN TO KEEP SAME
VALUE',/1X,'SURCHARGE=?',\)
 384 FORMAT(/1X,'NAME OF INPUT FILE',/1X,'IF THIS NAME ALREADY EXISTS',

   + ' PROGRAM WILL READ DATA DIRECTLY FROM THIS FILE',/1X,
   + 'IF NOT THE PROGRAM WILL CREATE THE DATA FILE AS YOU ENTER',
   + /1X,'NAME=?',\)
 385 FORMAT(/1X,'DATA WILL BE READ FROM EXISTING FILE',
   +           /1X,'IF NO CHANGE IN DATA NO FURTHER INPUT IS NEEDED',
   + ' AFTER THIS',/1X,'ANY CHANGE IN DATA(Y/N)?',\)
 386 FORMAT(/1X,'NEW DATA FILE IS CREATED')
 387 FORMAT(/1X,'NAME OF NEW DATA FILE AFTER CHANGES?',\)
 388 FORMAT( /1X,'FRICTION ANGLE IN DEGREES?',\)
 389 FORMAT(/1X,'COHESION IN PSF?',\)
 390 FORMAT(/1X,'FRICTION ANGLE IN DEGREES?',\)
 391 FORMAT(/1X,'UNDRAINED STRENGTH IN PSF?',\)
 392 FORMAT(/1X,'UNDRAINED STRENGTH MEASURED AT WHAT DEPTH IN FT?',\)
 393 FORMAT(/1X,'**INPUT COHESION AND FRICTION AS ZERO IF UNKNOWN '
   +        ,'AND TO BE CALCULATED FROM UNDRAINED STRENGTH',/,
   +       1X,'**INPUT UNDRAINED STRENGTH AS ZERO IF UNKNOWN',
   +        ' AND TO BE CALCULATED FROM COHESION AND FRICTION')
 394 FORMAT(//1X,'******* FINAL DESIGN SELECTION *******',
   +      /1X,'TIE ROD DIAMETER            =',F10.3,1X,'IN',
   +      /1X,'TIE ROD LENGTH             =',F10.3,1X,'FT',
   +      /1X,'CONCRETE ANCHOR LENGTH     =',F10.3,1X,'FT',
   +      /1X,'CONCRETE ANCHOR DIAMETER   =',F10.3,1X,'FT',//)
 395 FORMAT(/1X,'**ERROR**REENTER IN INTEGER(S)',\)
C
```

```
C    READ INPUT AND OUTPUT FILE NAMES
C
      WRITE(6,384)
      READ(5,11)FILEIN
      WRITE(6,380)
      READ(5,11)FILEOUT
      OPEN(UNIT=7,FILE=FILEOUT,STATUS='UNKNOWN')
      WRITE(6,340)
C
C    READ TITLE OF THE PROBLEM
C
      READ(5,10)TITLE
      WRITE(7,20)TITLE
C
C    OPEN EXISTING DATA FILE
C
      NAMEI=9
      OPEN(UNIT=NAMEI,FILE=FILEIN,STATUS='OLD',ERR=2)
C
C    READ DATA DIRECTLY FROM EXISTING FILE
C
      IFILE=0
      WRITE(6,385)
      READ(5,6)CD
      IF(CD .NE. YES)GO TO 4
      WRITE(6,387)
      READ(5,11)FNEW
      OPEN(UNIT=10,FILE=FNEW,STATUS='NEW')
      GO TO 4
C
C    NEW DATA FILE IS CREATED
C
    2 IFILE=1
      WRITE(6,386)
      CLOSE(UNIT=NAMEI,STATUS='KEEP')
      OPEN(UNIT=8,FILE=FILEIN,STATUS='NEW')
    4 CONTINUE
C
C    READ DATA
C
      WRITE(6,100)
      IF(IFILE .EQ. 1)GO TO 500
      CALL EDIT1(H)
      GO TO 501
  500 READ(5,*)H
      IF(IFILE .EQ. 1)WRITE(8,*)H
  501 WRITE(6,101)
      IF(IFILE .EQ. 1)GO TO 502
      CALL EDIT1(HPP)
      GO TO 503
  502 READ(5,*)HPP
      IF(IFILE .EQ. 1)WRITE(8,*)HPP
  503 WRITE(6,102)
      IF(IFILE .EQ. 1)GO TO 504
```

```
      CALL EDIT1(SLOPE)
      GO TO 505
  504 READ(5,*)SLOPE
      IF(IFILE .EQ. 1)WRITE(8,*)SLOPE
  505 WRITE(6,103)
      IF(IFILE .EQ. 1)GO TO 506
      CALL EDIT1(Q)
      GO TO 507
  506 READ(5,*)Q
      IF(IFILE .EQ. 1)WRITE(8,*)Q
  507 WRITE(6,110)
      IF(IFILE .EQ. 1)GO TO 508
      CALL EDIT1(DEL)
      GO TO 509
  508 READ(5,*)DEL
      IF(IFILE .EQ. 1)WRITE(8,*)DEL
  509 WRITE(6,111)
      IF(IFILE .EQ. 1)GO TO 510
      CALL EDIT1(TH)
      GO TO 511
  510 READ(5,*)TH
      IF(IFILE .EQ. 1)WRITE(8,*)TH
  511 WRITE(6,112)
      IF(IFILE .EQ. 1)GO TO 512
      CALL EDIT1(SH)
      GO TO 513
  512 READ(5,*)SH
      IF(IFILE .EQ. 1)WRITE(8,*)SH
  513 WRITE(6,113)
      IF(IFILE .EQ. 1)GO TO 514
      CALL EDIT1(FA)
      GO TO 515
  514 READ(5,*)FA
      IF(IFILE .EQ. 1)WRITE(8,*)FA
  515 WRITE(6,114)
      IF(IFILE .EQ. 1)GO TO 516
      CALL EDIT1(FS)
      GO TO 517
  516 READ(5,*)FS
      IF(IFILE .EQ. 1)WRITE(8,*)FS
  517 CONTINUE
      TTH=TH
C
C    CONCRETE ANCHOR DIMENSION - 2.5 FT CYLINDER UNLESS SPECIFIED
C
      WRITE(6,370)
      IF(IFILE .EQ. 1)GO TO 518
      CALL EDIT2(D)
      GO TO 519
  518 READ(5,18)D
      IF(D .EQ. 0.)D=2.5
      IF(IFILE .EQ. 1)WRITE(8,18)D
C
C    READ DATA
```

```
C
  519 WRITE(6,120)
      WRITE(6,122)
      K=1
      IF(IFILE .EQ. 1)GO TO 520
      CALL EDIT3(KCODE)
      GO TO 521
  520 READ(5,19,ERR=551)KCODE
      GO TO 552
  551 WRITE(6,395)
      GO TO 520
  552 CONTINUE
      IF(IFILE .EQ. 1)WRITE(8,19)KCODE
  521 IF(KCODE .EQ. 0)GO TO 14
      CALL DUNPRT(KCODE,K)
      CALL SOIL(KCODE,K)
      GAM1=-FFY(K)
      PH1=DUN(K,6)
      GO TO 15
   14 WRITE(6,121)
      IF(IFILE .EQ. 1)GO TO 522
      CALL EDIT1(GAM1)
      GO TO 533
  522 READ(5,*)GAM1
      IF(IFILE .EQ. 1)WRITE(8,*)GAM1
  533 WRITE(6,390)
      IF(IFILE .EQ. 1)GO TO 534
      CALL EDIT1(PH1)
      GO TO 15
  534 READ(5,*)PH1
      IF(IFILE .EQ. 1)WRITE(8,*)PH1
   15 CONTINUE
    7 WRITE(6,130)
      WRITE(6,122)
      K=1
      IF(IFILE .EQ. 1)GO TO 523
      CALL EDIT3(KCODE)
      GO TO 524
  523 READ(5,19,ERR=553)KCODE
      GO TO 554
  553 WRITE(6,395)
      GO TO 523
  554 CONTINUE
      IF(IFILE .EQ. 1)WRITE(8,19)KCODE
  524 IF(KCODE .EQ. 0)GO TO 16
      CALL DUNPRT(KCODE,K)
      CALL SOIL(KCODE,K)
      GAM2=-FFY(K)
      PH2=DUN(K,6)
      C2=DUN(K,5)
      SU=0.
      GO TO 17
   16 WRITE(6,393)
      WRITE(6,131)
```

```
      IF(IFILE .EQ. 1)GO TO 525
      CALL EDIT1(GAM2)
      GO TO 535
 525  READ(5,*)GAM2
      IF(IFILE .EQ. 1)WRITE(8,*)GAM2
 535  WRITE(6,389)
      IF(IFILE .EQ. 1)GO TO 536
      CALL EDIT1(C2)
      GO TO 537
 536  READ(5,*)C2
      IF(IFILE .EQ. 1)WRITE(8,*)C2
 537  WRITE(6,390)
      IF(IFILE .EQ. 1)GO TO 538
      CALL EDIT1(PH2)
      GO TO 539
 538  READ(5,*)PH2
      IF(IFILE .EQ. 1)WRITE(8,*)PH2
 539  WRITE(6,391)
      IF(IFILE .EQ. 1)GO TO 540
      CALL EDIT1(SU)
      GO TO 541
 540  READ(5,*)SU
      IF(IFILE .EQ. 1)WRITE(8,*)SU
 541  WRITE(6,392)
      IF(IFILE .EQ. 1)GO TO 542
      CALL EDIT1(ZT)
      GO TO 543
 542  READ(5,*)ZT
      IF(IFILE .EQ. 1)WRITE(8,*)ZT
 543  CONTINUE
  17  CONTINUE
      PH2=PH2*0.0174533
      PI=4.*ATAN(1.0)
      ITEST=0
C
C    IF SU IS NOT KNOWN, ESTIMATE FROM C2 AND PH2
C
      IF(SU .EQ. 0. .AND. C2 .NE. 0.) SU=GAM2*H/2.
     +        *(1.-TAN(PI/4.-PH2/2.)**2)+C2*TAN(PI/4.-PH2/2.)
C
C    IF C2 AND PH2 ARE NOT KNOWN, ESTIMATE FROM SU ASSUMING NORMALLY
C    CONSOLIDATED SOIL (C2=0.)
C
      PH2=PH2/0.0174533
      IF(C2 .NE. 0. .OR. PH2 .NE. 0.)GO TO 60
      TEM=1.-2.*SU/GAM2/ZT
      IF(TEM .GT. 0.)GO TO 70
      WRITE(6,80)
      GO TO 7
  70  PH2=PI/2.-2.*ATAN(SQRT(TEM))
      PH2=PH2/0.0174533
      IF(PH2 .GT. 50.)WRITE(6,90)PH2
  60  WRITE(7,30)H,HPP,SLOPE,Q,DEL,TH,SH,FA
      WRITE(7,31)GAM1,PH1,GAM2,C2,PH2,SU,ZT,D,FS
```

```
C
C    CONVERT ANGLES INTO RADIANS
C
      TH=TH*0.0174533
      DEL=DEL*0.0174533
      PH1=PH1*0.0174533
      PH2=PH2*0.0174533
C
C    CALCULATE AT-REST LATERAL EARTH PRESSURE
C
      XK=1.-SIN(PH1)
      PR=(GAM1*H**2/2.+Q*H)*XK*COS(DEL)
C
C    TIE ROD TENSION - FACTOR OF SAFETY IS CONSIDERED
C
      T=FS*PR/COS(TH)
      TMAX=T*SH
C
C    TIE ROD DIAMETER
C
      DA=SQRT(4.*TMAX/FA/PI)
      WRITE(7,40)DA
C
C    SHORT TERM STABILITY
C
      TEM=(3.*SU*D)**2+4.*TMAX*(GAM2*D/2.+SU/4.)
      H1=(-3.*SU*D+SQRT(TEM))/(GAM2*D+0.5*SU)
      IF(SU .EQ. 0.)H1=0.
      IF(H1 .NE. 0.)WRITE(7,50)H1
      IF(H1 .EQ. 0.)WRITE(7,260)
C
C    LONG TERM STABILITY
C    SOLUTION ITERATES UNTIL CONVERGENCE ERROR OF 0.01 OR
C    MAXIMUM ITERATION OF 20
C
      ITMAX=20
      XL=0.
      ITNO=-1
  140 ITNO=ITNO+1
      IF(ITNO .EQ. 0)GO TO 150
      IF(ITNO .EQ. ITMAX)GO TO 220
      ERR=ABS((XL-XXL)/XL)
      IF(ERR .LT. 0.01)GO TO 240
  150 XXL=XL
      PU1=0.
      PU2=0.
C
C    NUMERICAL INTEGRATION OF ULTIMATE SOIL RESISTANCE
C    CONSIDERING BOTH LONG AND SHORT PILE BEHAVIORS
C
      Z=0.
  160 Z=Z+1.
      ZD=(Z-0.5)/D
      AX=COEFA(ZD)
```

```
C
C   AT ITERATION 0, USE FOUNDATION SOIL PROPERTIES FOR ESTIMATION
C
      IF(ITNO .EQ. 0)GO TO 170
      IF(Z .LT. Z1)GO TO 180
C
C   FOUNDATION SOIL
C
  170 GAM=GAM2
      PH=PH2
      GO TO 190
C
C   BACKFILL SOIL PROPERTIES
C
  180 GAM=GAM1
      PH=PH1
  190 CONTINUE
C
C   ULTIMATE SOIL RESISTANCE
C
      BE=PI/4.+PH/2.
      AL=PH/2.
      YK=1.-SIN(PH)
      E1=TAN(BE)
      E2=TAN(PH)
      E3=TAN(BE-2.*AL)
      E4=TAN(BE-PH)
      E5=TAN(AL)
      E6=SIN(BE)
      T1=E3**2*(E1**8-1.)+YK*(E2*E1**4)
      T2=YK*E2*E6/E4/COS(AL)+YK*E1*(E2*E6-E5)+E1**2*E5/E4
      T3=E1/E4-E3**2
C
C   NUMERICAL INTEGRATION
C
      CALL GAUSS(1,Z,A1)
      CALL GAUSS(2,Z,A2)
      PU1=PU1+A1*D
      PU2=PU2+A2*D
C
C   ULTIMATE RESISTANCE IS SMALLER OF LONG AND SHORT PILE BEHAVIORS
C   PU1 - SHORT PILE BEHAVIOR
C   PU2 - LONG PILE BEHAVIOR
C
      PU=PU1
      IF(PU2 .LT. PU)PU=PU2
C
C   CHECK IF THE CONCRETE ANCHOR IS DEEP ENOUGH
C
      IF(PU .GT. TMAX)GO TO 200
      GO TO 160
C
C   LENGTH OF TIE ROD
C
```

