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16. Abstract

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This report is the first of two reports which provide the user's documentation for the program. This report describes the features and requirements of the program and describes the detailed procedures for preparing data input. The second report provides a series of seven example problems with input data listings which may be used as "benchmark" checks for the program and as a further guide in preparing input data and using the program.

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UTEXAS (University of Texas Analysis of Slopes)
A COMPUTER PROGRAM FOR SLOPE STABILITY CALCULATIONS

by

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and
James D. Roecker

Research Report Number 353-1

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
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THE UNIVERSITY OF TEXAS AT AUSTIN

November 1984

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PREFACE

During the early 1970's a general computer program for slope stability analyses was developed at The University of Texas at Austin. This program was developed partly in conjunction with Research Project 161 at the Center for Highway Research and was used extensively on the research conducted for this project, although the program was never implemented by the Texas State Department of Highways and Public Transportation. In 1974 documentation for the program was finalized and distribution of the program on a world-wide bases was initiated. This distribution continues presently through the Geotechnical Engineering Center, Bureau of Engineering Research, The University of Texas.

During the approximately ten years that the computer program has been in use a number of significant developments have taken place. A new standard for FORTRAN has been developed and implemented by most major computer manufacturers, new procedures for locating critical sliding surfaces used in slope stability calculations have been developed and some of the features, such as the one employed in the computer program SSTAB1 for interpolating pore water pressures, have been improved.

In response to the developments which have taken place in the last decade, the experience gained with the existing computer program, and the Texas State Department of Highways and Public Transportation's desire to adopt a new computer program for slope stability analyses, Research Project 353 was initiated by the Center for Transportation Research at The University of Texas in September 1982. The principal purposes of this project were to adapt the computer program SSTAB1 to the Department's computing system and to upgrade the program to reflect some of the developments during the last decade. It was originally planned that the existing program would be modified to a significant extent. However, at a very early stage in the work it became evident that very substantial revisions would be beneficial and the revisions were sufficiently major to warrant development of an entirely new computer program for slope stability computations. Accordingly, a new computer program has been developed. This manual reflects the results of this effort and represents the first completed version of a user's manual for the new computer program.

The new computer program described in this manual contains a number of new features not contained in the earlier program. The program conforms to the 1977 ANSI Standard for FORTRAN and has been run on CDC Cyber 170/750, IBM 3081-D, and VAX 11/780 computer systems. The program allows for completely free-field (format-free) input of data and contains over 200 error messages to inform the user of potential errors in input data and computations. The program has an option for performing an automatic search to locate a critical noncircular shear (sliding) surface, permits nonlinear (curved) shear strength envelopes to be used, and allows for multiple piezometric lines.

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November 1984

ABSTRACT

A general purpose computer program has been developed for the Texas State Department of Highways and Public Transportation for use in performing slope stability calculations. The computer program includes a number of improvements over a previous computer program (SSTAB1) developed by Wright (1982). The program improvements include the capabilities for handling multiple piezometric surfaces, curved shear strength envelopes, an automatic search routine for locating a critical noncircular shear surface, and seismic coefficients to approximate earthquake loading. In addition the program is coded in FORTRAN 77 (ANSI X3.9-1978) to enhance portability among computing systems and has implemented format-free ("free-field") input with extensive error checking of input data. The computer program is based on Spencer's procedure of slices as modified by Wright (1969, 1975), which is a procedure that fully satisfies the requirements of static equilibrium.

This report is the first of two reports which provide the user's documentation for the program. This report describes the features and requirements of the program and describes the detailed procedures for preparing data input. The second report provides a series of seven example problems with input data listings which may be used as "benchmark" checks for the program and as a further guide in preparing input data and using the program.

SUMMARY

A new computer program has been developed for use in performing stability computations for earth slopes. The program has been made operational on the computing facilities of the Texas State Department of Highways and Public Transportation and offers a number of improvements over a previous program developed over ten years ago. This report and a companion report provide the user's documentation for the computer program.

This new computer program includes a number of features which permit computations to be performed for a relatively wide range of practical slope stability problems. Considerable effort has been made to make the computer program especially "user friendly." The companion report to this one contains seven example problems which have been developed and solved specifically to assist the user in learning how to use the program.

IMPLEMENTATION STATEMENT

The computer program described in this report has been made operational on the IBM computing facilities of the Texas State Department of Highways and Public Transportation and it is expected that the program will be used by Department personnel. After review and study of the computer program and documentation are completed it is anticipated that a number of training workshops may be developed to instruct personnel in the use of the computer program and to provide a forum for questions and feedback on the program. It is anticipated that, although the research project under which this computer program was developed has terminated, the computer program will be used for other ongoing research projects and that modifications and corrections will be made as part of the ongoing work. Inasmuch as the computer program is a new program with relatively little use, it can be anticipated that errors and omissions will be discovered over at least the next several years. A program of continued maintenance and update by the Texas State Department of Highways and Public Transportation in close cooperation with and with the assistance of the Center for Transportation Research is recommended and necessary.

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SECTION 1 - INTRODUCTION

This report describes the general operation and input data formats for a general-purpose slope stability analysis computer program, UTEXAS (University of Texas Analysis of Slopes). Specifically, the program is used to compute a factor of safety, F, defined as

$$F = \frac{\text{Available Shear Strength}}{\text{Shear Strength (Stress) Required for Just-Stable Equilibrium}}$$

This definition of the factor of safety represents the most common definition of the factor of safety employed for slope stability analyses. The factor of safety is computed for an assumed shear (sliding) surface employing the procedure of slices first proposed by Spencer (1967) and later extended by Wright (1969, 1975). This procedure for computing the factor of safety satisfies all requirements of static equilibrium and is considered to be one of the most accurate procedures available.

The factor of safety may be computed using either circular or general shaped, noncircular shear surfaces. Either the shear surfaces may be specified as individual surfaces, one-by-one by the user, or the program can be directed to automatically search for a most critical shear surface having a minimum factor of safety. Regardless of the option chosen, the user will generally be most interested in the critical shear surface with the lowest factor of safety.

The slope geometry and soil profile are described by a series of straight, "profile" lines whose end-point coordinates are input to the computer program. The material beneath a given profile line is assumed to have a given set of properties (shear strength, unit weight, etc.) until the next, lower profile line is encountered. A number of different characterizations of shear strengths and pore water pressures (groundwater) can be selected by the user to describe a particular problem. In addition, the user may specify external loads on the surface of the slope to represent loads due to water, stockpiled materials, vehicles, etc.

In the next section (2) of this report the general requirements of data for the program, the terminology and nomenclature used, and an introduction to the input data are presented. The following nine sections (3 through 11) then describe specific groups of input data and, finally, the printed output produced by the program is described in the last section (12). A companion volume to this report (Wright and Roecker, 1984) presents a number of solved example problems with listings of the input data for the computer program.

SECTION 2 - GENERAL DESCRIPTION OF INPUT DATA REQUIREMENTS

INTRODUCTION

In this section the general formats and requirements for input of data to the computer program are described. This includes the sequence of input data, the coordinate system and units used, and the formats used by the computer to read data.

SEQUENCE OF INPUT

The input data are organized into a series of eight logical "Groups." The contents of individual Groups are discussed later group-by-group in Sections 4 through 11. The order in which one Group of data is input relative to another Group is selected entirely arbitrarily by the user. The specific order selected is indicated to the computer program through the use of "Command Words" which are described in detail in Section 3 of this report. A number of the Groups of data are optional and may be omitted by the user.

COORDINATE SYSTEM

All coordinates are defined using a right-hand coordinate system with the x axis being horizontal and positive to the right, and the y axis being vertical and positive in the upward direction. The origin of the coordinate system may be located arbitrarily; however, the origin should be in the vicinity of the slope, within a maximum distance of ten times the slope height. This is necessary because moments are taken about the origin of the coordinate system, and numerical roundoff errors could result if the moment arms become excessively large. No restriction is placed on the sign of the coordinate values, and both positive and negative values may be used in the same problem.

UNITS FOR DATA

The input data should be in consistent units of length and force. Output formats are setup assuming that units will be in feet (for length) and pounds (for force). Units other than feet and pounds may be used; however, the computer output may either overflow some output fields or have too few significant figures to be meaningful.

DIMENSIONED ARRAY SIZE LIMITS

A number of quantities which are either input as data or calculated by the computer program are stored in dimensioned arrays. The computer program will check these quantities and issue an error message when a dimensioned array size is exceeded. Presently the arrays are dimensioned to what have been found to be convenient sizes for typical problems; however, it is anticipated that array sizes will probably be changed from time-to-time. Accordingly, the dimensioned sizes of arrays are not included in this manual, but rather will be provided by the authors upon request as a separate document with each copy of the computer program.

FORMATS FOR READING INPUT DATA

All numerical data are input and read in a "free-field" format. When more than one numerical value, or alphanumeric character string, is to be input on a given line of data, the values (or character strings) are separated by one or more blanks. Commas are <u>not</u> allowed as separators. The first numerical value or alphanumeric character string on a line of data does <u>not</u> need to be left-justified; the program will scan the line of input until the first non-blank character is located and, thus, any amount of indentation is permissable. In most cases the program will check for the required number of numerical values on a line of input and will issue an error message if an insufficient number of quantities is input.

A number of the sets of input data described later involve several lines of similar data, which must be terminated by a blank line. A blank line is not the same as a line containing zeros; a blank line must contain no alphanumeric characters.

SECTION 3 - COMMAND WORDS

"Command Words" are used in the input data to designate that a particular "Group" of data (e.g., material properties, slope geometry, etc.) is to immediately follow. For example, the data defining the coordinates of lines used to describe the soil profile geometry are preceded by a line of input data with the Command Word(s) "PROFILE LINES." The computer program will read this line of data and determine that data for the "Profile Lines" are to be read next. The user would then follow this Command word, "PROFILE LINES," with the Group B, Profile Line data, as described in Section 5.

Command Words are also used to direct the program to take action which may require no following data. For example, the special Command Word "COMPUTE" directs the program to temporarily stop reading data, check the data which has been read for correctness and completeness, and then perform computations for the factor of safety. Once this is complete the program will then return to reading additional input data if desired. (The program attempts to read data until the end-of-file is detected.) Any additional data which are input after the Command Word "COMPUTE" may either be for an entirely new problem or to simply change one item of data before the Command Word "COMPUTE" is reissued to execute a new series of computations. In general all previous data are retained either until new data are input by the user to change the old data or a special Command "Word" consisting of asterisks (*) is issued.

Several Groups of data (Groups B, D, E, F and G) may be input in two modes, "Normal Mode" and "Modify Mode," which are selected through use of Command Words. Normal Mode is considered to be the normal mode of input and is initially assumed to be the input mode by the program. Modify Mode allows data within certain Groups to be selectively changed without input of all data in the group. The user may randomly "switch" between Normal and Modify Modes of input. The beginning user will probably choose to ignore the existence of the Modify Mode.

The allowable Command Words and their meaning are described in Tables 3.1 and 3.2. Table 3.1 contains the Command Words which must be immediately followed by additional data. Table 3.2 contains the Command Words which require no further data. The Command Words are generally shown as being one or more words of variable character length; however, <u>only the first three characters are actually read</u> and used by the program. (Leading blanks on a line are ignored, but all blanks following the first non-blank character are considered.) The key first-three characters of the Command Words are capitalized and underlined in Tables 3.1 and 3.2 to highlight their significance.

TABLE 3.1

Command Words which Designate and Require Additional Data to Immediately Follow

Command Word	Description and Meaning
HEAding	Designates that data which are to immediately follow contain a heading to be printed as an output heading. See Group A data description in Section 4.
PROfile line data	Designates that data which are to immediately follow are for the profile lines. See Group B data description in Section 5.
MATerial property	Designates that data which are to immediately follow are for material (soil) properties. See Group C data description in Section 6.
PIEzometric line data	Designates that data which are to immediately follow are for piezometric lines. See Group D data description in Section 7.
INTerpolation data data for pore water pressures	Designates that data which are to immediately follow are for points used to interpolate pore water pressures. See Group E data description in Section 8.
SLOpe geometry data	Designates that data which are to immediately follow are for the slope geometry. See Group F data description in Section 9.
SURface pressure data	Designates that data which are to immediately follow are for normal and shear stresses acting on the surface of the slope. See Group G data description in Section 10.
ANAlysis and computation data	Designates that data which are to immediately follow are for information needed for the stability computations. See Group H data description in Section 11.

