University of Nevada Reno

Computer Assisted Analysis of Discontinuous Rock Masses

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by

Michael John Nicholl

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The thesis of Michael John Nicholl is approved:

Thesis Advisor

Department Chair

Dean, Graduate School

University of Nevada Reno

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ABSTRACT

The stability of a rock slope is often controlled by planes of weakness or discontinuities that exist within the rock mass. These features, which include joints, faults, and bedding planes are characterized by their orientation. In addition, discontinuity spacing, area of exposure, infilling, and surface roughness are also important descriptive parameters. A computerized data handling system is developed to assist in analysis of discontinuous rock masses. Programs are developed to organize a data base, plot poles on an equal-area projection, determine mean orientations using the spherical normal distribution, plot great circle traces for planar features, and determine wedge intersections.

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CHAPTER 1 - INTRODUCTION

The design parameters for any major civil engineering project must be based on an analysis of the underlying earth materials. The vast majority of such projects involve only the surface soils and are routinely evaluated using ASTM standard soil mechanics techniques. However, many major engineering projects, including dams, roadcuts, and mining operations involve the creation of a sloping free surface in the bedrock. When the stability of the resultant slope is to be assessed, the mechanical properties of the rock mass must be thoroughly investigated.

Under certain conditions, preliminary investigation will indicate that the rock mass will exhibit properties similar to that of a soil. This occurs when the unit in question is sufficiently homogeneous in nature to satisfy the assumptions of a particular soil model. Highly weathered or partially consolidated rocks are low strength materials that differ from a soil only in that they exhibit a skeletal structure of cemented particles. The mechanical behavior of such units will resemble the strength behavior exhibited by cohesive soils and is typically modeled as such. Rock masses that have been highly shattered by processes such as tectonic activity may behave similarly to cohesionless granular material. When viewed on a large scale, the blocks delineated by closely spaced joint sets may cause the mass to appear homogeneous in nature. Methods for analysis of both cohesive and cohesionless granular soils are well documented and will not be considered in this discussion.

Unfortunately, most rock masses are heterogeneous rather than homogeneous in nature. Rock is a naturally occurring material which is subjected to continually varying conditions both during and after formation. A typical rock unit will exhibit spatial variability in both composition and texture, factors which in turn may influence its' mechanical behavior. Deviation in rock strength resulting from compositional heterogeneity can be a factor in the overall strength of a rock mass, but will not be addressed in this study. The primary concern of this study is abrupt changes in mechanical properties that are manifested as planes of weakness within the rock mass. The anisotropic and heterogeneous strength characteristics of rock masses is typically governed by these "discontinuities". These planar features normally result from the application of stress to the intact rock, but may also result from environmental changes during the depositional process.

This study involved the creation of a micro computer based data handling system to aid in the analysis of a discontinuous rock mass with respect to slope stability. A discontinuous rock mass is one comprised of comparatively high strength rock material that is dissected by planes of weakness. Such planes may consist of joints, faults, bedding, cleavage, or any other planar feature that is weaker than the parent material in at least one direction. The mechanical behavior of a rock mass with respect to a particular free surface is governed by the strength and orientation of these planar features. The design of an excavation involving a discontinuous rock mass must be made with these features as the primary concern.

METHOD OF ANALYSIS

The stability analysis of a rock slope can be approached in two different manners. One method is to treat the system as an elastic continuum, modeling the rock mass and excavation with either photoelastic stress or finite element methods (Hoek & Bray, 1981). This approach has been proven successful in the design of underground chambers located at great depth. At depth the tremendous confining pressure caused by the overburden creates a hydrostatic stress field within the rock mass. This seals fractures within the rock mass and increases the potential for elastic deformation of the rock itself. As a result, the system may be modeled as an elastic continuum.

Attempts to model near surface slopes using elastic continuum modeling techniques have led to mixed results (Blake, 1969). The finite element model is capable of evaluating potential stress distributions resulting from the removal of overburden along the free surface. However, without the high confining pressures present at depth the rock mass does not approximate an elastic continuum. Instead, the system must be treated as an assemblage of rigid blocks separated by low strength planar features. The strength parameters of such a system vary with respect to the relative orientation and strength along the discontinuities, thus violating the assumptions necessary for the use of a continuum model.

In order to adequately model a near surface system it must be treated as a discontinuous body rather than a continuum. The behavior of such a rock mass is dominated by the discontinuities, which primarily consist of faults, joints, and bedding planes (Muller, 1959). Any evaluation concerning a system of this type must be based on the angular relationships between the free surface and the discontinuities. The analytic process can also consider parameters such as cohesion, fracture roughness, seismic loading, dead loads and water pressure, all of which are difficult to quantify in the field. The techniques for analysis of discontinuous rock masses by utilization of stereographic projection are well documented (Hoek & Bray, 1981; CANMET, 1977; Priest, 1985; Billings, 1972; etc.). As these methods are both well known and easily understood, it will henceforth be assumed that the reader has at least a rudimentary knowledge of the subject.

COMPUTER APPLICATION

Stereographic analysis has several practical drawbacks. Plotting the data onto a stereo net is tedious, leading to a high potential for human error in the process. This is a major difficulty, because the nature of the plot greatly complicates the location of any existing errors. Due to the time involved in creating a plot, evaluation of data subsets or compilations (ie. only clay filled joints or all data for a region) is not always practical. The time required for plotting by hand also makes investigation of different potential free surface orientations inconvenient and expensive. Lastly, the quality of the finished plot is only as good as the draftsman employed.

The above problems can be mitigated to great extent through the use of a microcomputer. Once the data has been entered into a file it can be manipulated in many ways with a minimum of effort. The raw data can be printed out in a compiled form that is amenable to inspection for errors. By coupling the microcomputer with a pen plotter, error free stereographic plots can be created with minimal effort. Statistical analysis of the data can be based on a more rigorous mathematical foundation than the typical grid cell contouring methods. Stability analysis of free surfaces with various orientations can be readily performed in order to maximize understanding or optimize design for a given system. Overall, a microcomputer coupled with a plotter and the proper software could be of considerable assistance in the analysis of a discontinuous rock mass.

SCOPE OF PROJECT

The goal of this project was to produce a software package capable of assisting the engineer or geologist in the analysis of planar orientation data. The software will be able to perform the following manipulations on field discontinuity data:

1. Collate field data on the nature of the discontinuities into a concise, sorted, presentable form.
2. Plot the data on a stereographic projection for analysis.
3. Determine the mean orientation of a given data set using both statistical methods and operator interpretation.
4. Draw stereographic projections of the mean planes, along with the friction angle and free surface orientation in order to facilitate stability determination.

5. Use vector methods to evaluate potential instabilities for a given free surface in a discontinuous rock mass.

The primary goal of this project is to create a practical engineering tool. In order to fulfill this goal the software was written specifically to be user-friendly. Additionally, the internal filing system was designed such that it would be easily adaptable to many different tasks.

HARDWARE

In order to help realize the goal of creating a practical, user-friendly system, the hardware requirements were kept simple. The IBM Personal Computer PC has become the industry standard for microcomputers. Therefore, the software was designed such that it would operate on all IBM compatible equipment. The machine used for development had the following specifications:

Mother Board:	IBM PC-XT
Internal Memory:	640K
Graphics Board:	AST Color Graphics
Communications Board:	AST Six-Pack
Co-processor:	8087 Math Processor
Floppy Disk:	2 - 360K, Half-height
Hard Drive:	10 Megabyte Capacity
Operating System:	MS-DOS 2.1

Language: IBM BASICA

The above specifications do not constitute a minimum level required to run the project software. The software was written so that virtually all operations are carried out on a single record, minimizing the need for internal array storage. Therefore, a single floppy drive and 256K of memory should be sufficient for all but the largest data files. The only other absolute requirement is a means of communicating to the plotter; in this case an asynchronous communications adapter.

The techniques used in the analysis of orientation data lend themselves to a visual interpretation, rather than a mathematical one. Existing software packages such as PATCH (Mahtab, et al., 1972) have used a standard line printer in order to present such data. There are two major problems associated with using a line printer to produce graphical output. In order to display output on a line printer, the data must be sorted and handled such that each line can be printed in order. This requires that either large chunks of internal memory be set aside for array storage or an elaborate job specific sorting routine must be written into the code. More importantly the resultant output from a line printer often lacks a professional appearance. Both of these problems can be solved through the use of a pen plotter.

Recent advances in both hardware and software packages have led to a proliferation of relatively inexpensive plotting devices. The primary use of these machines is to produce graphs, both for business and scientific uses. In order to fulfill these needs the plotters are readily programable to anyone familiar with a simple language, typically BASIC. The pen plotter provides a superior quality output at high speed, without requiring large amounts of memory or complex sorting routines. For this project the Hewlett-Packard HP7875 six pen plotter was used, it provides high quality output and is readily available. The plotter drives used by different manufacturers tend to be very similar, hence there should be little modification required in order to run this software with other plotters.

SOFTWARE

The language used for this project was IBM's Advanced BASIC (BASICA). BASIC was chosen over FORTRAN and PASCAL for two major reasons. The primary reason was to make the code easy to read and understand. Languages such as BASIC and COBOL use literal commands that describe the resultant action; thus making it easier to follow the logic of a program. When the logic of a program is clear, the operator can readily understand any inherent advantages and limitations that exist within the package. Also, clear readable code makes it feasible for the operator to adapt the program to a specific purpose. In order to further clarify the logical processes, variables were given names relating to the parameters involved (ie. AZIMUTH, DIP, MEANDIP).

BASIC was also chosen because it is compatible with the plotter commands used by most manufacturers. If the software was not written in BASIC, it would be necessary to include separate plotter drives, which was not deemed practical. The limiting factor for execution speed in this system is plotter response time. For this reason the code was neither compiled nor optimized. Doing so would have made it much more difficult to follow the program logic, while yielding only a minimal increase in execution speed.

PROGRAM TESTING

When using a computer there is a dangerous tendency to rely excessively on the machine. Misleading results can occur due to inadequate program testing, or simply poor data (garbage in garbage out). To ensure accurate program testing, both mechanically generated test data sets and readily verifiable field data were used. The mechanically generated data sets were created by a random number generator set to operate in specific regions. The regions were chosen to optimize testing of the software package, especially those sections that required extensive decision making.

The primary goal of this project was not to evaluate a particular slope, but to develop a computer methodology for stability assessment. However, it was decided to use real data for example problems throughout the project. Field data was gathered from the rock slope along Highway 89 at Emerald Bay, Eldorado County, California (see Appendix A for a more complete description of this site). This rock slope has a long history of slides that have interfered with highway traffic (figure 1-1) and provided an excellent data set for both program testing and illustrative examples.

Figure 1-1
Oblique aerial photograph of Emerald Bay Rock Slide flown 9/3/71.

CHAPTER 2 - MATERIAL PARAMETERS

This section covers the material parameters that are employed in this study to describe field discontinuities. Although actual creation of data files will be covered in Chapter 3, this chapter will serve as user documentation for each parameter that may be entered into a data file. Included will be an explanation of the parameter, how it is entered in the data record, why it was chosen, acceptable values, and if necessary, references. A summarization of these parameters and the associated file handling information is included at the conclusion of this chapter (figure 2-1).

Prior to proceeding with this section it is essential that the reader be familiar with the terminology used to describe computer files. Data is stored as groups of characters in files, records and fields. A field is the smallest meaningful subdivision of data; it contains a single parameter such as "plane type" or "azimuth". When using random access files in the BASIC language, fields must be defined as alpha-numeric variables. As a result, variables that are numeric in nature (DIP, AZIMUTH, RC) must be converted into their string equivalent for storage. A group of fields that defines a single occurrence is a record, an example would be all of the information for a single discontinuity measurement. Finally, a group of records that pertains to some common area of interest is stored in a file.

Eight parameters were chosen to describe field discontinuities.

Three of these parameters are essential; it would be impossible to describe a discontinuity without stating the nature of the feature, along with its' dip and dip direction. These parameters are recorded as the first three fields of each record within a data file. There are many additional parameters to describe orientation data that could have been chosen. However, if an excessive number of parameters is used, both the data file and the associated entry process become cumbersome. Therefore, the additional parameters selected were limited to the five deemed most crucial; these are type of infilling, spacing, area of exposure, surface roughness, and general comment (Watters, R. J., personal communication). As many investigators do not use any of these parameters, their entry into a data file is not required. If no data is available for any of these five parameters, the software will automatically fill that portion of the record with blanks.

