TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-85/52+353-2		

4. Title and Subtitle	5. Report Date
EXAMPLE PROBLEMS FOR SLOPE STABILITY COMPUTATIONS WITH THE COMPUTER PROGRAM UTEXAS	November 1984
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Stephen G. Wright and James D. Roecker	Research Report 353-2
9. Performing Organization Name and Address	10. Work Unit No.
Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075	11. Contract or Grant No. Research Study 3-8-83-353
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	Interim
	14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration

Research Study Title: "Stability Evaluation for Earth Slopes"

16. Abstract

A series of seven example slope stability problems for the computer program, UTEXAS, is presented. The example problems consist of (1) a simple slope, (2) an embankment on a very strong foundation, (3) an embankment on a relatively weak foundation, (4) an excavated slope, (5) an embankment on a foundation containing a thin seam of weak material, (6) a natural slope, and (7) a partially submerged slope. A description of each example problem, a listing of the input data for the computer program, and the results of the computations are presented and discussed for each example problem. These examples are intended to serve both as a guide for input of data to the computer program, UTEXAS, and to illustrate a variety of typical slope stability problems.

17. Key Words	18. Distribution Statement
slope, stability, embankment, foundation, excavated, tension cracks, surcharge loads, ground water	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	144	

Form DOT F 1700.7 (8-69)

EXAMPLE PROBLEMS FOR SLOPE STABILITY COMPUTATIONS WITH THE COMPUTER PROGRAM UTEXAS

by

Stephen G. Wright
James D. Roecker

Research Report Number 353-2

Stability Evaluation for Earth Slopes
Research Project 3-8-83-353

conducted for

Texas State Department of Highways
and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

November 1984

PREFACE

A new computer program for performing slope stability calculations has been developed as part of Research Project 353 by the Center for Transportation Research at the University of Texas. A guide to the program, including a detailed description of the procedures for input of data and an explanation of the output has been prepared by Wright and Roecker (1984). In conjunction with the development of the user's documentation a series of seven example problems was developed to aid the user in developing input data and using the computer program for slope stability computations. The seven example problems are presented in this report.

Stephen G. Wright

James D. Roecker

September 1984

ABSTRACT

A series of seven example slope stability problems for the computer program, UTEXAS, is presented. The example problems consist of (1) a simple slope, (2) an embankment on a very strong foundation, (3) an embankment on a relatively weak foundation, (4) an excavated slope, (5) an embankment on a foundation containing a thin seam of weak material, (6) a natural slope and (7) a partially submerged slope. A description of each example problem, a listing of the input data for the computer program, and the results of the computations are presented and discussed for each example problem. These examples are intended to serve both as a guide for input of data to the computer program, UTEXAS, and to illustrate a variety of typical slope stability problems.

SUMMARY

A series of seven distinctly different example slope stability problems has been developed and solved using the computer program UTEXAS. Several sets of computations have been performed for most of the problems to examine both short-term and long-term stability and the effects of such variables as tension cracks, varying surcharge loads on the slope and different ground water conditions. This report describes each of the example problems, including the results of the slope stability computations which have been performed. A complete listing of the input data required to solve each problem with UTEXAS is included in the report.

IMPLEMENTATION STATEMENT

Users of the newly developed computer program, UTEXAS, are encouraged to study each of the example problems presented in this report and to "run" each example problem with the computer program before undertaking solutions to much more complex problems. The complete listing of data for each problem is included in the Appendix of this report and, thus, it should be relatively easy for even the inexperienced user to run each of the example problems.

As part of the implementation of the results of Project 353 and, specifically, the computer program, UTEXAS, a series of training workshops should be developed and conducted. The workshops could logically include coverage of both fundamentals of shear strength and slope stability along with a series of solutions to selected practical problems. The examples presented in this report could serve as problems for such a workshop.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SECTION 1

INTRODUCTION

A series of seven example problems has been developed as part of the documentation for a general purpose computer program for slope stability analyses, UTEXAS. This report presents these seven sample problems and the input data for UTEXAS. A description of the computer program and guide for input of data to the program "Users' Guide" is presented elsewhere by Wright and Roecker (1984). The example problems presented in this report have been developed as a supplement to the users' guide and to meet several needs. First, the example problems serve as documented examples which can be used as "benchmarks" to verify that the computer program is functioning correctly. Secondly, the example problems illustrate typical sets of input data for the computer program to supplement the user's guide presented by Wright and Roecker (1984). Finally, the examples have been selected to provide the user with a set of illustrative, instructional examples covering a variety of typical, basic slope stability problems, including excavated and fill slopes and short-term and long-term stability conditions.

The reader is assumed to have read and be familiar with the users' manual for the slope stability computer program, UTEXAS, before reading this report. In the following sections of this report each of the seven examples is described and the results of the stability calculations performed by the computer program are presented. Listings of input data for the computer program are contained in Appendices A through G for each of the example problems.

The printed output produced by the computer program for the seven example problems is approximately 450 pages in length. Because of the relatively great length of the printer output and because the primary intent of this report is to present sample data, rather than to discuss output in detail, the printed output is not included as part of this report. However, it is expected that the reader will execute the computer program with each of the example problem data sets included in the Appendices and refer to the output while studying each example problem presented in this report

The seven example problems are referred to as "Example Problems A through G," and are as follows:

A) Simple Slope. This problem is a relatively simple problem designed to help the beginning user become familiar with the computer program by beginning with a simple problem.

B) Embankment on Strong Foundation. This problem illustrates a series of slope stability calculations for a typical embankment where the foundation is sufficiently strong to have no influence on the stability of the embankment.

C) Embankment (Earth Fill) on Weak Foundation. This problem illustrates a series of slope stability calculations for an embankment on a relatively soft, weak foundation where the strength of the foundation has a significant effect on the stability of the embankment.

D) Excavated Slope. In this example a series of stability calculations are presented for a typical excavated slope.

E) Embankment on Foundation with "Thin" Weak Soil Layer. This example illustrates a series of stability calculations for an embankment where the foundation contains a relatively thin, weak soil layer which causes the most critical sliding surface to be noncircular in shape.

F) "Natural Slope. This example is taken from the user's manual for the slope stability computer program, STABL, by Siegel (1978). The example is used to illustrate a series of slope stability computations for what could be either a natural or an excavated slope where the most critical sliding surface may be slightly noncircular.

G) Partially Submerged Slope. This example is used to illustrate a series of slope stability computations for a partially submerged slope, which could be either an embankment slope or an excavated slope. The example illustrates several ways in which essentially the same type of computations may be performed, and serves as a good problem for checking the computer program for correctness: The several ways in which the calculations are performed must yield essentially identical results if the computer program is operating correctly.

In the following seven sections of this report the seven example problems are presented in more detail and the results of the stability calculations performed with the computer program are presented.

SECTION 2

EXAMPLE PROBLEM A - SIMPLE SLOPE

The first example problem involves the stability computations for the simple, homogeneous slope illustrated in Fig. 2.1 and is designed to aid the beginning user in becoming familiar with the computer program. The slope is 12 feet high and has a 3(horizontal)-to-1(vertical) side slope. The slope and its foundation are considered to consist of the same soil. The shear strength of the soil is expressed in terms of a cohesion value (c) of 200 psf and an angle of internal friction (ϕ) of 22 degrees. The shear strength is expressed in terms of total stresses, rather than effective stresses. Accordingly, no pore water pressures are specified in the input data. The unit weight of the soil is 123 pcf.

For a simple, homogeneous slope, like the one considered in this example, a circular shear surface will usually produce essentially the minimum factor of safety. Accordingly, stability computations are performed using only circular shear surfaces for this problem. An automatic search is performed to locate the most critical shear surface. The initial mode of search consists of finding the most critical circle passing through the toe of the slope. Then, once the most critical circle through the toe of the slope is found, the search is allowed to continue to determine if a more critical circle may exist.

The initial starting point of centers for the automatic search is at the coordinates x = 18, y = 24. The minimum size of the grid to be used, corresponding to the desired accuracy in the location of the center of the

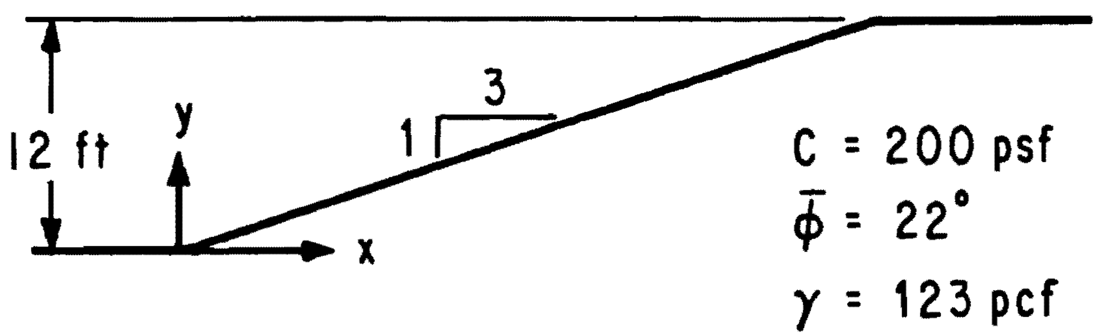

Figure 2.1 - Cross-Section and Coordinate Axes of Slope for Example Problem A.

critical circle, is 1 foot. This grid size (1 foot) was selected because it represents no more than 10 percent of the slope height, which has been found to be a good grid size to use for homogeneous slopes such as the one in this example. Default values are used for all of the other variables in the analysis/computation data.

The initial mode of search locates a critical circle through the toe of the slope with a center at the coordinates x = 13.0, y = 31.0 and with a radius of 33.6 feet. The corresponding factor of safety is 2.74 (side force inclination = 12.9 degrees). The automatic search then continues and finds a more critical circle with a slightly lower value for the factor of safety than the one found for the circle passing through the toe of the slope. This more critical circle has its center at the coordinates x = 13.0, y = 32.0 and a radius of 34.6 feet. The most critical circle is shown in Fig. 2.2. The minimum factor of safety for this most critical circle is 2.74. (The difference between the factors of safety for the most critical circle through the toe of the slope and the most critical circle found at the end of the final search is very small and can only be seen by examining the fourth significant digit of the factor of safety. The factors of safety are 2.740 for the critical circle through toe of slope versus 2.739 for the most critical circle.) It is generally known that the most critical circle will pass through the toe of the slope for a homogeneous slope like the one considered in this example where the friction angle, ϕ, is greater than zero. When ϕ is equal to zero, the critical circle may tend to go infinitely deep as discussed for Example Problem C. The results of the calculations for this example simply illustrate the known fact that the critical circle passes very nearly through the toe of the slope.

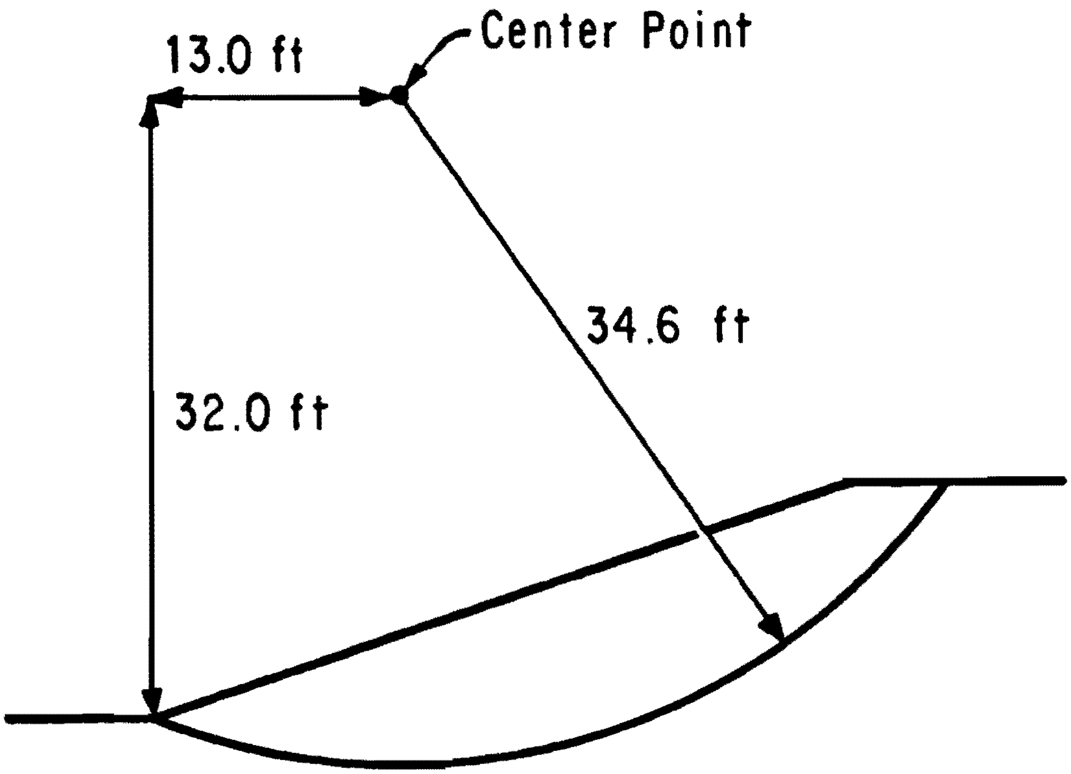

Figure 2.2 - Most Critical Circular Shear Surface Located by Automatic Search for Example Problem A.

SECTION 3

EXAMPLE PROBLEM B - EMBANKMENT ON STRONG FOUNDATION

INTRODUCTION

The second example consists of an earth fill embankment on a strong foundation. The embankment cross-section and coordinate axes used are shown in Fig. 3.1. The embankment side slopes are 3(horizontal)-to-1(vertical). The embankment is 25 feet high and has a crest width of 75 feet. The foundation is assumed to be sufficiently strong to prevent any sliding surface from passing into the foundation and, thus, the properties of the foundation are ignored and neglected in the stability computations.

The embankment in this problem is symmetrical. Thus, both side slopes will have the same factor of safety and computations only need to be performed for one side slope. The left-hand slope was arbitrarily selected for the computations.

Two separate groups of computations are performed for the embankment. The first group of computations is performed to compute the stability of the embankment immediately after construction and are referred to as "short-term," or "undrained," stability computations. The second group of stability computations are performed to compute the stability of the embankment after a sufficient period of time has passed for any drainage of water into or out of the embankment (consolidation or swell) to occur, which is likely to occur, i.e. the soil is assumed to have reached a final equilibrium state. The second

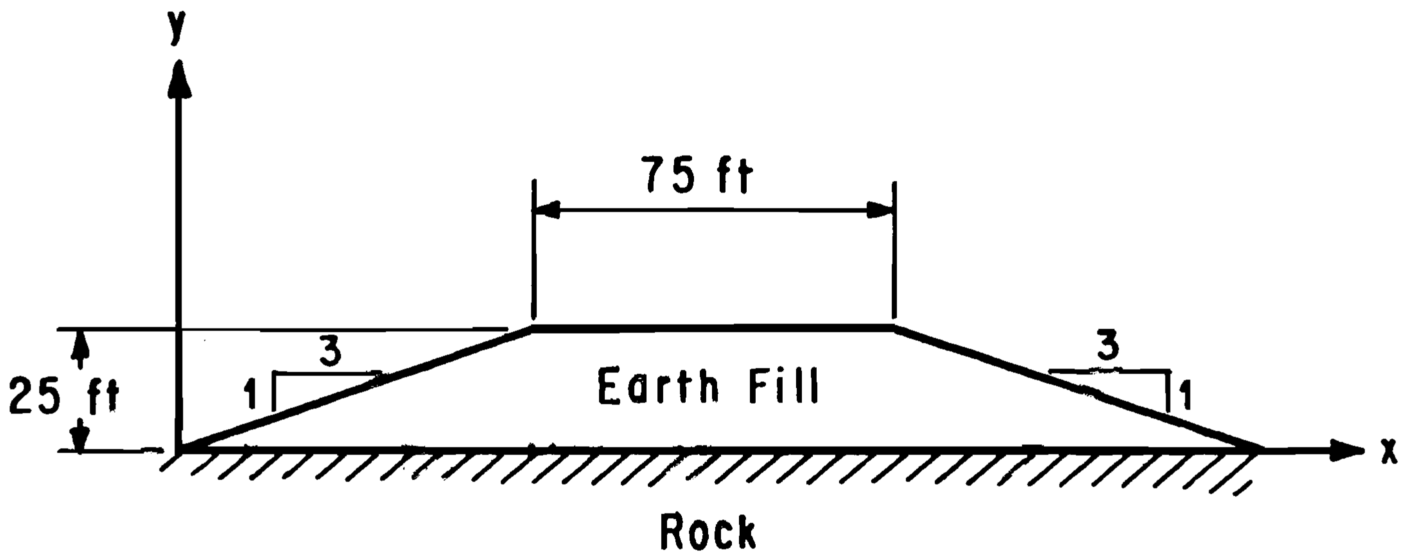

Figure 3.1 - Cross-Section of Slope and Coordinate Axes for Example Problem B.

series of computations are referred to as "long-term" or "drained" stability computations.

SHORT-TERM STABILITY COMPUTATIONS

The first group of computations are performed to determine the stability of the embankment immediately after construction. Since the embankment is considered to be constructed of clayey soil, it is assumed that there is insufficient time for a significant amount of water to flow into or out-of the soil. Thus, the embankment is assumed to be "undrained." The shear strength is assumed to be determined using unconsolidated-undrained (UU or Q) type triaxial testing procedures. The shear strength determined in this manner is expressed in terms of total stresses and, accordingly, all of the short-term stability computations will be performed using total, rather than effective stresses.

Except for the last series of short-term stability computations, the embankment material has a cohesion value of 1000 psf and an angle of internal friction of 10 degrees. For the last series of computations the strength of the embankment material is characterized by a nonlinear (curved) shear strength envelope. the embankment material has a total unit weight of 125 pcf for all of the short-term stability computations.

Computation Series No. 1

The first series of stability computations employs an automatic search to locate a critical circle. The initial mode for the search consists of finding the critical circle tangent to a horizontal line at the elevation of the toe of the slope. Once the initial mode of search is completed, the search is terminated because the circle cannot pass any deeper than the toe of the slope due to the presence of the rock; any shallower circle will not encompass the entire slope and, thus, will be less critical than the one found in the initial mode of search. The search is initiated from an initial estimated center point at x =

25, y = 50. The minimum spacing between grid points for the automatic search is 0.5 foot, which represents the accuracy attained in the location of the coordinates of the center of the critical circle. This spacing (0.5 feet) is only 2 percent of the slope height and should produce more than adequate accuracy for the location of the critical circle and corresponding minimum factor of safety (10 percent of the slope height would probably have been adequate).

The critical circle found by the automatic search has a center at the coordinates x = 37.5, y = 68.0 and the radius is 68.0 feet. The corresponding minimum factor of safety is 3.96 (side force inclination = 9.7 degrees).

Computation Series No. 2

The second series of computations is performed to illustrate the effect of an assumed vertical crack on the factor of safety. Computations are performed for crack depths of 3, 6, 9, and 12 feet. Except for the introduction of a crack into the computations, the second series of computations are identical to the first series. The coordinates of the centers and radii of critical circles and corresponding minimum factors of safety determined from Computation Series Nos. 1 and 2 for the various crack depths considered are summarized in Table 3.1. The factor of safety is also plotted versus the crack depth in Fig. 3.2 for the 5 crack depths (0 through 12 feet) considered. It can be seen that the factor of safety first decreases with an increase in crack depth from zero and then increases. The crack depth producing the minimum factor of safety is approximately 4.5 feet. This depth (4.5 feet) would generally be the depth which would be recommended for design calculations because it is the most critical (produces the lowest factor of safety) and is of a reasonable magnitude. The approximate location of the critical circle corresponding to a crack depth of 4.5 feet is shown in Fig. 3.3.

TABLE 3.1. SUMMARY OF SHORT-TERM STABILITY COMPUTATION SERIES NOS. 1 AND 2 FOR EXAMPLE PROBLEM B

Crack Depth (feet)	Critical Circle Information			Minimum Factor of Safety	Side Force Inclination (degrees)
	X-Coordinate of Center (feet)	Y-Coordinate of Center (feet)	Radius (feet)		
0	37.5	68.0	68.0	3.96	9.7
3	37.5	68.0	68.0	3.87	10.6
6	37.5	68.0	68.0	3.87	10.6
9	37.5	69.5	69.5	4.01	9.8
12	37.5	73.0	73.0	4.35	8.6

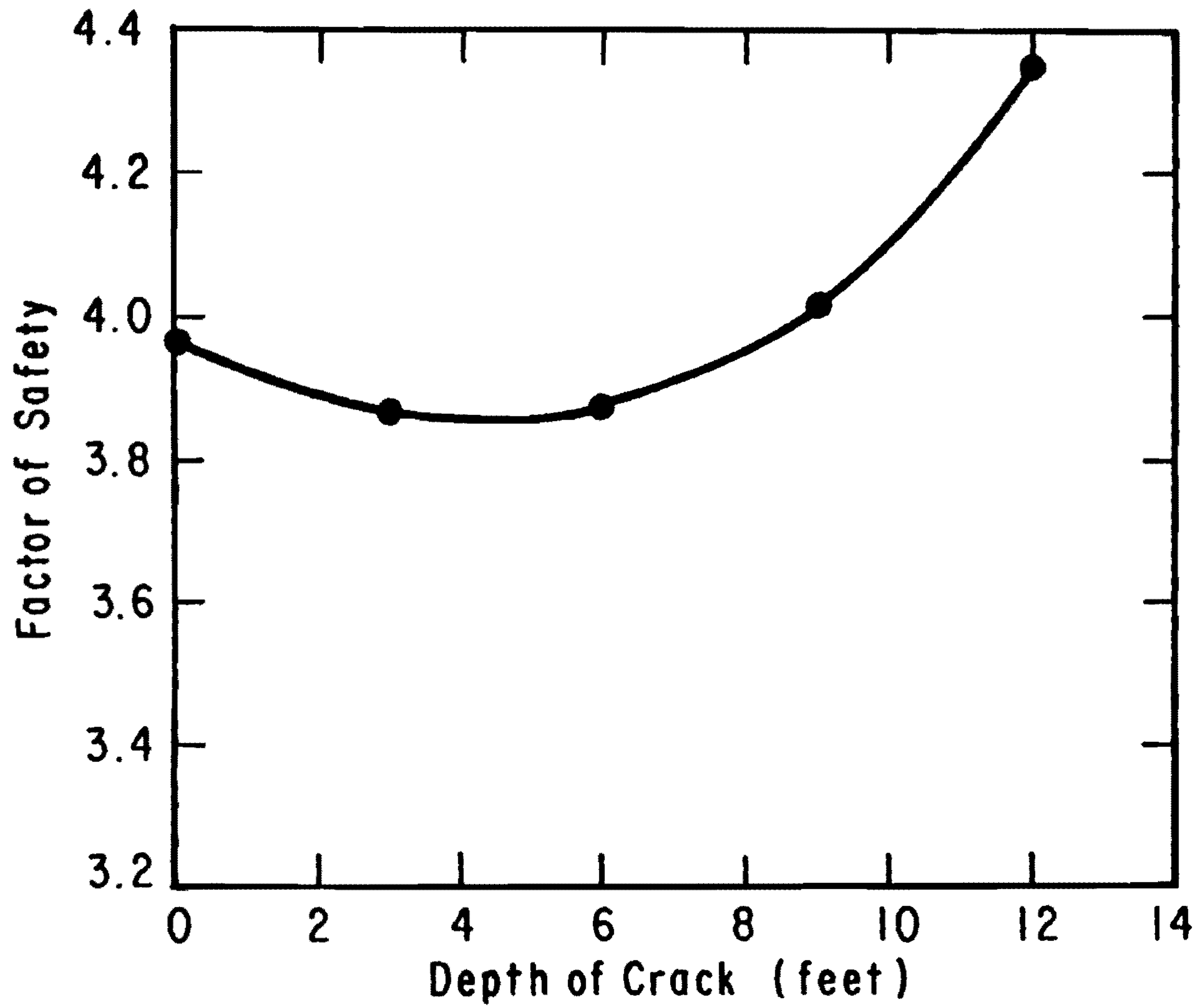

Figure 3.2 - Variation in the Factor of Safety with the Depth of Vertical Crack for Example Problem B - Short-Term Stability Computations.