TABLE 3.2

Command Words Which Do Not Necessarily Require Additional Data to Follow

Command Word	Description and Meaning
*********	Three or more asterisks (*) may be optionally used to separate distinctly different sets of data and problems. Then, if an error is encountered in data for one problem, the program will skip the remaining data up to this line of asterisks and begin with the new set of data; all data specified previous to the line of asterisks are ignored for the next problem. (This is true regardless of whether or not errors are encountered.)
COMpute results	Designates that computations are to be performed. When this Command Word is read, the program checks all of the data currently read and proceeds with computations. Once computations have been completed, the program returns to reading Command Words and new data. Unless specifically directed (i.e., by three asterisks, "***") all old data are retained and new data read simply replace selected old data. Thus, all or only a small part of data may be changed for the next problem.
NO compute	Designates that no computations are to be performed, but directs the program to perform the checks of input data and then resume reading input data. This is convenient for debugging data and the "NO COMPUTE" can later be re-edited to "COMPUTE" to activate execution.
MODify mode	Designates that the program is to be placed in Modify Mode for input of data: Certain groups of data (Groups B, D, E, F and G) can be input in either a Normal Mode or a Modify Mode. In the Modify Mode more selective changes to a portion of the data can be made, as described in later sections for each of the Groups where this option is available.
NORmal mode	Designates that the program is to be returned to the Normal Mode after being in the Modify Mode described above. These modes may be changed at any time and in any pattern. The "normal" mode is set initially and after "***" are encountered.

(continued)

Table 3.2 - con't.

Command Word	Description and Meaning
PRInt input data	Designates that all subsequent input data are to be printed. This is the default set initially and after "***" are encountered.
SUPpress printing input data	Designates that all subsequent input data are not to be printed. Input data may be alternatively printed and suppressed among Groups for a single problem, i.e., "PRI" and "SUP" could appear several times in the data for a single problem if necessary.
PLOt tape to be written	Designates that the file, TAPE2, is to be written for each "block" of data. (Applicable only if the plotting version of UTEXAS is being used.)
OFF plotting tape	Turns the writing of the plotting tape "off". This is default. (Applicable only if the plotting version of UTEXAS is being used.)

SECTION 4 - GROUP A DATA FOR HEADING (Optional)

The Group A data consist of a 3-line heading which is printed as an output heading above each table of output. The heading may be changed at any stage of the input data, i.e., it can be changed between each group of data (B, C, D etc.) or it can be left the same for all groups. To change the heading at any time input the Command Word "HEA" (or "HEADING"). A blank heading is assumed both initially and immediately after "***" is encountered in the Command Words. The heading may be input while the program is operating in either the Normal Mode or the Modify Mode of input. There is no difference in the form of input for the two modes. The form of input is shown in Table 4.1.

TABLE 4.1

Group A - Heading Data Input Format

Input Line No.	Data Field No.	Variable/Description
1	1	(HEADNG(1)) - First line of heading; up to 80 characters including blanks.
2	1	(HEADNG(2)) - Second line of heading; up to 80 characters including blanks.
3	1	(HEADNG(3)) - Third line of heading; up to 80 characters including blanks.

Resume input with Command Words after three lines of heading have been input. Three lines must be input; however, one or more of the lines may be blank.

SECTION 5 - GROUP B DATA FOR PROFILE LINES

Group B data consist of the "Profile Lines," which are used to describe the geometry of the soil profile and slope cross-section. Individual profile lines are defined by the coordinates of a series of points along each line from left-to-right. The points are assumed to be connected by straight lines to represent a continuous, piecewise linear, line.

Beneath a given profile line the soil or other material is considered to be of a given type until another profile line is encountered. Each profile line has a "Material Type" associated with it; the material type is specified as part of the input data for the profile line. The material type indicates which set of material properties (specified in the Group C data - See Section 6) are to be used for the soil beneath the profile line. Several profile lines may be assigned the same material type.

The coordinates defining the surface profile of the slope ("slope geometry") are automatically computed from the profile line data by the program when no other slope geometry data are input (See Section 9 - Group F, Slope Geometry data). Once profile lines have been defined and the program has computed the "slope geometry," the slope geometry will ordinarily not be recomputed by the program even if new profile lines are input. That is, the old slope geometry will normally be retained. However, the old slope geometry can be deleted so that new geometry will be computed if the user inputs a set of "null" slope geometry as described in Section 9. If the user desires, separate slope geometry data can <u>always</u> be input as Group F data in the manner described in Section 9.

Once a set of profile lines are defined, they ordinarily remain in effect until specifically replaced, one-by-one by new data. As an example, suppose that five profile lines are initially defined and at a later time new data are input for just one profile line. The new data may either replace one of the "old" profile lines (the other four profile lines being unchanged) or add to the old profile lines (creating a total of six profile lines). Whether the new data replace or add to the old data will depend on the number (NLINE) of the new profie line. If a line having the same number as the new line already exists, it will be replaced by the new data. If no line with the number of the new line exists, the new line is added to the previous lines. The only times profile line data are started entirely anew is when asterisks (***) have been input as a Command Word (See Table 3.2).

Group B data must immediately follow the Command Word "PRO" (or "PROFILE LINES"). The data may be input in either the Normal Mode or the Modify Mode. Input for the Normal Mode is described in Table 5.1; input for the Modify Mode is described in Table 5.2.

TABLE 5.1

Group B - Profile Line Data Input Format - Normal Mode

Input Line No.	Data Field No.	Variable/Description
1	1	(NLINE) - Number of the profile line to be defined next, i.e., on Line(s) 2 below. Any sequence of numbering and input of profile lines may be used.
1	2	(MTYPE) - Number of the material type for the material below the profile line.
1	3	(LABEL) - Any alphanumeric character(s) or character string(s) to be printed as a label for the profile line. Can be as many characters and/or blanks as will fit on an 80 column line (including Fields 1 and 2). Can also be blank.
2	1	(XPROFL) - X coordinate of point on the profile line which is currently being defined.
2	2	(YPROFL) - Y coordinate of point on the profile line which is currently being defined.

(a) Repeat Line(s) 2 for additional points on the profile line in a left-to-right sequence. Input a blank line to terminate data for the current profile line.

(b) Repeat Lines 1 and 2, as sets, for additional profile lines. Lines may be input in any order. (Line numbers, NLINE, may be missing from a sequence; however, there appears to be little need for omitting numbers from a sequence.) Input two blank lines after the last line of non-blank profile line data to terminate <u>all</u> Group B data and return to input of Command Words.

TABLE 5.2

Group B - Profile Line Data Input Format - Modify Mode

Line No.	Field No.	Variable/Description
1	1	(NPROF) - Number of the profile line for which coordinate is to be changed.
1	2	(NPOINT) - Number of the point on the given profile line where coordinate is to be changed.
1	3	(XPROFL) - New value of X coordinate for point.
1	4	(YPROFL) - New value of Y coordinate for point.

Repeat Line(s) for additional points whose coordinates are to be changed in modify mode. Input a single blank line to terminate all Group B data and return to input of Command Words.

SECTION 6 - GROUP C DATA FOR MATERIAL PROPERTIES

INTRODUCTION

The Group C data consist of material properties, which include the unit weights, shear strengths, and description of how pore water pressures, if any, will be defined for each of the materials in the soil profile. Each profile line, as described previously in Section 5, must have a set of material properties assigned to it; several profile lines may share a single set of material properties. Requirements for the material property data and the form of the input data are described in this section.

EFFECTIVE STRESS VERSUS TOTAL STRESS ANALYSES

The computer program permits analyses to be performed using either total or effective stresses to define shear strengths. In the case of total stresses the shear strengths are expressed by the equation

$$s = c + (\sigma) \tan \phi \qquad (6.1)$$

where σ is the total normal stress on the shear plane, and c and ϕ are shear strength parameters expressed in terms of total stresses. For the case of effective stresses the shear strengths are expressed by

$$s = \bar{c} + (\sigma - u) \tan \bar{\phi} \qquad (6.2)$$

where u is the pore water pressure, (σ - u is the effective normal stress), and $\bar{c}$ and $\bar{\phi}$ are shear strength parameters expressed in terms of effective stresses. In the input of data to the computer program the values for "cohesion" and "friction angle" must be the appropriate total stress (c,ϕ) or effective stress ($\bar{c},\bar{\phi}$) values. The only other distinction that is made between total and effective stresses is that in the case of effective stresses appropriate pore water pressures (including zero as a special case) must be specified, while for total stresses pore water pressures must be specified as zero.

The distinction between total and effective stresses is made on a material-by-material basis. Thus, the shear strengths of some materials may be defined using total stresses while the shear strengths for other materials may be defined using effective stresses.

UNIT WEIGHTS

In general the unit weight which is specified for each material should be the total unit weight (total weight divided by total volume). However, in two cases the submerged (buoyant) unit weight of soil may be used although it still is not necessary in these two cases:

1. The first case where submerged unit weights may be used occurs for total stress analyses where ϕ is equal to zero. In this case a submerged unit weight may be used for the portion of any soil which is submerged beneath water provided that there is <u>no flow</u> or tendency for flow (i.e., the hydraulic gradient is zero). If the submerged unit weight is used in this case, any surface loads due to the water which causes the submergence must <u>not</u> be specified as surface pressures (See Section 10 for description of Surface Pressures); the effects of the surface loads are already accounted for when the submerged unit weight

is used. If there is flow of water (non-zero hydraulic gradient) or ϕ is not equal to zero, submerged unit weights must not be used for total stress analyses.

2. The second case where submerged unit weights may be used occurs in the case of effective stress analyses. Submerged unit weights may be used for the portion of any soil which is submerged provided that there is no flow of water and no hydraulic gradient. If the submerged unit weight is used, pore water pressures and any surface pressures due to the water must <u>not</u> be specified in the input data; the effects of pore water pressures and surface pressures are already accounted for when the submerged unit weights are used.

If submerged unit weights are used for one material, they <u>must</u> be used for all materials for which the use of submerged unit weights is allowable, i.e., they must be used for all portions of materials which are submerged.

PORE WATER PRESSURE OPTIONS

Six options are available for defining pore water pressures in individual materials as follows:

<u>Option 1</u>: No pore water pressures are to be used, i.e., total stresses are being used, or the pore water pressures are equal to zero.

<u>Option 2</u>: The pore water pressure is constant throughout the given material; the constant value of pore water pressure is then input.

<u>Option 3</u>: The pore water pressures are expressed by a constant, given value of the pore water pressure coefficient, r_u, as defined by

Bishop and Morgenstern (1960). The pore water pressure coefficient is defined as

$$r_u = \frac{u}{\gamma h} \tag{6.3}$$

where u is the pore water pressure at any point and γh is the corresponding total vertical stress (overburden pressure). If this option is chosen, the value of r_u is then input. In computing pore water pressures using a value of r_u the computer program calculates "γh" due to the weight of overlying soil, but excludes any added vertical stress due to "surface pressures" which may be input as Group G data (See Section 10).

Option 4: The pore water pressure is defined by a piezometric line; piezometric line data must be input separately by use of Group D data as described in Section 7. The material property data must include an identification number for the piezometric line to be used. In computing pore water pressures from the piezometric line the computer program determines the vertical distance between the point of interest and the piezometric line and multiplies this distance by the unit weight of water to arrive at the pore water pressure. Pore water pressures are assumed to be positive below the piezometric line and negative above the piezometric line (See Section 7 for more details).

Option 5: Pore water pressures are computed by interpolating pore water pressures from an irregular "grid" of pore pressure values, which are specified separately by Group E data, as described in Section 8.

Option 6: Pore water pressures are computed by interpolating in a manner similar to that for Option 5, except that values of the pore water pressure coefficient, r_u, rather than actual values of pressure, are defined as the input data and used for interpolation. The values of r_u are used and defined in the same manner as described for Option 3. Further description of the interpolation is presented in Section 8.

Normally, the computer program will set any negative value of pore water pressure to zero before proceding with further calculations; however, the user can optionally override this feature if desired (See line No. 3, Field No. 3 in Table 6.1).

SHEAR STRENGTH OPTIONS

Four options are available for defining the shear strengths of any given material as follows:

Option 1: The shear strength is isotropic (shear strengths are independent of the orientation of the failure plane) and is defined in a conventional manner, expressed by a Mohr-Coulomb cohesion (c) and friction angle (ϕ). For total stress analyses the cohesion and friction angle should be the values of c and ϕ determined using total stresses to plot the failure envelope. (In this case the pore water pressures must be specified to be zero.) For effective stress analyses the values of c and ϕ ($\bar{c}$ and $\bar{\phi}$) should be values determined using effective stresses to plot the failure envelope. (In this case appropriate pore water pressures will need to be specified and pore pressures may or may not be zero.)

Option 2: The friction angle is zero, but the shear strength ($s = c$) varies linearly with depth below the profile line to which the material property data apply. The shear strength along the profile line and the rate of change (increase or decrease) with depth below the profile line must be specified.

Option 3: The shear strength parameters c and ϕ (or $\bar{c}$ and $\bar{\phi}$, as described for Option 1) vary with the orientation of the failure plane. Values of c and ϕ are input for selected failure plane orientations and linear interpolation is used to obtain values at orientations between the specified values. The computer program will later assign appropriate values of c and ϕ to each slice (See Section 11) based on the orientation of the base of the slice; the base of the slice is considered to represent the failure plane and the inclination of the base of the slice corresponds to the failure plane inclination.

