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Computer-Aided Structural Engineering (CASE) Project

User's Guide: Computer Program for Winkler Soil-Structure Interaction Analysis of Sheet-Pile Walls (CWALSSI)

by *William P. Dawkins, Oklahoma State University*

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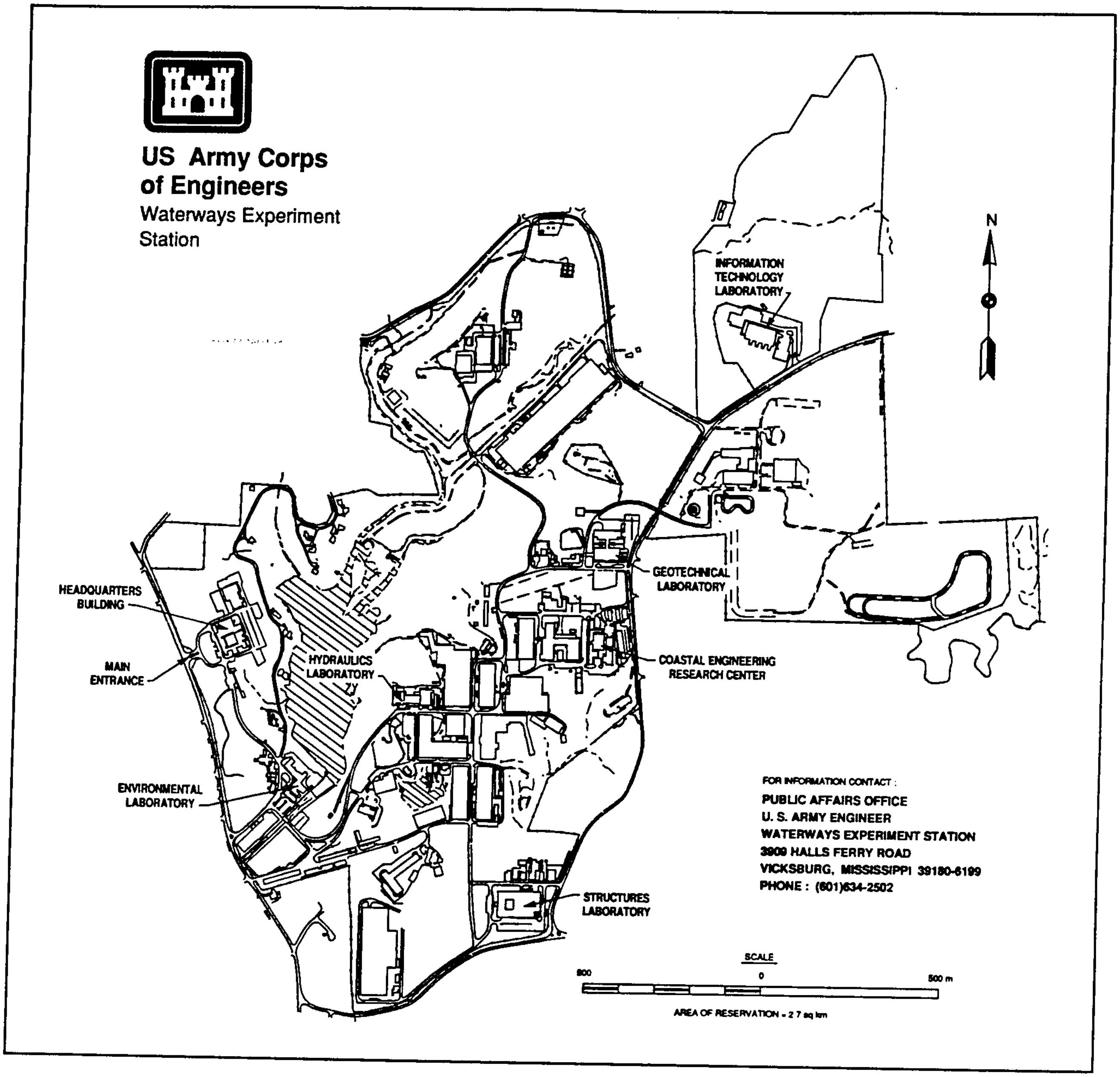

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Contents

Preface

This user's guide describes the computer program CWALSSI which performs soil-structure interaction analysis of sheet-pile retaining walls. The work in writing the computer program and user's guide was accomplished with funds provided to the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, by Headquarters, U.S. Army Corps of Engineers, Civil Works Directorate, under the Structural Engineering Research Program work unit of the Computer-Aided Structural Engineering (CASE) Project.

The program and user's guide were written by Dr. William P. Dawkins, P.E., Oklahoma State University, Stillwater, OK, under IPA agreement No. 93-15-M with WES.

The work was managed, coordinated, and monitored in the Information Technology Laboratory (ITL), WES, by Dr. Reed L. Mosher, Acting Chief, Computer-Aided Engineering Division (CAED). Mr. H. Wayne Jones, Chief, Scientific and Engineering Applications Center, CAED, is Project Manager for the CASE Project. Dr. N. Radhakrishnan is Director, ITL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters
kips (force)	4448.22	newtons
pounds (force)	4.4482	newtons
pounds (force) per square inch	6894.76	pascals
pounds (force) per square foot	47.8803	pascals

1 Introduction

This report describes the computer program CWALSSI which performs soil-structure interaction (SSI) analysis of sheet-pile walls using the Winkler assumption for representing the soil as nonlinear springs. The program uses classical soil mechanics procedures for determining the limiting active, at-rest, and passive soil pressures. Seepage effects are included in a simplified manner in the program. CWALSSI was developed from specifications provided by the Computer-Aided Structural Engineering (CASE) Task Group on Sheet-Pile Structures.

CWALSSI is a companion to Program CWALSHT (CORPS Program X0031) which performs design of anchored or cantilever sheet-pile walls by classical methods. CWALSSI performs no design functions. Design parameters such as depth of penetration, the sheet-pile section, and the characteristics of anchors (if any) must be supplied as input to CWALSSI.

Organization of Report

The remainder of this report is organized as follows:

a. Chapter 2 describes the general sheet-pile retaining structure and the soil system to be analyzed by the program.

b. Chapter 3 describes the procedures employed in the program for calculating the limiting earth pressures, water pressures due to unbalanced hydrostatic head, and the effects of surcharge loads on the soil surface.

c. Chapter 4 outlines the methods for converting the surrounding soil and anchors to nonlinear springs.

d. Chapter 5 summarizes the one-dimensional (1-D) finite element model (FEM) of the wall/soil system.

e. Chapter 6 describes the computer program and attendant sign conventions.

f. Chapter 7 presents example solutions obtained with the program.

Disclaimer

The program has been checked within reasonable limits to assure that the results produced by the program are accurate within the limitations of the procedures employed. However, there may exist unusual situations not anticipated and thus may cause the program to produce questionable results. The author assumes no responsibility for the performance of any structure designed on the basis of results produced by the program.

2 General Wall/Soil System

The general wall/soil system accommodated by CWALSSI is shown in Figure 1. The system is assumed to be uniform perpendicular to the plane of Figure 1. A typical 1-ft slice of the uniform system is used for analysis. All effects on the wall are assumed to be "per 1 ft" of the system.

The 1-ft slice of the wall is assumed to be composed of a sequence of prismatic segments which share a common straight, vertical, centroidal axis. The elevations at the top and bottom and the cross section properties (moment of inertia, cross section area and modulus of elasticity) of the wall must be supplied as input to the program. The material in the wall is assumed to be linearly elastic.

Anchors

Multiple anchors may be attached to the wall. It is implicitly assumed that all anchors extend away from the wall to the right. As discussed subsequently, suitable selection of anchor characteristics allows modeling of anchors which extend to the left. Anchors may be omitted for analysis of a cantilever wall.

Soil Surface

The soil surface on either side of the wall must intersect the wall at or below the top of the wall and above the bottom of the wall. The irregular surface illustrated in Figure 1 on each side of the wall is described by a sequence of distances from the wall and elevations for each point at which a change in slope occurs. The surface is assumed to be straight between successive points. The surface is assumed to extend ad infinitum horizontally at the elevation of the last surface point.

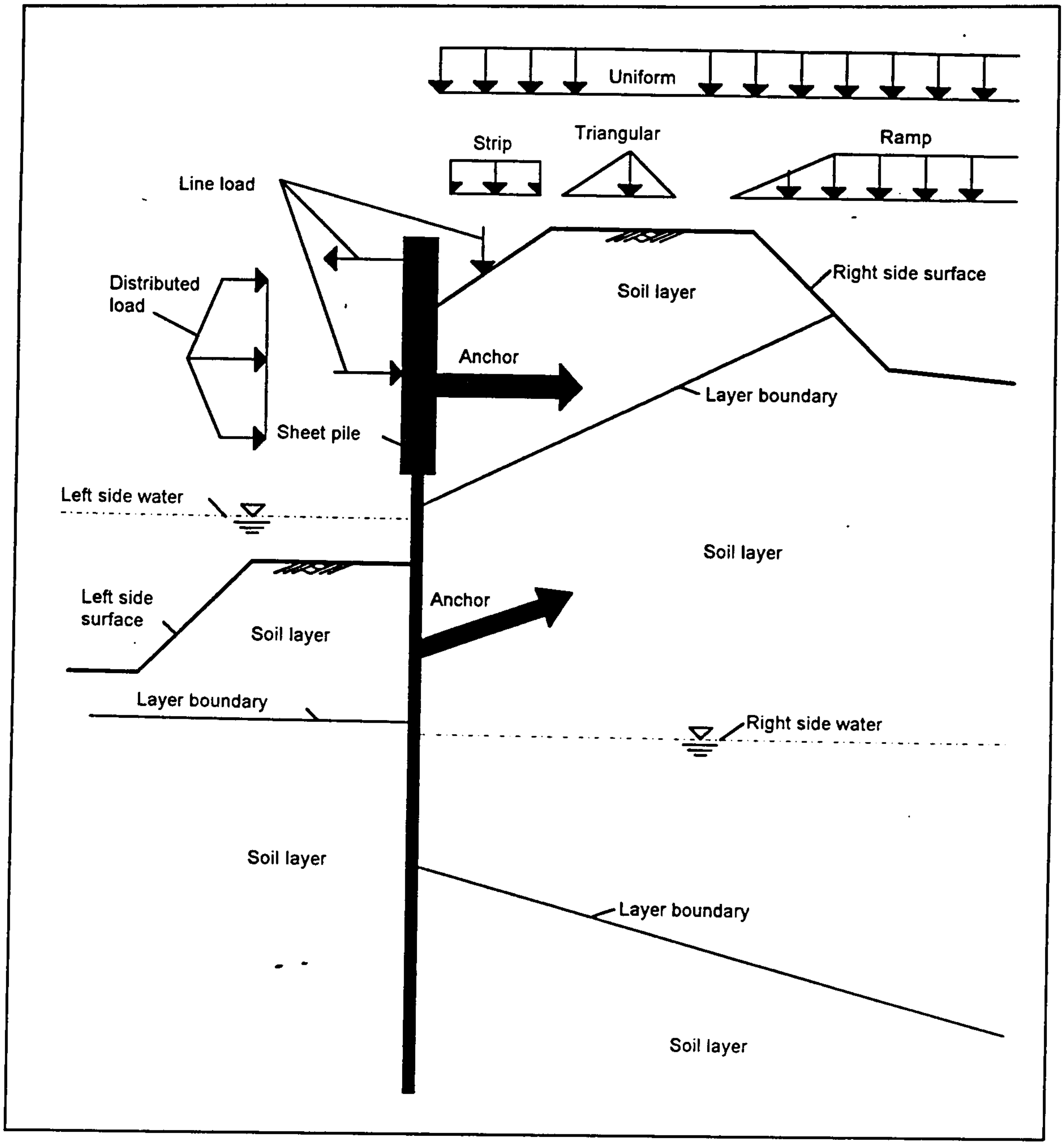

Figure 1. General wall/soil system

Soil Profile

A different soil profile is assumed on each side of the wall. Boundaries between subsurface layers are assumed to be straight lines and may slope up or down away from the wall. Sloping boundaries may not intersect within the soil mass. Soil layers whose boundaries do not intersect the surface are assumed to extend ad infinitum away from the wall. The lowest layer described on each side of the wall is assumed to extend ad infinitum downward.

Soil Properties

Each soil layer is assumed to be homogeneous. Properties required for each layer are:

a. Soil saturated unit weight — γ_{sat} (psf): The program determines the buoyant unit weight for submerged soil according to

$$\gamma' = \gamma_{sat} - \gamma_{we} \tag{1}$$

where

γ' = buoyant unit weight

γ_{we} = effective unit weight of water (Chapter 3)

b. Soil moist unit weight — γ_{mst} (psf): The moist unit weight is used for all soil above the water surface.

c. Angle of internal friction — ϕ (deg): The program uses the input angle of internal friction without alteration (i.e., no factor of safety (FS) or strength reduction factor is applied). The program determines the at-rest pressure coefficient according to

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

d. Cohesion — c (psf): The program uses the input cohesion without alteration (i.e., no FS or strength reduction factor is applied).

e. Angle of wall friction — δ (deg): The program uses the input angle of wall friction without alteration (i.e., no FS or strength reduction factor is applied). See Figure 2 for the assumed positive wall friction.

f. Wall/soil adhesion — a (psf): The program uses the input adhesion without alteration (i.e., no FS or strength reduction factor is applied). See Figure 2 for the assumed positive adhesion. It should be noted that a nonzero value of wall/soil adhesion requires the use of one of the wedge methods, described subsequently, for determining the limiting soil pressures.

g. Soil stiffness coefficient for active pressures — S_a (lb/in.^{3}).

h. Soil stiffness coefficient for passive pressures — S_p (lb/in.^{3}).

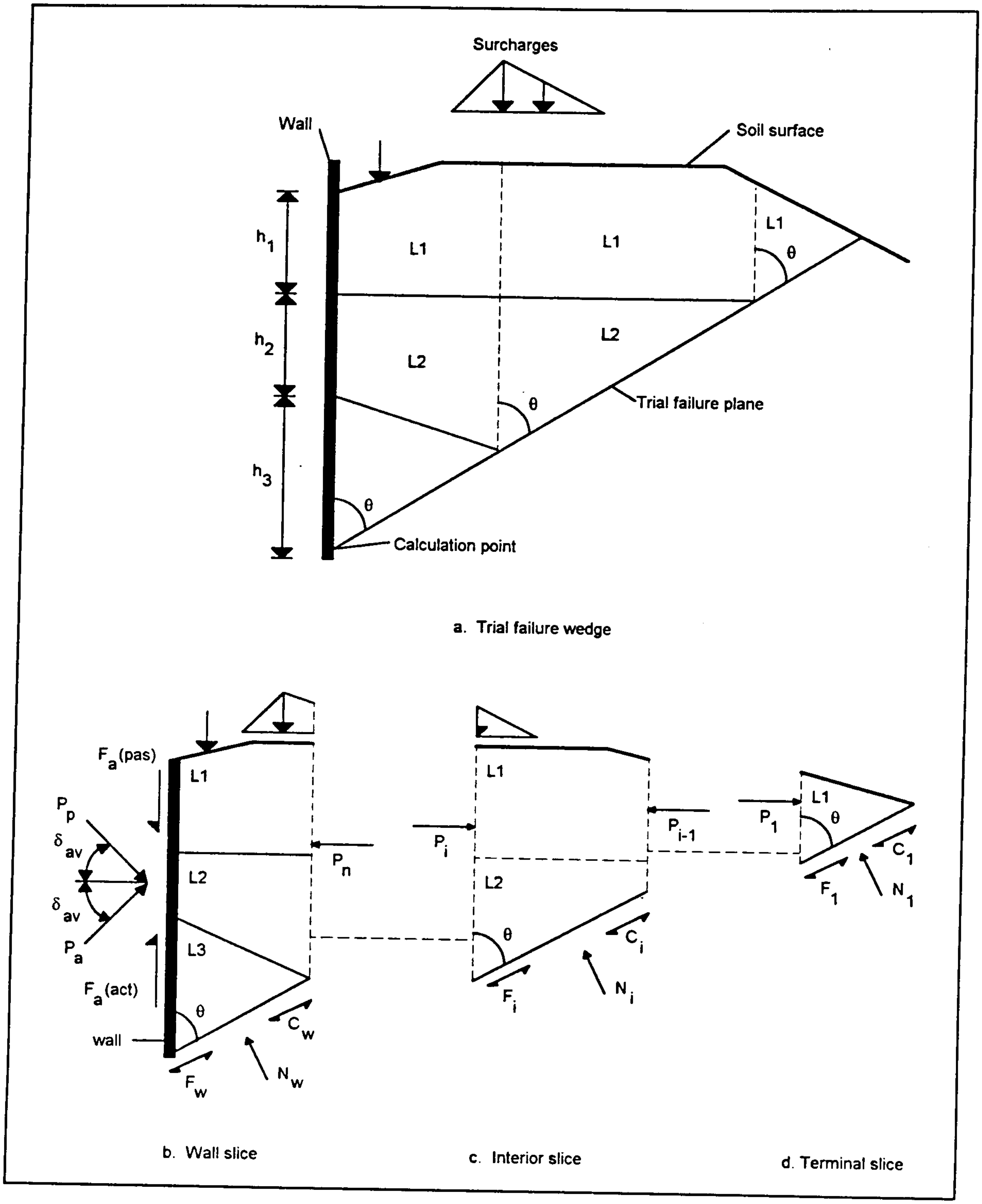

Figure 2. Sweep search wedge method

Water

The following effects due to water are considered:

a. Static water: Horizontal hydrostatic pressures are applied to either side of the wall. Static water surfaces may be at any elevation. When the water surface is above the top of the wall, only the trapezoidal pressure distribution below the top of the wall is used.

b. Seepage effects: Seepage effects alter static water pressures and the submerged weight of the soil. The approximations used to account for seepage are discussed in Chapter 3. When seepage is present, the water surface on the rightside[1] must be above that on the leftside.[1]

c. Earthquake effects: Earthquake effects alter hydrostatic pressures only on the rightside above the soil surface (page 6).

Soil stiffness coefficients for submerged soil differ from those for soil above water.[2] The program does not alter the input soil stiffness coefficients for water effects. Consequently, it may be necessary to subdivide an otherwise homogeneous soil layer when the water surface is within the layer boundaries.

Vertical Surcharge Loads

Surcharge loads may be applied to the soil surface on either side of the wall. Five types of surcharge loads are illustrated in Figure 1. All surcharge loads are assumed to be positive downward; upward surcharge loads are not permitted. All surcharge loads are assumed to extend horizontally ad infinitum perpendicular to the plane of Figure 1.

Vertical line loads

Vertical line loads are assumed to act on the soil surface. Several (see Appendix A for limitations) line loads may be applied to the surface on either side.

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1 The terms leftside and rightside are used in the one-word form in the text to be consistent with their use in the computer program CWALSSI.

2 Karl Terzaghi. (1955). "Evaluation of coefficients of subgrade reaction," *Geotechnique* 5, 297-326.

Vertical distributed loads

Four basic distributed load variations permitted by the program are shown in Figure 1. As an alternative to the basic distributions, a general distribution may be described by a sequence of distances and load intensities on a piecewise linear distribution. Distributed loads are interpreted as acting on the horizontal projection of the soil surface. Only one type of distributed load may be applied to the surface on either side. Characteristics assumed for each of the basic distributed loads are:

a. A uniform surcharge commences at the wall and extends horizontally ad infinitum.

b. A ramp load commences at some distance from the wall and extends horizontally ad infinitum as a uniform load from the terminus of the ramp.

c. Several (see Appendix A for limitations) strip loads may be applied to the surface on either side.

d. Several (see Appendix A for limitations) triangular loads may be applied to the surface on either side.

External Horizontal Loads

Two types of external horizontal loads, in addition to other soil and water loads, may be applied to the wall. Horizontal loads acting to the left are positive; horizontal loads may be positive or negative. The horizontal load is assumed to extend horizontally ad infinitum perpendicular to the plane of Figure 1.

Horizontal line loads

Several (see Appendix A for limitations) line loads may be applied to the wall and may be at any elevation.

Horizontal distributed loads

A single general horizontal load distribution described by a sequence of elevations and load intensities may be applied to the wall.

Earthquake Effects

Earthquake effects are assumed to increase the tendency of the wall to move to the left. Earthquake effects on soil pressures are simulated in the program by altering the soil unit weight on each side as follows:

Rightside: $\gamma_{eff} = \gamma_{mst}\,(1 + \alpha)$ for soil above water

$\gamma_{eff} = \gamma_{sat}\,(1 + \alpha) - \gamma_{we}$ for submerged soil (3)

Leftside: $\gamma_{eff} = \gamma_{mst}\,(1 - \alpha)$ for soil above water

$\gamma_{eff} = \gamma_{sat}\,(1 - \alpha) - \gamma_{we}$ for submerged soil (4)

where α is the earthquake acceleration expressed as a fraction ($0 \leq \alpha < 1$) of the acceleration of gravity.

Earthquake effects on water pressures for water above the rightside soil surface are included by application of an additional pressure distribution according to

$$p_y = C_a\,\alpha\sqrt{hy} \qquad (5)$$

where

$$C_a = 51\sqrt{1 - 0.72(h/1000)^2}$$

h = distance from rightside water surface to rightside soil surface

y = distance below rightside water surface

3 Limiting Soil and Water Pressures

Horizontal loads are imposed on the structure by the surrounding soil, surface surcharge loads, water pressures, and horizontal external loads applied directly to the wall. The following paragraphs describe procedures used in the program for determining the limiting soil and water pressures.

Calculation Points

Force magnitudes and wall response are calculated at the following points:

a. Top and bottom of the wall and at intervals of 6 in. or 1/40 of the wall height, whichever is smaller, starting at the top of the wall.

b. Elevations at which cross section properties change.

c. Intersections of the surfaces and/or soil layer boundaries on either side of the wall.

d. Elevations of anchor attachment points.

e. Elevations of the water surfaces on either side of the wall and elevation at which seepage commences.

f. Point of application of each horizontal line load and each elevation point of an applied horizontal distributed load.

g. Other locations as necessary to establish the final forces or pressures in the system.

Limiting Active and Passive Soil Pressures

Three methods (a coefficient method and two "wedge" methods) are available in the program to establish the limiting active and passive soil pressures. These limiting pressures result when the displacement of the wall is sufficient to produce a fully plastic state in the soil. The program determines whether the coefficient method or wedge method is to be used. A different method may be used for each side.

At-rest Soil Pressures

The limiting active and passive pressures described above are produced by large displacements of the wall. The at-rest pressure (at zero displacement) is determined at each calculation point as follows:

a. The effective vertical soil stress p_v at a calculation point is evaluated from the effective soil unit weight for the soil between the elevation at the intersection of the soil surface with the wall and the point of interest, including any uniform surcharge as well as the effects of submergence, seepage, and earthquake acceleration. The effects of an irregular surface, sloping soil layer boundaries, and surface surcharge loads other than a uniform surcharge are not included.

b. The at-rest pressure is obtained from

$$p_o = k_o \cdot p_v \tag{6}$$

Pressure Coefficient Method

Coulomb earth pressure coefficients relating horizontal pressure to vertical pressure are used when the soil surface is horizontal, all subsurface layer boundaries are horizontal, and the wall/soil adhesion is zero in all layers. Soil pressures are calculated as follows:

a. The vertical pressure p_v at each point is calculated using the effective soil unit weight (including submergence and/or earthquake effects) for the soil above that point and any uniform surface surcharge.

b. The Coulomb earth pressure coefficients are:

$$K_{a/p} = \left[\frac{\cos \phi}{1 \pm \sqrt{\frac{\sin (\phi + \delta) \sin \phi}{\cos \delta}}} \right]^2 \div \cos \delta \tag{7}$$

c. The horizontal earth pressures are calculated from:

$$p_{a/p} = \left(K_{a/p} \cdot p_v \mp 2C\sqrt{K_{a/p}}\right) \cdot \cos\delta \qquad (8)$$

where the minus signs in the preceding equations are used for active conditions and the plus signs for passive conditions.

Wedge Methods

For all cases involving an irregular soil surface, sloping subsurface layer boundaries, or wall/soil adhesion, one of the wedge methods described in the following paragraphs is used. The user is prompted by the program to select the method.

Sweep search wedge method

A continuous failure plane is assumed to emanate from each calculation point to its intersection with the soil surface as shown in Figure 2a. The trial wedge is then subdivided by vertical planes into slices as shown in Figures 2b, c, and d. The location of a vertical plane is established by the intersection of the continuous trial failure plane with each succeeding layer boundary. The intermediate vertical slice surfaces are assumed to be free of shear stresses. Friction and cohesion along the base of each intermediate slice are evaluated from the properties of the bottom layer in the slice.

Equilibrium of horizontal and vertical forces for each slice, except the slice in contact with the wall, requires that

$$P_i - P_{i-1} = \frac{W_i \cdot (1 \mp \tan\phi_i \tan\theta) \mp C_i \sec\theta}{\tan\phi_i \pm \tan\theta}$$

where

P_i, P_{i-1} = normal forces on the left- and rightside vertical surfaces of the slice, respectively

W_i = weight of the slice including surface surcharge loads

ϕ_i = angle of internal friction of the soil at the bottom of the slice

C_i = cohesion of the soil at the bottom of the slice multiplied by the length of the bottom surface

The upper signs are used for active conditions and the bottom signs refer to passive conditions.

Equilibrium analysis of the slice in contact with the wall results in

$$\begin{bmatrix} \pm \sin\delta_{av} & (\sin\theta \pm \tan\phi\cos\theta) \\ \cos\delta_{av} & -(\cos\theta \mp \tan\phi\sin\theta) \end{bmatrix} \begin{pmatrix} P_{a/p} \\ N_w \end{pmatrix} = \begin{pmatrix} W_w \mp C_w \cos\theta \mp F_a \\ P_n \mp C_w \sin\theta \end{pmatrix} \qquad (9)$$

where

δ_{av} = average wall friction angle given by $\delta_{av} = \sum h_j\delta_j / \sum h_j$

$P_{a/p}$ = active force (upper signs) or passive force (lower signs) for this trial wedge

W_w = weight of the wall slice including surface surcharge loads

C_w = cohesion of the soil at the bottom of the wall slice multiplied by the length of the bottom surface

F_a = wall/soil adhesion force given by $F_a = \sum h_j a_j$

N_w = normal force on the bottom of the wall slice

P_n = normal force on the inner vertical plane

The angle of inclination θ of the trial wedge is increased in 2-deg increments until the maximum active force and minimum passive force for that calculation point are determined. In some systems having downward sloping surfaces, maximum active and minimum passive forces may not be achieved before the trial failure plane no longer intersects the soil surface. When this situation is encountered, a warning is printed and the active and/or passive force for the last trial plane is used for that point.

Fixed-surface wedge method

The fixed-surface wedge method assumes that the angle of inclination of the failure plane within each layer is a function of the angle of internal friction of the soil in that layer. This assumption results in a single fixed broken failure surface as illustrated in Figure 3.

When the fixed surface for a calculation point has been established, the total wedge is subdivided into slices as indicated by the dashed lines in Figure 3. The determination of active and passive forces proceeds as described for the sweep search method.

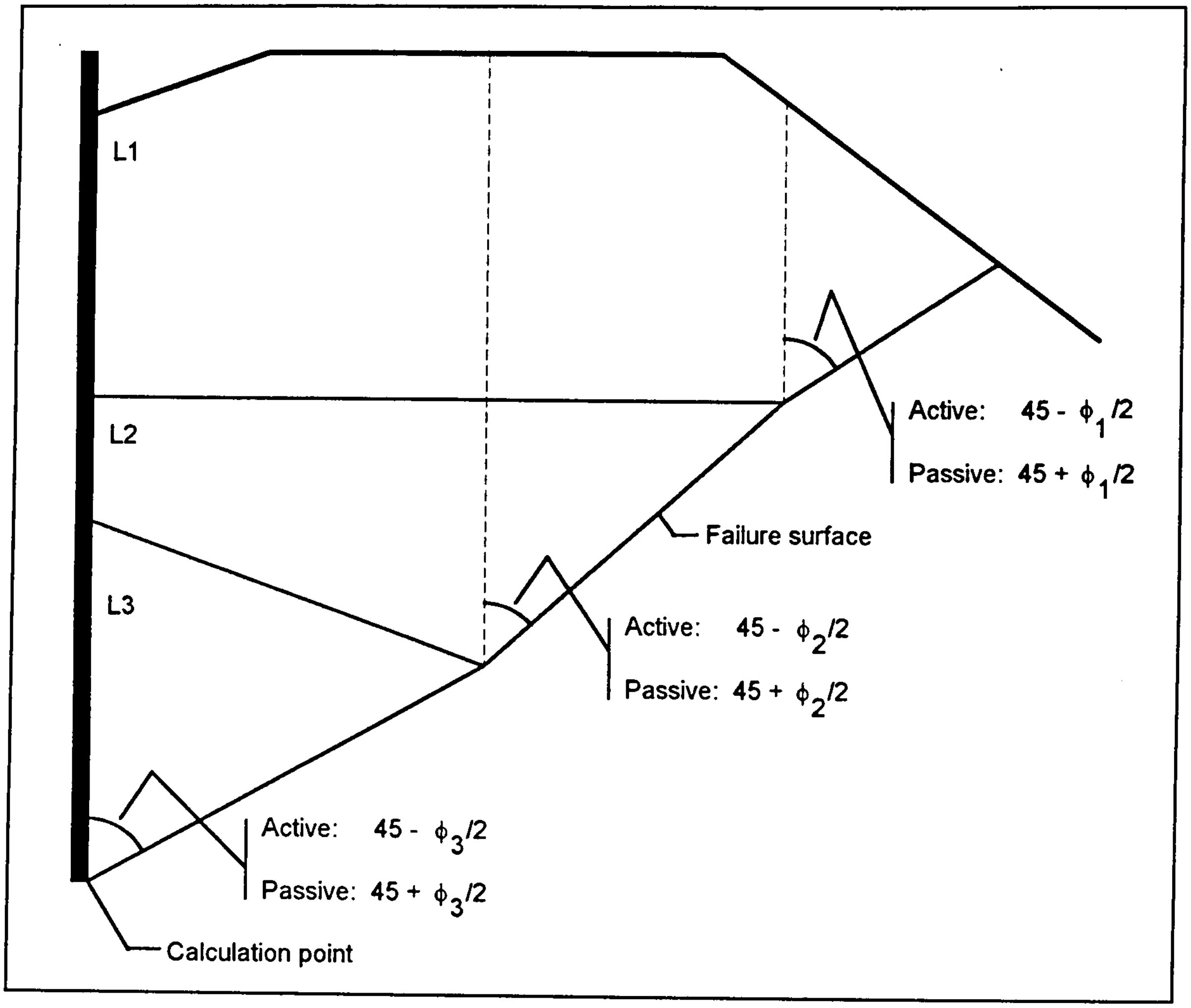


Figure 3. Fixed-surface wedge method

Final Pressures for Wedge Methods

For either wedge method, it is assumed that the difference between active or passive forces for two adjacent calculation points is the resultant of a linear pressure distribution between the two points.