```
  200 H2=Z
      HP=H1
      IF(H2 .GT. HP)HP=H2
  310 CONTINUE
      F1=TAN(PI/4.-PH1/2.)
      F2=TAN(PI/4.+PH1/2.)
      F3=TAN(PI/2.-PH1)
      F4=TAN(PI/4.+PH2/2.)
      TEM=H*F3
      HT=H*(1.-SLOPE*F1)/(1.+SLOPE*F2)
      IF(HP .GT. HT)GO TO 210
C
C    CONCRETE ANCHOR LIES ENTIRELY WITHIN BACKFILL
C
      XL=H*F1+HP*F2
      IF(XL .LT. TEM)XL=TEM
      Z1=H-XL*SLOPE
      IF(ITEST .EQ. 1)GO TO 320
      GO TO 140
C
C    CONCRETE ANCHOR LIES WITHIN BACKFILL AND FOUNDATION SOIL
C
  210 XL=(F1+F2-F4*(1.-SLOPE*F1))*H/(1.+SLOPE*F2)+HP*F4
      IF(XL .LT. TEM)XL=TEM
      Z1=H-XL*SLOPE
      IF(ITEST .EQ. 1)GO TO 320
      GO TO 140
C
C    ACCOUNT FOR SKEW ANGLE
C
  220 XL=XL/COS(TH)
      WRITE(7,270)H2
      WRITE(7,230)ITNO,ERR,XL,HP
      GO TO 280
  240 XL=XL/COS(TH)
      WRITE(7,270)H2
      WRITE(7,250)ITNO,ERR,XL,HP
C
C
C    INCREASE THE DEPTH OF CONCRETE ANCHOR IF DESIRED
C
C
  280 IF(HP .GT. H)GO TO 285
      WRITE(6,350)
  285 CONTINUE
      HPH=HP
      ITEST=0
      WRITE(6,290)
      IF(IFILE .EQ. 1)GO TO 526
      CALL EDIT2(HP)
      GO TO 527
  526 READ(5,18)HP
      IF(IFILE .EQ. 1)WRITE(8,18)HP
  527 IF(HP .NE. 0.)ITEST=1
```

```
      IF(ITEST .EQ. 0)GO TO 400
      GO TO 310
  320 XL=XL/COS(TH)
      WRITE(7,330)XL,HP
      HPH=HP
      GO TO 280
C
C
C    GENERALIZED 3-D PLANE STRAIN FINITE ELEMENT ANALYSIS
C
C
  400 CONTINUE
      WRITE(6,360)DA,XL,Q
      WRITE(6,381)
      IF(IFILE .EQ. 1)GO TO 528
      CALL EDIT2(XDA)
      DA=XDA
      GO TO 529
  528 READ(5,18)XDA
      IF(XDA .EQ. 0.)XDA=DA
      IF(XDA .NE. 0.)DA=XDA
      IF(IFILE .EQ. 1)WRITE(8,18)XDA
  529 WRITE(6,382)
      IF(IFILE .EQ. 1)GO TO 530
      CALL EDIT2(XXL)
      XL=XXL
      GO TO 531
  530 READ(5,18)XXL
      IF(XXL .EQ. 0.)XXL=XL
      IF(XXL .NE. 0.)XL=XXL
      IF(IFILE .EQ. 1)WRITE(8,18)XXL
  531 WRITE(6,383)
      IF(IFILE .EQ. 1)GO TO 532
      CALL EDIT2(XQ)
      Q=XQ
      GO TO 410
  532 READ(5,18)XQ
      IF(XQ .EQ. 0.)XQ=Q
      IF(XQ .NE. 0.)Q=XQ
      IF(IFILE .EQ. 1)WRITE(8,18)XQ
  410 CONTINUE
      WRITE(7,394)DA,XL,HPH,D
      XL=XL*COS(TH)
      CALL GPS(H,HPP,Q,TTH,XL,SH,DA,D,HPH)
 1000 STOP
      END
C
C
      SUBROUTINE GAUSS(IC,Z,AREA)
C
C    THIS SUBROUTINE PERFORMS TWO POINT GAUSSIAN NUMERICAL INTEGRATION
C    STARTING WITH 2 SUBINTERVALS.  CONTINUE TO DOUBLE-INCREASE THE
C    SUBINTERVALS UNTIL ERROR IS LESS THAN 1 % OR 50 ITERATIONS
C
```

```
      COMMON/BLK11/AX,GAM,T1,T2,T3
      DIMENSION C(2),U(2)
C
C    WEIGHTING FUNCTIONS
C
      C(1)=1.
      C(2)=1.
C
C    GAUSSIAN POINTS
C
      U(1)=0.57735
      U(2)=-0.57735
      D=2.5
      B=Z
      A=Z-1.
      IG=0
      M=2
    5 AM=M
      DELX=(B-A)/AM
      X2=A
      AREA=0.
      DO 10 K=1,M
      X1=X2
      X2=X1+DELX
      DO 10 J=1,2
      X=(DELX*U(J)+X1+X2)/2.
      IF(IC .EQ. 2)F=AX*GAM*X*T1
      IF(IC .EQ. 1)F=AX*GAM*X**2/D*(T2+T3*D/X)
   10 AREA=AREA+C(J)*F
      AREA=AREA*DELX/2.
      IF(IG)12,12,13
   12 AREA1=AREA
      M=2*M
      IG=1
      GO TO 5
   13 IF(ABS((AREA-AREA1)/AREA1)-0.01)15,15,16
   16 IF(M-50)12,12,15
   15 RETURN
      END
C
C
      FUNCTION COEFA(ZD)
C
C    THIS SUBROUTINE CALCULATES THE COEFFICIENT A IN ULTIMATE SOIL
C    RESISTANCE EXPRESSION
C
      IF(ZD .GE. 5.)GO TO 10
      COEFA=0.035777*(5.-ZD)**2.5+0.88
      GO TO 20
   10 COEFA=0.88
   20 RETURN
      END
C
C
```

```
      SUBROUTINE GPS(HH,HPP,QQ,ANGLE,XXL,Z10,Z11,Z12,ZDM)
C
C
C     GENERALIZED PLANE STRAIN THREE DIMENSIONAL ANALYSIS
C     BY FINITE ELEMENT METHOD.  INCLUDED ARE CONTINUUM
C     ELEMENT, REINFORCED CONTINUUM AND 3-D BEAM-COLUMN ELEMENT
C
C     THIS PROGRAM HAS FOLLOWING LIMITATIONS
C     MAXIMUM NO. OF NODES     =100
C     MAXIMUN NO. OF ELEMENTS  =102
C     MAXIMUM NO. OF MATERIALS = 10
C     MAXIMUM NO. OF UNKNOWNS  =323
C     MAXIMUM BANDWIDTH        =100
C
C
C    COMMON AND DIMENSION STATEMENTS
C
      COMMON /BLK1/AE(10),EIY(10),E(10),POIS(10),EX(102),GX(102),INR
      COMMON /BLK17/EIZ(10),GJX(10),IPILE,XPILE,INCR,XXS(102,5),
     +         YYS(102,5),IFILE
      COMMON /BLK12/ZZS(102,5),XYT(102,5),XZT(102,5),YZT(102,5)
      COMMON /BLK2/XQ(4),YQ(4),B(6,12),XN(4),ALP,EST,PHP,PHR,BA(6,6),
     +        BAP (6,6)
      COMMON /BLK3/LM(102,6),X(100),Y(100),ARE(102),EF(4,12)
      COMMON /BLK4/FX,FY,IOPT,EP(12),EK(12,12),TX,TY,ICONT
      COMMON /BLK5/DISN(100,6),SIGMA(6)
      COMMON /BLK6/SMX(5),SMY(5),SMZ(5),TXY(5),TXZ(5),TYZ(5),STR(5,6)
      COMMON /BLK7/DUN(10,9),PA
      COMMON /BLK8/A1,A2,A3,A4,A5,A6,B1,B2,C1,C2,C3,C4,C5,C6,C7,C8,C9,
     +        C10,C11,C12,C13,D1,D2,E1,E2,E3,E4,E5,E6,E7,F1,F2,F3,

     +        F4,F5,G1,SSH,DDA,DDM
      COMMON /BLK9/GK(323,100),GP(323)
      COMMON /BLK10/ID(100,6),PN(6),FFX(10),FFY(10),TTX(102),TTY(102)
      COMMON/BLK13/CD
      DIMENSION IEQ(100,6),TITLE(20),DGP(323),MNO(10),GGP(323),SG(6),
     +     IIQ(100,6),IID(100,6)
      CHARACTER*1 YES/'Y'/
      CHARACTER  CD*1
      CHARACTER ICONT*1,  ICNEQ*1 ,IOPT*1
C
C    FORMAT STATEMENTS
C
    3 FORMAT(//,36X,'NODAL POINT DATA'//1X,'NODAL POINT COORDINATES',
     +  10X,'BOUNDARY CONDITION CODES',18X,'GLOBAL EQUATION NUMBER',
     +      //35X,'**IN INCREMENT',I4,'**',//1X,
     +  'NODE',5X,'X(N)',5X,'Y(N)',4X,'D-X',3X,'D-Y',3X,'D-Z',2X,
     +  'TH-X',2X,'TH-Y',2X,'TH-Z',9X,'D-X',3X,'D-Y',3X,'D-Z',3X,
     +  'TH-X',2X,'TH-Y',2X,'TH-Z',/)
    4 FORMAT( 3X,'**TOTAL NUMBER OF EQUATIONS =',I4,' IN INCR=',I3)
    5 FORMAT(//,3X,'**BANDWIDTH OF MATRIX =',I4,' IN INCR=',I3)
    6 FORMAT(A1)
    7 FORMAT(F20.9)
    8 FORMAT(I1)
```

```
 26 FORMAT(I4,2F10.3,6I6,6X,6I6)
 31 FORMAT(//,31X,'NODAL POINT LOAD TO BE INCLUDED IN INCREMENT 2',
   +       //,5X,'NODE',15X,'PN(X)',15X,
   +  'PN(Y)',15X,'PN(Z)',15X,'M(X)',16X,'M(Y)',16X,'M(Z)',/)
 38 FORMAT(I9,6E20.5)
 53 FORMAT(                        /1X,'MAT.',4X,'AE',5X,'GJ1',
   +  5X,'EI2',5X,'EI3',7X,'E',5X,'POIS',4X,'FX',9X,'FY',/)
 57 FORMAT(/,10X,'MATERIAL PROPERTIES',//,1X,'MAT.',
   +  3X,'K',7X,'KUR',8X,'N',6X,'RF',
   +  6X,'C',6X,'PHI',5X,'DPHI',5X,'KB',7X,'M',5X,'PA',6X,'FX',8X,
   +  'FY',/)
 62 FORMAT(I4,1X,5E8.2,F5.2,2X,F7.4,2X,F9.4)
108 FORMAT(I4,46X,9F6.1,1X,F6.1,F7.4,2X,F9.4)
109 FORMAT(I4,1X,10F8.2,F9.4,1X,F9.4)
206 FORMAT(//,11X,'SOLUTION DID NOT CONVERGE AFTER',I4,
   +  ' ITERATIONS'/11X,'RESULTING ERROR IS',E13.5)
208 FORMAT(//,11X,'SOLUTION CONVERGED AFTER',I4,' ITERATIONS',
   +  /11X,'RESULTING ERROR IS',E13.5)
210 FORMAT(I5,2F10.3,I5,4F10.3)
216 FORMAT(I5,13F5.1)
222 FORMAT(//3X,'**BANDWIDTH IS TOO BIG --- CHANGE THE SECOND INTEGER'
   +  ,' OF GK ARRAY IN BLK9 AND NBAND ACCORDINGLY',//)
223 FORMAT(//3X,'**TOO MANY UNKNOWNS --- CHANGE THE FIRST INTEGER',
   +  ' OF GK AND GP ARRAY IN BLK9 DGP AND GGP ARRAY AND NUNKN ',
   +  'ACCORDINGLY',//)
350 FORMAT(//,50X,'ELEMENT STRAINS AND STRESSES',//,2X,'EL.NO.',
   +  2X,'LOC',6X,'DEXX',6X,'DEYY',
   +  6X,'DGXY',6X,'DGXZ',6X,'DGYZ',7X,'SXX',7X,'SYY',7X,'SZZ',7X,
   +  'TXY',7X,'TXZ',7X,'TYZ')
573 FORMAT(2X,'***MAT',I3,1X,'HAS CONSTANT POISSON RATIO OF',F7.3)
575 FORMAT(//55X,'DISPLACEMENTS AT NODES',//,5X,'NODE',12X,
   +  'X-TRAN',14X,'Y-TRAN',14X,'Z-TRAN',14X,'X-ROT',14X,'Y-ROT',14X,

   +  'Z-ROT',/)
580 FORMAT(I9,6E20.5)
642 FORMAT(10X,'REINFORCEMENT STRESS =',E12.4)
653 FORMAT(//,3X,'**DEVELOPED FORCES AND MOMENTS PER',
   +        ' FOOT OF ABUTMENT**',/,
   + 1X,'FOR AXIAL THRUST TENSION IS POSITIVE',/1X,
   + 'FOR BENDING MOMENT TENSION ON THE BACKFILL SIDE IS POSITIVE',//)

654 FORMAT(1X,'AXIAL THRUST OF ABUT STEM RIGHT ABOVE TIE-ROD LEVEL',
   +          4X,E10.3,1X,'LB/FT')
655 FORMAT(1X,'AXIAL THRUST OF ABUT STEM RIGHT BELOW TIE-ROD LEVEL',
   +          4X,E10.3,1X,'LB/FT')
656 FORMAT(1X,'SHEAR FORCE',44X,E10.3,1X,'LB/FT')
657 FORMAT(1X,'BENDING MOMENT',41X,E10.3,1X,'FT-LB/FT',/1X,//)
659 FORMAT(1X,'AXIAL THRUST OF ABUT STEM AT THE BASE',
   +          18X,E10.3,1X,'LB/FT')
660 FORMAT(1X,'SHEAR FORCE',44X,E10.3,1X,'LB/FT')
662 FORMAT(1X,'BENDING MOMENT',41X,E10.3,1X,'FT-LB/FT',/1X,//)
700 FORMAT(//3X, 'RELAXATION                  =',F5.2,/,3X,
   +            'MAXIMUM ERROR FOR ITERATION =',F5.2,/,3X,
   +            'MAXIMUM NO. OF ITERATION    =',I3,//)
```