Option 4: The shear strength ("Mohr-Coulomb" type) envelope in nonlinear, i.e., it is not a single straight line. Values of shear strength (s) are input for various values of total or effective normal stress (σ or $\bar{\sigma}$) to define points on a nonlinear shear strength envelope. The points are assumed to be connected by straight lines to form a piecewise linear envelope. The computer program will later assign a shear strength to the base of each slice (See Section 11) based on the total or effective normal stress on the base of the slice. An iterative procedure is used to assign the shear strengths because the computed normal stresses depend on the shear strength. The assignment of shear strengths defined by a nonlinear shear strength envelope is performed at the time the factor of safety is computed. Because the solution for the factor of safety also involves using a trial and error procedure, an additional level of iteration is introduced when a nonlinear shear strength envelope is used.

FORM FOR DATA INPUT

The form and guide for Group C data input are presented in Table 6.1. The Group C data must immediately follow the Command Word "MAT" (or "MATERIAL PROPERTIES"). Only the Normal Mode of input is available for material properties and will be used regardless of whether the Normal or Modify Mode is in effect.

Once data have been input for materials, they remain in effect until specifically replaced, material by material, with new data. If new data are input for only one material, after data for several materials have been previously input, then the new data will either replace the data for one material or add to the existing data. If the material type (MTYPE - See Line No. 1, Field No. 1 of Table 6.1) for the new material is identical to one previously defined, the new data will replace the previous data <u>for this material only</u>. If the material type for the new material has not been previously defined, the new data are <u>added to</u> the old data which were previously defined. Thus, while a Modify Mode is not available for material property data, the Normal Mode permits data to be selectively changed. The only times material property data are started entirely anew is when asterisks (***) have been input as a Command Word (See Table 3.2).

TABLE 6.1

Group C - Material Property Data Input Format

Input Line No.	Data Field No.	Variable/Description
1	1	(MTYPE) - Number used to identify the material (= material type) for which data will follow on Line(s) 2 through 6. This number corresponds with the material type numbers input for profile lines in Group B data.
1	2	(LABEL) - Any alphanumeric character(s) or character string(s) to be printed as a label with data for the current material type. Can be as many characters and/or blanks as will fit on an 80-column line (including Field 1). Can also be blank.
2	1	(GAMMA) - Unit weight for the current material.
3	1 and 2	(CHAR) - Two characters separated by blanks, or two character strings separated by blanks, to designate how pore water pressures are to be defined for this material. The acceptable characters or character strings and their interpretation are shown below. The key characters which must be input are capitalized and underlined. (Note: Only the first character of any character string is recognized and used.)

Character String	Interpretation
No pore pressure	Pore pressures are zero. (Only one character, N, is actually required in this case.) No Line 4 is required; proceed with Line 5.
Constant Pore pressure	Pore pressures are constant. Follow this line of data with Line 4 giving the value of the pore water pressure.
Constant R_u value	The value of the pore water pressure coefficient, r_u, is constant. Follow this line of data with Line 4 giving the value of the pore water pressure coefficient, r_u

(continued)

Table 6.1 - Con't.

Character String	Interpretation
Piezometric Line	A piezometric line is used to define pore water pressures in this material. Follow this line of data with Line 4 giving the identification number of the piezometric line which is to be used. Note: Group D data must eventually be input.
Interpolate Pore water pressure	Pore water pressures are to be determined by interpolation of values of pore water pressure. Note: Group E data must eventually be input, but no Line 4 is required below.
Interpolate R_u values	Pore water pressures are to be determined by interpolation of values of the pore water pressure coefficient, r_u. Note: Group E data must eventually be input, but no Line 4 is required below.

3	3	CHAR(3) - A character or character string to designate if negative pore water pressures are to be acceptable in this material. Specify "N" (i.e., "Negative") if negative pore pressures are acceptable. Any other character (or blank) in this field will cause negative pore water pressures to be set to zero.
4	1	Optional - Value of (1) the pore water pressure, or (2) r_u or (3) the identification number of the piezometric line depending on data on Line 3. Line 4 is not required in all cases and in such cases should be omitted.
5	1	(CHAR(1)) - A character, or character string beginning with an appropriate character, to designate the manner in which shear strengths are to be characterized. The acceptable characters or character strings and their interpretation are shown below. The key character which must be input is capitalized and underlined. (Note: only the first non-blank character is recognized and used.)

(continued)

Table 6.1 - Con't.

Input Line No.	Data Field No.	Character String	Interpretation
		Conventional shear strength or Isotropic shear strength ("C" and "I" have identical meanings)	Shear strengths are expressed by conventional Mohr-Coulomb parameters, c and ϕ Follow this line of data with line 6A below.
		Linear increase with depth	Shear strengths increase linearly with depth below the profile line, starting at a prescribed value along the profile line. Follow this line of data with Line 6B below.
		Anisotropic shear strengths	Shear strengths vary with the orientation of the failure plane. Follow this line of data with Lines 6C below.
		Nonlinear Mohr-Coulomb envelope	The shear strength envelope is nonlinear. Follow this line of data with Lines 6D below.
6A	1	(COHESN) - Cohesion value, c, for the soil.	
6A	2	(PHIANG) - Angle of internal friction, ϕ, for the soil - in degrees.	
		After the above line (6A) proceed with data for the next material. See notes following Line 6D description.	
6B	1	("COHESN") - Value of shear strength along the profile line.	
6B	2	("PHIANG") - Rate of increase in shear strength below the profile line, expressed as an increase in strength per unit of depth. (units = force/length^2/length = force/length^3)	
		After the above line (6B) proceed with data for the next material. See notes following Line 6D description.	

(continued)

Table 6.1 - Con't.

Input Line No.	Data Field No.	Variable/Description
6C	1	(FPANGL) - Orientation of failure plane for set of shear strength values in Fields 2 and 3 - expressed as an angle, in degrees, measured from the horizontal - positive counterclockwise. Both negative and positive values are allowed; typically values may range from -90^{o} to $+90^{o}$.
6C	2	(COHESN) - Cohesion value, c, for current failure plane orientation.
6C	3	(PHIANG) - Angle of internal friction, ϕ, for current failure plane orientation, in degrees.
		Repeat Line 6C for additional anisotropic shear strength values in a sequence of increasing angles of failure plane orientation. Input a blank line to terminate the current anisotropic shear strength data. See notes following Line 6D description.
6D	1	("COHESN") - Normal stress, σ or $\bar{\sigma}$, for point which is being defined on nonlinear failure envelope.
6D	2	("PHIANG") - Shear stress, τ, for point on nonlinear envelope.
		Repeat Line 6D for additional values to define a nonlinear failure envelope. Values must be input in a sequence of increasing values of normal stress. Input a blank line to terminate the current nonlinear failure envelope data.

Repeat Lines 1 through 6, as sets, for data for additional material types. Material types may be input in any order. (Material type numbers, MTYPE, may actually be missing from a sequence; however, there appears to be little need for omitting numbers from a sequence.) Input a blank line after data for the last material have been input to terminate all Group C data; then return to input of Command Words. Note: In some cases two blank lines will actually be used to terminate all the data, i.e., when Lines 6C or 6D are used.

SECTION 7 - GROUP D DATA FOR THE PIEZOMETRIC LINE (Optional)

The Group D data consist of the data for the piezometric lines. These data are required only when the material property data (See Section 6) have designated that the pore water pressures in one or more materials are to be defined by a piezometric line.

The computer program allows several piezometric lines to be defined. Each piezometric line is assigned an identification number in the range of from 1 to the maximum number of piezometric lines allowed. The identification number is used with the material property data to associate a given piezometric line with a given material (See Table 6.1 - Line No. 4). Several materials may share and use the same piezometric line. The sequence and pattern for assigning numbers to piezometric lines is arbitrarily selected by the user.

Each piezometric line is defined by the coordinates of a series of points from left to right along the line. The points are assumed to be connected by straight lines to form a continuous, piece-wise linear piezometric surface. Vertical segments of the piezometric lines are acceptable.

Pore water pressures are calculated by taking the vertical distance between any point of interest and the corresponding point on the piezometric line and multiplying the distance by the unit weight of water (or other fluid). The unit weight of water (or other fluid) may be input with the piezometric line data (if different from 62.4) and may be different for each piezometric line. Pore pressures are considered to be negative above the piezometric line and positive below the piezometric line (See Table 6.1 - Line No. 3, Field No. 3 - regarding negative pore water pressures).

Group D data for the piezometric line may be input in either the Normal Mode or Modify Mode. The forms for data input in the Normal and Modify Modes are presented in Tables 7.1 and 7.2, respectively.

TABLE 7.1

Group D - Piezometric Line Data Input Format - Normal Mode

Input Line No.	Data Field No.	Variable/Description
1	1	(PZLINE) - Number used to identify the piezometric line.
1	2	(GAMMAW) - Unit weight of water, or other fluid, to be used with this piezometric line - optional. If omitted, a value of 62.4 is assumed.
1	2 or 3	(LABEL) - Any alphanumeric character(s) or character string(s) to be printed on output as a label with data for the current piezometric line - optional. Must not start with a numeral (1, 2, 3 etc.) - this is required to distinguish if information in the second field is the unit weight of fluid or the label. Can be as many characters and/or blanks as will fit on an 80-column line (including Fields 1 and 2). Can also be blank.
2	1	(XPIEZL) - X coordinate of point on the piezometric line which is currently being defined.
2	2	(YPIEZL) - Y coordinate of point on the piezometric line which is currently being defined.
		Repeat Line 2 for additional points on the piezometric line in a left to right (increasing x value) sequence. Vertical segments are allowed. Input a blank line to terminate data for the current piezometric line.

Repeat Lines 1 and 2, as sets, for additional piezometric lines. Lines may be input in any order. (Piezometric line numbers, PZLINE, may actually be missing from a sequence; however, there appears to be little need for this option of omitting numbers from a sequence.) Input two blank lines (including the blank Line 2 for the last piezometric line) to terminate all Group D data; then return to input of Command Words.

TABLE 7.2

Group D - Piezometric Line Data Input Format - Modify Mode

Input Line No.	Data Field No.	Variable/Description
1	1	(NLINE) - Number of the piezometric line for which coordinate is to be changed.
1	2	(NPOINT) - Number of the point on the given piezometric line where coordinate values are to be changed.
1	3	(XPIEZL) - New value of X coordinate for point.
1	4	(YPIEZL) - New value of Y coordinate for point.
		Repeat Line 1 for additional points whose coordinates are to be changed in Modify Mode. Input a blank line to terminate all Group D data in Modify Mode; then return to input of Command Words.

SECTION 8 - GROUP E DATA FOR
PORE WATER PRESSURE INTERPOLATION (Optional)

INTRODUCTION

The Group E data consist of a series of discrete values of either pore water pressure (u) or pore water pressure coefficient (r_u). The values are specified at selected points and used to interpolate pore water pressures at desired points along the shear (potential sliding) surface. These data are required only when the material property data (see Section 6) have designated that the pore water pressures in one or more materials are to be defined by interpolation. The procedure used for interpolation of pore water pressures is based on the procedure proposed by Chugh (1981) and appears to be an improvement over the interpolation procedure formerly employed by Wright (1982). The interpolation procedure is briefly described below.

INTERPOLATION PROCEDURE

Pore water pressures are interpolated at a point corresponding to the center of the base of each vertical slice (See Section 11). The interpolation is carried out slice-by-slice for each slice whose base lies in a material where the pore pressure interpolation option was specified. The interpolation is initiated by locating the closest points to the point of interest (center of base of slice), which lie in each of the four quadrants surrounding the point of interest. The four quadrants are illustrated schematically in Fig. 8.1. Once the closest points in each of the four quadrants are located, three