Discussion of Soil Pressure Calculation Methods

The computer program determines from the input data whether the coefficient method may be used or whether a wedge method is required for evaluation of active and passive soil pressures. If a wedge method is required, the user is prompted to select either the sweep search or the fixed-surface method. The program can be forced to use a wedge method where the coefficient method would ordinarily apply by specifying more than one point on the soil surface on either side (Appendix A).

For a homogeneous soil system with a horizontal soil surface and no surcharge loads, the three pressure calculation methods produce identical pressure distributions. For layered soil profiles with a horizontal soil surface, horizontal layer boundaries, and no surcharge loads, the three methods yield essentially the same pressure distributions. The significant differences occur at layer boundaries where the coefficient method may produce stepped discontinuities in pressures while the wedge methods result in a single average pressure at the boundary.

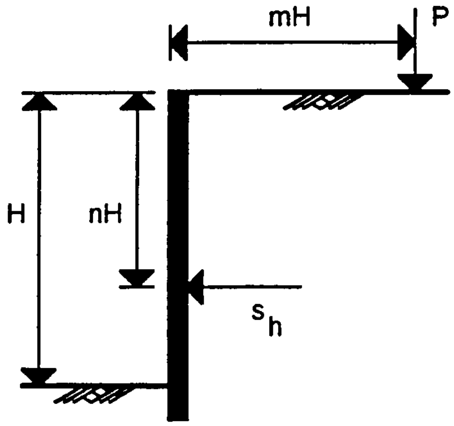
For all soil profiles without severe variations in soil layer strengths and with essentially horizontal surfaces, the two wedge methods produce comparable soil pressures. Although both methods overestimate passive pressures, the sweep search method is more consistent with the principles used in the development of the coefficient method. For systems with steep surface slopes, the fixed-surface method underestimates active pressures for upward sloping surfaces and overestimates passive pressures for downward sloping surfaces as compared to the sweep search method. The degree of under- or overestimation increases as the surface slope increases.

The sweep search method always seeks the maximum active and minimum passive condition. It may not be possible for the sweep search method to arrive at the desired extreme condition if the soil surface is grossly irregular. The user is warned when this condition is encountered. In systems with interspersed strong and weak layers, the sweep search method may arrive at an active and/or passive force at one calculation point which is significantly lower than the corresponding force at the next higher point. Conversion of active/passive forces to pressures in this case may result in "negative" pressures in the interval and the resulting pressure distributions are unreliable.

Pressures Due to Surcharge Loads

The effects of surcharge loads on the surface are included in the weight of the failure wedge, and no additional computations for surcharge loads are required when soil pressures are determined by the wedge method.

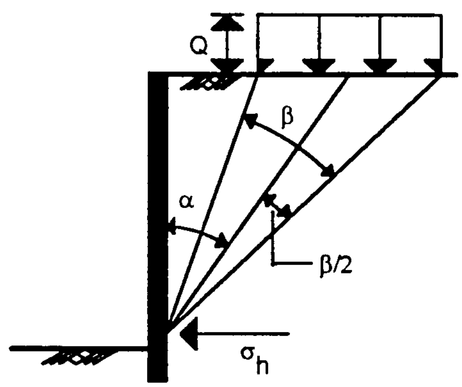
When the coefficient method is used to determine soil pressures, a uniform surcharge is added directly to the vertical soil pressure as indicated on page 11, "Pressure Coefficient Method." The additional horizontal pressures on the wall due to vertical line, strip, ramp, triangular, or varying surcharges are calculated from the theory of elasticity equations shown in Figure 4.



$$m > 0.4: \quad \sigma_h = \frac{4P}{\pi H}\left[\frac{m^2 n}{(m^2+n^2)^2}\right]$$

$$m \le 0.4: \quad \sigma_h = \frac{P}{H}\left[\frac{0.203n}{(0.16+n^2)^2}\right]$$

a. Line load



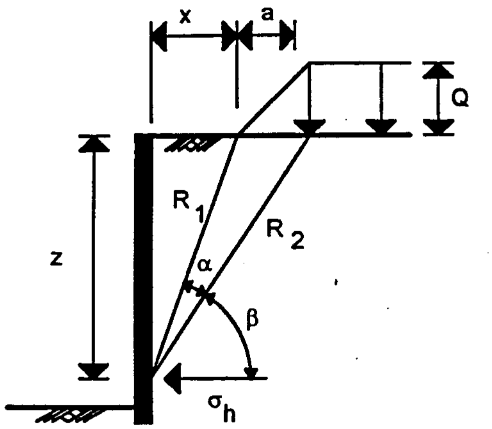
$$\sigma_h = \frac{Q}{\pi}(\beta - \sin\beta\cos 2\alpha)$$

b. Strip load

Figure 4. Theory of elasticity equations for surcharge loads (Continued)

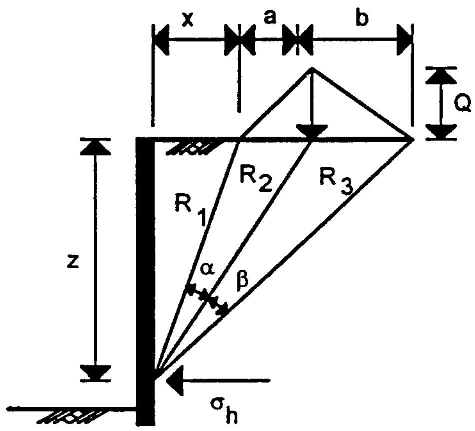
Water Pressures

In addition to "Earthquake Effects" (page 9), hydrostatic pressures may be altered by seepage. When seepage effects are included, the excess hydrostatic head is assumed to be dissipated by vertical flow downward on the rightside and upward on the leftside. The flow gradient i (feet/feet) is assumed to be constant at all points in the soil. Under this assumption, the effect of seepage is to alter the effective unit weight of water in the region of flow to:



$$\sigma_h = \frac{Q}{\pi a}\left(a\beta - x\alpha + 2z\log_e \frac{R_1}{R_2}\right)$$

c. Ramp load



$$\sigma_h = \left[\frac{a+b+x}{b}\beta - \frac{x}{a}\alpha + \frac{2z}{a}\log_e \frac{R_2}{R_1} + \frac{2z}{b}\log_e \frac{R_2}{R_3}\right]$$

d. Triangular load

Figure 4. (Concluded)

Rightside: $\gamma_{we} = \gamma_w\ (1 - i)$ (10)

Leftside: $\gamma_{we} = \gamma_w\ (1 + i)$ (11)

The user may elect to omit seepage effects, to specify the seepage gradient *i*, or to allow the program to automatically set the seepage gradient. If seepage is omitted, the net water pressure distribution shown in Figure 5a is applied. For "automatic" seepage, the program sets the seepage so that the point at which excess head is dissipated (i.e., the net water pressure becomes zero) coincides with the bottom of the wall. A user-supplied

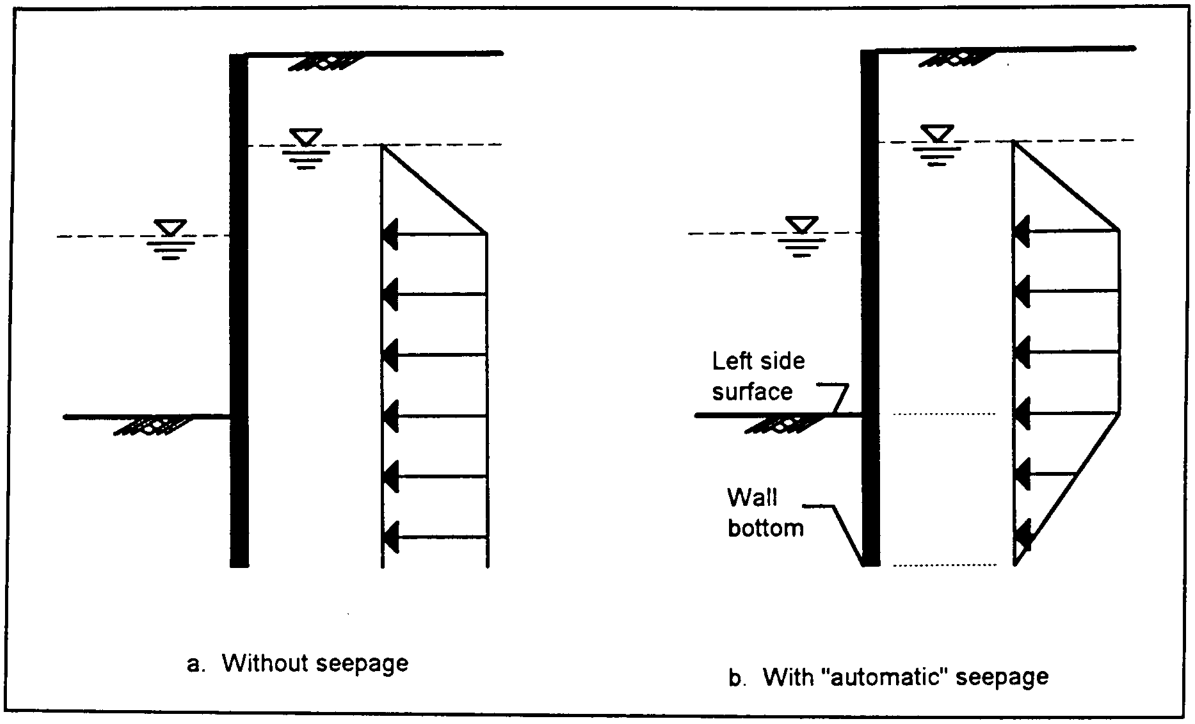


Figure 5. Net water pressure distributions

seepage gradient may result in dissipation of the excess head at some point other than the bottom of the wall.

4 Nonlinear Soil and Anchor Springs

The soil pressure or anchor force exerted on the wall at any point is assumed to depend only on the displacement of the wall at that point (i.e., the Winkler assumption). In effect, this assumption results in treating the soil and anchor springs as isolated translation resisting elements. The methods employed for relating soil pressures and anchor forces to wall displacements are described in the following paragraphs.

Soil Springs

The representation of the soil as a system of independent columns is illustrated in Figure 6. As shown in Figures 6b and 6c, the pressure exerted on the wall is assumed to vary with wall displacement between the limiting active and passive pressures at each calculation point. The displacements v_a and v_p at which the soil attains the limit pressure are dependent on the soil strength parameters ϕ and c and the soil stiffness coefficients s_a and s_p supplied as input for each soil layer, and the length of the soil column denoted as the "interaction distance - d" in Figure 6.

Interaction distance

The interaction distance is representative of the horizontal distance from the wall to which the SSI influences the state of soil stress. Terzaghi[1] suggests that zones of the soil tending toward passive conditions are the most significant and indicates that the depth of penetration be used

[1] Karl Terzaghi. (1955). "Evaluation of coefficients of subgrage reaction," *Geotechnique* 5, 297-326.

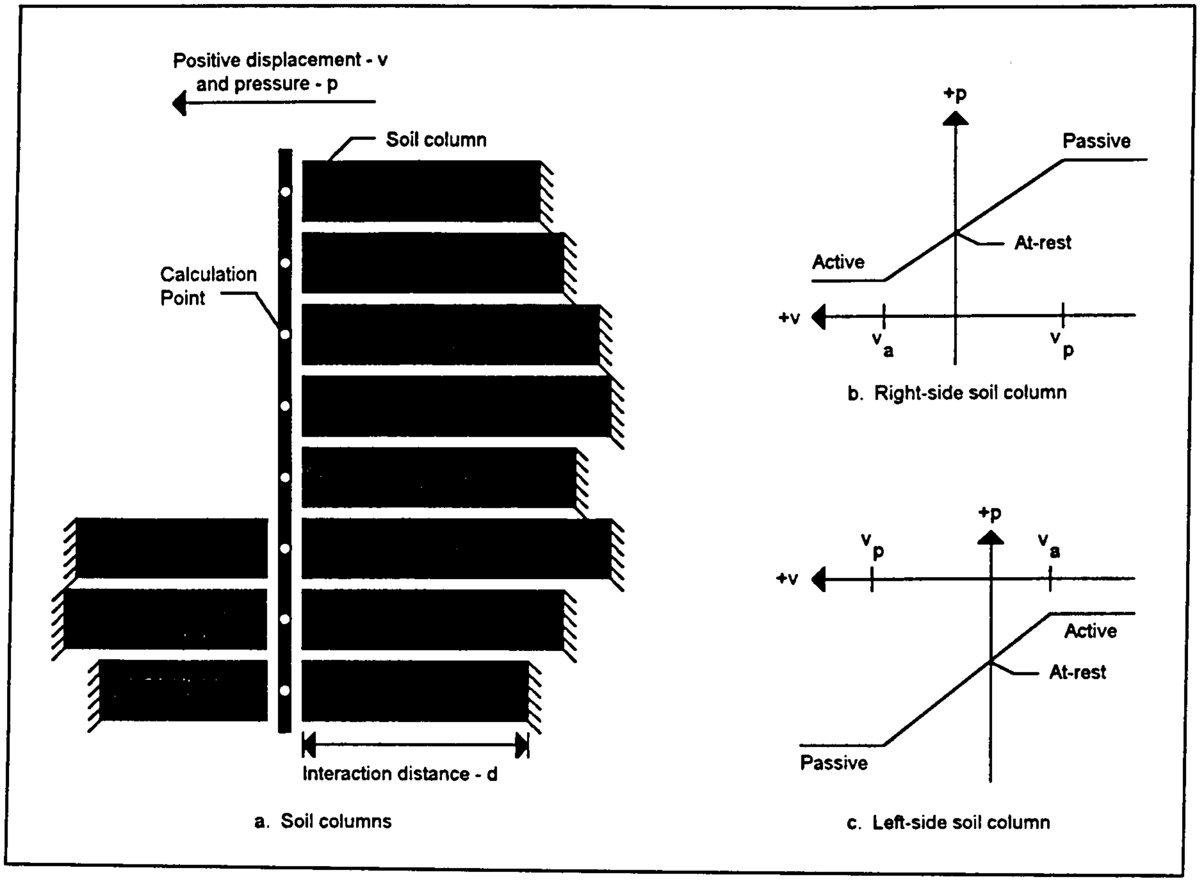


Figure 6. Soil columns and pressure-displacement curves

for the interaction distance for a single-anchored wall. Haliburton[1] suggests that the interaction distance be taken as the distance between adjacent struts in braced trenches. No other guidance for estimation of the interaction distance is available in the literature. In most cases iterative solutions should be performed, with the interaction distance being equal to the depth of passive zones from each preceding solution. For initial estimates of interaction distance, the distance shown in Figure 7 may be used. See Chapter 7, "Example Solutions," and Appendix A for further discussion of interaction distances.

Soil spring stiffness

The soil stiffness, i.e., the slopes of the soil pressure-displacement curves of Figure 6, is obtained from the input soil stiffness coefficients as follows (Terzaghi 1955 and Haliburton 1979)

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[1] T. A. Haliburton. (1979). "Soil structure interaction," Technical Publication No. 14, Oklahoma State University, Stillwater, OK.

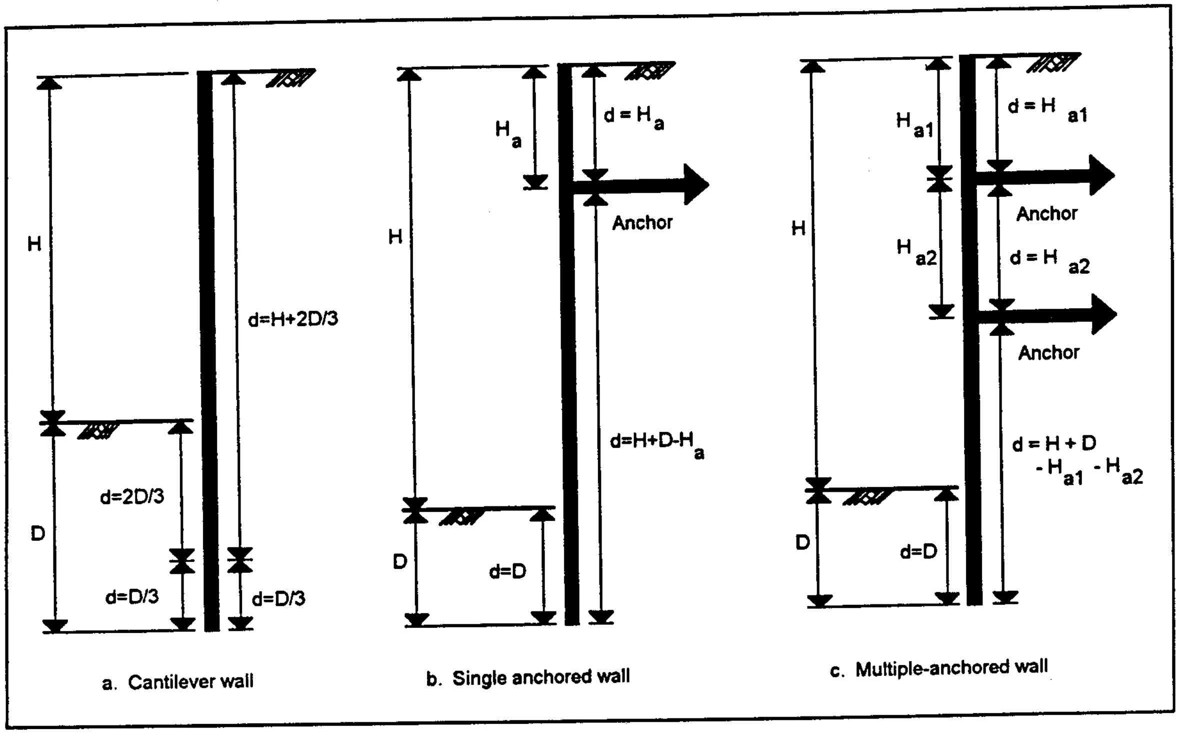

Figure 7. Initial estimates of interaction distances

a. For soil possessing a nonzero angle of internal friction ($\phi > 0$), the soil stiffness is assumed to increase linearly with confining the pressure. Hence, the input soil stiffness parameter for these materials is interpreted as the rate of increase of soil stiffness per foot of depth, and the soil stiffness is obtained from

$$S_{a/p} = s_{a/p} \cdot p_v / \gamma_e \tag{12}$$

where

$s_{a/p}$ = input soil active/passive soil stiffness coefficient

p_v = effective vertical soil pressure at the calculation point

γ_e = effective soil unit weight at the point

b. For soil with zero angle of internal friction, the soil stiffness is assumed to be independent of confining pressure and

$$S_{a/p} = s_{a/p} \tag{13}$$

Finally, the displacements at which the limiting active and passive pressures develop are given by

$$v_a = (p_o - p_a) \cdot d/S_a \qquad (14)$$

and

$$v_p = (p_p - p_o) \cdot d/S_p \qquad (15)$$

For any displacement between v_a and v_p, the soil pressure-displacement relationship may be represented by a combination of a distributed linear spring and a distributed lateral load. For displacements beyond v_a and v_p, the pressure-displacement relationship is composed only of a distributed load.

Anchor Springs

As stated previously, all anchors are implicitly assumed to be attached to the rightside of the wall and to extend away from the wall to the right. The characteristics of anchors accommodated by the program are illustrated in Figure 8 and discussed in the following:

a. Rigid anchor — Acts as a rigid pin support, hence prevents any lateral displacement but allows free rotation at the point of attachment.

b. Flexible anchor — Acts as a nonlinear concentrated spring in which the anchor force varies with anchor deformation as shown in Figure 8c.

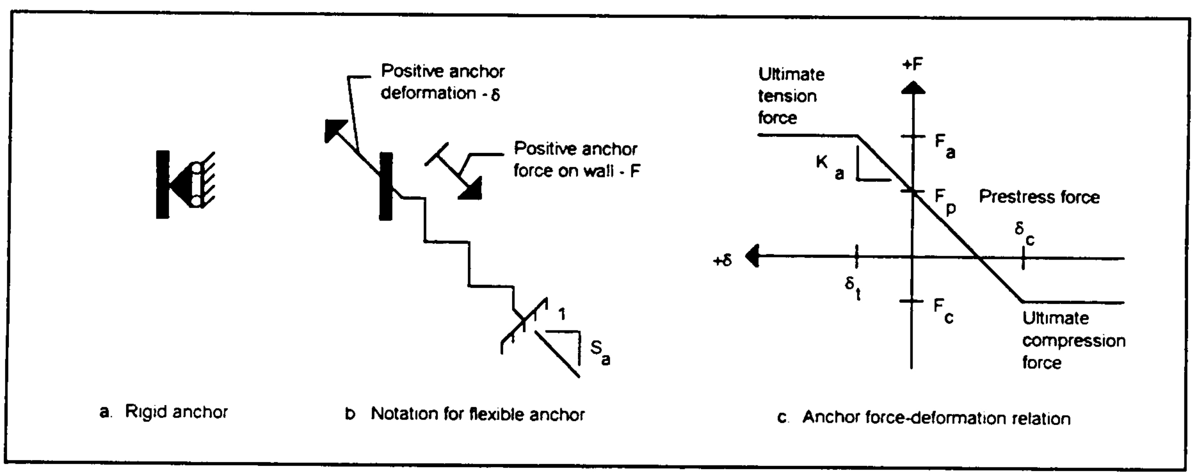

Figure 8. Anchor characteristics

The anchor force-deformation relationships for flexible anchors are obtained from the following:

$$\delta = (v_i - w_i \cdot S_a)/\sqrt{1 + S_a^2}$$

$$K_a = E_a \cdot A_a/L_a \tag{16}$$

$$\delta_t = (F_t - F_p)/K_a$$

$$\delta_c = (F_p - F_c)/K_a$$

where

δ = deformation of the anchor parallel to the anchor line of action

v_i and w_i = lateral and axial displacements, respectively, of the anchor attachment point

S_a = anchor slope (feet/feet)

E_a = modulus of elasticity of the anchor material

A_a = anchor cross-sectional area per foot of wall

L_a = effective length of the anchor

δ_t and δ_c = yield deformations in tension and compression, respectively

F_t and F_c = yield forces in tension and compression, respectively

F_p = prestress force.

For any anchor deformation in the range, $\delta_c < \delta < \delta_t$, the anchor functions as a linear spring. For deformation greater than δ_t or δ_c, the anchor produces a constant force equal to F_t or F_c.

5 Finite Element Model

Nodes and Elements

The 1-D model of the wall/soil system used for analysis is illustrated in Figure 9. Nodes are located at the points used for calculating soil pressures described previously.

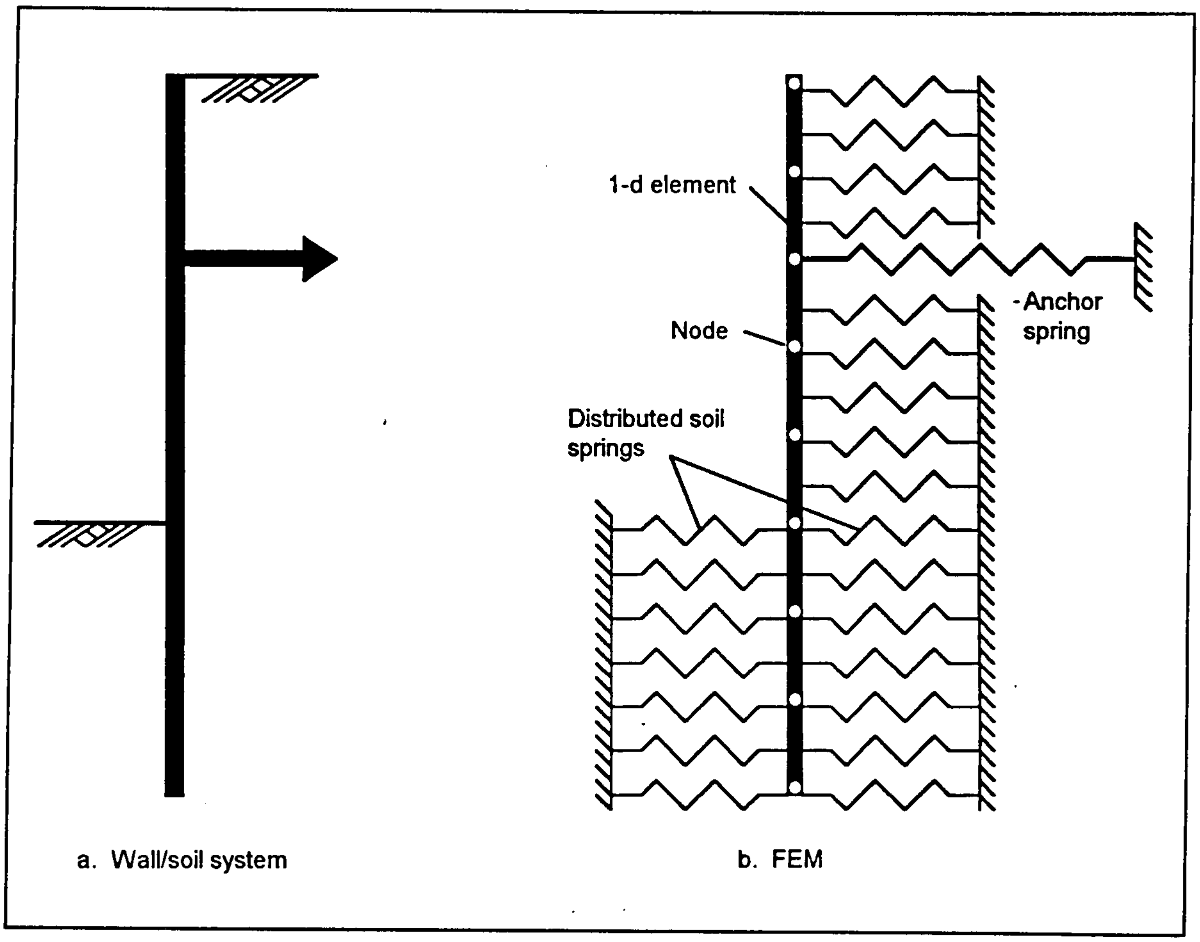

Figure 9. 1-D FEM of wall/soil system

A typical element between adjacent nodes is shown in Figure 10. The distributed spring is assumed to vary linearly between the soil stiffnesses evaluated at nodes i and j, respectively, and includes stiffnesses for soil on both sides of the wall. The distributed load includes the distributed load component due to the soil force-displacement relationship (page 14, "Discussion of Soil Pressure Calculation Methods"), the water pressure for unbalanced head, and any external horizontal distributed load. A free-body diagram of a typical node in the model is shown in Figure 11.

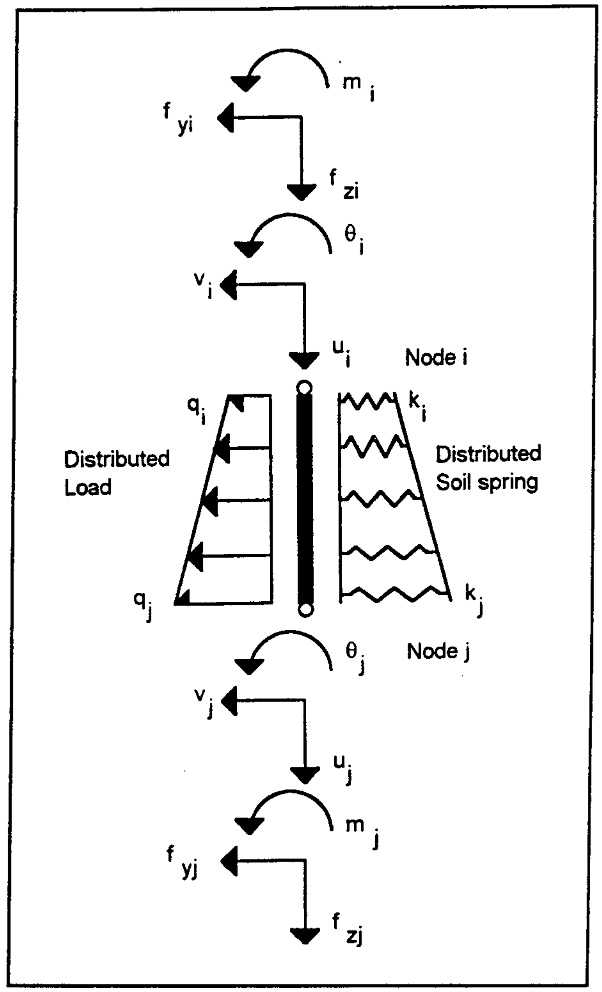

Figure 10. Typical element

External Supports

Restraint of lateral displacements is provided solely by the elastic components of the soil and anchor springs. When an inclined anchor produces a component of force parallel to the vertical axis of the wall, the bottom of the wall is assumed to be fixed against axial displacement. No attempt is made to account for the axial effects of wall friction or adhesion; wall friction and adhesion only influence the limiting active and passive soil pressures.

Method of Solution

The procedures for analyzing one-dimensional finite element models of the type employed for the wall/soil system herein are presented in detail by Dawkins.[1] In summary, a matrix relationship is established among the end forces, end displacements, loads, and soil springs on each element (including the effect of any axial force on wall bending stiffness). Combination of the element force-displacement relationships with nodal loads and anchor effects at each node results in a system of 3N (for N nodes in the

[1] William P. Dawkins. "User's guide: Computer program for analysis of beam-column structures with nonlinear supports (CBEAMC), Instruction Report in preparation, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

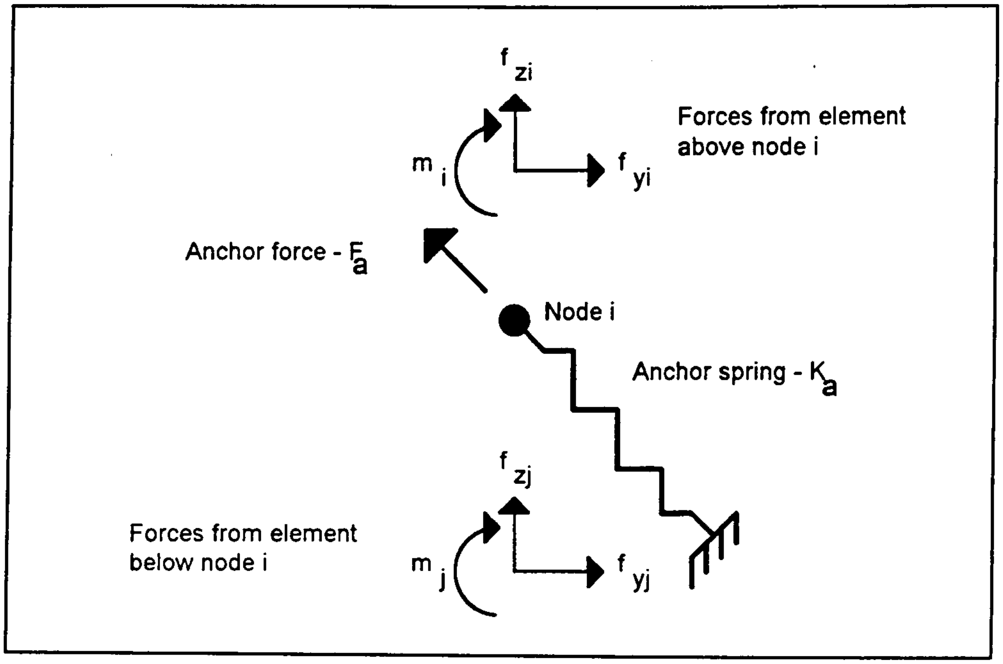

Figure 11. Typical node

model) simultaneous equations which are solved for the nodal displacements. Because the nodal displacements must be known before soil and anchor spring characteristics can be evaluated, iterative solutions are performed until compatibility of forces and displacements is achieved at each node.