```
901 FORMAT(//,25X,'ELEMENT DATA', //,
   +       10X,' IN INCR=1 ONLY ELEMENT 1 THRU 55 ARE CONSIDERED',//,
   +  1X,'ELEM',2X,'NODE1',1X,'NODE2',1X,'NODE3',1X,'NODE4',4X,
   +  'REINF',3X,'MAT',7X,'ANGLE',7X,'TX',7X,'TY',/)
903 FORMAT(5I6,I9,I6,F12.2,2F9.2)
906 FORMAT(2F10.3)
907 FORMAT(////,1X,'**GENERALIZED PLANE STRAIN FINITE ELEMENT '
   +   ,'ANALYSIS**')
908 FORMAT(/1X,'DO YOU NEED STRAINS AND STRESSES ALONG THE SIDES ',
   +        'OF ELEMENT(Y/N)?',\)
910 FORMAT(/1X,'TOTAL WIDTH OF ABUTMENT BASE IN FT?',\)
911 FORMAT(/1X,'FRONT ROW PILE BATTER TOWARD BERM IN V/H?',\)
912 FORMAT(/1X,'DIST FROM FRONT OF BASE TO FRONT PILES IN FT?',\)
914 FORMAT(/1X,     'GIRDER SUPPORT LOAD IN LBS PER FT?',\)
915 FORMAT(/1X,'SOIL PROPERTIES BEHIND ABUTMENT',/,
   +         1X,'ENTER KEL=1 FOR ELASTIC SOIL',/,
   +        11X,'ZERO FOR NONLINEAR SOIL',/,
   +         1X,'ENTER SOIL DESIGNATION NUMBER TO USE REFERENCE',/,

   +             5X,'OR ENTER ZERO TO INPUT PARAMETERS DIRECTLY',/1X,
   +               'TWO NUMBERS=?',\)
916 FORMAT(/1X,'ENTER DUNCAN SOIL PARAMETERS IN THE ORDER OF',/,
   +        7X,'K KUR N RF C PHI DPHI KB M POIS GX GY',/,
   +       10X,'**NOTE POIS OF NONZERO IS FOR CONSTANT POISSON',
   +     1X,'RATIO',/)
917 FORMAT(/1X,'SOIL PROPERTIES BELOW ABUTMENT TO HALF DEPTH OF PILE'
   +        ,/,1X,'ENTER KEL=1 FOR ELASTIC SOIL',/,
   +       11X,'ZERO FOR NONLINEAR SOIL',/,
   +        1X,'ENTER SOIL DESIGNATION NUMBER TO USE REFERENCE',/,

   +        5X,'OR ENTER -1 IF SAME AS PREVIOUS SOIL',/,
   +        5X,'OTHERWISE ENTER ZERO TO INPUT PARAMETERS',
   +         ' DIRECTLY',/1X,'TWO NUMBERS=?',\)
918 FORMAT(/1X,'SOIL PROPERTIES BELOW HALF DEPTH OF PILE',/,
   +        1X,'ENTER KEL=1 FOR ELASTIC SOIL',/,
   +       11X,'ZERO FOR NONLINEAR SOIL',/,
   +        1X,'ENTER SOIL DESIGNATION NUMBER TO USE REFERENCE',/,

   +        5X,'OR ENTER -1 IF SAME AS PREVIOUS SOIL',/,
   +        5X,'OTHERWISE ENTER ZERO TO INPUT PARAMETERS ',
   +           'DIRECTLY',/1X,'TWO NUMBERS=?',\)
919 FORMAT(/1X,'FRONT ROW PILE PROPERTIES',/,
   +           1X,'ENTER 1 FOR CIRCULAR PILE ZERO FOR OTHER PILE',
   +          /1X,'NUMBER=?',\)
920 FORMAT(/1X,'REAR PILE PROPERTIES'/,
   +           1X,'ENTER 1 FOR CIRCULAR PILE ZERO FOR OTHER PILE',
   +          /1X,'NUMBER=?',\)
921 FORMAT(/1X,'ABUTMENT PROPERTIES',/,
   +           1X,   'THICKNESS IN FT?',\)
922 FORMAT(/1X,'TIE ROD PROPERTIES',/,
   +           1X,  'MATERIAL MODULUS IN PSI?',\)
924 FORMAT(/1X,'ABUTMENT BASE PROPERTIES',/,
   +           1X,   'THICKNESS IN FT?',\)
926 FORMAT(/1X,'DO YOU NEED OUTPUT OF NODE CONDITION(Y/N)?',\)
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  927 FORMAT(/1X,'DO YOU NEED OUTPUT OF MATERIAL PROPERTIES(Y/N)?',\)
  928 FORMAT(/1X,'DO YOU NEED OUTPUT OF ELEMENT INFORMATION(Y/N)?',\)
  929 FORMAT(/1X,'DO YOU NEED OUTPUT OF ALL NODAL DISPLACEMENTS IN',
     +              ' INCR=',I4,1X,'(Y/N)?',\)
  930 FORMAT(/1X,'DO YOU NEED OUTPUT OF ELEMENT STRESS AND STRAIN',
     +          '(Y/N)?',\)
  931 FORMAT(/1X,'DO YOU NEED OUTPUT OF NODAL LOAD(Y/N)?',\)
  932 FORMAT(//3X,'**HORIZONTAL WALL MOVEMENT**',/,
     +           5X,'AT THE TOP        =',F10.5,' FT.',/,
     +           5X,'AT THE TIE-ROD    =',F10.5,' FT.',/,
     +           5X,'AT THE BASE       =',F10.5,' FT.')
  933 FORMAT( 3X,'**NOTE THAT THE CALCULATED DISPLACEMENTS',
     +              ' WILL NOT BE SUMMED IN INCR=2',/)
  934 FORMAT(/1X,'SOIL YOUNGS MODULUS?',\)
  935 FORMAT(/,10X,'MATERIAL PROPERTIES',//,1X,'MAT.',10X,'E',10X,'POIS'
     +        ,10X,'FY')
  936 FORMAT(5X,'**SOLUTION HAS TWO INCREMENTS',/,
     +         7X,'IN INCR 1 ONLY FOUNDATION SOIL STRESSES ARE ',
     +        'CALCULATED')
  937 FORMAT(5X,'**SOLUTION HAS ONE INCREMENT')
  938 FORMAT(/,I4,5X,E10.3,5X,F7.3,5X,F8.2)
  941 FORMAT(/1X,'RELAXATION FACTOR',
     +        /1X,'HIT RETURN IF DEFAULT IS USED',/1X,'RF=?',\)
  943 FORMAT(/1X,'ERROR ALLOWED DURING ITERATION',
     +        /1X,'HIT RETURN IF DEFAULT IS USED',/1X,'ERROR=?',\)
  945 FORMAT(/1X,'ENTER 1 FOR INCREMENTAL ANALYSIS',
     +        /1X,'HIT RETURN FOR NONINCREMENTAL ANALYSIS',
     +        /1X,'NUMBER=?',\)
  947 FORMAT(/1X,'DIST FROM FRONT OF ABUTMENT TO GIRDER SUPPORT IN FT',
     +         /1X,'**GIRDER SUPPORT MUST BE BETWEEN PILES**',
     +         /1X,'DISTANCE=?',\)
  948 FORMAT(/1X,'HORIZ EXTENSION OF BERM IN FRONT OF ABUTMENT IN FT',
     +         /1X,'**MUST BE GREATER THAN ZERO**',/1X,'EXTENSION=?',\)

  949 FORMAT(/1X,'SLOPE OF SOIL BEYOND BERM IN H/V?',\)
  950 FORMAT(/1X,'REAR ROW PILE BATTER TOWARD BACKFILL IN V/H',/,
     +         1X,'HIT RETURN IF SAME AS FRONT ROW PILE',/1X,
     +         'BATTER=?',\)
  951 FORMAT(/1X,    'LENGTH OF FRONT ROW PILES IN FT?',\)
  952 FORMAT(/1X,'LENGTH OF REAR ROW PILES IN FT',/,
     +         1X,'HIT RETURN IF SAME AS FRONT ROW PILE',/1X,
     +         'LENGTH=?',\)
  953 FORMAT(/1X,   'ENTER ZERO FOR POINT BEARING PILES',/,
     +     1X, '     1 FOR FRICTION PILES',/1X,'NUMBER=?',\)
  960 FORMAT(/1X,'MAXIMUM NUMBER OF ITERATIONS (BETWEEN 1 AND 9)',
     +        /1X,'HIT RETURN IF DEFAULT IS USED',/1X,'NUMBER=?',\)
  961 FORMAT(/1X,'DIST FROM REAR EDGE OF BASE TO REAR PILES IN FT?',\)
  962 FORMAT(/1X,'SOIL POISSON RATIO?',\)
  963 FORMAT(/1X,'SOIL UNIT WEIGHT?',\)
  964 FORMAT(/1X,'**ERROR**REENTER IN INTEGER(S)',\)
C
C   INITIALIZATION
C
      DO 2 I=1,6
```

```
    2 PN(I)=0.
      WRITE(7,907)
      A1=HH
      E1=HPP
      E2=XXL
      IOPT=0
      SSH=Z10
      DDA=Z11
      DDM=Z12
      NUNKN=323
      NBAND=100
      MAXNP=100
C
C    ATMOSPHERIC PRESSURE IN PSF
C
      PA=2116.8
      DO 530 II = 1,NUNKN
      DO 520 JJ=1,NBAND
  520 GK(II,JJ)=0.
      GGP(II)=0.
  530 GP(II)=0.
C
C    DEFAULT BOUNDARY CONDITIONS
C
      DO 527 II=1,MAXNP
      DO 525 KK=1,3
      ID(II,KK)=0
  525 ID(II,KK+3)=1
  527 CONTINUE
C
C    READ DATA FOR NONLINEAR INCREMENTAL ANALYSIS
C
      WRITE(6,960)
      IF(IFILE .EQ. 1)GO TO 111
      CALL EDIT6(ITMAX)
      GO TO 112
  111 READ(5,8,ERR=551)ITMAX
      GO TO 554
  551 WRITE(6,964)
      GO TO 111
  554 CONTINUE
      IF(ITMAX .EQ. 0)ITMAX=9
      IF(IFILE .EQ. 1)WRITE(8,8)ITMAX
  112 WRITE(6,941)
      IF(IFILE .EQ. 1)GO TO 113
      CALL EDIT2(RELAX)
      GO TO 114
  113 READ(5,7)RELAX
      IF(RELAX .EQ. 0.)RELAX=0.8
      IF(IFILE .EQ. 1)WRITE(8,7)RELAX
  114 WRITE(6,943)
      IF(IFILE .EQ. 1)GO TO 115
      CALL EDIT2(ERMAX)
      GO TO 116
```

```
  115 READ(5,7)ERMAX
      IF(ERMAX .EQ. 0.)ERMAX=0.05
      IF(IFILE .EQ. 1)WRITE(8,7)ERMAX
  116 WRITE(6,945)
      IF(IFILE .EQ. 1)GO TO 117
      CALL EDIT6(INR)
      GO TO 118
  117 READ(5,8,ERR=552)INR
      GO TO 555
  552 WRITE(6,964)
      GO TO 117
  555 CONTINUE
      IF(INR .EQ. 0)INR=0
      IF(IFILE .EQ. 1)WRITE(8,8)INR
  118 ALP=0.
      EST=0.
      PHP=0.
      PHR=0.
      WRITE(7,700)RELAX,ERMAX,ITMAX
      IF(INR .EQ. 1)WRITE(7,936)
      IF(INR .NE. 1)WRITE(7,937)
C
C    CONVERT ANGLES INTO DEGREES
C
      PHP=PHP*0.0174533
      PHR=PHR*0.0174533
      IF(ALP .NE. 0.)CALL ROTATE
      NUMNP=0
C
C    INPUT NODAL POINT DATA AND GENERATE NODAL POINTS ON STRAIGHT LINE
C
      WRITE(6,910)
      IF(IFILE .EQ. 1)GO TO 119
      CALL EDIT1(A3)
      GO TO 120
  119 READ(5,*)A3
      IF(IFILE .EQ. 1)WRITE(8,*)A3
  120 WRITE(6,947)
      IF(IFILE .EQ. 1)GO TO 121
      CALL EDIT1(B1)
      GO TO 122
  121 READ(5,*)B1
      IF(IFILE .EQ. 1)WRITE(8,*)B1
  122 WRITE(6,948)
      IF(IFILE .EQ. 1)GO TO 123
      CALL EDIT1(D1)
      GO TO 124
  123 READ(5,*)D1
      IF(IFILE .EQ. 1)WRITE(8,*)D1
  124 WRITE(6,949)
      IF(IFILE .EQ. 1)GO TO 125
      CALL EDIT1(D2)
      GO TO 126
  125 READ(5,*)D2
```

```
      IF(IFILE .EQ. 1)WRITE(8,*)D2
  126 IF(D1 .LT. 0.01)D1=0.01
      WRITE(6,911)
      IF(IFILE .EQ. 1)GO TO 127
      CALL EDIT2(C3)
      GO TO 128
  127 READ(5,7)C3
      IF(IFILE .EQ. 1)WRITE(8,7)C3
  128 WRITE(6,950)
      IF(IFILE .EQ. 1)GO TO 129
      CALL EDIT2(C7)
      GO TO 130
  129 READ(5,7)C7
      IF(C7 .EQ. 0.)C7=C3
      IF(IFILE .EQ. 1)WRITE(8,7)C7
  130 WRITE(6,951)
      IF(IFILE .EQ. 1)GO TO 131
      CALL EDIT2(C9)
      GO TO 132
  131 READ(5,7)C9
      IF(IFILE .EQ. 1)WRITE(8,7)C9
  132 WRITE(6,952)
      IF(IFILE .EQ. 1)GO TO 133
      CALL EDIT2(C10)
      GO TO 134
  133 READ(5,7)C10
      IF(C10 .EQ. 0.)C10=C9
      IF(IFILE .EQ. 1)WRITE(8,7)C10
  134 WRITE(6,953)
      IF(IFILE .EQ. 1)GO TO 135
      CALL EDIT6(IPILE)
      GO TO 136
  135 READ(5,8,ERR=553)IPILE
      GO TO 558
  553 WRITE(6,964)
      GO TO 135
  558 CONTINUE
      IF(IFILE .EQ. 1)WRITE(8,8)IPILE
  136 C3=1./C3
      C7=1./C7
      XPILE=1.
      IF(IPILE .EQ. 1)XPILE=1.5
      WRITE(6,912)
      IF(IFILE .EQ. 1)GO TO 137
      CALL EDIT1(C4)
      GO TO 138
  137 READ(5,*)C4
      IF(IFILE .EQ. 1)WRITE(8,*)C4
  138 WRITE(6,961)
      IF(IFILE .EQ. 1)GO TO 150
      CALL EDIT1(C8)
      GO TO 151
  150 READ(5,*)C8
      IF(IFILE .EQ. 1)WRITE(8,*)C8
```