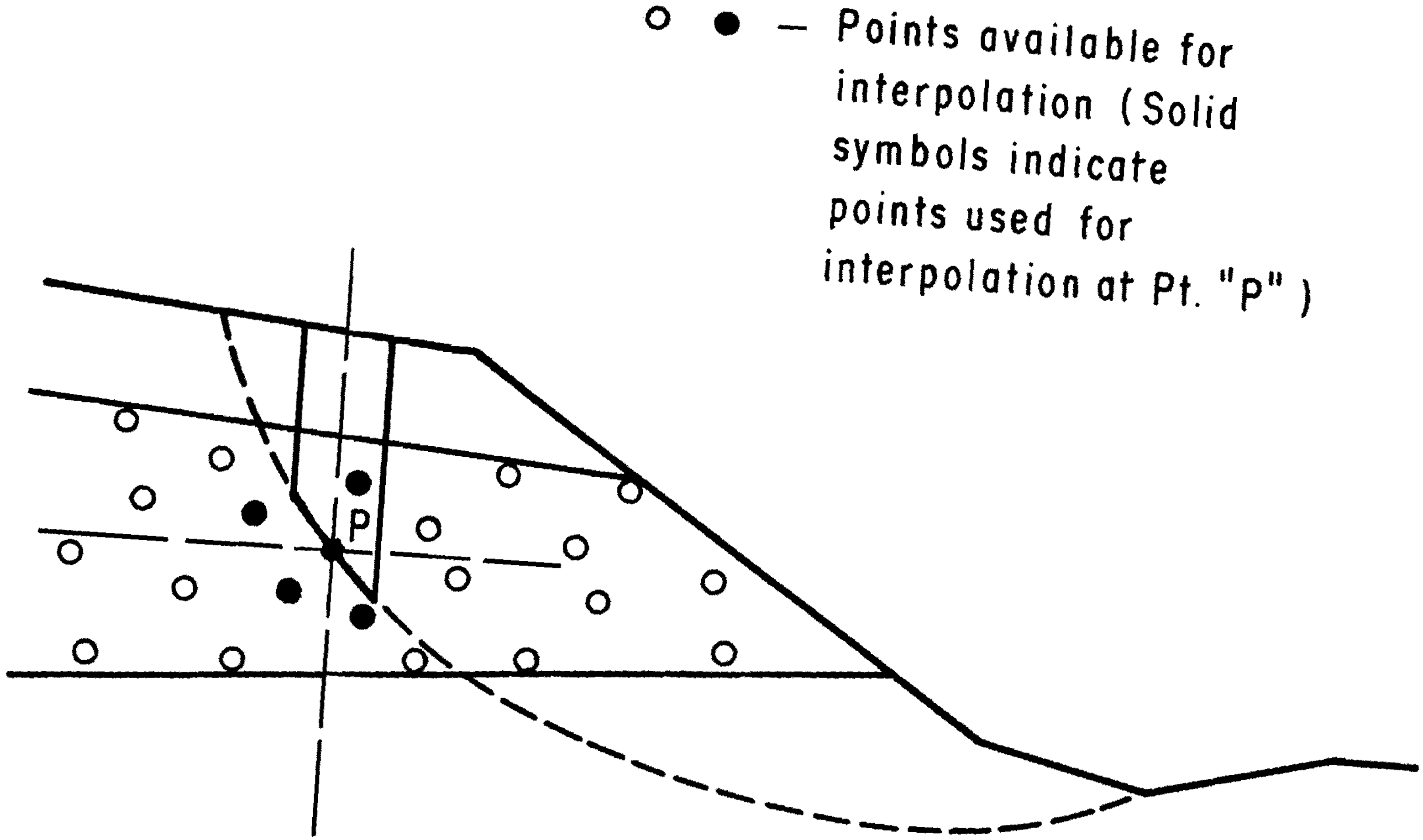

Fig. 8.1 Illustration of Pore Pressure Points Used for Interpolation

of the four points are then selected (arbitrarily) and used to evaluate the coefficients a, b and c in a linear interpolation function of the form

$$u = a + bx + cy \tag{8.1}$$

where u is the pore water pressure, x and y represent the coordinates of the point where the pore water pressure (u) exists, and a, b, and c are interpolation coefficients. Equation 8.1 is solved for the interpolation coefficients (a, b, and c) using the known pore water pressures and corresponding coordinates of the three selected points. The values of the coefficients are next used in Eq. 8.1 to calculate the pore water pressure at the center of the base of the slice. This process is then repeated using another combination of three of the four points found previously and a new set of calculations is performed to calculate the pore water pressure at the center of the base of the slice. This sequence of calculations is performed a total of four times, each time using a different combination of three of the four points. Finally, after four values of pore water pressure have been determined by interpolation, the four values are averaged arithmetically, and the average value is used for the slice. This process is repeated for each slice (and each shear surface) where pore water pressures are to be calculated by interpolation.

In the case where the pore pressure coefficient, r_u, rather than the pore water pressure is to be used for interpolation, the same procedures as those described above are used, except that u is replaced by r_u. Once an average value of r_u for the center of the base of the slice is obtained by interpolation, the average value is used to calculate the pore water pressure. Thus, the computer program interpolates r_u first, and then calculates the pore water pressure, rather than calculating u first, and then interpolating values of u to the base of the slice.

FORM OF DATA INPUT

The Group E data must immediately follow the Command Word "INT" (for "INTERPOLATION DATA"). The data may be input in either the Normal Mode or the Modify Mode. The forms of input for the Normal and Modify Modes are presented in Tables 8.1 and 8.2, respectively.

TABLE 8.1

Group E - Pore Pressure Interpolation Data Format - Normal Mode

Input Line No.	Data Field No.	Variable/Description
1	1	(CHAR) - A single character, or a character string starting with the appropriate character, to designate if the data which will follow (on Line 2) represent values of pore water pressure or values of the dimensionless pore pressure coefficient, r_u. The character should be either a "P" to indicate that values represent pore water pressure, or an "R" to indicate that values represent values of r_u. A blank line is interpreted to represent the end of all Group E data.
2	1	(XINTPT) - X coordinate for interpoltation point.
2	2	(YINTPT) - Y coordinate for interpolation point.
2	3	(UINTPT) - Value of pore water pressure or pore pressure coefficient, r_u (depending on designation on Line 1), at the specified coordinate point.
2	4	(MINTPT) - Material type (with reference to Group C data) for which this specified pore pressure information is to be used. If zero, this information (point) will be used for all materials where pore pressures are interpolated, provided that the type of data (pore pressures or r_u) at this point is consistent with what was indicated by the material data, e.g., if r_u values are to be interpolated, this line of data must contain an r_u value or it will not be used.

Repeat Line(s) 2 for additional points with data of a similar type (e.g., pore pressure or r_u). Input a blank line to terminate data of one type (pore pressure or r_u), then follow with another Line 1. The data on Line 1 following the above Line(s) 2 may either designate another type of data (e.g., pore pressures vs. r_u) and be followed by more Line(s) 2, or may serve to terminate all Group E data.

TABLE 8.2

Group E - Pore Pressure Interpolation Data Format - Modify Mode

Input Line No.	Data Field No.	Variable/Description
1	1	(CHAR) - A single character, or a character string beginning with the appropriate character, to designate whether the data which are to follow are to replace existing data, or are to be added to existing data. The character should be either an "R", to indicate that values are to be replaced, or an "A", to indicate that values are to be added. If the character is R, proceed with Line(s) 2A to replace data; if the character is A, proceed with Lines 2B and 3 to add data. A blank character (blank line) is interpreted as the end of all Group E data designated by the current Command Word.
2A	1	Number identifying the number of the point which is to be replaced. (On previous input the first point input was assumed to be Point No. 1, the second input was assumed to be Point No. 2, etc.)
2A	2	(XINTPT) - New X coordinate for point which is being replaced.
2A	3	(YINTPT) - New Y coordinate for point which is being replaced.
2A	4	(UINTPT) - New value of either pore water pressure or r_u at point which is being replaced. Note: The type of value (pore pressure or r_u) must be the same as it was originally at this point.

Repeat Line(s) 2A for additional points which are to be replaced. Input a blank line to terminate Line(s) 2A, then proceed with Line 1 again.

(continued)

Table 8.2 - Con't.

Input Line No.	Data Field No.	Variable/Description
2B	1	(CHAR) - A single character, or a character string beginning with the appropriate character, to designate whether the data which are to follow represent values of pore water pressure or values of the dimensionless pore water pressure coefficient, r_u. The character should be either a "P", to indicate that values represent pore water pressure, or an "R", to indicate that values represent values of r_u. A blank line is not allowed here.
3	1	(XINTPT) - X coordinate for interpolation point.
3	2	(YINTPT) - Y coordinate for interpolation point.
3	3	(UINTPT) - Value of pore water pressure or pore pressure coefficient, r_u (depending on designation on Line 2B), at the specified coordinate point.
3	4	(MINTPT) - Material type (with reference to Group C data) for which this specified pore pressure information is to be used. If zero, this information (point) will be used for all materials where pore pressures are interpolated, provided that the type of data (pore pressures or r_u) at this point is consistent with what was indicated by the material data, e.g., if r_u values are to be interpolated, this line of data must contain an r_u value or it will not be used.

Repeat Line(s) 3 for additional points with data of a similar type (e.g., pore pressure or r_u), which are to be added. Input a blank line to terminate data of one type (pore pressure or r_u), then proceed with Line 1 again.

SECTION 9 - GROUP F DATA FOR THE SLOPE GEOMETRY (Optional)

INTRODUCTION

The Group F data are used to define (optionally) the slope geometry. The Group F data may also be used to input a null data set to cancel old slope geometry data, which have been computed from an earlier set of profile line data. Old slope geometry data may need to be canceled when a new set of profile lines (Group B data) has been input which alters the slope geometry. However, the principal reason why the Group F slope geometry data exist separately from the profile lines is to permit the user to consider several possible slope geometries "cut" from a given soil profile (set of profile lines).

DESCRIPTION OF DATA

The slope geometry data define the surface profile of the slope and consist of the coordinates of a series of points from left-to-right along the surface of the slope. The points are assumed to be connected by straight lines to form a continuous slope profile. All material (soil, rock, etc.) which has been defined by profile to exist lines above the surface of the slope, as defined by the slope geometry data in Group F, is ignored. Thus, profile lines specified in Group B could define an original soil profile, and the slope geometry data could describe one or more excavated slope profiles within the original soil profile.

Both left and right facing slopes are allowed, and a single slope may contain both a left and a right face in its specified geometry. Vertical "slopes" and horizontal "slopes" are also allowed. In the case of a horizontal "slope," loads would be applied by surface pressures and the problem becomes essentially one of bearing capacity.

SPECIAL NOTE FOR FLAT SLOPES

Special care is required when using the computer program with either very flat or horizontal slopes. The computer program determines the direction (left or right) of potential sliding by comparing the elevations of the two ends of the shear surface. If the left end is higher than the right end, the direction of potential sliding is assumed to be to the right for the specific shear surface examined. Otherwise the direction of potential sliding is assumed to be to the left. Thus, for horizontal slopes the direction of sliding is assumed to be to the left. Accordingly, for horizontal "slopes" shear surfaces should be directed to the left of the area of the applied surface loading. For flat, but not horizontal, slopes the direction of sliding is assumed to be in the direction which gravity would produce, i.e., from high to low. If sliding in the opposite direction from gravity were possible due to relatively high surface pressures, special features of the program would have to be invoked. Specifically, a special "opposite sign convention option" must be activated by optional data in the Group H - Analysis/Computation data (See Table 11.3 - Sub-Command Word "OPP").

FORM FOR DATA INPUT

The Group F data must immediately follow the Command Word "SLO" (or "SLOPE GEOMETRY"). The data may be input in either the Normal or Modify Modes. The forms of input for the Normal and Modify Modes are presented in Tables 9.1 and 9.2, respectively.

TABLE 9.1

Group F - Slope Geometry Data Input Format - Normal Mode

Input Line No.	Data Field No.	Variable/Description
1	1	(XSLOPE) - X coordinate of slope point.
1	2	(YSLOPE) - Y coordinate of slope point.
		Repeat Line(s) 1 for additional points on the surface of the slope from left-to-right. Input a blank line to terminate slope geometry data (all Group F data); then return to input of Command Words. If only a blank line, not preceded by x and y coordinates, is input, the slope geometry data are canceled, i.e., a null set of data are input. When slope geometry data are canceled new coordinates defining the slope geometry will be computed by the computer program using the profile line data.

TABLE 9.2

Group F - Slope Geometry Data Input Format - Modify Mode

Input Line No.	Data Field No.	Variable/Description
1	1	(N) - Number of slope point whose coordinates are to be changed.
1	2	(XSLOPE) - New X coordinate value for the point.
1	3	(YSLOPE) - New Y coordinate value for the point.
		Repeat Line 1 for points whose coordinates are to be changed. Input a blank line to terminate current slope geometry data in Modify Mode; then return to input of Command Words.

SECTION 10 - GROUP G DATA FOR SURFACE PRESSURES (Optional)

Group G data consist of the "Surface Pressures" which are used to define any stresses acting on the surface of the slope. The surface pressures are specified in terms of values of stress acting normal (perpendicular) to the slope and tangential (parallel) to the slope. The pressures are specified in the input data by specifying coordinates of points on the surface of the slope and the corresponding values of normal and shear stress at the point. Points are specified in a left-to-right sequence. The pressures are assumed to be zero to the left of the first point specified and to the right of the last point specified. The normal and shear stresses are assumed to vary linearly between specified points. If an abrupt change in stress occurs at a point, the coordinates of the point are input twice, first with the value of stress just to the left of the point and then with the value of the stress just to the right of the point.

Compression is considered to be positive for the normal stresses acting on the surface of the slope; tension is considered to be negative. The shear stresses are considered to be positive when they act to the right and negative when they act to the left.

The coordinates of points which are input to define the surface pressures should be specified as precisely on the surface of the slope as is practically possible. If the points do not coincide with the surface of the slope an error condition may result and computations will be abandoned with an appropriate warning message.

Surface pressures cannot be specified (input) on vertical segments of the slope, because surface pressures are considered to produce loads on the tops of vertical slices. All loads on the vertical sides of slices are considered to be included in side forces, which are computed as unknowns.

Surface pressure data must immediately follow the Command Word "SUR" (or "SURFACE PRESSURES"). The data may be input in either the Normal or Modify Modes. The forms of input for the Normal and Modify Modes are presented in Tables 10.1 and 10.2, respectively.

TABLE 10.1

Group G - Surface Pressure Data Input Format - Normal Mode

Input Line No.	Data Field No.	Variable/Description
1	1	(XSURFP) - X coordinate value of point where stress acts.
1	2	(YSURFP) - Y coordinate value of point where stress acts.
1	3	(PNORML) - Normal stress at point.
1	4	(PSHEAR) - Shear stress at point.