Stability of Solution

If the nodal displacements are excessive, the elastic component of the soil and/or anchor springs may not be present. If all elastic restraint against lateral displacement is lost, the wall/soil system is unstable. The program checks for "reasonable" displacements during each iteration and terminates if instability is detected.

6 Computer Program

The computer program, CWALSSI, which implements the procedures described in this guide, is written in the FORTRAN language for execution on IBM or compatible microcomputers having a minimum of 640K bytes of central processing memory. All arithmetic operations are performed in double precision.

Input Data

Input data may be provided interactively from the keyboard during execution or from a predefined data file. When data are input interactively, the program provides prompting messages to indicate the type and amount of data to be entered. The characteristics of a predefined data file are described in Appendix A.

Whenever an input sequence is completed, from a data file or from the keyboard, the program provides an opportunity to change the input data in an editing mode.

Whenever input data are entered from the keyboard, the program provides for saving the input data in a permanent file in input file format.

Output Data

The program provides several options regarding the amount and destination of output data as described below. In all cases, the data may be directed to the user's monitor, a file, both, or, in some cases, may be omitted.

a. Echoprint of input data — An optional tabulation of current input data.

b. Water and limiting soil pressures — An optional tabulation of net water pressures, and active, at-rest, and passive soil pressures for each side of the wall.

c. Summary of results — A tabulation of the maximum bending moment, deflection, and soil pressure on each side of the wall along with the elevation at which the maximum occurs. Includes deformations and forces in any anchors.

d. Complete results — An optional tabulation of axial and lateral deflections, wall internal forces (axial, shear, and bending moment), and soil pressure on each side of the wall at each calculation point.

Optional Graphics Display of Input Data

Portrayal of input data consists of three parts:

a. Input Geometry — A plot of all structure (including anchors), soil profile, and water elevations. The user is allowed to select horizontal and vertical limits for the display. The plot of geometry may be distorted.

b. Input Surface Surcharges — A schematic displaying all surcharge loads applied to the surface on each side of the wall.

c. Input Horizontal Loads — A schematic of horizontal line loads, horizontal distributed loads, and input water pressures (see Appendix A for discussion of input water pressures).

Optional Display of Soil and Water Pressures

Plots of active, at-rest, and passive limiting soil pressures for each side of the wall are available. A plot of water pressures due to input water elevations is included.

Optional Display of Results

Plots of deflection, wall shear force and bending moment, and final soil pressures on each side of the wall are available.

Units and Sign Conventions

Units and sign conventions for forces and displacements are shown in Table 1.

Table 1
Units and Sign Conventions

Item	Units	Sign Convention
Horizontal distances	ft	Always positive
Elevations	ft	Positive or negative, decreasing downward
Modulus of elasticity	psi	Always positive
Wall moment of inertia	$in.^4/ft$	Always positive
Soil unit weight	pcf	Always positive
Angle of internal friction	deg	Always positive, or zero
Cohesion	psf	Always positive, or zero
Angle of wall friction	deg	Positive, negative, or zero
Adhesion	psf	Positive, negative, or zero
Horizontal line loads	plf	Positive if act to left on wall
Horizontal distributed loads	psf	Positive if act to left on wall
Vertical line surcharge loads	plf	Always positve downward
Vertical distributed surcharge loads	psf	Always positive downward
Water unit weight	pcf	Always positive
Earthquake acceleration	g's	Always positive
Soil and water pressures	psf	Positive if act to left on wall
Bending moment	lb-ft/ft	Positive if produces compression on left side of wall
Shear force	lb/ft	Positive if acts to left on top end of a wall section
Deflection	in.	Positive to left
Anchor force	lb/ft	Positive if tension

7 Example Solutions

Numerous wall/soil systems have been investigated to test and verify the computational processes used in the program. The example solutions presented are intended to illustrate the operation of the program and are not to be interpreted as recommendations for its application.

Example 1

The cantilever floodwall shown in Figure 12 was designed for penetration by the classical cantilever wall design procedure with an FS of 1.5 for

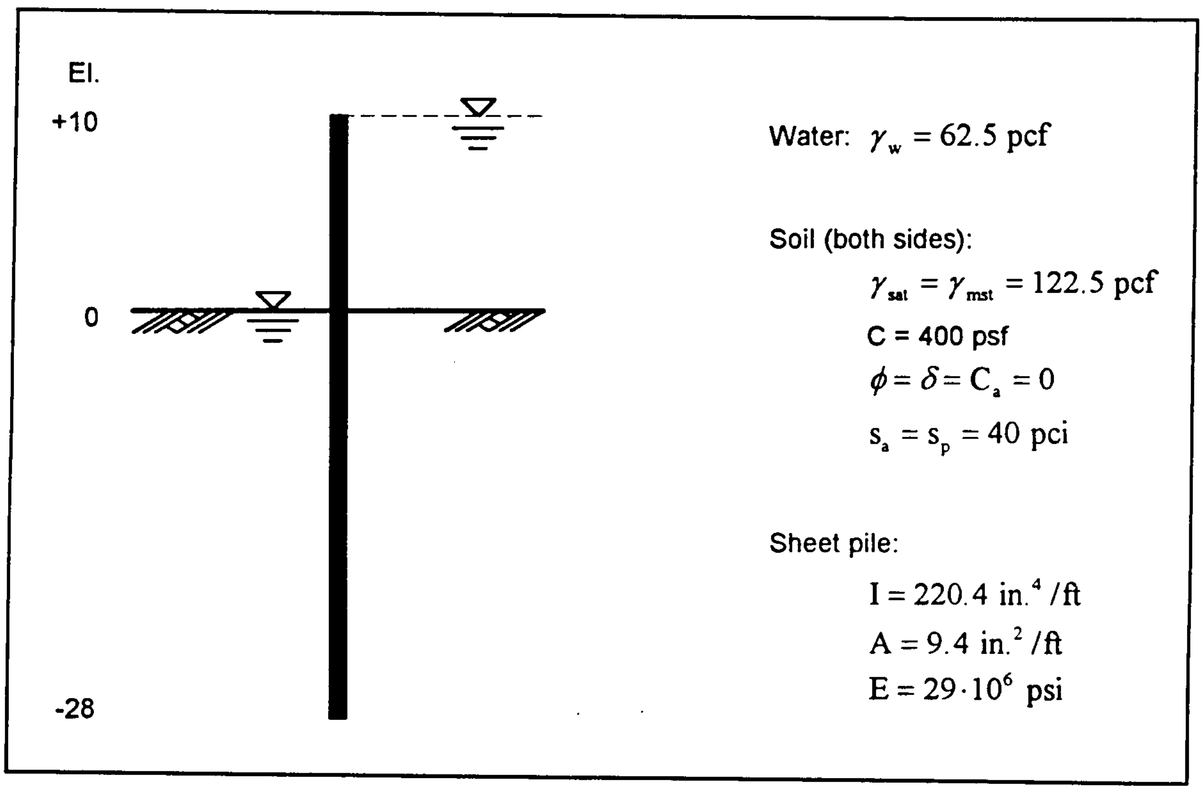

Figure 12. System for Example 1

both active and passive pressures. The attendant input file is shown in Figure 13. In the classical design procedure, it is assumed that the wall rotates about a point somewhere in the embedded depth. Consequently, interaction distances were estimated from the assumption that the point of rotation is at approximately one-third of the embedded depth above the bottom of the wall.

```
1000 'CANTILEVER FLOODWALL DRIVEN IN CLAY
1010 'PENETRATION FROM CLASSICAL DESIGN FOR FS = 1.5
1020 WALL     10.00    2.900E+07    2.204E+02    9.400E+00
1030 WALL    -28.00
1040 SURFACE BOTHSIDES    1
1050          .00        .00
1060 SOIL BOTHSIDES    STRENGTH     1
1070    122.50  122.50    .0  400.00    .0      .00    40.00     40.00
1080 INTERACTION BOTHSIDES  1      .00    20.00
1090 WATER ELEVATIONS     62.50    10.00      .00
1100 FINISH
```

Figure 13. Input file for Example 1

The echoprint of input data from CWALSSI is given in Figure 14 and the graphics display of input geometry from CWALSSI is shown in Figure 15. Because the surface is horizontal on both sides of the wall, limiting soil pressures were calculated using Coulomb soil pressure coefficients. Note that the soil strength parameters are not altered by a factor of safety in the SSI analysis. The water pressures and limiting soil pressures due to the unbalanced head, are tabulated in Figure 16 and displayed graphically in Figures 17, 18, and 19. The user is offered the opportunity to terminate execution of the program after each tabulation and/or graphical presentation is completed. If execution is terminated at any point, the user is offered the opportunity to edit existing input data or to make another run.

Upon successful completion of the solution, the program provides a summary of the maximum response of the system as shown in Figure 20 and a complete tabulation (optional) of results at each calculation point as shown in Figure 21. Plots of the response generated by the program are shown in Figures 22 through 24. It should be noted that the deflections of the system, Figure 22, do not indicate reversal in the embedded depth as assumed in the classical design procedure which served as the basis for the interaction distances provided as input. Consequently, the interaction distances should be revised to account for this effect and another analysis should be performed.

```
PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 30-MAR-1994                                                   TIME: 13.13.31
                                   ****************
                                   *  INPUT DATA  *
                                   ****************
I.--HEADING:
  'CANTILEVER FLOODWALL DRIVEN IN CLAY
  'PENETRATION FROM CLASSICAL DESIGN FOR FS = 1.5

II.--WALL SEGMENT DATA
     ELEVATION                                         CROSS
     AT TOP OF      MODULUS OF       MOMENT OF       SECTION
      SEGMENT      ELASTICICTY        INERTIA          AREA
       (FT)           (PSI)           (IN**4)         (SQIN)
       10.00        2.900E+07         220.40           9.40

     ELEVATION AT BOTTOM OF WALL =    -28.00 (FT).

III.--ANCHOR DATA
     NONE

IV.--SURFACE POINT DATA
  IV.A.--RIGHTSIDE
     DIST. FROM       ELEVATION
     WALL (FT)          (FT)
           .00             .00

  IV.B.-- LEFTSIDE
     DIST. FROM       ELEVATION
     WALL (FT)          (FT)
           .00             .00

V.--SOIL LAYER DATA
  V.A.--RIGHTSIDE LAYER DATA
                   ANGLE OF               ANGLE OF   WALL
<UNIT WEIGHT>      INTERNAL   COH-          WALL     ADH-    <STIFF. COEF.>    <--BOTTOM-->
SAT.     MOIST     FRICTION   ESION      FRICTION    ESION   ACT.      PASS.   ELEV.   SLOPE
(PCF)    (PCF)       (DEG)    (PSF)        (DEG)     (PSF)   (PCI)     (PCI)   (FT)     (FT)
122.50   122.50        .00    400.00        .00        .00   40.00     40.00

  V.B.-- LEFTSIDE LAYER DATA
                   ANGLE OF               ANGLE OF   WALL
<UNIT WEIGHT>      INTERNAL   COH-          WALL     ADH-    <STIFF. COEF.>    <--BOTTOM-->
SAT.     MOIST     FRICTION   ESION      FRICTION    ESION   ACT.      PASS.   ELEV.   SLOPE
(PCF)    (PCF)       (DEG)    (PSF)        (DEG)     (PSF)   (PCI)     (PCI)   (FT)     (FT)
122.50   122.50        .00    400.00        .00        .00   40.00     40.00
```

Figure 14. Echoprint of input data for Example 1 (Continued)

```
VI.--INTERACTION ZONE DATA
  VI.A.--RIGHTSIDE
     ELEVATION AT          INTERACTION
   TOP OF ZONE (FT)        DISTANCE (FT)
          .00                 20.00

  VI.B.-- LEFTSIDE
     ELEVATION AT          INTERACTION
   TOP OF ZONE (FT)        DISTANCE (FT)
          .00                 20.00

VII.--WATER DATA
     UNIT WEIGHT          =    62.50 (PCF)
     RIGHTSIDE ELEVATION =    10.00 (FT)
      LEFTSIDE ELEVATION =      .00 (FT)
     NO SEEPAGE

VIII.--SURFACE LOADS
     NONE

IX.--HORIZONTAL LOADS
     NONE
```

Figure 14. (Concluded)

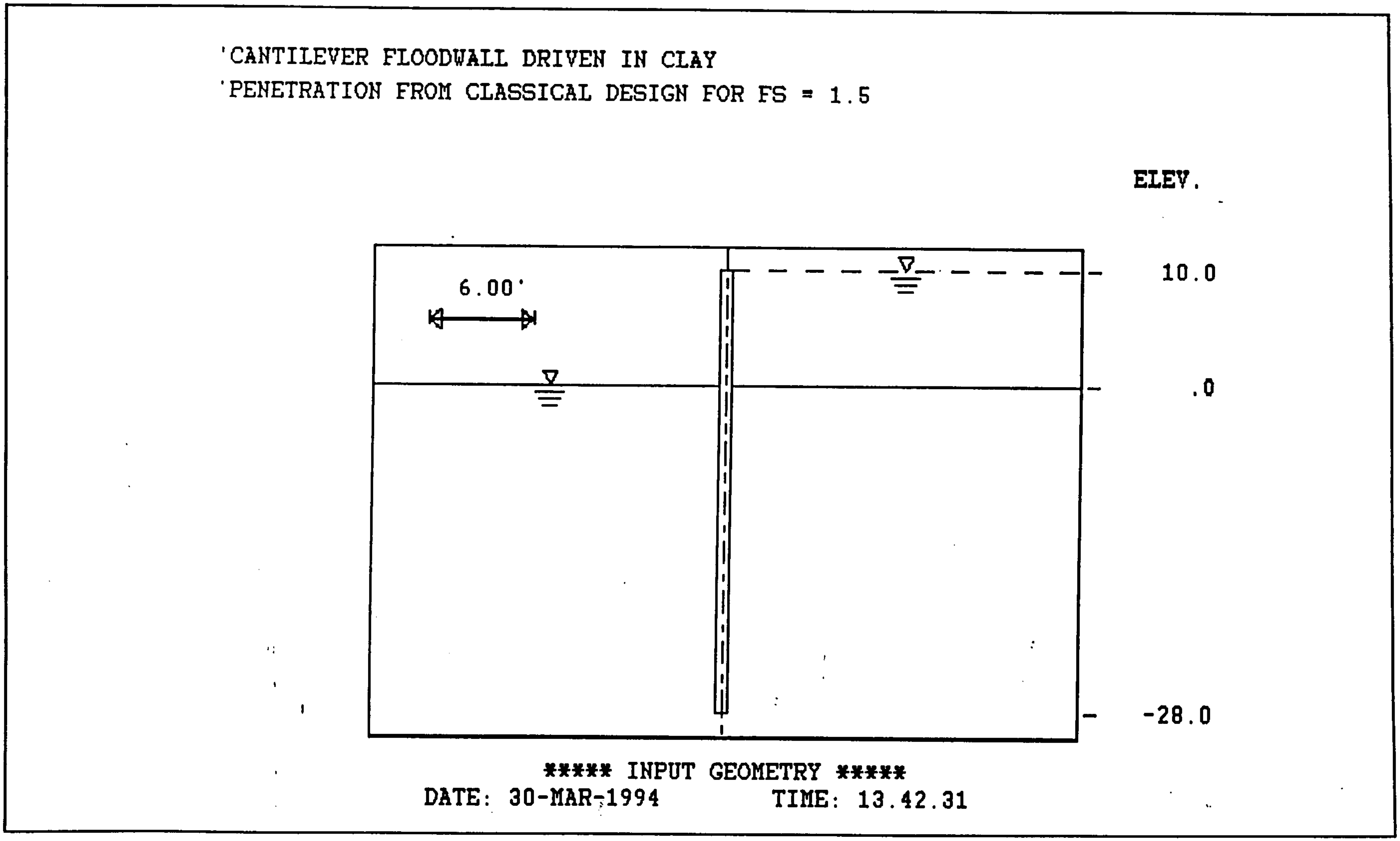

Figure 15. Graphics display of input geometry for Example 1

```
PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 30-MAR-1994                                         TIME: 13.14.40

                       ************************
                       * LIMITING PRESSURES *
                       ************************

     RIGHTSIDE SOIL PRESSURES DETERMINED BY COULOMB COEFFICIENTS
     AND THEORY OF ELASTICITY EQUATIONS FOR SURCHARGE LOADS.

      LEFTSIDE SOIL PRESSURES DETERMINED BY COULOMB COEFFICIENTS
     AND THEORY OF ELASTICITY EQUATIONS FOR SURCHARGE LOADS.
```

ELEV. (FT)	NET WATER PRESSURE (PSF)	< LEFTSIDE SOIL PRESSURES> PASSIVE (PSF)	AT-REST (PSF)	ACTIVE (PSF)	<RIGHTSIDE SOIL PRESSURES> ACTIVE (PSF)	AT-REST (PSF)	PASSIVE (PSF)
10.00	.00	.00	.00	.00	.00	.00	.00
9.50	31.25	.00	.00	.00	.00	.00	.00
9.00	62.50	.00	.00	.00	.00	.00	.00
8.50	93.75	.00	.00	.00	.00	.00	.00
8.00	125.00	.00	.00	.00	.00	.00	.00
7.50	156.25	.00	.00	.00	.00	.00	.00
7.00	187.50	.00	.00	.00	.00	.00	.00
6.50	218.75	.00	.00	.00	.00	.00	.00
6.00	250.00	.00	.00	.00	.00	.00	.00
5.50	281.25	.00	.00	.00	.00	.00	.00
5.00	312.50	.00	.00	.00	.00	.00	.00
4.50	343.75	.00	.00	.00	.00	.00	.00
4.00	375.00	.00	.00	.00	.00	.00	.00
3.50	406.25	.00	.00	.00	.00	.00	.00
3.00	437.50	.00	.00	.00	.00	.00	.00
2.50	468.75	.00	.00	.00	.00	.00	.00
2.00	500.00	.00	.00	.00	.00	.00	.00
1.50	531.25	.00	.00	.00	.00	.00	.00
1.00	562.50	.00	.00	.00	.00	.00	.00
.50	593.75	.00	.00	.00	.00	.00	.00
.00+	625.00	.00	.00	.00	.00	.00	.00
.00-	625.00	800.00	.00	.00	.00	.00	800.00
-.50	625.00	830.00	30.00	.00	.00	30.00	830.00
-1.00	625.00	860.00	60.00	.00	.00	60.00	860.00
-1.50	625.00	890.00	90.00	.00	.00	90.00	890.00
-2.00	625.00	920.00	120.00	.00	.00	120.00	920.00
-2.50	625.00	950.00	150.00	.00	.00	150.00	950.00
-3.00	625.00	980.00	180.00	.00	.00	180.00	980.00
-3.50	625.00	1010.00	210.00	.00	.00	210.00	1010.00
-4.00	625.00	1040.00	240.00	.00	.00	240.00	1040.00
-4.50	625.00	1070.00	270.00	.00	.00	270.00	1070.00

Figure 16. Water pressures and limiting soil pressures for Example 1 (Continued)

-5.00	625.00	1100.00	300.00	.00	.00	300.00	1100.00
-5.50	625.00	1130.00	330.00	.00	.00	330.00	1130.00
-6.00	625.00	1160.00	360.00	.00	.00	360.00	1160.00
-6.50	625.00	1190.00	390.00	.00	.00	390.00	1190.00
-7.00	625.00	1220.00	420.00	.00	.00	420.00	1220.00
-7.50	625.00	1250.00	450.00	.00	.00	450.00	1250.00
-8.00	625.00	1280.00	480.00	.00	.00	480.00	1280.00
-8.50	625.00	1310.00	510.00	.00	.00	510.00	1310.00
-9.00	625.00	1340.00	540.00	.00	.00	540.00	1340.00
-9.50	625.00	1370.00	570.00	.00	.00	570.00	1370.00
-10.00	625.00	1400.00	600.00	.00	.00	600.00	1400.00
-10.50	625.00	1430.00	630.00	.00	.00	630.00	1430.00
-11.00	625.00	1460.00	660.00	.00	.00	660.00	1460.00
-11.50	625.00	1490.00	690.00	.00	.00	690.00	1490.00
-12.00	625.00	1520.00	720.00	.00	.00	720.00	1520.00
-12.50	625.00	1550.00	750.00	.00	.00	750.00	1550.00
-13.00	625.00	1580.00	780.00	.00	.00	780.00	1580.00
-13.33	625.00	1600.00	800.00	.00	.00	800.00	1600.00
-13.50	625.00	1610.00	810.00	10.00	10.00	810.00	1610.00
-14.00	625.00	1640.00	840.00	40.00	40.00	840.00	1640.00
-14.50	625.00	1670.00	870.00	70.00	70.00	870.00	1670.00
-15.00	625.00	1700.00	900.00	100.00	100.00	900.00	1700.00
-15.50	625.00	1730.00	930.00	130.00	130.00	930.00	1730.00
-16.00	625.00	1760.00	960.00	160.00	160.00	960.00	1760.00
-16.50	625.00	1790.00	990.00	190.00	190.00	990.00	1790.00
-17.00	625.00	1820.00	1020.00	220.00	220.00	1020.00	1820.00
-17.50	625.00	1850.00	1050.00	250.00	250.00	1050.00	1850.00
-18.00	625.00	1880.00	1080.00	280.00	280.00	1080.00	1880.00
-18.50	625.00	1910.00	1110.00	310.00	310.00	1110.00	1910.00
-19.00	625.00	1940.00	1140.00	340.00	340.00	1140.00	1940.00
-19.50	625.00	1970.00	1170.00	370.00	370.00	1170.00	1970.00
-20.00	625.00	2000.00	1200.00	400.00	400.00	1200.00	2000.00
-20.50	625.00	2030.00	1230.00	430.00	430.00	1230.00	2030.00
-21.00	625.00	2060.00	1260.00	460.00	460.00	1260.00	2060.00
-21.50	625.00	2090.00	1290.00	490.00	490.00	1290.00	2090.00
-22.00	625.00	2120.00	1320.00	520.00	520.00	1320.00	2120.00
-22.50	625.00	2150.00	1350.00	550.00	550.00	1350.00	2150.00
-23.00	625.00	2180.00	1380.00	580.00	580.00	1380.00	2180.00
-23.50	625.00	2210.00	1410.00	610.00	610.00	1410.00	2210.00
-24.00	625.00	2240.00	1440.00	640.00	640.00	1440.00	2240.00
-24.50	625.00	2270.00	1470.00	670.00	670.00	1470.00	2270.00
-25.00	625.00	2300.00	1500.00	700.00	700.00	1500.00	2300.00
-25.50	625.00	2330.00	1530.00	730.00	730.00	1530.00	2330.00
-26.00	625.00	2360.00	1560.00	760.00	760.00	1560.00	2360.00
-26.50	625.00	2390.00	1590.00	790.00	790.00	1590.00	2390.00
-27.00	625.00	2420.00	1620.00	820.00	820.00	1620.00	2420.00
-27.50	625.00	2450.00	1650.00	850.00	850.00	1650.00	2450.00
-28.00	625.00	2480.00	1680.00	880.00	880.00	1680.00	2480.00

Figure 16. (Concluded)

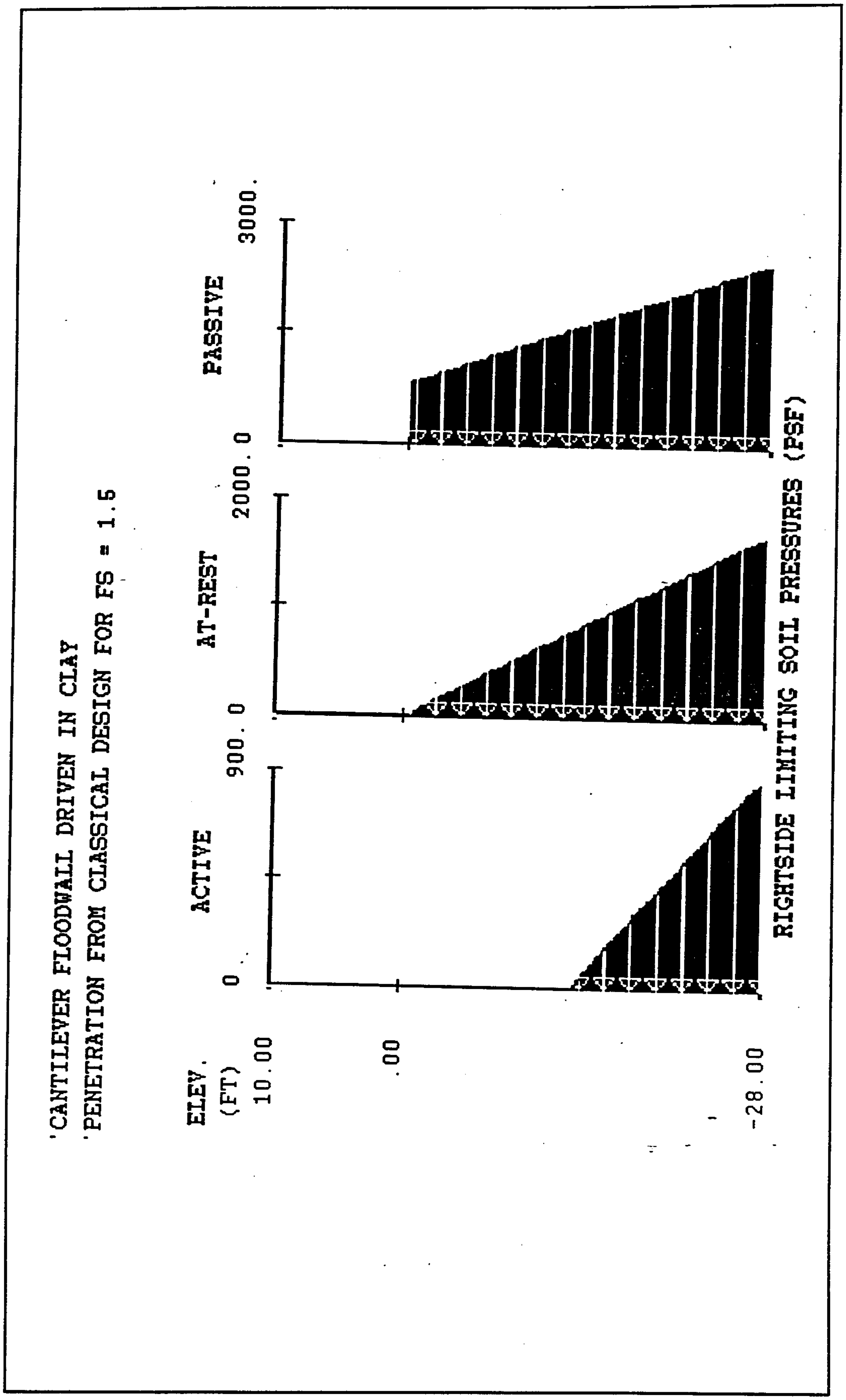

Figure 17. Rightside limiting soil pressures for Example 1

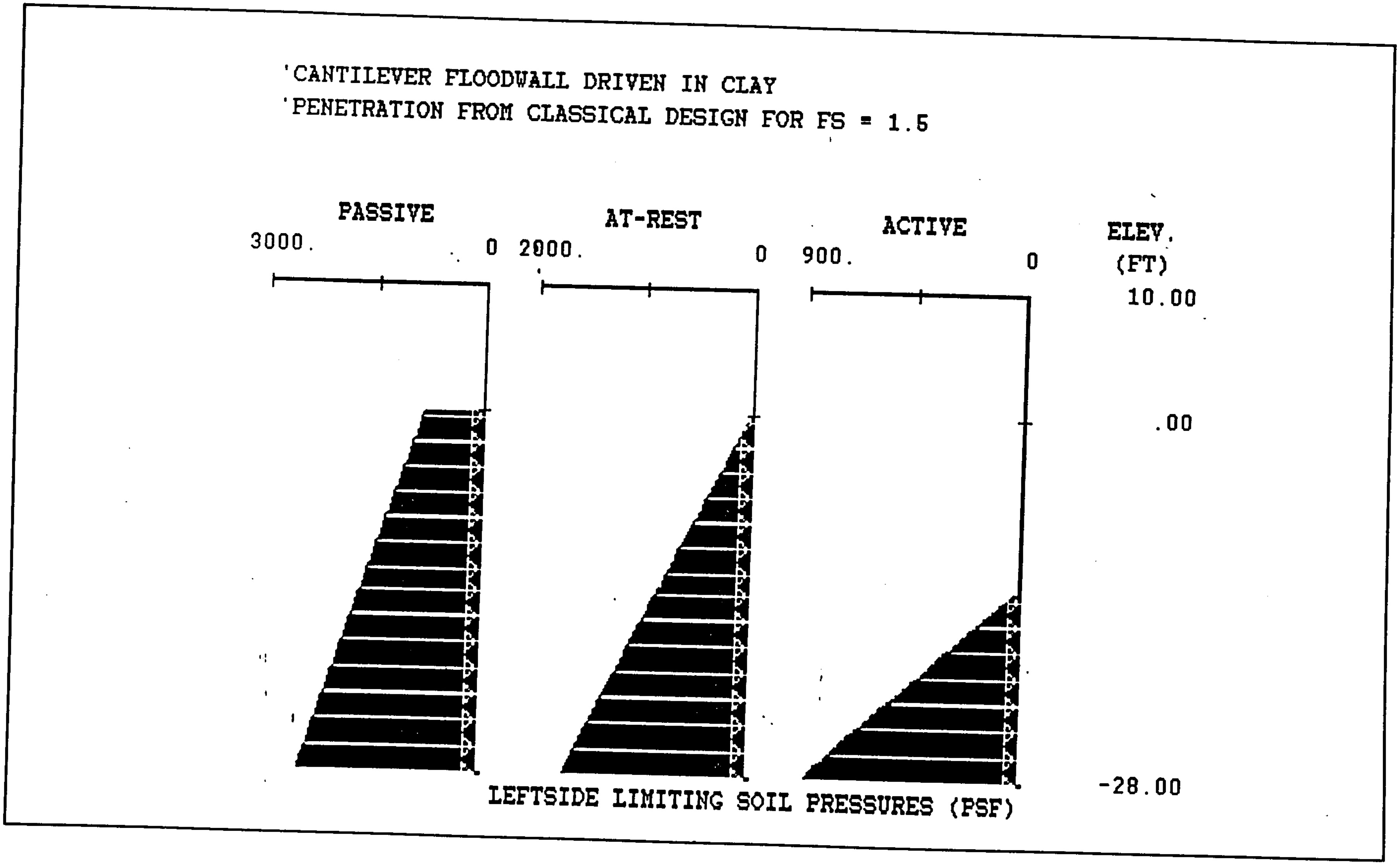

Figure 18. Leftside limiting soil pressures for Example 1

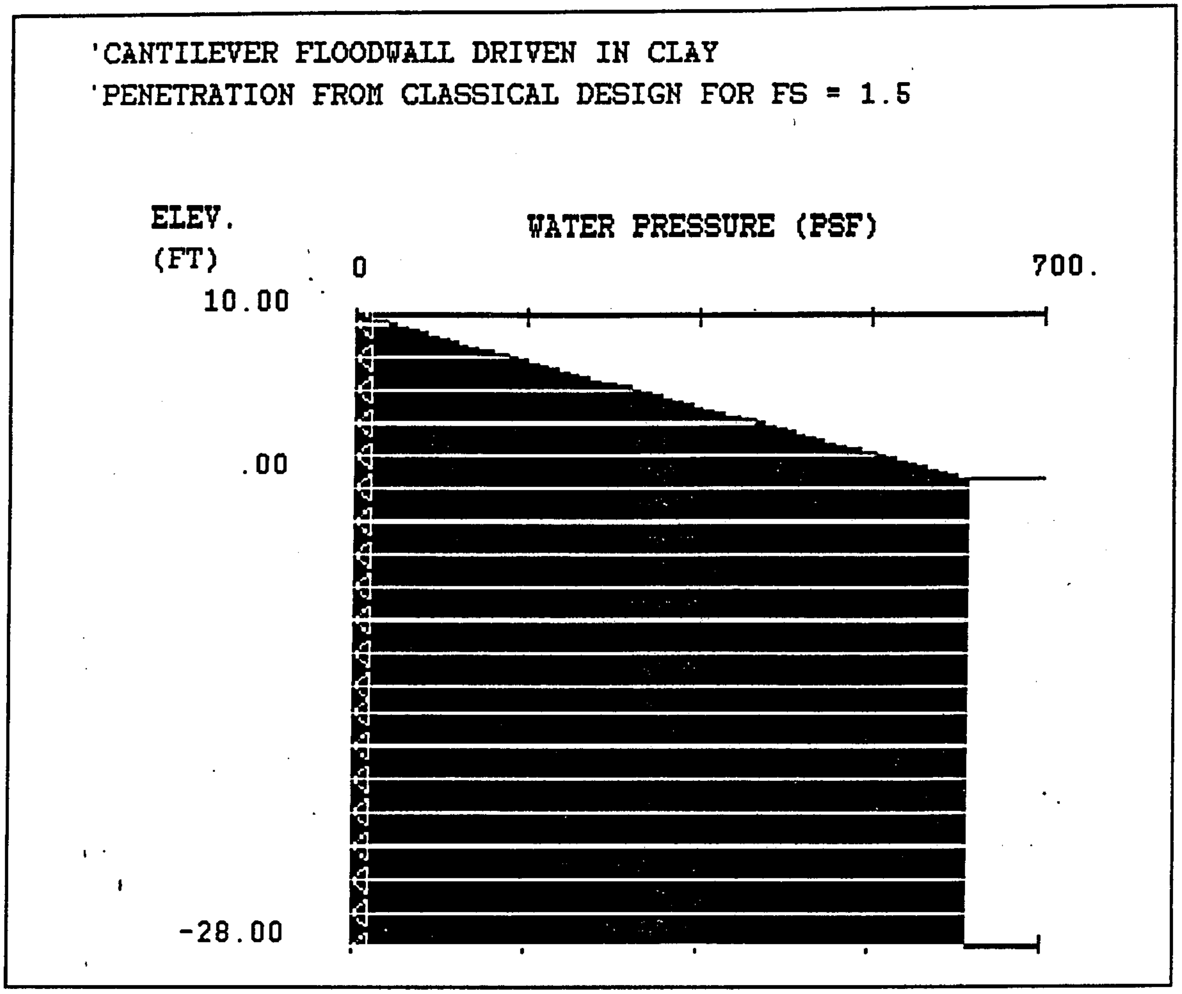

Figure 19. Net water pressures for Example 1

```
PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 30-MAR-1994                                            TIME: 13.16.39

                       **********************
                       * SUMMARY OF RESULTS *
                       **********************

I.   --MAXIMA

                                                MAXIMUM          MINIMUM
     BENDING MOMENT (LB-FT)          :         2.575E+04       -7.872E-09
          AT ELEVATION (FT)          :             -9.00           -28.00
     DEFLECTION (IN)                 :         5.064E+00        4.335E-01
          AT ELEVATION (FT)          :             10.00           -28.00
     RIGHTSIDE SOIL PRESSURE (PSF):              1555.14
          AT ELEVATION (FT)          :            -28.00
     LEFTSIDE SOIL PRESSURE (PSF)  :             1804.86
          AT ELEVATION (FT)          :            -28.00
```