TYPE OF DISCONTINUITY

As previously noted, there are several types of linear or planar features that can be found within a rock mass. However, only those considered dominant in controlling mechanical behavior within the rock mass are utilized for stability evaluation. The three dominant discontinuity types are joints, faults, and bedding planes (Muller, 1959). Joints are defined as stress induced fractures in the rock that exhibit no evidence of parallel movement along the fracture surface (Billings, 1972). Faults differ from joints in that they show appreciable displacement along the fracture plane (Ragan, 1973). Finally, a bedding plane can be defined as the boundary between two distinct sedimentary lithologic layers (CANMET, 1977). Each type of discontinuity exhibits distinct mechanical characteristics and spatial distributions. Hence, in the analysis of a free surface it is imperative that each type of discontinuity be recognized as a separate entity.

Every record that is entered must have the discontinuity type defined. In order to reduce the time required to enter data, each type of discontinuity was assigned a number according to the following arbitrary convention:

1 - Joint Plane

2 - Bedding Plane

3 - Fault Plane

0 - End-Of-File (EOF)

The first three choices (1, 2, & 3) are discontinuity types, while the fourth (0) serves as an indicator that the last record in the file has been entered. Any other entry will result in an error message. Internally this parameter is called PLANETYPE$ and is stored as a single character alpha-numeric.

<u>PLANE ORIENTATION</u>

This consists of two inter-related parameters, dip and dip direction. Dip is the maximum inclination of a discontinuity plane, measured downward with respect to the horizontal (Hoek & Bray, 1981). The dip of a discontinuity may vary from 0 to 90 degrees. The dip direction (or dip azimuth) is defined as the azimuthal direction of the horizontal trace of the line of maximum dip, measured clockwise from north (Hoek & Bray, 1981). The dip direction may lie between 0 and 360 degrees. The software will only accept integer values within the specified limits for these parameters, any other entry will result in an error message. In order to facilitate mathematical analysis, the software may assign values outside these limits to dip and azimuth, but bearing the same spherical trigonometric relationship (ie. 90 degrees is equivalent to 450). These parameters are assigned variable names DIP and AZIMUTH. They are entered and used mathematically as integer numbers, but are stored in the record as two character alpha-numerics.

INFILLING MATERIAL

Open fractures such as joints and fault planes are often filled with other earth materials. This material may be derived from the parent rock mass; either by weathering along the fracture surface or as debris resulting from movement. Alternatively, material may be precipitated out from fluid moving along the fracture plane. Regardless of its origin, the infilling material will have an important effect on shear strength along the discontinuity (Hoek & Bray, 1981). In extreme cases, the infilling may be thick enough for the walls of the fracture to be separated under design loads, in such cases shear strength will be that of the infilling material. The infilling type is entered as a word (calcite, ironstain, etc.) of up to nine characters. The software will not accept any character string longer than nine characters. Internally this parameter is named INFILL$ and is carried as a nine character alpha-numeric.

FEATURE SPACING

The distance between sets of similar features can be of extreme importance. This is particularly true for regularly spaced joint sets. The spacing between fractures defines the size of blocks that are free to move. If the spacing is sufficiently small the blocks will be of a size that is best modeled as a soil. In addition, information on spacing will be important if artificial support measures (rockbolts) are to be installed. This parameter is entered as a distance with units (eg. 20 feet) and is limited to eight characters in length. The parameter is stored as SPACING$, in an alpha-numeric variable eight characters in length.

AREA OF EXPOSURE

If the field discontinuity is exposed at the surface, then the physical dimensions of the exposure can be measured. Typically this parameter is stated as either the area of exposure or the greatest length along the exposed surface. The size of the exposed fracture is indicative of its persistence or continuity within the rock mass. If a fracture is continuous throughout the rock mass, then movement can occur without breaking intact rock, an important factor when considering strength along that plane. This variable is entered as a length with units (200 ft, 400sqft) of up to eight characters. This parameter is stored internally as AREA$ in an alpha-numeric variable eight characters in length.

SURFACE ROUGHNESS

All fracture planes exhibit an inherent surface roughness or waviness that varies about the mean plane. This parameter has an important effect on the shear strength along the fracture. Waviness occurring along a fault plane may be of sufficient magnitude that determination of the true surface orientation becomes difficult. Due to the potential large scale differences in surface roughness, several different techniques of evaluating this parameter have been suggested. Patton (1966) suggested calculations involving the angular variation of the surface about the mean. Ladanyi and Archambault (1970) carried this concept further; developing a complex mathematical relationship for shear strength, based on the dilation during strain that results from surface roughness. Barton (1973) proposed an empirical quantity, the JRC (joint roughness coefficient) based on comparison between the surface and a chart illustrating various values for the JRC. There are other methods for evaluating surface roughness, but none is universally accepted or applicable.

The lack of agreement between the different evaluation techniques greatly increased the difficulty in describing this parameter. It was decided to describe surface roughness by defining a roughness coefficient (RC), which would be an integer value from 1 - 9 (Watters, R. J., personal communication). This allows the operator to set his own standards for RC and thereby use any method desired in order to evaluate surface roughness. The range selected for RC also concurs with the standards suggested by the ISRM Commission on Standardization of

Laboratory and Field Tests (1978a) as listed below (after Brady & Brown, 1985):

1 - rough or irregular,stepped
2 - smooth, stepped
3 - slickensided, stepped
4 - rough or irregular, undulating
5 - smooth, undulating
6 - slickensided, undulating
7 - rough or irregular, planar
8 - smooth, planar
9 - slickensided, planar

Additionally, if this parameter is of critical importance it could be described in the comment section of the record. The software records an integer value for RC and then transforms it into a two character alpha-numeric for storage.

COMMENTS

This is an extremely important section of the data file. Unfortunately, it is not possible to classify all discontinuity data into the neat pigeonholes described thus far. The analyst is dealing with a natural system that tends to defy mathematical description or exact classification. In dealing with geologic data some amount of qualitative description will always be required. This creates the necessity for a comment section.

There are two comments available on each record; it is left to the operators discretion as to how and if they should be used. The first section is a fourteen character alpha-numeric field named COMMENT$ and the second is a sixty character field designated COMMENT2$. The operator can put any data desired into either field, as long as the field length is not exceeded.

RECORD TYPE

The large number of parameters involved in describing discontinuities in this project dictates the type of files that are used by the software package for storage. BASIC can access two types of files from disc storage, sequential and random access. Sequential files are marked by a carriage return at the end of each line. Each record in a sequential file contains 128 characters, even if only 1 is needed. Random access files are stored as a block, one record begins immediately after the end of the previous record. Data may be entered into sequential files with a text editor (Wordstar, Edlin, etc.) while random access files must be filled by a job-specific editor.

Random access files were chosen for this project for several reasons. Each record contains nine fields and 106 characters. Using sequential files with 128 characters in each record would have resulted in a 21% waste of available disk storage. Only the first 3 parameters: plane type, dip direction and dip must be entered, however the ensuing software requires that any additional parameters be in exactly their defined positions. Use of sequential files would require that long strings of blanks be entered to space the data properly. Sequential files cannot be accessed out of order, hence it is impossible to reach the middle of a data file without reading all the preceding records. Lastly, using random access files creates an internal buffer capable of handling blocks of records, both input and output simultaneously. Sequential files must be accessed one at a time in either output or input mode. The internal buffer in a random access filing system greatly increases the execution speed, particularly if large data files are involved.

VARIABLE NAME	VARIABLE TYPE	FIELD DESIGNATION	FIELD LENGTH
PLANETYPE$	alpha-num	F1$	1
AZIMUTH	numeric	F2$	2
DIP	numeric	F3$	3
INFILL$	alpha-num	F4$	9
SPACING$	alpha-num	F5$	8
AREA$	alpha-num	F6$	8
RC	numeric	F7$	2
COMMENT$	alpha-num	F8$	14
COMMENT2$	alpha-num	F9$	60

			106

FIGURE 2-1

Summary of variables included in each record

CHAPTER 3 - ELEMENTARY FILE OPERATIONS

As noted in the previous chapter, the complexity of the data in this project mandates the use of random access files. Unfortunately, the creation of a random access file is a relatively involved process when compared to that for a sequential file. Sequential files can be created and edited on screen using a text editor, such as Wordstar or Edlin (IBM). While this is possible for random access files, it is not practical. Records in a random access data file do not end with a carriage return; hence, data is not displayed on the screen in the consistent columnar fashion essential for data entry with a text editor. As a result, random access files are typically created using a job-specific editor.

An editor of this type normally accepts data from the screen in a user-friendly question and answer manner. Records are created sequentially; as a result, it is not viable to perform on-screen editing of previously entered data. Therefore, a means for correcting errors within the data file is essential. The most efficient means for locating errors in a data file is to print it out in a legible, hard copy format for inspection. Separate programs performing each of these functions are discussed in this chapter: they are CREATE, PRINT, and EDIT.

This chapter covers the mechanical processes for the creation and handling of data files. No analytic manipulations of the data are performed by the programs discussed within. For each program there will be a discussion of the task it performs, operating instructions, and a synopsis of the underlying logic. The last section is of importance to those who wish to modify the code. The logical steps will be outlined in pseudocode, which consists of abbreviated, plain english expressions describing the logical process. Typically, a programmer will outline the tasks that a program is to perform using pseudocode; later, those steps can be coded into a program language. The actual code for each program is listed in Appendix B.

<u>CREATING A DATA FILE</u>

The job-specific editor written to provide a user-friendly method for creating data files is named "CREATE". In order to fulfill it's purpose, CREATE must perform several tasks. To assure that the data is recorded properly, each file must be opened and closed according to the rules for random access files. As a data set may involve hundreds or thousands of data fields it is important that the entry process allows maximum speed and efficiency. When entering large amounts of repetitive data, entry error is inevitable. In order to minimize errors, each entry is checked to ascertain that the value is appropriate for the parameter involved. The critical reason for using a job-specific editor is to guarantee that the data is placed into the proper position within the record. The unused spaces in the record must accordingly be filled with blanks. CREATE fulfills all of these functions while accepting data in a user-friendly question and answer format.

When the file creation option on the main menu is selected, the program CREATE is loaded and execution begun. The first set of instructions to appear on the screen regard the initialization parameters; they establish guidelines for data entry. The first prompt displayed asks whether a new or existing file is to be opened. This option allows the operator to append additional records to an existing file. When the new file option is chosen, the file begins with record number one, thus destroying any preexisting file with the same name. Next, the operator is requested to enter the file name with a drive specification. The file name must be from 1-8 characters in length, and may contain numbers 0-9 and letters A-Z in any combination. Further information on file names can be found in the BASIC language manual for the system being used. The drive specification is only required if the data file is not on the default drive. For example, if drive A is used as the default drive, the response SLOPE would open a file named slope on drive A; while C:SLOPE would open a similar file on drive C. If a preexisting file is to be appended there will be a short delay while the end of the file is located.

Prior to entering data, the operator has two choices regarding the amount of data to be contained in each record. The default choice is to enter the full data set: plane type, azimuth, dip, infilling, spacing, area of exposure, roughness coefficient and comments. The other option is to enter only orientation data, with all other parameters automatically assigned null values. Selection of this option will greatly expedite the entry process because only three parameters (plane type, dip, and azimuth) must be entered for each record, as opposed to nine. Completion of this step ends the initialization procedure. Figure

3-1 illustrates the entries required to open a new file that will accept the full data set.

```
1 - OPEN A NEW FILE
2 - ADD RECORDS TO AN EXISTING FILE

ENTER CHOICE ? 1


ENTER FILE NAME WITH DRIVE SPECIFICATION (B:FILENAME) ? B:BOTTOM


WILL THERE BE DATA OTHER THAN PLANE TYPE AND ORIENTATION ? YES
```

Figure 3-1

Operator input for setting data entry parameters.

After initialization is complete, the data entry process begins. The first parameter to be entered in each record is the plane type; the acceptable values for this were described in chapter 2. However, one parameter is of particular importance: in order to exit this program it is necessary to enter zero for the plane type. Throughout this entire software package, a zero in the field designated PLANETYPE$ serves as an indicator that the end of the file has been reached. It is necessary to include a flag in the data set when using random access files, as no other end-of-file (EOF) message is recognized. After plane type, the orientation parameters are entered; both of these have error traps so that impossible values will not be accepted. If the short data set option has been specified, the program will loop back to the entry of plane type until a zero is entered.