Repeat Line(s) 1 for additional points to define the surface pressures in a left-to-right sequence. Input a blank line to terminate the surface pressures data (all Group G data); then return to input of Command Words (Section 3).

TABLE 10.2

Group G - Surface Pressure Data Input Format - Modify Mode

Input Line No.	Data Field No.	Variable/Description
1	1	(N) - Number of points where coordinates and/or surface pressures are to be changed.
1	2	(XSURFP) - New X coordinate of point.
1	3	(YSURFP) - New Y coordinate of point.
1	4	(PNORML) - New normal stress at point.
1	5	(PSHEAR) - New shear stress at point.

Repeat Line(s) 1 for additional points to modify previously defined surface pressure data points. (Not all points need to be modified.) Input a blank line to terminate the surface pressure data in Modify Mode; then return to Command Words (Section 3).

SECTION 11 - GROUP H DATA FOR THE ANALYSIS AND COMPUTATIONS

INTRODUCTION

The Group H input data are used to define the shape of the shear (potential sliding) surfaces used to compute the factor of safety. The factor of safety is computed using the procedure of slices developed by Spencer (1967) and extended by Wright (1969, 1975). The solution involves subdividing the soil mass, which is bounded by the surface of the slope and an assumed shear surface, into a finite number of vertical slices and using an iterative procedure to compute the factor of safety for a given trial shear surface. A number of trial shear surfaces must be tried to locate the surface which produces the minimum factor of safety.

In addition to defining the locations of the shear surfaces used to compute the factor of safety, the Group H input data also include data which determine the manner in which the soil mass is subdivided into vertical slices and several parameters which affect and/or control the iterative solution for the factor of safety. All of the Group H data are described in this section.

The computer program allows the user either to specify individually selected shear surfaces, and the factor of safety is computed for each, or to designate that an automatic search is to be performed to locate a most critical shear surface having a minimum factor of safety. Shear surfaces may be either circular or noncircular in shape for both the case of individually specified surfaces and the case of an automatic search. Individually specified shear surfaces are described below, first, followed by a description of the automatic searches. The iterative procedure used to compute the factor of safety involves several variables which the user may optionally select and these variables are described following the description of the shear surfaces and automatic search. Finally, in the last section, the format of the input data is described and presented.

INDIVIDUALLY SPECIFIED SHEAR SURFACES

Individually selected shear surfaces may be either circular or noncircular. A combination of separate circular and noncircular shear surfaces may be selected and used to compute the factor of safety for a given problem. The shear surfaces may face to either the left or the right of the slope, so that both faces may be analyzed for a given set of slope coordinate geometry. The data for circular shear surfaces are somewhat different from the data for noncircular shear surfaces and, accordingly, the two shapes of shear surfaces are treated and described separately below.

Circular

The location of a given circular shear surface is defined in terms of the coordinates of the center of the circle and the radius of the circle. "The x and y coordinates of the center of the circle are specified as input data. The radius either may be specified directly as input data or may be specified indirectly and calculated by the computer program using either of two indirect means. The two indirect means consist of specifying (with the input data for the circle) either the coordinates of a point through which the circle passes or the elevation of a horizontal line to which the circle is tangent.

Subdivision into Slices. The soil mass bounded by the circular shear surface and the surface of the slope is subdivided into vertical slices automatically by the computer program. The subdivision into slices is performed using either one of the following two means, which may be selected by the user:

1. The mass is subdivided so that the angle which is subtended by the two radii extended to each side of the base of the slice (shear surface) does not exceed a certain, given value, "SUBDEG." In most cases many of the slices which are actually created will have a base which subtends an angle of less than the prescribed angle (SUBDEG) because of other constraints. For example, when the bottom of a slice tends to cross a boundary between two materials, a smaller base width is used to ensure that the base of the slice lies in no more than one material.
2. The mass is subdivided so that the arc length along the base of each slice does not exceed a certain, given value, "ARCMAX." As in the first case, the actual arc length will be less than the value of ARCMAX for slices where other constraints require a narrower slice.

Initially the first option (1) above is selected and used as a default by the computer program. That is, slices are created using a constant subtended angle; a value of 3 degrees is used for the angle. If the user desires, another value for the subtended angle or the alternate option, using a constant arc length (ARCMAX), may be selected. If either of the selected options and corresponding values of the parameters SUBDEG and ARCMAX results in more slices than the program can accommodate (due to the dimensioned size of arrays), the values of the angle or arc length will be successively doubled until a small enough number of slices results.

Vertical ("Tension") Crack. A vertical ("tension") crack of selected depth, "DCRACK," may be specified for each individually selected circular shear surface with the Group H input data for the surface. The vertical crack is considered by the computer program to be located at the point where the shear surface reaches a depth equal to the specified depth (DCRACK) below the surface of the slope near the upslope portion of the shear surface. Thus, the lateral position of the crack is determined indirectly based on the location of the circle, the specified crack depth, and the slope geometry. The upslope end of the shear surface is determined by the program by comparing the elevation of the two ends of the shear surface; the highest end (excluding the presence of a crack) is determined to be the upslope end. In the case of a horizontal ground surface, the right end of the shear surface is assumed to be the upslope end of the shear surface.

In addition to specifying a crack, the user may specify that the crack contains water or some other fluid. The presence of water in the crack is specified in the input data by specifying the depth of water, DWATER, in the crack. The user may also specify the unit weight of the water or other fluid in the crack, GAMAWC; otherwise a unit weight of 62.4 is assumed (See Table 11.3 - Sub-Command Word ("UNI"). The water specified in a crack is considered to produce a horizontal force in the crack equivalent to the force produced by hydrostatic pressures acting over the depth of water specified. However, such water is <u>not</u> considered to produce any pore water pressures in the soil or any other form of loading; pore water pressures and other loads must be specified separately by means of other input data (e.g., piezometric line, surface pressures, etc.).

<u>Noncircular</u>

The location of a noncircular shear surface is defined in the input data by specifying the x and y coordinates of a selected number of points along the shear surface from left to right. The specified points are assumed to be connected by straight lines; vertical segments may not be specified. Specific shear surface coordinates required by the computer program, e.g., where the shear surface crosses a soil profile line, do not need to be included in the input data; those coordinates needed by the program will be computed and added by the program during computation.

In specifying the end points for a noncircular shear surface the user should be careful to specify the end point coordinates to be as precisely on the surface of the slope as is practically possible. However, if the specified end point coordinates do lie above (outside of) the slope, the computer program will attempt to adjust the coordinates so that they are located more precisely on the slope. This is done by determining the intersection of the shear surface specified with the surface of the slope and then changing the coordinates of the end point to those of the intersection point. However, the first two or last two end points on a shear surface must never both lie above the surface of the slope or an error condition will result. No adjustment is made to the end point coordinates for a noncircular shear surface when the point lies below the surface of the slope; in such instances a crack is assumed, as described later.

Subdivision into Slices. The soil mass above the noncircular shear surface is subdivided into a number of vertical slices by one of the following two means; which can be selected by the user as part of the input data:

1. The soil mass is subdivided so that the length of the base of each slice does not exceed a specified maximum value (BASEMX). To accomplish this the program first computes the coordinates which are required for other purposes, such as where the shear surface crosses a boundary between materials, and adds these required coordinates to the coordinates which were input. The program then checks the distance between each pair of adjacent points and if the distance exceeds the prescribed distance (BASEMX), the distance between the pair of points where the distance is exceeded is divided into a sufficient

number of equal length increments to meet the required maximum slice base length.

2. The soil mass is subdivided to produce an approximate minimum number of slices, BASINC. The procedure used by the program takes the horizontal distance between the first and last point specified for the shear surface in the input data, divides the distance by the "minimum number of slices," BASINC, and then applies the computed distance as a maximum slice base length (equivalent to BASEMX) in the same manner as described for the first option above.

Initially the second option (2) above is selected and used as a default by the computer program. That is, slices are created using a minimum number of slices, "BASINC;" thirty is used as the minimum number of slices. If the user desires, either another minimum number of slices or a "maximum slice base length," BASEMX, may be selected. If either of the selected options and corresponding values of the parameters BASEMX and BASINC results in more slices than the program can accommodate (due to the dimensioned size of arrays) the "maximum number of slices" will be reduced or "maximum base length" will be increased until a small enough number of slices results.

Vertical("Tension") Crack. A vertical ("tension") crack, similar to what was described for a circular shear surface above, can be introduced for a noncircular shear surface; however, the manner in which the crack is designated in the input data is different. In the case of a circular shear surface the crack depth (DCRACK) is specified as a quantity in the input data. In the case of a noncircular shear surface the crack depth is not specifically input. Instead, the coordinates of the noncircular shear surface should be terminated (in the case of a left facing slope) or initiated (in the case of a right facing slope) at a point some depth below the surface of the slope corresponding to the desired depth of the "crack." A vertical crack is then assumed to extend from the last (or first) coordinate point specified to the top of the slope.

AUTOMATIC SEARCHES

Automatic searches may be performed using either circular or noncircular shear surfaces. The search procedures used are very different, depending on whether the shear surface is circular or noncircular, and, thus, the procedures are described separately below.

Circular Shear Surfaces

During an automatic search the program uses one or more of the following three modes to locate the center of a critical circle:

Mode 1 - All circles are to pass through a given point, whose coordinates are specified.

Mode 2 - All circles will be tangent to a given horizontal line, whose elevation (y coordinate) has been specified.

Mode 3 - All circles will have a given radius, which is specified as part of the input data.

By successively varying the three available modes of search, according to the sequence of steps outlines below, the program is capable of locating an overall "critical" circle corresponding to a minimum value for the factor of safety.

Step 1: The critical circle is located for an initial mode of search which is specified as input data; the initial mode of search may be either Mode 1, 2 or 3. If Mode 1 is selected, the x and y coordinates of the point through which the circles pass is specified. If Mode 2 is selected, the y coordinate elevation of the horizontal tangent line must be specified. If Mode 3 is selected, the radius must be specified.

Step 2: Once the critical circle has been located for the initial mode of search, the mode of search is changed. If the initial mode of search was Mode 1 or Mode 3, the mode of search is changed to Mode 2, and a horizontal tangent line is defined at the elevation of the bottom of the critical circle which was located using the previous mode (Modes 1 or 3). If Mode 2 is specified for the initial search, the mode is changed to Mode 3, and the radius of the critical circle found in the previous search mode (Mode 2) is selected for subsequent use. If the difference between the values of the factor of safety for the two critical circles, located using the modes of Step 1 and Step 2, is less than 0.001, the critical circle is considered to be the most critical circle located in Step 2, and the search is completed. However, if the criterion is not satisfied, the search will continue to Step 3.

Step 3: After Step 2, the mode of search will be alternated between Modes 2 and 3, until the difference between the values of the minimum factors of safety for the critical circles found in successive modes is less than 0.001. Mode 1 will never be used beyond Step 1 and, thus, may be used only for the initial mode of search.

The program includes the option of terminating the search after Step 1 is completed (See Table 11.3 - Sub-Command Word "STO").

When locating the overall critical circle it may be desirable to impose some limiting depth below which the critical circle cannot pass. This may be achieved either by specifying a stratum of soil at the selected limiting depth and assigning a high shear strength to the particular stratum or by specifying an appropriate limiting elevation below which the critical circle is not allowed to pass. The selected limiting y elevation is specified in the data input for the search as the variable YLIMIT.

For each mode of search the location of the center of the critical circle is found by using a 3 by 3, 9-point, square grid. The spacing between grid points is reduced during the search, and the location of the center point of the grid is shifted until the center of the grid corresponds to the center of a circle which has a lower value for the factor of safety than any of the eight other circles whose centers are located on the perimeter of the grid. Computed values for the factor of safety are stored by the program, and in most cases only those values which have not been previously calculated are computed. The search is terminated when the grid spacing has been reduced to a specified accuracy (ACCURC).

The center point of the first grid used for the initial mode of search is specified in the input data and should represent a best estimate of the x and y coordinates of the center of the critical circle. For all subsequent grids used during the remainder of the search, the center of the grid is located at the grid point found to have the lowest value for the factor of safety.

In some cases it will be possible to find several local "critical" circles with minimum factors of safety. The center of each such locally critical circle will be surrounded by center points having higher values for the factor of safety. In such cases, when a given search is performed, only one of the locally critical circles will be searched-out and located; the circle so found may not be the one with the absolute, lowest value for the factor of safety. In order to locate the circle with the absolute, lowest value for the factor of safety, several automatic searches will need to be performed using different starting points for the circles and, perhaps, different initial modes for the search. The values of the factor of safety for each of the "critical" circles located by these independently started searches must then be compared by the user to determine the actual value of the minimum factor of safety and the location of the overall critical circle. This will require that several sets of Group H data be specified for a given problem.

When the search option is used, the procedure for subdividing the circle into slices is identical to the procedure described previously for individual circular shear surfaces. Similarly, a vertical ("tension") crack depth may be specified and the crack may be designated to contain water or some other fluid, as described earlier for individually specified circular shear surfaces.