```
  151 CONTINUE
      F2=ZDM-HPP
      CALL AUTO(1,NUMNP,K,NUMEL,ANGLE)
C
C     BOUNDARY CONDITIONS
C
      CALL AUTO(2,NUMNP,K,NUMEL,ANGLE)
C
C     CHANGE ID ARRAY TO GLOBAL EQN NUMBERS IN INCR=2 OR LAST INCREMENT
C
      WRITE(6,926)
      IF(IFILE .EQ. 1)GO TO 139
      CALL EDIT7(ICNEQ)
      GO TO 19
  139 READ(5,6)ICNEQ
      IF(IFILE .EQ. 1)WRITE(8,6)ICNEQ
   19 NEQ=0
      INCR=2
      IF(INR .NE. 1)INCR=1
      IF(ICNEQ .EQ. YES)WRITE(7,3)INCR
      DO 30 N=1,NUMNP
      DO 25 I=1,6
C
C     SKIP TRIVIAL EQUATIONS
C
      IF(ID(N,I).GT.0) GO TO 23
      NEQ=NEQ+1
      IEQ(N,I)=NEQ
      GO TO 25
   23 IEQ(N,I)=0
   25 CONTINUE
      IF(ICNEQ .NE. YES)GO TO 30
      WRITE(7,26) N,X(N),Y(N),(ID(N,I),I=1,6),(IEQ(N,I),I=1,6)
   30 CONTINUE
      WRITE(7,4) NEQ,INCR
      IF(NEQ .GT. NUNKN)WRITE(6,223)
      NNEQ=NEQ
      DO 33 I=1,100
      DO 33 J=1,6
      IIQ(I,J)=IEQ(I,J)
   33 IID(I,J)=ID(I,J)
C
C
C     READ NODAL POINT LOAD AND PUT IN GLOBAL LOAD VECTOR
C
C
      WRITE(6,914)
      IF(IFILE .EQ. 1)GO TO 140
      CALL EDIT1(PN(2))
      GO TO 141
  140 READ(5,*)PN(2)
      IF(IFILE .EQ. 1)WRITE(8,*)PN(2)
  141 NODE=29
      PN(2)=-PN(2)
```

```
      WRITE(6,931)
      IF(IFILE .EQ. 1)GO TO 142
      CALL EDIT7(ICONT)
      GO TO 143
  142 READ(5,6)ICONT
      IF(IFILE .EQ. 1)WRITE(8,6)ICONT
  143 IF(ICONT .NE. YES)GO TO 49
      WRITE(7,31)
      WRITE(7,38)NODE,(PN(J),J=1,6)
   49 CONTINUE
      DO 50 I=1,6
      IG=IEQ(NODE,I)
      IF(IG .EQ. 0)GO TO 50
      GGP(IG)=0.
      GGP(IG)=PN(I)
   50 CONTINUE
C
C     READ TABLE OF MATERIAL PROPERTIES
C     K=1-3 SOILS
C       4-9 STRUCTURAL ELEMENTS
C
   51 CONTINUE
      WRITE(6,927)
      IF(IFILE .EQ. 1)GO TO 144
      CALL EDIT7(ICONT)
      GO TO 145
  144 READ(5,6)ICONT
      IF(IFILE .EQ. 1)WRITE(8,6)ICONT
  145 K=0
   68 K=K+1
      IF(K .EQ. 1)WRITE(6,915)
      IF(K .EQ. 2)WRITE(6,917)
      IF(K .EQ. 3)WRITE(6,918)
      IF(K .EQ. 4)WRITE(6,919)
      IF(K .EQ. 5)WRITE(6,920)
      IF(K .EQ. 6)WRITE(6,921)
      IF(K .EQ. 7)WRITE(6,922)
      IF(K .EQ. 9)WRITE(6,924)
      IF(K .LE. 3)GO TO 110
C
C     BEAM ELEMENTS
C
      CALL AUTO(3,NUMNP,K,NUMEL,ANGLE)
      IF(ICONT .NE. YES)GO TO 55
      IF(K .EQ. 4)WRITE(7,53)
      WRITE(7,62)K,AE(K),GJX(K),EIY(K),EIZ(K),E(K),POIS(K),FFX(K),FFY(K)

   55 CONTINUE
      MNO(K)=ITYP
      IF(K .EQ. 9)GO TO 69
      GO TO 68
  110 IF(IFILE .EQ. 1)GO TO 146
      CALL EDIT8(KEL,KCODE)
      GO TO 147
```

```
  146 READ(5,*,ERR=557)KEL,KCODE
      GO TO 556
  557 WRITE(6,964)
      GO TO 146
  556 CONTINUE
      IF(IFILE .EQ. 1)WRITE(8,*)KEL,KCODE
  147 CONTINUE
      IF(KCODE .EQ. 0 .OR. KCODE .EQ. -1)GO TO 302
      CALL DUNPRT(KCODE,K)
      CALL SOIL(KCODE,K)
  302 CONTINUE
      IF(KCODE .NE. 0)GO TO 56
      IF(KEL .EQ. 1)GO TO 59
      WRITE(6,916)
C
C    CONTINUUM ELEMENTS - NONLINEAR
C
      IF(IFILE .EQ. 1)GO TO 148
      CALL EDIT9(K)
      GO TO 149
  148 READ(5,*)(DUN(K,I),I=1,9),POIS(K),FFX(K),FFY(K)
      IF(IFILE .EQ. 1)WRITE(8,*)(DUN(K,I),I=1,9),POIS(K),FFX(K),FFY(K)
  149 GO TO 58
   59 WRITE(6,934)
C
C    CONTINUUM ELEMENTS - LINEAR
C
      IF(IFILE .EQ. 1)GO TO 152
      CALL EDIT1(E(K))
      GO TO 153
  152 READ(5,*)E(K)
      IF(IFILE .EQ. 1)WRITE(8,*)E(K)
  153 WRITE(6,962)
      IF(IFILE .EQ. 1)GO TO 154
      CALL EDIT1(POIS(K))
      GO TO 155
  154 READ(5,*)POIS(K)
      IF(IFILE .EQ. 1)WRITE(8,*)POIS(K)
  155 WRITE(6,963)
      IF(IFILE .EQ. 1)GO TO 156
      CALL EDIT1(FFY(K))
      GO TO 157
  156 READ(5,*)FFY(K)
      IF(IFILE .EQ. 1)WRITE(8,*)FFY(K)
  157 CONTINUE
      DUN(K,1)=E(K)/2116.8
      DUN(K,2)=DUN(K,1)*2
      DO 61 I=3,9
   61 DUN(K,I)=0.
      FFX(K)=0.
   58 CONTINUE
   56 CONTINUE
      IF(KCODE .NE. -1)GO TO 54
      DO 52 I=1,9
```

```
      IF(ITYP.NE.1) GO TO 301
C
C    MODULUS AND POISSON RATIO OF ELASTIC SOIL
C
      EX(NE)=E(MX)
      GX(NE)=POIS(MX)
      GO TO 401
C
C IN INCR=1 AND ITERATION ZERO CALCULATE STRESS FROM DEPTH OF SOIL
C
  301 IF(LM(NE,3) .EQ. 0 )GO TO 401
      XC=0.
      YC=0.
      DO 194 J=1,4
      N=LM(NE,J)
      XC=XC+0.25*X(N)
  194 YC=YC+0.25*Y(N)
      HC=0.
      HCPP=0.
      SY=0.
      DO 195 N=1,NUMEL
      DO 196 JJ=1,4
      J=JJ
      K=J+1
      IF(K .GT. 4)K=1
      J=IABS(LM(N,J))
      K=IABS(LM(N,K))
      XJ=X(J)
      XK=X(K)
      IF((XJ-XK) .EQ. 0.)GO TO 196
      IF(XC .GT. XJ .AND. XC .GT. XK)GO TO 196
      IF(XC .LT. XJ .AND. XC .LT. XK)GO TO 196
      HCP=Y(J)+(XC-XJ)/(XK-XJ)*(Y(K)-Y(J))-YC
      IF(HCP .GT. HC)HC=HCP
  196 CONTINUE
      SY=-(HC-HCPP)*FFY(LM(NE,6))+SY
      HCPP=HC
  195 CONTINUE
      GU=0.3
      SX=GU*SY/(1.0-GU)
      SDD=SY-SX
      MX=LM(NE,6)
C
C    ESTIMATE NONLINEAR SOIL MODULUS AND POISSON RATIO
C
      CALL DUNT(SX,SDD,EZ,GU,MX)
      EX(NE)=EZ
      GX(NE)=GU
      IF(POIS(MX) .NE. 0.)GX(NE)=POIS(MX)
  401 CONTINUE
C
C    INCREMENT STARTS
C
C    FOR ANALYSIS WITH TWO INCREMENTS (INR=1)
```

```
C    IN INCR=1 FOUNDATION SOIL STRESSES ARE CALCULATED
C    WITH NO DISPLACEMENTS
C    IN INCR=2 BACKFILL AND STRUCTURES ARE ADDED
C
      INCR=0
C
C    INITIALIZE TOTAL ACCUMULATED STRESSES
C
      DO 403 II=1,102
      DO 403 N=1,5
      XXS(II,N)=0.
      YYS(II,N)=0.
      ZZS(II,N)=0.
      XYT(II,N)=0.
      XZT(II,N)=0.
  403 YZT(II,N)=0.
  402 INCR=INCR+1
      IF(INR .NE. 1 .AND. INCR .EQ. 2)RETURN
      IF(INR .EQ. 1 .AND. INCR .EQ. 3)RETURN
      IF(INR .NE. 1)GO TO 417
C
C    NUMBER OF ELEMENTS IS SET
C
      IF(INCR .EQ. 1)NUMEL=55
      IF(INCR .EQ. 2 .AND. IPILE .EQ. 1)NUMEL=100
      IF(INCR .EQ. 2 .AND. IPILE .NE. 1)NUMEL=102
      GO TO 418
  417 IF(IPILE .EQ. 1)NUMEL=100
      IF(IPILE .NE. 1)NUMEL=102
  418 CONTINUE
C
C    BOUNDARY CONDITIONS CHANGED
C
      IF(INR .NE. 1)GO TO 416
      IF(INCR .EQ. 1)GO TO 404
C
C    RESTORE BOUNDARY CONDITIONS AND IEQ ARRAY IN INCR=2
C
      NEQ=NNEQ
      DO 411 I=1,100
      DO 411 J=1,6
      IEQ(I,J)=IIQ(I,J)
  411 ID(I,J)=IID(I,J)
      GO TO 416
C
C    BOUNDARY CONDITIONS IN INCR=1
C
  404 CONTINUE
      DO 405 I=1,24
      DO 405 J=1,6
  405 ID(I,J)=1
      DO 410 J=4,6
      DO 406 I=27,31
  406 ID(I,J)=1
```

```
      DO 407 I=35,47,12
  407 ID(I,J)=1
      DO 408 I=40,76,12
  408 ID(I,J)=1
      DO 409 I=42,78,12
  409 ID(I,J)=1
  410 CONTINUE
C
C    CHANGE ID ARRAY INTO GLOBAL EQUATION NUMBERS IN INCR=1
C
      NEQ=0
      IF(ICNEQ .EQ. YES)WRITE(7,3)INCR
      DO 414 N=1,NUMNP
      DO 412 I=1,6
C
C    SKIP TRIVIAL EQUATIONS
C
      IF(ID(N,I).GT.0) GO TO 413
      NEQ=NEQ+1
      IEQ(N,I)=NEQ
      GO TO 412
  413 IEQ(N,I)=0
  412 CONTINUE
      IF(ICNEQ .NE. YES)GO TO 414
      WRITE(7,26) N,X(N),Y(N),(ID(N,I),I=1,6),(IEQ(N,I),I=1,6)
  414 CONTINUE
      WRITE(7,4) NEQ,INCR
      IF(NEQ .GT. NUNKN)WRITE(6,223)
  416 CONTINUE
C
C    ITERATION STARTS
C
      DO 201 I=1,NUNKN
  201 DGP(I)=0.
      ITNO=0
  202 ITNO=ITNO+1
      ISTOP=0
      DO 531 II=1,NUNKN
      DO 521 JJ=1,NBAND
  521 GK(II,JJ)=0.
  531 GP(II)=GGP(II)
C
C    NO GIRDER LOADING IN INCR=1
C
      IF(INR .NE. 1)GO TO 533
      IF(INCR .EQ. 2)GO TO 533
      DO 532 II=1,NUNKN
  532 GP(II)=0.
  533 CONTINUE
C
C    ADD ELEMENT STIFFNESS AND LOAD TO GLOBAL ASSEMBLY FOR COMPACTED
C    STORAGE
C
      DO 300 NE=1,NUMEL
```

```
      FX=FFX(LM(NE,6))
      FY=FFY(LM(NE,6))
      TX=TTX(NE)
      TY=TTY(NE)
      IRE=0
C
C    ELEMENT STIFFNESS MATRIX AND LOAD VECTOR ARE CALULATED
C    FROM SUBROUTINE
C
      L=4
      IF(LM(NE,3) .EQ. 0)L=2
      GO TO (85,85,95,95),L
   85 CALL BECOL(IRE,NE,NDEL,NDFPN,ISTOP)
      GO TO 96
   95 CALL QUAD(IRE,NE,NDEL,NDFPN,ISTOP)
   96 I=0
      DO 300 NDI=1,NDEL
      NODEI=LM(NE,NDI)
      DO 300 NFI=1,NDFPN
      I=I+1
      IG=IEQ(NODEI,NFI)
      IF(IG.EQ.0) GO TO 300
      J=0
      DO 100 NDJ=1,NDEL
      NODEJ=LM(NE,NDJ)
      DO 100 NFJ=1,NDFPN
      J=J+1
      JG=IEQ(NODEJ,NFJ)
      IF(JG.LT.IG) GO TO 100
      JGC=JG-IG+1
      IF(JGC.GT.MB) MB=JGC
      IF(MB .GT. NBAND)WRITE(6,222)
      GK(IG,JGC)=GK(IG,JGC)+EK(I,J)
  100 CONTINUE
      GP(IG)=GP(IG)+EP(I)
  300 CONTINUE
      IF(ITNO.GT.1) GO TO 501
      WRITE(7,5) MB,INCR
C
C    SOLVE FOR UNKNOWN DISPLACEMENTS(COMPACTED SOLVER)
C
  501 IFLAG=0
      CALL CSOLVE(NEQ,MB,200,100,IFLAG)
C
C     DISPLACEMENTS AT NODES
C
      DO 560 N=1,NUMNP
      DO 560 I=1,6
      NQ=IEQ(N,I)
      IF(NQ.EQ.0) GO TO 550
      DISN(N,I)=GP(NQ)
      GO TO 560
  550 DISN(N,I)=0.
  560 CONTINUE
```