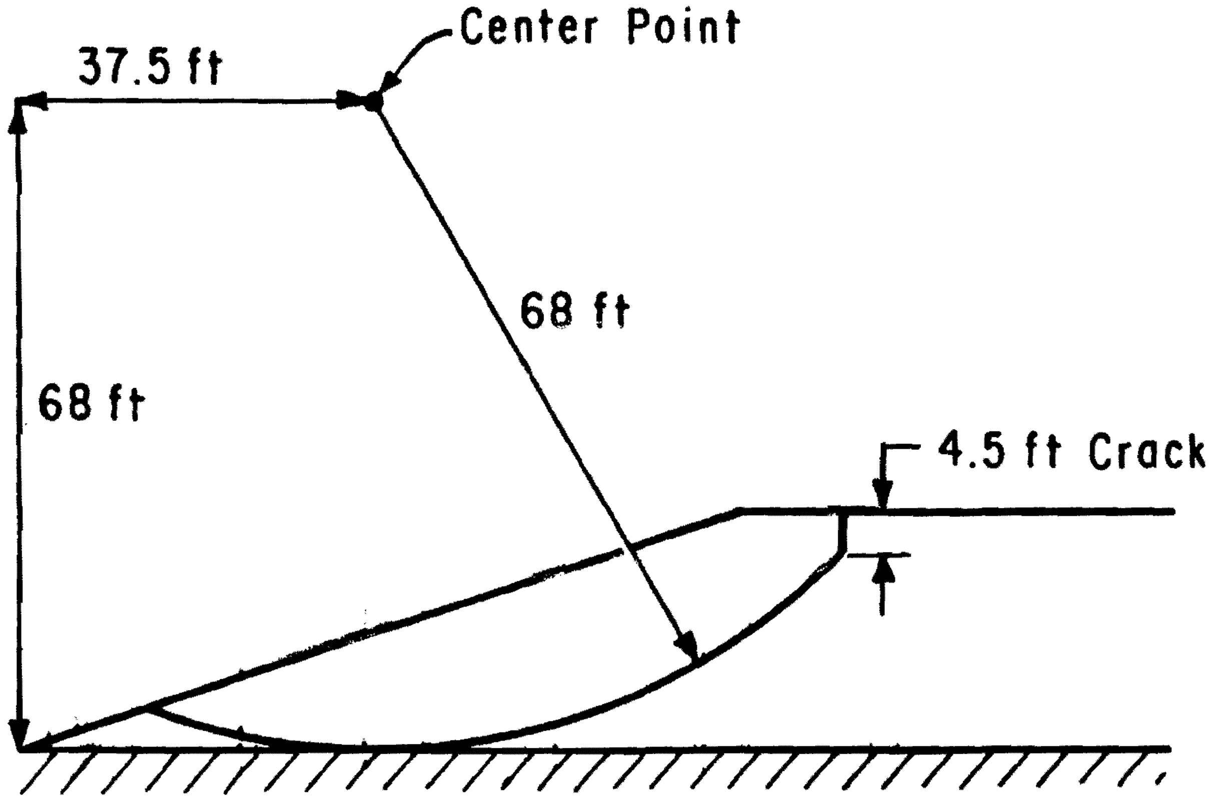

Figure 3.3 - Most Critical Circle Corresponding to "Critical" Vertical Crack Depth Based on Short-Term Stability Calculations for Example Problem B.

Although the critical depth of crack can be found in the manner illustrated by this example and the results plotted in Fig. 3.2, such an approach is somewhat tedious. As an alternative, experience has shown that a reasonable estimate for the depth of crack can be made based on Rankine active earth pressure theory; the depth of crack is selected as the depth to which the active earth pressures are negative (tensile). Based on active Rankine earth pressure theory the depth of the crack (d_c) is given by the following equation:

$$d_c = \frac{2c_m}{\gamma \cdot \tan(45 - \phi_m/2)} \tag{3.1}$$

where c_m and ϕ_m are "mobilized" shear strength parameters defined by

$$c_m = \frac{c}{F} \tag{3.2}$$

and,

$$\phi_m = \text{arc}\tan(\tan\phi/F) \tag{3.3}$$

and γ is the unit weight of the soil. Crack depths estimated using Eq. 3.1 usually are sufficiently close to the crack depth producing the minimum factor of safety that they can be used without the need for a series of calculations with varying crack depths, as were performed above. For example, for the present problem the crack depth computed from Eq. 3.1, using c = 1000 psf, ϕ = 10 degrees, and a factor of safety of 3.9, is 4.3 feet, which agrees very closely with the value suggested by the stability computations and results presented in Fig. 3.2.

Computation Series No. 3

The third series of short-term stability computations are performed to estimate the effect of a surcharge at the top of the slope on the stability. The surcharge was assumed to be 200 psf across the top of the slope with a setback of 3 feet as shown in Fig. 3.4. Such a surcharge might be produced by vehicles on the top of the slope although such a high distributed surcharge pressure (200 psf) may be improbable due to vehicles alone.

Stability computations are performed with the surcharge and assuming no vertical crack. Two sets of computations are performed. For the first set of computations an automatic search is initiated to find the most critical circle tangent to a line at the elevation of the toe of the slope. For the second set of computations an automatic search is initiated to find the most critical circle tangent to a horizontal line located at an elevation 15 feet above the toe of the slope. Once the critical circle tangent to the line 15 feet above the toe of the slope is found, the program is directed to continue the search to determine if a more critical circle can be found. The purpose of the second set of computations and search is to determine if a "local" failure near the crest of the slope may be possible due to the surcharge.

Both of the automatic searches result in the same final critical circle. The most critical circle found for both sets of computations has the center located at the coordinates x = 39.5, y = 73.0 and has a radius of 73.0 feet. The critical circle is tangent to the base of the slope at the foundation surface. The critical circle is shown in Fig. 3.5.

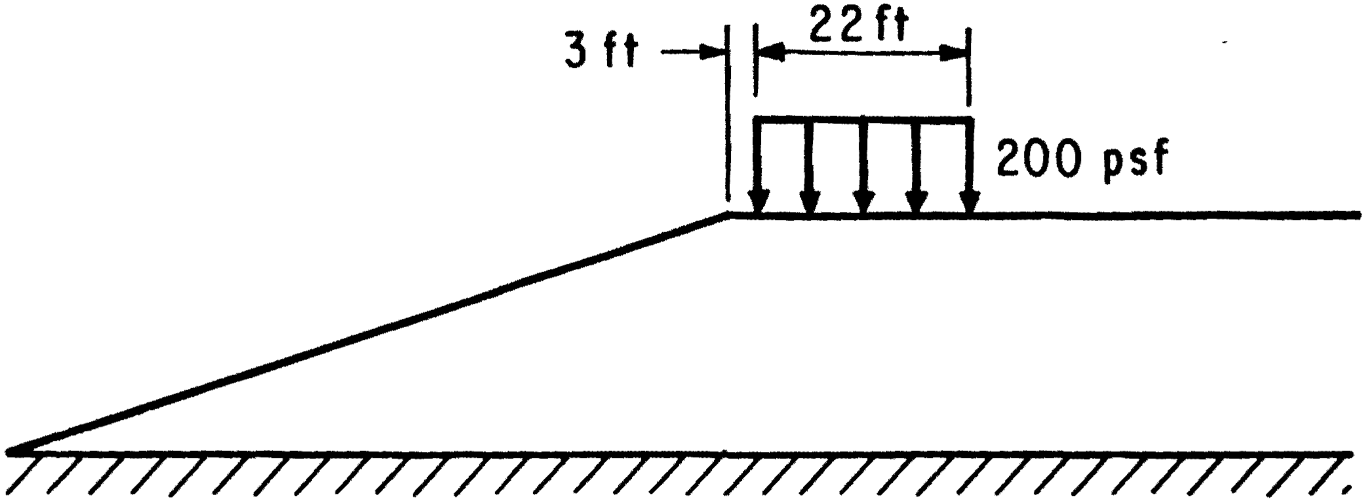

Figure 3.4 - Surcharge Pressures on Slope for Example Problem B - Short-Term Stability Computation Series No. 3.

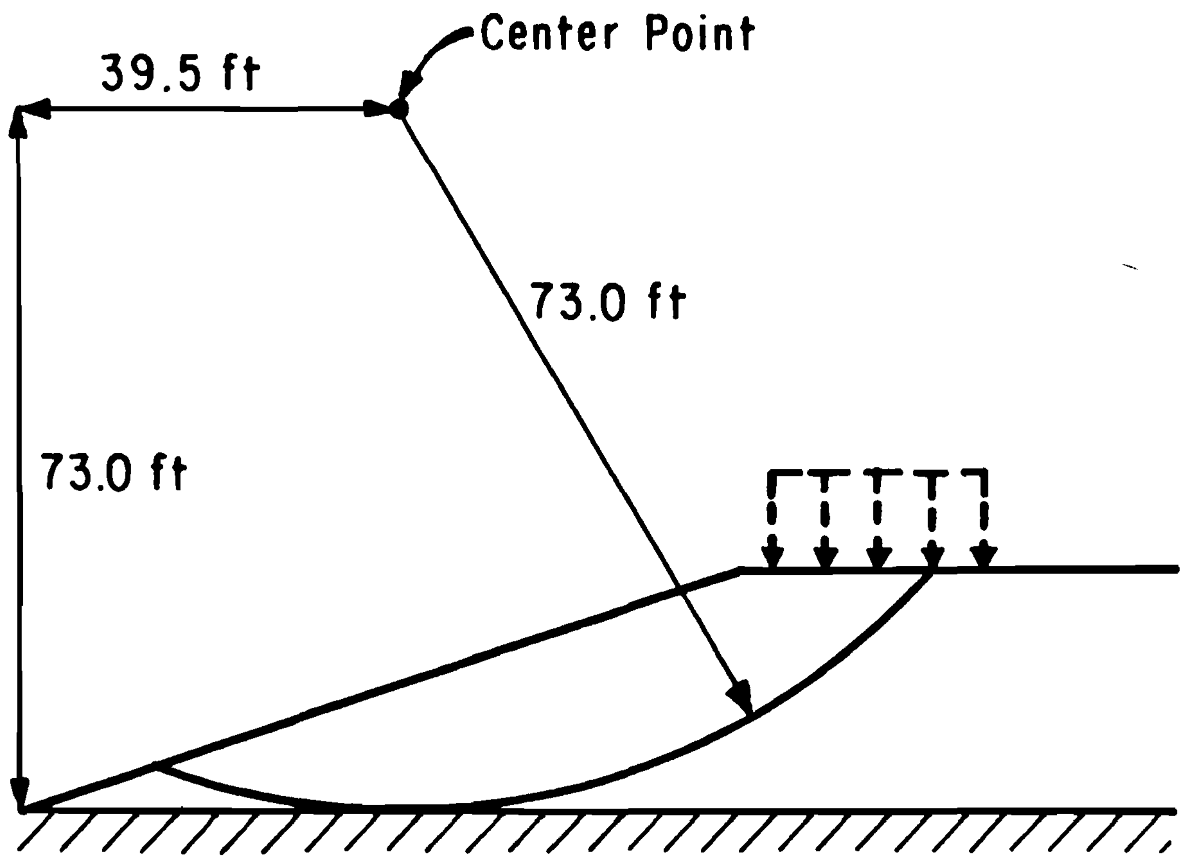

Figure 3.5 - Most Critical Circular Shear Surface from Short-Term Stability Computations for Example Problem B with Surcharge Pressures Applied to the Top of the Slope.

Computation Series No. 4

The fourth series of short-term stability computations is performed using a nonlinear shear strength envelope which may be more representative of the actual shear strength envelopes from UU (Q) type triaxial shear tests on compacted fill materials than the linear envelope used previously. The shear strength envelope used for the computations is illustrated in Fig. 3.6. The linear shear strength envelope used in the preceding computations is also shown in this figure (broken-line) for comparison. It can be seen that the straight line envelope used previously is a reasonable approximation of the curved shear strength envelope used in this fourth series of computations for normal stresses ranging from zero to 2500 psf. The larger normal stress of 2500 psf represents approximately the maximum normal stress along the most critical shear surface for the slope. Thus, reasonably close agreement between the factors of safety computed is expected using the straight line and the nonlinear shear strength envelopes. However, if the normal stresses were to be significantly higher than 2500 psf, it can be seen that the two envelopes in Fig. 3.6 begin to diverge and, thus, very different results could be obtained using the two envelopes for much higher slopes and deeper shear surfaces.

For this series of computations an automatic search very similar to the ones performed previously for Computation Series Nos. 1 and 2 is performed using a vertical crack depth of 5 feet. The critical circle found using the nonlinear shear strength envelope has its center located at x = 40.0, y = 67.0 with a radius of 67.0 feet. The corresponding minimum factor of safety is 3.87 (side force inclination = 10.1 degrees). This value for the factor of safety (3.87) is essentially identical to the value suggested by the results based on a straight line shear strength envelope; the value of F for a straight line shear strength envelope with a 5 foot deep crack is approximately 3.85 as shown in Fig. 3.2.

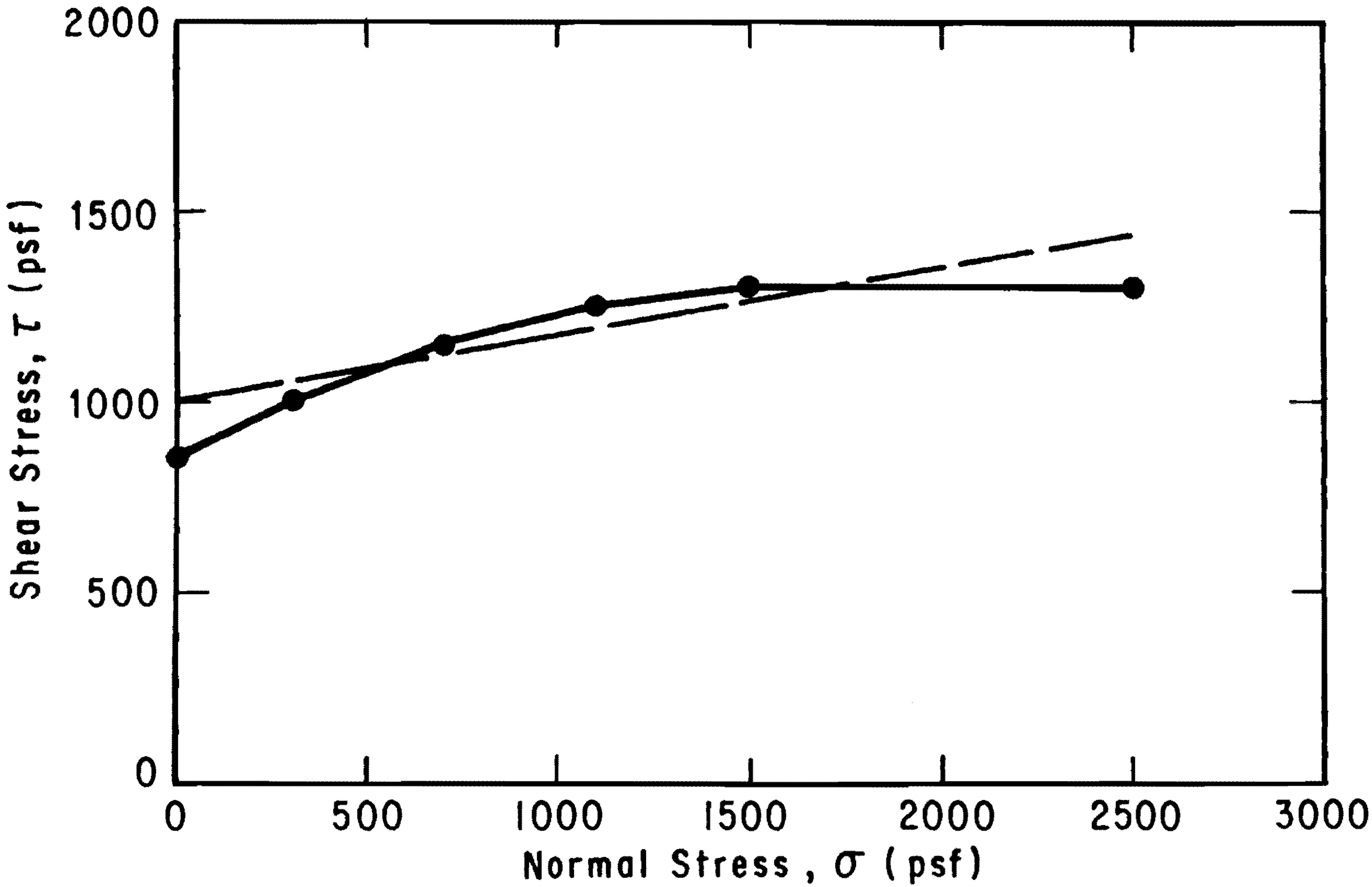

Figure 3.6 - Nonlinear Shear Strength Envelope Used for Example Problem B - Short-Term Stability Computation Series No. 4.

If a vertical crack is not introduced in this example the results could be very different from the results obtained in Computation Series No. 1 with a straight line shear strength envelope because of differences in the shear strength for negative values of normal stress (σ). The use of a straight line envelope implies that the strengths continue to be defined by the extension of the envelope at negative stresses, while the use of a nonlinear envelope could enable the user to make the shear strengths zero for negative values of normal stress.

LONG-TERM STABILITY COMPUTATIONS

The second group of stability computations for Example Problem B are performed to estimate the long-term stability of the slope after a sufficient period of time has elapsed for the soil to fully consolidate or swell and reach a final equilibrated state. The shear strengths in this case are expressed in terms of effective stresses and effective stresses are used for all of the stability computations. The shear strength parameters are determined using either consolidated-drained (CD or S) type triaxial or direct shear tests or consolidated-undrained (CU, R) type triaxial shear tests with pore water pressure measurements. For all of the long-term stability computations, excepting those in Computation Series No. 4, the shear strength is expressed by a cohesion value ($\bar{c}$) of 100 psf and an angle of internal friction ($\bar{\phi}$) of 20 degrees. For Computation Series No. 4 the cohesion value ($\bar{c}$) is assumed to be zero to examine the effect of ignoring the cohesion value on the factor of safety. The total unit weight of soil used in the stability computations is 125 pcf.

Computation Series No. 1

The first series of long-term slope stability computations is performed with zero pore water pressures throughout the slope. An automatic search is performed to locate a most critical circle tangent to a horizontal line at the elevation of the toe of the slope. The search is started from a center point at the coordinates x = 25, y = 50 using a minimum grid spacing of 0.5 foot.

The critical circle is found to have its center at the coordinates x = 17.0, y = 92.5 and the radius is 92.5 feet. The factor of safety obtained for the critical circle is 1.63 (side force inclination = 15.7 degrees). The critical circle is shown in Fig. 3.7.

Computation Series No. 2

The second series of long-term stability computations is identical to the first series except that a 1 foot deep vertical crack is introduced. This depth of 1 foot was arrived at using Eq. 3.1 with a cohesion value of 100 psf, a friction angle of 20 degrees, a unit weight of 125 pcf and an estimated factor of safety of 1.6 (from Computation Series No. 1). An automatic search, identical to the one in the first computation series, is performed.

The center of the critical circle is found to be at the coordinates x = 17.0, y = 92.5, and the corresponding minimum factor of safety is 1.63. Thus, in this case the effect of the crack with the appropriate depth is minimal and has almost no effect on the factor of safety. This is typically the case in long-term stability computations where the "cohesion" value is small compared to the cohesion value for undrained (i.e. short-term) loading conditions.

Computation Series No. 3

The third series of long-term stability computations is performed with pore water pressures expressed in terms of the pore water pressure coefficient r_u. The pore water pressure coefficient r_u is defined as the ratio of the pore water pressure at a point divided by the corresponding total vertical overburden pressure at the point. For the present computations the value of r_u is constant throughout the slope; the value of r_u used for the computations is 0.15. (Normally a value would be estimated based either on experience with slopes and

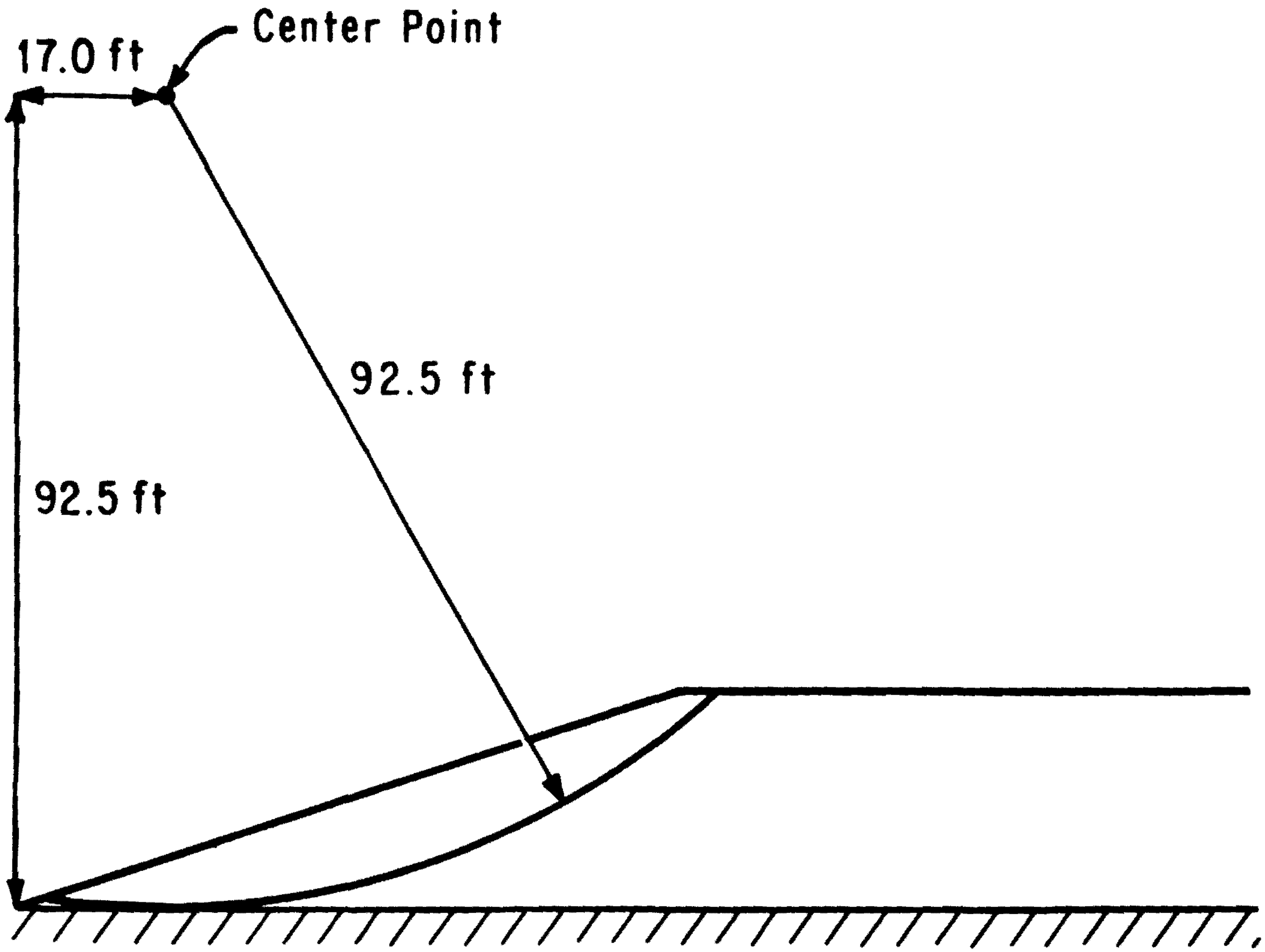

Figure 3.7 - Most Critical Circular Shear Surface from Long-Term Stability Computations with Zero Pore Water Pressures for Example Problem B.

groundwater conditions in a particular area or a value would be calculated from the anticipated ground water and seepage conditions in the slope as outlined by Bishop and Morgenstern (1960), and illustrated later in Example Problem D.)

An automatic search is performed to locate the most critical circle using the same parameters for the search as used for Computation Series Nos. 1 and 2. The critical circle is found to have a center located at the coordinates x = 18.5, y = 89.5 with a radius of 92.5 feet. The corresponding minimum factor of safety is found to be 1.43 (side force inclination = 15.5 degrees).

Computation Series No. 4

Computation Series No. 4 is identical to Computation Series No. 3 except that the cohesion value is assumed to be zero, rather than 100 psf. In the case of a homogeneous slope where the cohesion is zero, like the one in this case, the most critical sliding surface is theoretically a plane surface passing parallel to, and only an infinitesimal distance below, the surface of the face of the slope. To locate such a surface in the automatic search it is necessary to locate the most critical circle through the toe of the slope, rather than the most critical circle tangent to a given line.

The center of the critical circle is found to be located at the coordinates x = -5.0, y = 16.5 and the circle has a radius of 17.2 feet. The corresponding value for the factor of safety is 0.91 (side force inclination = 18.4 degrees). The critical circle is illustrated in Fig. 3.8 and discussed in further detail below.