Noncircular Shear Surfaces

An automatic search for a critical noncircular shear surface is performed using a procedure very similar to the procedure developed by Celestino and Duncan (1981). In this procedure the shear surface is systematically moved from an initial (starting) position, which is assumed by the user, until a minimum factor of safety is calculated. The initial position of the shear surface is specified by the user and should correspond to the best estimate for the location of a critical shear surface. If the slope contains a thin seam of relatively weak material, through which the critical shear surface is expected to pass, the initial shear surface should be input so that it passes through the weaker material. The location of the initial shear surface is specified in the input data by a series of coordinates along the shear surface (from left to right), much as an individual shear surface is specified when no search is to be performed.

At the user's option, the coordinate points which are input to define the initial shear surface either may be allowed to move during the search or may be considered fixed; however, in most cases all points would be considered to be moveable. As the first step in an automatic search, each moveable point on the shear surface is moved an incremental distance (specified by the input data) in each of two opposite directions (e.g., up and down). Points are moved one by one on a TEMPORARY basis and a factor of safety is calculated for each point at each of the two positions to which it is moved. When any one point is moved, all other points are left at their original (initial) positions; no points are permanently shifted during the first step of the automatic search. The direction in which points are moved may be specified by the user as input data for each point, or the computer program will automatically compute a direction for shifting each point. When the computer program computes a direction for shifting each point, the direction is taken as approximately normal (perpendicular) to the shear surface; the direction may, thus, change somewhat as the shear surface moves. End points on the shear surface are moved along, or parallel to (in the case of a vertical, "tension" crack), the slope and, thus, the user has no control over the direction of movement at the end points.

Once each point on the shear surface has been shifted and the factor of safety has been computed for each shift, a new estimate for the position of the most critical shear surface is made and the initial shear surface is PERMANENTLY moved. The new estimate for the position of the shear surface is made using the procedure of Celestino and Duncan (1981); the factor of safety is assumed to vary parabolically with the position of the shear surface. Once the new estimate of position for the shear surface is made and the surface is moved, each point is again shifted in the manner used for the first step and the process is repeated to find yet another estimate for the critical shear surface.

The distance each point is temporarily shifted to compute the factor of safety is determined based on a "minimum incremental shift distance" (ACCURC), which is specified by input data. Initially the points will be shifted a distance equal to five times the specified distance, i.e., the points will be shifted a distance 5 x ACCURC. The distance shifted will later be reduced automatically by the computer program as the distance which the shear surface is permanently moved (as opposed to temporarily shifted) on each "step" or "trial" diminishes. (The actual distance the shear surface is permanently moved on each step is controlled by the computer program.) Relatively little experience is presently available to designate what criteria should be used to arrive at the "minimum incremental shift distance," ACCURC; however, it appears that the distance should at least satisfy the following two criteria:

1. The distance (ACCURC) should not exceed the thickness of the thinnest portion of the thinnest stratum through which the critical shear surface may pass; preferably the distance will be only a fraction (10 to 25 percent) of the thickness of the thinnest stratum.
2. The distance (ACCURC) should not cause the shifting of any point on the shear surface to make the shear surface exceptionally steep. In particular, the shear surface should not be allowed to become steeper than 45 degrees near the toe of the shear surface, or unreasonable solutions for the factor of safety may result. This second criterion will usually be satisfied if the minimum shift distance (ACCURC) does not exceed 2 percent (0.02) of the minimum distance (spacing) between adjacent points on the shear surface, especially near the toe of the slope.

A vertical crack, similar to the ones described previously, may be used in an automatic search with noncircular shear surfaces. The crack is designated in essentially the same way as described for individually specified noncircular shear surfaces by terminating (or starting) the end point coordinates of the initial shear surface at some depth below the surface of the slope. The crack depth determined for the initial trial shear surface is assumed to apply to <u>all</u>

of the noncircular shear surfaces attempted during a search. The crack depth (DCRACK) which can be input as a separate quantity for circular shear surfaces has no significance for noncircular shear surfaces.

SEISMIC COEFFICIENT

The computer program permits the user to perform "pseudo-static" analyses in which a horizontal body force is applied to each slice to simulate earthquake loading. This is accomplished using a single seismic coefficient (SEISCF) by which the weight of each slice is multiplied to obtain the horizontal body force. The body force is assumed to act through the approximate center of gravity for each slice. A positive seismic coefficient corresponds to a force acting to the left for the left face of a slope and to the right for the right face of a slope. The seismic coefficient is specified as part of the Group H data (See Table 11.3 - Sub-Command Word "SEI"). The computer program assumes that there are no seismic forces (default) unless a seismic coefficient is input; however, once a value is input it remains in effect either until another value, including zero, is input with Group H data or asterisks ("***") are encountered in the Command Words. No special treatment is given to shear strengths when a seismic coefficient is used; the shear strengths are defined and interpreted in the normal manner as described in Section 6. The only effect which a seismic coefficient has on the computations is to produce an added, horizontal body force on each slice.

COMPUTATION FOR FACTOR OF SAFETY

Computation of the factor of safety for a given shear surface involves an iterative (trial and error) procedure. Default values are assumed by the computer program for the various parameters involved in the iterative solution. Experience to date (1984) indicates that the default values have been adequate for most of the problems which have been worked; however, needs may arise to change some of the values from those assumed by the program. Accordingly, several of the important parameters used in the iterative solution are described and discussed in further detail in this section.

Initial values for the factor of safety (FZERO) and the inclination of the resultant side forces between slices (TZERO) are assumed at the start of the iterative solution. These assumed values are then changed by successive approximations on each iteration until the following conditions are satisfied (i.e., the solution converges):

1. Static equilibrium is satisfied within acceptable limits of accuracy. These limits are defined in terms of "allowed" imbalances of force and moment, "FIMBAL" and "MIMBAL," respectively.
2. The values of the factor of safety and the side force inclination are "correct" to within 0.0001 and 0.0001 radians, respectively, i.e., the values change by no more than these amounts on successive iterations.

If either of the above two conditions for convergence is not satisfied within a certain maximum number of iterations (MXITER), computations for the particular shear surface will be abandoned.

The initial trial values (FZERO and TZERO), the force and moment imbalances (FIMBAL and MIMBAL), and the allowable number of iterations (MXITER) are all assigned default values by the computer program. The default values are given in Table 11.3 and any one or all of the values may be changed by the user through selective input of data. Several important features of the iterative solution for the factor of safety and side force inclination as well as the variables FZERO, TZERO, FIMBAL, MIMBAL, and MXITER are described below.

Factor of Safety

The value of the factor of safety is permitted to change only by a maximum of five-tenths (0.5) on successive iterations. This constraint is placed on the solution to ensure proper convergence. However, if a very inaccurate estimate is made and specified for the initial value of the factor of safety (FZERO), the correct value may not be reached within the prescribed maximum number of iterations and the solution will fail to converge. Similar problems may develop when an automatic search is being performed and a trial shear surface passes through a zone of very high shear strength, such as concrete or a firm (rock) stratum, which has been specified for the purpose of limiting the extent of the critical shear surface. In this case a relatively large value for the factor of safety will be sought, but probably the value will not be reached by the program. Thus, an indication will be given on the printed output that the solution did not converge. The problem of a solution not converging for one of the trial shear surfaces attempted during an automatic search is normally of no practical consequence, and the user should verify that, for the shear surfaces where the solution did not converge, the values for the factor are relatively large.

In addition to the constraint described above for the change in the factor of safety on successive iterations (0.5), the value of the factor of safety is not permited to become less than one-tenth (0.10). While this constraint should be of little practical consequence, it should be noted that the solution will be terminated when the value for the factor of safety reaches a value of one-tenth.

During an automatic search some efficiency may be realized by changing the initial trial values used for the factor of safety and side force inclination (FZERO and TZERO, respectively) from the values used at the start of the search. This is accomplished by activating an option in the computer program whereby the initial trial values (FZERO and TZERO) will be reset to the values obtained for the current most critical shear surface at each stage of the search (See Table 11.3 - Sub-Command Word "CHA"). Activation of this option may improve the efficiency of the calculations during a search, but can also cause problems with convergence of the numerical solution to correct values. The option should be used with caution.

A considerable amount of experience has shown that the numerical solution for the factor of safety and side force inclination is better conditioned and more likely to converge when the initial trial value for the factor of safety overestimates, rather than underestimates, the correct value. In many cases by simply increasing the initial estimate for the factor of safety (FZERO) the solution can be made to converge, where otherwise convergence was not achieved.

Side Force Inclination

The inclination of the resultant forces acting between the vertical slices is assumed to be the same for all slices and is calculated along with the factor of safety as part of the iterative solution. The angle of inclination of the side forces is measured from the horizontal plane and positive values are measured in a counterclockwise direction. The side force inclination will normally be positive for a left facing slope and negative for a right facing slope.

In the iterative solution procedure, the value of the side force inclination is not permitted to change by more than 0.15 radians (approximately 8.6 degrees) on successive iterations and will be adjusted accordingly by the program when this limit is reached. In addition, the side force is not permitted to reach an inclination steeper than either +80 degrees for a left facing slope or -80 degrees for a right facing slope. If these limits are reached, the iterative solution will be terminated with an appropriate message. Also, a side force inclination of less than -10 degrees for a left facing slope or greater than +10 for a right facing slope will cause the solution to be terminated with an appropriate message.

Allowed Force and Moment Imbalance

The values for the maximum allowed force and moment imbalances correspond essentially to the maximum permissible error in static equilibrium. Experience with the computer program and Spencer's procedure of analysis has shown that, for most typical slopes analyzed, the values of the factor of safety and side force inclination are both accurate to within a minimum of four significant figures (0.01 percent) when the allowed force and moment imbalances are 100 lb. and 100 lb.-ft., respectively. (The values for the limits of force and moment imbalance may not be specified as zero, because roundoff error and use of a finite number of significant figures by the computer normally preclude computation of precisely zero values for verifying convergence.)

Iteration Limit

When reasonable values are assumed for the initial trial values of the factor of safety and side force inclination, convergence to a solution is normally attained within from three to ten iterations. This assumes that the factor of safety is estimated to within the correct value by approximately 1.5 and that the side force inclination is estimated to within 20 degrees of the correct value. If the solution fails to converge within an apparently reasonable number of iterations, the user should examine the step-by-step output from the iterative solution to establish the reasons for non-convergence. When severe non-convergence problems are encountered during an automatic search, the user should specify a single, individual shear surface and examine the step-by-step output from the iterative solution (See Section 12 - Description of Table 18).

For an automatic search, step-by-step output from the iterative solution is available only for the final, most critical surface.

Special Note for Nonlinear Strength Envelope

When the Mohr-Coulomb shear strength envelope is nonlinear, the calculations for the factor of safety are repeated several times for each trial shear surface. Shear strengths are first estimated for each slice where a nonlinear envelope applies and a factor of safety is calculated. This permits the normal stresses on the shear surface to then be calculated (the normal stresses depend on the shear strength and the factor of safety) and new shear strengths are calculated. This process is repeated until a consistent set of values of shear strength and normal stress are found for each slice.

FORM FOR DATA INPUT

The Group H data are used to designate whether circular or noncircular shear (sliding) surfaces are to be used to compute the factor of safety and whether a single, individually specified shear surface is to be considered or an automatic search is to be performed to locate a most critical shear surface with a minimum factor of safety. Depending on the options selected (circular versus noncircular; search versus individual shear surface) certain additional information is required. For example, for a single circular shear surface, the coordinates of the center of the circle and the radius might be input.

In addition to the required data in Group H there are numerous quantities and options for which the computer program assumes default values, but which the user may change. Once the required data have been input, the user can designate by optional "Sub-Command" words, which of the quantities and options he/she wishes to change from the default values. (The prefix "Sub" is used to distinguish Sub-Command words from Command Words, which are input as described in Section 3.) One of the optional quantities is the depth of vertical crack

(DCRACK) to which the user may frequently wish to assign a value other than the default value of zero. Once any optional quantity has been defined by Group H input data it remains as it has been defined until new Group H data specifically redefine or reset the optional quantity. Thus, new Group H data may be input, but if they do not specifically redefine the optional quantity from the value set by previous Group H data, the optional quantity remains as it was previously set.

The Group H data must immediately follow the Command Word "ANA" (or "ANALYSIS/COMPUTATION"). The form for the required data which must be input first is presented in Table 11.1 and Tables 11.2a through 11.2d. The form for the optional Sub-Command Words and data which may follow the required data is presented in Table 11.3.

TABLE 11.1

Group H - Analysis and Computation
Data Input Format - Required Input Line No. 1

Input Line No.	Data Field No.	Variable/Description
1	1	(CHAR(1)) A single character or a single, continuous character string beginning with one of the appropriate characters to indicate the shape of the shear surface as follows: "C" (or "CIRCULAR") to designate that circular shear surfaces are to be used to compute the factor of safety. "N" (or "NONCIRCULAR") to designate that noncircular shear surfaces are to be used to compute the factor of safety.
1	2	(CHAR (2)) A single character or a single, continuous character string beginning with the appropriate character or blank to indicate whether a single shear surface or an automatic search is to be used for the analysis as follows: "S" (or SEARCH) to designate that an automatic search is to be performed to find a shear surface with a minimum factor of safety. " " (= blank) to designate that only a single shear surface is to be considered. Note: Additional single shear surfaces may be input by additional sets of Group H - Analysis/Computation data.