```
C
C    NEED FOR ADDITIONAL ITERATION CHECKED
C    JSTOP=0 FOR  LINEAR SOILS ONLY
C    ISTOP=1 ITERATION TERMINATES
C
      JSTOP=0
      DO 661 I=1,NUMEL
      ITYP=MNO(LM(I,6))
  661 IF(ITYP.NE.1) JSTOP=1
      IF(JSTOP.EQ.0) ISTOP=1
      ERR=0.
      DU1=0.
C
C    ERROR DURING ITERATION - SECOND VECTOR NORM
C
      DO 203 I=1,NEQ
      ERR=(GP(I)-DGP(I))**2+ERR
  203 DU1=DU1+GP(I)**2
      IF(DU1.EQ.0.) DU1=0.0000001
      ERR=SQRT(ERR/DU1)
      IF(JSTOP .EQ. 0)GO TO 939
      IF(ERR.LT.ERMAX) GO TO 207
      IF(ITNO.EQ.ITMAX) GO TO 205
      DO 204 I=1,NEQ
  204 DGP(I)=GP(I)
      ISTOP=0
      GO TO 939
  205 WRITE(7,206) ITNO,ERR
      ISTOP=1
      GO TO 939
  207 WRITE(7,208) ITNO,ERR
      ISTOP=1
  939 CONTINUE
C
C    PRINT DISPLACEMENTS AT NODES
C
      IF(ISTOP .EQ. 0)GO TO 579
      WRITE(6,929)INCR
      IF(IFILE .EQ. 1)GO TO 160
      CALL EDIT7(ICONT)
      GO TO 161
  160 READ(5,6)ICONT
      IF(IFILE .EQ. 1)WRITE(8,6)ICONT
  161 IF(ICONT .NE. YES)GO TO 578
      WRITE(7,575)
      IF(INR .EQ. 1 .AND. INCR .EQ. 1)WRITE(7,933)
      DO 576 N=1,NUMNP
  576 WRITE(7,580)N,(DISN(N,I),I=1,6)
  578 CONTINUE
C
C    HORIZONTAL ABUTMENT DISPLACEMENT IN INCR=2
C
      IF(INR .EQ. 1 .AND. INCR .EQ. 1)GO TO 577
      WRITE(7,932)DISN(1,1),DISN(13,1),DISN(31,1)
```

```
  577 CONTINUE
C
C   RECOVERY OF ELEMENT STRAINS AND STRESSES (MOMENT AND THRUST)
C
      WRITE(6,930)
      IF(IFILE .EQ. 1)GO TO 162
      CALL EDIT7(ICONT)
      GO TO 163
  162 READ(5,6)ICONT
      IF(IFILE .EQ. 1)WRITE(8,6)ICONT
  163 IF(ICONT .NE. YES)GO TO 579
      WRITE(6,908)
      IF(IFILE .EQ. 1)GO TO 164
      CALL EDIT7(IOPT)
      GO TO 579
  164 READ(5,6)IOPT
      IF(IFILE .EQ. 1)WRITE(8,6)IOPT
  579 CONTINUE
      IF(ISTOP .EQ. 1 .AND. ICONT .EQ. YES)WRITE(7,350)
      DO 650 NE=1,NUMEL
      IRE=1
C
C   ELEMENT STRAINS AND STRESSES ARE CALCULATED FROM SUBROUTINE
C
      L=4
      IF(LM(NE,3) .EQ. 0)L=2
      GO TO (610,610,630,630),L
  610 IF(ISTOP .EQ. 0)GO TO 650
      CALL BECOL(IRE,NE,NDEL,NDFPN,ISTOP)
      GO TO 650
  630 CALL QUAD(IRE,NE,NDEL,NDFPN,ISTOP)
C
C   CALCULATE REINFORCEMENT STRESS
C
      IF(LM(NE,5).NE.1) GO TO 646
      EPS=0.
      DO 645 J=1,6
  645 EPS=EPS+BA(J,1)*STR(1,J)
      RSTRES=EPS*EST
      IF(ISTOP.EQ.0) GO TO 632
      IF(ICONT .EQ. YES)WRITE(7,642)RSTRES
      IF(ISTOP.EQ.1) GO TO 219
C
C   CALCULATE SOIL STRESS IN LOCAL COORDINATES
C
  632 CONTINUE
      DO 647 I=1,6
      SG(I)=0.
      DO 647 J=1,6
  647 SG(I)=SG(I)+BAP(J,I)*SIGMA(J)
      SG(1)=SG(1)-RSTRES*ALP
C
C   CALCULATE SOIL STRESS IN GLOBAL COORDINATES
C
```

```
      DO 648 I=1,6
      SIGMA(I)=0.
      DO 648 J=1,6
  648 SIGMA(I)=SIGMA(I)+BA(I,J)*SG(J)
  646 CONTINUE
      CALL PRST(SIGMA,SGM1,SGM3,SDEV)
C
C   CALCULATE NEW MODULUS AND POISSON'S RATIO OF CONTINUUM
C
      M=LM(NE,6)
      ITYP=MNO(M)
      IF(ITYP.EQ.1) GO TO 219
      CALL DUNT(SGM3,SDEV,EXX,GXX,M)
      EX(NE)=EX(NE)+RELAX*(EXX-EX(NE))
      GX(NE)=GXX
      IF(POIS(M).NE.0.) GX(NE)=POIS(M)
  219 CONTINUE
  650 CONTINUE
      IF(ISTOP.EQ.1) GO TO 209
      GO TO 202
  209 CONTINUE
C
C   THRUST, SHEAR, BENDING MOMENT OF ABUTMENT STEM
C
      IF(INR .EQ. 1 .AND. INCR .EQ. 1)GO TO 402
      WRITE(7,653)
C
C   AXIAL THRUST OF ABUTMENT STEM AT TIE-ROD LEVEL
C
      WRITE(7,654)EF(2,7)
      WRITE(7,655)EF(3,7)
C
C   SHEAR FORCE AT TIE-ROD LEVEL
C
      TM1=ABS(EF(2,9))
      TM2=ABS(EF(3,3))
      TMAX=TM1
      IF(TM2 .GT. TMAX)TMAX=TM2
      WRITE(7,656)TMAX
C
C   BENDING MOMENT AT TIE-ROD LEVEL
C
      WRITE(7,657)EF(3,5)
C
C   AXIAL THRUST AT THE BASE
C
      WRITE(7,659)EF(4,7)
C
C   SHEAR FORCE AT THE BASE
C
      TM1=ABS(EF(4,9))
      WRITE(7,660)TM1
C
C   BENDING MOMENT AT THE BASE
```

```
C
      TM1=-EF(4,11)
      WRITE(7,662)TM1
      GO TO 402
 1000 RETURN
      END
C
C
      SUBROUTINE CSOLVE(NEQ,MB,NEQD,MBD,IFLAG)
C
C
C    THIS SUBROUTINE SOLVES THE SYSTEM  A  X = B  BY GAUSS ELIMINATION
C    IFLAG=0, TRIANGULARIZE A, FORWARD REDUCE B, BACKSUBSTITUTE
C    IFLAG=1, FORWARD REDUCE B, BACKSUBSITITUTE
C
      COMMON /BLK9/GK(323,100),GP(323)
      NQ=NEQ-1
      DO 300 N=1,NQ
      N1=N+1
      NM1=N+MB-1
      DO 200 I=N1,NM1
      IF(I.GT.NEQ) GO TO 300
C
C    FORWARD REDUCTION
C
      IS=I-N+1
      C=GK(N,IS)/GK(N,1)
      GP(I)=GP(I)-GP(N)*C
      IF(IFLAG.EQ.1) GO TO 200
C
C    TRIANGULARIZATION  A
C
      DO 100 J=I,NM1
      J1=J-I+1
      J2=J-N+1
  100 GK(I,J1)=GK(I,J1)-C*GK(N,J2)
  200 CONTINUE
  300 CONTINUE
C
C    BACKSUBSTITUTION
C
      GP(NEQ)=GP(NEQ)/GK(NEQ,1)
      DO 500 K=2,NEQ
      NI=NEQ-K+1
      NI1=NI+1
      NIM1=NI+MB-1
      SUM=0.
      DO 400 J=NI1,NIM1
      IF(J.GT.NEQ) GO TO 500
      JS=J-NI+1
  400 SUM=SUM+GK(NI,JS)*GP(J)
  500 GP(NI)=(GP(NI)-SUM)/GK(NI,1)
      RETURN
      END
```

```
C
C
      SUBROUTINE BECOL(IRE,NE,NDEL,NDFPN,ISTOP)
C
C
C    THIS SUBROUTINE CALCULATES THE ELEMENT STIFFNESS MATRIX AND
C    LOAD VECTOR OF BEAM ELEMENT.  ALSO RECOVERS ELEMENT FORCES AND
C    MOMENTS
C
      COMMON /BLK1/AE(10),EIY(10),E(10),POIS(10),EX(102),GX(102),INR
      COMMON /BLK17/EIZ(10),GJX(10),IPILE,XPILE,INCR,XXS(102,5),
     +         YYS(102,5),IFILE
      COMMON /BLK12/ZZS(102,5),XYT(102,5),XZT(102,5),YZT(102,5)
      COMMON /BLK3/LM(102,6),X(100),Y(100),ARE(102),EF(4,12)
      COMMON /BLK4/FX,FY,IOPT,EP(12),EK(12,12),TX,TY,ICONT
      COMMON /BLK5/DISN(100,6),SIGMA(6)
      DIMENSION T(12,12),U(12),F(12),TEM(12,12)
      INTEGER PNE
      CHARACTER ICONT*1 ,IOPT*1
      CHARACTER*1 YES/'Y'/
C
C    FORMAT STATEMENTS
C
   30 FORMAT(//45X,'BENDING ELEMENT FORCES AND MOMENTS',//,
     +  2X,'EL.NO.',5X,'1-P1',6X,'1-P2',6X,'1-P3',6X,'1-M1',6X,
     +  '1-M2',6X,'1-M3',6X,'2-P1',6X,'2-P2',6X,'2-P3',6X,'2-M1',6X,
     +  '2-M2',6X,'2-M3')
   50 FORMAT(I7,12E10.3)
C
C    NO. OF NODES PER ELEMENT AND DEGREE OF FREEDOM SET
C
      NDEL=2
      NDFPN=6
C
C
      DO 4 J=1,12
      DO 2 K=1,12
    2 EK(J,K)=0.
    4 EP(J)=0.
      N1=LM(NE,1)
      N2=LM(NE,2)
      MT=LM(NE,6)
      ANG=ARE(NE) *0.0174533
      XI=X(N1)
      XJ=X(N2)
      YI=Y(N1)
      YJ=Y(N2)
      XL=XJ-XI
      YL=YJ-YI
      XS=XL**2
      YS=YL**2
      SXY=XS+YS
      SL=SQRT(SXY)/COS(ANG)
      CO=XL/SL
```

```
      SI=YL/SL
C
C     ELEMENT STIFFNESS MATRIX (LOCAL COORDINATES)
C
      EML=EIY(MT)/SL
      EMM=EIZ(MT)/SL
      EMN=GJX(MT)/SL
      S=AE(MT)/SL
      A11=S
      A22=12.*EMM/SL**2
      A26=6.*EMM/SL
      A33=12.*EML/SL**2
      A35=-6.*EML/SL
      A44=EMN
      A55=4.*EML
      A511=2.*EML
      A66=4.*EMM
      A612=2.*EMM
      EK(1,1)=A11
      EK(1,7)=-A11
      EK(2,2)=A22
      EK(2,6)=A26
      EK(2,8)=-A22
      EK(2,12)=A26
      EK(3,3)=A33
      EK(3,5)=A35
      EK(3,9)=-A33
      EK(3,11)=A35
      EK(4,4)=A44
      EK(4,10)=-A44
      EK(5,5)=A55
      EK(5,9)=-A35
      EK(5,11)=A511
      EK(6,6)=A66
      EK(6,8)=-A26
      EK(6,12)=A612
      EK(7,7)=A11
      EK(8,8)=A22
      EK(8,12)=-A26
      EK(9,9)=A33
      EK(9,11)=-A35
      EK(10,10)=A44
      EK(11,11)=A55
      EK(12,12)=A66
      DO 20 I=2,12
      DO 10 J=1,11
      IF(J.GE.I) GO TO 20
      EK(I,J)=EK(J,I)
   10 CONTINUE
   20 CONTINUE
C
C     ROTATION MATRIX
C
      DO 5 I=1,12
```

```
      DO 5 J=1,12
    5 T(I,J)=0.
      CX=XL/SL
      CY=YL/SL
      CZ=SIN(ANG)
      CON=SQRT(CX**2+CY**2)
      T21=-CX*CZ/CON
      T22=-CY*CZ/CON
      T31=CY/CON
      T32=-CX/CON
      T(1,1)=CX
      T(1,2)=CY
      T(1,3)=CZ
      T(2,1)=T21
      T(2,2)=T22
      T(2,3)=CON
      T(3,1)=T31
      T(3,2)=T32
      DO 6 K=3,9,3
      DO 6 I=1,3
      DO 6 J=1,3
    6 T(I+K,J+K)=T(I,J)
      DO 7 I=1,12
      DO 7 J=1,12
      TEM(I,J)=0.
      DO 7 K=1,12
    7 TEM(I,J)=TEM(I,J)+EK(I,K)*T(K,J)
      IF(IRE .NE. 0)GO TO 21
C
C     ELEMENT STIFFNESS MATRIX (GLOBAL COORDINATES)
C
      DO 8 I=1,12
      DO 8 J=I,12
      EK(I,J)=0.
      DO 8 K=1,12
      Q=T(K,I)*TEM(K,J)
    8 EK(I,J)=EK(I,J)+Q
      DO 9 I=2,12
      DO 9 J=1,I-1
    9 EK(I,J)=EK(J,I)
      GO TO 60
C
C     RECOVERY OF ELEMENT FORCES AND MOMENTS
C
   21 CONTINUE
      DO 70 I=1,6
      U(I)=DISN(N1,I)
   70 U(I+6)=DISN(N2,I)
      DO 80 I=1,12
      F(I)=0.
      DO 80 K=1,12
   80 F(I)=F(I)+TEM(I,K)*U(K)
      PNE=NE-1
      IF(ICONT .NE. YES)GO TO 45
```