If the full data set is to be entered, the remaining parameters will now be requested. With the exception of surface roughness, these are all alpha-numeric variables that may not exceed the length of the associated field. If the maximum length is accidentally exceeded, an error message will appear. When no data is available for any of these parameters, a carriage return will assure that the field is filled with the proper number of blanks. After the second comment field has been entered, the program loops back to allow entry of the next record. Figure 3-2 shows an example illustrating the entry of a typical data record for the full data set. Also, shown in this example is the system response to an invalid entry. The initial entry for the first comment was fifteen characters in length; one longer than the field. The system immediately realizes this and prompts the operator to correct the error.

When a zero is entered into the plane type field, the data entry phase ends and the closing process begins. After receiving the EOF flag (PLANETYPE$ = "0"), control passes from the data entry loop to the closure sequence. All remaining fields of the last record are set to null values. The buffer is then emptied and the data file closed. The screen will then display the number of records entered and the file name with drive specification. Program control is then returned to the main menu.

```
PLEASE ENTER THE DATA FOR RECORD NUMBER  1  AS REQUESTED.

ENTER PLANE TYPE (1,2 or 3, 0 to quit) ? 1

ENTER DIP AZIMUTH (345, 034 etc.) ? 46

ENTER DIP (87, 07) ? 39

ENTER TYPE OF  INFILLING (IRONSTAIN) ? EXPOSED

ENTER FEATURE SPACING (20 FT) ?

ENTER AREA OF EXPOSURE (100 SQFT) ? 175 FT

ENTER THE SURFACE ROUGHNESS COEFFICIENT (1 - 6) ?

ENTER THE FIRST CHARCTER STRING ? FAILURE SURFACE

STRING IS TOO LONG, RE-ENTER

ENTER THE FIRST CHARCTER STRING ? FAILURE PLANE

NOW ENTER THE REMAINDER
? ELLIPTICAL EXPOSURE 175 x 85 FT BELOW HIGHWAY 89
```

Figure 3-2

Typical entry for a single discontinuity measurement, including an error.

PSEUDOCODE FOR CREATE

```
Initialize execution
    create a new file or add records to an existing file?
    accept filename
    open file
          set fields within buffer
          set record number to one
    if this is a new file jump to *
          find last data record in old file
          set record number to begin after last existing file
```

```
*   if a full data record is to be entered skip to #
         set infilling, area, spacing, roughness, comment to " "

# Loop for data entry
    accept plane type
         check for acceptable value
         if "0"  end of file message received, jump to @
    accept dip azimuth
         check for acceptable value
    accept dip
         check for acceptable value
    if orientation data only jump to +
    accept infilling type
         check string length
    accept feature spacing
         check string length
    accept area of exposure
         check string length
    accept surface roughness
         check for acceptable value
    accept first comment
         check string length
    accept second comment
         check string length
+   put record into file
         convert numbers to string equivalents
         write record to data file
    increment record number by one
    return to beginning of loop

@ End program execution
    set final record to zero as a flag
         write record to data file
    close data file
    display number of records in file with name
    chain to main menu
```

HARD COPY OUTPUT OF A DATA FILE

The program entitled "PRINT" is designed to produce hard copy output of a data file. The most important reason for obtaining hard copy is to verify that the data has been entered correctly by cross checking against the field notes. Additionally, hand written field notes are not suitable for inclusion in a professional engineering report. The program PRINT provides output of appropriate quality by aligning the field data into an organized columnar format. In the process of performing this task PRINT aligns the data into columns, allows for the use of either cut sheet or fanfold paper, calculates subtotals and changes numeric designations for plane type into the appropriate word.

Hard copy output is obtained by selecting the appropriate option on the main menu. This loads PRINT and commences execution. Prior to initiating the print process, the operator must enter several format control parameters. Obviously, the first and most important parameter is the file name with drive specification as described for CREATE. Along with the headings for the appropriate data columns, PRINT allows the operator to specify a single heading that will appear at the top of each page. This heading may be of up to sixty characters in length and will be automatically centered on the page. If any commas or semicolons are to appear in the heading, the entire line must be enclosed in quotation marks or an error message will result. Additionally, the type of paper to be used (cut sheet or fanfold) must be specified prior to printing so that page breaks are inserted at the proper positions. When the screen displays a reminder to ready the line printer (figure 3-3), a carriage return will initiate the printing process.

```
ENTER FILE NAME WITH DRIVE SPECIFICATION (B:FILENAME) ? B:BOTTOM


ENTER A PAGE TITLE OF UP TO 60 CHARACTERS

NOTE: Inclusion of a comma in the title will cause an error
unless the entire statement is enclosed by quotation marks

? ORIENTATION DATA MEASURED ON LARGE PLANE BELOW HIGHWAY 89


ARE YOU USING SINGLE SHEETS OF PAPER (YES or NO) ? NO


READY PRINTER AND THEN HIT <CR> TO BEGIN ?
```

Figure 3-3

Operator entry required to initiate the printing process for fanfold paper.

Unless cut sheet paper is being used, there is no operator input during the printing process; it is entirely controlled by two nested loops. The outer loop controls the printing of entire pages until the EOF message is received. It prints headings at the top of each page and then assures that the plane type is included on the first line of each page. Control is then passed to the record printing loop until either an end of page or EOF message is received. The action taken at a page break depends on the type of paper used. If fan fold paper is being used, the printer advances to the correct position on the next sheet, otherwise printing will pause until a new sheet is readied. The page printing proceeds until a zero in the plane type field is perceived; control then passes to the closing sequence.

The internal loop prints individual records within the page loop. After reading a record, several decisions are made based on the value of the PLANETYPE$ field. If it is zero the EOF has been reached and the closure process is begun. In chapter 2 a convention was established to expedite data entry by representing different plane types with numeric values (1, 2 & 3). Appearance of the output is enhanced by reversing this process, such that the name of the plane type is printed. To avoid redundancy, the plane type is only printed when it differs from the one on the previous line, otherwise that space is blank. In addition, running totals of all plane types in the file are kept by incrementing the appropriate counter each time a record is read. The first eight fields of each record are printed in a predetermined columnar format. Since it requires an entire line, the second comment field (field F9$) is only printed if it contains information. The line counter is then advanced by the number of lines printed for this record. This sequence goes on until the counter ascertains that a page has been completed or the EOF received.

The closing sequence of this program also performs several tasks. The program first checks the line counter to verify that sufficient room exists on the current page to print out totals, if not it advances to the next page. During the print process running totals of the planes printed were recorded, each non-zero total is included in the output. The printing process is then completed (figure 3-4) by printing the total number of discontinuities recorded in the file. The data file is then closed and control passed to the main menu.

ORIENTATION DATA MEASURED ON LARGE PLANE BELOW HIGHWAY 89

PLANE TYPE	DIP DIR	DIP	TYPE OF INFILLING	FEATURE SPACING	AREA OF EXPOSURE	Rc	COMMENT
JOINT	46	39	EXPOSED		175 FT		FAILURE PLANE
*	ELLIPTICAL EXPOSURE 175 x 85 FT BELOW HIGHWAY 89						
	46	44					
	40	42					
	47	43					
	43	43					
	35	52					
	48	46					
	47	38					
	37	33					
	38	35					
	46	44					
	34	37					
	44	42					
	38	41					
	44	41					
	45	42					
	41	45					
	42	37					
	40	39					
	39	39					
	37	36					
	44	30					
	52	31					
	46	38					
	44	36					
	44	36					
	48	35					
	47	36					
	48	38					
	46	42					
	46	39					
	48	39					
	42	43					

33 JOINT PLANES WERE RECORDED

Figure 3-4

Example output produced by PRINT; (shown after 20% reduction).

PSEUDOCODE FOR PRINT

```
Initialize execution
   accept filename
   set values for constants and headings
   open file
       set fields within buffer
```

```
         read first record
         if file is empty display message, jump to *
         set plane type number to appropriate term,"joint, etc"
add to appropriate counter
    accept print parameters
         accept and center page heading
         choose between single sheet and fanfold
         pause for printer preparation

Page printing loop
    if EOF jump to #
    print headings
    record printing loop
         print first eight fields, perform 1 counted line feed
         if second comment blank, jump to @
              print second comment, 1 counted line feed
@        get next record
              if EOF jump to #
              set plane type into words, add to counter
              if plane type is the same as previous set to "   "
         if line count < page length repeat record loop
    if fan fold paper advance to next page
    else pause for paper change
    go to beginning of page printing loop

# Print totals
    if insufficient room on page for totals, perform following
         if fan fold advance to next page
              else pause for paper change
    if number of faults greater than 0, print it
    if number of joints greater than 0, print it
    if number of beds greater than 0, print it
    if file contains a single plane type jump to *
         print total number of planes in file

* End program execution
    close file
    chain to main menu
```

EDITING A DATA FILE

Even when using the utmost care it is extremely unlikely that any data file could be created completely error free. The program named "EDIT" was written to provide a means for correcting these inevitable errors. In order to correct a record within a random access file, it is necessary to know the position (record #) of that record within the file. This can best be accomplished by browsing through the file and examining groups of records. Approximately fifteen records can be displayed on the screen at a time. EDIT displays records in order, so that the operator may select the ones that require correcting. After selecting a record for correction, any field within that record may be altered individually or the entire record may be deleted.

EDIT is divided into three separate functions: browsing, editing, and closure. Rather than following a set pattern of operations while passing through a file, EDIT allows the operator to move from one section to another as desired. As a result, the easiest way to understand the logical process is to follow the pseudocode. The initialization process is simple: it merely requires that the name of the file for editing be entered with the appropriate drive specification. After opening the file, browsing begins by filling the screen with the first fifteen records of the file (figure 3-5). The operator is then offered three options: edit, exit program, and continue browsing. If the continue browsing option is chosen, the process repeats itself with the next set of records.

ENTER FILE FOR EDITING WITH DRIVE SPEC (B:FILENAME) ? B:BOTTOM

COUNTING THE DATA FILE, EXECUTION WILL BEGIN SHORTLY

REC#	TYPE	AZMTH	DIP	INFILL	SPACING	AREA	RC	COMMENT
----	----	-----	---	------	-------	----	--	-------
1	1	46	39	EXPOSED		175 FT		FAILURE PLANE
2	1	46	44					
3	1	40	42					
4	1	47	43					
5	1	43	43					
6	1	35	52					
7	1	48	46					
8	1	47	38					
9	1	37	33					
10	1	38	35					
11	1	46	44					
12	1	34	37					
13	1	44	42					
14	1	38	41					
15	1	44	41					

1. END EDITING SESSION
2. EDIT FILES
3. CONTINUE BROWSING

ENTER CHOICE ?

Figure 3-5

Screen display of the browse function in EDIT.

The edit option is more complex. The operator enters the number of the record to be edited. All fields for that record are then displayed on the screen along with the associated field numbers (figure 3-6). By selecting the appropriate choice, the operator can either alter a specific field, save the record as shown, or mark it for deletion. After a field has been altered, the record is re-displayed in it's amended form until either the save or delete option is chosen. The operator is then given the choice of returning to browsing, additional editing, or ending the editing session.

```
     EDITING RECORD NUMBER  1

     1. PLANE TYPE         : 1
     2. DIP AZIMUTH        :  46
     3. DIP                :  39
     4. INFILLING          : EXPOSED
     5. FEATURE SPACING    :
     6. AREA OF EXPOSURE   : 175 FT
     7. ROUGHNESS COEF     :
     8. FIRST COMMENT      : FAILURE PLANE
     9. SECOND COMMENT     :
ELLIPTICAL EXPOSURE 175 x 85 FT BELOW HIGHWAY 89

     D. DELETE THIS RECORD
     S. SAVE THIS RECORD AS SHOWN

  ENTER FIELD FOR EDITING (1-9) OR ACTION DESIRED (D or S) ? S
```

Figure 3-6

Screen display for editing record number one, shown as saving the record.

When the end of editing option is chosen, the closure process is initiated. The first step in this process is to eliminate the records that were marked for deletion. In a random access filing system, a record is deleted by writing an existing record over top of it. In a large data file this may take over an hour because a single deletion requires that every record following the deletion be moved forward one position in the file. After this step is completed the file is closed and control is passed back to the main menu.