The critical circle which is found and illustrated in Fig. 3.8 actually "slices" through only a small portion of the slope and represents within the numerical errors associated with the computations, a shallow plane surface. During the automatic search for Computation Series No. 4, a relatively large number of "circles" are tried which either do not intersect the slope or which

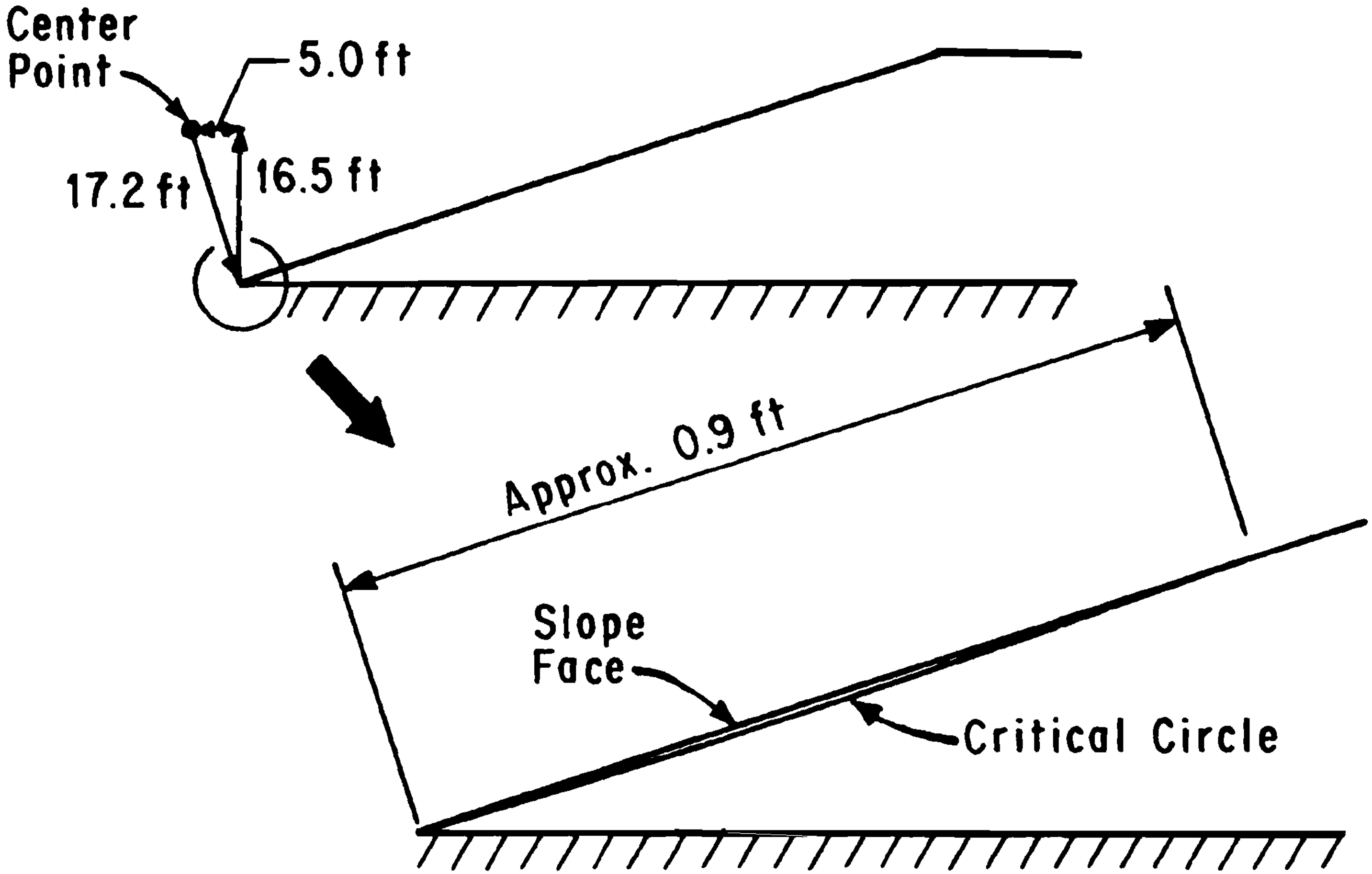

Figure 3.8 - Most Critical Circular Shear Surface from Long-Term Stability Computations for Example Problem B when Cohesion is Neglected.

expected when a search is performed to locate a critical circle in a slope consisting entirely of cohesionless material. In similar examples of homogeneous cohesionless slopes the automatic search sometimes tends to produce a center for the critical circle which lies a great distance away from the slope. (Theoretically the critical center for a cohesionless slope should lie an infinite distance away from the slope on a line which passes through the midpont of the slope face and is perpendicular to the face of the slope.) However, regardless of what appear to be wide variations among the locations of critical circles for various cohesionless slopes, the circles can all be expected to approximate a shallow plane and the factor of safety should be the correct value. In fact, an automatic search with the computer program should not actually be attempted. The exact factor of safety is more appropriately calculated from the following equation which is derived by "infinite slope" analysis procedures (Taylor, 1948):

$$F = [\cot \beta - r_u (\cot \beta + \tan \beta)] \tan \phi \qquad (3.4)$$

in which F is the factor of safety, β is the slope angle and "tan" and "cot" designate the tangent and cotangent, respectively.

The fourth series of computations is performed to illustrate what may happen when the computer program is used for analyses of slopes in cohesionless materials, rather than to present what would be considered a realistic use of the program. Eq. 3.4 produces precisely the correct solution desired and there is no need for the computer program in this instance.

The result of the fourth series of computations clearly show that the cohesion value ($\bar{c}$) is a dominant factor in the stability of the slope considered. The factor of safety computed previously with a cohesion value of 100 psf (Computation Series No. 3) was 1.43 compared to the value of 0.91 which is computed in this series of computations with zero cohesion. Thus, any cohesion value which would be relied upon for stability should be carefully considered and verified by the results of laboratory tests, especially tests at low confining pressures where the cohesion is an important component of the strength.

COMPARISON OF RESULTS FROM SHORT-TERM AND LONG-TERM SLOPE STABILITY COMPUTATIONS

For design of embankments like the ones considered in this example both short-term and long-term stability computations are ordinarily required and should be performed. The lowest (most critical) factor of safety computed for the two conditions should then govern the design.

For the present example the lowest factors of safety are computed for the long-term stability condition and, thus, the long-term stability condition governs. However, this is not always the case. For higher slopes the short-term stability condition may become the more critical condition.

SECTION 4

EXAMPLE PROBLEM C - EMBANKMENT ON A WEAK FOUNDATION

INTRODUCTION

This example consists of a compacted earth fill resting on a relatively weak clay foundation. A cross-section of the slope and foundation is shown in Fig. 4.1 with the coordinate axes used for this problem. The slope is 18 feet high and has a 3(horizontal)-to-1(vertical) side slope. The fill material is sand. The sand has a total unit weight of 115 pcf and an angle of internal friction of 35 degrees with no cohesion. The clay foundation is 15 feet thick and is underlain by rock. The clay is saturated.

Both short-term and long-term stability computations are performed for this example problem. Different shear strength properties are used for the foundation clay for the short-term and the long-term stability computations; the strength properties for the foundation clay are described in the appropriate sections below.

SHORT-TERM STABILITY COMPUTATIONS

The first three sets of stability computations are performed to compute the factor of safety immediately after construction. Undrained shear strengths, such as those determined by unconfined compression, unconsolidated-undrained (UU, Q) and vane shear test procedures, are used for the clay foundation. The variation in undrained shear strength (S_u) with depth in the foundation is shown in Fig. 4.2. The undrained shear strength is 300 psf in the

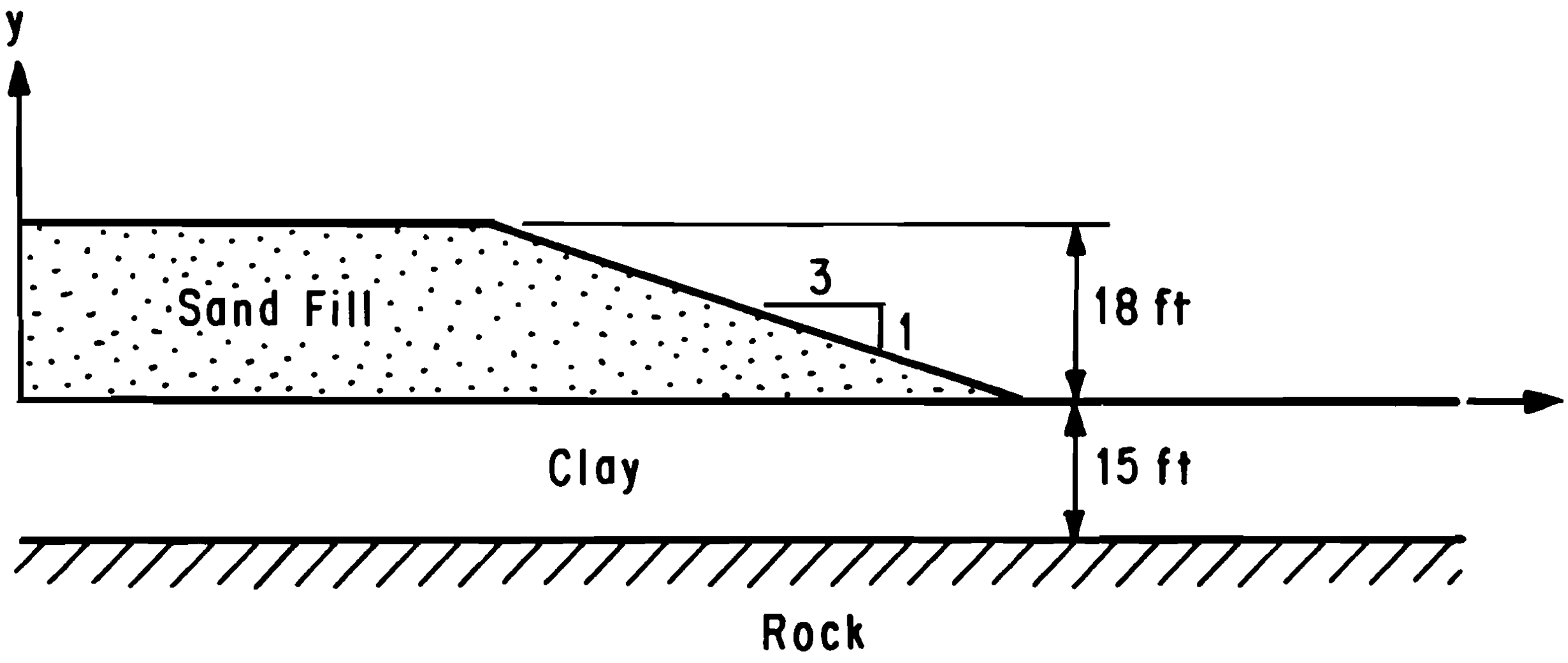

Figure 4.1 - Cross-Section of Slope and Coordinate Axes for Example Problem C.

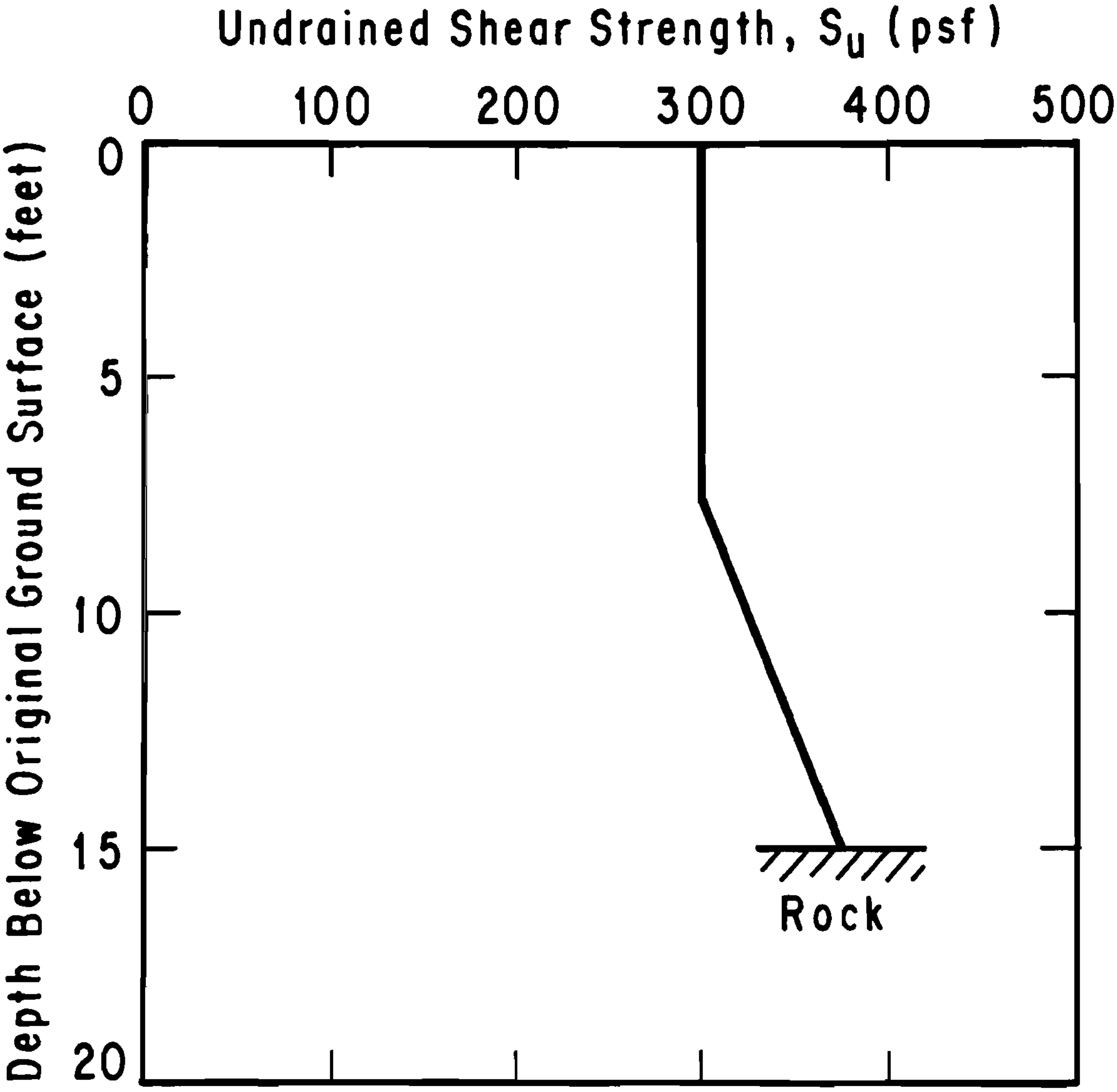

Figure 4.2 - Variation of Undrained Shear Strength with Depth for the Foundation in Example Problem C.

upper one-half of the foundation, and then increases from the value of 300 psf at the rate of 10 psf per foot of depth below a depth of 7.5 feet. The total unit weight of the clay in the foundation is 98 pcf for the short-term computations.

Computation Series No. 1

The first series of computations is performed to locate the most critical circular shear surface. An automatic search is performed beginning with a center point at the coordinates x = 75, y = 35 and locating the critical circle tangent to a line at the bottom of the weak clay foundation (15 foot depth), after which the search is allowed to continue in order to find a more critical circle if one exists. A grid spacing of 1 foot is used. This spacing (1 foot) was selected to represent a small fraction of both the slope height and the thickness of the clay foundation layer. The spacing is less than 10 percent of these distances (slope height and foundation thickness), which is considered adequate for the relatively homogeneous conditions in this problem.

The computations show that the center of the most critical circle is at the coordinates x = 77, y = 34 and the circle has a radius of 46 feet. The critical circle is shown in Fig. 4.3 and passes to a depth of 12 feet into the foundation, which is nearly to the bottom of the clay layer. The minimum factor of safety corresponding to the critical circle is 1.16 (side force inclination is -7.4 degrees).

Computation Series No. 2

The second series of computations is performed to determine the approximate influence of the shear strength assigned to the embankment on the stability. To determine the potential influence of embankment strength the embankment is assigned a strength of zero ($c = 0$, $\phi = 0$). The factor of safety is then computed for a single circular shear surface which is the most critical circle

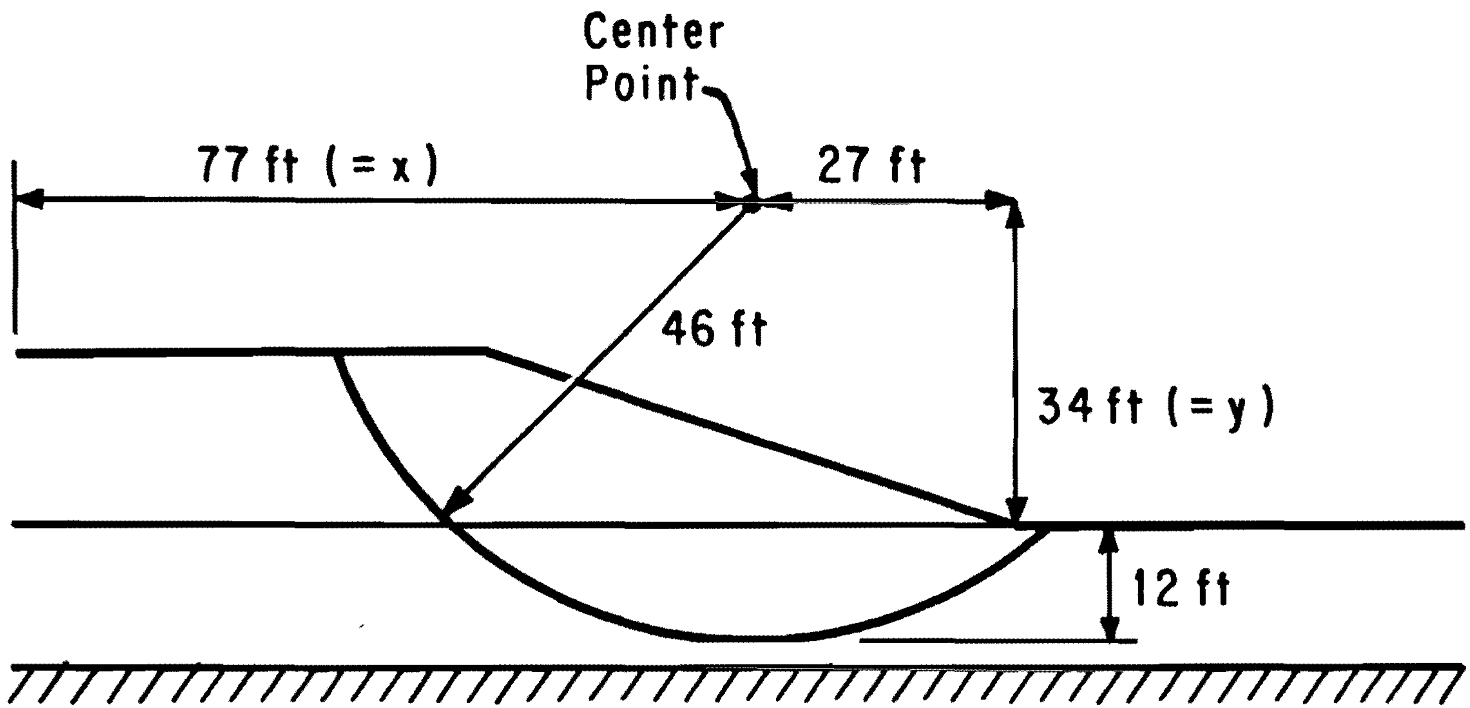

Figure 4.3 - Most Critical Circular Shear Surface from Short-Term Stability Computations for Example Problem C.

found in Computation Series No. 1 (center at x = 77, y = 34 - radius = 46 feet). An automatic search for a critical circle would be meaningless in the case of zero embankment strength because the search would lead to the most critical circle being located entirely within the embankment where, because of its zero strength, the factor of safety would have been zero (an obvious minimum).

The factor of safety computed in the second computation series is 0.83, compared with the value of 1.16 computed in Computation Series No. 1. Thus, the effect of reducing the embankment strength to zero is to reduce the factor of safety by at least 30 percent.

Computation Series No. 3

For the third computation series the embankment is treated as a vertical surcharge and replaced by vertical "surface pressures" acting on a horizontal ground surface as shown in Fig. 4.4. The surcharge pressures are equal to the vertical stress produced by the embankment and vary from 2070 psf (= 18 ft x 115 psf) beneath the horizontal, top portion of the embankment to zero at the toe of the embankment and beyond. For the input data the original profile lines and material property data for the embankment are not changed; instead a new slope geometry consisting of a horizontal "slope" at the top of the clay surface is specified. The embankment material above the "slope" is then automatically ignored by the computer program in any computations.

An automatic search is performed for the third computation series using the same starting point and grid spacing used for the first series. The most critical circle is found to have its center at the coordinates x = 77, y = 33 and the radius is 48 feet. This circle is almost identical to the critical circle found in the first computation series. However, the factor of safety for the third computation series is 1.37, which is somewhat higher than the value (1.16) computed for the first computation series. The higher value for the

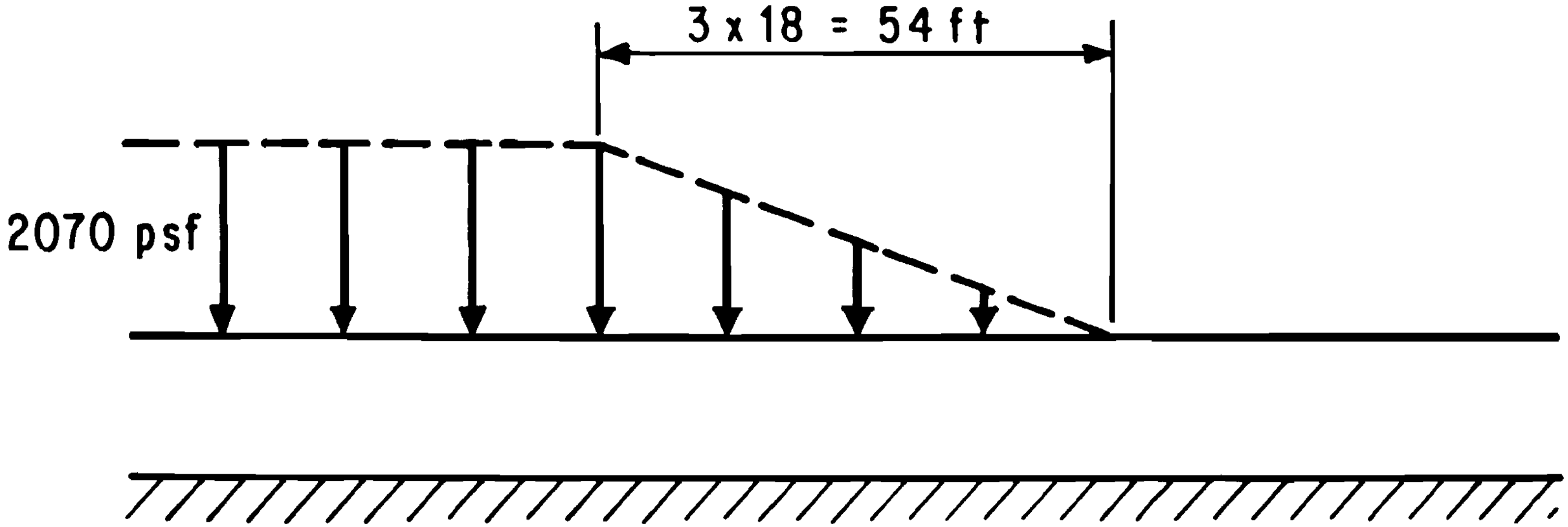

Figure 4.4 - Illustration of Vertical Surcharge Pressures Used to Represent the Embankment for Example Problem C - Short-Term Stability Computation Series No. 3.

factor of safety in Computation Series No. 3 occurs because when the embankment is treated as a surcharge, the horizontal thrust, which is exerted by the embankment and reflected in the results of Computation Series No. 1, is ignored. In reality the sand embankment will exert a horizontal thrust (earth pressure force) which will increase the driving forces tending to cause instability and, thus, reduce the factor of safety. Thus, Computation Series No. 1 is considered to be fundamentally more correct than Computation Series No. 3.

LONG-TERM STABILITY COMPUTATIONS

One series of long-term stability computations is performed to determine the factor of safety, which the embankment would ultimately attain, once the foundation has ample opportunity to consolidate (or swell). The strengths for the long-term stability computations are based on effective stresses and determined from either consolidated-drained (CD, S) or consolidated-undrained (CU, R) tests with pore water pressure measurements. The effective stress shear strength parameters for the clay are $c = 0$ and $\phi = 23$ degrees. The total unit weight of the clay is increased to 101 pcf from the value of 98 pcf used in the short-term stability computations. The groundwater table is at the surface of the foundation (ground surface) and pore water pressures are described in the input data using a horizontal piezometric line.

An automatic search is performed to locate a critical circle. The search is initiated by finding the most critical circle through the toe of the slope and then is allowed to continue to find the most critical circle. A 1 foot grid spacing is used for the search.

The center of the critical circle is found to be located at the coordinates $x = 98$, $y = 21$ and the radius is 26.7 feet. The critical circle is shown in Fig. 4.5. As shown in this figure, the critical circle passes to a depth of only approximately 5.7 feet into the foundation, which is considerably shallow-

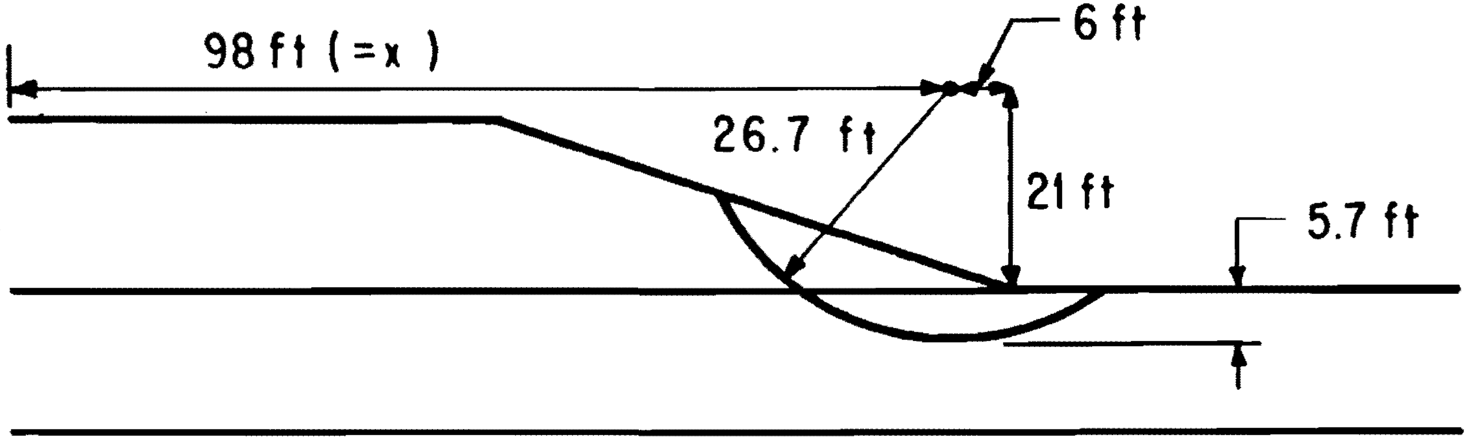

Figure 4.5 - Most Critical Circular Shear Surface from Long-Term Stability Computations for Example Problem C.

er than the depth of approximately 12 feet found for the critical circles for the short-term stability computations. The factor of safety for the long-term stability computations is 1.44 (side force inclination = -10.9 degrees).