```
      IF(LM(NE,3).EQ.LM(PNE,3)) GO TO 40
      WRITE(7,30)
   40 WRITE(7,50) NE, (F(I),I=1,12)
   45 CONTINUE
C
C   STORE MAXIMUM AXIAL FORCE, SHEAR, MOMENT OF THE ABUTMENT STEM
C
      IF(NE .GT. 79)GO TO 60
      DO 65 I=1,12
   65 EF(NE-75,I)=F(I)
   60 RETURN
      END
C
C
      SUBROUTINE QUAD(IRE,NE,NDEL,NDFPN,ISTOP)
C
C
C   THIS SOUBROUTINE CALCULATES ELEMENT STIFFNESS MATRIX AND
C   LOAD VECTOR, AND THE RECOVERY OF ELEMENT STRAINS AND STRESSES
C   OF 4-NODAL QUADRILATERAL ELEMENT
C
      COMMON /BLK1/AE(10),EIY(10),E(10),POIS(10),EX(102),GX(102),INR
      COMMON /BLK17/EIZ(10),GJX(10),IPILE,XPILE,INCR,XXS(102,5),
     +         YYS(102,5),IFILE
      COMMON /BLK12/ZZS(102,5),XYT(102,5),XZT(102,5),YZT(102,5)
      COMMON /BLK2/XQ(4),YQ(4),B(6,12),XN(4),ALP,EST,PHP,PHR,BA(6,6),
     +        BAP(6,6)
      COMMON /BLK3/LM(102,6),X(100),Y(100),ARE(102),EF(4,12)
      COMMON /BLK4/FX,FY,IOPT,EP(12),EK(12,12),TX,TY,ICONT
      COMMON /BLK5/DISN(100,6),SIGMA(6)
      COMMON /BLK6/SMX(5),SMY(5),SMZ(5),TXY(5),TXZ(5),TYZ(5),STR(5,6)
      DIMENSION U(4),V(4),SA(4),TA(4),SR(5),TR(5)
      DIMENSION RE(5),C(6,6),CB(6,12),W(4),TEM(6,6)
      CHARACTER ICONT*1 ,IOPT*1
      CHARACTER*1 YES/'Y'/
      DATA RE/3HCEN,3HI-J,3HJ-K,3HK-L,3HL-I/
C
C   FORMAT STATEMENTS
C
  550 FORMAT(I7,3X,A3,1X,11E10.3)
  551 FORMAT(10X,A3,1X,11E10.3)
  610 FORMAT(8X,'**ELEMENT',I4,1X,'IS REINFORCED')
C
C   NO. OF NODES PER ELEMENT AND DEGREE OF FREEDOM SET
C
      NDEL=4
      NDFPN=3
C
C
      MT=LM(NE,6)
      EM=EX(NE)
      POI=GX(NE)
C
C   STRESS-STRAIN RELATIONSHIP
```

```
C
      DO 5 I=1,6
      DO 5 J=1,6
      TEM(I,J)=0.
    5 C(I,J)=0.
      A1=1./EM
      A2=-POI*A1
      A3=2.*(1.+POI)/EM
      IF(LM(NE,5).NE.1) GO TO 10
C
C    REINFORCED SOIL ELEMENT
C
      CALL PROP(EM,POI,NE,A3,C)
C
C    ROTATE TO GLOBAL COORDINATES
C
      DO 60 I=1,6
      DO 60 J=1,6
      DO 60 K=1,6
   60 TEM(I,J)=TEM(I,J)+BA(I,K)*C(K,J)
      DO 70 I=1,6
      DO 70 J=1,6
      C(I,J)=0.
      DO 70 K=1,6
   70 C(I,J)=C(I,J)+TEM(I,K)*BA(J,K)
      GO TO 20
C
C    UNREINFORCED SOIL ELEMENT
C
   10 C(1,1)=A1
      C(2,2)=A1
      C(1,2)=A2
      C(2,1)=A2
      C(1,3)=A2
      C(2,3)=A2
      C(3,1)=A2
      C(3,2)=A2
      C(3,3)=A1
      C(4,4)=A3
      C(5,5)=A3
      C(6,6)=A3
      CALL STIFIV(C,6,6)
   20 CONTINUE
      DO 30 J=1,4
      NP=LM(NE,J)
      XQ(J)=X(NP)
   30 YQ(J)=Y(NP)
      IF(IRE.NE.0) GO TO 210
C
C    ELEMENT STIFFNESS MATRIX
C
      YL=YQ(4)-YQ(3)
      XL=XQ(4)-XQ(3)
      SQL=XL**2+YL**2
```

```
      SL=SQRT(SQL)
      SA(1)=1.
      SA(2)=-1.
      SA(3)=-1.
      SA(4)=1.
      TA(1)=1.
      TA(2)=1.
      TA(3)=-1.
      TA(4)=-1.
      DO 50 J=1,12
      DO 40 K=1,12
   40 EK(J,K)=0.
   50 EP(J)=0.
      DO 199 N=1,4
      SAM=3.
      SN=SA(N)/SQRT(SAM)
      TN=TA(N)/SQRT(SAM)
      CALL FORMB(SN,TN,DJ,XS,YS)
      DO 100 I=1,6
      DO 100 J=1,12
      CB(I,J)=0.
      DO 100 K=1,6
  100 CB(I,J)=CB(I,J)+C(I,K)*B(K,J)
      DO 110 I=1,12
      DO 110 J=I,12
      DO 110 K=1,6
      Q=B(K,I)*CB(K,J)
      EK(I,J)=EK(I,J)+Q/DJ
  110 IF(N .EQ. 4) EK(J,I)=EK(I,J)
C
C   ELEMENT LOAD VECTOR BY BODY FORCE
C
C   FOUNDATION SOIL HAS NO BODY FORCE IN INCR=2
C
      IF(INR .NE. 1)GO TO 202
      IF(INCR .EQ. 2 .AND. NE .LE. 55)GO TO 199
  202 CONTINUE
      DO 200 M=1,4
      L1=3*M-2
      L2=3*M-1
      L3=3*M
      EP(L1)=EP(L1)+XN(M)*FX*DJ
      EP(L2)=EP(L2)+XN(M)*FY*DJ
  200 CONTINUE
  199 CONTINUE
      IF(INR .EQ. 1 .AND. INCR .EQ. 1)GO TO 600
C
C   ELEMENT LOAD VECTOR BY TRACTION
C
      EP(7)=EP(7)+TX*SL/2.
      EP(8)=EP(8)+TY*SL/2.
      EP(10)=EP(10)+TX*SL/2.
      EP(11)=EP(11)+TY*SL/2.
      GO TO 600
```

```
  210 CONTINUE
C
C   RECOVERY OF ELEMENT STRAINS AND STRESSES
C
      DO 220 J=1,4
      NP=LM(NE,J)
      U(J)=DISN(NP,1)
      V(J)=DISN(NP,2)
  220 W(J)=DISN(NP,3)
      SR(1)=0.
      SR(2)=0.
      SR(3)=1.
      SR(4)=0.
      SR(5)=-1.
      TR(1)=0.
      TR(2)=-1.
      TR(3)=0.
      TR(4)=1.
      TR(5)=0.
      N=1
  250 SI=SR(N)
      TI=TR(N)
      SMX(N)=0.
      SMY(N)=0.
      SMZ(N)=0.
      TXY(N)=0.
      TXZ(N)=0.
      TYZ(N)=0.
      CALL FORMB(SI,TI,DJ,XS,YS)
      DO 260 L=1,6
  260 STR(N,L)=0.
      DO 300 M=1,4
      M1=3*M-2
      M2=3*M-1
      M3=3*M
C
C   ELEMENT STRAINS
C
      DO 300 L=1,6
  300 STR(N,L)=STR(N,L)+(B(L,M1)*U(M)+B(L,M2)*V(M)+B(L,M3)*W(M))/DJ
C
C   ELEMENT STRESSES
C
      DO 310 J=1,6
      SMX(N)=SMX(N)+C(1,J)*STR(N,J)
      SMY(N)=SMY(N)+C(2,J)*STR(N,J)
      SMZ(N)=SMZ(N)+C(3,J)*STR(N,J)
      TXY(N)=TXY(N)+C(4,J)*STR(N,J)
      TXZ(N)=TXZ(N)+C(5,J)*STR(N,J)
  310 TYZ(N)=TYZ(N)+C(6,J)*STR(N,J)
C
C   ACCUMULATED STRESSES IN INCR=1
C
      IF(INR .EQ. 1 .AND. INCR .EQ. 2)GO TO 320
```

```
      XXS(NE,N)=SMX(N)
      YYS(NE,N)=SMY(N)
      ZZS(NE,N)=SMZ(N)
      XYT(NE,N)=TXY(N)
      XZT(NE,N)=TXZ(N)
      YZT(NE,N)=TYZ(N)
      GO TO 330
C
C    ACCUMULATED STRESSES IN INCR=2
C
  320 SMX(N)=SMX(N)+XXS(NE,N)
      SMY(N)=SMY(N)+YYS(NE,N)
      SMZ(N)=SMZ(N)+ZZS(NE,N)
      TXY(N)=TXY(N)+XYT(NE,N)
      TXZ(N)=TXZ(N)+XZT(NE,N)
      TYZ(N)=TYZ(N)+YZT(NE,N)
  330 CONTINUE
      IF(ISTOP .EQ. 0)GO TO 400
      IF(N .EQ. 1)GO TO 500
      GO TO 510
  500 IF(ICONT .EQ. YES)WRITE(7,550)NE,RE(N),(STR(N,I),I=1,2),
     +  (STR(N,I),I=4,6),SMX(N),SMY(N),SMZ(N),TXY(N),TXZ(N),TYZ(N)
      GO TO 555
  510 CONTINUE
      IF(ICONT .EQ. YES .AND. IOPT .EQ. YES)
     +             WRITE(7,551)RE(N),(STR(N,I),I=1,2),
     + (STR(N,I),I=4,6),SMX(N),SMY(N),SMZ(N),TXY(N),TXZ(N),TYZ(N)
  555 CONTINUE
      N=N+1
      IF(N.LE.5) GO TO 250
  400 CONTINUE
C
C    STRESSES AT THE CENTER OF ELEMENT IN MID-INCREMENT
C
      SIGMA(1)=(SMX(1)+XXS(NE,1))/2.
      SIGMA(2)=(SMY(1)+YYS(NE,1))/2.
      SIGMA(3)=(SMZ(1)+ZZS(NE,1))/2.
      SIGMA(4)=(TXY(1)+XYT(NE,1))/2.
      SIGMA(5)=(TXZ(1)+XZT(NE,1))/2.
      SIGMA(6)=(TYZ(1)+YZT(NE,1))/2.
      IF(LM(NE,5).EQ.0) RETURN
      IF(ISTOP.EQ.0) RETURN
      IF(ICONT .EQ. YES)WRITE(7,610)NE
  600 RETURN
      END
C
C
      SUBROUTINE FORMB(S,T,DJ,XS,YS)
C
C
C    THIS SUBROUTINE CALCULATES 'B' MATRIX OF 4-NODAL QUADRILATERAL
C    ELEMENT
C
      COMMON /BLK2/XQ(4),YQ(4),B(6,12),XN(4),ALP,EST,PHP,PHR,BA(6,6),
```

```
     +          BAP(6,6)
      T1=0.25*(1.-T)
      T2=0.25*(1.+T)
      S1=0.25*(1.-S)
      S2=0.25*(1.+S)
C
C    ELEMENT SHAPE FUNCTIONS
C
      XN(1)=T1*(1.-S)
      XN(2)=T1*(1.+S)
      XN(3)=T2*(1.+S)
      XN(4)=T2*(1.-S)
      XS=-T1*XQ(1)+T1*XQ(2)+T2*XQ(3)-T2*XQ(4)
      XT=-S1*XQ(1)-S2*XQ(2)+S2*XQ(3)+S1*XQ(4)
      YS=-T1*YQ(1)+T1*YQ(2)+T2*YQ(3)-T2*YQ(4)
      YT=-S1*YQ(1)-S2*YQ(2)+S2*YQ(3)+S1*YQ(4)
      DJ=XS*YT-XT*YS
      XS1=S1*XS
      XS2=S2*XS
      YS1=S1*YS
      YS2=S2*YS
      XT1=T1*XT
      XT2=T2*XT
      YT1=T1*YT
      YT2=T2*YT
C
C    DERIVATIVES OF SHAPE FUNCTION
C
      F1=YS1-YT1
      F2=YT1+YS2
      F3=YT2-YS2
      F4=-YT2-YS1
      G1=XT1-XS1
      G2=-XS2-XT1
      G3=XS2-XT2
      G4=XS1+XT2
      DO 10 I=1,6
      DO 10 J=1,12
   10 B(I,J)=0.
      B(1,1)=F1
      B(1,4)=F2
      B(1,7)=F3
      B(1,10)=F4
      B(2,2)=G1
      B(2,5)=G2
      B(2,8)=G3
      B(2,11)=G4
      B(4,1)=G1
      B(4,2)=F1
      B(4,4)=G2
      B(4,5)=F2
      B(4,7)=G3
      B(4,8)=F3
      B(4,10)=G4
```