PSEUDOCODE FOR EDIT

```
Initialize execution
    accept filename
    open file
         set fields within buffer
         set record number to one
    count data file
% Edit files
    browse files
         fill screen with formatted records
         if end of file reached display end of file menu
              1 - edit records, jump to #
              2 - end editing session, jump to *
         else offer options
              1 - continue browsing, browse next set of records
              2 - end editing session, jump to *
              3 - edit records jump to #
#   edit records
         accept record number for editing
         display all parameters, by number
         offer choices
              1 - delete this record, mark  with flag, jump to @
              2 - save record as shown, jump to @
              3 - edit a field
                   accept new value for field
                   display   record   parameters   and   choices  until
                   option 1 or 2 chosen
@        display choices
              1 - edit more records, jump to #
              2 - continue browsing, jump to %
              3 - end editing session, jump to *

* End editing session
    delete all records flagged for deletion
    "pack" the data file
    close file
```

CHAPTER 4 - ADVANCED FILE OPERATIONS

The previous chapter outlined the essential programs needed in order to create a data file. However, there are other manipulations that may be performed on the data set that will ease analysis. Recurring planar features could be readily recognized if the data set was sorted into a predetermined order. In addition, a subset of the data file may be of particular interest (ie. clay filled joints). The simplest method for analyzing a portion of a data set is to create a sub-file containing only those records that match the specified parameters. The programs described in this chapter perform those functions; they are named SORT and SEARCH.

SORTING A DATA FILE

The program entitled "SORT" is designed to arrange the records within a data file into ascending order. By definition, each record in a data file must contain a minimum of three parameters (plane type, azimuth, and dip). These three were arbitrarily chosen as the sort keys. All records are arranged in ascending order: first by plane type, then by azimuth, and lastly by dip. This particular order reduces the time required for plotting by decreasing the distance between successive points. While sorting does not alter the data in any way, it does group similar data records, thus making major trends more obvious in a hard copy output of the data file.

One of the original goals in this project was to keep the hardware requirements to a minimum. The restrictions caused by this goal are most apparent in the sort routine. In order to fulfill the goals of using a single disk machine with 256K memory the sort is limited to a file of 1000 records. Minor modifications to the code would allow larger files to be sorted on a machine with additional disk storage. The modifications would consist of increasing the size of both the sort and the position arrays along with the associated for-next loops. When the sort option is chosen from the main menu, SORT begins execution by displaying a warning regarding file length. It is imperative that there be sufficient storage available for an additional file (sort file) of equal length to the original (target) file. This is because during execution SORT uses a second file to store the sorted records. After the warning is displayed, the operator is given the option of continuing or exiting to the main menu. To continue the operator must enter names for both the original file and a second name for the sort file (figure 4-1). SORT then opens channel #1 to the target file and channel #2 to the sort file. If the warning is not heeded and insufficient storage is available both files would then be destroyed.

The sorting procedure begins with the creation of a sort array and a position array. Each entry in the sort array is a alpha-numeric (string variable) equivalent of the summation of the sort keys: plane type, azimuth and dip. Since azimuth and dip are not of a specified string length, each variable is first padded with zeros so that the numbers fall into the appropriate columns (1,45,5 becomes 104505). The position array simply contains the original location number of each record. The sort array is then put into ascending order using the algorithm described in the following paragraph. As each move is made in the sort array, a corresponding move is made in the position array. Once the sort procedure is completed, the position array can be used to move records from the target file to the sort file in the proper order. Using position and sort arrays in this manner decreases the available memory, both in RAM and on disk. However, the increase in speed due to reduced disk access time is significant; execution time on a 1000 record data file was improved from five hours to less than 20 minutes by utilizing sort and position arrays.

There are literally hundreds of different sorting algorithms that have been designed for different tasks. The Shell-Metzner sort was chosen for this project because the code is relatively simple and it is much faster than other simple routines such as the Bubble sort (Kernighan, 1975). The basic premise of the Shell-Metzner sort is similar to that of the Bubble sort: records are compared and if necessary, exchanged. The Shell-Metzner sort works by comparing widely separated records rather than adjacent ones, as in the Bubble sort. The result is that large amounts of disorder are reduced quickly. As the process proceeds, the comparison interval is decreased until it reaches one, at which point the file is sorted.

```
                    *********CAUTION*********

      THERE MUST BE SUFFICIENT STORAGE AVAILABLE FOR A FILE
              OF THE SAME LENGTH AS THE SORT FILE

      DO YOU WISH TO CONTINUE (YES or NO) ? YES


ENTER FILE TO BE SORTED, WITH DRIVE SPECIFICATION (B:FILENAME)? B:EMRLDBAY

ENTER NAME FOR SORTED FILE, WITH DRIVE SPECIFICATION (B:FILENAME)? B:TEMP


          ******SORT IS IN PROGRESS******

            THIS MAY TAKE SEVERAL MINUTES


          1 - SAVE BOTH FILES
          2 - DESTROY THE UNSORTED FILE

          ENTER CHOICE ? 1

     THE SORTED FILE IS STORED AS B:TEMP

     NUMBER OF RECORDS SORTED :    315

     EXECUTION TIME OF SORT    :   00:06:47
```

Figure 4-1

Operator input required to perform the sorting process.

The Shell-Metzner procedure is only used to arrange the position array into the correct order. After sorting the arrays, SORT simply puts records into the sorted file using the order found in the position array. After all records have been moved, the operator is then given several choices regarding the original and sorted files (figure 4-1). If both files are to be saved they retain their original names. However, if the original file is to be destroyed, the sort file can be named with either the name used during the sort, or the name of the original file. Execution is then completed by closing all files, displaying the time required for the sort (figure 4-1), and returning control to the main menu.

PSEUDOCODE FOR SORT

```
Initialize execution
    display warnings about file length and destruction
         offer continue option, if no exit to main menu
    accept name of the file to be sorted
    accept name of file to store sorted data
    open target file as #1
         set fields in buffer for #1
     open the second file as #2
         set fields in buffer for #2
    dimension arrays for sort parameter, position indicator
    display message on sort time
    start clock

Sort procedure
    fill position array
    create sort array
         read plane type, azimuth and dip from a record
         force them into proper columns and link variables
              together  (ie. 1,34,9 = 103409)
         place this into the array
         repeat for entire file
         count array
    sort array
         outer loop
              set gap between records for comparison to count/2
```

```
                    inner loop
                            compare records separated by gap
                            if rec #1 < rec #2 jump to #
                                    swap rec #1 an rec #2
                                    swap variables in position array
#                           repeat until loop passes through file once
                    set gap = gap/2
                    if gap < 1 jump to %
                            perform inner loop
%           fill temporary file
                    for 1 to length of file
                            use position array to move records from
original to temporary file

Close procedure
      close all files
      stop clock
      display options
              1 - save both files, jump to *
              2 - destroy original
                      erase original file, offer to re-name sorted file
*     display results
              name of sorted file
              number of records in file
              execution time of sort
      chain to main menu
```

CREATING SUB-FILES

One of the primary problems associated with manual manipulation of orientation data is the difficulty involved in analyzing data subsets. The operator may wish to analyze only a specific portion of the data set, such as clay filled joints. The program entitled "SEARCH" allows the input of desired parameters and then creates a sub-file containing only those records that match the specified parameters.

When SEARCH is called from the main menu, it immediately begins execution by displaying a warning regarding disk space. As in SORT it is essential that there be sufficient space available to contain the additional file that will be created, lest both files be destroyed. If the operator chooses to continue, file names for the original and sub-file must be entered, along with their respective drive specifications (figure 4-2). SEARCH then opens the original file as channel #1 and the sub-file as channel #2. The search array is then initialized by assigning null values to the search parameters.

```
******CAUTION*****
BE SURE THAT THERE IS ENOUGH DISK SPACE AVAILABLE FOR TWO FILES

DO YOU WISH TO CONTINUE (YES or NO) ? YES

ENTER ORIGINAL FILE NAME WITH DRIVE SPECIFICATION (B:FILENAME) ? B:EMRLDBAY

ENTER TITLE FOR SUBFILE WITH DRIVE SPECIFICATION (B:FILENAME) ? B:FAILPLANE
```

Figure 4-2

Operator input for initializing the search process.

The screen then displays the search parameters that may be entered, along with their current values and option choices (figure 4-3). Since the array was initially assigned null values, no values are shown at first. The operator may then choose a parameter for the search and enter the desired value. The array with the operators choice is then re-displayed for verification or further entry until the "begin search" option (figure 4-4) is selected.

Upon receiving the begin search command the search process is initiated. SEARCH reads each record in the original data file, comparing it to the search array. If no search parameter was entered for a given field, any value in that field is deemed acceptable. If any field in the record does not fit the search array, it is rejected and the next record read. If all fields match, the record is then written to the sub-file. After all records have been read, both files are closed and control is passed to the main menu.

```
ONLY THE DESIRED SEARCH PARAMETERS NEED BE ENTERED

          1. PLANE TYPE              :
          2. DIP AZIMUTH             :
          3. DIP                     :
          4. INFILLING MATERIAL      :
          5. FEATURE SPACING         :
          6. AREA OF EXPOSURE        :
          7. ROUGHNESS COEFFICIENT   :
          8. BEGIN SEARCH
          9. RETURN TO MAIN MENU

        ENTER DESIRED ACTION (1-9) ? 2

ENTER MINIMUM DIP AZIMUTH FOR SEARCH ? 20

ENTER MAXIMUM DIP AZIMUTH FOR SEARCH ? 60
```

Figure 4-3

Process for entering dip azimuth parameters into the search array.

```
ONLY THE DESIRED SEARCH PARAMETERS NEED BE ENTERED
              1. PLANE TYPE                 :
              2. DIP AZIMUTH                :  20 - 60
              3. DIP                        :
              4. INFILLING MATERIAL         :
              5. FEATURE SPACING            :
              6. AREA OF EXPOSURE           :
              7. ROUGHNESS COEFFICIENT      :
              8. BEGIN SEARCH
              9. RETURN TO MAIN MENU

          ENTER DESIRED ACTION (1-9) ? 3

ENTER MINIMUM DIP FOR SEARCH ? 30

ENTER MAXIMUM DIP FOR SEARCH ? 50


ONLY THE DESIRED SEARCH PARAMETERS NEED BE ENTERED
              1. PLANE TYPE                 :
              2. DIP AZIMUTH                :  20 - 60
              3. DIP                        :  30 - 50
              4. INFILLING MATERIAL         :
              5. FEATURE SPACING            :
              6. AREA OF EXPOSURE           :
              7. ROUGHNESS COEFFICIENT      :
              8. BEGIN SEARCH
              9. RETURN TO MAIN MENU

          ENTER DESIRED ACTION (1-9) ? 8
```

Figure 4-4

Entering dip parameters and beginning the search.

PSEUDOCODE FOR SEARCH

```
Initialization procedure
    display warning regarding disk space
         allow exit to main menu
    accept name of original file
         open as #1
         set fields in buffer for #1
    accept name of sub-file to be created
         open as #2
         set fields in buffer for #2
    set constants, dimension search array

Set search parameters
    zero search array
    display search menu
         1 - plane type
         2 - azimuth          ____ to ____
         3 - dip              ____ to ____
         4 - infilling
         5 - spacing          ____ to ____
         6 - area
         7 - roughness        ____ to ____
         8 - begin search
         9 - return to main menu
    on choice accept parameters or begin action

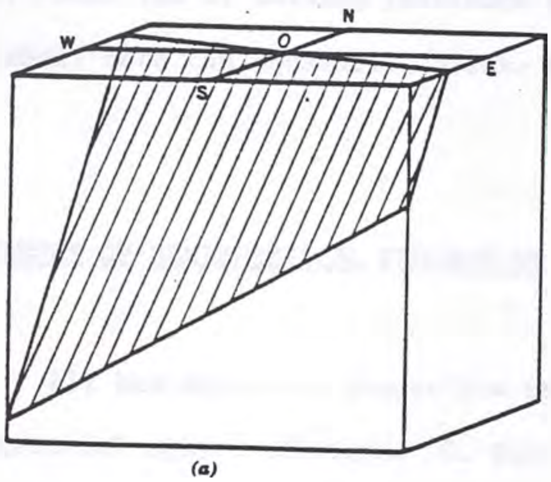
Begin search loop
    read first record
    check against all search parameters
         if it checks write to sub-file
    get next record
         if EOF jump to *
         else continue loop

* Closure procedure
    close files
    chain to main menu
```

CHAPTER 5 - GRAPHICAL DISPLAY OF ORIENTATION DATA

The previous chapters have served to outline a system for handling data regarding discontinuities within a rock mass. Discontinuities are treated as planar features that may be characterized by a specific orientation in three dimensional space. Unfortunately, the media available for graphic display of such data (paper, video monitor, etc.) is of a two dimensional nature. In order to retain all of the information contained in the data, it must be viewed in a manner that emphasizes the three dimensional perspective. The use of a projection technique allows the data to be transferred onto a two dimensional media in a manner that preserves the three dimensional relationships. Geologic data is typically projected using either an orthographic or hemispherical projection technique. Detailed descriptions of the methodology and underlying theory of these projection techniques can be found in any comprehensive structural geology text (Billings, 1972; Priest, 1985; Phillips, 1971; etc.).