Figure 20. Summary of results for Example 1

PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 30-MAR-1994 TIME: 13.16.39

****
* COMPLETE RESULTS *
****

II.A.--WALL DEFLECTIONS AND FORCES

ELEVATION (FT)	<------DEFLECTION-----> AXIAL (IN)	LATERAL (IN)	<--WALL INTERNAL FORCES-> AXIAL (LB)	SHEAR (LB)	MOMENT (LB-FT)
10.00	0.000E+00	5.064E+00	0.	0.	0.
9.50	0.000E+00	4.974E+00	0.	8.	1.
9.00	0.000E+00	4.884E+00	0.	31.	10.
8.50	0.000E+00	4.794E+00	0.	70.	35.
8.00	0.000E+00	4.704E+00	0.	125.	83.
7.50	0.000E+00	4.614E+00	0.	195.	163.
7.00	0.000E+00	4.524E+00	0.	281.	281.
6.50	0.000E+00	4.434E+00	0.	383.	447.
6.00	0.000E+00	4.344E+00	0.	500.	667.
5.50	0.000E+00	4.254E+00	0.	633.	949.
5.00	0.000E+00	4.164E+00	0.	781.	1302.
4.50	0.000E+00	4.075E+00	0.	945.	1733.
4.00	0.000E+00	3.985E+00	0.	1125.	2250.
3.50	0.000E+00	3.895E+00	0.	1320.	2861.
3.00	0.000E+00	3.806E+00	0.	1531.	3573.
2.50	0.000E+00	3.717E+00	0.	1758.	4395.
2.00	0.000E+00	3.628E+00	0.	2000.	5333.
1.50	0.000E+00	3.540E+00	0.	2258.	6397.
1.00	0.000E+00	3.452E+00	0.	2531.	7594.
.50	0.000E+00	3.365E+00	0.	2820.	8931.
.00+	0.000E+00	3.278E+00	0.	3125.	10417.
.00-	0.000E+00	3.278E+00	0.	3125.	10417.
-.50	0.000E+00	3.192E+00	0.	3030.	11956.
-1.00	0.000E+00	3.106E+00	0.	2920.	13444.
-1.50	0.000E+00	3.022E+00	0.	2795.	14874.
-2.00	0.000E+00	2.938E+00	0.	2655.	16237.
-2.50	0.000E+00	2.856E+00	0.	2500.	17526.
-3.00	0.000E+00	2.775E+00	0.	2328.	18734.
-3.50	0.000E+00	2.695E+00	0.	2149.	19853.
-4.00	0.000E+00	2.617E+00	0.	1967.	20883.
-4.50	0.000E+00	2.539E+00	0.	1781.	21820.
-5.00	0.000E+00	2.464E+00	0.	1591.	22663.
-5.50	0.000E+00	2.390E+00	0.	1396.	23410.
-6.00	0.000E+00	2.317E+00	0.	1197.	24058.
-6.50	0.000E+00	2.246E+00	0.	994.	24606.
-7.00	0.000E+00	2.177E+00	0.	785.	25051.
-7.50	0.000E+00	2.110E+00	0.	572.	25390.

Figure 21. Complete results for Example 1 (Sheet 1 of 4)

-8.00	0.000E+00	2.044E+00	0.	353.	25622.
-8.50	0.000E+00	1.980E+00	0.	128.	25742.
-9.00	0.000E+00	1.917E+00	0.	-103.	25749.
-9.50	0.000E+00	1.857E+00	0.	-332.	25639.
-10.00	0.000E+00	1.798E+00	0.	-546.	25419.
-10.50	0.000E+00	1.741E+00	0.	-743.	25097.
-11.00	0.000E+00	1.685E+00	0.	-923.	24679.
-11.50	0.000E+00	1.631E+00	0.	-1088.	24176.
-12.00	0.000E+00	1.579E+00	0.	-1238.	23594.
-12.50	0.000E+00	1.529E+00	0.	-1373.	22940.
-13.00	0.000E+00	1.480E+00	0.	-1494.	22223.
-13.33	0.000E+00	1.448E+00	0.	-1566.	21713.
-13.50	0.000E+00	1.432E+00	0.	-1601.	21449.
-14.00	0.000E+00	1.386E+00	0.	-1694.	20625.
-14.50	0.000E+00	1.341E+00	0.	-1774.	19757.
-15.00	0.000E+00	1.298E+00	0.	-1841.	18853.
-15.50	0.000E+00	1.256E+00	0.	-1897.	17918.
-16.00	0.000E+00	1.215E+00	0.	-1940.	16958.
-16.50	0.000E+00	1.175E+00	0.	-1972.	15980.
-17.00	0.000E+00	1.137E+00	0.	-1992.	14988.
-17.50	0.000E+00	1.099E+00	0.	-2001.	13990.
-18.00	0.000E+00	1.062E+00	0.	-2000.	12989.
-18.50	0.000E+00	1.027E+00	0.	-1988.	11991.
-19.00	0.000E+00	9.915E-01	0.	-1966.	11002.
-19.50	0.000E+00	9.573E-01	0.	-1935.	10026.
-20.00	0.000E+00	9.237E-01	0.	-1893.	9069.
-20.50	0.000E+00	8.908E-01	0.	-1842.	8135.
-21.00	0.000E+00	8.584E-01	0.	-1781.	7229.
-21.50	0.000E+00	8.265E-01	0.	-1711.	6356.
-22.00	0.000E+00	7.950E-01	0.	-1632.	5519.
-22.50	0.000E+00	7.639E-01	0.	-1544.	4725.
-23.00	0.000E+00	7.331E-01	0.	-1447.	3977.
-23.50	0.000E+00	7.025E-01	0.	-1341.	3279.
-24.00	0.000E+00	6.722E-01	0.	-1227.	2637.
-24.50	0.000E+00	6.421E-01	0.	-1104.	2054.
-25.00	0.000E+00	6.121E-01	0.	-972.	1535.
-25.50	0.000E+00	5.823E-01	0.	-831.	1084.
-26.00	0.000E+00	5.524E-01	0.	-682.	705.
-26.50	0.000E+00	5.227E-01	0.	-524.	403.
-27.00	0.000E+00	4.930E-01	0.	-358.	182.
-27.50	0.000E+00	4.632E-01	0.	-183.	46.
-28.00	0.000E+00	4.335E-01	0.	0.	0.

Figure 21. (Sheet 2 of 4)

II.B.--SOIL PRESSURES

ELEVATION (FT)	LEFTSIDE	RIGHTSIDE	NET
	<---------SOIL	PRESSURES	(PSF)-------->
10.00	.00	.00	.00
9.50	.00	.00	.00
9.00	.00	.00	.00
8.50	.00	.00	.00
8.00	.00	.00	.00
7.50	.00	.00	.00
7.00	.00	.00	.00
6.50	.00	.00	.00
6.00	.00	.00	.00
5.50	.00	.00	.00
5.00	.00	.00	.00
4.50	.00	.00	.00
4.00	.00	.00	.00
3.50	.00	.00	.00
3.00	.00	.00	.00
2.50	.00	.00	.00
2.00	.00	.00	.00
1.50	.00	.00	.00
1.00	.00	.00	.00
.50	.00	.00	.00
.00+	.00	.00	.00
.00-	800.00	.00	-800.00
-.50	830.00	.00	-830.00
-1.00	860.00	.00	-860.00
-1.50	890.00	.00	-890.00
-2.00	920.00	.00	-920.00
-2.50	950.00	.00	-950.00
-3.00	979.19	.00	-979.19
-3.50	986.19	.00	-986.19
-4.00	993.58	.00	-993.58
-4.50	1001.37	.00	-1001.37
-5.00	1009.59	.00	-1009.59
-5.50	1018.25	.00	-1018.25
-6.00	1027.36	.00	-1027.36
-6.50	1036.94	.00	-1036.94
-7.00	1047.00	.00	-1047.00
-7.50	1057.55	.00	-1057.55
-8.00	1068.59	.00	-1068.59
-8.50	1080.13	.00	-1080.13
-9.00	1092.17	.00	-1092.17
-9.50	1104.71	35.29	-1069.43
-10.00	1117.75	82.25	-1035.51
-10.50	1131.29	128.71	-1002.58
-11.00	1145.31	174.69	-970.63

Figure 21. (Sheet 3 of 4)

-11.50	1159.82	220.18	-939.64
-12.00	1174.79	265.21	-909.59
-12.50	1190.23	309.77	-880.45
-13.00	1206.11	353.89	-852.21
-13.33	1216.94	383.06	-833.87
-13.50	1222.42	397.58	-824.84
-14.00	1239.15	440.85	-798.30
-14.50	1256.28	483.72	-772.56
-15.00	1273.80	526.20	-747.60
-15.50	1291.68	568.32	-723.36
-16.00	1309.91	610.09	-699.83
-16.50	1328.48	651.52	-676.95
-17.00	1347.35	692.65	-654.70
-17.50	1366.51	733.49	-633.03
-18.00	1385.95	774.05	-611.90
-18.50	1405.64	814.36	-591.28
-19.00	1425.56	854.44	-571.13
-19.50	1445.70	894.30	-551.40
-20.00	1466.03	933.97	-532.07
-20.50	1486.54	973.46	-513.09
-21.00	1507.21	1012.79	-494.42
-21.50	1528.02	1051.98	-476.04
-22.00	1548.95	1091.05	-457.90
-22.50	1569.99	1130.01	-439.98
-23.00	1591.12	1168.88	-422.25
-23.50	1612.33	1207.67	-404.66
-24.00	1633.61	1246.39	-387.21
-24.50	1654.93	1285.07	-369.86
-25.00	1676.29	1323.71	-352.59
-25.50	1697.69	1362.31	-335.38
-26.00	1719.11	1400.89	-318.21
-26.50	1740.54	1439.46	-301.07
-27.00	1761.97	1478.03	-283.95
-27.50	1783.41	1516.59	-266.83
-28.00	1804.86	1555.14	-249.71

Figure 21. (Sheet 4 of 4)

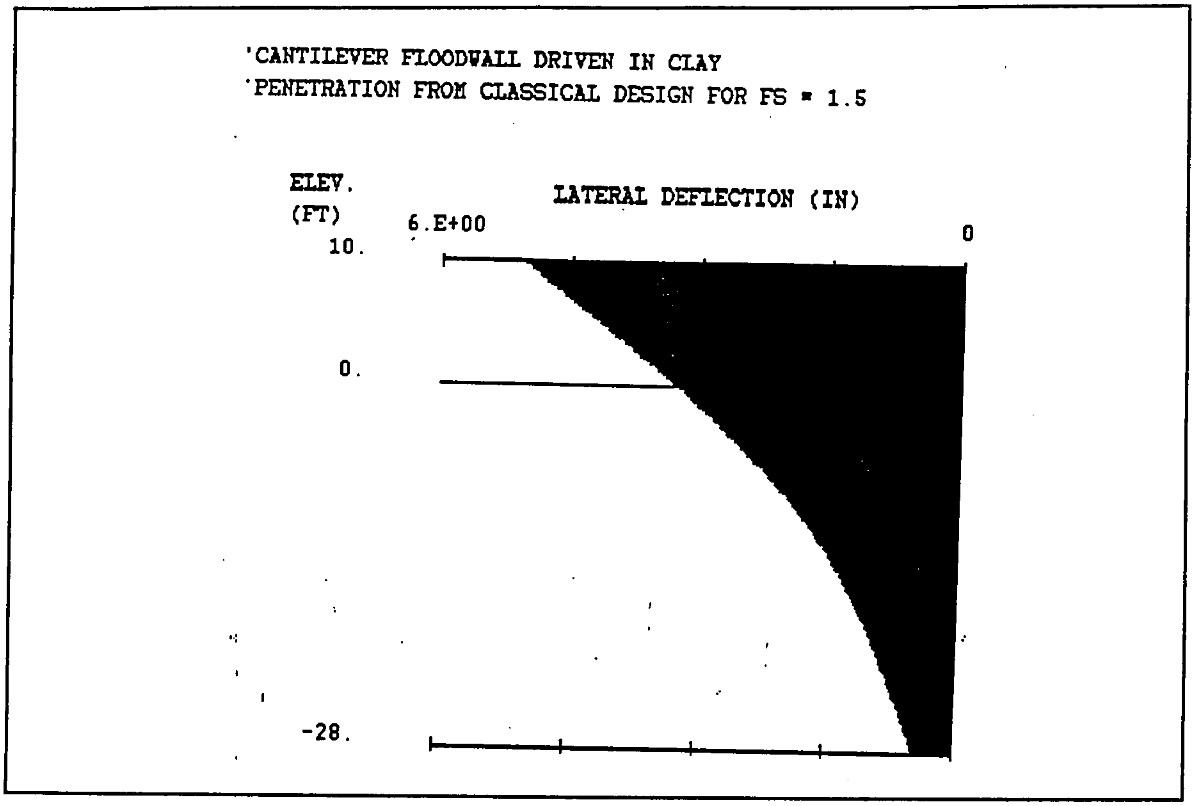

Figure 22. Lateral deflections for Example 1

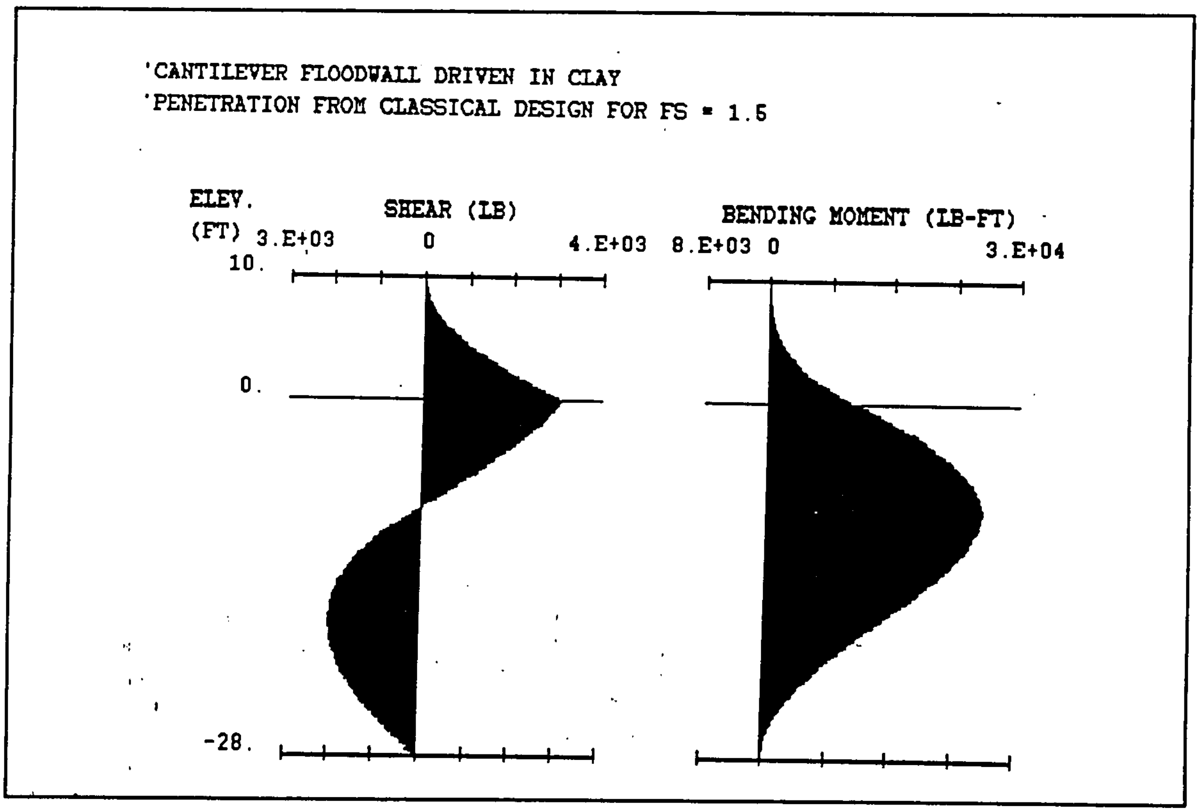

Figure 23. Shear force and bending moment for Example 1

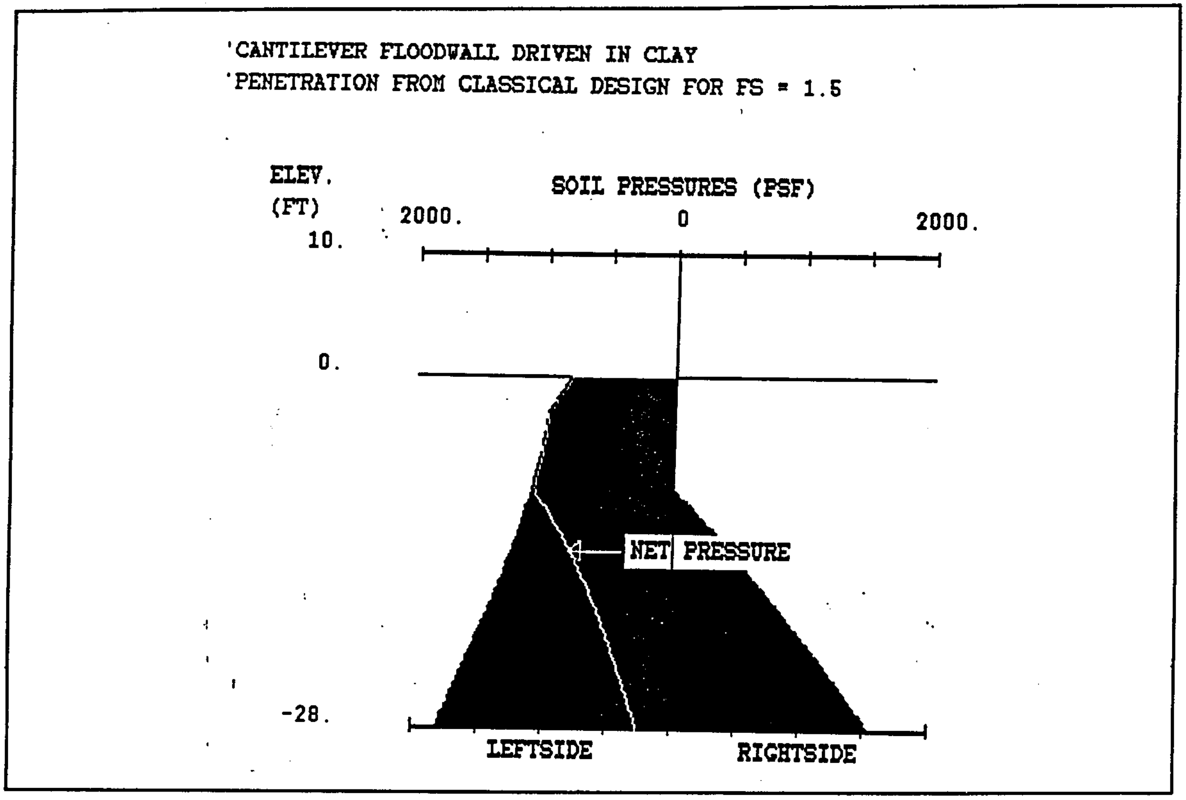

Figure 24. Final soil pressures for Example 1

Example 2

The single-anchored wall shown in Figure 25 was designed by the classical "fixed earth" design procedure. The attendant input file for analysis with CWALSSI is shown in Figure 26.

The echoprint of input data and graphical display of input data generated by the program are shown in Figures 27, 28, and 29. Limiting soil pressures and water pressures are tabulated in Figures 30 through 33. The summary of results and complete results are shown in Figures 34 and 35. Graphical presentation of the results is given in Figures 36 through 38.

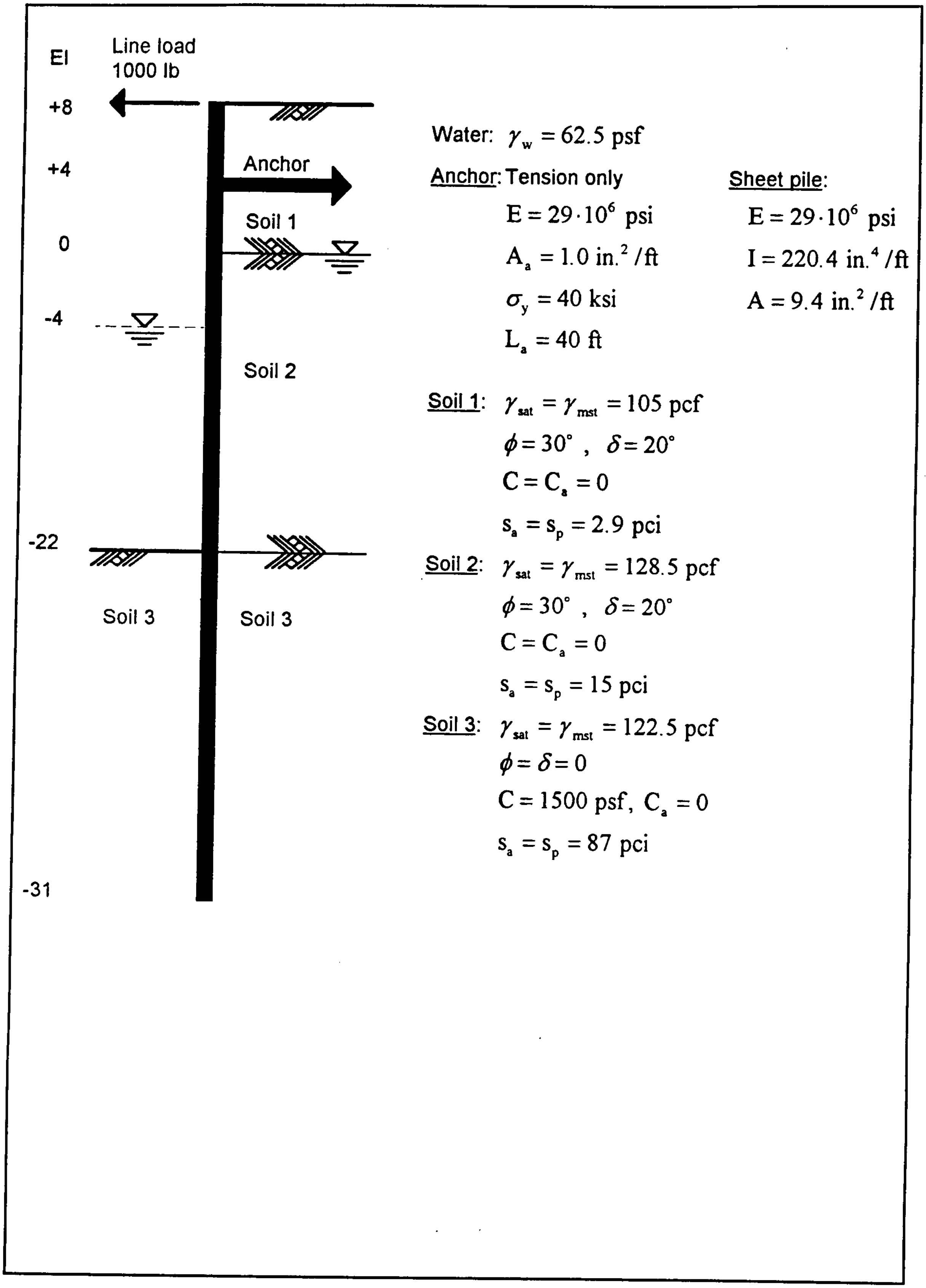

Figure 25. System for Example 2

```
1000 'ANCHORED RETAINING WALL DRIVEN IN CLAY
1010 'WITH SAND BACKFILL
1020 'PENETRATION FROM CLASSICAL "FIXED EARTH" DESIGN
1030 WALL 8 2.9E7 220.4 9.4
1040 WALL -31
1050 ANCHOR 4 F 4.0E4 0 0 60417
1060 SURFACE RIGHTSIDE 1 0 8
1070 SURFACE LEFTSIDE 1 0 -22
1080 SOIL RIGHTSIDE  STRENGTHS 3
1090 105 105  30 0 20 0 2.9 2.9 0 0
1100 128.5 128.5 30 0 20 0 15 15 -22 0
1110 122.5 122.5 0 1500 0 0 87 87
1120 SOIL LEFTSIDE  STRENGTHS 1
1130 122.5 122.5 0 1500 0 0 87 87
1140 INTERACT RIGHTSIDE 3 8 4 0 22 -22 9
1150 INTERACT LEFTSIDE 1 -22 9
1160 WATER ELEVATIONS 62.5 0 -4
1170 HORIZONTAL LINE 1 8 1000
1180 FINISH
```

Figure 26. Input file for Example 2

PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 30-MAR-1994 TIME: 15.53.26

****
* INPUT DATA *
****

I.--HEADING:
'ANCHORED RETAINING WALL DRIVEN IN CLAY
'WITH SAND BACKFILL
'PENETRATION FROM CLASSICAL "FIXED EARTH" DESIGN

II.--WALL SEGMENT DATA

ELEVATION AT TOP OF SEGMENT (FT)	MODULUS OF ELASTICICTY (PSI)	MOMENT OF INERTIA (IN**4)	CROSS SECTION AREA (SQIN)
8.00	2.900E+07	220.40	9.40

ELEVATION AT BOTTOM OF WALL = -31.00 (FT).