```
      DO 12 I=1,N
      IF(I-ICOL) 10,12,10
   10 TEMP=A(I,ICOL)
      A(I,ICOL)=0.
      DO 11 J=1,N
   11 A(I,J)=A(I,J)-A(ICOL,J)*TEMP
   12 CONTINUE
      GO TO 4
   21 WRITE(6,100)
  100 FORMAT(1X,'SINGULAR MATRIX',//)
   20 RETURN
      END
C
C
      SUBROUTINE PRST(SIGMA,SGM1,SGM3,SDEV)
C
C
C    THIS SUBROUTINE CALCULATES THREE REAL ROOTS OF A RATIONAL
C    CUBIC EQUATION.  THEY ARE THREE PRINCIPAL STRESSES
C
      DIMENSION SIGMA(6)
      DATA ZC,ZD/-0.5,0.866025404/
      S1=SIGMA(1)
      S2=SIGMA(2)
      S3=SIGMA(3)
      S4=SIGMA(4)
      S5=SIGMA(5)
      S6=SIGMA(6)
      B1=-(S1+S2+S3)
      B2=S2*S3+S1*S3+S2*S1-S4**2-S5**2-S6**2
      B3=S1*S6**2+S2*S5**2+S3*S4**2-S1*S2*S3-2.*S4*S5*S6
      T3=1./3.
      Q=2.*(B1*T3)**3-B1*B2*T3+B3
      Q2=Q*ZC
      P=B2-B1*B1*T3
      R=Q2**2+(P*T3)**3
      R2=SQRT(ABS(R))
      A=Q2+R2
      B=Q2-R2
      TERM=-B1*T3
      THETA=ATAN2(R2,Q2)
      RO=(SQRT(Q2*Q2+R2*R2))**T3
      ZA=RO*COS(THETA*T3)
      ZB=RO*SIN(THETA*T3)
C
C    THREE PRINCIPAL STRESSES ( NEGATIVE OF ROOTS )
C
      B1=-(2.0*ZA+TERM)
      B2=-(2.0*(ZA*ZC-ZB*ZD)+TERM)
      B3=-(2.0*(ZA*ZC+ZB*ZD)+TERM)
      SGM1=B1
      IF(B2 .GT. SGM1)SGM1=B2
      IF(B3 .GT. SGM1)SGM1=B3
      SGM3=B1
```

```
      IF(B2 .LT. SGM3)SGM3=B2
      IF(B3 .LT. SGM3)SGM3=B3
      SDEV=SGM1-SGM3
      RETURN
      END
C
C
      SUBROUTINE AUTO(IX,NUMNP,K,NUMEL,ANGLE)
C
C
C    THIS SUBROUTINE SETS UP DATA FOR AUTOMATIC GENERATION
C
      COMMON /BLK1/AE(10),EIY(10),E(10),POIS(10),EX(102),GX(102),INR
      COMMON /BLK17/EIZ(10),GJX(10),IPILE,XPILE,INCR,XXS(102,5),
     +          YYS(102,5),IFILE
      COMMON /BLK12/ZZS(102,5),XYT(102,5),XZT(102,5),YZT(102,5)
      COMMON /BLK3/LM(102,6),X(100),Y(100),ARE(102),EF(4,12)
      COMMON /BLK8/A1,A2,A3,A4,A5,A6,B1,B2,C1,C2,C3,C4,C5,C6,C7,C8,C9,
     +         C10,C11,C12,C13,D1,D2,E1,E2,E3,E4,E5,E6,E7,F1,F2,F3,

     +         F4,F5,G1,SSH,DDA,DDM
      COMMON/BLK10/ID(100,6),PN(6),FFX(10),FFY(10),TTX(102),TTY(102)
      COMMON/BLK13/CD
      CHARACTER  CD*1
C
C    FORMAT STATEMENTS
C
  500 FORMAT(//3X,'**END OF TIE ROD MUST BE BEYOND TIP OF REAR PILE',//)

  501 FORMAT(I1)
  510 FORMAT(//3X,'**FRONT ROW PILES TOO LONG OR TOO MUCH BATTERED',//)

  520 FORMAT(//3X,'**GIRDER SUPPORT MUST BE BETWEEN PILES',//)
  530 FORMAT(//3X,'**FRONT ROW PILE TOO SHORT',//)
  550 FORMAT(//3X,'**TOP OF CONCRETE ANCHOR MUST BE ABOVE TIE ROD',//)
  560 FORMAT(//3X,'**TIP OF CONCRETE ANCHOR MUST BE BELOW ABUTMENT
BASE',
     +          //)
  570 FORMAT(//3X,'**TIP OF CONCRETE ANCHOR MUST BE ABOVE MID-DEPTH OF',

     +           ' REAR PILE',//)
  580 FORMAT(/1X,'PILE PROPERTIES',/,
     +           1X,  'NO OF PILES PER GROUP?',\)
  581 FORMAT(   /1X,'CROSS SECTIONAL AREA IN SQ IN?',\)
  582 FORMAT(   /1X,'MAJOR AXIS MOMENT OF INERTIA IN IN**4?',\)
  583 FORMAT(   /1X,'MINOR AXIS MOMENT OF INERTIA IN IN**4?',\)
  584 FORMAT(   /1X,'PILE MATERIAL MODULUS IN PSI?',\)
  585 FORMAT(   /1X,'PILE GROUP SPACING IN FT?',\)
  590 FORMAT(/1X,'CIRCULAR PILE PROPERTIES',/,
     +           1X,  'NO OF PILES PER GROUP?',\)
  591 FORMAT(   /1X,'OUTSIDE DIAMETER OF PILE IN FT?',\)
  592 FORMAT(   /1X,'INSIDE DIAMETER OF PILE IN FT?',\)
  593 FORMAT(   /1X,'PILE MATERIAL MODULUS IN PSI?',\)
  594 FORMAT(   /1X,'PILE GROUP SPACING IN FT?',\)
```

```
  595 FORMAT(/1X,'**ERROR**REENTER IN INTEGER(S)',\)
C
C   NODAL COORDINATES
C
      GO TO(10,60,90,120),IX
   10 NUMNP=96
      DO 12 I=1,NUMNP
      X(I)=0.
   12 Y(I)=0.
      DO 15 K=1,6
      DO 15 I=1,6
      KK=(K-1)*6+I
      X(KK)=(I-1)*0.25*E2
      IF(I .EQ. 6)X(KK)=1.5*E2
      IF(K .EQ. 1)Y(KK)=A1
      IF(K .EQ. 2)Y(KK)=A1-E1/2.
      IF(K .EQ. 3)Y(KK)=A1-E1
      IF(K .EQ. 4)Y(KK)=(A1-E1)/2.
   15 CONTINUE
      X(25)=-(A3+D1)
      X(26)=-(A3+D1/2.)
      X(27)=-A3
      X(28)=-(A3-C4)
      X(29)=-(A3-B1)
      X(30)=-C8
      X(90)=X(30)+C10*C7/SQRT(1.+C7**2)*XPILE
      Y(90)=-C10/SQRT(1.+C7**2)*XPILE
      X(88)=X(28)-C9*C3/SQRT(1.+C3**2)*XPILE
      Y(88)=-C9/SQRT(1.+C3**2)*XPILE
      X(64)=(X(28)+X(88))/2.
      Y(64)=Y(88)/2.
C
C   TIP OF PILE COORDINATES
C
      X(76)=(X(64)+X(88))/2.
      Y(76)=(Y(64)+Y(88))/2.
      IF(IPILE .EQ. 1)X(76)=X(28)+(X(88)-X(28))/XPILE
      IF(IPILE .EQ. 1)Y(76)=Y(88)/XPILE
      X(40)=X(28)+(X(64)-X(28))/3.
      Y(40)=Y(64)/3.
      X(52)=X(28)+(X(64)-X(28))*2./3.
      Y(52)=Y(64)*2./3.
      X(61)=4.*X(25)
      Y(61)=(X(61)-X(25))/D2
      X(85)=X(61)
      Y(85)=Y(88)
      X(73)=X(61)
      Y(73)=(Y(61)+Y(85))/2.
      X(37)=X(25)+(X(61)-X(25))/3.
      Y(37)=Y(61)/3.
      X(49)=X(25)+(X(61)-X(25))*2./3.
      Y(49)=Y(61)*2./3.
      DO 17 I=38,74,12
      X(I)=X(I+2)+(X(I-1)-X(I+2))*2./3.
```

```
   17 Y(I)=Y(I+2)+(Y(I-1)-Y(I+2))*2./3.
      X(86)=X(88)+(X(85)-X(88))/3.*2.
      Y(86)=Y(88)
      DO 19 I=39,75,12
      X(I)=X(I+1)+(X(I-2)-X(I+1))/3.
   19 Y(I)=Y(I+1)+(Y(I-2)-Y(I+1))/3.
      X(87)=X(88)+(X(85)-X(88))/3.
      Y(87)=Y(88)
      X(89)=(X(88)+X(90))/2.
      Y(89)=(Y(88)+Y(90))/2.
      X(65)=(X(29)+X(89))/2.
      Y(65)=Y(89)/2.
      X(77)=(X(65)+X(89))/2.
      Y(77)=(Y(65)+Y(89))/2.
      X(41)=X(29)+(X(65)-X(29))/3.
      Y(41)=Y(65)/3.
      X(53)=X(29)+(X(65)-X(29))*2./3.
      Y(53)=Y(65)*2./3.
      DO 21 I=1,3
      Y(12*I+30)=Y(90)*I/6.
   21 Y(12*I+31)=Y(90)*I/6.
C
C   TIP OF PILE COORDINATES
C
      Y(78)=Y(90)*0.75
      IF(IPILE .EQ. 1)Y(78)=Y(90)/XPILE
      Y(79)=Y(78)
      X(66)=(X(30)+X(90))/2.
      X(78)=(X(66)+X(90))/2.
      IF(IPILE .EQ. 1)X(78)=X(30)+(X(90)-X(30))/XPILE
      X(42)=X(30)+(X(66)-X(30))/3.
      X(54)=X(30)+(X(66)-X(30))*2./3.
      X(96)=E2*1.5
      X(91)=X(90)+(X(96)-X(90))/6.
      X(67)=X(91)/2.
      X(43)=X(67)/3.
      X(55)=X(43)*2.
      X(79)=(X(67)+X(91))/2.
      Y(91)=Y(90)
      Y(96)=Y(90)
      DO 23 I=92,95
      X(I)=X(90)+(X(96)-X(90))*(I-90)/6.
   23 Y(I)=Y(90)
      DO 25 I=44,48
      X(I)=X(I-12)+(X(I+48)-X(I-12))/6.
   25 Y(I)=Y(90)/6.
      X(47)=X(35)
      Y(47)=Y(17)-F2
      DO 27 I=56,60
      X(I)=X(I-24)+(X(I+36)-X(I-24))/3.
   27 Y(I)=Y(90)/3.
      DO 29 I=68,72
      X(I)=(X(I-36)+X(I+24))/2.
   29 Y(I)=Y(90)/2.
```

```
  111 WRITE(6,595)
      GO TO 302
  112 CONTINUE
      IF(IFILE .EQ. 1)WRITE(8,501)ITP
  303 IF(ITP .EQ. 1)GO TO 108
      WRITE(6,580)
      IF(IFILE .EQ. 1)GO TO 304
      CALL EDIT6(IC1)
      GO TO 305
  304 READ(5,501,ERR=113)IC1
      GO TO 114
  113 WRITE(6,595)
      GO TO 304
  114 CONTINUE
      IF(IFILE .EQ. 1)WRITE(8,501)IC1
  305 WRITE(6,581)
      IF(IFILE .EQ. 1)GO TO 306
      CALL EDIT1(XA)
      GO TO 307
  306 READ(5,*)XA
      IF(IFILE .EQ. 1)WRITE(8,*)XA
  307 WRITE(6,582)
      IF(IFILE .EQ. 1)GO TO 308
      CALL EDIT1(YI)
      GO TO 309
  308 READ(5,*)YI
      IF(IFILE .EQ. 1)WRITE(8,*)YI
  309 WRITE(6,583)
      IF(IFILE .EQ. 1)GO TO 310
      CALL EDIT1(ZI)
      GO TO 311
  310 READ(5,*)ZI
      IF(IFILE .EQ. 1)WRITE(8,*)ZI
  311 WRITE(6,584)
      IF(IFILE .EQ. 1)GO TO 312
      CALL EDIT1(C11)
      GO TO 313
  312 READ(5,*)C11
      IF(IFILE .EQ. 1)WRITE(8,*)C11
  313 WRITE(6,585)
      IF(IFILE .EQ. 1)GO TO 314
      CALL EDIT1(C13)
      GO TO 315
  314 READ(5,*)C13
      IF(IFILE .EQ. 1)WRITE(8,*)C13
  315 C11=C11*144.
      XA=XA/144.*IC1
      YI=YI/20736.*IC1
      ZI=ZI/20736.*IC1
      GO TO 109
C
C   CIRCULAR PILE
C
  108 WRITE(6,590)
```

```
      IF(IFILE .EQ. 1)GO TO 316
      CALL EDIT6(IC1)
      GO TO 317
  316 READ(5,501,ERR=115)IC1
      GO TO 116
  115 WRITE(6,595)
      GO TO 316
  116 CONTINUE
      IF(IFILE .EQ. 1)WRITE(8,501)IC1
  317 WRITE(6,591)
      IF(IFILE .EQ. 1)GO TO 318
      CALL EDIT1(C2)
      GO TO 319
  318 READ(5,*)C2
      IF(IFILE .EQ. 1)WRITE(8,*)C2
  319 WRITE(6,592)
      IF(IFILE .EQ. 1)GO TO 320
      CALL EDIT1(C14)
      GO TO 321
  320 READ(5,*)C14
      IF(IFILE .EQ. 1)WRITE(8,*)C14
  321 WRITE(6,593)
      IF(IFILE .EQ. 1)GO TO 322
      CALL EDIT1(C11)
      GO TO 323
  322 READ(5,*)C11
      IF(IFILE .EQ. 1)WRITE(8,*)C11
  323 WRITE(6,594)
      IF(IFILE .EQ. 1)GO TO 324
      CALL EDIT1(C13)
      GO TO 325
  324 READ(5,*)C13
      IF(IFILE .EQ. 1)WRITE(8,*)C13
  325 C11=C11*144.
  106 CONTINUE
      XA=(C2**2-C14**2)*3.141592/4.*IC1
      YI=(C2**4-C14**4)*3.141592/64.*IC1
      ZI=YI
  109 AE(K)=XA*C11/C13
      GJX(K)=(YI+ZI)*C11/2.5/C13
      EIY(K)=YI*C11/C13
      EIZ(K)=ZI*C11/C13
      E(K)=C11
      POIS(K)=0.25
      FFX(K)=0.
      FFY(K)=0.
C
C     TIE ROD HAS NO BENDING AND TORSION RESISTENCE
C
      IF(K .NE. 7)RETURN
      GJX(K)=0.0001*GJX(K)
      EIY(K)=0.0001*EIY(K)
      EIZ(K)=0.0001*EIZ(K)
   95 RETURN
```