COMPARISON OF SHORT-TERM AND LONG-TERM COMPUTATIONS

The factor of safety for the long-term stability computations (1.44) is significantly higher than the factor of safety for the short-term stability computations (1.16), indicating that an increase in the factor of safety can be expected to occur with time after the embankment is completed. In the majority of cases, with the possible exception of water-impounding structures, the factors of safety of embankments on weak foundation will be higher for long-term stability conditions because the foundation soils will consolidate and become stronger with time. In those few cases where the foundation may swell, and, thus, become weaker with time, the factor of safety may be lower for the long-term stability condition. Also, if the embankment strength, rather than the foundation strength is the governing factor contributing to stability, then the long-term stability condition may be critical in the manner illustrated by Example Problem B.

SECTION 5

EXAMPLE PROBLEM D - EXCAVATED SLOPE

INTRODUCTION

Example Problem D consists of an excavated slope in a relatively homogeneous clay stratum. The slope is 20 feet high and has a side slope of 3(horizontal)-to-1(vertical). Rock exists at a depth of 20 feet below the toe of the slope. A cross-section of the slope with the coordinate axes used is shown in Fig. 5.1.

Both short-term and long-term stability computations are performed for the slope. Different shear strengths are used for each set of computations (short-term and long-term) and are described below.

SHORT-TERM STABILITY COMPUTATIONS

The slope and portion of the foundation above the rock are considered to be saturated clay. The undrained shear strength of the clay is considered to be relatively uniform and equal to 1500 psf (ϕ = 0). The total unit weight of the clay is 128 pcf. Two series of short-term stability computations are performed: In the first series there is no vertical crack; in the second series a vertical crack of appropriate depth is used.

Computation Series No. 1

An automatic search is performed to locate a critical circular shear surface for the first series of computations. In cases like the current one, where the angle of internal friction (ϕ) is equal to zero and the shear

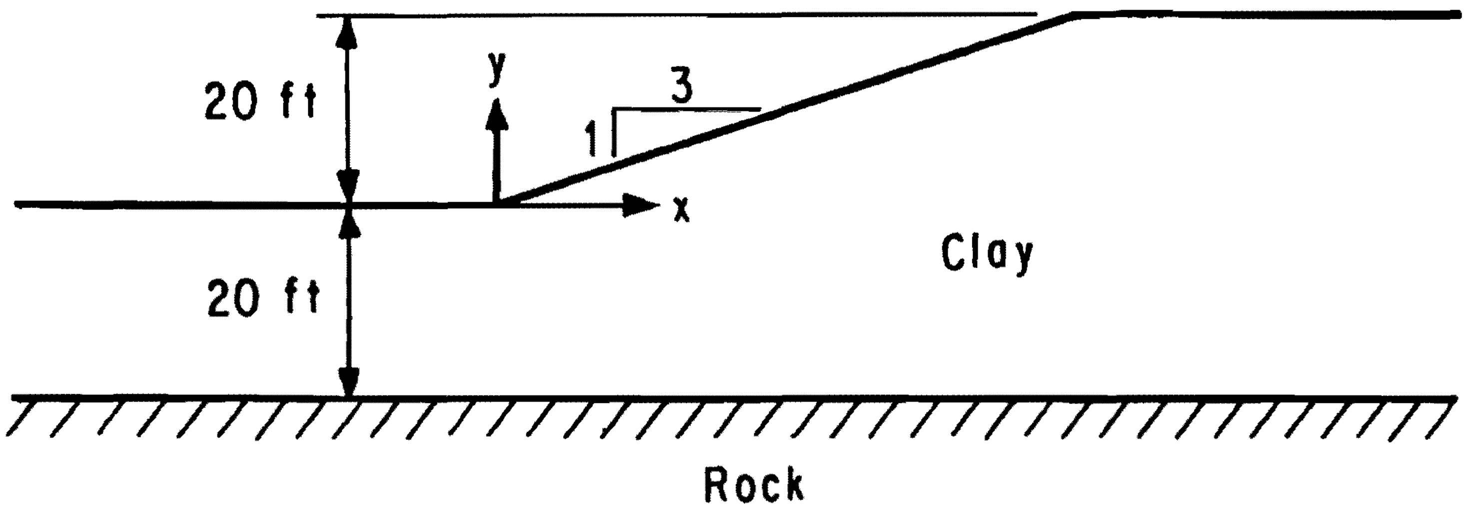

Figure 5.1 - Cross-Section of Excavated Slope and Coordinate Axes for Example Problem D.

strength is constant (c does not vary) it can be shown that the most critical circle will tend to pass to an infinite depth provided that the slope is flatter than 53 degrees (Taylor, 1948). Thus, it is known that the critical circle for the current problem will go as deeply as possible and will be limited by the underlying rock to a depth of 20 feet. Accordingly, the automatic search is performed to locate the most critical circle tangent to a line at the elevation of the top of the rock and the search is terminated once the initial mode of search is completed. A minimum spacing of 0.5 foot between grid points is used for the automatic search. This distance (0.5 foot) is 2.5 percent of the slope height and is considered to be more than adequate with respect to obtaining an accurate estimate for the factor of safety; a distance of as much as 10 percent of the slope height would be expected to give adequate accuracy for the relatively homogeneous slope in this example.

The critical circle located by the automatic search has a center point at the coordinates x = 30.0, y = 46.5 and a radius of 66.5 feet. The corresponding minimum factor of safety is 3.68 (side force inclination = 3.8 degrees).

Computations Series No. 2

The second series of computations is performed with a vertical crack introduced. The crack depth is 6.5 feet. This depth (6.5 feet) is calculated in the manner described previously for Example Problem B (Computation Series No. 2) using the following equation (for $\phi = 0$):

$$d_c = \frac{2 \cdot c}{F \cdot \gamma} \tag{5.1}$$

To calculate the crack depth a cohesion value (c) of 1500 psf, a unit weight (γ) of 128 pcf, and a factor of safety of 3.68 (estimated based on the results of

Computation Series No. 1) are used. Except for the introduction of the vertical crack, everything else in the second computation series is identical to the first computation series.

The center of the critical circle for the second computation series is found to be at x = 30.0, y = 44.0; the corresponding radius is 64.0 feet. the critical circle is shown in Fig. 5.2. The minimum factor of safety corresponding to the critical circle is 3.56 (side force inclination = 5.0 degrees). In this case (Example Problem D) the factor of safety is only reduced by approximately 3 percent by the introduction of the vertical crack. Thus, the crack has little influence except that it eliminates a significant zone where the stresses are calculated to be negative (tensile). Such negative stresses may be unrealistic.

LONG-TERM STABILITY COMPUTATIONS

The long-term stability computations are performed using effective stresses. The shear strength parameters are determined from either consolidated-drained (CD, S) or consolidated-undrained (CU, R) tests with pore water pressure measurements. The effective stress shear strength parameters are $\bar{c}$ = 100 psf and $\bar{\phi}$ = 25 degrees. The total unit weight of the soil is 125 pcf. This value (125 pcf) is slightly lower than the value (128 pcf) used for the short-term stability computations, reflecting the fact that the soil has swelled with time as a result of the stress relief associated with excavation of the slope.

Four series of long-term stability computations are performed. The four series are similar except that different sets of pore water pressure conditions are used for each series. For each series of computations an automatic search is performed to locate a critical circle beginning with finding the most critical circle passing through the toe of the slope. In the input data the most critical circle is not allowed to pass below the top of the rock; however,

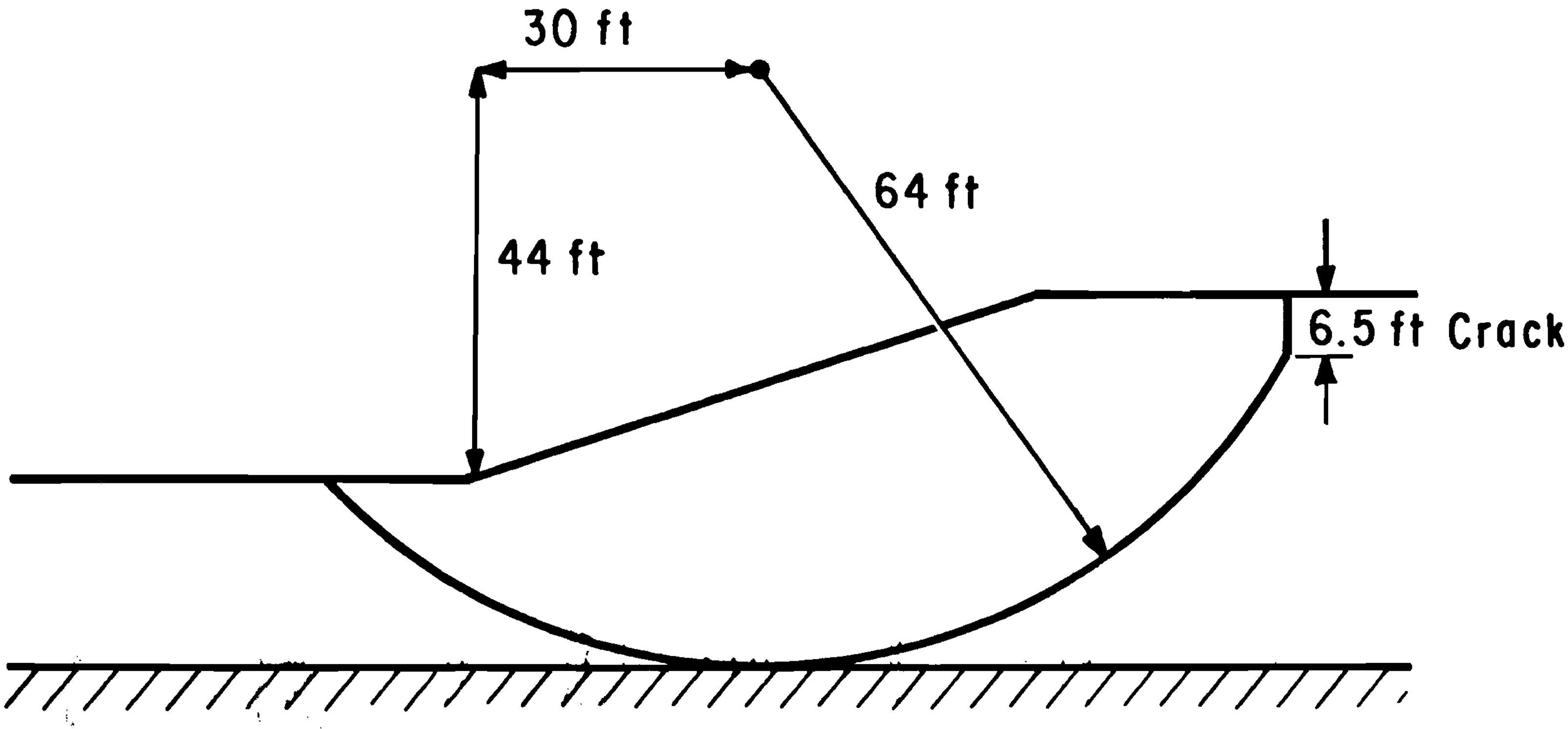

Figure 5.2 - Most Critical Circular Shear Surface for Short-Term Stability Computations for Example Problem D with a 6.5 Foot Deep Vertical Crack.

there is no tendency for the circle to pass that deeply and, thus, no such limit needs to be imposed. The automatic search is initiated at an estimated center point at the coordinates x = 30, y = 30. A grid spacing of 0.5 foot is used.

Computation Series No. 1

Pore water pressures are zero for the first series of long-term stability computations. The center of the most critical circle is found to be at x = 13.5, y = 69.5 and the corresponding radius is 70.8 feet. Although the critical circle was not restricted to pass through the toe of the slope, the critical circle was found to pass essentially through the toe of the slope. The minimum factor of safety for the critical circle is 2.05 (side force inclination = 15.7 degrees).

Computation Series No. 2

For the second series of computations the pore water pressures are defined by the piezometric line shown in Fig. 5.3. The automatic search locates a critical circle with the center point at the coordinates x = 17.0, y = 50.0 and with a radius of 55.1 feet. The corresponding factor of safety is 1.56 (side force inclination = 13.4 degrees). A comparison of the results of the first and second series of computations, shows that the factor of safety is reduced by approximately 24 percent (from 2.05 to 1.56) by the presence of seepage and pore water pressures like those assumed for the second series of computations. However, the factor of safety (1.56) still appears to be adequate with the pore water pressures used.

The critical circles for Computation Series Nos. 1 and 2 are shown together for comparison in Fig. 5.4. The critical circle shown for Computation Series No. 2, where the pore water pressures are higher, can be seen to pass to a greater depth then the critical circle for Computation Series No. 1 (zero pore water pressures). This trend of an increase in depth for the critical

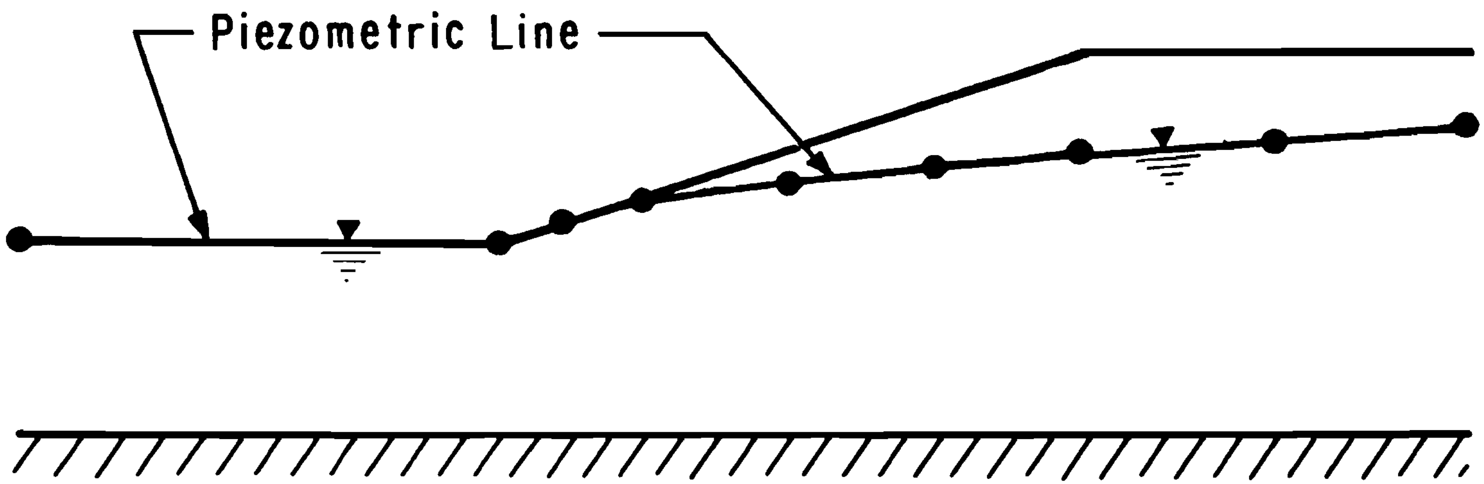

Figure 5.3 - Piezometric Line Used for Example Problem D - Computation Series Nos. 2 and 3.

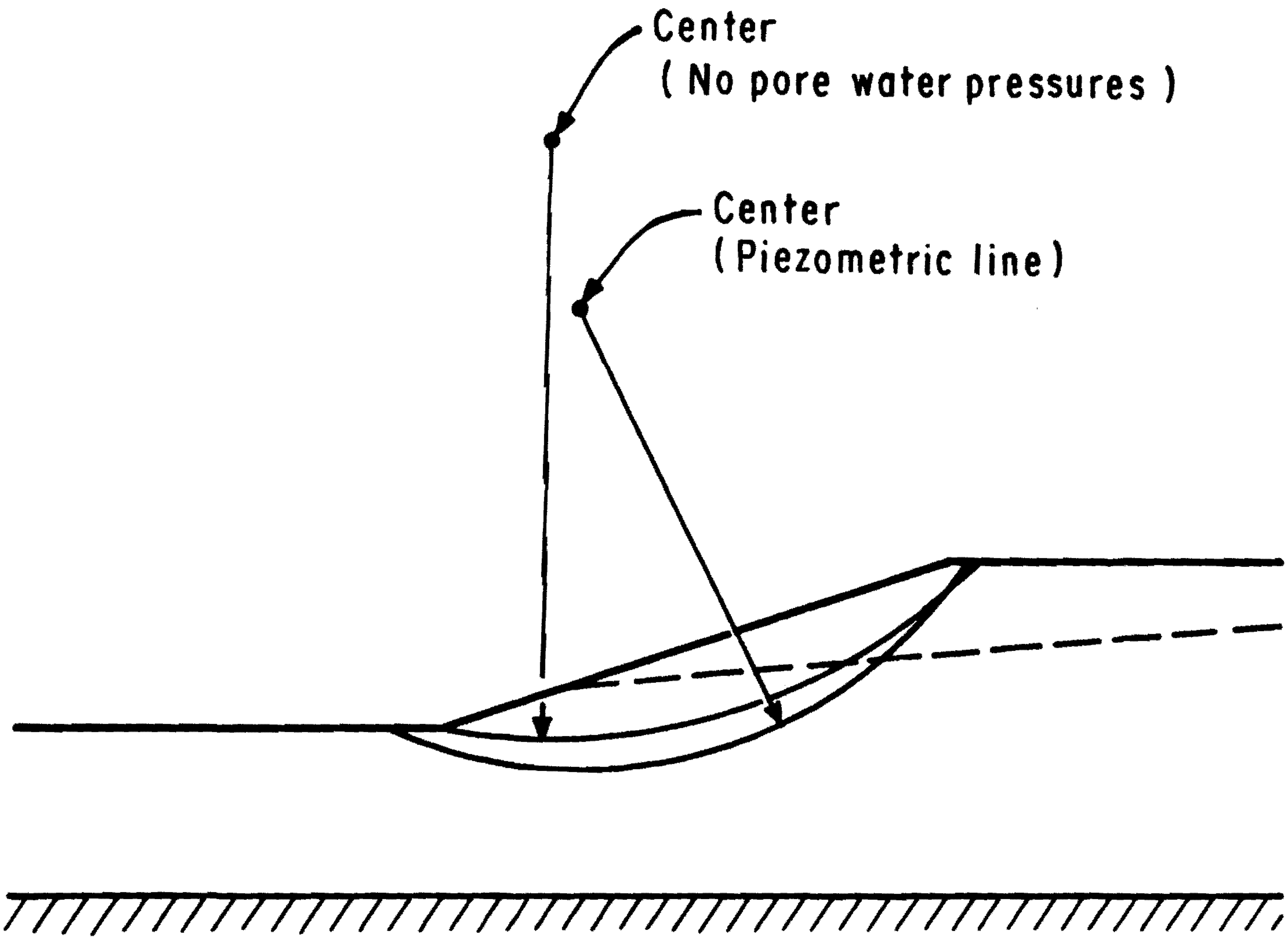

Figure 5.4 - Most Critical Circular Shear Surfaces for Short-Term Stability Computation Series Nos. 1 and 2 for Example Problem D.

shear surface with an increase in pore water pressure is generally observed and should be expected.

Computation Series No. 3

The third series of computations is identical to the second series except that negative pore water pressures (above the piezometric line) are permitted, while in the second series of computations negative pore water pressures were not permitted and, thus, the pore water pressures were set to zero above the piezometric line. The center of the critical circle for the third series of computations is found to be at x = 18.0, y = 48.0 and the radius of the circle is 54.6 feet. The corresponding minimum factor of safety is 1.64 (side force inclination = 11.2 degrees). This value for the factor of safety (1.64) is approximately 5 percent higher than the value (1.56) which was calculated with no negative pore water pressures. However, negative pore water pressures are not normally relied on for slope stability.

Computation Series Nos. 4, 5 and 6

The next three series of computations are performed with pore water pressures defined using a constant value of the pore water pressure coefficient r_u. Values for r_u of 0.13, 0.21 and 0.26 are used for Computation Series Nos. 4, 5 and 6, respectively. These values of r_u represent average values of r_u which were calculated by averaging values over selected areas of the slope in the manner first suggested by Bishop and Morgenstern (1960). The averaged values were obtained by first calculating values of r_u at selected points, using the pore water pressure from the piezometric line shown in Fig. 5.3 and the corresponding overburden pressure at the selected point. The selected points represent the approximate centroids of rectangular or triangular subdivisions of the slope as illustrated in Fig. 5.5. The extent of the region which was subdivided into triangles and rectangles was varied. In the first case the region

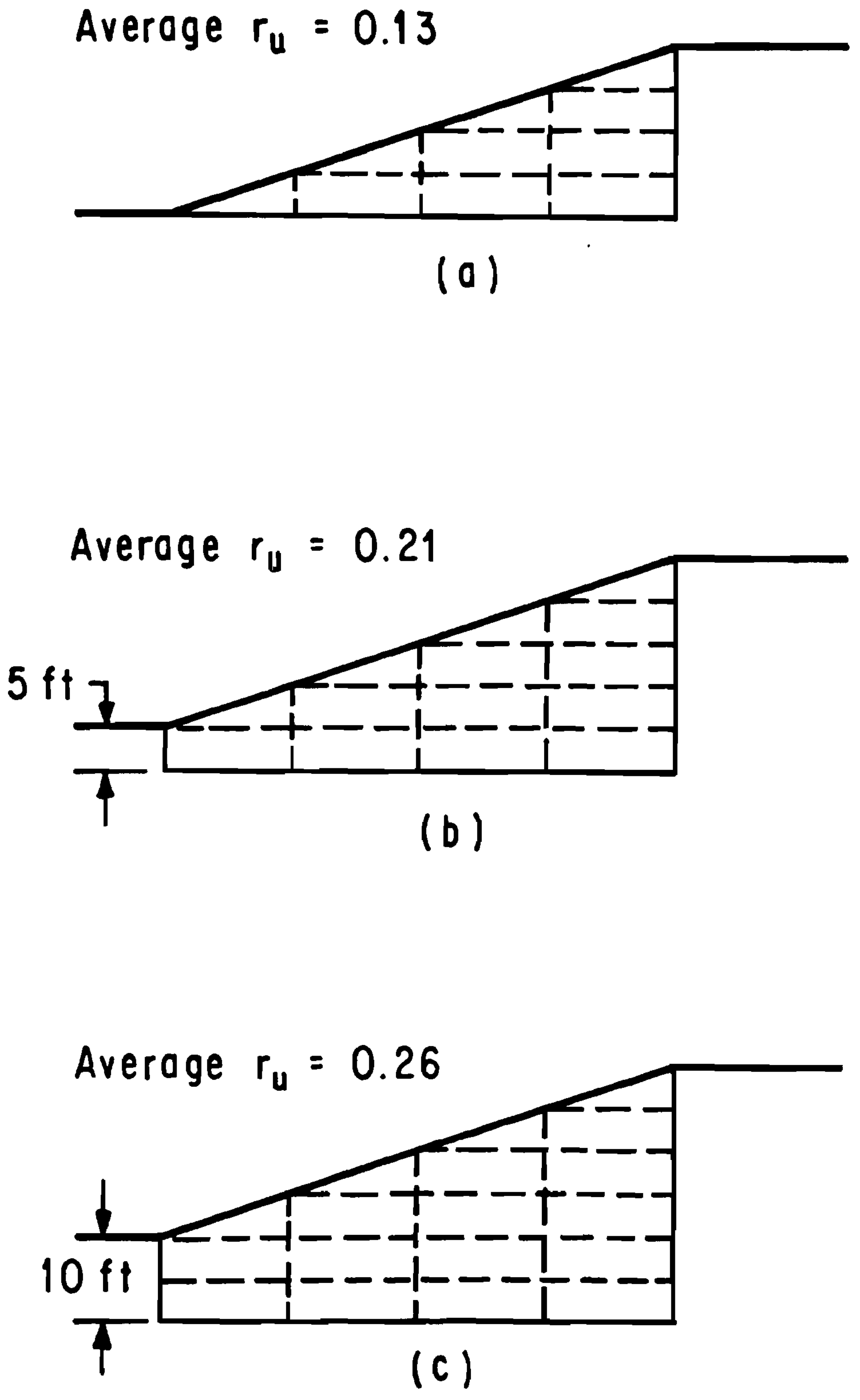

Figure 5.5 - Subdivision Regions Used to Average Values of r_u for Example Problem D - Computation Series Nos. 4, 5 and 6.

consisted of the area beneath the slope face down to the level of the toe of the slope as shown in Fig. 5.5a. In the second case, the region included the region shown in Fig. 5.5a, plus an additional area extending to a depth below the slope equal to 25 percent of the slope height, as shown in Fig. 5.5b. In the third case, the region extended to an even greater depth below the slope, equal to 50 percent of the slope height, as shown in Fig. 5.5c. Once values of r_u were calculated at the centroids of each triangular or rectangular area an overall average value of r_u for the slope was calculated by averaging values from the subdivided areas (weighted based on the size of the area).

The coordinates for the center of the critical circles found for each value of r_u and the corresponding factors of safety (and side force inclination) are summarized in Table 5.1. The critical circle for Computation Series No. 5 (r_u = 0.21 - intermediate value) is shown in Fig. 5.6.

COMPARISON OF FACTORS OF SAFETY FOR SHORT-TERM AND LONG-TERM STABILITY

The factors of safety calculated for the long-term stability condition are all lower than the factors of safety calculated for the short-term stability condition, regardless of the pore water pressures used. This reflects the fact that the soil will probably swell with time and the factor of safety will diminish. In such cases the slope will frequently fail a number of years after it has been completed.