Depending on the characters input on Line 1, proceed as follows:

Characters Input	Interpretation - Required Additional Input
"C" " " (= blank)	Single circular shear surface; input lines 2A, 3A, 4A, 5A and 6A as required - See Table 11.2A.
"N" " " (= blank)	Single noncircular shear surface; input lines 2B and and 3B - See Table 11.2b.
"C" "S"	Search with circular shear surfaces; input lines 2C, 3C, 4C and 5C as required - See Table 11.2c.
"N" "S"	Search with noncircular shear surfaces; input lines 2D, 3D and 4D - See Table 11.2d.

TABLE 11.2a

Group H - Analysis and Computation
Data Input Format - Single Circular Shear
Surface, Required Input Line Nos. 2A through 6A.

Input Line No.	Data Field No.	Variable/Description
2A	1	(XCENTR) - X coordinate for center of circle.
2A	2	(YCENTR) - Y coordinate for center of circle.
2A	3	(RADIUS) - Radius of circle. Note: The radius can be left blank and will then be computed by the program using data input on lines 3A through 5A. If radius is blank, proceed with line 3A. If not blank, skip lines 3A through 5A and proceed to line 6A.
3A	1	(CHAR(1)) - A single character or character string beginning with the appropriate character to indicate how the radius is to be defined as follows: "P" (or "POINT") to designate that the circle passes through a fixed point; proceed to Line 4A. "T" (or "TANGENT") to designate that the circle is to be tangent to a specified horizontal line; proceed to Line 5A.
4A	1	(XFIXED) - X coordinate value of point through which circle passes.
4A	2	(YFIXED) - Y coordinate value of point through which circle passes. After this line (4A) proceed to Line 6A below.
5A	1	(YTANLN) - Y coordinate of horizontal line to which circle is tangent. After this line (5A) proceed to Line 6A below.
6A	1	Use a blank line to terminate <u>all</u> Group H data and then proceed with Command Words (Section 3) when none of the Optional quantities is to be defined or reset. If the Optional quantities are to be input, omit this blank line (6A) and proceed directly with the Sub-Command Words in Table 11.3.

TABLE 11.2b

Group H - Analysis and Computation
Data Input Format - Single Noncircular
Shear Surface, Required Input Line Nos. 2B and 3B.

Input Line No.	Data Field No.	Variable/Description
2B	1	(X) - X coordinate of point used to define the noncircular shear surface.
2B	2	(Y) - Y coordinate of point used to define the noncircular shear surface.
		Repeat Line(s) 2B for additional points, from left to right, to define the noncircular shear surface. Input a blank line to terminate the data for the shear surface.
3B	1	When none of the optional quantities in the Group H data is to be defined or reset, input a blank line here as Line 3B to terminate all Group H data, and then proceed with the Command Words as described in Section 3. (Note: In this case the Group H data will actually end in two blank lines - one Line 2B and one Line 3B.) If optional quantities in Group H are to be input, omit this blank line (3B) and proceed directly with the Sub-Command Words as described in Table 11.3.

TABLE 11.2c

Group H - Analysis and Computation Data Input
Format - Automatic Search with Circular Shear Surfaces,
Required Input Line Nos. 2C through 5C.

Input Line No.	Data Field No.	Variable/Description
2C	1	(XSTART) - Starting X coordinate for center of circle used in search.
2C	2	(YSTART) - Starting Y coordinate for center.
2C	3	(ACCURC) - Accuracy for finding center of critical circle (= minimum grid spacing).
2C	4	(YLIMIT) - Y coordinate for limiting depth to which critical circle will be allowed to pass.
3C	1	(CHAR(1)) - Single character or continuous character string beginning with appropriate character to indicate what initial mode of search will be used as follows: "P" (Point) - Circles all pass through a common fixed point; proceed next to Line 4C-1. "T" (Tangent) - Circles all tangent to specified horizontal line; proceed next to Line 4C-2. "R" (Radius) - Circles all have the same radius; proceed next to Line 4C-3.
4C-1	1	(XFIXED) - X coordinate value of fixed point.
4C-1	2	(YFIXED) - Y coordinate value of fixed point.
		After Line 4C-1, proceed directly to Line 5C.
4C-2	1	(YTANLN) - Y coordinate of horizontal line to which all circles are tangent.
		After Line 4C-2, proceed directly to Line 5C

(continued)

Table 11.2c - Con't.

Input Line No.	Data Field No.	Variable/Description
4C-3	1	(RADIUS) - Constant radius to be used in the initial mode of search.
		After Line 4C-3, proceed with Line 5C.
5C	1	When none of the optional quantities in the Group H data is to be defined or reset, input a blank line here as Line 5C to terminate all Group H data, and then proceed with the Command Words as described in Section 3. If optional quantities in Group H are to be input, omit this blank line (5C) and proceed directly with the Sub-Command Words as described in Table 11.3.

TABLE 11.2d

Group H - Analysis and Computation Data Input Format - Automatic Search with Noncircular Shear Surfaces Required Input Line Nos. 2D through 4D.

Input Line No.	Data Field No.	Variable/Description
2D	1	(X) - X coordinate of point used to define the initial, trial noncircular shear surface for the automatic search.
2D	2	(Y) - Y coordinate of point used to define the initial, trial noncircular shear surface for the automatic search.
2D	3	Information to designate if and how this point is to be shifted, as follows: - If blank, the point is considered to be moveable and it is moved in a direction approximately perpendicular to the shear surface at that point. - If a numerical value (non-blank) is input, the point is considered to be moveable and the numerical value, which was input, is interpreted to define the direction in which the point is to be moved. The numerical value, i.e., the direction, should be an angle measured in degrees from the horizontal and being positive in the counterclockwise direction. - If the characters, "FIX", are input in Field No. 3 then the point is assumed to be fixed and is not moved during the automatic search.
		Repeat Line(s) 2D for additional points, from left to right, to define the initial, trial noncircular shear surface. Input a blank line of data (Line 2D) to terminate the coordinates for the initial trial noncircular shear surface and then proceed with Line 3D.

(continued)

Table 11.2d - Con't.

Input Line No.	Data Field No.	Variable/Description
3D	1	(ACCURC) - Approximate value of the accuracy required in the location of the critical shear surface; expressed as a distance, i.e., in units of length. This distance also represents the minimum incremental distance which points on the shear surface are moved on each trial to search for a more critical shear surface.
4D	1	When none of the optional quantities in the Group H data is to be defined or reset, input a blank line here as Line 4D to terminate all Group H data, and then proceed with the Command Words as described in Section 3. If optional quantities in Group H are to be input, omit this blank line (4D) and proceed directly with the Sub-Command Words as described in Table 11.3.

TABLE 11.3

Group H - Analysis and Computation Data Input
Format - Optional Input following Required Input

Input Line No.	Data Field No.	Variable/Description
1	1	(COMWRD) - Sub-Command Word consisting of a character string, the first three characters of which designate which optional quantity is to be defined or reset. The acceptable characters and the optional quantities which they designate are as follows: "FAC" (FACtor of safety) - An initial trial value for the factor of safety will be input; proceed next to Line 2A. "SID" (SIDe force inclination) - An initial trial value for the side force inclination will be input; proceed next to Line 2B. "ITE" (ITEration limit) - An iteration limit will be input; proceed next to Line 2C. "FOR" (FORce imbalance) - A value for allowable force imbalance will be input; proceed next to Line 2D. "MOM" (MOMent imbalance) - A value for allowable moment imbalance will be input; proceed next to Line 2E. "CHA" (CHAnge initial trial factor of safety) - This designates that during an automatic search the initial trial value for the factor of safety will be automatically changed and assumed to be equal to the lowest value of the factor of safety computed at any point in the search. This can reduce the time required to compute the factor of safety, but can also lead to occasional convergence problems in the solution. If this option is not set the initial trial value remains as the default/input value - See "FAC" above.

(continued)

Table 11.3 - Con't.

Input Line No.	Data Field No.	Variable/Description	
			Proceed directly with additional Sub-Command Words (Line 1) after this "word."
		"OPP"	(OPPosite sign convention) - This designates that the opposite sign convention from the one assumed by the program based on a direction of potential sliding is to be used. See the special note for flat slopes in Section 9. Proceed directly with additional Sub-Command Words (Line 1) after this "word."
		"SEI"	(SEIsmic Coefficient) - A value for the seismic coefficient will be input; proceed next to line 2F.
		"SUB"	(SUBtended angle) - A value of subtended angle for slice generation with a circular shear surface will be input; proceed next to line 2G.
		"ARC"	(ARC length) - A value of maximum arc length for slice generation with a circular shear surface will be input; proceed next to Line 2H.
		"CRA"	(CRAck depth) - A crack depth is to be input; proceed next to Line 2I.
		"BAS"	(BASe length) - A value of maximum slice base length for slice generation with a noncircular shear surface is to be input; proceed next to Line 2J.
		"INC"	(INCrements for slice generation) - A value for the number of increments for slice generation with a noncircular shear surface is to be input; proceed next to Line 2K.
		"STO"	(STOp) - Designates that an automatic search with circular shear surfaces is to be terminated after the initial mode has been completed (See Line 3C - Table 11.2c). After this Sub-Command word proceed directly with additional Sub-Command words, i.e., input another Line 1.

(continued)

Table 11.3 - Con't.

Input Line No.	Data Field No.	Variable/Description
		"CRI" (CRItical) - Designates that automatic search is to be continued (after the initial mode has been completed) to locate a most critical circle. This is the default unless set by "STO" above. After this Sub-Command Word proceed directly with additional Sub-Command words, i.e., input another Line 1.
		"WAT" (WATer depth) - A depth of water in the vertical crack is to be input; proceed next to Line 2K.
		"UNI" (UNIt weight of water) - A unit weight for water (or other fluid) in the vertical crack is to be input; proceed next to Line 2L.
		Input a blank Sub-Command word to terminate all the Group H input data.
2A	1	(FZERO) - Initial trial value of factor of safety used in iterative solution. A default value of 3.0 is used if none is input. After input return to Line 1.
2B	1	(TZERO) - Initial trial value of side force inclination used in iterative solution (in degrees). A default value of 15 degrees is used if none is specified. After input return to Line 1.
2C	1	(MXITER) - Maximum number of iterations to be permitted in iterative solution for factor of safety. A default value of 40 is used if none is input. After input return to Line 1.
2D	1	(FIMBAL) - Maximum force imbalance permitted for convergence of iterative solution for factor of safety. A default value of 100 is used if none is input. After input return to Line 1.

(continued)

Table 11.3 - Con't.

Input Line No.	Data Field No.	Variable/Description
2E	1	(MIMBAL) - Maximum moment imbalance permitted for convergence of iterative solution for factor of safety. A default value of 100 is used if none is input. After input return to Line 1.
2F	1	(SEISCF) - Seismic coefficient. No (zero) seismic coefficient is assumed initially. After input return to Line 1.
2G	1	(SUBDEG) - Subtended angle for slice generation (in degrees). A default value of 3 degrees is used if none is input. After input return to Line 1.
2H	1	(ARCMAX) - Maximum arc length for slice generation. See Line 2G for SUBDEG above regarding relevant default values. After input return to Line 1.
2I	1	(DCRACK) - Vertical ("tension") crack depth. A default value of zero (no crack) is used if none is input. After input return to Line 1.
2J	1	(BASEMX) - Maximum slice base length for slice generation (noncircular shear surfaces only). See Line 2K for BASINC below regarding relevant default values. After input return to Line 1.
2K	1	(BASINC) - Number of increments into which shear surface is subdivided for slice generation (noncircular shear surfaces only). A default value of 30 is used if none is input. After input return to Line 1.
2L	1	(DWATER) - Depth of water or other fluid in vertical crack. A default value of zero (no water) is used if none is input. After input return to Line 1.
2M	1	(GAMAWC) - Unit weight of water (or other fluid) in vertical crack. A default value of 62.4 is used if none is input. After input return to Line 1.

SECTION 12 - DESCRIPTION AND EXPLANATION OF PRINTED OUTPUT TABLES

Nineteen different types of output tables are printed by the computer program. The forms of these tables and the information which they contain are described in this section. Each type of table is identified by a table number for reference and identification in the following discussion. The table number is printed on the computer output in the vicinity of the upper, right-hand corner of the table. The table number corresponds to the type of information which the table contains. Tables are printed in the order in which the information contained in the tables are either input to or generated by the computer program. Accordingly, tables will not necessarily be printed in the order of ascending or descending table numbers. Some tables may not be printed at all, and other tables may be printed several times, depending on the type of data which is input and the program options which are used.