```
C
C   ABUTMENT STEM AND BASE
C
  110 IF(IFILE .EQ. 1)GO TO 326
      CALL EDIT1(A2)
      GO TO 327
  326 READ(5,*)A2
      IF(IFILE .EQ. 1)WRITE(8,*)A2
C
C   MODULUS OF CONCRETE
C
  327 E(K)=5.76E+08
      POIS(K)=0.25
      FFX(K)=0.
      FFY(K)=0.
      AE(K)=A2*E(K)
      YI=A2**3/12.
      ZI=A2/12.
      GJX(K)=(YI+ZI)*E(K)/2.5
      EIY(K)=YI*E(K)
      EIZ(K)=ZI*E(K)
      RETURN
C
C   ELEMENT GENERATION
C
  120 NUMEL=102
      IF(IPILE .EQ. 1)NUMEL=100
      IS=5
      IF(IPILE .EQ. 1)IS=4
      DO 126 I=1,NUMEL
      DO 125 J=1,6
  125 LM(I,J)=0
      ARE(I)=0.
      TTX(I)=0.
  126 TTY(I)=0.
C
C   ELEMENTS 1 THRU 55
C
      DO 130 J=1,5
      DO 130 I=1,11
      K=(J-1)*11+I
      L=23*(J-1)-K
      LM(K,1)=84-L
      LM(K,2)=85-L
      LM(K,3)=73-L
      LM(K,4)=72-L
      LM(K,6)=3
  130 IF(J .GT. 2)LM(K,6)=2
C
C   ELEMENTS 56 THRU 60
C
      DO 180 I=56,60
      LM(I,1)=I-25
      LM(I,2)=I-24
```

```
      LM(I,3)=I-36
      LM(I,4)=I-37
  180 LM(I,6)=2
      LM(56,6)=1
C
C   ELEMENTS 61 THRU 75
C
      DO 190 J=1,3
      DO 190 I=1,5
      K=(J-1)*5+60+I
      L=11*(J-1)
      LM(K,1)=K-42-L
      LM(K,2)=K-41-L
      LM(K,3)=K-47-L
      LM(K,4)=K-48-L
      LM(K,6)=1
  190 IF(J .EQ. 3)TTY(K)=-G1
      LM(63,6)=2
      LM(64,6)=2
      LM(65,6)=2
      LM(69,6)=2
      LM(70,6)=2
      LM(75,6)=2
C
C   ELEMENTS 76 THRU 79
C
      DO 240 I=1,3
      LM(75+I,1)=1+6*(I-1)
      LM(75+I,2)=7+6*(I-1)
  240 LM(75+I,6)=6
      LM(79,1)=19
      LM(79,2)=31
      LM(79,6)=6
C
C   ELEMENTS 80 THRU 83
C
      DO 250 I=80,83
      ARE(I)=ANGLE
      LM(I,1)=I-67
      LM(I,2)=I-66
  250 LM(I,6)=7
C
C   ELEMENTS 84 THRU 86
C
      DO 260 I=1,3
      LM(83+I,1)=5+6*(I-1)
      LM(83+I,2)=11+6*(I-1)
  260 LM(83+I,6)=8
C
C   ELEMENTS 87 THRU 88
C
      DO 270 I=1,2
      LM(86+I,1)=23+12*(I-1)
      LM(86+I,2)=35+12*(I-1)
```

```
  270 LM(86+I,6)=8
C
C   ELEMENTS 89 THRU 92
C
      DO 280 I=89,92
      LM(I,1)=I-62
      LM(I,2)=I-61
  280 LM(I,6)=9
C
C   ELEMENTS 93 THRU 101
C
      DO 220 I=1,IS
      LM((91+I*2),1)=28+12*(I-1)
      LM((91+I*2),2)=40+12*(I-1)
  220 LM((91+I*2),6)=4
C
C   ELEMENTS 94 THRU 102
C
      DO 230 I=1,IS
      LM((92+I*2),1)=30+12*(I-1)
      LM((92+I*2),2)=42+12*(I-1)
  230 LM((92+I*2),6)=5
      RETURN
      END
C
C
      SUBROUTINE ROTATE
C
C   THIS SUBROUTINE FORMS BA AND B'A' MATRICES NECESSARY FOR
C   ROTATION OF REINFORCED EARTH ELEMENTS
C
      COMMON /BLK2/XQ(4),YQ(4),B(6,12),XN(4),ALP,EST,PHP,PHR,BA(6,6),
     +          BAP(6,6)
      DIMENSION A(6,6),B1(6,6),AP(6,6),BP(6,6)
C
C   INITIALIZATION
C
      DO 10 I=1,6
      DO 10 J=1,6
      A(I,J)=0.
      B1(I,J)=0.
      AP(I,J)=0.
      BP(I,J)=0.
      BA(I,J)=0.
   10 BAP(I,J)=0.
C
C   A MATRIX
C
      AC=COS(PHP)
      AS=SIN(PHP)
      AC2=AC**2
      AS2=AS**2
      A(1,1)=AC2
      A(1,3)=AS2
```

```
      A(1,5)=2.*AC*AS
      A(2,2)=1.
      A(3,1)=AS2
      A(3,3)=AC2
      A(3,5)=-A(1,5)
      A(4,4)=AC
      A(4,6)=AS
      A(5,1)=-AC*AS
      A(5,3)=AC*AS
      A(5,5)=AC2-AS2
      A(6,4)=-AS
      A(6,6)=AC
C
C    B MATRIX
C
      BC=COS(PHR)
      BS=SIN(PHR)
      BC2=BC**2
      BS2=BS**2
      B1(1,1)=BC2
      B1(1,2)=BS2
      B1(1,4)=-2.*BC*BS
      B1(2,1)=BS2
      B1(2,2)=BC2
      B1(2,4)=2.*BC*BS
      B1(3,3)=1.
      B1(4,1)=BC*BS
      B1(4,2)=-B1(4,1)
      B1(4,4)=BC2-BS2
      B1(5,5)=BC
      B1(5,6)=-BS
      B1(6,5)=BS
      B1(6,6)=BC
C
C    A' AND B' MATRICES
C
      DO 20 I=1,6
      DO 20 J=1,6
      AP(I,J)=A(I,J)
   20 BP(I,J)=B1(I,J)
      AP(1,5)=0.5*AP(1,5)
      AP(3,5)=0.5*AP(3,5)
      AP(5,1)=2.*AP(5,1)
      AP(5,3)=2.*AP(5,3)
      BP(1,4)=0.5*BP(1,4)
      BP(2,4)=0.5*BP(2,4)
      BP(4,1)=2.*BP(4,1)
      BP(4,2)=2.*BP(4,2)
C
C    BA AND B'A' MATRICES
C
      DO 30 I=1,6
      DO 30 J=1,6
      DO 30 K=1,6
```

```
      BA(I,J)=BA(I,J)+B1(I,K)*A(K,J)
   30 BAP(I,J)=BAP(I,J)+BP(I,K)*AP(K,J)
      RETURN
      END
C
C
      SUBROUTINE DUNPRT(KCODE,K)
C
C
C    THIS SUBROUTINE ESTABLISHES MODIFIED DUNCAN'S SOIL PROPERTIES
C    FOR NONLINEAR FINITE ELEMENT ANALYSIS
C
C    KCODE = 1 CRUSHED LIMESTONE BACKFILL
C          2 CRUSHED QUARTZITE BACKFILL
C          3 REDDISH BROWN SILTY CLAY,          MEADE   Z= 8-10 FT

C          4 REDDISH BROWN SILTY CLAY,          MEADE   Z=13-15
C          5 REDDISH BROWN SILTY CLAY,          MEADE   Z=18-20
C          6 GRAY SILTY CLAY WITH PEBBLES,       PENNING Z=8.5-10.5

C          7 GRAY SHALE,                     PENNING Z=14-16
C          8 LIGHT BROWN SILTY CLAY,           PENNING Z= 8- 9
C          9 LIGHT BROWN SILTY CLAY,           PENNING Z=13-15
C         10 BROWN SILTY CLAY WITH PEBBLES,       PENNING Z=18-20
C         11 BROWN SILTY CLAY WITH SAND & PEBBLES, MINNEHA Z=13-14
C         12 BROWN SILTY CLAY WITH SAND,         MINNEHA Z=16-17
C         13 GRAY BROWN SHALE,                JONES   Z=32-56
C         14 GRAY SILTY CLAY,                 LAWRENC Z=7.5- 9
C         15 GRAY SILTY CLAY,                 LAWRENC Z=14-15
C         16 GRAY SILTY CLAY,                 LAWRENC Z=19-20
C         17 BROWN SILTY CLAY,                BRULE   Z= 3-16
C         18 BROWN SILTY CLAY,                BRULE   Z=32-42
C         19 BROWN SILTY CLAY,                BRULE   Z=51-55
C         20 GRAY SHALE,                     BUFFALO Z=38-41.5
C
C    GENERAL COMPACTED SOIL PROPERTIES
C
C         21 GW,GP,SW,SP SOIL WITH STANDARD RC=105 OF AASHTO
C         22                          100
C         23                           95
C         24                           90
C         25 SM SOIL WITH STANDARD RC=100 OF AASHTO
C         26                     95
C         27                     90
C         28                     85
C         29 SM,SC SOIL WITH STANDARD RC=100 OF AASHTO
C         30                       95
C         31                       90
C         32                       85
C         33 CL SOIL WITH STANDARD RC=100 OF AASHTO
C         34                     95
C         35                     90
C         36                     85
C
```

```
      COMMON /BLK1/AE(10),EIY(10),E(10),POIS(10),EX(102),GX(102),INR
      COMMON /BLK17/EIZ(10),GJX(10),IPILE,XPILE,INCR,XXS(102,5),
     +          YYS(102,5),IFILE
      COMMON /BLK12/ZZS(102,5),XYT(102,5),XZT(102,5),YZT(102,5)
      COMMON /BLK7/DUN(10,9),PA
      COMMON/BLK10/ID(100,6),PN(6),FFX(10),FFY(10),TTX(102),TTY(102)
      DO 5 I=1,9
    5 DUN(K,I)=0.
      IF(KCODE .GT. 9)GO TO 100
      GO TO(10,20,30,40,50,60,70,80,90),KCODE
C
C
C     KCODE = 1
C
C
   10 DUN(K,1)=700.
      DUN(K,2)=1400.
      DUN(K,3)=0.85
      DUN(K,4)=0.74
      DUN(K,5)=0.
      DUN(K,6)=50.
      FFX(K)=0.
      FFY(K)=-103.5
      POIS(K)=0.3
      RETURN
C
C
C     KCODE = 2
C
C
   20 DUN(K,1)=525.
      DUN(K,2)=1050.
      DUN(K,3)=0.95
      DUN(K,4)=0.76
      DUN(K,5)=0.
      DUN(K,6)=50.
      FFX(K)=0.
      FFY(K)=-103.5
      POIS(K)=0.3
      RETURN
C
C
C     KCODE = 3
C
C
   30 DUN(K,1)=140.
      DUN(K,2)=280.
      DUN(K,3)=0.34
      DUN(K,4)=0.59
      DUN(K,5)=2400.
      DUN(K,6)=17.
      FFX(K)=0.
      FFY(K)=-137.5
      POIS(K)=0.3
```

```
      RETURN
C
C
C    KCODE = 4
C
C
   40 DUN(K,1)=150.
      DUN(K,2)=300.
      DUN(K,3)=0.23
      DUN(K,4)=0.43
      DUN(K,5)=1700.
      DUN(K,6)=30.
      FFX(K)=0.
      FFY(K)=-137.5
      POIS(K)=0.3
      RETURN
C
C
C    KCODE = 5
C
C
   50 DUN(K,1)=215.
      DUN(K,2)=430.
      DUN(K,3)=0.41
      DUN(K,4)=0.6
      DUN(K,5)=1100.
      DUN(K,6)=35.
      FFX(K)=0.
      FFY(K)=-136.0
      POIS(K)=0.3
      RETURN
C
C
C    KCODE = 6
C
C
   60 DUN(K,1)=290.
      DUN(K,2)=580.
      DUN(K,3)=0.32
      DUN(K,4)=0.65
      DUN(K,5)=0.
      DUN(K,6)=50.
      FFX(K)=0.
      FFY(K)=-125.3
      POIS(K)=0.3
      RETURN
C
C
C    KCODE = 7
C
C
   70 DUN(K,1)=70.
      DUN(K,2)=140.
      DUN(K,3)=1.57
```

```
      DUN(K,4)=0.73
      DUN(K,5)=1550.
      DUN(K,6)=15.
      FFX(K)=0.
      FFY(K)=-124.8
      POIS(K)=0.3
      RETURN
C
C
C    KCODE = 8
C
C
   80 DUN(K,1)=90.
      DUN(K,2)=180.
      DUN(K,3)=0.26
      DUN(K,4)=0.63
      DUN(K,5)=1850.
      DUN(K,6)=25.
      FFX(K)=0.
      FFY(K)=-125.
      POIS(K)=0.3
      RETURN
C
C
C    KCODE = 9
C
C
   90 DUN(K,1)=235.
      DUN(K,2)=470.
      DUN(K,3)=0.1
      DUN(K,4)=0.79
      DUN(K,5)=1650.
      DUN(K,6)=30.
      FFX(K)=0.
      FFY(K)=-126.6
      POIS(K)=0.3
      RETURN
C
C
  100 IF(KCODE .GT. 18)GO TO 200
      KK=MOD(KCODE,9)
      IF(KK .EQ. 0)KK=9
      GO TO(110,120,130,140,150,160,170,180,190),KK
C
C
C    KCODE = 10
C
C
  110 DUN(K,1)=220.
      DUN(K,2)=440.
      DUN(K,3)=0.36
      DUN(K,4)=0.82
      DUN(K,5)=0.
      DUN(K,6)=36.
```

```
      FFX(K)=0.
      FFY(K)=-125.5
      POIS(K)=0.3
      RETURN
C
C
C    KCODE = 11
C
C
  120 DUN(K,1)=125.
      DUN(K,2)=250.
      DUN(K,3)=0.26
      DUN(K,4)=0.76
      DUN(K,5)=0.
      DUN(K,6)=32.
      FFX(K)=0.
      FFY(K)=-134.3
      POIS(K)=0.3
      RETURN
C
C
C    KCODE = 12
C
C
  130 DUN(K,1)=140.
      DUN(K,2)=280.
      DUN(K,3)=0.53
      DUN(K,4)=0.67
      DUN(K,5)=0.
      DUN(K,6)=42.
      FFX(K)=0.
      FFY(K)=-127.8
      POIS(K)=0.3
      RETURN
C
C
C    KCODE = 13
C
C
  140 DUN(K,1)=470.
      DUN(K,2)=940.
      DUN(K,3)=0.21
      DUN(K,4)=0.37
      DUN(K,5)=0.
      DUN(K,6)=40.
      FFX(K)=0.
      FFY(K)=-121.5
      POIS(K)=0.3
      RETURN
C
C
C    KCODE = 14
C
C
```