The differences between the orthographic and hemispherical projection methods can best be discerned by examining figure 5-1. Both drawings depict a planar discontinuity with a surface trace in the compass plane (NESW) which passes through point O. The exact orientation of the plane can not be determined from either drawing. This is due to the distortion of angular relationships that is inherent in such pseudo 3-D drawings. The drawing on the left (5-1a) is a block diagram that serves to illustrate the orthographic projection technique. By projecting the discontinuity plane onto any two of the cubes faces (orthographic projection) its' orientation could be determined through the use of analytic geometry. Alternatively, the same plane may be viewed as cutting through the lower half of a sphere (Figure 5-1b). Then using hemispherical projection (figure 5-2a), the trace of the plane is projected onto plane NESW (figure 5-2b), where it is uniquely defined. Thus, hemispherical projection has an inherent advantage in that three dimensional angular relationships are uniquely defined by a single two dimensional representation.



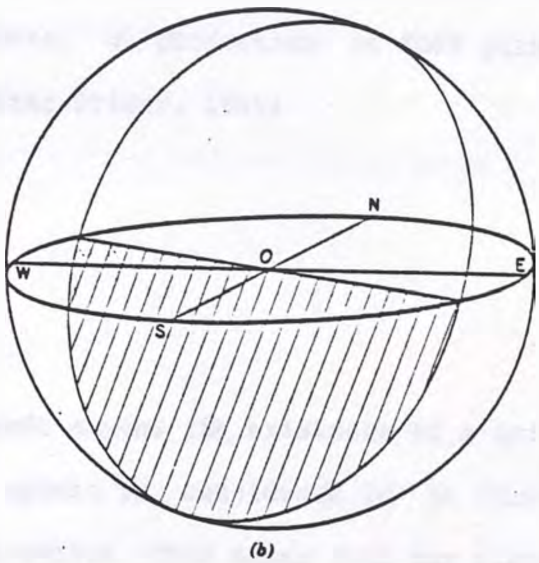


FIGURE 5-1

a) Block diagram, with a discontinuity plane. b) A plane of the same orientation shown intersecting a reference sphere (after Priest, 1985).

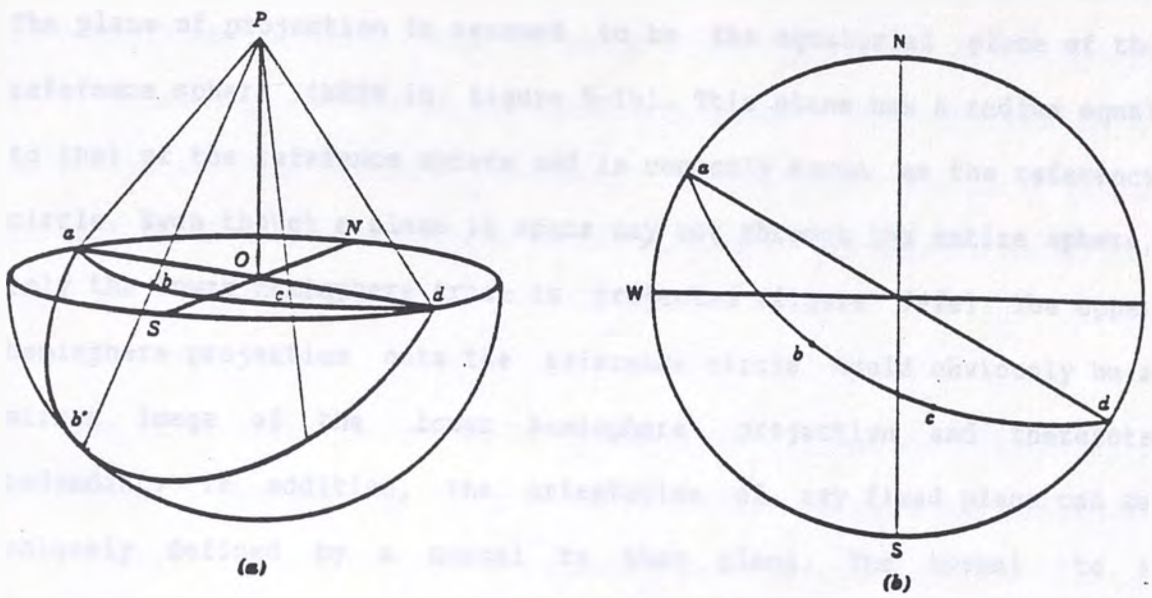


FIGURE 5-2

a) Plane (ab'd) cutting reference sphere. b) projection of that plane (abcd) onto the equatorial plane. (after Priest, 1985)

THEORY OF HEMISPHERICAL PROJECTION

All hemispherical projection methods assume the existence of a unit reference sphere of radius R. This sphere is considered to be fixed with respect to rotation, but not location. This means that any plane in space can be considered to pass through the origin of this sphere, without altering its original orientation. Every point on the surface of the sphere thus maintains a unique angular relationship with the center of the sphere. Defining the reference sphere in this manner allows the angular relationships between planes (or lines) in space to be considered regardless of their spatial locations.

Before proceeding, there are several conventions that bear mention. The plane of projection is assumed to be the equatorial plane of the reference sphere (NESW in figure 5-1b). This plane has a radius equal to that of the reference sphere and is commonly known as the reference circle. Even though a plane in space may cut through the entire sphere, only the lower hemisphere trace is projected (figure 5-2a). The upper hemisphere projection onto the reference circle would obviously be a mirror image of the lower hemisphere projection and therefore redundant. In addition, the orientation of any fixed plane can be uniquely defined by a normal to that plane. The normal to a discontinuity plane is referred to as its' pole, and is assumed to intersect the plane at the origin of the reference sphere. Because the pole is a line, its' intersection with the reference sphere projects as a single point. In some instances clarity requires that the trace of the plane be drawn, but in general planar features are represented on a hemispherical projection by the pole.

EQUAL-AREA AND EQUAL-ANGLE PROJECTIONS

There are several methods for projecting a point located on the surface of a sphere onto a two dimensional surface. This is evidenced by the numerous types of map projections used by cartographers. Two such methods, the equal-angle and equal-area projections, are useful in the presentation of geologic orientation data. These are illustrated in figures 5-3a and b. These figures show vertical cross sections through the reference sphere, with a line OP' (representing a pole) trending parallel to the cross section and dipping at an angle β from the horizontal. In the equal-angle projection technique (figure 5-3a) a straight line is drawn from the point P' on the surface of the sphere to T, located at the top of the reference sphere. The intersection of this line with the horizontal projection plane defines the point P. The point P on the horizontal plane is then a unique representation of the line OP' in three space.

The equal-area projection of the line OP' (figure 5-3b) requires a more complex methodology. The point B is defined as the intersection of the bottom of the reference sphere with a horizontal plane. An arc centered at point B is drawn through the point P', the intersection of this arc with the lower horizontal plane then defines the point P", at a horizontal distance r'. It can be shown mathematically (Priest, 1985) that this technique creates a projection that is larger than the original by a constant factor. Therefore, dividing r' by this constant $(2^{.5})$ gives the normalized radius r, which uniquely locates point P on the horizontal plane.

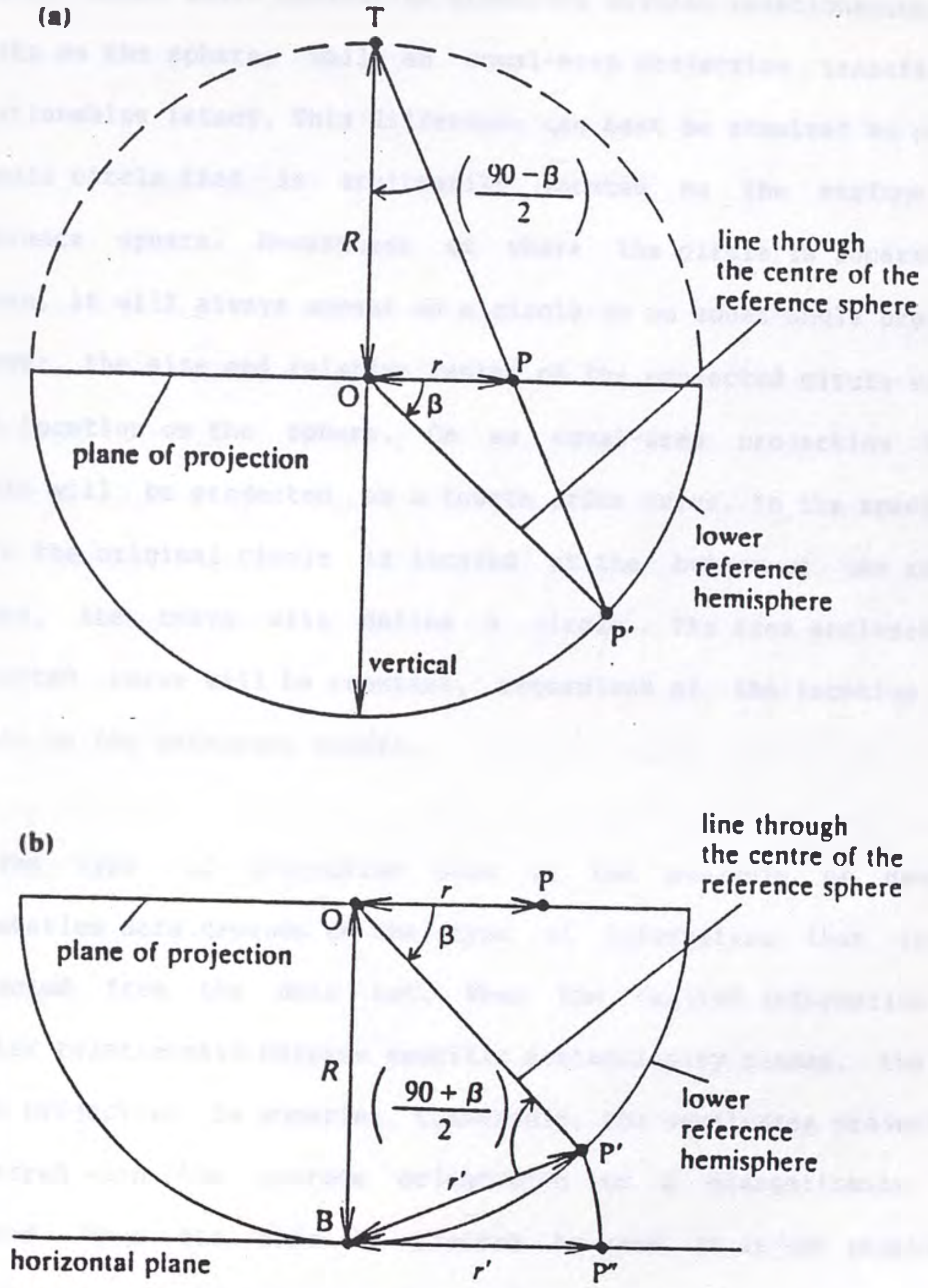


FIGURE 5-3

Descriptive geometry for the: a) Equal-angle projection. b) Equal-area projection. (after Priest, 1985)

The different methods used in the two projection techniques result in distinctly different physical properties. The basic difference is that an equal-angle projection preserves angular relationships between points on the sphere, while an equal-area projection transfers areal relationships intact. This difference can best be examined by picturing a small circle that is arbitrarily located on the surface of the reference sphere. Regardless of where the circle is located on the sphere, it will always appear as a circle on an equal-angle projection. However, the size and relative center of the projected circle will vary with location on the sphere. On an equal-area projection the same circle will be projected as a fourth order curve. In the special case where the original circle is located at the bottom of the reference sphere, the curve will define a circle. The area enclosed by the projected curve will be constant, regardless of the location of the circle on the reference sphere.