III.--ANCHOR DATA

ELEVATION AT WALL (FT)	ANCHOR TYPE ('R/F')	ULTIMATE TENSION FORCE (LB)	PRE-STRESS FORCE (LB)	ULTIMATE COMPRESSION FORCE (LB)	ANCHOR STIFFNESS (LB/IN)	ANCHOR SLOPE (FT)
4.00	FLEXIBLE	4.00E+04	0.00E+00	0.00E+00	6.042E+04	.00

IV.--SURFACE POINT DATA

IV.A.--RIGHTSIDE

DIST. FROM WALL (FT)	ELEVATION (FT)
.00	8.00

IV.B.-- LEFTSIDE

DIST. FROM WALL (FT)	ELEVATION (FT)
.00	-22.00

V.--SOIL LAYER DATA

V.A.--RIGHTSIDE LAYER DATA

<UNIT WEIGHT> SAT. (PCF)	MOIST (PCF)	ANGLE OF INTERNAL FRICTION (DEG)	COH-ESION (PSF)	ANGLE OF WALL FRICTION (DEG)	WALL ADH-ESION (PSF)	<STIFF. ACT. (PCI)	COEF.> PASS. (PCI)	<--BOTTOM--> ELEV. (FT)	SLOPE (FT)
105.00	105.00	30.00	.00	20.00	.00	2.90	2.90	.00	.000
128.50	128.50	30.00	.00	20.00	.00	15.00	15.00	-22.00	.000
122.50	122.50	.00	1500.00	.00	.00	87.00	87.00		

Figure 27. Echoprint of input data for Example 2 (Continued)

```
     V.B.-- LEFTSIDE LAYER DATA
                      ANGLE OF          ANGLE OF  WALL
<UNIT WEIGHT>   INTERNAL  COH-      WALL      ADH-    <STIFF. COEF.>  <--BOTTOM-->
SAT.     MOIST   FRICTION  ESION    FRICTION  ESION   ACT.       PASS.  ELEV.   SLOPE
(PCF)    (PCF)    (DEG)    (PSF)     (DEG)    (PSF)   (PCI)      (PCI)  (FT)     (FT)
122.50   122.50     .00  1500.00      .00      .00    87.00      87.00

   VI.--INTERACTION ZONE DATA
     VI.A.--RIGHTSIDE
        ELEVATION AT          INTERACTION
      TOP OF ZONE (FT)        DISTANCE (FT)
              8.00                4.00
               .00               22.00
            -22.00                9.00

     VI.B.-- LEFTSIDE
        ELEVATION AT          INTERACTION
      TOP OF ZONE (FT)        DISTANCE (FT)
            -22.00                9.00

   VII.--WATER DATA
        UNIT WEIGHT          =    62.50 (PCF)
        RIGHTSIDE ELEVATION =       .00 (FT)
         LEFTSIDE ELEVATION =     -4.00 (FT)
        NO SEEPAGE

   VIII.--SURFACE LOADS
        NONE

   IX.--HORIZONTAL LOADS

     IX.A.--EARTHQUAKE ACCELERATION =       .00 (G'S)

     IX.B.--HORIZONTAL LINE LOADS

        ELEVATION      LINE LOAD
          (FT)           (PLF)
           8.00         1000.00

     IX.C.--HORIZONTAL DISTRIBUTED LOADS
        NONE
```

Figure 27. (Concluded)

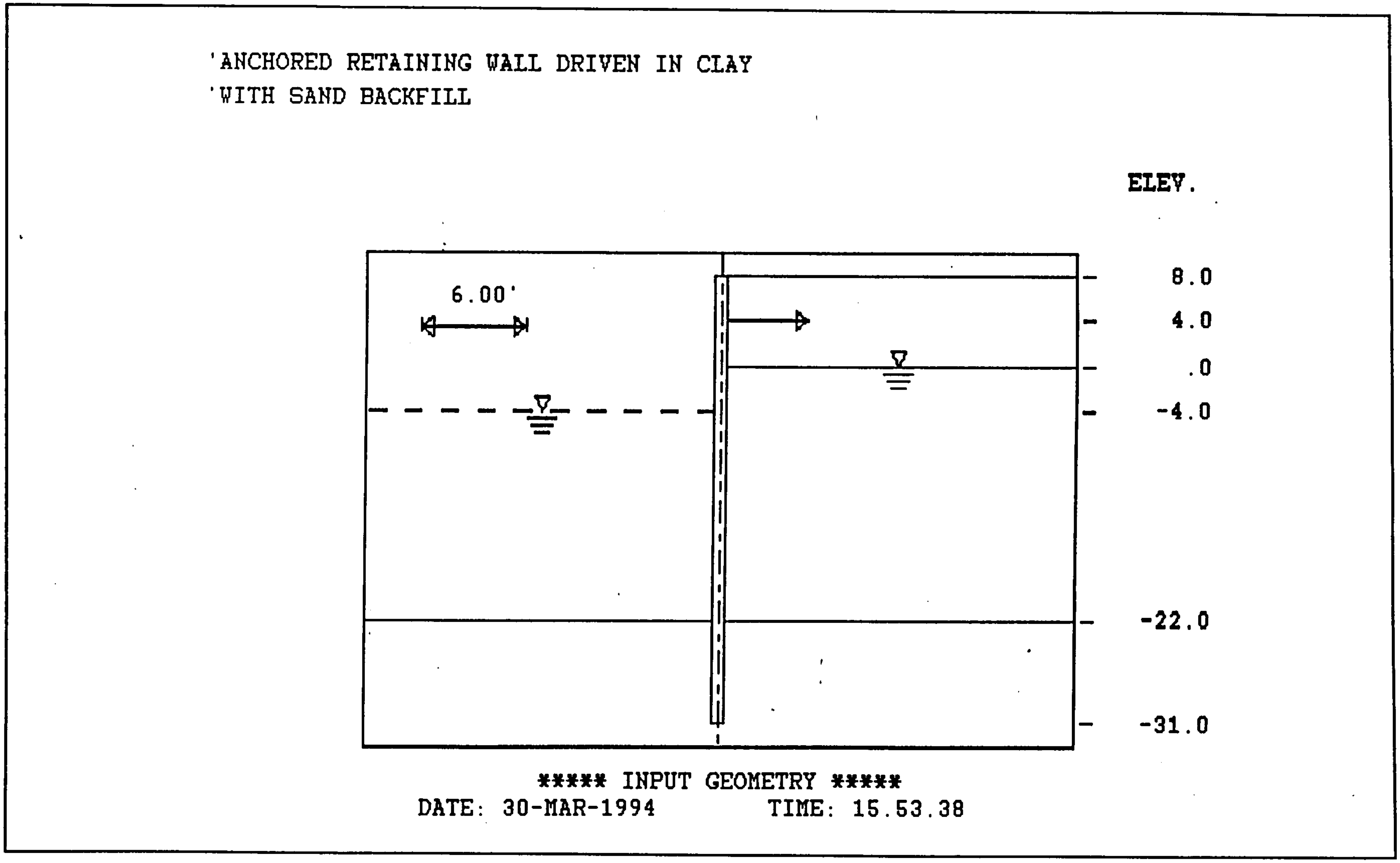

Figure 28. Graphics display of input geometry for Example 2

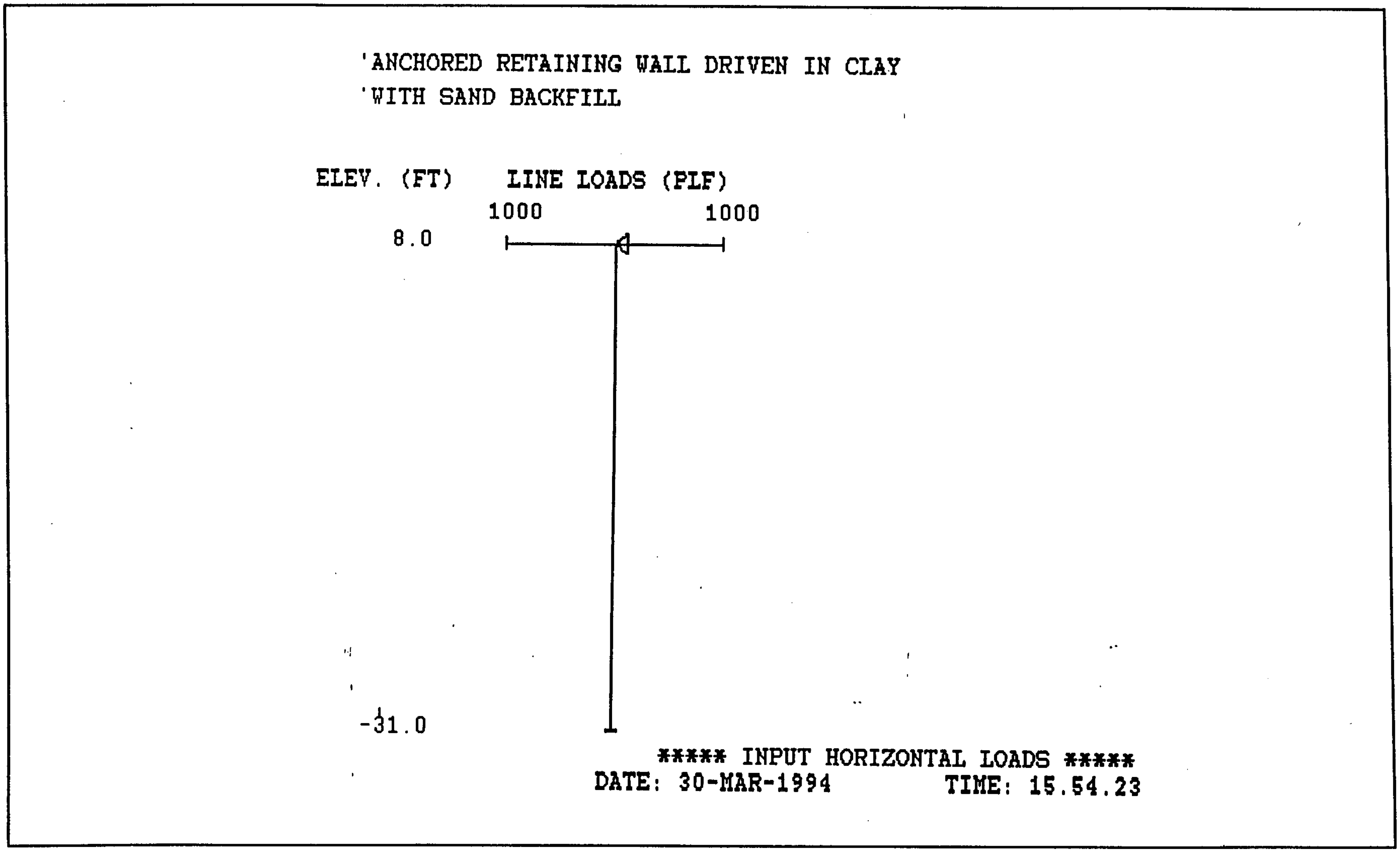

Figure 29. Graphics display of input horizontal loads for Example 2

```
PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 30-MAR-1994                                        TIME: 15.58.18

                    **********************
                    * LIMITING PRESSURES *
                    **********************

RIGHTSIDE SOIL PRESSURES DETERMINED BY COULOMB COEFFICIENTS
AND THEORY OF ELASTICITY EQUATIONS FOR SURCHARGE LOADS.

LEFTSIDE SOIL PRESSURES DETERMINED BY COULOMB COEFFICIENTS
AND THEORY OF ELASTICITY EQUATIONS FOR SURCHARGE LOADS.
```

	NET WATER	< LEFTSIDE SOIL PRESSURES>			<RIGHTSIDE SOIL PRESSURES>		
ELEV. (FT)	PRESSURE (PSF)	PASSIVE (PSF)	AT-REST (PSF)	ACTIVE (PSF)	ACTIVE (PSF)	AT-REST (PSF)	PASSIVE (PSF)
8.00	.00	.00	.00	.00	.00	.00	.00
7.50	.00	.00	.00	.00	14.67	26.25	301.20
7.00	.00	.00	.00	.00	29.34	52.50	602.40
6.50	.00	.00	.00	.00	44.00	78.75	903.60
6.00	.00	.00	.00	.00	58.67	105.00	1204.80
5.50	.00	.00	.00	.00	73.34	131.25	1506.00
5.00	.00	.00	.00	.00	88.01	157.50	1807.21
4.50	.00	.00	.00	.00	102.67	183.75	2108.41
4.00	.00	.00	.00	.00	117.34	210.00	2409.61
3.50	.00	.00	.00	.00	132.01	236.25	2710.81
3.00	.00	.00	.00	.00	146.68	262.50	3012.01
2.50	.00	.00	.00	.00	161.34	288.75	3313.21
2.00	.00	.00	.00	.00	176.01	315.00	3614.41
1.50	.00	.00	.00	.00	190.68	341.25	3915.61
1.00	.00	.00	.00	.00	205.35	367.50	4216.81
.50	.00	.00	.00	.00	220.01	393.75	4518.01
.00	.00	.00	.00	.00	234.68	420.00	4819.21
-.50	31.25	.00	.00	.00	243.90	436.50	5008.54
-1.00	62.50	.00	.00	.00	253.12	453.00	5197.87
-1.50	93.75	.00	.00	.00	262.34	469.50	5387.19
-2.00	125.00	.00	.00	.00	271.56	486.00	5576.52
-2.50	156.25	.00	.00	.00	280.78	502.50	5765.85
-3.00	187.50	.00	.00	.00	290.00	519.00	5955.17
-3.50	218.75	.00	.00	.00	299.22	535.50	6144.50
-4.00	250.00	.00	.00	.00	308.44	552.00	6333.82
-4.50	250.00	.00	.00	.00	317.66	568.50	6523.15
-5.00	250.00	.00	.00	.00	326.88	585.00	6712.48
-5.50	250.00	.00	.00	.00	336.10	601.50	6901.80
-6.00	250.00	.00	.00	.00	345.32	618.00	7091.13
-6.50	250.00	.00	.00	.00	354.54	634.50	7280.46
-7.00	250.00	.00	.00	.00	363.76	651.00	7469.78
-7.50	250.00	.00	.00	.00	372.98	667.50	7659.11

Figure 30. Water and limiting soil pressures for Example 2 (Continued)

-8.00	250.00	.00	.00	.00	382.20	684.00	7848.43
-8.50	250.00	.00	.00	.00	391.42	700.50	8037.76
-9.00	250.00	.00	.00	.00	400.64	717.00	8227.09
-9.50	250.00	.00	.00	.00	409.86	733.50	8416.41
-10.00	250.00	.00	.00	.00	419.08	750.00	8605.74
-10.50	250.00	.00	.00	.00	428.30	766.50	8795.07
-11.00	250.00	.00	.00	.00	437.51	783.00	8984.39
-11.50	250.00	.00	.00	.00	446.73	799.50	9173.72
-12.00	250.00	.00	.00	.00	455.95	816.00	9363.04
-12.50	250.00	.00	.00	.00	465.17	832.50	9552.37
-13.00	250.00	.00	.00	.00	474.39	849.00	9741.70
-13.50	250.00	.00	.00	.00	483.61	865.50	9931.02
-14.00	250.00	.00	.00	.00	492.83	882.00	10120.35
-14.50	250.00	.00	.00	.00	502.05	898.50	10309.68
-15.00	250.00	.00	.00	.00	511.27	915.00	10499.00
-15.50	250.00	.00	.00	.00	520.49	931.50	10688.33
-16.00	250.00	.00	.00	.00	529.71	948.00	10877.65
-16.50	250.00	.00	.00	.00	538.93	964.50	11066.98
-17.00	250.00	.00	.00	.00	548.15	981.00	11256.31
-17.50	250.00	.00	.00	.00	557.37	997.50	11445.63
-18.00	250.00	.00	.00	.00	566.59	1014.00	11634.96
-18.50	250.00	.00	.00	.00	575.81	1030.50	11824.29
-19.00	250.00	.00	.00	.00	585.03	1047.00	12013.61
-19.50	250.00	.00	.00	.00	594.25	1063.50	12202.94
-20.00	250.00	.00	.00	.00	603.47	1080.00	12392.26
-20.50	250.00	.00	.00	.00	612.69	1096.50	12581.59
-21.00	250.00	.00	.00	.00	621.91	1113.00	12770.92
-21.50	250.00	.00	.00	.00	631.13	1129.50	12960.24
-22.00+	250.00	.00	.00	.00	640.35	1146.00	13149.57
-22.00-	250.00	3000.00	.00	.00	.00	2292.00	5292.00
-22.50	250.00	3030.00	30.00	.00	.00	2322.00	5322.00
-23.00	250.00	3060.00	60.00	.00	.00	2352.00	5352.00
-23.50	250.00	3090.00	90.00	.00	.00	2382.00	5382.00
-24.00	250.00	3120.00	120.00	.00	.00	2412.00	5412.00
-24.50	250.00	3150.00	150.00	.00	.00	2442.00	5442.00
-25.00	250.00	3180.00	180.00	.00	.00	2472.00	5472.00
-25.50	250.00	3210.00	210.00	.00	.00	2502.00	5502.00
-26.00	250.00	3240.00	240.00	.00	.00	2532.00	5532.00
-26.50	250.00	3270.00	270.00	.00	.00	2562.00	5562.00
-27.00	250.00	3300.00	300.00	.00	.00	2592.00	5592.00
-27.50	250.00	3330.00	330.00	.00	.00	2622.00	5622.00
-28.00	250.00	3360.00	360.00	.00	.00	2652.00	5652.00
-28.50	250.00	3390.00	390.00	.00	.00	2682.00	5682.00
-29.00	250.00	3420.00	420.00	.00	.00	2712.00	5712.00
-29.50	250.00	3450.00	450.00	.00	.00	2742.00	5742.00
-30.00	250.00	3480.00	480.00	.00	.00	2772.00	5772.00
-30.50	250.00	3510.00	510.00	.00	.00	2802.00	5802.00
-31.00	250.00	3540.00	540.00	.00	.00	2832.00	5832.00

Figure 30. (Concluded)

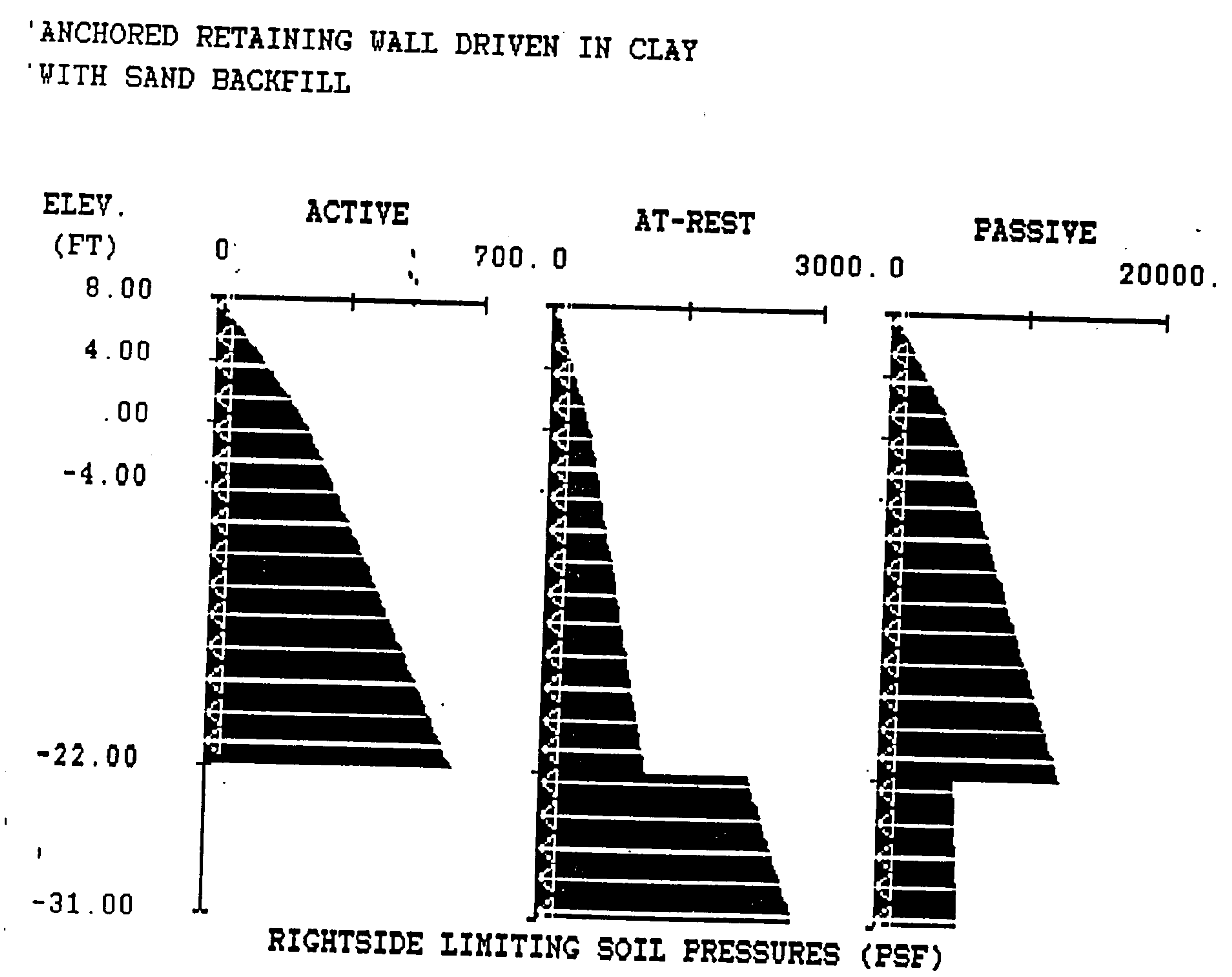

Figure 31. Rightside limiting soil pressures for Example 2

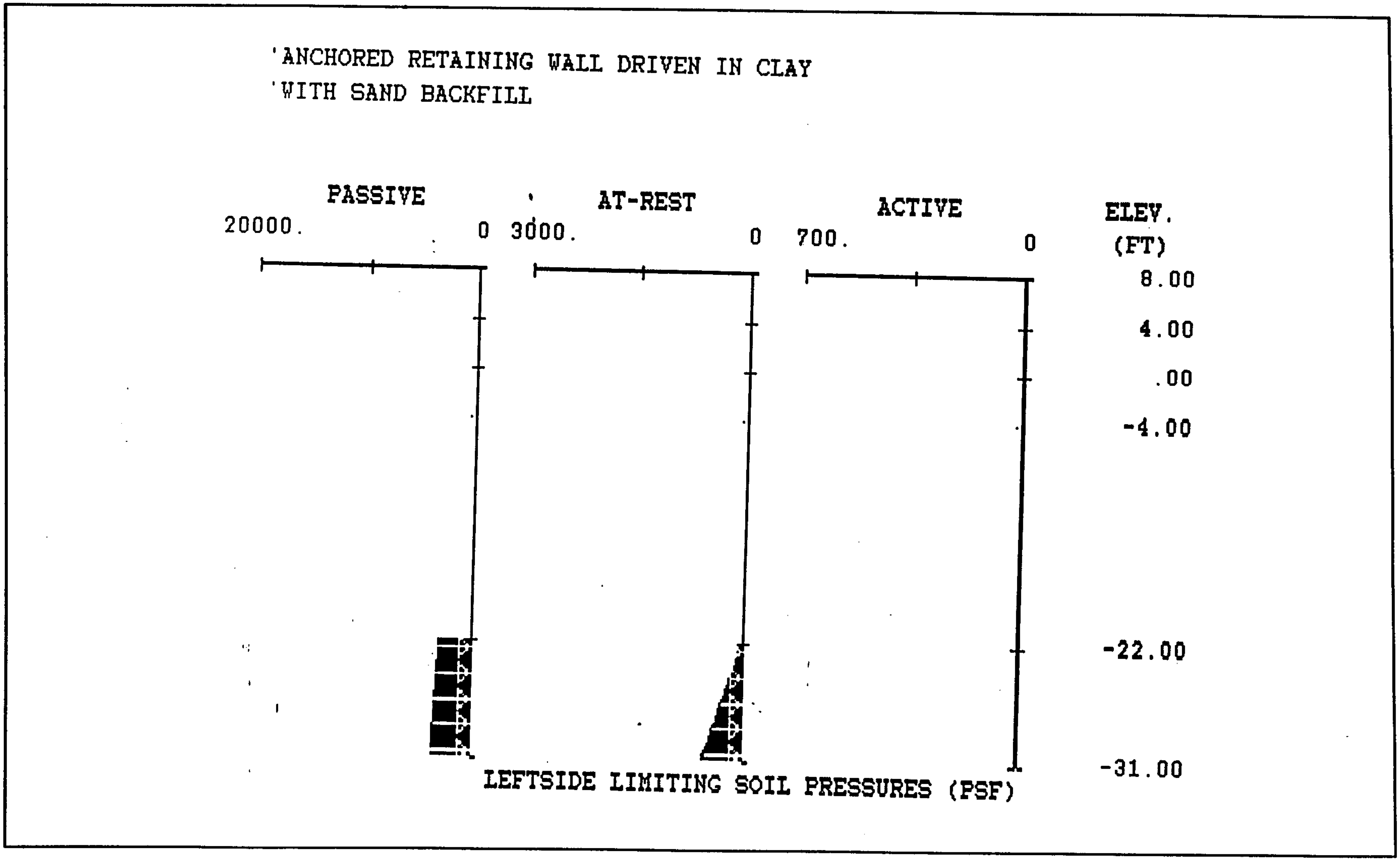

Figure 32. Leftside limiting soil pressures for Example 2

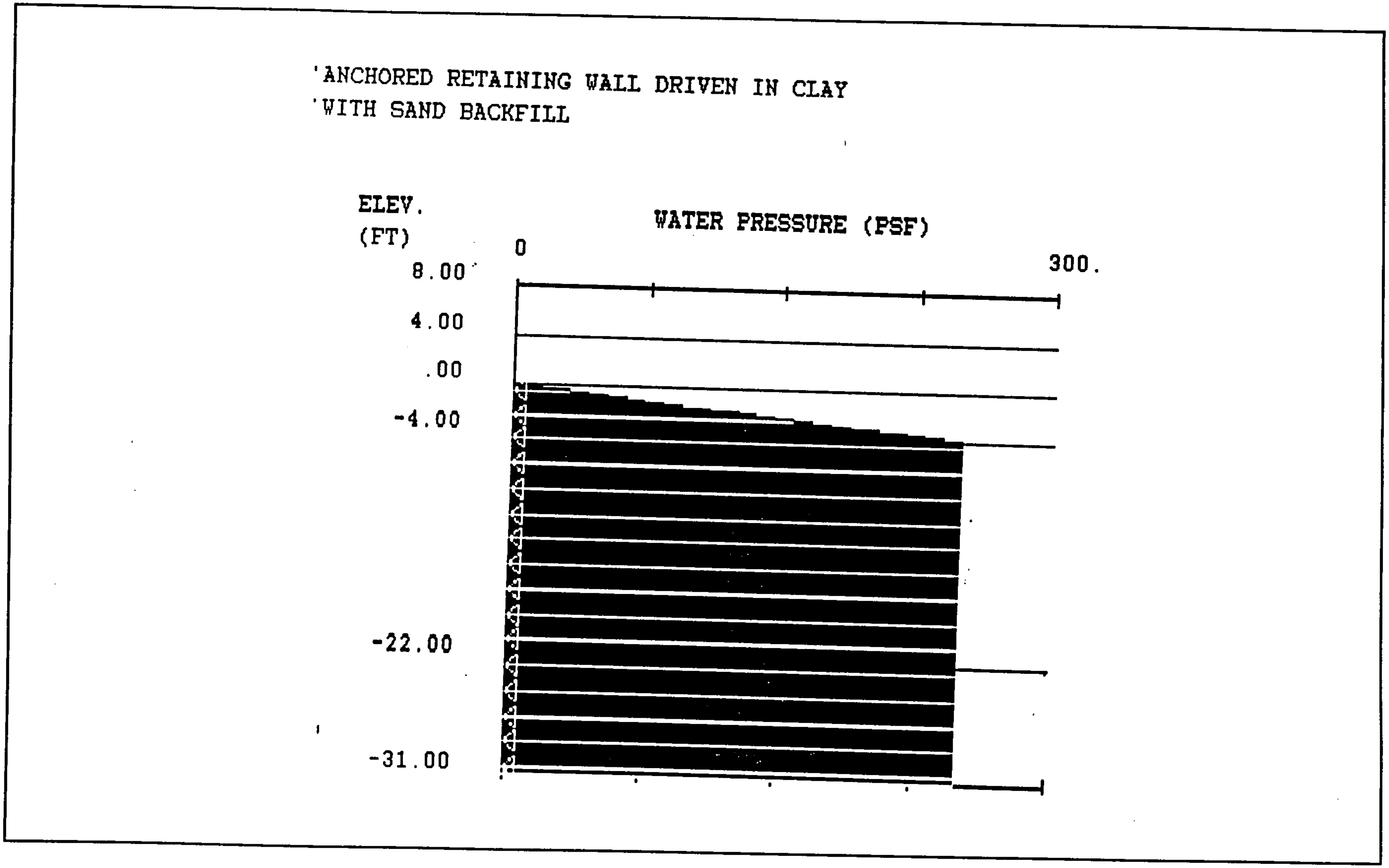

Figure 33. Net water pressures for Example 2

```
PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 30-MAR-1994                                        TIME: 15.59.21

                  **********************
                  * SUMMARY OF RESULTS *
                  **********************

I.A.--MAXIMA

                                          MAXIMUM      MINIMUM
   BENDING MOMENT (LB-FT)       :       4.824E+03   -6.171E+04
      AT ELEVATION (FT)         :            4.00       -11.50
   DEFLECTION (IN)              :       2.260E+00   -6.129E-01
      AT ELEVATION (FT)         :          -13.50         8.00
   RIGHTSIDE SOIL PRESSURE (PSF):         1792.09
      AT ELEVATION (FT)         :          -31.00
   LEFTSIDE SOIL PRESSURE (PSF) :         2429.77
      AT ELEVATION (FT)         :          -22.00

I.B.--ANCHOR FORCES

   ELEVATION      ANCHOR       ANCHOR        ANCHOR
   AT ANCHOR       TYPE      DEFORMATION      FORCE
     (FT)                       (IN)          (LB)
      4.00       FLEXIBLE        .14        8455.33
```

Figure 34. Summary of results for Example 2

PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 30-MAR-1994 TIME: 15.59.21

****
* COMPLETE RESULTS *
****

II.A.--WALL DEFLECTIONS AND FORCES

	<------DEFLECTION----->		<--WALL INTERNAL FORCES->		
ELEVATION (FT)	AXIAL (IN)	LATERAL (IN)	AXIAL (LB)	SHEAR (LB)	MOMENT (LB-FT)
8.00	0.000E+00	-6.129E-01	0.	1000.	0.
7.50	0.000E+00	-5.192E-01	0.	1014.	502.
7.00	0.000E+00	-4.254E-01	0.	1052.	1018.
6.50	0.000E+00	-3.316E-01	0.	1109.	1557.
6.00	0.000E+00	-2.376E-01	0.	1181.	2129.
5.50	0.000E+00	-1.436E-01	0.	1262.	2740.
5.00	0.000E+00	-4.931E-02	0.	1348.	3392.
4.50	0.000E+00	4.518E-02	0.	1433.	4087.
4.00+	0.000E+00	1.399E-01	0.	1513.	4824.
4.00-	0.000E+00	1.399E-01	0.	-6942.	4824.
3.50	0.000E+00	2.350E-01	0.	-6874.	1371.
3.00	0.000E+00	3.301E-01	0.	-6805.	-2049.
2.50	0.000E+00	4.251E-01	0.	-6728.	-5433.
2.00	0.000E+00	5.198E-01	0.	-6643.	-8776.
1.50	0.000E+00	6.138E-01	0.	-6552.	-12075.
1.00	0.000E+00	7.070E-01	0.	-6453.	-15326.
.50	0.000E+00	7.992E-01	0.	-6346.	-18526.
.00	0.000E+00	8.902E-01	0.	-6233.	-21671.
-.50	0.000E+00	9.796E-01	0.	-6105.	-24757.
-1.00	0.000E+00	1.067E+00	0.	-5957.	-27773.
-1.50	0.000E+00	1.153E+00	0.	-5790.	-30711.
-2.00	0.000E+00	1.237E+00	0.	-5601.	-33559.
-2.50	0.000E+00	1.319E+00	0.	-5393.	-36309.
-3.00	0.000E+00	1.398E+00	0.	-5164.	-38949.
-3.50	0.000E+00	1.474E+00	0.	-4915.	-41470.
-4.00	0.000E+00	1.548E+00	0.	-4646.	-43861.
-4.50	0.000E+00	1.619E+00	0.	-4365.	-46114.
-5.00	0.000E+00	1.686E+00	0.	-4079.	-48225.
-5.50	0.000E+00	1.751E+00	0.	-3788.	-50192.
-6.00	0.000E+00	1.812E+00	0.	-3493.	-52012.
-6.50	0.000E+00	1.869E+00	0.	-3193.	-53684.
-7.00	0.000E+00	1.923E+00	0.	-2888.	-55204.
-7.50	0.000E+00	1.973E+00	0.	-2579.	-56571.
-8.00	0.000E+00	2.019E+00	0.	-2265.	-57782.
-8.50	0.000E+00	2.062E+00	0.	-1947.	-58835.
-9.00	0.000E+00	2.100E+00	0.	-1624.	-59728.
-9.50	0.000E+00	2.134E+00	0.	-1296.	-60458.