TABLE 5.1. SUMMARY OF LONG-TERM STABILITY COMPUTATION SERIES NOS. 4, 5 AND 6 FOR EXAMPLE PROBLEM D

	Critical Circle Information			Minimum Factor of Safety	Side Force Inclination (degrees)
Pore Water Pressure Coefficient, r_u	X-Coordinate of Center (feet)	Y-Coordinate of Center (feet)	Radius (feet)		
0.13	14.5	66.5	68.1	1.83	15.5
0.21	15.0	65.5	67.2	1.69	15.4
0.26	15.0	65.5	67.2	1.60	15.3

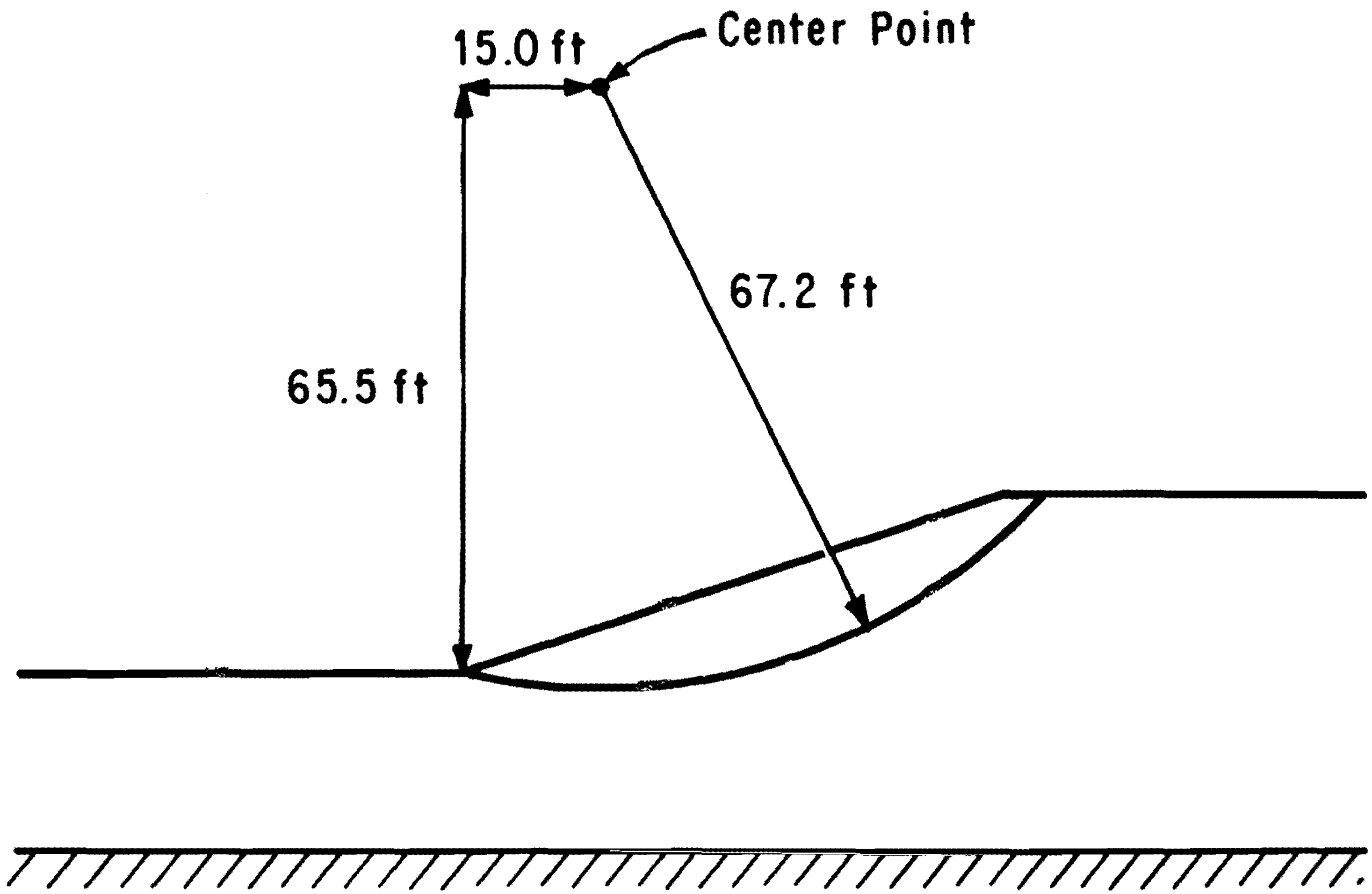

Figure 5.6 - Most Critical Circular Shear Surface from Long-Term Stability Computation Series No. 5 for Example Problem E.

SECTION 6

EXAMPLE PROBLEM E - EMBANKMENT ON FOUNDATION WITH WEAK STRATUM

INTRODUCTION

Example Problem E consists of a cohesionless earth fill embankment resting on a foundation containing a relatively weak, thin clay stratum as shown in Fig. 6.1. This example is taken from the FHWA "Soils and Foundations Workshop Manual" by Cheney and Chassie (1982). The embankment is 30 feet high and has 2(horizontal)-to-1(vertical) side slopes. The embankment consists of sand having a total unit weight of 120 pcf and an angle of internal friction of 30 degrees.

The foundation for the embankment is predominately sand with a 5 foot thick clay stratum located between the depths of 10 and 15 feet. The sand in the foundation has an angle of internal friction of 30 degrees. The groundwater table is located at the top of the clay layer at a depth of 10 feet, except for Computation Series No. 7, where the effect of a rise in the water table is examined. The total unit weight of the sand above the water table is 120 pcf; below the water table the sand has a submerged unit weight of 60 pcf. The clay stratum is saturated. The undrained shear strength of the clay is 250 psf (i.e. $c = 250$ psf, $\phi = 0$). The clay is submerged and has a submerged unit weight of 37.6 pcf (total unit weight = 100 pcf).

Only the short-term stability condition was considered by Cheney and Chassie (1982) for this example and, thus, only the short-term stability condition is considered for the computations presented herein. However, as previously

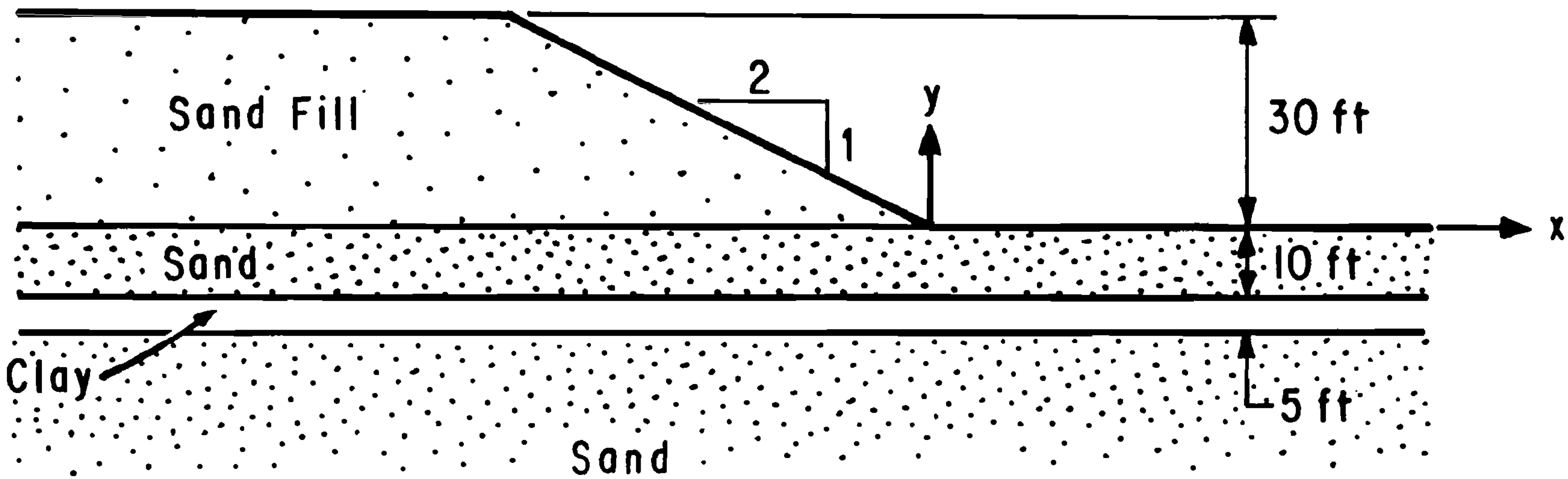

Figure 6.1 - Cross-Section of Slope and Coordinate Axes for Example Problem E.

shown and discussed for Example Problem C, the short-term stability condition is often the most critical stability condition for embankments on weak foundations, like the embankments considered in this example and Example Problem C.

COMPUTATION SERIES NO. 1

The first series of computations is performed using a single, selected noncircular shear surface. The noncircular shear surface used is shown in Fig. 6.2 and is essentially identical to the shear surface used by Cheney and Chassie (they considered only one shear surface for all of their computations). The shear surface passes downward from the crest of the embankment as a plane through the embankment and upper sand portion of the foundation, then horizontally along the top of the clay, and finally exits upward through the upper sand of the foundation as another plane surface.

The factor of safety computed for the shear surface shown in Fig. 6.2, using the computer program UTEXAS, is 1.20 (side force inclination = -10.6 degrees). This value for the factor of safety (1.20) is significantly higher than the value of 1.03 which is reported by Cheney and Chassie. The difference in values (1.20 versus 1.03) for the factor of safety occurs because different theoretical procedures have been used to compute the factor of safety. The procedure used by Cheney and Chassie to compute the factor of safety is a "force equilibrium" procedure, which is approximate and has been found to consistently produce lower values for the factor of safety than the more rigorous procedures used in the computer program, UTEXAS.

COMPUTATION SERIES NO. 2

The second series of computations consists of performing an automatic search to locate a critical circular shear surface. The search is initiated by finding the most critical circle tangent to a line coinciding with the bottom

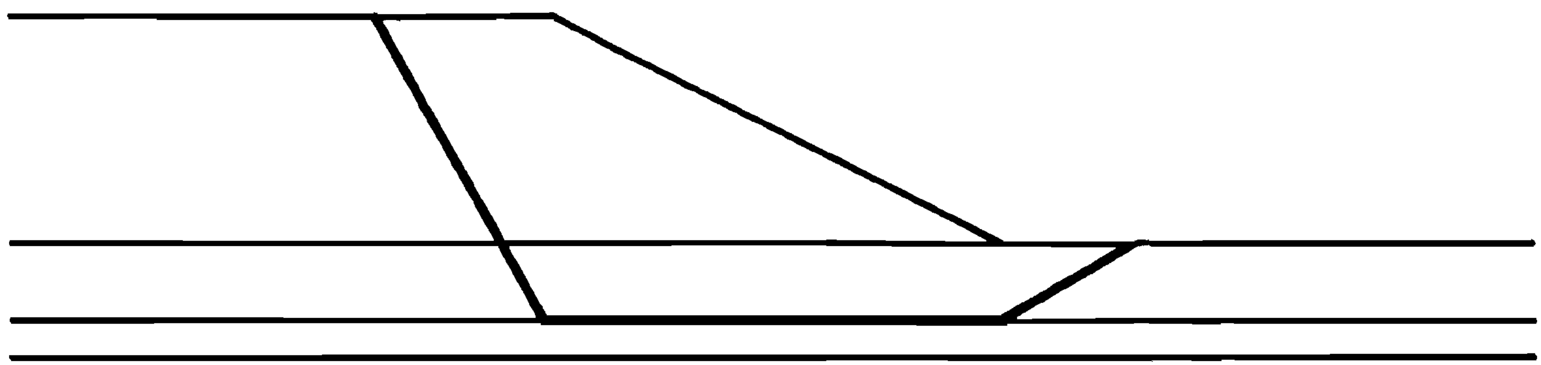

Figure 6.2 - Single Noncircular Shear Surface Used for Example Problem E - Computation Series No. 1.

of the clay layer for the initial mode of search and, then, the search is permitted to continue to find a more critical circle if a more critical circle exists. The minimum grid spacing (required accuracy) specified for the search is 0.5 feet. This distance (0.5 feet) is selected to represent a small fraction of both the slope height and the thickness of the clay stratum. The distance corresponds to less than 2 percent of the slope height and is a small fraction (10 percent) of the thickness of the clay stratum.

The critical circle found by the automatic search is shown in Fig. 6.3. The critical circle has its center located at the coordinates x = -24.0, y = 40.0 and has a radius of 55.0 feet. The corresponding minimum factor of safety is 1.15 (side force inclination = 9.2 degrees). The most critical circle produces a slightly lower value for the factor of safety than the noncircular shear surface which was used in Computation Series No. 1 (1.15 versus 1.20). However, the noncircular surface used in Computation Series No. 1 is not necessarily the most critical noncircular shear surface.

COMPUTATION SERIES NO. 3

The third series of computations consists of an automatic search to locate a critical noncircular shear surface. The search is initiated with a noncircular shear surface similar in shape to the one shown in Fig. 6.2 for Computation Series No. 1, except that the horizontal portion of the shear surface passes along the bottom of the clay layer, rather than the top of the clay layer. As discussed previously for Example Problem D and illustrated by the results of Computation Series No. 2 for this current example, the most critical shear surface usually passes to the bottom of any layer where the shear strength is constant, although this is not always the case. The bottom of the clay layer was considered to be a logical starting point for the automatic search for this example.

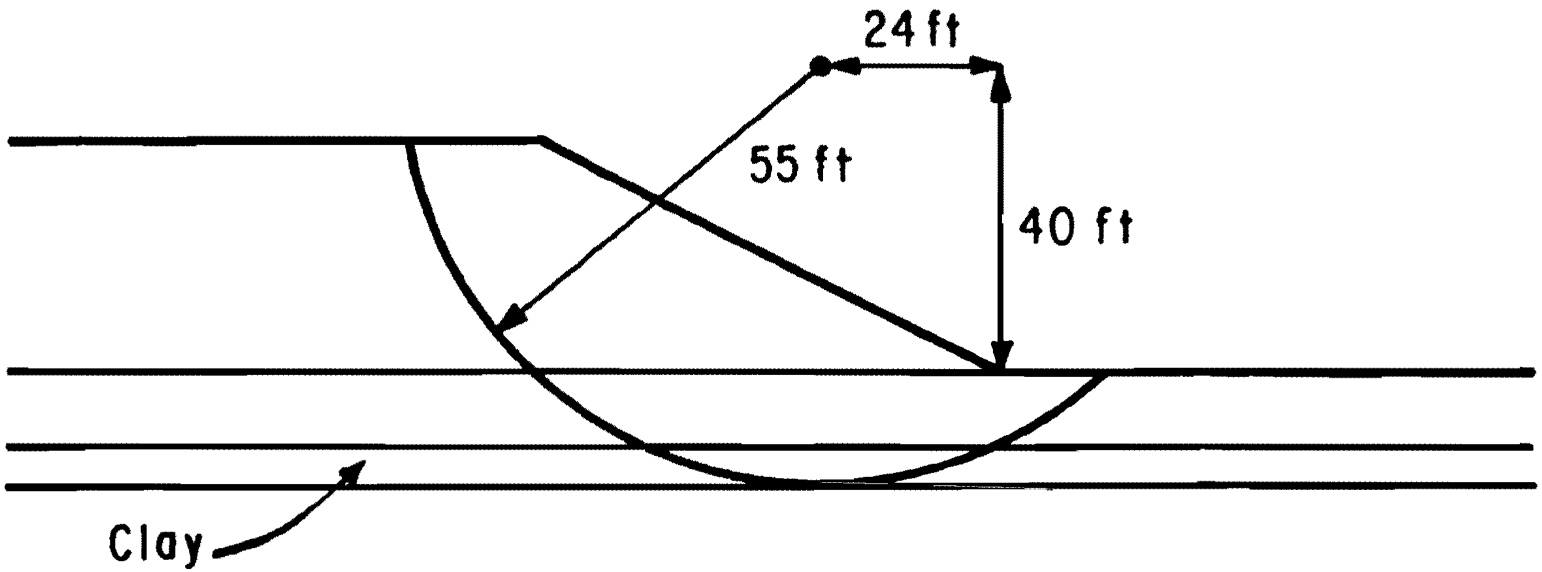

Figure 6.3 - Critical Circle Located with Automatic Search for Example Problem E.

The minimum incremental shift distance (accuracy) specified for the automatic search is 0.25 feet. This specified distance of 0.25 feet will result in an initial increment for shifting the shear surface of 1.25 feet (= 5 times 0.25). The distance is selected because it produces an incremental shift distance which is a small fraction of the thickness of the clay layer (25 percent initially and decreasing to 5 percent as a critical shear surface is approached).

The critical noncircular shear surface located by the automatic search is shown in Fig. 6.4. The factor of safety calculated for the critical noncircular shear surface is 0.93 (side force inclination = -6.3 degrees) and is approximately 19 percent less than the value (1.15) found for the most critical circular shear surface in Computation Series No. 2. Thus, a noncircular shear surface is clearly more critical for this example and should be employed in any computations which are to be used for design.

COMPUTATION SERIES NO. 4

Computation Series No. 4 is performed to determine the effect which flattening the slope would have on the factor of safety. The slope is flattened from 2:1 to 3:1 and an automatic search is performed to locate a critical noncircular shear surface. The critical noncircular shear surface is shown in Fig. 6.5 and has a factor of safety of 1.01 (side force inclination = -5.6 degrees). The effect of flattening the slope is to produce an approximately 8 percent increase in the factor of safety. Such a small increase (8 percent) in the factor of safety would probably be considered inadequate for a slope which is unstable before flattening.

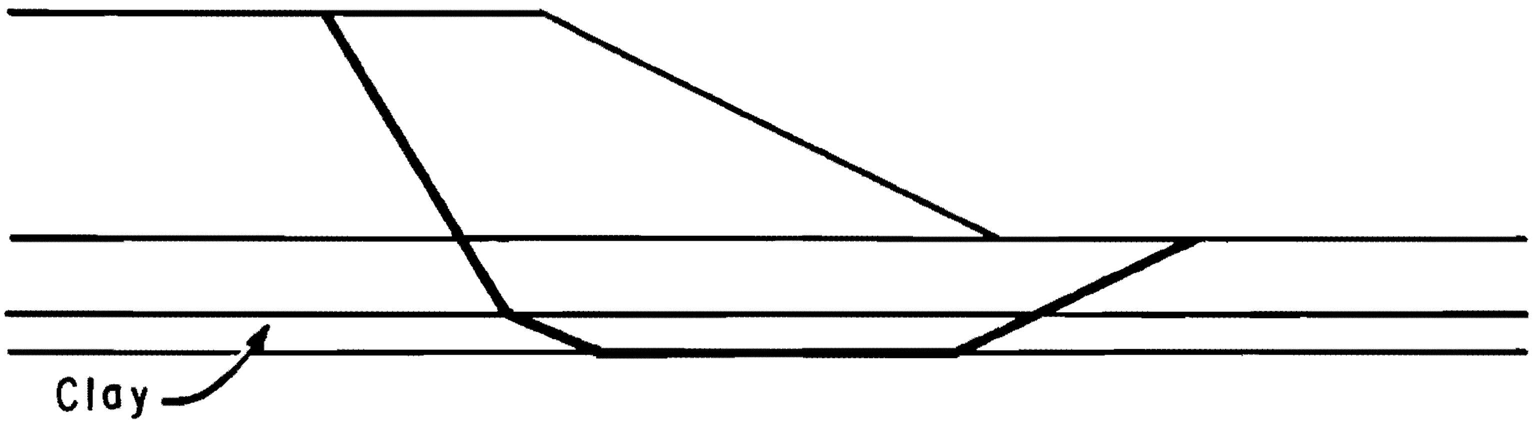

Figure 6.4 - Critical Noncircular Shear Surface Found with Automatic Search for Example Problem E.

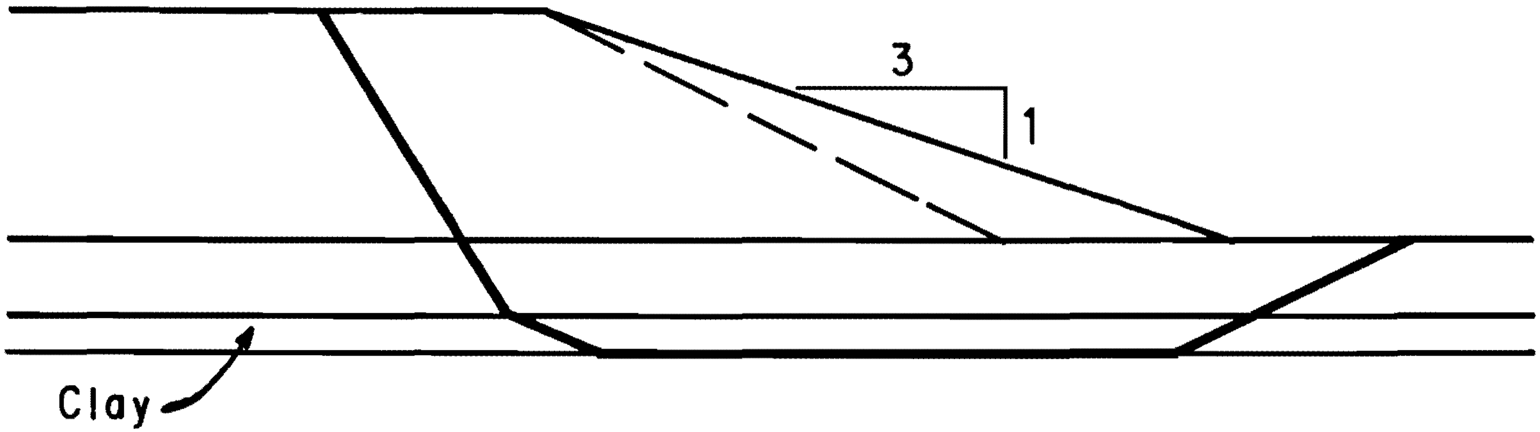

Figure 6.5 - Critical Noncircular Shear Surface Found with Automatic Search for Example Problem E when the Slope is Flattened from 2:1 to 3:1.

COMPUTATION SERIES NO. 5

This computation series is similar to the previous one (4) except that the slope is benched rather than flattened. The bench is 10 feet high and 30 feet wide as shown in Fig. 6.6. The toe of the bench is located at the same point as the toe of the slope was located when the slope was flattened for Computation Series No. 5. Thus, in both cases the same portion of the foundation is covered by the embankment and the critical shear surfaces for both cases would be expected to be similar. Consequently, the factor of safety for this computation series was computed using only the critical shear surface found in Computation Series No. 4 (shown in Fig. 6.6 and previously in Fig. 6.5). The new factor of safety is 1.02 (side force inclination = -5.7 degrees) and, as expected, is almost identical to the value of 1.01 computed for Computation Series No. 4.

COMPUTATION SERIES NO. 6

For this series of computations an alternate measure for increasing the stability of the embankment is considered: A "shear key" is placed through the clay stratum as shown in Fig. 6.7. The shear key replaces the clay with sand and the sand has identical properties to the adjacent foundation sand. The shear key is 10 feet wide. Due to the assumption of two-dimensional plane conditions, which is made in the computer program for all stability calculations, the shear key is implicitly assumed to extend along the full length of the slope, perpendicular to the plane of reference and Fig. 6.7.

The shear key in this computation series is represented in a manner somewhat similar to the manner in which "Stone Columns" (Engelhardt et al., 1974) have been represented in using the computer program in other instances. However, in the case of "Stone Columns," or any other cylindrical element placed in the cross-section, the width of the column in the cross-section must be an

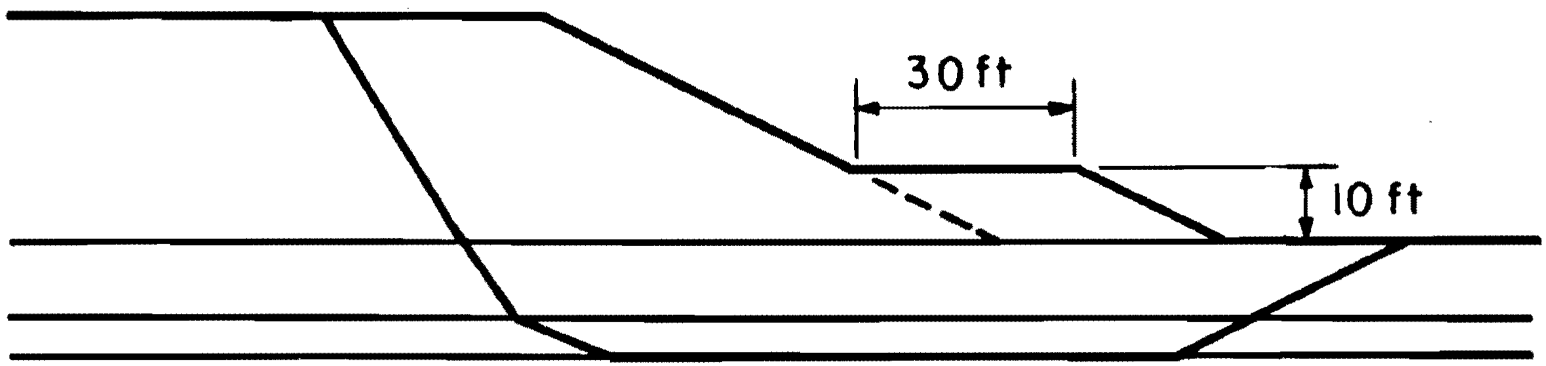

Figure 6.6 - Cross-Section of Slope for Example Problem E after Slope has been Benched.