The type of projection used in the analysis of geological orientation data depends on the type of information that is to be extracted from the data set. When the desired information is the angular relationship between specific discontinuity planes, the equal-angle projection is superior. Conversely, the equal-area projection is preferred when the average orientation of a discontinuity set is desired. When the data is plotted by hand, it is not practical to switch back and forth between the methods. As a result, some authors (Hoek & Bray, 1981) recommend that the equal-area projection be used in all cases, as its angular limitations are insignificant when compared to the spatial inaccuracy inherent in the equal-angle projection. In this project however, the data exists as numbers in a data base. Since each projection method can be defined by a series of mathematical relationships, this software package will use whichever projection is superior for the task at hand.

THE POLAR STEREO NET

Orientation data can be projected onto paper using a stereo net, which is a reference circle with a superimposed measurement grid. While there are several types of grids currently in use, for the purposes of this project the polar stereo net (figure 5-4), is the most practical. The concentric circles are the projection of a line of constant dip that is rotated about the vertical axis. The radial lines of the net are the projection of a line of constant azimuth that is rotated from the vertical to the horizontal plane. Discontinuity poles can be plotted directly onto such a net; the mechanics of this technique are outlined in Priest (1985).

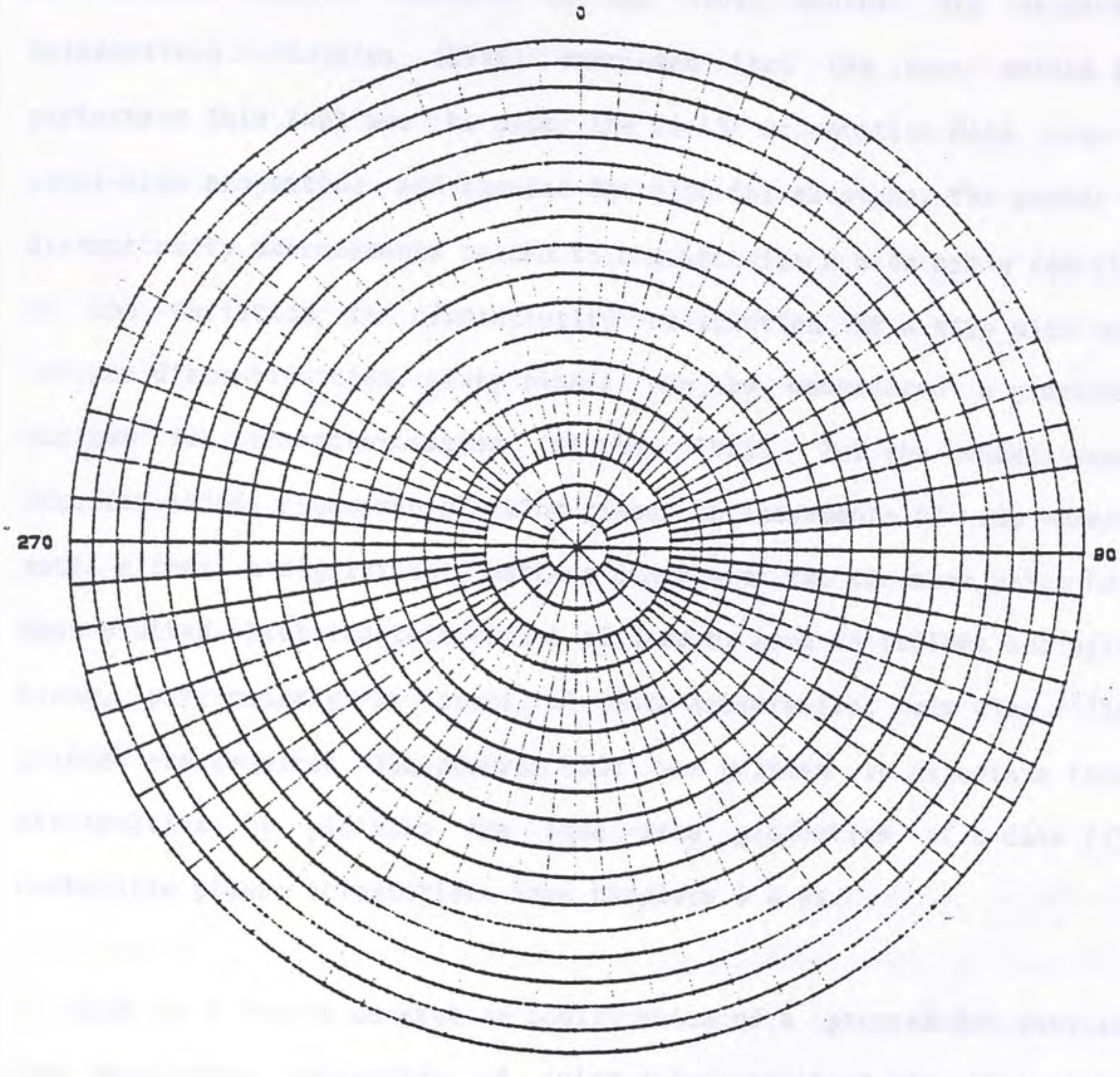


FIGURE 5-4

Polar equal-area stereo net, generated using the program PLOT (Appendix B, 10% reduction from original).

COMPUTERIZED PLOTTING OF DISCONTINUITY POLES

The mechanical analysis of a rock mass is begun by determining if the discontinuities measured in the field exhibit any preferred orientations. Stauffer (1966) concluded that the best method for performing this task was to plot the field orientation data onto an equal-area projection and examine the plot for clusters. The number of discontinuity measurements needed to characterize a site are a function of the variation in discontinuity orientation. At a site with well defined discontinuities, sixty planes can be considered a practical minimum for characterization (Pincus, 1951). For the general case, Stauffer (1966) suggested plotting planes in increments of one hundred until either a significant pattern emerges or two thousand poles have been plotted. Plotting this amount of data by hand is tedious and error prone, particularly if plots of data subsets (ie. only clay filled joints) are required. The program PLOT was written to alleviate these difficulties by plotting the equal-area projection of a data file containing planar orientations (see chapters 3 & 4).

PLOT is a fourth generation modification of a program for plotting the equal-area projection of joint poles, entitled B18.plt (Gen-hua Shi, et al., 1984). The original program (B18.plt) proved inappropriate for the desired usage and the subsequent modifications evolved into PLOT. In addition to drawing the equal-area projection of a data set, PLOT also labels the output and calculates the total number of planes plotted.

PROGRAMMING LOGIC FOR PLOT

The program PLOT performs four primary tasks. These are initialization, drawing the reference circle, drawing the projections and labeling the output. After PLOT is called from the main menu, it begins execution by opening communications to the plotter (line 1040). This sets the baud rate (9600) and handshake parameters for the asynchronous communications adapter. When communications are opened, the plotter orients itself to the default coordinate system. This is an X-Y coordinate system with the origin in the lower left hand corner of the paper and the X-axis parallel to the long side of the paper. Incremental measurements in the default coordinate system are made in plotter units of .025mm each (Hewlett-Packard, 1984). This coordinate system is suitable for creating X-Y graphs, but is impractical for the hemispherical projection techniques used in PLOT and subsequent programs (STAT, NET, & GRTCRCLE).

In order for the programs using hemispherical projection to operate efficiently, the coordinate system must be redefined. The program line accomplishing this task (1050) is explained in detail, because it is written in language specific to the Hewlett-Packard plotter.

```
1050  PRINT#1,"IN;RO90;IP;IW;IP3754,5130,6754,8130;SC",0,1,0,1";"
```

The command IN tells the plotter to accept the initialization parameters that follow. The command RO90 rotates the coordinate system by 90 degrees, such that the Y axis is parallel to the long axis of the paper. The remainder of line 1050 defines a transformed coordinate system where one scaled unit is equal to 3000 plotter units. The point 3754,5130 in the default coordinate system is redefined as the origin (X,Y = 0,0), and the point 6754,8130 becomes 1,1. This places the origin at a point slightly below the center of the page, thus leaving sufficient room for labels above the plot. Defining the scaling factor in this manner allows the radius of the reference circle to be set as one, causing that parameter to drop out of all further calculations. Line 1050 is written for standard size A/A4 paper (8.5 x 11). In order to use the larger size B/A3 (11 x 17) paper, line 1040 must be replaced by the line given at the end of the program listing (Appendix B).

With communications to the plotter established, the remainder of the initialization process is relatively straightforward. After the name of the data file for plotting is entered in response to screen prompts, PLOT opens communications to that file. The operator then has the choice of drawing a simple reference circle or an entire polar stereo net. Choosing the polar net will provide a background facilitating measurements, however the net may obscure the poles. Regardless of the choice, an interval for numbering the reference circle must be entered. This number (large step) must be an integer value that is an even divisor of 360, and not less than 10. For example, if 30 is entered for the large step, the reference circle will be numbered as follows: 0, 30, 60, 90, etc.. If the polar net is to be drawn, it will be divided into regions based on the large step and a second interval (small step) that subdivides the large step, figure 5-4 shows a polar net with a large step of 15 degrees and a small step of 5 degrees. Setting the small step equal to the large step causes the small step to be ignored. Initialization is finished by entering pen numbers for the reference circle, poles and labels.

The reference circle is drawn with a radius of one scaled unit. The circumference of the reference circle is then numbered according to the large step, beginning with due north (azimuth = 0). If a polar net was requested, radial lines are drawn from the perimeter of the circle towards the origin according to the step size. PLOT decides how far they will proceed towards the origin so that the center does not become overly cluttered. Concentric circles of radius r are then drawn about the origin using the relationship (after Gen-hua Shi, et al., 1984):

$$r = 2^{.5} * \mathrm{SIN}(\text{--}\frac{D}{2}\text{--})$$

Where D is varied incrementally according to the desired step size. This procedure is then repeated for the subdivisions specified by the small step size, such that previously drawn circles and lines are passed over.

The routine that plots the poles follows a relatively simple logical process. During the sequential handling of records in the data file, the logic process is controlled by the value of the first field (PLANETYPE$) in each record. The values 1,2 or 3 result in the plotting of a pole using the appropriate symbol (dot, triangle, or square). The second and third fields in each record give the dip azimuth and dip of the discontinuity. The X-Y coordinates of the pole are located using the following relationships (after Gen-hua Shi, et al., 1984):

$$r = 2^{.5} * SIN(\frac{dip}{2})$$

$$X = (-r) * COS(azimuth)$$

$$Y = (-r) * SIN(azimuth)$$

After the pole is plotted, the appropriate counter is incremented and the next record read. This process continues until a zero is perceived in the first field, thus indicating that the final record has been read and causing control to be passed to the labeling sequence.

The labeling routine performs three separate procedures, two of which require operator input. First, the total number of each type of plane plotted is automatically printed in the upper left hand corner of the paper. Then the operator is allowed to place up to four lines, with a maximum of sixty characters each immediately below the plot. Since this function is primarily intended for titling the plot, all character strings entered will be automatically centered below the stereo net. The last labeling function allows the operator to place labels of any size at any location on the paper. This is accomplished by moving the pen to the desired location with the plotter cursor controls; then the character size and desired label may be entered in response to the screen prompts. It is important to note that the Hewlett-Packard plotter perceives commas and semi-colons as control characters. If a label is to include either of these, the entire character string must be enclosed in quotation marks (ie. "January 5, 1987" will appear as: January 5, 1987). After labeling is completed, the plot is finished and control passes back to the main menu.