Figure 35. Complete results for Example 2 (Sheet 1 of 4)

-10.00	0.000E+00	2.165E+00	0.	-964.	-61023.
-10.50	0.000E+00	2.191E+00	0.	-627.	-61421.
-11.00	0.000E+00	2.213E+00	0.	-286.	-61650.
-11.50	0.000E+00	2.231E+00	0.	61.	-61706.
-12.00	0.000E+00	2.244E+00	0.	411.	-61588.
-12.50	0.000E+00	2.254E+00	0.	766.	-61294.
-13.00	0.000E+00	2.259E+00	0.	1126.	-60821.
-13.50	0.000E+00	2.260E+00	0.	1491.	-60167.
-14.00	0.000E+00	2.258E+00	0.	1860.	-59330.
-14.50	0.000E+00	2.251E+00	0.	2234.	-58306.
-15.00	0.000E+00	2.240E+00	0.	2612.	-57095.
-15.50	0.000E+00	2.225E+00	0.	2995.	-55693.
-16.00	0.000E+00	2.207E+00	0.	3383.	-54099.
-16.50	0.000E+00	2.185E+00	0.	3775.	-52310.
-17.00	0.000E+00	2.159E+00	0.	4171.	-50324.
-17.50	0.000E+00	2.130E+00	0.	4573.	-48138.
-18.00	0.000E+00	2.098E+00	0.	4979.	-45750.
-18.50	0.000E+00	2.063E+00	0.	5389.	-43158.
-19.00	0.000E+00	2.025E+00	0.	5805.	-40360.
-19.50	0.000E+00	1.984E+00	0.	6224.	-37353.
-20.00	0.000E+00	1.940E+00	0.	6649.	-34135.
-20.50	0.000E+00	1.894E+00	0.	7078.	-30703.
-21.00	0.000E+00	1.846E+00	0.	7512.	-27056.
-21.50	0.000E+00	1.797E+00	0.	7950.	-23191.
-22.00+	0.000E+00	1.746E+00	0.	8393.	-19106.
-22.00-	0.000E+00	1.746E+00	0.	8393.	-19106.
-22.50	0.000E+00	1.693E+00	0.	7314.	-15180.
-23.00	0.000E+00	1.639E+00	0.	6268.	-11787.
-23.50	0.000E+00	1.585E+00	0.	5294.	-8900.
-24.00	0.000E+00	1.530E+00	0.	4397.	-6480.
-24.50	0.000E+00	1.475E+00	0.	3577.	-4490.
-25.00	0.000E+00	1.419E+00	0.	2834.	-2890.
-25.50	0.000E+00	1.363E+00	0.	2169.	-1642.
-26.00	0.000E+00	1.307E+00	0.	1582.	-708.
-26.50	0.000E+00	1.251E+00	0.	1073.	-48.
-27.00	0.000E+00	1.195E+00	0.	642.	378.
-27.50	0.000E+00	1.139E+00	0.	289.	607.
-28.00	0.000E+00	1.083E+00	0.	14.	680.
-28.50	0.000E+00	1.027E+00	0.	-183.	634.
-29.00	0.000E+00	9.706E-01	0.	-302.	510.
-29.50	0.000E+00	9.147E-01	0.	-343.	345.
-30.00	0.000E+00	8.588E-01	0.	-307.	179.
-30.50	0.000E+00	8.029E-01	0.	-192.	51.
-31.00	0.000E+00	7.471E-01	0.	0.	0.

Figure 35. (Sheet 2 of 4)

II.B.--SOIL PRESSURES

ELEVATION (FT)	<---------SOIL PRESSURES LEFTSIDE	(PSF)--------> RIGHTSIDE	NET
8.00	.00	.00	.00
7.50	.00	53.35	53.35
7.00	.00	96.91	96.91
6.50	.00	130.68	130.68
6.00	.00	154.62	154.62
5.50	.00	168.72	168.72
5.00	.00	172.94	172.94
4.50	.00	167.24	167.24
4.00+	.00	151.56	151.56
4.00-	.00	151.56	151.56
3.50	.00	132.01	132.01
3.00	.00	146.68	146.68
2.50	.00	161.34	161.34
2.00	.00	176.01	176.01
1.50	.00	190.68	190.68
1.00	.00	205.35	205.35
.50	.00	220.01	220.01
.00	.00	234.68	234.68
-.50	.00	243.90	243.90
-1.00	.00	253.12	253.12
-1.50	.00	262.34	262.34
-2.00	.00	271.56	271.56
-2.50	.00	280.78	280.78
-3.00	.00	290.00	290.00
-3.50	.00	299.22	299.22
-4.00	.00	308.44	308.44
-4.50	.00	317.66	317.66
-5.00	.00	326.88	326.88
-5.50	.00	336.10	336.10
-6.00	.00	345.32	345.32
-6.50	.00	354.54	354.54
-7.00	.00	363.76	363.76
-7.50	.00	372.98	372.98
-8.00	.00	382.20	382.20
-8.50	.00	391.42	391.42
-9.00	.00	400.64	400.64
-9.50	.00	409.86	409.86
-10.00	.00	419.08	419.08
-10.50	.00	428.30	428.30
-11.00	.00	437.51	437.51
-11.50	.00	446.73	446.73
-12.00	.00	455.95	455.95
-12.50	.00	465.17	465.17
-13.00	.00	474.39	474.39

Figure 35. (Sheet 3 of 4)

-13.50	.00	483.61	483.61
-14.00	.00	492.83	492.83
-14.50	.00	502.05	502.05
-15.00	.00	511.27	511.27
-15.50	.00	520.49	520.49
-16.00	.00	529.71	529.71
-16.50	.00	538.93	538.93
-17.00	.00	548.15	548.15
-17.50	.00	557.37	557.37
-18.00	.00	566.59	566.59
-18.50	.00	575.81	575.81
-19.00	.00	585.03	585.03
-19.50	.00	594.25	594.25
-20.00	.00	603.47	603.47
-20.50	.00	612.69	612.69
-21.00	.00	621.91	621.91
-21.50	.00	631.13	631.13
-22.00+	.00	640.35	640.35
-22.00-	2429.77	.00	-2429.77
-22.50	2386.61	.00	-2386.61
-23.00	2342.02	69.98	-2272.04
-23.50	2296.31	175.69	-2120.63
-24.00	2249.77	282.23	-1967.54
-24.50	2202.61	389.39	-1813.22
-25.00	2155.02	496.98	-1658.05
-25.50	2107.17	604.83	-1502.33
-26.00	2059.15	712.85	-1346.30
-26.50	2011.07	820.93	-1190.13
-27.00	1962.97	929.03	-1033.95
-27.50	1914.92	1037.08	-877.83
-28.00	1866.92	1145.08	-721.83
-28.50	1818.98	1253.02	-565.96
-29.00	1771.10	1360.90	-410.20
-29.50	1723.27	1468.73	-254.53
-30.00	1675.47	1576.53	-98.94
-30.50	1627.69	1684.31	56.63
-31.00	1579.91	1792.09	212.18

Figure 35. (Sheet 4 of 4)

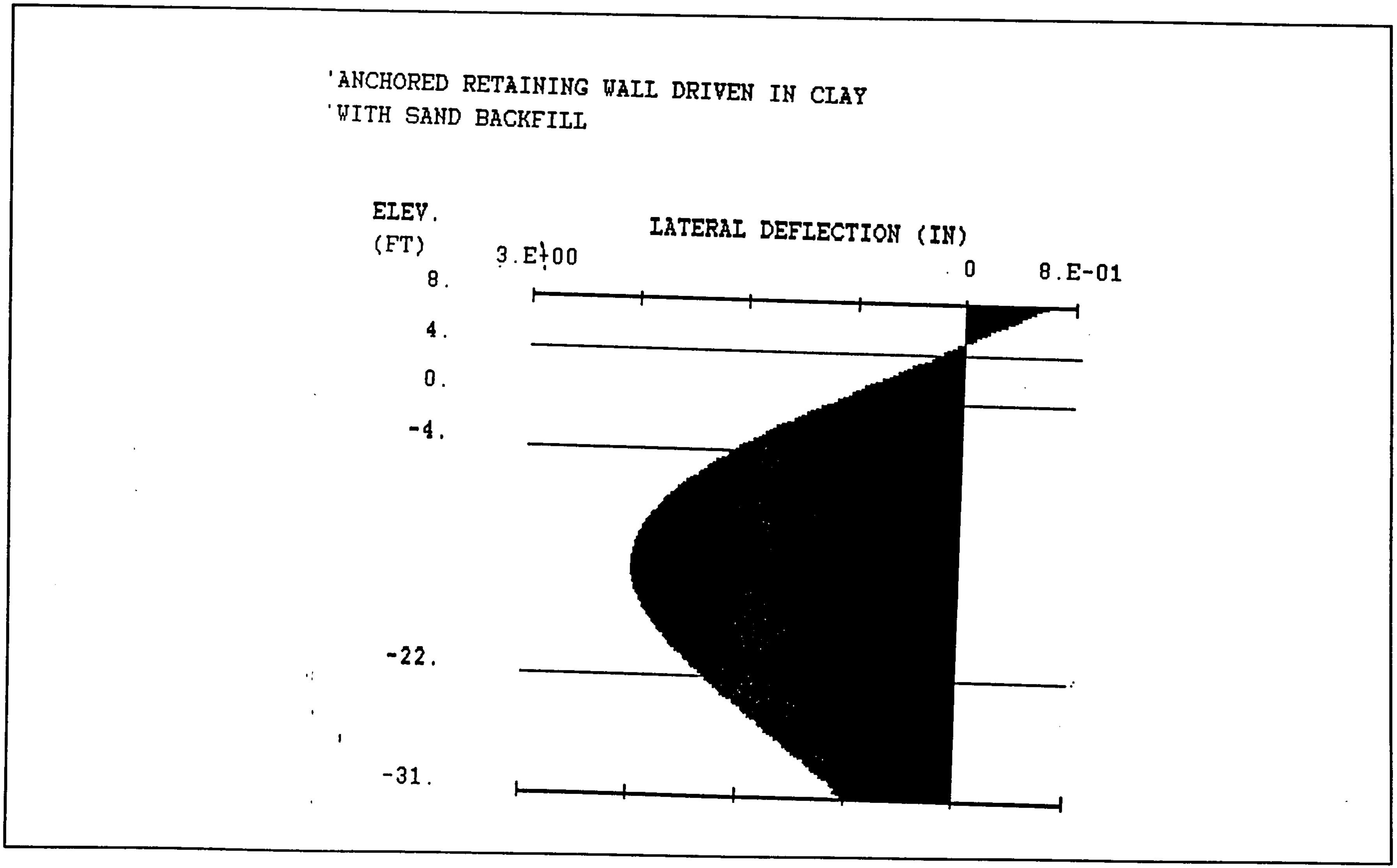

Figure 36. Lateral deflections for Example 2

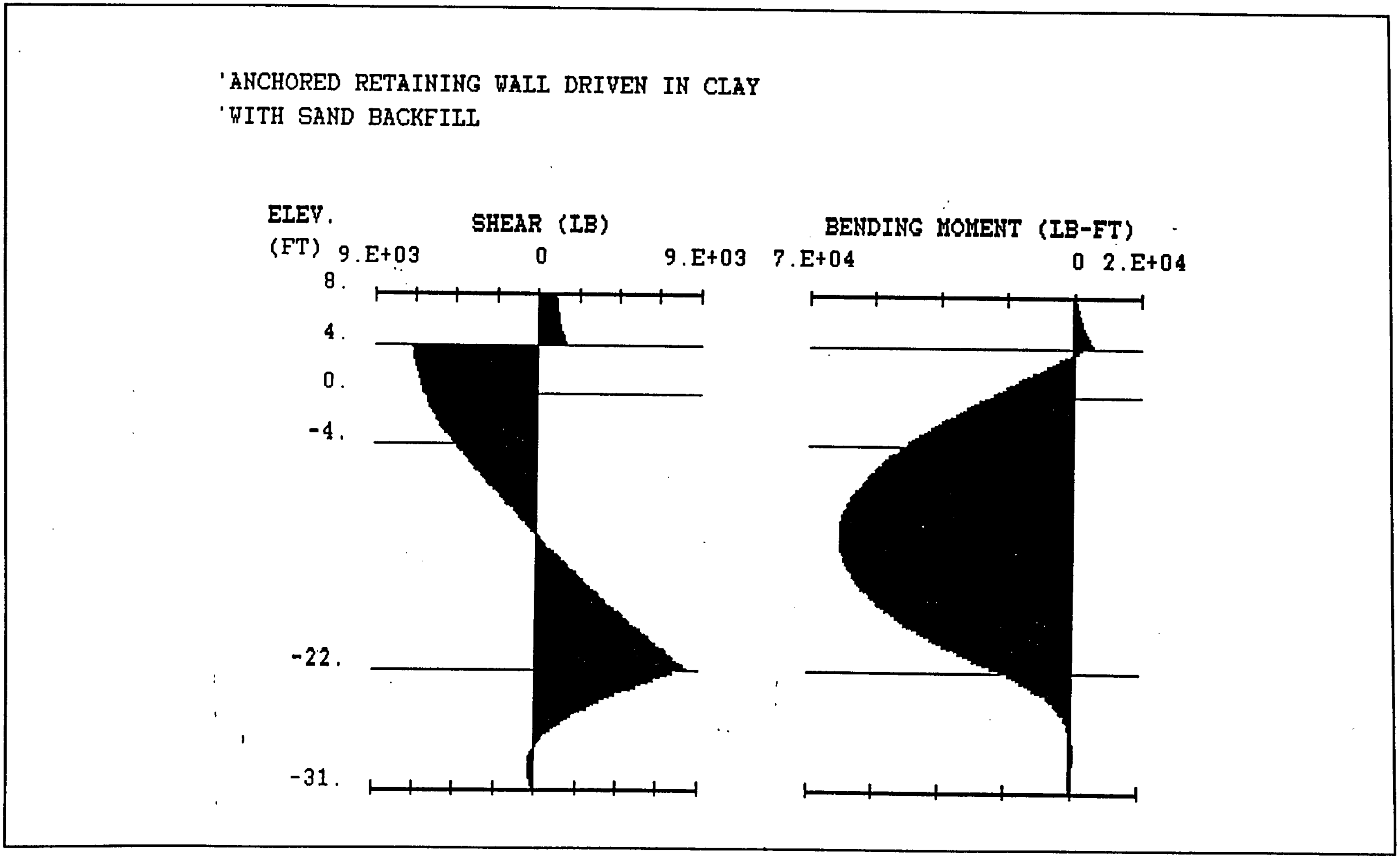

Figure 37. Shear force and bending moment for Example 2

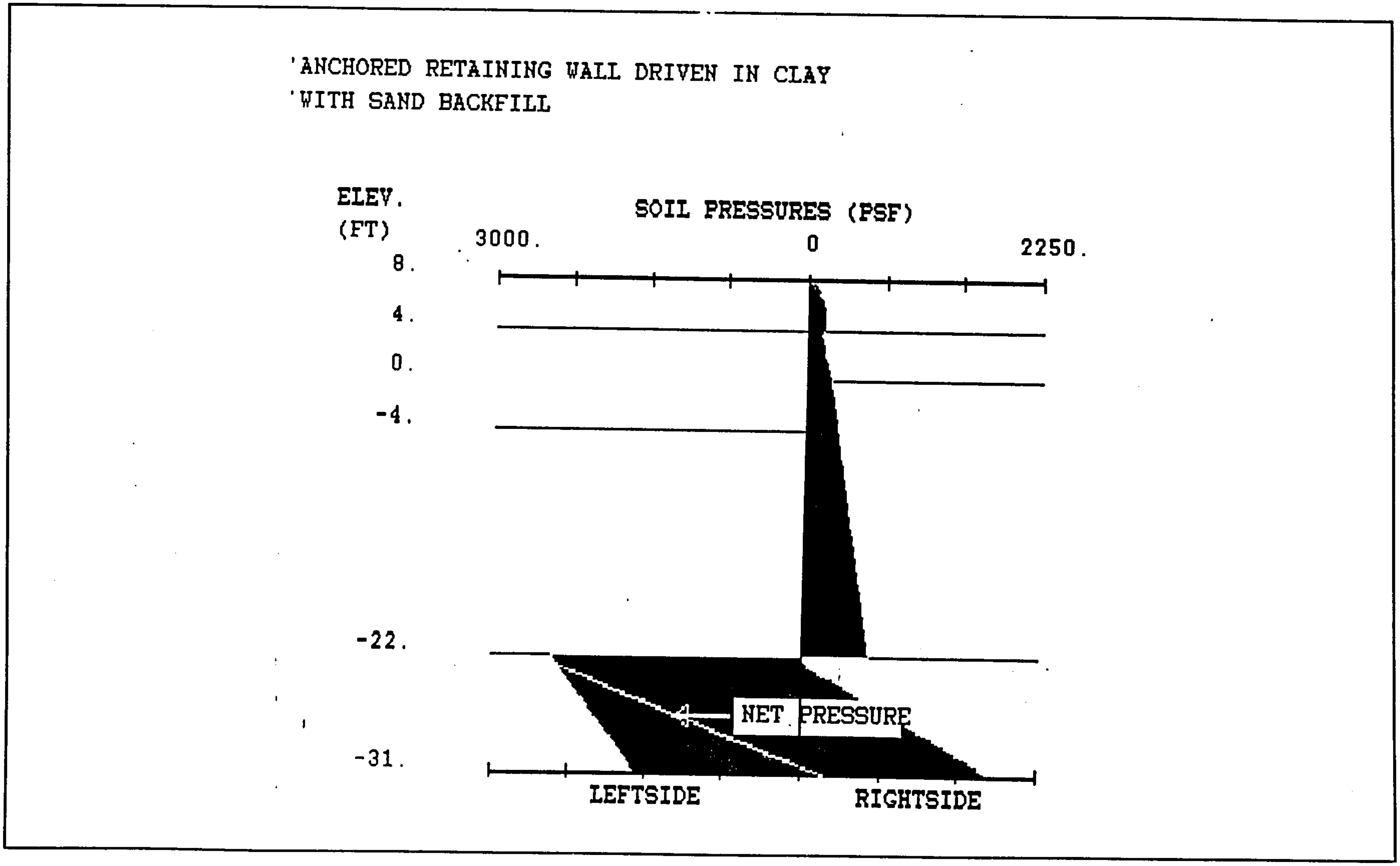

Figure 38. Final soil pressures for Example 2

Example 3

The system shown in Figure 39 is one wall of a lock structure. The concrete floor slab resists motion of the wall to the left but does not impede rightward motion. At the same time, the slab acts as a surcharge on the leftside soil surface. The slab was modeled as a pair of "tension only" flexible anchors with properties representative of the slab dimensions and

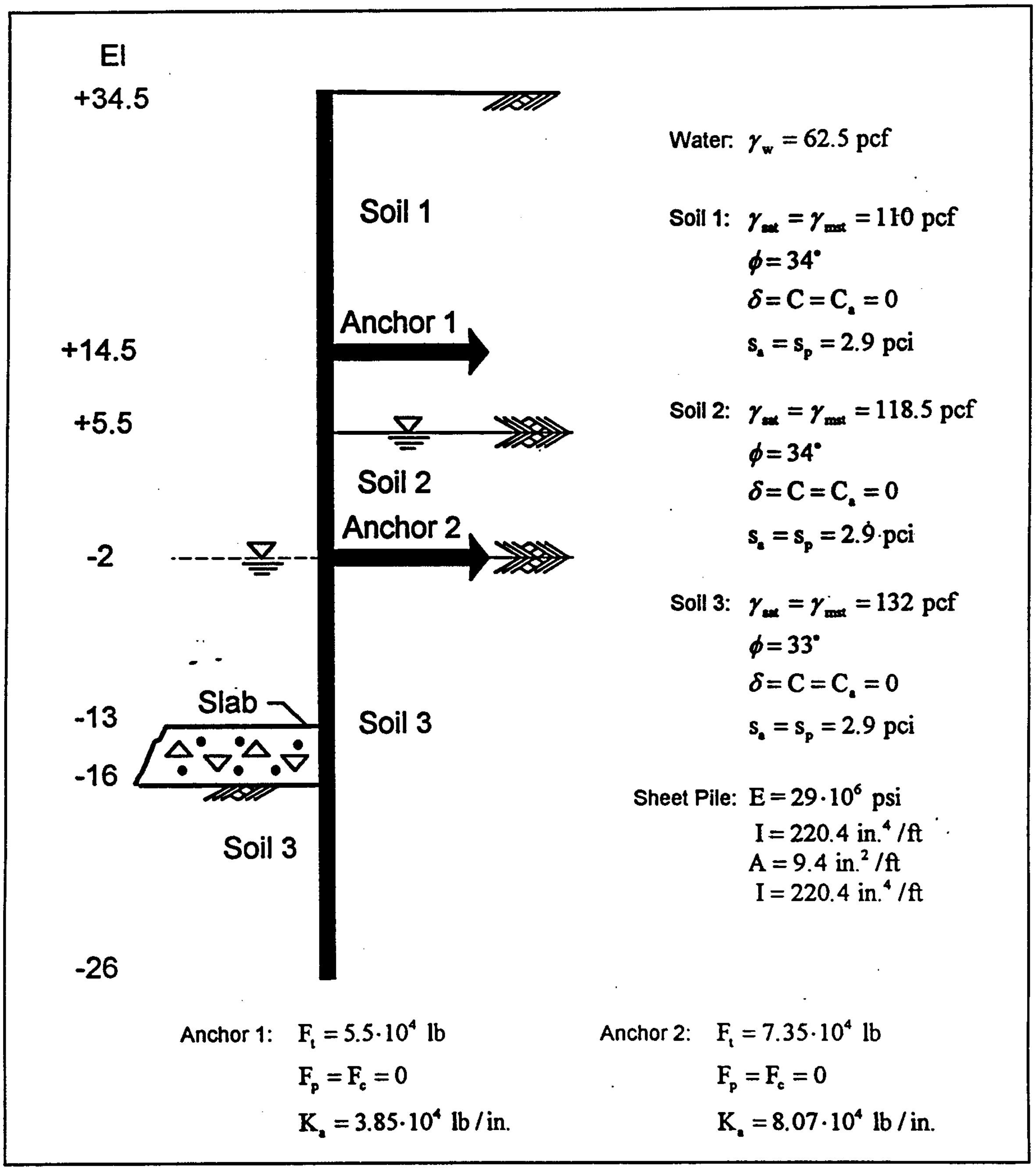

Figure 39. System for Example 3

material. The input file for CWALSSI for this system is shown in Figure 40. The input data are echoprinted in Figure 41 and displayed graphically in Figures 42 and 43.

Because interaction distance data were not provided as input, the program automatically estimates the interaction distance and performs two solutions before reporting the final results. For the first solution, interaction distances are estimated using the process illustrated in Figure 7c, Chapter 4, as shown in Table 2.

Following completion of the first solution, CWALSSI revises the interaction distances on each side of the wall based on the deflections calculated from the first solution. The interaction distances used in the second solution are given (approximate values) in Table 3 (see Figures 45 and 46).

Results after the second solution are shown in Figures 44 through 46. The results indicate that the slab is not in contact with the wall at the level of the upper anchor used to model the slab.

```
1000 'MULTIPLE ANCHORED WALL
1010 'DRIVEN IN SAND WITH SAND BACKFILL
1020 'CONCRETE SLAB TREATED AS TWO TENSION ONLY ANCHORS
1030 WALL     34.50    2.900E+07    2.204E+02    9.400E+00
1040 WALL    -26.00
1050 ANCHOR     14.5  F  5.50E4  0  0  3.85E4  0
1060 ANCHOR     -2.0  F  7.35E4  0  0  8.07E4  0
1070 ANCHOR    -14.0  F  6.48E5  0  0  9.00E6  0
1080 ANCHOR    -15.0  F  6.48E5  0  0  9.00E6  0
1090 SURFACE RIGHTSIDE   1  0     34.50
1100 SURFACE  LEFTSIDE   1  0    -16.00
1110 SOIL RIGHTSIDE  STRENGTH    3
1120   110.00  110.00 34.0     .00   .0      .00     2.90     2.90     5.50     .00
1130   128.50  128.50 34.0     .00   .0      .00     2.90     2.90    -2.00     .00
1140   132.00  132.00 33.0     .00   .0      .00     2.90     2.90
1150 SOIL  LEFTSIDE  STRENGTH    1
1160   132.00  132.00 33.0     .00   .0      .00     2.90     2.90
1170 WATER ELEVATIONS     62.50    5.50   -2.00
1180 VERTICAL UNIFORM  LEFTSIDE     450.00
1190 FINISH
```

Figure 40. Input file for Example 3

PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 31-MAR-1994 TIME: 10.51.54

****
* INPUT DATA *
****

I.--HEADING:
'MULTIPLE ANCHORED WALL
'DRIVEN IN SAND WITH SAND BACKFILL
'CONCRETE SLAB TREATED AS TWO TENSION ONLY ANCHORS

II.--WALL SEGMENT DATA

ELEVATION AT TOP OF SEGMENT (FT)	MODULUS OF ELASTICICTY (PSI)	MOMENT OF INERTIA (IN**4)	CROSS SECTION AREA (SQIN)
34.50	2.900E+07	220.40	9.40

ELEVATION AT BOTTOM OF WALL = -26.00 (FT).

III.--ANCHOR DATA

ELEVATION AT WALL (FT)	ANCHOR TYPE ('R/F')	ULTIMATE TENSION FORCE (LB)	PRE-STRESS FORCE (LB)	ULTIMATE COMPRESSION FORCE (LB)	ANCHOR STIFFNESS (LB/IN)	ANCHOR SLOPE (FT)
14.50	FLEXIBLE	5.50E+04	0.00E+00	0.00E+00	3.850E+04	.00
-2.00	FLEXIBLE	7.35E+04	0.00E+00	0.00E+00	8.070E+04	.00
-14.00	FLEXIBLE	6.48E+05	0.00E+00	0.00E+00	9.000E+06	.00
-15.00	FLEXIBLE	6.48E+05	0.00E+00	0.00E+00	9.000E+06	.00

IV.--SURFACE POINT DATA

IV.A.--RIGHTSIDE

DIST. FROM WALL (FT)	ELEVATION (FT)
.00	34.50

IV.B.-- LEFTSIDE

DIST. FROM WALL (FT)	ELEVATION (FT)
.00	-16.00

Figure 41. Echoprint of input data for Example 3 (Continued)

V.--SOIL LAYER DATA

V.A.--RIGHTSIDE LAYER DATA

<UNIT WEIGHT> SAT. (PCF)	MOIST (PCF)	ANGLE OF INTERNAL FRICTION (DEG)	COH-ESION (PSF)	ANGLE OF WALL FRICTION (DEG)	WALL ADH-ESION (PSF)	<STIFF. ACT. (PCI)	COEF.> PASS. (PCI)	<--BOTTOM--> ELEV. (FT)	SLOPE (FT)
110.00	110.00	34.00	.00	.00	.00	2.90	2.90	5.50	.000
128.50	128.50	34.00	.00	.00	.00	2.90	2.90	-2.00	.000
132.00	132.00	33.00	.00	.00	.00	2.90	2.90		

V.B.-- LEFTSIDE LAYER DATA

<UNIT WEIGHT> SAT. (PCF)	MOIST (PCF)	ANGLE OF INTERNAL FRICTION (DEG)	COH-ESION (PSF)	ANGLE OF WALL FRICTION (DEG)	WALL ADH-ESION (PSF)	<STIFF. ACT. (PCI)	COEF.> PASS. (PCI)	<--BOTTOM--> ELEV. (FT)	SLOPE (FT)
132.00	132.00	33.00	.00	.00	.00	2.90	2.90		

VI.--INTERACTION ZONE DATA
NONE

VII.--WATER DATA

UNIT WEIGHT = 62.50 (PCF)
RIGHTSIDE ELEVATION = 5.50 (FT)
LEFTSIDE ELEVATION = -2.00 (FT)
NO SEEPAGE

VIII.--SURFACE LOADS

VIII.A.--RIGHTSIDE SURFACE LOADS
NONE

VIII.B.-- LEFTSIDE SURFACE LOADS

VIII.B.1.--SURFACE LINE LOADS
NONE

VIII.B.2.--SURFACE DISTRIBUTED LOADS
UNIFORM LOAD = 450.00 (PSF)

IX.--HORIZONTAL LOADS
NONE

Figure 41. (Concluded)