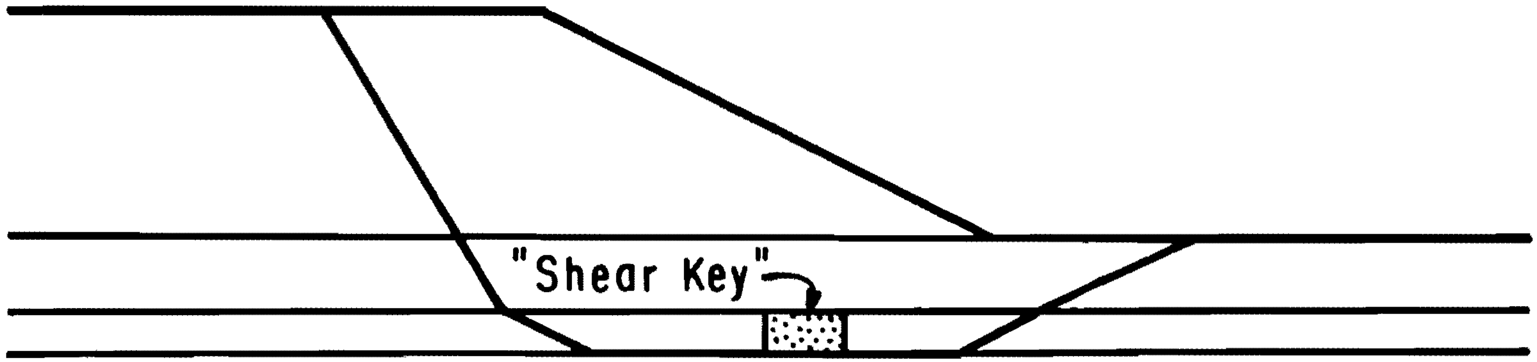

Figure 6.7 - Cross-Section of Slope for Example Problem E with "Shear Key" - Computation Series No. 6.

equivalent width. The equivalent width should be the width of a continuous "strip" having the same average amount of material per lineal distance (foot, inch, meter, etc.) of slope as the actual cylindrical elements would provide. (Stauffer and Wright, 1984)

Computations with the shear key are performed using only a single noncircular shear surface, rather than an automatic search. The shear surface employed for the computations is the same as the most critical noncircular shear surface found in Computation Series No. 3 (shown in Fig. 6.4). Although a more critical shear surface may exist, this surface is used for illustrative purposes only and is not intended to produce necessarily the minimum factor of safety. The factor of safety calculated with the selected noncircular shear surface is 1.18 (side force inclination = -8.7 degrees). This value of (1.18) is approximately 27 percent higher than the value calculated for the slope without the shear key and indicates that if such a key could be constructed, it could potentially have a significant effect on stability. Before such an alternative is adopted, an automatic search should be performed to locate the appropriate critical shear surface.

COMPUTATION SERIES NO. 7

The final set of computations is performed to determine the effect of a rise in the water table from a depth of 10 feet below the ground surface (top of clay) to the ground surface. In the input data file it can be seen that the "shear key" from Computation Series No. 6 is replaced with clay to return the foundation to its original condition and the upper sand is assigned a submerged unit weight of 60 pcf which is used for all previous computations.

Computations are performed using the most critical noncircular shear surface found in Computation Series No. 3 where the water table was at its lower location, 10 feet below the ground surface. This single shear surface is selected and used to reduce the computations required for this illustrative example, but ordinarily an automatic search would have been performed. The factor of safety for the shear surface considered is 0.80 (side force inclination = -7.9 degrees). This value (0.80) is approximately 14 percent lower than the value (0.93) determined when the water table was at a depth of 10 feet below the ground surface. If a critical shear surface had been located for the current computation series, the differences in the factors of safety would have been even greater. Thus, fluctuations in the ground water level could have a potentially significant effect on the stability of the embankment.

SECTION 7

EXAMPLE PROBLEM F - "NATURAL" SLOPE

INTRODUCTION

Example Problem F consists of a slope which could be either a natural or an excavated slope. The example slope is taken from the user's manual for the slope stability computer program, STABL, by Siegel (1978). The example problem is selected to provide a comparison with results obtained using another slope stability computer program (STABL) to provide an additional example problem, which could be representative of a natural slope.

A cross-section of the slope for example Problem F is shown in Fig. 7.1. The slope consists primarily of a relatively homogeneous stratum of soil which is underlain by rock and overlain by approximately 11 feet of relatively weak soil. The underlying rock is considered to have sufficient strength to prevent any potential sliding surface from passing through the rock. Thus, the actual strength of the rock is immaterial; a shear strength of 200,000 psf is assigned to the rock for the stability computations.

All of the stability computations for this problem are performed for the long-term condition using effective stresses. As shown previously for Example Problem D, the long-term stability condition is usually more critical than the short-term stability condition for an excavated slope. For a natural slope only the long-term stability condition has any meaning. Thus, regardless of whether the slope in this example is an excavated or a natural slope, the long-term stability condition would probably be of most interest.

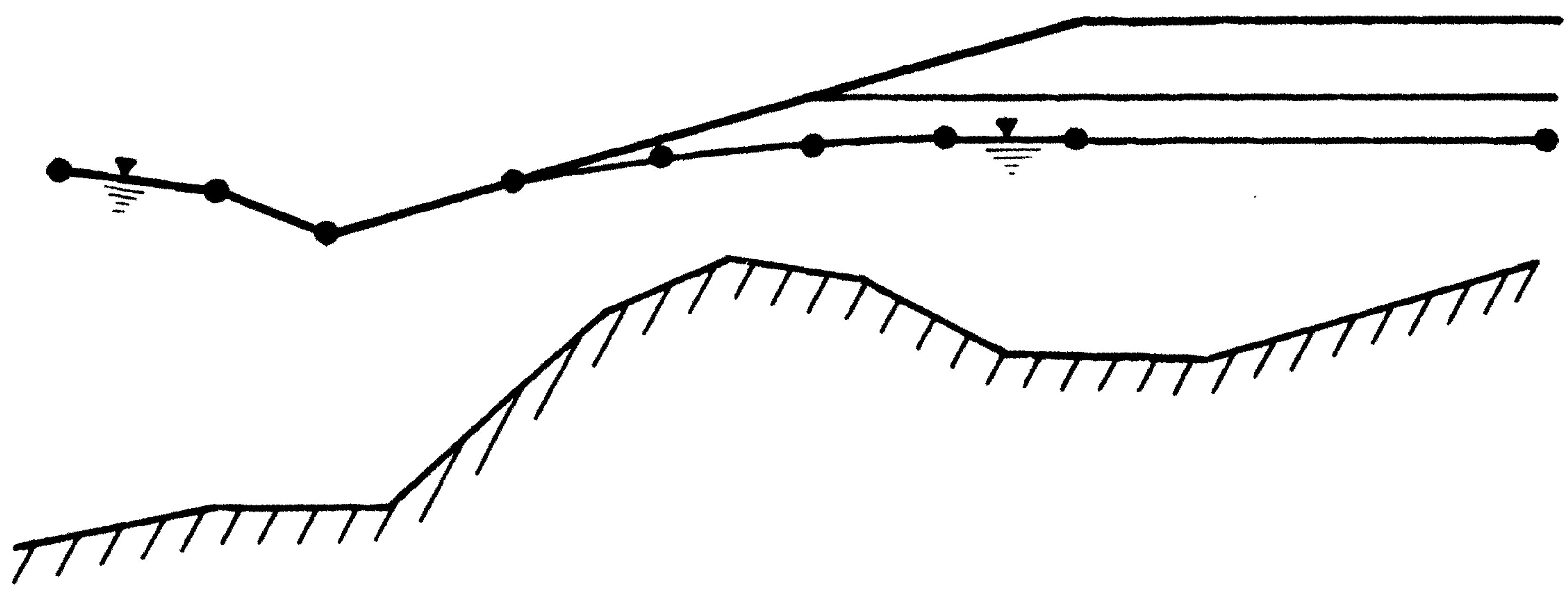

Figure 7.1 - Cross-Section of Slope and Coordinate Axes for Example Problem F.

The intermediate clay stratum which comprises most of the slope material in this example contains a free water surface (water table) which is shown in Fig. 7.1. The pore water pressures are assumed to be zero above the water surface; below the water surface the pore water pressures are assumed to be equal to the vertical depth below the water surface times the unit weight of water. Thus, the water surface is a piezometric line for the soil below the water surface. The intermediate clay stratum has total unit weights of 116.4 pcf above the water surface and 124.2 pcf below the water surface. The shear strength parameters for the intermediate stratum of clay were apparently determined from either consolidated-drained (CD, S) tests or consolidated-undrained (CU, R) tests with pore water pressure measurements. The effective stress shear strength parameters for the clay are $\bar{c}$ = 500 psf and $\bar{\phi}$ = 14 degrees.

The shear strength for the uppermost stratum is considered to be negligible and is covered in further detail in the discussion of the various Computation Series below. Four series of stability computations are performed for this example problem.

COMPUTATION SERIES NO. 1

The first series of computations is performed assuming that the uppermost stratum of soil has zero shear strength and a total unit weight of 116.4 pcf. This is identical to what Siegel (1978) also assumed. Computations are performed for the single shear surface shown in Fig. 7.2. This shear surface is identical to one reported by Siegel (1978) to be a "most critical" shear surface for an initial series of trial computations, which Siegel referred to as a "first run." The factor of safety computed for this surface using the current slope stability computer program (UTEXAS) is 1.42 (side force inclination = 16.4 degrees). This value for the factor of safety (1.42) is aproximately 7

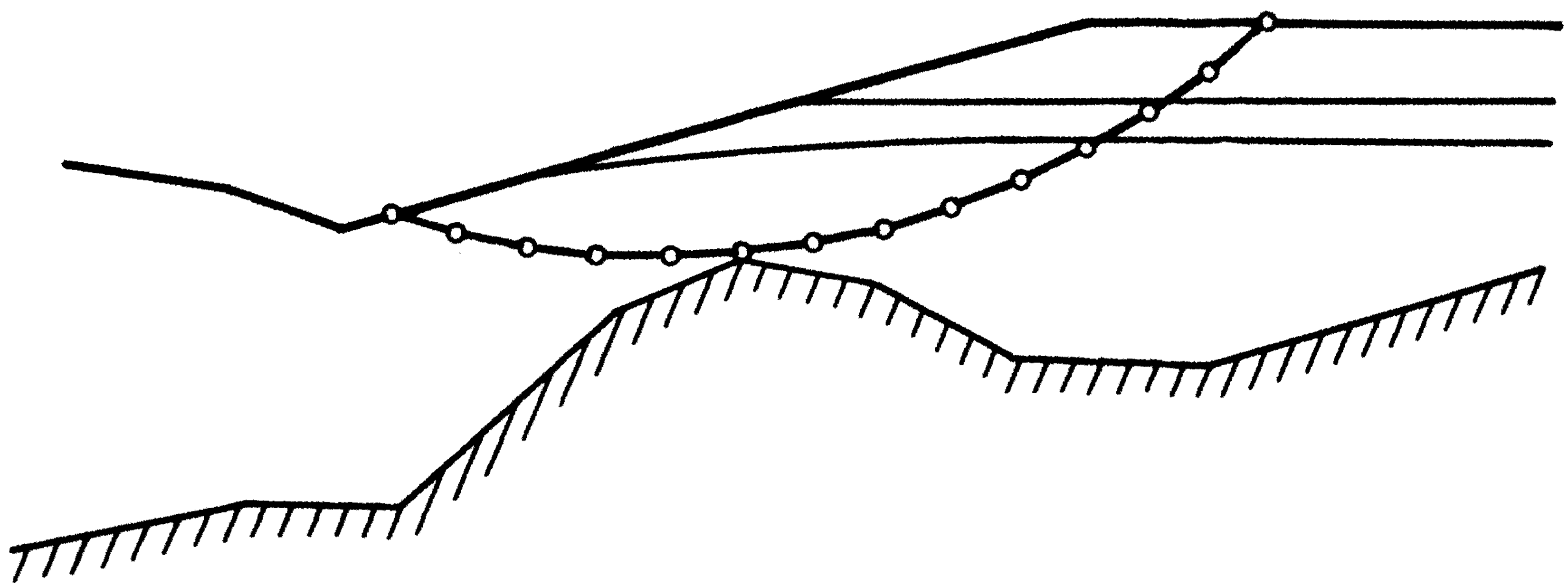

Figure 7.2 - Single Shear Surface Obtained by Siegel (1978) for Example Problem F.

percent higher than the value of 1.325 reported by Siegel. Such a difference (7 percent) is to be expected because the procedure used by Siegel to compute the factor of safety is an approximate procedure which does not satisfy static equilibrium completely. The procedure used by Siegel has been shown to consistently produce lower values for the factor of safety than those computed by the theoretical procedure (Spencer's) used in UTEXAS, which fully satisfies static equilibrium.

COMPUTATION SERIES NO. 2

The second series of computations is performed to locate a most critical circular shear surface using the same material properties as those used in Computation Series No. 1. A search is initiated by locating the most critical circle passing through a point near the toe of the slope; the search is then allowed to continue to determine if a more critical circle than the one through the toe of the slope exists. The minimum grid spacing specified for the search is 1 foot. This distance corresponds to approximately 2 percent of the slope height and is only a small fraction of the thickness of any strata. Accordingly, good accuracy is expected.

The center of the most critical circle is found to be at x = 61.0, y = 190.0 and the corresponding radius is 129.1 feet. The critical circle is shown in Fig. 7.3. It can be seen that the circle is limited in the depth to which it passes by a portion of the underlying rock foundation. The factor of safety for the critical circle is 1.37 (side force inclination = 17.0 degrees).

COMPUTATION SERIES NO. 3

Computation Series No. 3 is performed to locate a critical noncircular shear surface. However, because the upper portion of the soil in the cross-section shown in Fig. 7.1 is considered to have zero strength a search

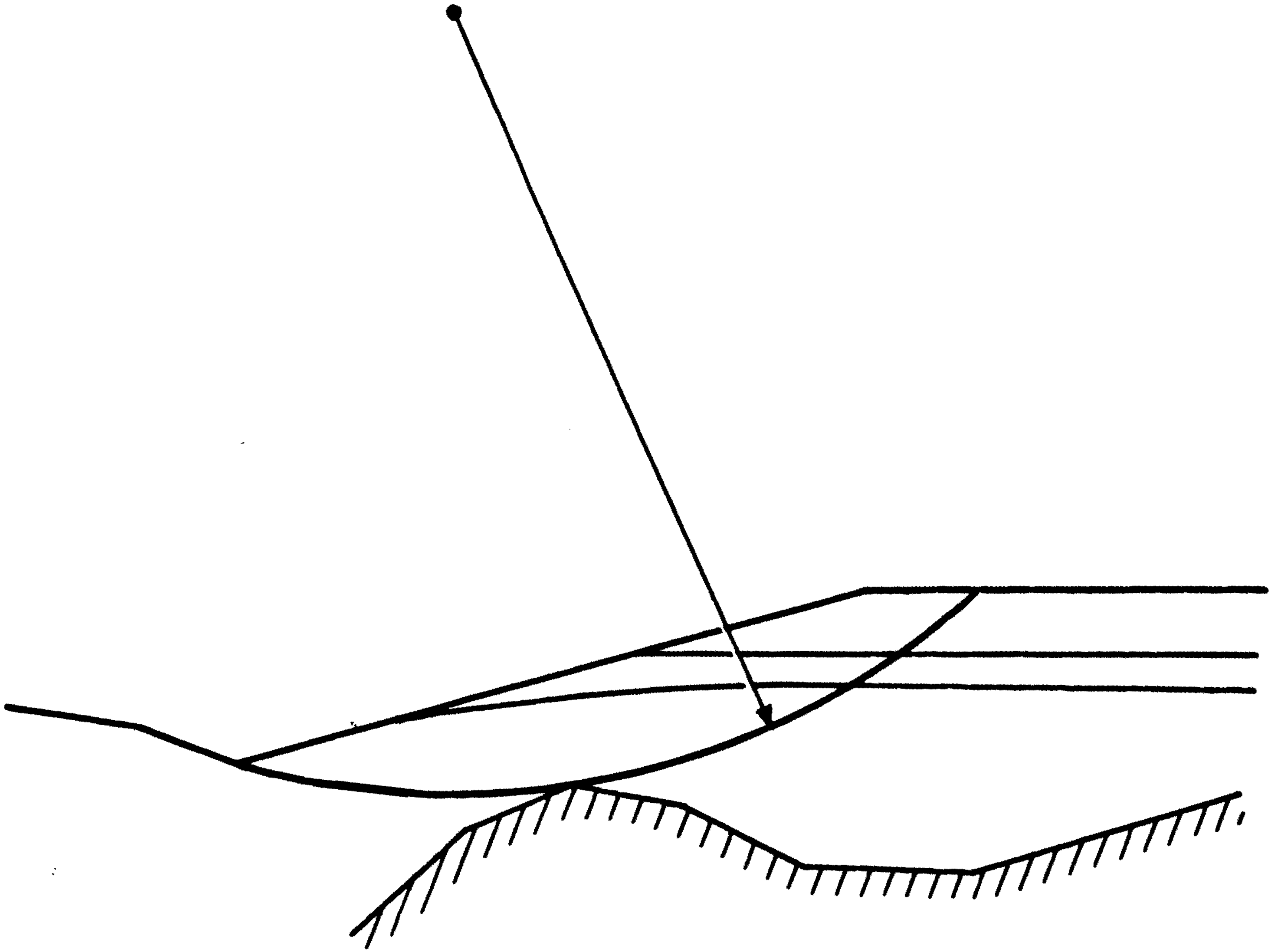

Figure 7.3 - Critical Circular Shear Surface for Example Problem F.

for a critical shear surface can be meaningless. That is, the search may cause the shear surface to migrate to entirely within the zero strength zone where the factor of safety is zero and an obvious minimum. This, in fact, occured when an automatic search for a critical noncircular shear surface was first attempted for this example, although no such similar problem was encountered with the automatic search for the critical circle in Computation Series No. 2. Accordingly, for a search for the critical noncircular shear surface to be meaningful, the zero strength zone needs to be treated in a different manner. For the present computations the upper, zero strength zone is replaced by an equivalent series of surface pressures applied at the top of the intermediate clay stratum as shown in Fig. 7.4. The surface pressures applied consist of both a normal stress and a shear stress to account for the sloping surface, along which the surface pressures are applied. The surface pressures are calculated using "infinite slope" procedures to determine the normal and shear components of stress as shown in Fig. 7.4. (Note: The shear component is considered to be negative in the input data because it acts to the left.)

The automatic search to locate the critical noncircular shear surface is initiated using approximately the same shear surface used in Computation Series No. 1 as a starting point. The minimum incremental shift distance specified in the input data is 0.5 feet.

The most critical noncircular shear surface located is shown in Fig. 7.5. The effect of a protruding segment of the rock foundation on the position of the critical shear surface can be clearly seen in this figure. The factor of safety for the most critical noncircular shear surface found is 1.45 (side force inclination = 14.0 degrees).

The value for the factor of safety (1.45) for the critical noncircular shear surface found in Computation Series No. 3 is greater than the value for

Normal Stress, $\sigma = \gamma \cdot h \cdot \cos^2 \beta$

Shear Stress, $\tau = \gamma \cdot h \cdot \sin \beta \cdot \cos \beta$

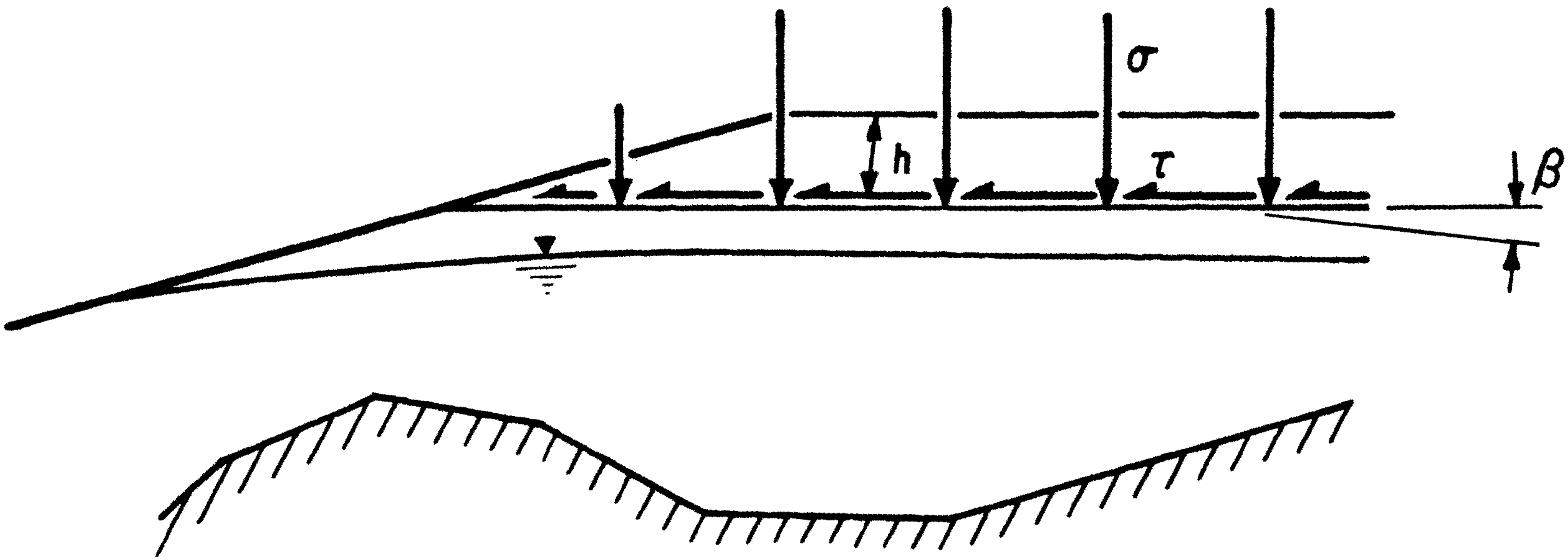

Figure 7.4 - Surface Pressures Used to Replace Zero Strength Stratum in Example Problem F.

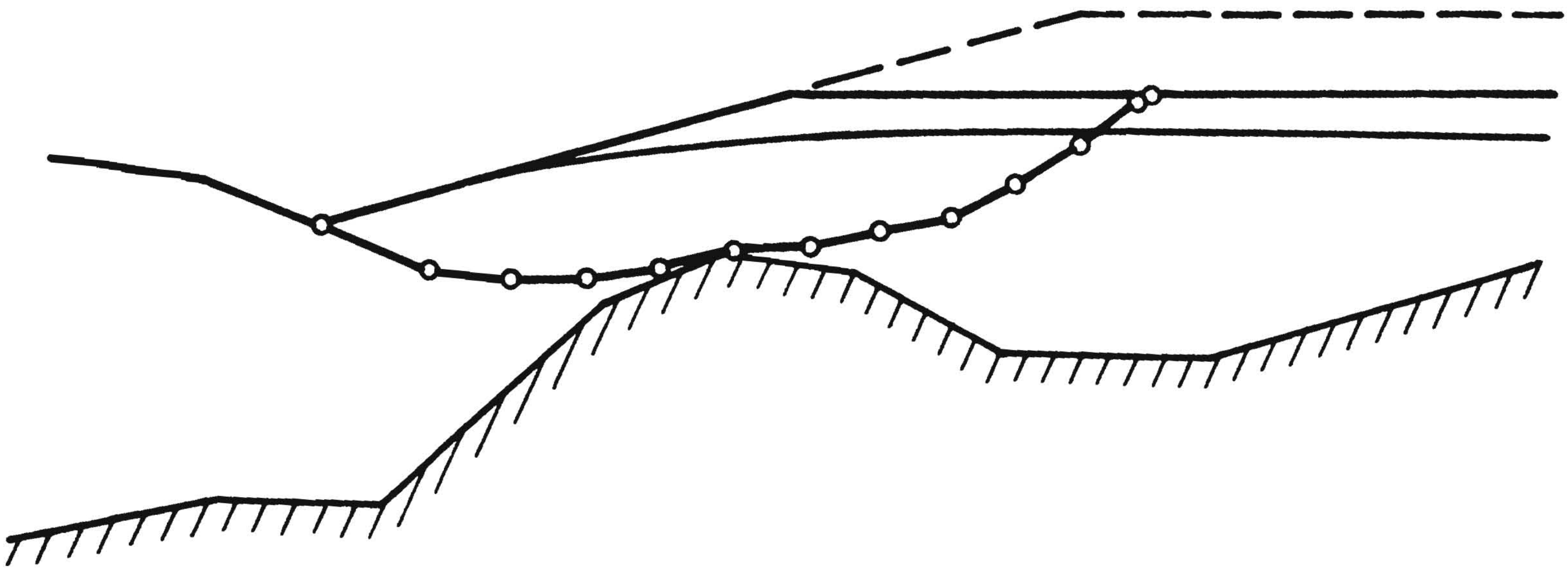

Figure 7.5 - Critical Noncircular Shear Surface Found for Example Problem F.

the critical circle found in Computation Series No. 2. However, this does not suggest that a circle is a more critical shear surface. Instead, a difference exists between the two sets of computations due to the fact that with the circular shear surface the overburden was assigned zero shear strength, while for the noncircular shear surface the overburden was treated as a surcharge. In the first case, where a circular shear surface and zero strength overburden is used, a significant horizontal stress is exerted by the overburden; in the second case, where the noncircular shear surface is used and the overburden is represented by surface pressures, no such horizontal thrust is exerted by the weak overburden. Thus, this problem illustrates the effect of horizontal thrust in surface materials in a way which is similar to what was shown for Example Problem C, where the embankment was treated both as a surcharge and as a zero strength material.