The first table (Table No. 1) contains general information pertaining to the computer program and is printed only once at the start of program execution. The next eight tables (Table Nos. 2 through 9) contain data which are used to define the problem. All of these eight tables, with the exception of Table No. 9, contain data which are input by the user; Table No. 9 contains slope coordinate geometry data generated, optionally, by the computer program. Each of these eight tables (2 through 9) is printed separately any time the specific data contained in the table is changed by new input data. If a specific set of data is not changed, the corresponding table will not be printed. The remaining ten tables (Table Nos. 10 through 19) contain information which is generated by the program during computations. These ten tables contain intermediate information, as well as the final solution. The contents of all nineteen output tables are described in further detail below.

TABLE 1 - PROGRAM HEADER

Table No. 1 contains the computer program header message: the program name (UTEXAS), the version number of the program, and the program serial number. Table No. 1 also contains a disclaimer and warning message.

TABLE 2 - INPUT DATA FOR PROFILE LINES

This table contains the input data used to describe the profile lines (Group B data). The table is printed every time new profile line data are input to the program and only when new data are input. Any data which have been previously input and are to be retained when the new data are input will not be printed again. Instead a note will be printed to the effect that previous data are retained and the user should refer to earlier output.

TABLE 3 - INPUT DATA FOR MATERIAL PROPERTIES

This table contains the input data for material properties (Group C data). The table is printed every time new material property data are input and only when new data are input. Any data for material which are retained from previous input will not be printed again. Instead a message will be printed to designate the number of materials for which previous data are retained, and the user should refer to earlier printed output tables for the retained data.

TABLE 4 - INPUT DATA FOR PIEZOMETRIC LINES

This table contains data for the piezometric lines (Group D data). Restrictions on when the table is printed and what information is contained are essentially the same as those that apply to profile lines, as described for Table 2 above.

TABLE 5 - INPUT DATA FOR PORE PRESSURE INTERPOLATION

This table contains the input data used for interpolation of either pore water pressure or r_u values (Group E data). The table is printed whenever these data are input. If only some of the data are new and some other data input previously are retained, only the new data will be printed. A message will be printed indicating that previous data will not be printed again. The user should refer to earlier printed output for the data which are retained.

TABLE 6 - INPUT DATA FOR SLOPE GEOMETRY

This table contains the coordinates defining the slope geometry (Group F data) when the coordinates are specifically defined as input data (See also Table No. 9). The table is printed whenever the coordinates are defined or redefined by input data. If only some of the coordinates are changed (as in the case of Modify Mode), then only the new coordinates are printed; the coordinates which are not modified are not printed again. This table is printed only when the slope coordinates are defined specifically by Group F input data (See Table 9 for the case where slope coordinates are generated by the program).

TABLE 7 - INPUT DATA FOR SURFACE PRESSURES

Table No. 7 contains the input data used to define the pressures acting on the surface of the slope (Group G data). The table is printed only when these data are defined or redefined by new input data. If only some of the data values are changed by the input data (as in the case of Modify Mode), then only the data values which are changed are printed.

TABLE 8 - INPUT DATA FOR ANALYSIS/COMPUTATIONS

This table contains the information for the analysis and computations which is input by means of Group H data. The table is printed only when new Group H data are input. In addition to containing the values input as data, the table contains values of parameters which either were set as default values by the program or were defined by previous input data.

TABLE 9 - SLOPE GEOMETRY DATA GENERATED BY THE COMPUTER PROGRAM

This table contains the slope geometry data and is printed when the slope coordinates are generated by the computer program from the profile line coordinate data. The table is printed every time that the program generates new slope geometry coordinates from profile lines; otherwise the table is not printed.

TABLES 10, 11, AND 12 - AUTOMATIC SEARCH OUTPUT (CIRCLES)

These tables are printed during an automatic search for a critical circular shear surface and contain the center point coordinates, radius and factor of safety for each trial circle attempted. In addition, a message may be printed for some trial circles. For example, messages are printed to indicate when a circle does not intersect the slope and when the solution for the factor of safety does not converge. In some cases the spaces on the printed line where the factor of safety and side force inclination are ordinarily printed will contain strings of asterisks (*****) beneath which are printed values in parentheses. This format for the output occurs when for some reason (usually explained by a message) the solution for the factor of safety did not converge to a proper value. The values printed in parentheses beneath the string of asterisks are the values at the time the solution was terminated and are NOT CORRECT SOLUTION VALUES. The values at the time of termination are printed for information only.

Table 10 is printed when the search is being conducted with all circles passing through a given, fixed point; Table 11 is printed when the search is being conducted with all circles tangent to a given, horizontal line; Table 12 is printed when the search is conducted with all circles having the same radius. With the exception of the heading at the top of each of these tables, the forms of Table Nos. 10, 11 and 12 are identical. When a search is performed to locate the overall most critical circle, several of these tables may be printed and some may be printed more than once. At the conclusion of each mode of search, i.e., at the end of each table, the coordinates of the most critical circle and corresponding values for the factor of safety and side force inclination found in the current mode are printed before continuing to either the next mode or completion of the search.

TABLE 13 - SUMMARY OF AUTOMATIC SEARCH (CIRCLES)

This table is printed at the conclusion of an automatic search for a critical circular shear surface. The table contains the x and y coordinates of the center point of the critical circle, the radius of the critical circle, and the corresponding minimum factor of safety and side force inclination. The table also contains the number of circles which were attempted and the number of circles for which the factor of safety could be successfully calculated. For example, some trial circles which are attempted may not intersect the slope and, thus, are attempted, but the factor of safety is not calculated.

TABLE 14 - PRELIMINARY SEARCH INFORMATION (NONCIRCULAR SURFACE)

This table is printed at the start of an automatic search for a critical noncircular shear surface. The table contains the value of the crack depth which has been computed based on the initial trial shear surface and slope geometry. The table will also contain any information pertaining to adjustments in the coordinates of the initial trial shear surface if the coordinates lie slightly above the surface of the slope. Finally, the table will contain the factor of safety and side force inclination for the initial trial noncircular shear surface.

TABLE 15 - SEARCH INFORMATION (NONCIRCULAR SURFACE)

This table contains information pertaining to each trial shear surface generated during an automatic search to locate a critical noncircular shear surface. This table is printed for each new trial position of the noncircular shear surface. One line of information is printed in the table each time that a point on the given trial shear surface is temporarily moved and the factor of safety is computed. Each line contains the temporary x and y coordinates of the point which has been shifted and the corresponding factor of safety and side force inclination along with any messages pertinent to the computations for the particular, temporary shear surface configuration, e.g., "SOLUTIONS FOR FACTOR OF SAFETY DID NOT CONVERGE WITHIN 40 ITERATIONS." Once all points have been temporarily shifted and the factor of safety has been computed, the newly estimated coordinates for each point on the shear surface are printed, followed by the factor of safety and side force inclination computed for the newly estimated position of the shear surface. A new trial is then initiated, a new Table 15 is printed, and the output begins again as described above.

TABLE 16 - FINAL RESULTS OF SEARCH (NONCIRCULAR SURFACE)

This table is printed at the conclusion of an automatic search for a critical noncircular shear surface. This table contains the number of trial positions used to locate the critical shear surface, the coordinates of the points defining the critical noncircular shear surface found by the search, the minimum factor of safety, and the corresponding side force inclination.

TABLE 17 - INDIVIDUAL SLICE INFORMATION

Table No. 17 contains information on the individual vertical slices into which the soil mass is subdivided for computing the factor of safety. When individual shear surfaces are specified one by one by the user as input data, this table is printed for each such shear surface. When an automatic search is performed to locate a most critical shear surface, this table is printed for only the most critical shear surface.

Table 17 contains twelve columns of information. The first column contains the slice number. The next two columns contain the x and y coordinates of the left edge, the center, and the right edge of the slice at the level of the shear surface. (Note: The center coordinates of the slice are printed on the same line as the slice number and other slice information; the coordinates of the left and right edges of the slice are printed on lines by themselves, above and below the center coordinates, respectively.)

The fourth column in Table 17 contains the slice weight followed by the material type for the material at the base of the slice in the fifth column. The sixth and seventh columns contain the cohesion and friction angle for the material at the base of the slice, except when the shear strength envelope is nonlinear; in the case of a nonlinear envelope the words "NONLINEAR ENVELOPE" are printed in the sixth and seventh columns. The eighth column contains the value of the pore water pressure at the center of the base of the slice.

The remaining columns in Table No. 17 (Cols. 9 - 12) contain information pertaining to the forces due to surface pressures acting on the top of the slice (surface of the slope). The ninth and tenth columns contain the resultant forces acting normal to and tangential to the top of the slice, respectively. The eleventh and twelfth columns contain the respective x and y coordinates of the point of action of the resultant force on the top of the slice.

TABLE 18 - ITERATIVE SOLUTION FOR THE FACTOR OF SAFETY

Table No. 18 contains a detailed iteration-by-iteration summary of the trial and error calculations performed during computation of the factor of safety for a given shear surface. This table is printed every time that Table 17 is printed, i.e., the table is printed for individual shear surfaces selected by the user, or for the most critical shear surface in the case of an automatic search. The information contained in this table, other than the values for the final factor of safety and side force inclination, is ordinarily only of interest when difficulties are encountered in obtaining a solution for the factor of safety and the iterative solution fails to converge. In such case the pattern by which the factor of safety and side force inclination are varying in the iterative solution can be seen and corrective action can often be taken. Corrective action usually consists of altering the initial trial values used for the factor of safety and side force inclination (See Group H data in Section 11).

TABLE 19 - FINAL SOLUTION INFORMATION

This table contains important information pertaining to the solution of the equilibrium equations for the factor of safety. The table is printed whenever Table Nos. 17 and 18 are printed provided that the solution for the factor of safety has converged. The first portion of the table contains twelve columns of information with one line of information printed for each slice. The first column contains the slice number followed by the x and y coordinates of the center of the base of the slice in the second and third columns, respectively.

The "total" normal stress, "effective" normal stress and shear stress at the center of the base of the slice (shear surface) are printed in the fourth, fifth, and sixth columns, respectively. However, some deviations from the normal stresses implied by the labeling of these columns may exist as follows:

(1) The "total" normal stress printed in the fourth column will actually be the effective normal stress if submerged unit weights are used for the soil; otherwise the stress printed in the fourth column is the actual total normal stress.

(2) The "effective" normal stress printed in the fifth column is actually the "total" normal stress, minus any value of pore water pressure which has been defined by input data. Thus, in the case of total stress analyses where no pore water pressures are specified, the "effective" normal stress printed in Table 19 will actually be the same as the total normal stress.

Compression is considered to be positive for the normal stresses; tension is considered to be negative. The shear surface opposite to the direction of movement of the soil mass; any reasonable value of shear stress should be positive.

The remaining columns in Table 19 contain information pertaining to the forces which act between slices, along the vertical boundaries. The seventh column contains the x coordinate of the right-hand boundary of the slice. The eighth column contains the value of the resultant force on the right-hand vertical boundary, and the ninth column contains the corresponding y coordinate of the point of action of the resultant on the right-hand boundary. (Note: The inclination of the resultant side force, measured from the horizontal, is equal to the "side force inclination," which is computed with the factor of safety and is assumed to be the same for all slices.) The tenth column contains additional information pertaining to the location of the side force on the vertical slice boundary as follows:

A numerical value, e.g., 0.331, will be printed in the tenth column when the side force acts at a point on the boundary which lies between the shear surface and the surface of the slope. In such cases the numerical value which is printed is the fractional distance above the shear surface to the point where the force acts, expressed as a fraction of the total height of the vertical slice boundary. If the side force acts below the shear surface, the word "BELOW" is printed in the tenth column; if the side force acts above the surface of the slope the word "ABOVE" is printed in the tenth column.

The final two columns (11 and 12) printed in Table 19 contain values of the stresses acting normal to the vertical slice boundary (i.e., horizontal stresses), which are computed using the magnitude and the location of the side force and assuming a linear distribution of stress along the vertical boundary between slices.

Following the information described above, two additional sets of information are printed in Table No. 19. The first set of information consists of four "check-sums" for forces and moments, which are computed to verify the correctness of a solution. The values of the check-sums should all be small and not exceed values of the force and moment imbalances which are used as solution tolerances in the iterative calculations for the factor of safety and side force inclination. (Note: Default values are used for these solution tolerances unless reset as part of the Group H data.)

The final set of information printed in Table No. 19 is printed as warning and caution messages when certain conditions are detected in a solution; messages are not printed when no such conditions are detected. Caution level messages are designated by the word CAUTION and are printed when tensile stresses are detected from a solution for the upper portion of a shear surface near the crest (top) of the slope. Such tensile stresses may or may not be permissible, depending on the nature of the problem (e.g., short-term versus long-term stability) and the nature of the materials involved (e.g., clean sand versus highly cemented clay). However, tensile stresses should be accepted only with caution. Warning level messages are designated on the printed output by the word WARNING and are printed either when tensile stresses are calculated in areas near the toe of the slope or when the shear stress acts in an apparently incorrect direction. Warning messages are printed twice for each warning and in most such cases the solution should be rejected.

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