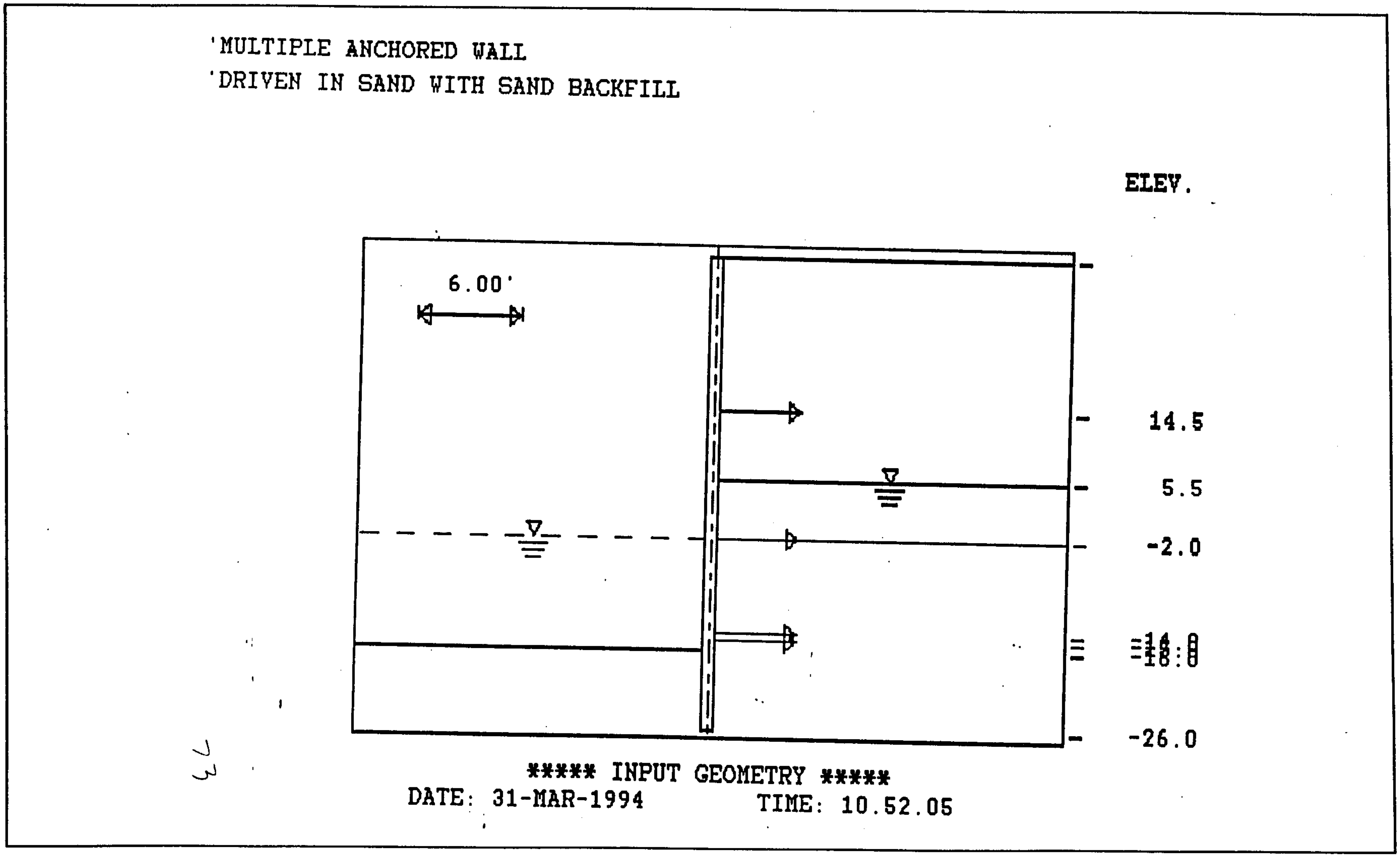

Figure 42. Graphics display of input geometry for Example 3

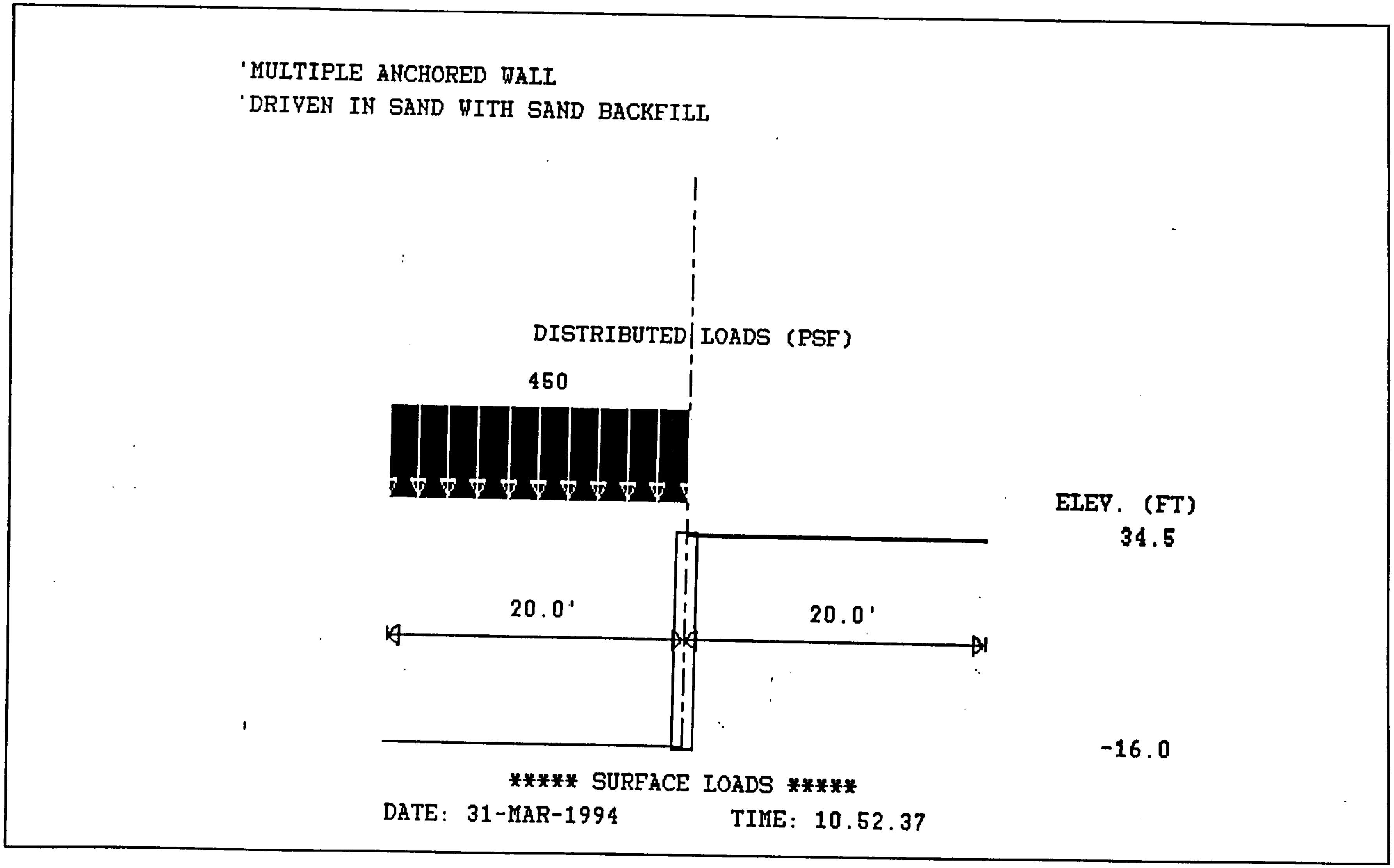

Figure 43. Graphics display of input surcharge loads for Example 3

Table 2
Initial Estimates of Interaction Distances

	Zone Top, ft	Zone Bottom, ft	Interaction Dist., ft
Rightside Soil	+34.5	+14.5	20.0
	+14.5	-2.0	16.5
	-2.0	-14.0	12.0
	-14.0	-15.0	1.0
Leftside Soil	-16.0	-26.0	10.0

Table 3
Interaction Distances for Final Solution

	Zone Top, ft	Zone Bottom, ft	Interaction Dist., ft
Rightside Soil	+34.5	-12.0	22.5
	-12.0	-15.0	3.0
	-15.0	-26.0	11.0
Leftside Soil	-16.0	-26.0	10.0

```
PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 31-MAR-1994                                          TIME: 10.58.03

                    **********************
                    * SUMMARY OF RESULTS *
                    **********************

I.A.--MAXIMA

                                           MAXIMUM        MINIMUM
   BENDING MOMENT (LB-FT)        :       7.934E+04     -1.481E+04
       AT ELEVATION (FT)         :          -15.00           4.00
   DEFLECTION (IN)               :       2.257E+00     -1.260E-02
       AT ELEVATION (FT)         :           34.50         -13.50
   RIGHTSIDE SOIL PRESSURE (PSF):          2154.28
       AT ELEVATION (FT)         :          -14.00
   LEFTSIDE SOIL PRESSURE (PSF)  :         1131.24
       AT ELEVATION (FT)         :          -26.00

I.B.--ANCHOR FORCES

   ELEVATION      ANCHOR        ANCHOR         ANCHOR
   AT ANCHOR       TYPE       DEFORMATION       FORCE
     (FT)                        (IN)           (LB)
     14.50       FLEXIBLE         .51        19484.41
     -2.00       FLEXIBLE         .24        19576.01
    -14.00       FLEXIBLE        -.01             .00
    -15.00       FLEXIBLE         .00        38093.95
```

Figure 44. Summary of results for Example 3

```
PROGRAM CWALSSI - SOIL-STRUCTURE INTERACTION ANALYSIS OF SHEET PILE WALLS
DATE: 31-MAR-1994                                          TIME: 10.58.03
                         ********************
                         * COMPLETE RESULTS *
                         ********************

II.A.--WALL DEFLECTIONS AND FORCES
```

	<------DEFLECTION----->		<--WALL INTERNAL FORCES-->		
ELEVATION (FT)	AXIAL (IN)	LATERAL (IN)	AXIAL (LB)	SHEAR (LB)	MOMENT (LB-FT)
34.50	0.000E+00	2.257E+00	0.	0.	0.
34.00	0.000E+00	2.207E+00	0.	4.	1.
33.50	0.000E+00	2.157E+00	0.	16.	5.
33.00	0.000E+00	2.107E+00	0.	35.	17.
32.50	0.000E+00	2.057E+00	0.	62.	41.
32.00	0.000E+00	2.007E+00	0.	97.	81.
31.50	0.000E+00	1.957E+00	0.	140.	140.
31.00	0.000E+00	1.907E+00	0.	190.	222.
30.50	0.000E+00	1.857E+00	0.	249.	332.
30.00	0.000E+00	1.807E+00	0.	317.	473.
29.50	0.000E+00	1.757E+00	0.	394.	651.
29.00	0.000E+00	1.708E+00	0.	480.	869.
28.50	0.000E+00	1.658E+00	0.	576.	1132.
28.00	0.000E+00	1.608E+00	0.	681.	1446.
27.50	0.000E+00	1.559E+00	0.	797.	1815.
27.00	0.000E+00	1.509E+00	0.	922.	2245.
26.50	0.000E+00	1.460E+00	0.	1058.	2739.
26.00	0.000E+00	1.411E+00	0.	1204.	3304.
25.50	0.000E+00	1.362E+00	0.	1362.	3945.
25.00	0.000E+00	1.313E+00	0.	1530.	4668.
24.50	0.000E+00	1.265E+00	0.	1709.	5477.
24.00	0.000E+00	1.217E+00	0.	1900.	6379.
23.50	0.000E+00	1.170E+00	0.	2103.	7379.
23.00	0.000E+00	1.123E+00	0.	2317.	8484.
22.50	0.000E+00	1.076E+00	0.	2544.	9699.
22.00	0.000E+00	1.030E+00	0.	2782.	11030.
21.50	0.000E+00	9.853E-01	0.	3033.	12483.
21.00	0.000E+00	9.411E-01	0.	3297.	14065.
20.50	0.000E+00	8.979E-01	0.	3573.	15782.
20.00	0.000E+00	8.557E-01	0.	3862.	17641.
19.50	0.000E+00	8.148E-01	0.	4164.	19647.
19.00	0.000E+00	7.751E-01	0.	4479.	21807.
18.50	0.000E+00	7.370E-01	0.	4807.	24128.
18.00	0.000E+00	7.005E-01	0.	5148.	26616.
17.50	0.000E+00	6.657E-01	0.	5502.	29278.
17.00	0.000E+00	6.330E-01	0.	5870.	32120.
16.50	0.000E+00	6.024E-01	0.	6251.	35150.

Figure 45. Complete results for Example 3 (Sheet 1 of 6)

16.00	0.000E+00	5.742E-01	0.	6645.	38373.
15.50	0.000E+00	5.486E-01	0.	7052.	41797.
15.00	0.000E+00	5.258E-01	0.	7471.	45427.
14.50+	0.000E+00	5.061E-01	0.	7904.	49270.
14.50-	0.000E+00	5.061E-01	0.	-11580.	49270.
14.00	0.000E+00	4.896E-01	0.	-11135.	43591.
13.50	0.000E+00	4.761E-01	0.	-10677.	38138.
13.00	0.000E+00	4.651E-01	0.	-10207.	32916.
12.50	0.000E+00	4.564E-01	0.	-9725.	27932.
12.00	0.000E+00	4.495E-01	0.	-9231.	23193.
11.50	0.000E+00	4.442E-01	0.	-8726.	18703.
11.00	0.000E+00	4.402E-01	0.	-8208.	14469.
10.50	0.000E+00	4.372E-01	0.	-7680.	10497.
10.00	0.000E+00	4.349E-01	0.	-7140.	6791.
9.50	0.000E+00	4.330E-01	0.	-6588.	3359.
9.00	0.000E+00	4.314E-01	0.	-6025.	205.
8.50	0.000E+00	4.298E-01	0.	-5451.	-2665.
8.00	0.000E+00	4.280E-01	0.	-4866.	-5245.
7.50	0.000E+00	4.258E-01	0.	-4269.	-7529.
7.00	0.000E+00	4.232E-01	0.	-3661.	-9512.
6.50	0.000E+00	4.199E-01	0.	-3041.	-11188.
6.00	0.000E+00	4.158E-01	0.	-2409.	-12551.
5.50+	0.000E+00	4.109E-01	0.	-1766.	-13595.
5.50-	0.000E+00	4.109E-01	0.	-1766.	-13595.
5.00	0.000E+00	4.051E-01	0.	-1141.	-14323.
4.50	0.000E+00	3.983E-01	0.	-493.	-14732.
4.00	0.000E+00	3.905E-01	0.	179.	-14812.
3.50	0.000E+00	3.818E-01	0.	874.	-14550.
3.00	0.000E+00	3.720E-01	0.	1594.	-13933.
2.50	0.000E+00	3.613E-01	0.	2339.	-12951.
2.00	0.000E+00	3.498E-01	0.	3108.	-11591.
1.50	0.000E+00	3.374E-01	0.	3901.	-9840.
1.00	0.000E+00	3.244E-01	0.	4720.	-7685.
.50	0.000E+00	3.109E-01	0.	5565.	-5115.
.00	0.000E+00	2.970E-01	0.	6434.	-2116.
-.50	0.000E+00	2.830E-01	0.	7330.	1324.
-1.00	0.000E+00	2.691E-01	0.	8251.	5218.
-1.50	0.000E+00	2.555E-01	0.	9198.	9579.
-2.00+	0.000E+00	2.426E-01	0.	10170.	14420.
-2.00-	0.000E+00	2.426E-01	0.	-9406.	14420.
-2.50	0.000E+00	2.305E-01	0.	-8385.	9972.
-3.00	0.000E+00	2.192E-01	0.	-7355.	6037.
-3.50	0.000E+00	2.082E-01	0.	-6314.	2619.
-4.00	0.000E+00	1.974E-01	0.	-5263.	-276.
-4.50	0.000E+00	1.866E-01	0.	-4202.	-2642.
-5.00	0.000E+00	1.756E-01	0.	-3131.	-4476.
-5.50	0.000E+00	1.644E-01	0.	-2049.	-5772.
-6.00	0.000E+00	1.527E-01	0.	-957.	-6524.

Figure 45. (Sheet 2 of 6)

-6.50	0.000E+00	1.406E-01	0.	145.	-6727.
-7.00	0.000E+00	1.281E-01	0.	1259.	-6377.
-7.50	0.000E+00	1.151E-01	0.	2383.	-5467.
-8.00	0.000E+00	1.018E-01	0.	3518.	-3992.
-8.50	0.000E+00	8.815E-02	0.	4665.	-1947.
-9.00	0.000E+00	7.441E-02	0.	5823.	675.
-9.50	0.000E+00	6.072E-02	0.	6993.	3879.
-10.00	0.000E+00	4.730E-02	0.	8174.	7670.
-10.50	0.000E+00	3.440E-02	0.	9367.	12055.
-11.00	0.000E+00	2.232E-02	0.	10571.	17039.
-11.50	0.000E+00	1.139E-02	0.	11786.	22628.
-12.00	0.000E+00	1.994E-03	0.	13002.	28825.
-12.50	0.000E+00	-5.449E-03	0.	14246.	35635.
-13.00	0.000E+00	-1.048E-02	0.	15524.	43076.
-13.50	0.000E+00	-1.260E-02	0.	16825.	51162.
-14.00	0.000E+00	-1.125E-02	0.	18137.	59903.
-14.50	0.000E+00	-5.853E-03	0.	19442.	69298.
-15.00+	0.000E+00	4.233E-03	0.	20723.	79340.
-15.00-	0.000E+00	4.233E-03	0.	-17371.	79340.
-15.50	0.000E+00	1.947E-02	0.	-16102.	70973.
-16.00+	0.000E+00	3.951E-02	0.	-14847.	63236.
-16.00-	0.000E+00	3.951E-02	0.	-14847.	63236.
-16.50	0.000E+00	6.382E-02	0.	-13726.	56094.
-17.00	0.000E+00	9.193E-02	0.	-12644.	49503.
-17.50	0.000E+00	1.234E-01	0.	-11606.	43443.
-18.00	0.000E+00	1.578E-01	0.	-10617.	37889.
-18.50	0.000E+00	1.947E-01	0.	-9685.	32816.
-19.00	0.000E+00	2.339E-01	0.	-8813.	28195.
-19.50	0.000E+00	2.750E-01	0.	-8005.	23993.
-20.00	0.000E+00	3.177E-01	0.	-7265.	20177.
-20.50	0.000E+00	3.618E-01	0.	-6546.	16725.
-21.00	0.000E+00	4.070E-01	0.	-5844.	13629.
-21.50	0.000E+00	4.532E-01	0.	-5160.	10878.
-22.00	0.000E+00	5.000E-01	0.	-4495.	8465.
-22.50	0.000E+00	5.475E-01	0.	-3851.	6379.
-23.00	0.000E+00	5.954E-01	0.	-3228.	4611.
-23.50	0.000E+00	6.435E-01	0.	-2627.	3148.
-24.00	0.000E+00	6.920E-01	0.	-2051.	1979.
-24.50	0.000E+00	7.405E-01	0.	-1498.	1093.
-25.00	0.000E+00	7.891E-01	0.	-972.	477.
-25.50	0.000E+00	8.378E-01	0.	-472.	117.
-26.00	0.000E+00	8.864E-01	0.	0.	0.

Figure 45. (Sheet 3 of 6)

II.B.--SOIL PRESSURES

ELEVATION (FT)	<---------SOIL PRESSURES (PSF)--------> LEFTSIDE	RIGHTSIDE	NET
34.50	.00	.00	.00
34.00	.00	15.55	15.55
33.50	.00	31.10	31.10
33.00	.00	46.65	46.65
32.50	.00	62.20	62.20
32.00	.00	77.75	77.75
31.50	.00	93.30	93.30
31.00	.00	109.31	109.31
30.50	.00	126.73	126.73
30.00	.00	144.61	144.61
29.50	.00	162.93	162.93
29.00	.00	181.70	181.70
28.50	.00	200.92	200.92
28.00	.00	220.59	220.59
27.50	.00	240.69	240.69
27.00	.00	261.24	261.24
26.50	.00	282.23	282.23
26.00	.00	303.64	303.64
25.50	.00	325.48	325.48
25.00	.00	347.75	347.75
24.50	.00	370.42	370.42
24.00	.00	393.50	393.50
23.50	.00	416.96	416.96
23.00	.00	440.80	440.80
22.50	.00	465.01	465.01
22.00	.00	489.56	489.56
21.50	.00	514.44	514.44
21.00	.00	539.63	539.63
20.50	.00	565.09	565.09
20.00	.00	590.80	590.80
19.50	.00	616.74	616.74
19.00	.00	642.85	642.85
18.50	.00	669.12	669.12
18.00	.00	695.48	695.48
17.50	.00	721.90	721.90
17.00	.00	748.32	748.32
16.50	.00	774.68	774.68
16.00	.00	800.92	800.92
15.50	.00	826.97	826.97
15.00	.00	852.75	852.75
14.50+	.00	878.18	878.18
14.50-	.00	878.18	878.18
14.00	.00	903.20	903.20
13.50	.00	927.80	927.80

Figure 45. (Sheet 4 of 6)

13.00	.00	952.02	952.02
12.50	.00	975.90	975.90
12.00	.00	999.47	999.47
11.50	.00	1022.78	1022.78
11.00	.00	1045.87	1045.87
10.50	.00	1068.78	1068.78
10.00	.00	1091.56	1091.56
9.50	.00	1114.26	1114.26
9.00	.00	1136.92	1136.92
8.50	.00	1159.59	1159.59
8.00	.00	1182.33	1182.33
7.50	.00	1205.16	1205.16
7.00	.00	1228.14	1228.14
6.50	.00	1251.30	1251.30
6.00	.00	1274.69	1274.69
5.50+	.00	1298.34	1298.34
5.50-	.00	1226.45	1226.45
5.00	.00	1241.71	1241.71
4.50	.00	1257.45	1257.45
4.00	.00	1273.70	1273.70
3.50	.00	1290.47	1290.47
3.00	.00	1307.78	1307.78
2.50	.00	1325.61	1325.61
2.00	.00	1343.95	1343.95
1.50	.00	1362.76	1362.76
1.00	.00	1382.00	1382.00
.50	.00	1401.61	1401.61
.00	.00	1421.51	1421.51
-.50	.00	1441.60	1441.60
-1.00	.00	1461.78	1461.78
-1.50	.00	1481.90	1481.90
-2.00+	.00	1501.81	1501.81
-2.00-	.00	1561.62	1561.62
-2.50	.00	1582.18	1582.18
-3.00	.00	1602.52	1602.52
-3.50	.00	1622.76	1622.76
-4.00	.00	1643.01	1643.01
-4.50	.00	1663.36	1663.36
-5.00	.00	1683.90	1683.90
-5.50	.00	1704.70	1704.70
-6.00	.00	1725.79	1725.79
-6.50	.00	1747.22	1747.22
-7.00	.00	1769.00	1769.00
-7.50	.00	1791.11	1791.11
-8.00	.00	1813.54	1813.54
-8.50	.00	1836.24	1836.24
-9.00	.00	1859.12	1859.12
-9.50	.00	1882.11	1882.11

Figure 45. (Sheet 5 of 6)

-10.00	.00	1905.07	1905.07
-10.50	.00	1927.86	1927.86
-11.00	.00	1950.31	1950.31
-11.50	.00	1972.21	1972.21
-12.00	.00	1977.91	1977.91
-12.50	.00	2055.97	2055.97
-13.00	.00	2114.64	2114.64
-13.50	.00	2149.16	2149.16
-14.00	.00	2154.28	2154.28
-14.50	.00	2124.19	2124.19
-15.00+	.00	2078.99	2078.99
-15.00-	.00	2078.99	2078.99
-15.50	.00	2056.90	2056.90
-16.00+	.00	2022.22	2022.22
-16.00-	215.59	2022.22	1806.63
-16.50	239.33	1976.02	1736.69
-17.00	265.26	1919.27	1654.02
-17.50	293.48	1852.91	1559.44
-18.00	324.05	1777.80	1453.75
-18.50	357.02	1694.75	1337.73
-19.00	392.41	1604.52	1212.11
-19.50	430.24	1507.80	1077.57
-20.00	470.49	1455.14	984.65
-20.50	513.15	1465.38	952.23
-21.00	558.19	1475.63	917.43
-21.50	605.58	1485.87	880.29
-22.00	655.29	1496.11	840.83
-22.50	707.26	1506.36	799.10
-23.00	761.46	1516.60	755.15
-23.50	817.84	1526.85	709.01
-24.00	876.36	1537.09	660.74
-24.50	936.98	1547.34	610.35
-25.00	999.69	1557.58	557.89
-25.50	1064.44	1567.82	503.38
-26.00	1131.24	1578.07	446.83

Figure 45. (Sheet 6 of 6)

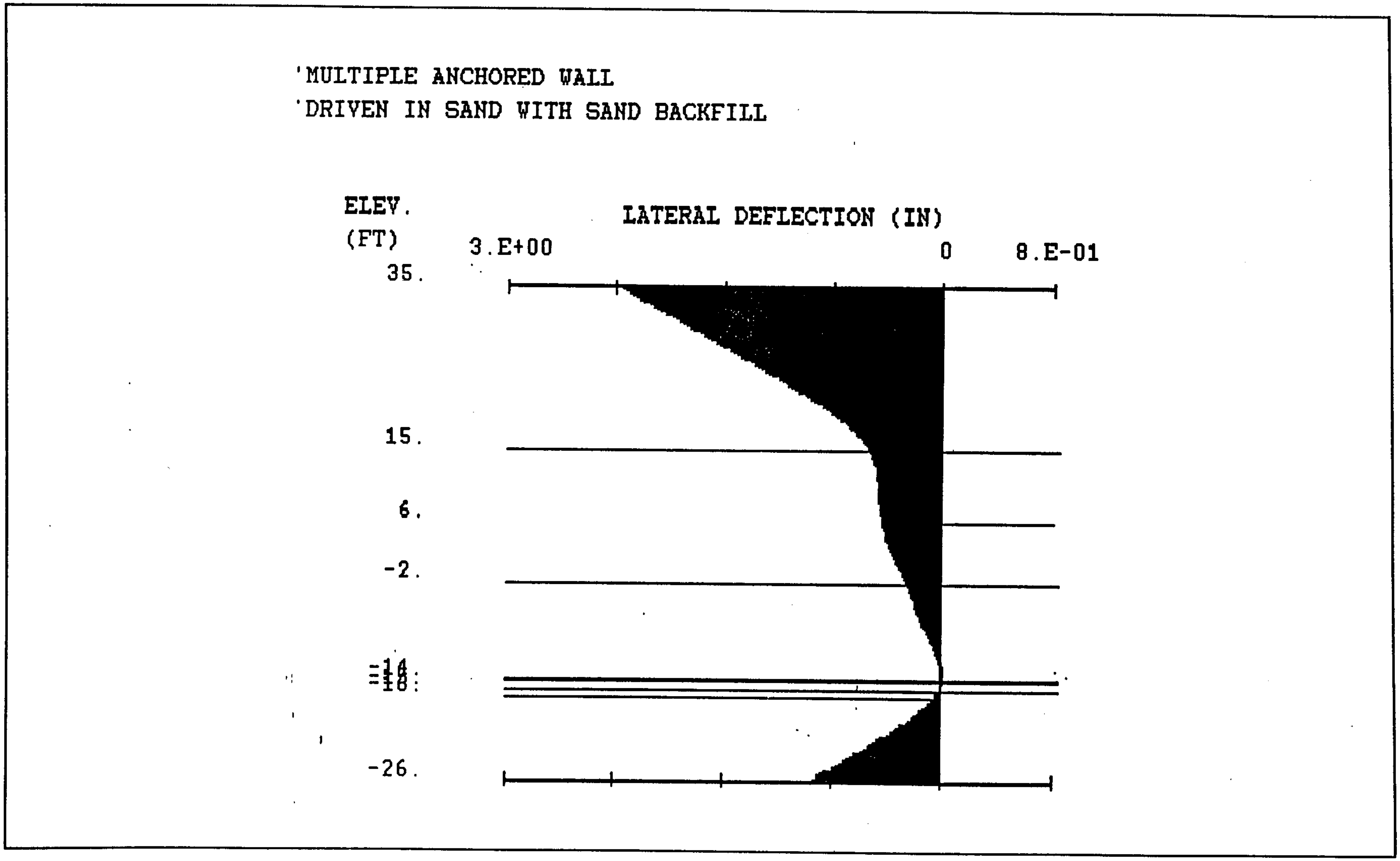

Figure 46. Lateral deflections for Example 3

Appendix A
Guide for Data Input

Source of Input

Input data may be supplied from a predefined data file or from the keyboard during execution. If data are supplied from the keyboard, prompting messages indicate the amount and character of data to be entered.

Data Editing

When all data for a problem have been entered, the user is offered the opportunity to revise any or all sections of the input data before a solution is attempted. When editing is performed during execution, each section must be entered in its entirety.

Input Data File Generation

After data have been entered from the keyboard, either initially or after editing, the user may direct the program to write the input data to a permanent file in input file format.

Data Format

All input data (whether supplied from the keyboard or from a file) are read free-field format and must conform to:

a. Data items must be separated by one or more blanks.

b. Integer numbers may not contain a decimal point.

c. Real numbers may be of the form

±xxxx, ±xx.xx, or ±xx.xxE±ee

d. User responses to all requests for control by the program for alphanumeric input may be abbreviated by the first letter of the indicated word response, e.g.,

ENTER 'YES' OR 'NO' — respond Y or N

ENTER 'CONTINUE' OR 'END' — respond C or E

Sections of Input

Input data are divided into the following sections:

I. HEADING (Required)

II. WALL DATA (Required)

III. ANCHOR DATA (Optional)

IV. SOIL SURFACE DATA (required)

V. SOIL PROFILE DATA (Required)

VI. INTERACTION DATA (Optional)

VII. WATER DATA (Optional)

VIII. VERTICAL SURCHARGE DATA (Optional)

IX. HORIZONTAL LOAD DATA (Optional)

X. TERMINATION (Required)

Units

The program expects data to be provided in units of inches, feet, or pounds as noted in the guide that follows. No provision is made for conversion to other systems of units by the program.

Predefined Data File

In addition to the general format requirements given in this appendix, the following items pertain to a predefined data file and to the input data description which follows:

a. Each line must commence with a nonzero, positive line number, denoted LN.

b. A line of input may require both alphanumeric and numeric data items. Alphanumeric data items are enclosed in single quotes in the following paragraphs.

c. A line of input data may require a keyword. The acceptable abbreviation for the keyword is indicated by underlined capital letters, e.g., the acceptable abbreviations for the keyword 'SUrface' is 'SU'.

d. Lower case words in single quotes indicate that a choice of keywords defined follows.

e. Items designated by upper case letters and numbers without quotes indicate numeric data values. Numeric data values are either real or integer according to standard FORTRAN default variable naming conventions.

f. Data items enclosed in brackets [ ] may not be required. Data items enclosed in braces { } indicate that a special note follows.

g. Input data are divided into the sections discussed in this appendix, "Sections of Input." Except for the heading, each section consists of a header-line and one or more data lines.

h. Comment lines may be inserted in the input file by enclosing the line, following the line number, in parentheses. Comment lines are ignored, e.g.,

1234 (THIS LINE IS IGNORED)

General Discussion of Input Data

Each data section contains a descriptor {'side'} to indicate the side of the system to which the data apply. For symmetric effects , {'side'} = 'Both', the data section is entered only once, and symmetric data are applied to both sides automatically. For unsymmetric conditions, the description for the rightside[1] (if present) must be entered first and must be immediately followed by the description for the leftside[1] (if present).

"Rightside" and "Leftside" descriptions must be supplied either explicitly or implicitly (i.e., {'side'} = 'Both') for surface points and soil profile data sections. Other data may be applied for the rightside, leftside, both sides, or may be omitted entirely.

Input Description

HEADING — One (1) to four (4) lines

a. Line contents

LN 'heading'

b. Definition

'heading' = any alphanumeric information up to 70 characters including LN and any embedded blanks; the first nonblank character following LN must be a single quote (').

WALL SEGMENT DATA — Two (2) to eleven (11) lines; one line for each wall segment.

a. Line contents

LN 'WALl' ELSEG [WALLE WALLI WALLA]

b. Definitions

'WALl' = section title.

ELSEG = elevation (FT) at top of segment.

[WALLE] = modulus of elasticity (PSI) of segment.

[WALLI] = moment of inertia ($IN.^4$) per foot of wall.

[WALLA] = cross-sectional area ($IN.^2$) per foot of wall.