COMPUTATION SERIES NO. 4

The fourth series of computations is performed using the same conditions used for Computation Series No. 3, with the upper, weak soil represented as a surcharge, except that an automatic search is performed to locate a critical circular shear surface. Results of this series of computations can be compared with those of Computation Series No. 3 to determine the effect of the assumed shapes of the shear surface alone, independently of treatment of the weak overburden. The search for a critical circle is performed in the same manner as the search performed for Computation Series No. 2, only the slope profile is changed (Surface pressures versus zero strength overburden).

The critical circle for Computation Series No. 4 has a center at the coordinates x = 61.0, y = 193.0 and a radius of 132.0 feet. the corresponding minimum factor of safety is 1.49 (side force inclination = 154.2 degrees). This factor of safety (1.49) is greater than the value determined for the circular shear surface in Computation Series No. 2 because the surface pressures do not reflect the horizontal thrust which would be applied by the zero strength material. However,clearly no material with zero strength could remain at the slope angle of approximately 22 degrees shown in Fig. 7.1 and, thus, the results of Computation Series No. 2 are perhaps of little practicial interest. Comparison of the results of Computation Series Nos. 3 and 4 shows that the computations employing a noncircular shear surface produced only a slightly lower value for the factor of safety than the computations employing a circular shear surface: 1.45 versus 1.49.

The critical circle found for Computation Series No. 4 is shown in Fig. 7.6. Also shown in this figure (broken line) is the critical noncircular shear surface from Computation Series No. 3. The two critical shear surfaces can be seen to be very similar. The close similarity between the two surfaces and the corresponding factors of safety suggest that a circular shear surface could have been assumed for the computations for this problem with little loss of accuracy. In fact, in virtually all cases where the slope is as homogeneous as the slope considered in this example, circular shear surfaces are adequate for computing the factor of safety.

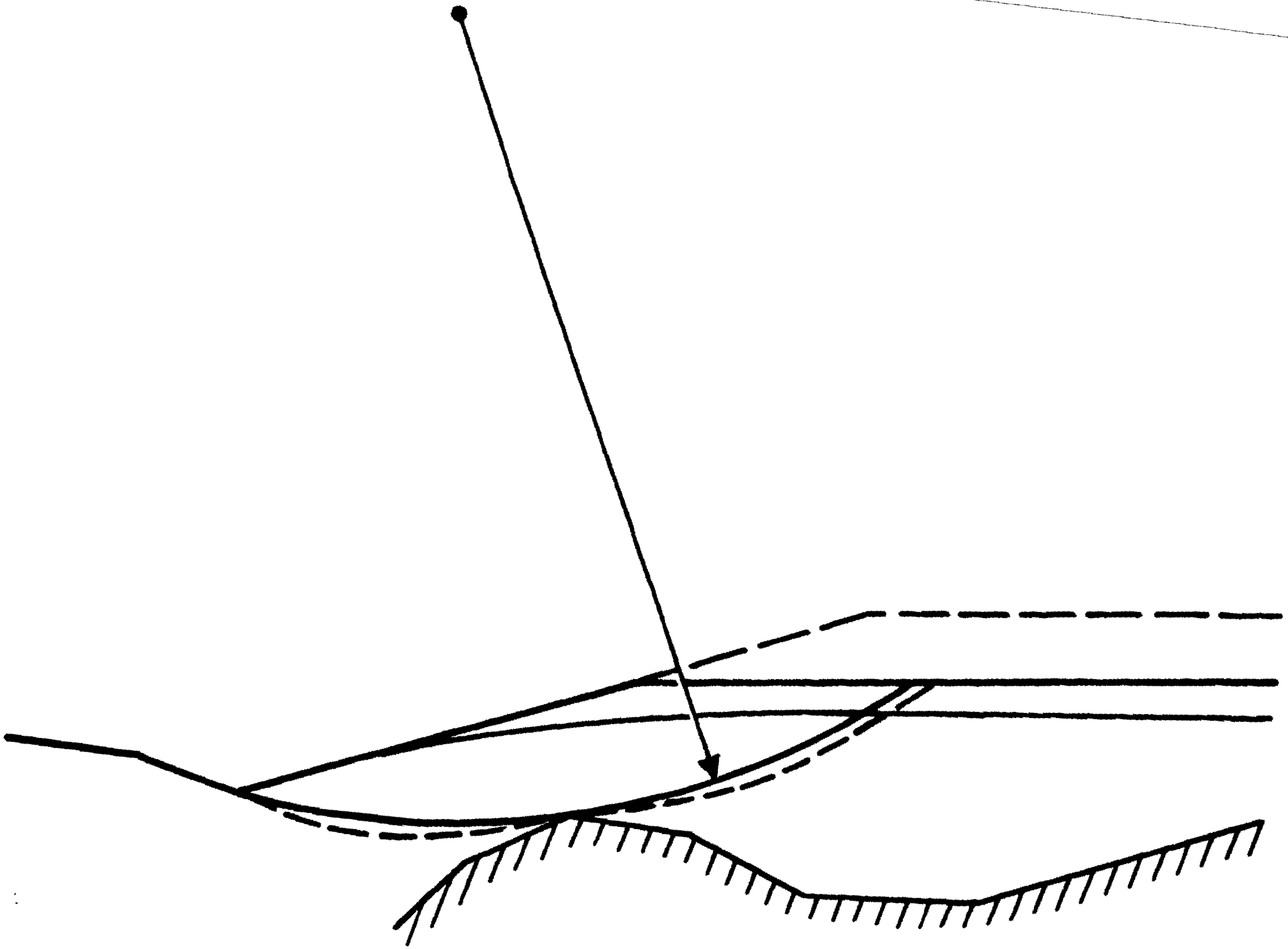

Figure 7.6 - Critical Circular Shear Surface for Example Problem F with Weak Overburden Treated as a Surcharge.

SECTION 8

EXAMPLE PROBLEM G - PARTIALLY SUBMERGED SLOPE

INTRODUCTION

This example consists of a series of stability computations for a partially submerged slope. The slope is 20 feet high and has a 2.5(horizontal)-to-1(vertical) side slope. The slope is homogeneous and the foundation has the same properties as the slope. The water level is 15 feet above the toe of the slope (5 feet below the crest of the slope). A cross-section of the slope and the coordinate axes are shown in Fig. 8.1.

All stability calculations for this example are performed for the long-term stability condition, which in most cases will be more critical than the short-term stability condition. The shear strengths are determined from either consolidated-drained (CD, S) or consolidated-undrained (CU, R) tests with pore water pressure measurement. The shear strength parameters are expressed in terms of effective stresses. The effective stress cohesion value is 100 psf and the effective stress friction angle is 18 degrees. The soil is saturated both above and below the water surface; the saturated (total) unit weight of soil is 124 pcf.

Three series of stability computations are performed. The three series of computations differ only in the way in which the water is represented for the analyses. All three series should produce essentially identical values for the factor of safety.

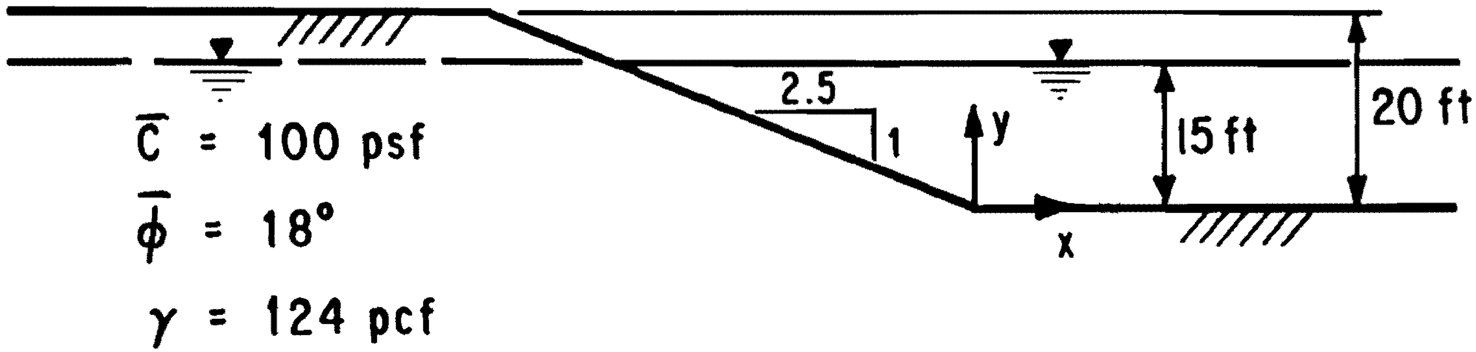

Figure 8.1 - Cross-Section of Partially Submerged Slope for Example Problem G.

COMPUTATION SERIES NO. 1

The first series of computations is performed using submerged unit weights for the soil below the water level and total unit weights above the water level. The submerged unit weight of soil is 61.6 pcf (= 124 - 62.4 pcf). By using submerged unit weights for the soil below the water level, the effect of the water on the effective stresses AND the effect of the water loads on the face of the slope are both automatically accounted for in the equilibrium equations used to compute the factor of safety.

An automatic search is performed to locate the most critical circle through the toe of the slope. As discussed for Example Problem A, the most critical circle for a homogeneous slope, like the slope in this example, usually passes through the toe of the slope. Accordingly, and to reduce the computational effort required for this illustrative example problem, the search is terminated once the critical circle through the toe of the slope is found.

The most critical circle found for the first series of computations is shown in Fig. 8.2. The circle has its center point at the coordinates x = -16.0, y = 51.5, and the radius is 53.9 feet. The corresponding factor of safety is 1.48 (side force inclination = 17.0 degrees).

COMPUTATION SERIES NO. 2

The second series of computations is performed using total unit weights and the pore water pressures are defined using a piezometric line. When total unit weights and pore water pressures are used, any external loads on the slope due to water must also be defined. Accordingly, "surface pressures" are used to define the water loads imposed on the slope by the partial submergence. Even though the piezometric line data reflect the fact that there is water above the slope, the piezometric line data do not result in the application of

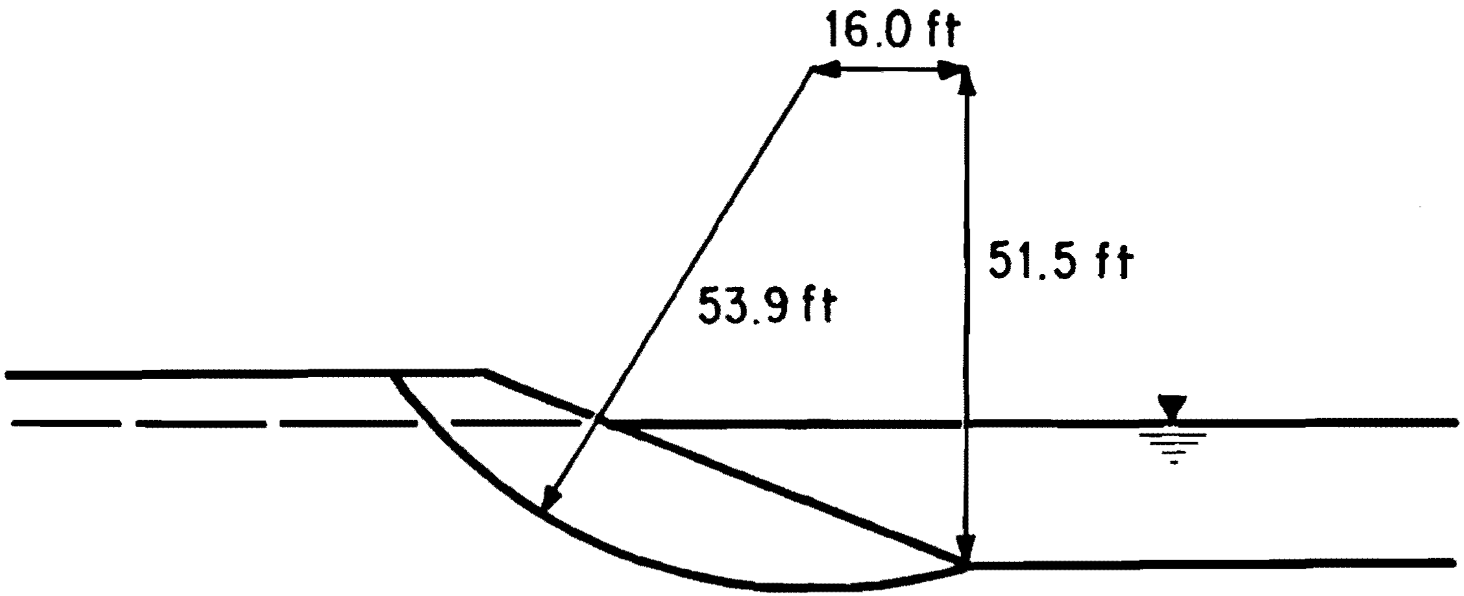

Figure 8.2 - Critical Circle for Example Problem G - Computation Series No. 1 (Also Computation Series Nos. 2 and 3).

surface pressures; separate surface pressure data are required to define the external loads.

For the second series of computations it is more convenient to start the input data anew, rather than modify the data from the previous series of computations. Thus, a line of asterisks (*****) appears in the input data file separating the data for Computation Series No. 2 from the data for Computation Series No. 1.

The computations for Computation Series No. 2 employ an automatic search with parameters identical to those used in the first series of computations. The center of the critical circle is found to be at the coordinates x = -16.0, y = 51.5 and the radius is 53.9 feet. The factor of safety is 1.48 (side force inclination = -7.2 degrees).

COMPUTATION SERIES NO. 3

The third series of computations is identical to the second series except that the pore water pressures are defined using the interpolation option available in UTEXAS. In the input data pore water pressures are defined at 6 discrete points as shown in Fig. 8.3. The points are at three levels: the crest of the slope, the water surface, and a point twenty feet below the toe of the slope. The location of the points was chosen to insure that there would always be at least one point in each of the four quadrants surrounding any point on a potential sliding surface. The value of the pressure at each level where points are input is the same for all points in the horizontal direction; the value of the pressure (u) is also shown in Fig. 8.2. Because of the linear nature of the interpolation function used in the computer program to calculate pore water pressures, the pore water pressures calculated from the points shown

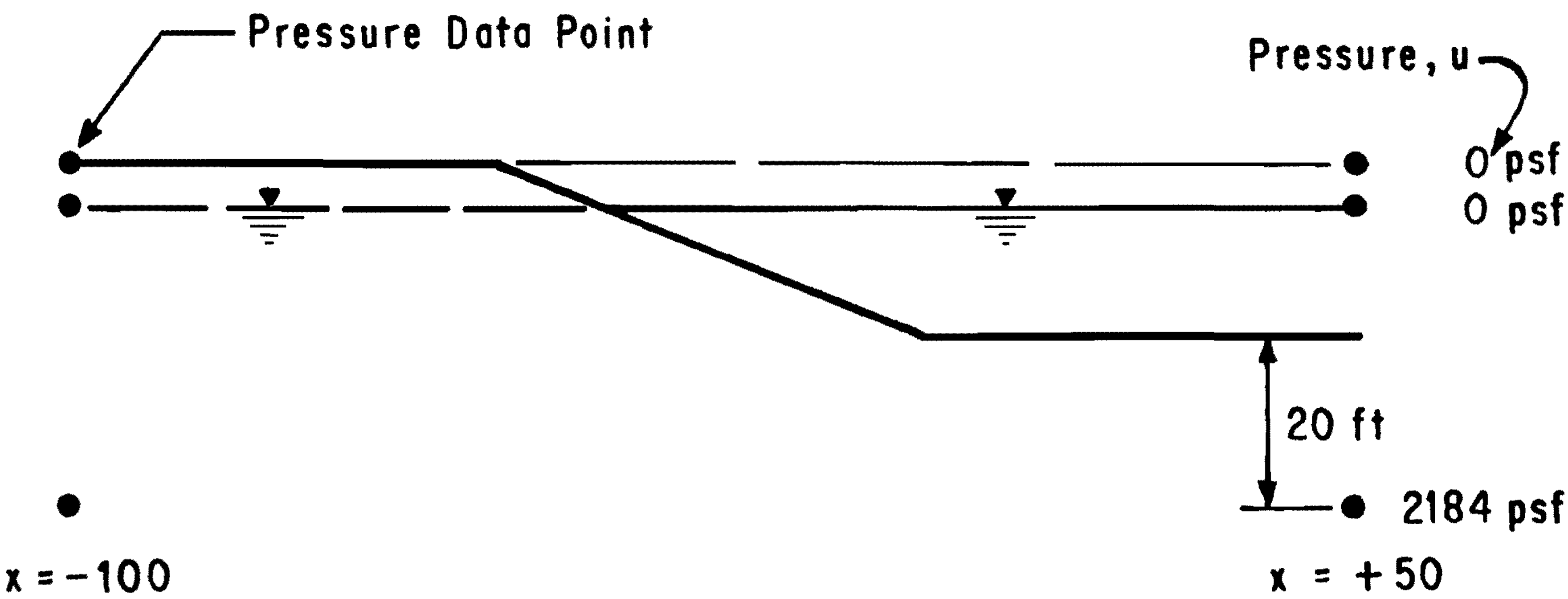

Figure 8.3 - Points Where Pore Water Pressures are Defined for Interpolation in Example Problem G - Computation Series No. 3

in Fig. 8.2 will be identical to those calculated using the piezometric line in Computation Series No. 2.

The center of the critical circle in Computation Series No. 3 is at x = -16.0, y = 51.5 and the radius is 53.9 feet. The factor of safety is 1.48 (side force inclination = -7.2 degrees).

COMPARISON OF RESULTS FROM COMPUTATION SERIES NOS. 1, 2 AND 3

The first series of computations was performed using submerged unit weights, while the second two series of computations were performed using total unit weights and water pressures (pore pressure and surface pressure). As expected, the three series of computations yield essentially identical results; the factors of safety differ in only the fourth significant figure (1.480 for the first series versus an identical 1.484 for each of the second two series).

The inclination of the side forces between slices is significantly different from the first to the second two computation series (-17.0 degrees versus -7.2 degrees). This difference is due to the fact that in the first case the forces between slices are the effective forces, while in the second two cases the forces between slices are the total forces. The effective side forces (Computation Series No. 1) will generally be more steeply inclined than the total side forces (Computation Series No. 2 and 3). However, differences in the side force inclinations, whether total of effective have very little effect on the factor of safety as demonstrated by this example.

This example problem illustrates that it is possible to represent the influence of the water in two ways: with submerged unit weights, and with total unit weights and water pressures. However, if there had been any flow (seepage) within the slope, only the procedure employing total unit weights and water pressures could have been used. Use of submerged unit weights where there is flow also requires that any seepage forces be input as body forces on each individual slice. Such body forces are difficult to compute and represent as input data and, accordingly, the computer program does not allow such body forces to be specified in the input data. In cases where there is flow of water the approach is based on total unit weights and water pressures should be used.

REFERENCES

1. Bishop, A.W., and Norbert Morgenstern (1960), "Stability Coefficients for Earth Slopes," Geotechnique, Vol 10, No. 4, December, pp 129-150.

2. Cheney, Richard S., and Ronald G. Chassie (1982), Soils and Foundations Workshop Manual, Federal Highway Administration, Washington, D.C., November, 338 pages.

3. Engelhardt, Klaus, William A. Flynn, and Albert A. Bayuk (1974), "Vibro-Replacement - A Method to Strengthen Cohesive Soils In Situ, " Meeting Preprint 2281, ASCE National Structural Engineering Meeting, Cincinnati, Ohio, April.

4. Siegel, Ronald A. (1978), "Stabl User Manual," Joint Highway Research Project Report JHRP-75-9, Purdue University, Indiana, Originally published June 4, 1975 - Revised June 26, 1978, 104 pages.

5. Stauffer, Peter A., and Stephen G. Wright (1984), "An Examination of Earth Slope Failures in Texas," Research Report 353-3F, Center for Transportation Research, The University of Texas at Austin, November.

6. Taylor, Donald W. (1948), Fundamentals of Soil Mechanics, John Wiley and Sons, Inc., New York, 700 pages.

7. Wright, Stephen G., and James D. Roecker (1984), "UTEXAS (University of TEXas Analysis of Slopes) - A Computer Program For Slope Stability Calculations," Research Report No. 353-1, Center for Transportation Research, The University of Texas at Austin, October.

APPENDIX A

LISTING OF INPUT DATA FOR EXAMPLE PROBLEM A

```
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM A - SIMPLE, HOMOGENEOUS SLOPE


PROFILE LINE DATA FOLLOW -
     1 1 ALL SOIL
          -100 0
          0 0
          36 12
          100 12


MATERIAL PROPERTY DATA FOLLOW -
     1 ALL SOIL
          123 = UNIT WEIGHT OF SOIL
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               200 22

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          18 24 1 -80
          POINT THROUGH WHICH CIRCLE PASSES FOLLOWS -
               0 0

COMPUTE
```

APPENDIX B

LISTING OF INPUT DATA FOR EXAMPLE PROBLEM B

```
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
SHORT-TERM STABILITY COMPUTATIONS USING TOTAL STRESSES

     PROFILE LINE DATA FOLLOW -
          1 1 ALL MATERIAL
               0 0
               75 25
               150 25
               225 0


     MATERIAL PROPERTY DATA FOLLOW -
          1 ALL MATERIAL
               125
               NO PORE WATER PRESSURES - TOTAL STRESS ANALYSIS
               CONVENTIONAL SHEAR STRENGTHS
                    1000 10

HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
SHORT-TERM STABILITY COMPUTATIONS USING TOTAL STRESSES
COMPUTATION SERIES NO. 1 - CRACK DEPTH = 0 (NO CRACK)
     ANALYSIS/COMPUTATION DATA FOLLOW -
          CIRCULAR SEARCH
               25 50 0.5 0
          TANGENT LINE ELEVATION FOLLOWS
               0
          STOP SEARCH AFTER INITIAL MODE COMPLETED

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
SHORT-TERM STABILITY COMPUTATIONS USING TOTAL STRESSES
COMPUTATION SERIES NO. 2A - CRACK DEPTH = 3 FEET.
     ANALYSIS/COMPUTATION DATA FOLLOW -
          CIRCULAR SEARCH
               25 50 0.5 0
          TANGENT LINE ELEVATION FOLLOWS
               0
          CRACK DEPTH FOLLOWS
               3

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
SHORT-TERM STABILITY COMPUTATIONS USING TOTAL STRESSES
COMPUTATION SERIES NO. 2B - CRACK DEPTH = 6 FEET.
     ANALYSIS/COMPUTATION DATA FOLLOW -
          CIRCULAR SEARCH
               25 50 0.5 0
          TANGENT LINE ELEVATION FOLLOWS
               0
          CRACK DEPTH FOLLOWS
               6

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
SHORT-TERM STABILITY COMPUTATIONS USING TOTAL STRESSES
COMPUTATION SERIES NO. 2C - CRACK DEPTH = 9 FEET.
     ANALYSIS/COMPUTATION DATA FOLLOW -
```

```
          CIRCULAR SEARCH
               25 50 0.5 0
          TANGENT LINE ELEVATION FOLLOWS
               0
          CRACK DEPTH FOLLOWS
               9

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
SHORT-TERM STABILITY COMPUTATIONS USING TOTAL STRESSES
COMPUTATION SERIES NO. 2D - CRACK DEPTH = 12 FEET.
     ANALYSIS/COMPUTATION DATA FOLLOW -
          CIRCULAR SEARCH
               25 50 0.5 0
          TANGENT LINE ELEVATION FOLLOWS
               0
          CRACK DEPTH FOLLOWS
               12

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
SHORT-TERM STABILITY COMPUTATIONS USING TOTAL STRESSES
COMPUTATION SERIES NO. 3A - TRAFFIC LOADS ON SLOPE - NO CRACK
     SURFACE PRESSURE DATA FOLLOW -
          78 25 200 0
          100 25 200 0

     ANALYSIS/COMPUTATION DATA FOLLOW -
          CIRCULAR SEARCH
               25 50 0.5 0
          TANGENT LINE ELEVATION FOLLOWS
               0
          CRACK DEPTH FOLLOWS (RE-SETS DEPTH TO ZERO)
               0

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
SHORT-TERM STABILITY COMPUTATIONS USING TOTAL STRESSES
COMPUTATION SERIES NO. 3B - TRAFFIC LOADS ON SLOPE - NO CRACK
     ANALYSIS/COMPUTATION DATA FOLLOW -
          CIRCULAR SEARCH
               70 38 0.8 0
          TANGENT LINE ELEVATION FOLLOWS -
               15
          CRITICAL CIRCLE TO BE FOUND AFTER INITIAL MODE COMPLETED
          FACTOR OF SAFETY
               10.0
          SIDE FORCE INCLINATION
               20.0

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
SHORT-TERM STABILITY COMPUTATIONS USING TOTAL STRESSES
COMPUTATION SERIES NO. 4 - NONLINEAR SHEAR STRENGTH ENVELOPE
     MATERIAL PROPERTY DATA FOLLOW -
          1 ALL MATERIAL
               125
               NO PORE WATER PRESSURES - TOTAL STRESS ANALYSIS
```

```
          NONLINEAR SHEAR STRENGTH ENVELOPE
                   0  850
                 300 1000
                 700 1150
                1100 1250
                1500 1300
                2500 1300

     SURFACE PRESSURE DATA FOLLOW (RE-SETS VALUES TO ZERO) -

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          25 50 0.5 0
     TANGENT LINE ELEVATION FOLLOWS
          0
     CRACK DEPTH FOLLOWS
          5
     FACTOR OF SAFETY (RE-SETS VALUE TO DEFAULT VALUE)
          1.5
     SIDE FORCE INCLINATION (RE-SETS VALUE TO DEFAULT VALUE)
          15.0
     STOP SEARCH AFTER INITIAL MODE

COMPUTE
HEADING FOLLOWS ------------------------------
EXAMPLE PROBLEM 8 - EMBANKMENT ON A STRONG FOUNDATION
LONG-TERM STABILITY COMPUTATIONS USING EFFECTIVE STRESSES

     MATERIAL PROPERTY DATA FOLLOW -
          1 ALL MATERIAL
          125
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               100 20

HEADING FOLLOWS ------------------------------
EXAMPLE PROBLEM 8 - EMBANKMENT ON A STRONG FOUNDATION
LONG-TERM STABILITY COMPUTATIONS USING EFFECTIVE STRESSES
COMPUTATION SERIES NO. 1 - NO PORE WATER PRESSURES - NO CRACK
     ANALYSIS/COMPUTATION DATA FOLLOW -
          CIRCULAR SEARCH
              25 50 0.5 0
              TANGENT LINE ELEVATION FOLLOWS
                   0
          CRACK DEPTH FOLLOWS (RE-SETS DEPTH TO ZERO)
               0

COMPUTE
HEADING FOLLOWS ------------------------------
EXAMPLE PROBLEM 8 - EMBANKMENT ON A STRONG FOUNDATION
LONG-TERM STABILITY COMPUTATIONS USING EFFECTIVE STRESSES
COMPUTATION SERIES NO. 2 - NO PORE WATER PRESSURES - 1 FT. CRACK DEPTH
     ANALYSIS/COMPUTATION DATA FOLLOW -
          CIRCULAR SEARCH
               25 50 0.5 0
               TANGENT LINE ELEVATION FOLLOWS
                    0
          CRACK DEPTH FOLLOWS -
               1

COMPUTE
```

```
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
LONG-TERM STABILITY COMPUTATIONS USING EFFECTIVE STRESSES
COMPUTATION SERIES NO. 3 - R-SUB-U = 0.15 - NO CRACK
     MATERIAL PROPERTY DATA FOLLOW -
          1 ALL MATERIAL
          125
          CONSTANT R-SUB-U
               0.15
          CONVENTIONAL
               100 20

     ANALYSIS/COMPUTATION DATA FOLLOW-
          CIRCULAR SEARCH
               25 50 0.5 0
               TANGENT LINE ELEVATION FOLLOWS
                    0
          CRACK DEPTH FOLLOWS (RE-SETS DEPTH TO ZERO)
               0

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM B - EMBANKMENT ON A STRONG FOUNDATION
LONG-TERM STABILITY COMPUTATIONS USING EFFECTIVE STRESSES
COMPUTATION SERIES NO. 4 - R-SUB-U = 0.15 - NO CRACK - COHESION SET TO ZERO
     MATERIAL PROPERTY DATA FOLLOW -
          1 ALL MATERIAL
          125
          CONSTANT R-SUB-U VALUE FOLLOWS
               0.15
          CONVENTIONAL
               0 20

     ANALYSIS/COMPUTATION DATA FOLLOW -
          CIRCULAR SEARCH
               25 50 0.5 -25
               POINT THROUGH WHICH CIRCLE PASSES FOLLOWS
                    0 0

COMPUTE
```