PSEUDOCODE FOR PLOT

```
Initialize execution
    set constants
    open communications to plotter as #1
    initialize plotter (rotation, paper center, scaling)
    accept name of file for plotting
         open file as #2
         field buffer
    accept plot type
         1 - reference circle only
         2 - polar net
    accept plot parameters
         divisions for reference circle (and net)
         pen number for reference circle (and net)
         pen number for poles
         pen number for labels

Draw reference circle
    select appropriate pen
    draw circle radius 1 about center
    number perimeter according to division choice
    if reference circle only jump to *
         draw major divisions of polar net
         select appropriate pen
         draw subdivisions of polar net

* Draw projection of poles
    select appropriate pen
+   read record
         if plane type = "0" jump to #
    use dip & azimuth to calculate location of pole
         move pen to location
         on plane type
              1 - draw dot
              2 - draw triangle
              3 - draw square
              add 1 to appropriate counter
    add 1 to record number
    loop to +

# Label plot
```

```
set constants
    select appropriate pen
    print labels below net
         display prompt for label entry
         count length of label
         center under net and print label
    print total number of poles plotted
         for each of the 3 plane types
              check number of poles plotted
              if > 0 print in the upper left hand corner

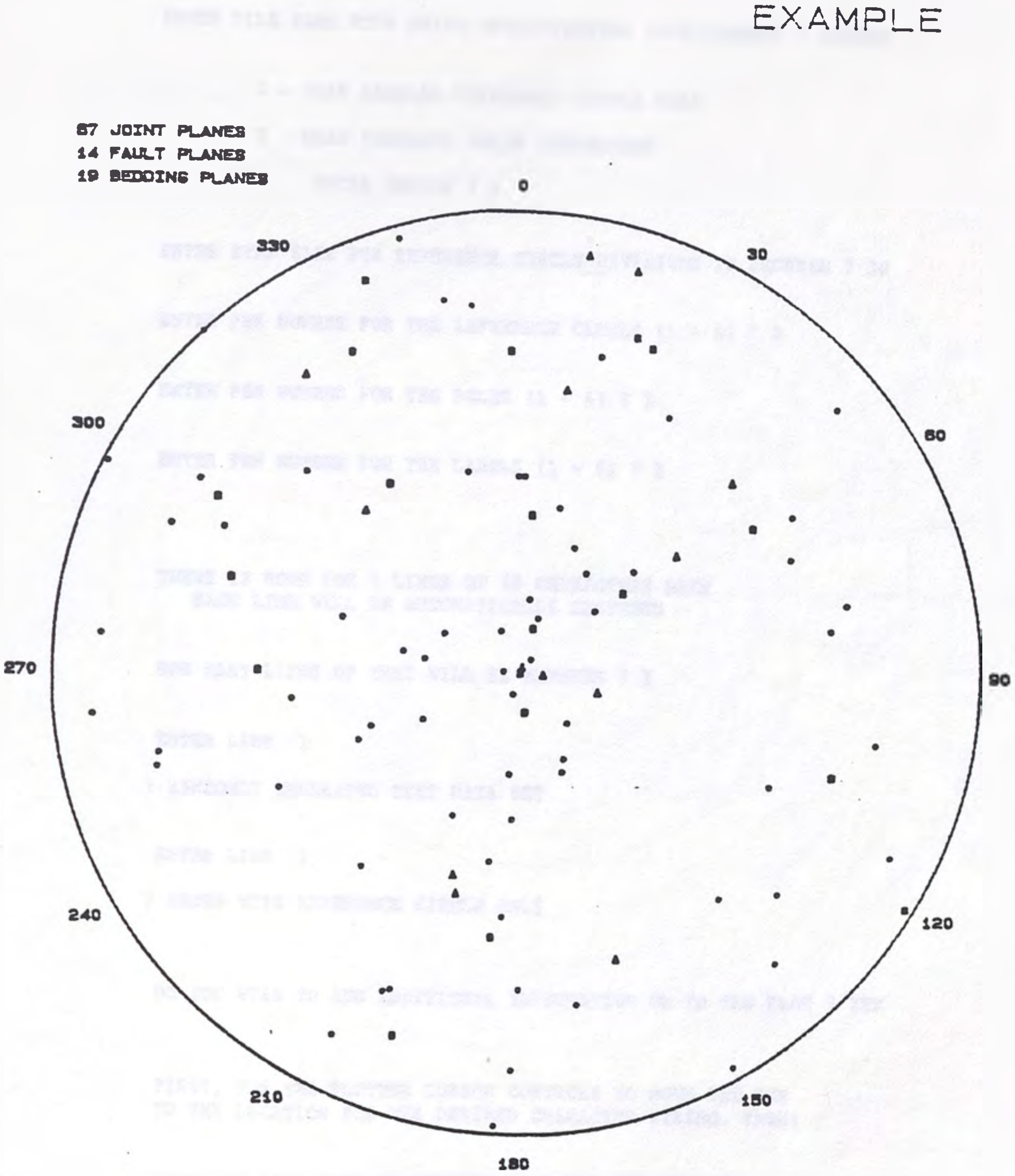
Print additional labels
@   if not desired jump to %
    display prompts for:
         1 - move pen to desired location
         2 - accept letter size for labels
         3 - accept actual label
    print label
    loop back to @

% Closing sequence
    close channels to #1 and #2
    chain to main menu
```

__RUNNING THE PROGRAM PLOT__

In this section the process for obtaining a plot from a pre-existing data file will be demonstrated with the aid of examples. In order to illustrate all of the capabilities of PLOT, a completely random data file was used for the first example. This random file was created by replacing the keyboard data entry sequence in the program CREATE with a random number generator. The resultant data file, RANDOM, contains a total of 100 records representing joint, fault, and bedding planes that are randomly oriented in space. Figure 5-5 shows the file RANDOM plotted onto a reference circle that is numbered in 30 degree intervals. Also, an additional label (EXAMPLE) was placed on this plot in the upper right hand corner. The corresponding operator input required to produce this plot is shown as figure 5-6. The total execution time required to perform this task was less than seven minutes. However, the operator was only necessary for the small amount of time required to ready the plotter and input the information shown on the screen dumps.

Data for the second example consists of field orientation measurements collected at Emerald Bay. Field investigation of the rock slide was conducted in September of 1986 with an emphasis on measurement of discontinuity planes. A total of 315 discontinuity measurements were made at this site, the poles of the measured planes are plotted in figure 5-7. For this example, a polar stereo net was superimposed on the data plot in order to aid in the determination of primary discontinuities. It can be readily seen that there is a persistent joint set that has an approximate dip of 40 degrees in a direction of 45 degrees. It is also evident that there are two additional joint clusters that bear investigation (Chapter 6). This plot was generated using the input shown in figure 5-8; the total execution time including labeling was twenty minutes.



RANDOMLY GENERATED TEST DATA SET
SHOWN WITH REFERENCE CIRCLE ONLY

FIGURE 5-5

Random data plotted on to a reference circle with an additional label (EXAMPLE, 10% reduction).

```
ENTER FILE NAME WITH DRIVE SPECIFICATION (B:FILENAME) ? RANDOM

          1 - DRAW LABELED REFERENCE CIRCLE ONLY

          2 - DRAW COMPLETE POLAR STEREO-NET

              ENTER CHOICE ? 1

ENTER STEP SIZE FOR REFERENCE CIRCLE DIVISIONS IN DEGREES ? 30

ENTER PEN NUMBER FOR THE REFERENCE CIRCLE (1 - 6) ? 3

ENTER PEN NUMBER FOR THE POLES (1 - 6) ? 3

ENTER PEN NUMBER FOR THE LABELS (1 - 6) ? 3


THERE IS ROOM FOR 4 LINES OF 60 CHARACTERS EACH
   EACH LINE WILL BE AUTOMATICALLY CENTERED

HOW MANY LINES OF TEXT WILL BE ENTERED ? 2

ENTER LINE  1

? RANDOMLY GENERATED TEST DATA SET

ENTER LINE  2

? SHOWN WITH REFERENCE CIRCLE ONLY


DO YOU WISH TO ADD ADDITIONAL INFORMATION ON TO THE PLOT ? YES


FIRST, USE THE PLOTTER CURSOR CONTROLS TO MOVE THE PEN
TO THE LOCATION FOR THE DESIRED CHARACTER STRING. THEN:


CHARCTER SIZE MUST BE ENTERED AS WIDTH AND HEIGHT
THE SIZE OF THE STEREO-NET LABELS IS (1.6,2) AND THE BOTTOM
LABELS ARE (2.6,3.1). ENTER (WIDTH,HEIGHT) ? 4,4.5

ENTER THE DESIRED CHARACTER STRING ?
? EXAMPLE

DO YOU WISH TO ENTER MORE INFORMATION ? NO
```

FIGURE 5-6

Operator input required to produce figure 5-5.

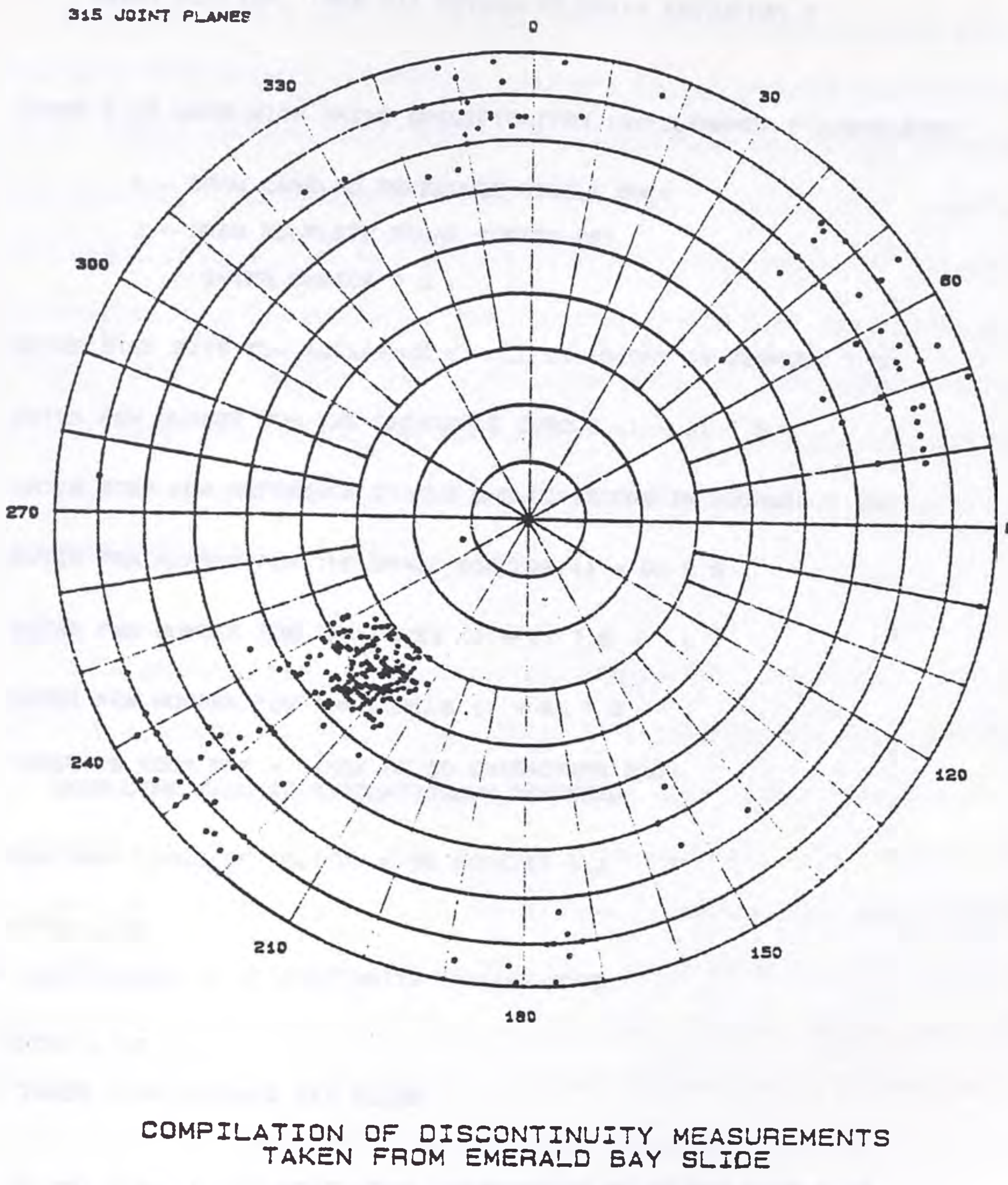


Figure 5-7

Field data from Emerald Bay superimposed onto a polar stereo net (10% reduction).

```
READY PLOTTER, THEN HIT RETURN TO BEGIN EXECUTION ?

ENTER FILE NAME WITH DRIVE SPECIFICATION (B:FILENAME) ? A:EMRLDSRT

     1 - DRAW LABELED REFERENCE CIRCLE ONLY

     2 - DRAW COMPLETE POLAR STEREO-NET
          ENTER CHOICE ? 2

ENTER STEP SIZE FOR REFERENCE CIRCLE DIVISIONS IN DEGREES ? 30

ENTER PEN NUMBER FOR THE REFERENCE CIRCLE (1 - 6) ? 5

ENTER STEP FOR REFERENCE CIRCLE SUB-DIVISIONS IN DEGREES ? 10

ENTER PEN NUMBER FOR THE SMALL CIRCLES (1 - 6) ? 5

ENTER PEN NUMBER FOR THE POLES (1 - 6) ? 5

ENTER PEN NUMBER FOR THE LABELS (1 - 6) ? 5

THERE IS ROOM FOR 4 LINES OF 60 CHARACTERS EACH
  EACH LINE WILL BE AUTOMATICALLY CENTERED

HOW MANY LINES OF TEXT WILL BE ENTERED ? 2

ENTER LINE  1

? COMPILATION OF DISCONTINUITY MEASUREMENTS

ENTER LINE  2

? TAKEN FROM EMERALD BAY SLIDE

DO YOU WISH TO ADD ADDITIONAL INFORMATION ON TO THE PLOT ? NO
```

Figure 5-8

Operator input required to produce figure 5-7.