---

1 The terms leftside and rightside are used in the one-word form in this appendix to be consistent with their use in the Computer Program CWALSSI.

c. Discussion

(1) The wall may be composed of one (1) to ten (1) prismatic segments.

(2) The segment data must begin with the topmost segment and proceed sequentially downward.

(3) The elevation on the last line is assumed to be the bottom of the wall (ELBOT in subsequent discussions).

(4) Omit WALLE, WALLI, and WALLA on the last line.

ANCHOR DATA — zero (0) or one (1) to ten (10) lines; one line for each anchor; entire section may be omitted.

a. Line contents

LN 'Anchor' ELANCH {'type'} [FYTENS FPRES FYCOMP ANCSTF [ANSLO]]

b. Definitions

'Anchor' = section title.

ELANCH = elevation (FT) of anchor attachment at wall.

{'type'} = 'Rigid' for no translation at anchor attachment.

= 'Flexible' if anchor force is proportional to attachment point displacement.

[FYTENS] = ultimate anchor force (LB) in tension.

[FPRES] = anchor force (LB) at zero displacement of attachment point (i.e., prestress force).

[FYCOMP] = ultimate anchor force (LB) in compression.

[ANCSTF] = anchor stiffness (LB/IN.).

[ANCSLO] = anchor slope (FT/FT); assumed to be zero if omitted.

c. Discussion

(1) Anchors are assumed to extend to the right away from the wall.

(2) Anchor elevations may be in any order.

(3) A positive anchor slope is downward away from the wall. ANCSLO is the drop (FT) per foot of horizontal projection of the anchor.

(4) See Chapter 4, pages 21 and 22, for further definitions of anchor properties.

SOIL SURFACE DATA — One(1) or more lines

a. Line contents

LN '<u>SU</u>rface' {'side'} NSUR DSUR(1) ELSUR(1) [... DSUR(NSUR) ELSUR(NSUR)]

b. Definitions

'<u>SU</u>rface' = section title

{'side'} = '<u>L</u>eftside', '<u>R</u>ightside', or '<u>B</u>oth'.

NSUR = number of surface points (1 to 21) on this {'side'}.

DSUR(i) = horizontal distance (FT) from wall to i^{th} surface point.

ELSUR(i) = elevation (FT) at i^{th} surface point.

c. Discussion

(1) If identical soil surfaces exist on each side of the wall, i.e., {'side'} = '<u>B</u>oth', enter data for rightside. The program will generate a mirror image for the leftside.

(2) At least one surface point must be provided for each side. Up to 21 surface points are permitted. Pairs of DSUR(i) and ELSUR(i) may be continued on subsequent lines following a line number.

(3) If DSUR(1) is greater than zero, a horizontal surface at ELSUR(1) is assumed from the wall to a distance DSUR(1).

(4) ELSUR(1) must be less than or equal to ELSEG(1) and greater than ELBOT.

(5) If more than one surface point is provided, a broken surface is assumed and limiting soil pressures will be calculated by a wedge method. Distances and elevations must commence for the surface point nearest to the wall and progress outward.

(6) Consecutive surface points may not describe a vertical line.

(7) If different surface conditions exist on each side, surface data must be entered twice, first for the 'Rightside' and then for the 'Leftside'.

(8) The surface is assumed to extend horizontally ad infinitum at the elevation of the last point entered for each side.

SOIL PROFILE DATA — Two (2) or more lines

a. Control — One (1) line

(1) Line contents

LN 'SOil' {'side'} {'type'} NLAY

(2) Definitions

'SOil' = section title.

{'side'} = 'Rightside', 'Leftside', or 'Both'.

{'type'} = 'Strengths' if internal friction angles, soil cohesions, wall friction angles, and adhesions are provided. Required if a broken surface exists on this {'side'}.

= 'Coefficients' if active, passive, and at-rest pressure coefficients are provided. Not allowed if a broken surface exists on this {'side'}.

NLAY = number of soil layers (1 to 15) on this {'side'}.

b. Soil layer data for {'type'} = 'Strengths' NLAY lines; one line for each layer.

(1) Line contents

LN GAMSAT GAMMST PHI DELTA ADH SKA SKP [ELLAYB [SLOBOT]]

(2) Definitions

GAMSAT = saturated unit weight (PCF) of soil; program subtracts unit weight of water from GAMSAT to obtain effective unit weight of submerged soil.

GAMMST = unit weight (PCF) of soil above water.

PHI = angle of internal friction (DEG).

C = cohesion (PSF).

DELTA = angle of wall friction (DEG).

ADH = unit wall/soil adhesion (PSF).

SKA = soil stiffness coefficient for active soil pressure.

SKP = soil stiffness coefficient for passive soil pressure.

[ELLAYB] = elevation (FT) at intersection of bottom of layer with wall; omit if last layer.

[SLOBOT] =slope (FT/FT) of bottom of layer; interpreted as rise per foot of horizontal projection; positive if layer boundary slopes upward; assumed to be zero if omitted; omit if last layer.

(3) Discussion

(*a*) At least one soil layer on each side of the wall is required. Up to 15 layers on each side of the wall are permitted.

(*b*) Soil layer data must commence with the topmost layer and proceed sequentially downward.

(*c*) The last soil layer on each side is assumed to extend ad infinitum downward.

(*d*) Either PHI or C must be greater than zero for each soil layer.

(*e*) DELTA must be less than PHI.

(*f*) ADH must be less than C.

(*g*) Bottom slopes of adjacent layers boundaries must not intersect within the soil mass.

(*h*) Layer bottom elevations must conform to

ELLAYB(1) < ELSEG(1)

ELLAYB(1) < ELSUR(1)

ELLAYB(i) < ELLAYB(i-1)

(*i*) The program will generate identical soil layer descriptions "for both sides of the wall if {'side'} - 'Both'."

(*j*) If different soil profiles exist on each side of the wall, soil layer data must be entered twice, first for the 'Rightside' and then for the 'Leftside'.

(*k*) If any soil layer has a nonzero boundary slope or a nonzero adhesion, soil active and passive pressures on that side will be calculated by a wedge method.

c. Soil layer data for {'type'} = 'Coefficients' — NLAY lines; one (1) line for each soil layer

(1) Line contents

LN GAMSAT GAMMST AK PK RK SKA SKP {'type'} [ELLAYB]

(2) Definitions

GAMSAT = saturated unit weight (PCF) of soil; program subtracts unit weight of water from GAMSAT to obtain effective unit weight of submerged soil.

GAMMST = unit weight (PCF) of soil above water.

AK = active soil pressure coefficient.

PK = passive soil pressure coefficient.

RK = at-rest soil pressure coefficient.

SKA = soil stiffness coefficient (PCI) for active soil pressure.

SKP = soil stiffness coefficient (PCI) for passive soil pressure.

{'type'} = 'Sand' or 'Clay'.

[ELLAYB] = elevation (FT) at intersection of bottom of layer with wall; omit if last layer.

(3) Discussion

(*a*) At least one soil layer on each side of the wall is required. Up to 15 layers on each side of the wall are permitted.

(*b*) Soil layer data must commence with the topmost layer and proceed sequentially downward.

(*c*) The last soil layer on each side is assumed to extend ad infinitum downward.

(*d*) AK, PK, and RK must all be nonzero and conform to AK RK PK

(*e*) Layer bottom elevations must conform to

ELLAYB(1) < ELSEG(1)

ELLAYB(1) < ELSUR(1)

ELLAYB(i) < ELLAYB(i-1)

(*f*) The program will generate identical soil layer descriptions "for both sides of the wall if {'side'} - 'Both'."

(*g*) If different soil profiles exist on each side of the wall, soil layer data must be entered twice, first for the 'Rightside' and then for the 'Leftside'.

(*h*) For {'type'} = 'Sand', soil stiffness is assumed to increase linearly with depth; for {'type'} = 'Clay', soil stiffness is assumed to be constant with depth (Chapter 4, pages 20 and 21).

INTERACTION DISTANCE DATA — Zero (0) or one (1) to fifteen (15) lines; entire section may be omitted.

a. Line contents

LN 'Interaction' {'side'} NZONES ELDACT(1) DACT(1)
[... ELDACT(NZONES) DACT(NZONES)]

b. Definitions

'Interaction' = section title.

{'side'} = 'Rightside', 'Leftside', or 'Both'.

NZONES = number (1 to 15) of interaction zones provided.

ELDACT(i) = elevation (FT) at top of i^{th} zone.

DACT(i) = interaction distance (FT) for i^{th} zone.

c. Discussion

(1) If Interaction zone data are omitted, interaction distances are estimated by the program. The initial estimate is that indicated in Figure 7, Chapter 4. Following the solution for the initial estimate, a second solution is performed in which the interaction distances are taken as the distances between reversals in deflection along the wall.

(2) Interaction zone data must commence with the topmost zone and proceed sequentially downward.

(3) ELDACT(1) must be at or above the elevation of the first surface point (ELSUR(1) for this {'side'}.

(4) ELDACT(i) must be less than ELDACT(i-1).

(5) DACT(i) must be greater than zero.

(6) The last zone entered is assumed to extend ad infinitum downward.

(7) If interaction zone data are provided, data must be available for both sides of the wall. If different interaction zone data exist on each side of the wall, interaction zone data must be entered twice, first for the 'Rightside' and then for the 'Leftside'.

WATER DATA — Zero (0) or one (1) or more lines; entire section may be omitted; choose a or b of the following:

a. Water elevations provided

(1) Line contents

LN 'WATer Elevations' GAMWAT ELWATR ELWATL [ELSEEP {seep spec}]

(2) Definitions

'WATer Elevations' = section title.

GAMWAT = unit weight of water (PCF).

ELWATR = elevation (FT) of water surface on rightside.

ELWATL = elevation (FT) of water surface on leftside.

[ELSEEP] = elevation (FT) on rightside at which seepage commences; omit if seepage is not to be considered; omit if ELWATR ≤ ELWATL.

[{seep spec}] = seepage gradient SEEP (FT/FT); 0 < SEEP < 1; omit if ELSEEP omitted.

= 'Automatic' if seepage gradient is to be determined by the program to result in zero net water pressure at bottom of wall; omit if ELSEEP omitted.

(3) Discussion

(*a*) Effective soil unit weight for submerged soil is calculated by the program by subtracting the effective weight of water from the saturated unit weight of the soil.

(*b*) Seepage effects cannot be included unless ELWATR > ELWATL.

(*c*) ELSEEP must conform to the following:

ELSEEP ≤ Min (ELWATR, ELSUR(rightside 1))

ELSEEP ≥ Min (ELWATL, ELSUR(leftside 1)).

(*d*) If {seep spec} = 'Automatic' is specified, the seepage gradient is determined by the program. The gradient selected will produce zero net water pressure at the bottom of the wall or will be a maximum value that ensures that the submerged unit weight of the leftside soil remains greater than zero.

b. Net water pressure specified — one (1) or more lines

(1) Line contents

LN 'WATer Pressure' NWPR ELWPR(1) WPR(1) ELWPR(2) WPR(2) [... ELWPR(NWPR) WPR(NWPR)]

(2) Definitions

'WATer Pressure' = section title.

NWPR = number (2 to 21) of points on water pressure distribution.

ELWPR(i) = elevation (FT) of i^{th} pressure point

WPR(i) = net water pressure at i^{th} pressure point, positive to the left.

(3) Discussion

(*a*) At least two pressure points must be provided. A maximum of 21 points is permitted. Pairs of ELWPR(i) and WPR(i) may be continued on subsequent lines following a line number.

(*b*) Elevations must begin at the uppermost point and proceed sequentially downward with:

ELWPR(i) ≤ ELSEG(1)

ELWPR(i) ≤ ELWPR(i-1)

(*c*) Specified water pressures do not alter soil pressures. GAMMST is used for the effective weight of the soil at all elevations on both sides of the wall.

VERTICAL LOADS ON SURFACE — Zero (0) or one (1) or more lines; entire section may be omitted.

a. Line loads — zero (0) or one (1) or more lines

(1) Line contents

LN 'Vertical Line' {'side'} NVL DL(1) QL(1) [... DL(NVL) QL(NVL)]

(2) Definitions

'Vertical Line' = subsection title.

{'side'} = 'Rightside', 'Leftside', or 'Both'.

NVL =number (1 to 21) of line loads on this {'side'}.

DL(i) = Distance (FT) from the wall to the i^{th} line load.

QL(i) = magnitude (PLF) of i^{th} line load; positive downward.

(3) Discussion

(*a*) If {'side'} = 'Both', enter data for the rightside surface. Mirror image line loads will be generated for the leftside.

(*b*) Up to 21 line loads may be applied to the surface on each side.

(*c*) Pairs of DL(i) and QL(i) may be continued on subsequent lines following a line number.

(*d*) DL(i) must be greater than zero.

(*e*) QL(i) must be greater than zero (i.e., upward loads are not permitted).

b. Distributed loads — zero (0) or one (1) or more lines; only one of the following distributed load types may be applied on either side of the wall.

(1) Uniform load — zero (0) or one (1) line

(*a*) Line contents

LN 'Vertical Uniform' {'side'} QU

(*b*) Definitions

'Vertical Uniform' = subsection title.

{'side'} = 'Rightside', 'Leftside', or 'Both'.

QU = magnitude (PSF) of uniform load, positive downward.

(c) Discussion

- A uniform load is interpreted as acting on the horizontal projection of a sloping surface.
- The uniform load extends to infinity away from the wall.
- If {'side'} = 'Both', identical uniform loads are applied to the surface on each side.
- QU must be greater than zero (i.e., upward loads are not permitted).

(2) Strip loads — zero (0) or one (1) or more lines

(*a*) Line contents

LN 'Vertical Strip' {'side'} NVS DS1(1) DS2(1) QS(1) ...[DS1(NVS) DS2(NVS) QS(NVS)] (*b*) Definitions

'Vertical Strip' = subsection title.

{'side'} = 'Rightside', 'Leftside', or 'Both'.

NVS = number (1 to 21) of strip loads on this side.

DS1(i) = distance (FT) from wall to beginning of i^{th} strip load.

DS2(i) = distance (FT) from wall to end of i^{th} strip load.

QS(i) = magnitude (PSF) of i^{th} strip load; positive downward.

(*c*) Discussion

- A strip load is interpreted as acting on the horizontal projection of a sloping surface.

- Up to 21 strip loads may be applied to the surface on each side of the wall. Triads of DS1(i), DS2(i), and QS(i) may be continued on subsequent lines following a line number.

- If {'side'} = 'Both', enter data for rightside and mirror image loads are generated for the leftside.

- QS(i) must be greater than zero (i.e., upward loads are not permitted.)

- Distances must conform to:

  DS1(i) ≥ zero

  DS2(i) > DS1(i).

(3) Ramp loads — zero (0) or one (1) line

(*a*) Line contents

LN 'Vertical Ramp' {'side'} DR1 DR2 QR

(*b*) Definitions

'Vertical Ramp' = subsection title.

{'side'} = 'Rightside', 'Leftside', or 'Both'.

DR1 = distance (FT) from wall to beginning of ramp load.

DR2 = Distance (FT) to end of ramp.

QR = magnitude (PSF) of uniform extension of ramp load, positive downward.

(*c*) Discussion

- A ramp load is interpreted as acting on the horizontal projection of a sloping surface.
- Only one ramp load is permitted on each side of the wall.
- If {'side'} = 'Both', enter data for the rightside and a mirror image ramp load will be generated for the leftside.
- Distances must conform to:

  DR1 ≥ zero

  DR2 > DR1.
- QR must be greater than zero (i.e., upward loads are not permitted).

(4) Triangular loads — zero (0) or one (1) or more lines

(*a*) Line contents

LN 'Vertical Triangular' {'side'} NVT DT1(1) DT2(1) DT3(1) QT(1) ...[DT1(NVT) DT2(NVT) DT3(NVT) QT(NVT)]

(*b*) Definitions

'Vertical Triangular' = subsection title.

{'side'} = 'Rightside', 'Leftside', or 'Both'.

DT1(i) = distance (FT) to beginning of i^{th} triangular load.

DT2(i) = distance (FT) to peak of i^{th} triangular load.

DT3(i) = distance (FT) to end of i^{th} triangular load.

QT(i) = magnitude (PSF) at peak of i^{th} triangular load, positive downward.

(*c*) Discussion

- A triangular load is interpreted as acting on the horizontal projection of a sloping surface.

- Up to 21 triangular loads may be applied to the surface on each side of the wall. Quartets of DT1(i), DT2(i), DT3(i), and QT(i) may be entered on subsequent lines following a line number.

- If {'side'} = 'Both', enter data for rightside and mirror loads will be generated for the leftside.

- Distances must conform to:

  DT1(i) ≥ zero

  DT2(i) > DT1(i) if DT3(i) = DT2(i)

  DT3(i) > DT2(i) if DT2(i) = DT1(i)

  DT3(i) > DT1(i).

- QT(i) must be greater than zero (i.e., upward loads are not permitted).

(5) Variable distributed loads — zero (0) or one (1) or more lines

(*a*) Line contents

LN 'Vertical Variable' {'side'} NVV DV(1) QV(1) DV(2) QV(2) [... DV(NVV) QV(NVV)]

(*b*) Definitions

'Vertical Variable' = subsection title.

{'side'} = 'Rightside', 'Leftside', or 'Both'.

NVV = number (2 to 21) of points on variable load distribution.

DV(i) = distance (FT) from wall to i^{th} point on distribution.

QV(i) = magnitude (PSF) of distributed load at i^{th} point on distribution.

(*c*) Discussion

- A variable load distribution is interpreted as acting on the horizontal projection of a sloping surface.

- At least two points are required, up to 21 points are permitted.

- If {'side'} = 'Both', enter data for the rightside and a mirror image distribution will be generated for the leftside.

- Distances must conform to:

  DV(1) ≥ zero

  DV(i) > DV(i-1).

- QV(i) must be greater than or equal to zero (i.e., upward loads are not permitted).

HORIZONTAL LOADS — zero (0) or one (1) or more lines, entire section may be omitted

a. Horizontal line loads — zero (0) or one (1) or more lines

(1) Line contents

LN 'Horizontal Line' NHL ELL(1) HL(1) ... [ELL(NHL) HL(NHL)]

(2) Definitions

'Horizontal Line' = subsection title.

NHL = number (1 to 21) of horizontal line loads.

ELL(i) = elevation (FT) of i^{th} horizontal line load.

HL(i) = magnitude (PLF) of i^{th} horizontal line load, positive to the left.

(3) Discussion

(*a*) Up to 21 horizontal line loads may be applied to the wall.

(*b*) Pairs of ELL(i) and HL(i) may be entered on subsequent lines following a line number.

(*c*) ELL(i) must be less than or equal to ELSEG(1).

b. Horizontal distributed loads — zero (0) or one (1) or more lines

(1) Line contents

LN 'Horizontal Distributed' NHD ELD(1) HD(1) ELD(2) HD(2) [... ELD(NHD) HD(NHD)]

(2) Definitions

'Horizontal Distributed' = subsection title.

NHD = number (2 to 21) of points on horizontal load distribution.

ELD(i) = elevation (FT) at i^{th} point on distribution.

HD(i) = magnitude (PSF) of distributed load at i^{th} point on distribution, positive to the left.

(3) Discussion

(*a*) At least two points on the distribution are required, up to 21 points are permitted.

(*b*) Pairs of ELD(i) and HD(i) may be entered on subsequent lines following a line number.

(*c*) Points on the distribution must conform to:

$ELD(1) \leq ELSEG(1)$

$ELD(i) < ELD(i-1)$.

c. Horizontal earthquake acceleration — zero (0) or one (1) line

(1) Line contents

LN 'Horizontal Acceleration' EQACC

(2) Definitions

'Horizontal Acceleration' = subsection title.

EQACC = earthquake acceleration (G's), positive, $0.0 \leq EQACC < 1.0$.

(3) Discussion

(*a*) Earthquake acceleration is assumed to increase horizontal soil and water loads on the rightside of the wall and to decrease horizontal soil and water loads on the leftside.

(*b*) If a water pressure distribution has been provided, earthquake effects on water pressures are ignored.

TERMINATION — one (1) line

LN 'Finished'

Abbreviated Input Guide

HEADING—one (1) to four (4) lines

Ln 'heading'

[LN 'heading']

[LN 'heading']

[LN 'heading']

WALL SEGMENT DATA — two (2) to eleven (11) lines

LN 'WALl' ELSEG [WALLE WALLI WALLA]

ANCHOR DATA — zero (0) or one (1) to ten (10) lines

LN 'Anchor' ELANCH {'Rigid' / 'Flexible'} [FYTENS FPRES

FYCOMP ANCSTF [ANCSLO]]

SURFACE DATA — one (1) or more lines

LN 'SUrface' {'side'} NSUR DSUR(1) ELSUR(1)...[
DSUR(NSUR) ELSUR(NSUR)]

SOIL DATA — two (2) or more lines

a. Control — one (1) line

LN 'SOil' {'side'} {'Strengths' / 'Coefficients'} NLAY *b.* Layer data — NLAY lines

(1) Data lines for 'Strengths'

LN GAMSAT GAMMST PHI C DELTA ADH SKA SKP [ELLAYB [SLOBOT]]

(2) Data lines for 'Coefficients'

LN GAMSAT GAMMST AK PK RK SKA SKP { 'Sand' / 'Clay' } [ELLAYB]

INTERACTION DISTANCE DATA — zero (0) or one (1) to fifteen (15) lines

LN 'Interaction' {'side'} NZONES ELDACT(1) DACT(1) [... ELDACT(NZONES) DACT(NZONES)]

WATER DATA — zero (0) or one (1) or more lines

a. Water elevation data

LN 'WATer Elevations' GAMWAT ELWATR ELWATL [ELSEEP { SEEP / 'Automatic' }]

b. Water pressure data

LN 'WATer Pressures' NWPR ELWPR(1) WPR(1) ELWPR(2) WPR(2) [... ELWPR(NWPR) WPR(NWPR)]

VERTICAL LOAD DATA

a. Line loads — zero (0) or one (1) or more lines

LN 'Vertical Line' {'side'} NVL DL(1) QL(1) [... DL(NVL) QL(NVL)]

b. Uniform load — zero (0) to two (2) lines

LN 'Vertical Uniform' {'side'} QU

c. Strip loads — zero (0) or one (1) or more lines

LN 'Vertical Strip' {'side'} NVS DS1(1) DS2(1) QS(1)[... DS1(NVS) DS2(NVS) QS(NVS)] *d.* Ramp loads — zero (0) to two (2) lines

LN 'Vertical Ramp' {'side'} DR1 DR2 QR

e. Triangular loads — zero (0) or one (1) or more lines

LN 'Vertical Triangular' {'side'} NVT DT1(1) DT2(1) DT3(1) QT(1)[... DT1(NVT) DT2(NVT) DT3(NVT) QT(NVT)]

f. Variable loads — zero (0) or one (1) or more lines

LN 'Vertical Variable' {'side'} NVV DV(1) QV(1) DV(2) QV(2) [... DV(NVV) QV(NVV)]

HORIZONTAL LOAD DATA

a. Line loads — zero (0) or one (1) or more lines

LN 'Horizontal Line' NHL ELL(1) HL(1) [... ELL(NHL) L(NHL)]

b. Distributed loads — zero (0) or one (1) or more lines

LN 'Horizontal Distributed' NHD ELD(1) HD(1) [... ELD(NHD) HD(NHD)]

c. Earthquake acceleration — zero (0) or one (1) line

LN 'Horizontal Acceleration' EQACC

TERMINATION — one (1) line

LN 'Finish'

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13. ABSTRACT *(Maximum 200 words)*

This report describes the computer program CWALSSI which performs soil-structure interaction (SSI) analysis of sheet-pile walls using the Winkler assumption for representing the soil as nonlinear springs. The program uses classical soil mechanics procedures for determining the limiting active, at-rest, and passive soil pressures. Seepage effects are included in a simplified manner in the program. CWALSSI was developed from specifications provided by the Computer-Aided Structural Engineering (CASE) Task Group on Sheet-Pile Structures.

CWALSSI is a companion to Program CWALSHT (CORPS Program X0031) which performs design of anchored or cantilever sheet-pile walls by classical methods. CWALSSI performs no design functions. Design parameters such as depth of penetration, the sheet-pile section, and the characteristics of anchors (if any) must be supplied as input to CWALSSI.

The remainder of this report is organized as follows: Chapter 2 describes the general sheet-pile retaining structure and the soil system to be analyzed by the program. Chapter 3 describes the procedures employed in the program for calculating the limiting earth pressures, water pressures due to unbalanced hydrostatic head, and the effects of surcharge loads on the soil surface. Chapter 4 outlines the methods for converting the surrounding soil and anchors to nonlinear springs. Chapter 5 summarizes the

(Continued)

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11. (Concluded).

This User's Manual is available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. The computer program is available to U.S. Government employees and can be obtained through the Engineering Computer Program Library at the U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

13. (Concluded).

one-dimensional (1-D) finite element model (FEM) of the wall/soil system. Chapter 6 describes the computer program and attendant sign conventions. Chapter 7 presents example solutions obtained with the program.

The program has been checked within reasonable limits to assure that the results produced by the program are accurate within the limitations of the procedures employed. However, there may exist unusual situations not anticipated and thus may cause the program to produce questionable results. The author assumes no responsibility for the performance of any structure designed on the basis of results produced by the program.

WATERWAYS EXPERIMENT STATION REPORTS PUBLISHED UNDER THE COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT

	Title	Date
Technical Report K-78-1	List of Computer Programs for Computer-Aided Structural Engineering	Feb 1978
Instruction Report O-79-2	User's Guide: Computer Program with Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)	Mar 1979
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Instruction Report K-80-3	A Three-Dimensional Finite Element Data Edit Program	Mar 1980
Instruction Report K-80-4	A Three-Dimensional Stability Analysis/Design Program (3DSAD)	
	Report 1: General Geometry Module	Jun 1980
	Report 3: General Analysis Module (CGAM)	Jun 1982
	Report 4: Special-Purpose Modules for Dams (CDAMS)	Aug 1983
Instruction Report K-80-6	Basic User's Guide: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Instruction Report K-80-7	User's Reference Manual: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
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Instruction Report K-81-2	User's Guide: Computer Program for Design and Analysis of Sheet Pile Walls by Classical Methods (CSHTWAL)	
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	Report 2: Interactive Graphics Options	Mar 1981
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Instruction Report K-81-4	User's Guide: Computer Program for Design and Analysis of Cast-in-Place Tunnel Linings (NEWTUN)	Mar 1981
Instruction Report K-81-6	User's Guide: Computer Program for Optimum Nonlinear Dynamic Design of Reinforced Concrete Slabs Under Blast Loading (CBARCS)	Mar 1981
Instruction Report K-81-7	User's Guide: Computer Program for Design or Investigation of Orthogonal Culverts (CORTCUL)	Mar 1981
Instruction Report K-81-9	User's Guide: Computer Program for Three-Dimensional Analysis of Building Systems (CTABS80)	Aug 1981
Technical Report K-81-2	Theoretical Basis for CTABS80: A Computer Program for Three-Dimensional Analysis of Building Systems	Sep 1981
Instruction Report K-82-6	User's Guide: Computer Program for Analysis of Beam-Column Structures with Nonlinear Supports (CBEAMC)	Jun 1982

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Instruction Report K-83-1	User's Guide: Computer Program with Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)	Jan 1983
Instruction Report K-83-2	User's Guide: Computer Program for Generation of Engineering Geometry (SKETCH)	Jun 1983
Instruction Report K-83-5	User's Guide: Computer Program to Calculate Shear, Moment, and Thrust (CSMT) from Stress Results of a Two-Dimensional Finite Element Analysis	Jul 1983
Technical Report K-83-1	Basic Pile Group Behavior	Sep 1983
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Instruction Report K-84-2	User's Guide: Computer Program for Optimum Dynamic Design of Nonlinear Metal Plates Under Blast Loading (CSDOOR)	Jan 1984
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Instruction Report ITL-87-1	User's Guide: Computer Program for Two-Dimensional Analysis of U-Frame Structures (CUFRAM)	Apr 1987
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Technical Report ITL-87-4	Finite Element Studies of a Horizontally Framed Miter Gate Report 1: Initial and Refined Finite Element Models (Phases A, B, and C), Volumes I and II Report 2: Simplified Frame Model (Phase D) Report 3: Alternate Configuration Miter Gate Finite Element Studies–Open Section Report 4: Alternate Configuration Miter Gate Finite Element Studies–Closed Sections Report 5: Alternate Configuration Miter Gate Finite Element Studies–Additional Closed Sections Report 6: Elastic Buckling of Girders in Horizontally Framed Miter Gates Report 7: Application and Summary	Aug 1987
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	Volume A: Program Criteria and Documentation	
	Volume B: User's Guide for Basins	
	Volume C: User's Guide for Channels	
Instruction Report ITL-90-6	User's Guide: Computer Program for Two-Dimensional Analysis of U-Frame or W-Frame Structures (CWFRAM)	Sep 1990
Instruction Report ITL-90-2	User's Guide: Pile Group–Concrete Pile Analysis Program (CPGC) Preprocessor to CPGA Program	Jun 1990
Technical Report ITL-91-3	Application of Finite Element, Grid Generation, and Scientific Visualization Techniques to 2-D and 3-D Seepage and Groundwater Modeling	Sep 1990
Instruction Report ITL-91-1	User's Guide: Computer Program for Design and Analysis of Sheet-Pile Walls by Classical Methods (CWALSHT) Including Rowe's Moment Reduction	Oct 1991
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	Report 3: Scheme C	Jun 1992
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	Title	Date
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Technical Report ITL-92-7	Refined Stress Analysis of Melvin Price Locks and Dam	Sep 1992
Contract Report ITL-92-2	Knowledge-Based Expert System for Selection and Design of Retaining Structures	Sep 1992
Contract Report ITL-92-3	Evaluation of Thermal and Incremental Construction Effects for Monoliths AL-3 and AL-5 of the Melvin Price Locks and Dam	Sep 1992
Instruction Report GL-87-1	User's Guide: UTEXAS3 Slope-Stability Package; Volume IV, User's Manual	Nov 1992
Technical Report ITL-92-11	The Seismic Design of Waterfront Retaining Structures	Nov 1992
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	Report 1: Development of Computer Modeling Techniques for Miter Lock Gates	Nov 1992
	Report 2: Field Test and Analysis Correlation at John Hollis Bankhead Lock and Dam	Dec 1992
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Instruction Report GL-87-1	User's Guide: UTEXAS3 Slope-Stability Package; Volume III, Example Problems	Dec 1992
Technical Report ITL-93-1	Theoretical Manual for Analysis of Arch Dams	Jul 1993
Technical Report ITL-93-2	Steel Structures for Civil Works, General Considerations for Design and Rehabilitation	Aug 1993
Technical Report ITL-93-3	Soil-Structure Interaction Study of Red River Lock and Dam No. 1 Subjected to Sediment Loading	Sep 1993
Instruction Report ITL-93-3	User's Manual—ADAP, Graphics-Based Dam Analysis Program	Aug 1993
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	Title	Date
Instruction Report ITL-94-5	User's Guide: Computer Program for Winkler Soil-Structure Interaction Analysis of Sheet-Pile Walls (CWALSSI)	Nov 1994