APPENDIX C

LISTING OF INPUT DATA FOR EXAMPLE PROBLEM C

```
HEADING FOLLOWS ------------------------------------
EXAMPLE PROBLEM C - EMBANKMENT ON WEAK FOUNDATION
SHORT-TERM STABILITY - COMPUTATION SERIES NO. 1

PROFILE LINE DATA FOLLOW -
     1 1 LOWER ONE-HALF OF SOFT CLAY FOUNDATION STRATUM
            0.0 -7.5
          150.0 -7.5

     2 2 UPPER ONE-HALF OF SOFT CLAY FOUNDATION STRATUM
            0.0 0.0
          150.0 0.0

     3 3 COMPACTED FILL
            0.0 18.0
           50.0 18.0
          104.0  0.0


MATERIAL PROPERTY DATA FOLLOW -
     1 LOWER ONE-HALF OF FOUNDATION
          98 = TOTAL UNIT WEIGHT
          NO PORE PRESSURES
          LINEAR INCREASE IN SHEAR STRENGTH WITH DEPTH
               300 20
     2 UPPER ONE-HALF OF FOUNDATION
          98 = TOTAL UNIT WEIGHT
          NO PORE PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               300 0
     3 COMPACTED SAND FILL
          115 = TOTAL UNIT WEIGHT
          NO PORE PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               0 35

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          75 35 1 -15
          TANGENT LINE ELEVATION FOR INITIAL MODE OF SEARCH FOLLOWS -
               -15

COMPUTE
HEADING FOLLOWS ------------------------------------
EXAMPLE PROBLEM C - EMBANKMENT ON WEAK FOUNDATION
SHORT-TERM STABILITY - COMPUTATION SERIES NO. 2
EMBANKMENT ASSIGNED ZERO SHEAR STRENGTH
MATERIAL PROPERTY DATA FOLLOW -
     3 COMPACTED SAND FILL
          115  = TOTAL UNIT WEIGHT
          NO PORE PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               0 0

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCLE
          77.0 34.0 48.0

COMPUTE
HEADING FOLLOWS ------------------------------------
EXAMPLE PROBLEM C - EMBANKMENT ON WEAK FOUNDATION
SHORT-TERM STABILITY - COMPUTATION SERIES NO. 3 - EMBANKMENT REPRESENTED BY
```

```
VERTICAL SURCHARGE PRESSURES ACTING ON HORIZONTAL GROUND SURFACE
SLOPE GEOMETRY DATA FOLLOW -
        0.0 0.0
      150.0 0.0

SURFACE PRESSURE DATA FOLLOW -
        0.0 0.0 2070.0 0.0
       50.0 0.0 2070.0 0.0
      104.0 0.0    0.0 0.0

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          75 35 1 -15
          TANGENT LINE ELEVATION FOR INITIAL MODE OF SEARCH FOLLOWS -
               -15
     OPPOSITE SIGN CONVENTION FROM NORMAL TO BE USED
     CRITICAL CIRCLE TO BE FOUND (NO STOP AFTER INITIAL MODE IS COMPLETE)

COMPUTE
********** ENTIRELY NEW DATA FOLLOW **********
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM C - EMBANKMENT ON WEAK FOUNDATION
LONG-TERM STABILITY

PROFILE LINE DATA FOLLOW -
     1 1 ALL FOUNDATION MATERIAL
            0.0 0.0
          150.0 0.0

     2 2 COMPACTED SAND FILL
            0.0 18.0
           50.0 18.0
          104.0  0.0


MATERIAL PROPERTY DATA FOLLOW -
     1 FOUNDATION MATERIAL
          101 - TOTAL UNIT WEIGHT
          PIEZOMETRIC LINE
               1
          CONVENTIONAL SHEAR STRENGTHS
               0 23
     2 COMPACTED SAND FILL
          115 - TOTAL UNIT WEIGHT
          NO PORE PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               0 35

PIEZOMETRIC LINE DATA FOLLOW -
     1 PIEZOMETRIC LINE IN FOUNDATION REPRESENTING GROUNDWATER TABLE
            0.0 0.0
          150.0 0.0


ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          75 35 1 -15
          POINT THROUGH WHICH CIRCLES PASS FOR INITIAL MODE OF SEARCH FOLLOWS
               104 0

COMPUTE
```

APPENDIX D

LISTING OF INPUT DATA FOR EXAMPLE PROBLEM D

```
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM D - EXCAVATED SLOPE
SHORT-TERM STABILITY - COMPUTATION SERIES NO. 1 - NO TENSION CRACK

PROFILE LINE DATA FOLLOW -
     1 1 ALL SOIL
          -60 0
          0 0
          80 20
          100 20


MATERIAL PROPERTY DATA FOLLOW -
     1 ALL SOIL
          128 = TOTAL UNIT WEIGHT
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               1800 0

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          30 30 0.5 -20
          TANGENT LINE ELEVATION FOLLOWS
               -20
     STOP AFTER INITIAL MODE OF SEARCH IS COMPLETED

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM D - EXCAVATED SLOPE
SHORT-TERM STABILITY - COMPUTATION SERIES NO. 2 - 8.5 FOOT DEEP TENSION CRACK

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          30 30 0.5 -20
          TANGENT LINE ELEVATION FOLLOWS -
               -20
     CRACK DEPTH FOLLOWS -
          8.5

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM D - EXCAVATED SLOPE
LONG-TERM STABILITY - COMPUTATION SERIES NO. 1 - NO PORE WATER PRESSURES

MATERIAL PROPERTY DATA FOLLOW -
     1 ALL SOIL
          125 = TOTAL UNIT WEIGHT
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               100 25

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          30 30 0.5 -20
          POINT THROUGH WHICH CIRCLES PASS FOR INITIAL MODE OF SEARCH FOLLOW
               0 0
     CRACK DEPTH FOLLOWS -
          0
     CRITICAL CIRCLE TO BE FOUND (NO STOP AFTER INITIAL MODE IS COMPLETE)

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

```
EXAMPLE PROBLEM D - EXCAVATED SLOPE
LONG-TERM STABILITY - COMPUTATION SERIES NO. 2 - PORE WATER PRESSURES
DESCRIBED BY A PIEZOMETRIC LINE
MATERIAL PROPERTY DATA FOLLOW -
     1 ALL SOIL
          125 = TOTAL UNIT WEIGHT
          PIEZOMETRIC LINE
               1 = PIEZOMETRIC LINE NO.
          CONVENTIONAL SHEAR STRENGHTS
               100 25

PIEZOMETRIC LINE DATA FOLLOW -
     1 PIEZOMETRIC LINE FOR ALL SOIL
          -60.0  0.0
            0.0  0.0
            6.6  2.2
           15.0 4.2
           30.0 6.3
           45.0 7.9
           60.0 9.2
           80.0 10.7
          100.0 12.0


COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM D - EXCAVATED SLOPE
LONG-TERM STABILITY - COMPUTATION SERIES NO. 3 - PORE WATER PRESSURES
DESCRIBED BY PIEZOMETRIC LINE - FULL CAPILLARY (NEGATIVE) PRESSURES USED
MATERIAL PROPERTY DATA FOLLOW -
     1 ALL SOIL
          125 = TOTAL UNIT WEIGHT OF SOIL
          PIEZOMETRIC LINE NEGATIVE O.K.
               1
          CONVENTIONAL SHEAR STRENGTHS
               100 25

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM D - EXCAVATED SLOPE
LONG-TERM STABILITY - COMPUTATION SERIES NO. 4 - PORE WATER PRESSURES
DESCRIBED USING A CONSTANT VALUE FOR R-SUB-U (R-SUB-U = 0.13)
MATERIAL PROPERTY DATA FOLLOW -
     1 ALL SOIL
          125 = TOTAL UNIT WEIGHT
          CONSTANT R-SUB-U
               0.13
          CONVENTIONAL SHEAR STRENGTHS
               100 25

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM D - EXCAVATED SLOPE
LONG-TERM STABILITY - COMPUTATION SERIES NO. 5 - PORE WATER PRESSURES
DESCRIBED USING A CONSTANT VALUE FOR R-SUB-U (R-SUB-U = 0.21)
MATERIAL PROPERTY DATA FOLLOW -
     1 ALL SOIL
          125 = TOTAL UNIT WEIGHT
          CONSTANT R-SUB-U
               0.21
          CONVENTIONAL SHEAR STRENGTHS
               100 25
```

```
COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM D - EXCAVATED SLOPE
LONG-TERM STABILITY - COMPUTATION SERIES NO. 6 - PORE WATER PRESSURES
DESCRIBED USING A CONSTANT VALUE FOR R-SUB-U (R-SUB-U = 0.26)
MATERIAL PROPERTY DATA FOLLOW -
     1 ALL SOIL
          125 = TOTAL UNIT WEIGHT
          CONSTANT R-SUB-U
               0.26
          CONVENTIONAL SHEAR STRENGTHS
               100 25

COMPUTE
```

APPENDIX E

LISTING OF INPUT DATA FOR EXAMPLE PROBLEM E

```
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM E - FROM FHWA SOILS AND FOUNDATIONS WORKSHOP MANUAL
SAND FILL ON SAND FOUNDATION WITH 5 FOOT THICK CLAY LAYER

PROFILE LINE DATA FOLLOW -
     1 1 LOWER SAND STRATUM IN FOUNDATION
          -130 -15
          70 -15

     2 2 FOUNDATION CLAY STRATUM
          -130 -10
          70 -10

     3 3 UPPER SAND STRATUM IN FOUNDATION
          -130 0
          70 0

     4 4 SAND FILL
          -130 30
          70 30


MATERIAL PROPERTY DATA FOLLOW -
     1 LOWER SAND
          60 - SUBMERGED UNIT WEIGHT
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               0 30
     2 FOUNDATAION CLAY
          37.6 - SUBMERGED UNIT WEIGHT
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               250 0
     3 UPPER SAND
          120 - TOTAL UNIT WEIGHT
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               0 30
     4 SAND FILL
          120 - TOTAL UNIT WEIGHT
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               0 30

SLOPE GEOMETRY DATA FOLLOW -
     -130 30
     -60 30
     0 0
     70 0

HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM E - FROM FHWA SOILS AND FOUNDATIONS WORKSHOP MANUAL
SAND FILL ON SAND FOUNDATION WITH 5 FOOT THICK CLAY LAYER
COMPUTATION SERIES NO. 1 - SELECTED NON-CIRCULAR SHEAR SURFACE
ANALYSIS/COMPUTATION DATA FOLLOW -
     NON-CIRCULAR
          -63.09 30.0
          -60.0 -10.001
          0 -10.001
          17.32 0.0
```

```
COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM E - FROM FHWA SOILS AND FOUNDATIONS WORKSHOP MANUAL
SAND FILL ON SAND FOUNDATION WITH 5 FOOT THICK CLAY LAYER
COMPUTATION SERIES NO. 2 - AUTOMATIC SEARCH FOR CRITICAL CIRCLE
ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCLE SEARCH
          -30 50 0.5 -31
          TANGENT LINE
              -15
     CRITICAL SHEAR SURFACE

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM E - FROM FHWA SOILS AND FOUNDATIONS WORKSHOP MANUAL
SAND FILL ON SAND FOUNDATION WITH 5 FOOT THICK CLAY LAYER
COMPUTATION SERIES NO. 3 - AUTOMATIC SEARCH FOR CRITICAL NON-CIRCULAR SURFACE
ANALYSIS/COMPUTATION DATA FOLLOW -
     NON-CIRCULAR SEARCH
          -85.0  30.00
          -69.0   0.00 0
          -63.0 -10.00 0
          -60.0 -14.99 0
            0.0 -14.99 0
            9.0 -10.00 0
           25.0   0.00

          0.25 = MINIMUM INCREMENTAL SHIFT DISTANCE (ACCURACY)

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM E - FROM FHWA SOILS AND FOUNDATIONS WORKSHOP MANUAL
SAND FILL ON SAND FOUNDATION WITH 5 FOOT THICK CLAY LAYER
COMPUTATION SERIES NO. 4 - SLOPE FLATTENED FROM 2/1 TO 3/1
SLOPE GEOMETRY DATA FOLLOW -
     -130 30
      -60 30
       30  0
       70  0

ANALYSIS/COMPUTATION DATA FOLLOW -
     NON-CIRCULAR SEARCH
          -85.0  30.00
          -69.0   0.00 0
          -63.0 -10.00 0
          -60.0 -14.99 0
           30.0 -14.99 0
           39.0 -10.00 0
           55.0   0.00

          0.25 = MINIMUM INCREMENTAL SHIFT DISTANCE (ACCURACY)

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM E - FROM FHWA SOILS AND FOUNDATIONS WORKSHOP MANUAL
SAND FILL ON SAND FOUNDATION WITH 5 FOOT THICK CLAY LAYER
COMPUTATION SERIES NO. 5 - SLOPE WITH 10 FT. HIGH, 30 FT. WIDE, 2/1 BERM AT TOE
SLOPE GEOMETRY DATA FOLLOW -
      -130 30
       -60 30
       -20 10
        10 10
```

```
      30 0
      70 0

ANALYSIS/COMPUTATION DATA FOLLOW -
     NON-CIRCULAR
          -80.21  30.00
          -70.79   0.00
          -64.38 -10.00
          -61.50 -14.99
           22.86 -14.99
           33.04 -10.00
           53.95   0.00


COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM E - FROM FHWA SOILS AND FOUNDATIONS WORKSHOP MANUAL
SAND FILL ON SAND FOUNDATION WITH 5 FOOT THICK CLAY LAYER
COMPUTATION SERIES NO. 6 - 'SHEAR KEY' THROUGH CLAY
PROFILE LINE DATA FOLLOW -
     2 1 SHEAR KEY (SUBMERGED)
          -30 -10
          -20 -10

     5 2 FOUNDATION CLAY STRATUM - UPSTREAM OF KEY
          -130 -10
          -30 -10

     6 2 FOUNDATION CLAY STRATUM - DOWNSTREAM OF KEY
          -20 -10
          70 -10


SLOPE GEOMETRY DATA FOLLOW -
     -130 30
      -60 30
        0  0
       70  0

ANALYSIS/COMPUTATION DATA FOLLOW -
     NON-CIRCULAR
          -88.71  30.00
          -70.89   0.00
          -64.60 -10.00
          -62.82 -14.99
           -6.30 -14.99
            4.41 -10.00
           26.44   0.00


COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM E - FROM FHWA SOILS AND FOUNDATIONS WORKSHOP MANUAL
SAND FILL ON SAND FOUNDATION WITH 5 FOOT THICK CLAY LAYER
COMPUTATION SERIES NO. 7 - ORIGINAL GEOMETRY, EFFECT OF RISE IN WATER TABLE
PROFILE LINE DATA FOLLOW -
     2 2 SHEAR KEY REPLACED WITH CLAY FOR COMPUTATION SERIES NO. 7
          -30 -10
          -20 -10


MATERIAL PROPERTY DATA FOLLOW -
```

```
3 UPPER SAND STRATUM IN FOUNDATION
     60 - SUBMERGED UNIT WEIGHT
     NO PORE WATER PRESSURES
     CONVENTIONAL SHEAR STRENGTHS
          0 30

COMPUTE
```

APPENDIX F

LISTING OF INPUT DATA FOR EXAMPLE PROBLEM F

```
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM F - PROB. DESCRIBED IN STABL USER MANUAL, BY RONALD A. SIEGEL,
REPORT JHRP-75-9 ON JOINT HIGHWAY RESEARCH PROJECT NO. C-36-36K, PURDUE UNIV.,
REPORT DATED JUNE 4, 1975 - REVISED JUNE 26, 1976
PROFILE LINE DATA FOLLOW -
     1 1 UPPERMOST (ZERO SHEAR STRENGTH) STRATUM
          101 88
          138 103
          205 110

     2 2 INTERMEDIATE STRATUM - ABOVE WATER TABLE
          63 73
          101 88
          205 99

     3 3 INTERMEDIATE STRATUM - BELOW WATER TABLE
          0 68
          22 67
          38 63
          63 73
          83 78
          104 82
          122 85
          140 87
          205 93

     4 4 LOWEST STRATUM (BEDROCK)
          0 15
          29 24
          51 26
          78 56
          94 65
          113 64
          133 56
          161 58
          205 76


MATERIAL PROPERTY DATA FOLLOW -
     1 UPPERMOST (ZERO STRENGTH) STRATUM
          116.4 = UNIT WEIGHT
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               0 0
     2 INTERMEDIATE STRATUM - ABOVE WATER TABLE
          116.4 = UNIT WEIGHT
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               500 14
     3 INTERMEDIATE STRATUM - BELOW WATER TABLE
          124.2 = UNIT WEIGHT
          PIEZOMETRIC LINE
               1
          CONVENTIONAL SHEAR STRENGTHS
               500 14
     4 LOWEST STRATUM (BEDROCK)
          125
          NO PORE PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               200000 0

PIEZOMETRIC LINE DATA FOLLOW -
```

```
     1 PIEZOMETRIC LINE FOR INTERMEDIATE STRATUM
          0 66
          22 67
          38 63
          63 73
          83 78
          104 82
          122 85
          140 87
          205 93


HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM F -
COMPUTATION SERIES NO. 1 - USING MOST CRITICAL SHEAR
SURFACE FOUND BY SIEGEL ON HIS FIRST RUN
ANALYSIS/COMPUTATION DATA FOLLOW -
     NONCIRCULAR
          45.11 65.82
          55.00 64.31
          64.97 63.57
          74.97 63.83
          84.93 64.47
          94.80 66.10
          104.51 68.50
          114.00 71.66
          123.21 75.55
          132.08 80.18
          140.56 85.46
          148.60 91.40
          156.15 97.97
          163.15 105.10
          163.63 105.68


COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM F -
COMPUTATION SERIES NO. 2 - AUTOMATIC SEARCH FOR CRITICAL CIRCLE

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          70 140 1 15
          POINT THROUGH WHICH CIRCLES PASS FOR INITIAL MODE OF SEARCH FOLLOWS
               38 63

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM F -
COMPUTATION SERIES NO. 3 - ZERO STRENGTH STRATUM REPLACED W/ SURFACE PRESSURES
AUTOMATIC SEARCH FOR CRITICAL NONCIRCULAR SHEAR SURFACE
SLOPE GEOMETRY DATA FOLLOW -
       0.0 88.0
      22.0 87.0
      38.0 63.0
      63.0 73.0
     101.0 88.0
     205.0 99.0

SURFACE PRESSURE DATA FOLLOW -
     101.0 88.00    0.0   0.0
     138.0 91.91 1276.6 -135.0
```

```
     205.0 99.00 1266.6 -133.9

ANALYSIS/COMPUTATION DATA FOLLOW -
     NONCIRCULAR SEARCH
          45.5 66
          55 64
          65 64
          75 64
          85 64
          95 66
          105 69
          114 72
          123 76
          132 80
          141 85
          149 91
          150.7 93.3

     0.5 = MINIMUM INCREMENTAL SHIFT DISTANCE / ACCURACY

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM F
COMPUTATION SERIES NO. 4 - ZERO STRENGTH STRATUM REPLACED W/ SURFACE PRESSURES
AUTOMATIC SEARCH FOR CRITICAL CIRCLE
ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          70 140 1 15
          POINT THROUGH WHICH CIRCLES PASS FOR INITIAL MODE OF SEARCH FOLLOWS
               39 63

COMPUTE
```

APPENDIX G

LISTING OF INPUT DATA FOR EXAMPLE PROBLEM G

```
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM 6 - PARTIALLY SUBMERGED SLOPE
COMPUTATION SERIES NO. 1 - USING SUBMERGED UNIT WEIGHTS

PROFILE LINE DATA FOLLOW -
     1 1 SOIL ABOVE WATER
          -100 20
          50 20

     2 2 SOIL BELOW WATER
          -100 15
          50 15


MATERIAL PROPERTY DATA FOLLOW -
     1 SOIL ABOVE WATER
          124 = TOTAL UNIT WEIGHT
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               100 18
     2 SOIL BELOW WATER
          61.6 = SUBMERGED UNIT WEIGHT
          NO PORE WATER PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               100 18

SLOPE GEOMETRY DATA FOLLOW -
     -100 20
     -60 20
     0 0
     50 0

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          -20 40 0.5 -20
          POINT THROUGH WHICH CIRCLE PASSES FOLLOWS
               0 0
     STOP AFTER INITIAL MODE OF SEARCH IS COMPLETED

COMPUTE
********** ENTIRELY NEW DATA FOLLOW **********
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM 6 - PARTIALLY SUBMERGED SLOPE
COMPUTATION SERIES NO. 2 - USING TOTAL UNIT WEIGHTS AND PORE WATER PRESSURES
DESCRIBED BY A PIEZOMETRIC LINE
PROFILE LINE DATA FOLLOW -
     1 1 ALL SOIL
          -100 20
          -60 20
          0 0
          50 0


MATERIAL PROPERTY DATA FOLLOW -
     1 ALL SOIL
          124 = TOTAL UNIT WEIGHT
          PIEZOMETRIC LINE
               1 = PIEZOMETRIC LINE NUMBER
          CONVENTIONAL SHEAR STRENGTHS
               100 18

PIEZOMETRIC LINE DATA FOLLOW -
```

```
     1 PIEZOMETRIC LINE FOR ALL MATERIAL
          -100 15
          50 15

SURFACE PRESSURE DATA FOLLOW -
     -37.5 15 0 0
     0 0 936 0
     50 0 936 0

ANALYSIS/COMPUTATION DATA FOLLOW -
     CIRCULAR SEARCH
          -20 40 0.5 -20
          POINT THROUGH WHICH CIRCLES PASS FOLLOWS -
               0 0
     STOP AFTER INITIAL MODE OF SEARCH IS COMPLETE

COMPUTE
HEADING FOLLOWS - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXAMPLE PROBLEM 6 - PARTIALLY SUBMERGED SLOPE
COMPUTATION SERIES NO. 3 - USING TOTAL UNIT WEIGHTS AND PORE WATER PRESSURES
DEFINED USING THE INTERPOLATION OPTION
MATERIAL PROPERTY DATA FOLLOW -
     1 ALL SOIL
          124 - TOTAL UNIT WEIGHT
          INTERPOLATE PRESSURES
          CONVENTIONAL SHEAR STRENGTHS
               100 18

INTERPOLATION DATA POINTS FOLLOW -
     PRESSURE VALUES FOLLOW -
          -100 20 0 1
          50 20 0 1
          -100 15 0 1
          50 15 0 1
          -100 -20 2184 1
          50 -20 2184 01

COMPUTE
```