CHAPTER 6 - STATISTICAL ANALYSIS OF DISCONTINUITY CLUSTERS

Even data from sites that exhibit well defined discontinuity planes will show some degree of scatter (figure 6-1). In such heterogeneous media, design criteria is often based on a mean or average value for discontinuity orientation. This chapter deals with various methodologies that may be applied in order to determine the preferred orientation of a discontinuity set. Scatter in the data may result from either variance within the sample population or measurement errors. Because these two sources of deviation are statistically inseparable, it will subsequently be assumed that all scatter is the result of variance within the sample.

It is obvious from observation of figure 6-1 that this data set exhibits a preferred orientation. There is a definite clustering of the data points, indicating the existence of a mean plane dipping in a northeasterly direction. The first consideration with regards to analysis of this cluster, is to verify its existence. In other words, it must be shown that this particular group of data points differs significantly from a random distribution. This evaluation is important because there is a tendency to visualize clusters where none actually exist. Although there is little question regarding the existence of a preferred orientation in the data shown in figure 6-1, such clarity is not always the case. Once the existence of a cluster is established, then the next step is to determine the center, or mean, of the cluster.

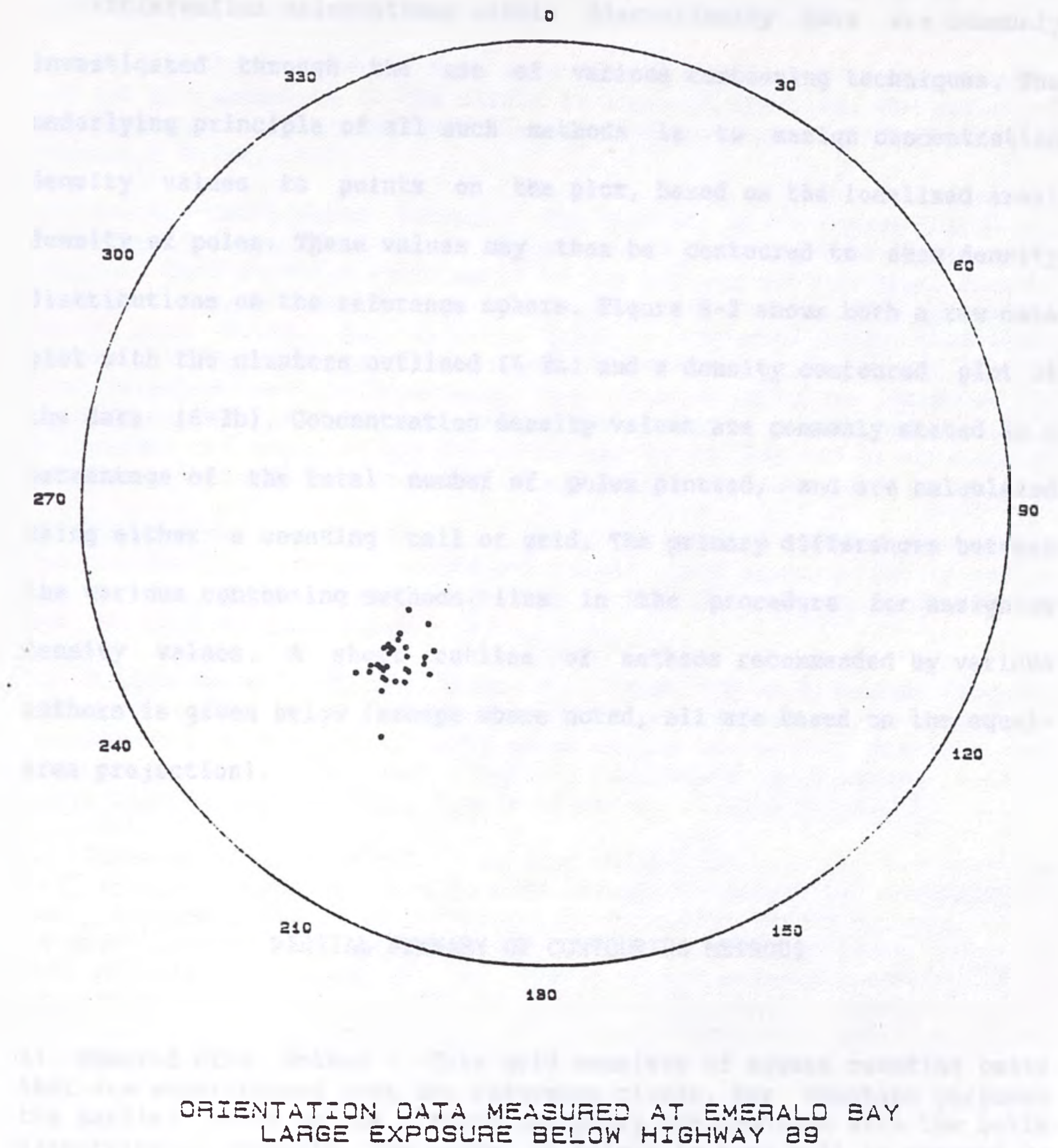


Figure 6-1

Example data set showing a well defined joint cluster (reduced 10% from original size as drawn by PLOT).

CONTOURING OF DISCONTINUITY DATA

Preferential orientations within discontinuity data are commonly investigated through the use of various contouring techniques. The underlying principle of all such methods is to assign concentration density values to points on the plot, based on the localized areal density of poles. These values may then be contoured to show density distributions on the reference sphere. Figure 6-2 shows both a raw data plot with the clusters outlined (6-2a) and a density contoured plot of the data (6-2b). Concentration density values are commonly stated as a percentage of the total number of poles plotted, and are calculated using either a counting cell or grid. The primary differences between the various contouring methods lies in the procedure for assigning density values. A short outline of methods recommended by various authors is given below (except where noted, all are based on the equal-area projection).

PARTIAL SUMMARY OF CONTOURING METHODS

1) Squared Grid Method - This grid consists of square counting cells that are superimposed over the reference circle. For counting purposes the partial cells on the circles periphery are combined with the cells diametrically opposite. The number of points in each cell is assumed to occur at the center of the cell. This method partially compensates for its obvious inaccuracies by the ease and speed with which it may be used (Stauffer, 1966).

2) Schmidt Method - The number of points within a circular counting cell (typically 1% of the area of the reference circle) are tallied at each intersection of a square grid which is superimposed over the reference circle (Billings, 1972).

3) Floating Circle Method - After determining a suitable contour interval, a 1% area circular counting cell is moved about the reference circle in a manner such that it always contains the number of points required for that interval. The path traced by the center of the counting cell defines a contour line (Hoek & Bray, 1981).

4) Mellis Circle Method - A 1% area circle is centered over each pole, and the circumference of the circle is drawn on the plot. The number of overlapping circles at arbitrarily located points is then contoured (Turner & Weiss, 1963).

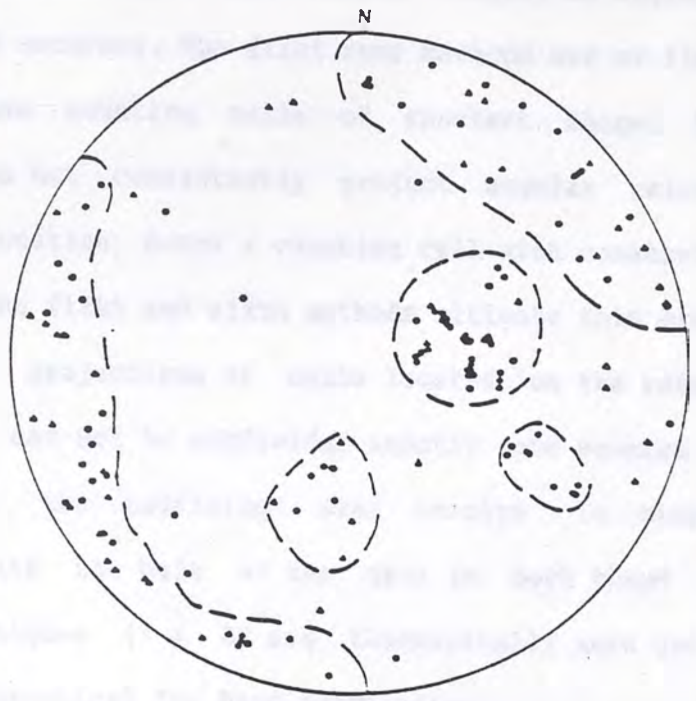
5) Denness Curvilinear Method - The Denness grids (types A & B) are equal area projections of a reference sphere divided into square regions, each of which contains 1% of the spheres surface area. Because a sphere can not be exactly subdivided into squares, some irregular areas must exist. The Type A grid is designed such that these irregularities will not adversely effect contouring of steeply dipping discontinuity sets. Conversely, the Type B grid is intended for contouring shallowly dipping planes. The number of points in each cell is assumed to occur at the cells center. Contouring may be enhanced by rotating the grid to create additional points (Denness, 1972).

6) Triangular Grid Method - Similar to the Denness method except that the projections are of triangles, rather than squares. The triangles are sized such that six of them form a hexagon comprising 1% of the spheres surface area (Ragan, 1973).

7) Mellis Variable-Circle Method - This method is different from the others mentioned in that it uses the equal-angle projection. Points are counted within a circular cell whose radius varies with distance from the center of the plot, such that it maintains a constant area of projection on the reference sphere (Stauffer, 1966 & Mellis, 1942).

8) Variable-Ellipse Method - In this method the shape of the counting cell changes, while the area remains constant. Along the periphery of the reference circle the counting cell is modeled as an ellipse; as it is moved inward, the eccentricity of the cell decreases until it attains circular form at the center of the reference circle. It is important to note that an ellipse is not a completely accurate model; the true equal-area projection of a circle takes the form of a fourth order curve (Stauffer, 1966).

a)



b)

Figure 6-2

a) Discontinuity data, with regions of significant clustering outlined.

b) The same data after contouring (after CANMET, 1977).

The above techniques are listed roughly in increasing order of complexity and accuracy. The first four methods are of limited accuracy since they use counting cells of constant shape. The equal-area projection does not consistently project angular relationships with variation in location, hence a counting cell with constant shape is not appropriate. The fifth and sixth methods mitigate this problem by using the equal-area projections of cells located on the reference sphere. Since a sphere can not be subdivided exactly into squares or triangles, projection of the remaining area results in shapes that are inconsistent with the bulk of the grid in both shape and area. The remaining techniques (7 & 8) are theoretically more correct, but are obviously not practical for hand calculation.

The contouring methods listed above are all labor intensive processes in which a great amount of time and effort is required to produce meaningful output. Unfortunately, contouring is an interpretive art rather than an exact science. This has greatly hindered the development, and more importantly the acceptance, of computerized contouring techniques.

VECTOR DETERMINATION OF THE MEAN POLE

As noted in the previous chapter, the orientation of a plane can be defined by the lower hemisphere projection of its' normal vector (line OP in figure 6-3). By definition, the length of this vector is equal to the radius of the reference sphere, which for convenience is generally assumed to be unity. The components of a vector, such as line OP, may be expressed using its' direction cosines (CN, CE, CD). The direction cosines for the pole of a plane (figure 6-3) are related to the dip and dip azimuth of the plane by equations 6.1-3 (equations are listed at the conclusion of this section).

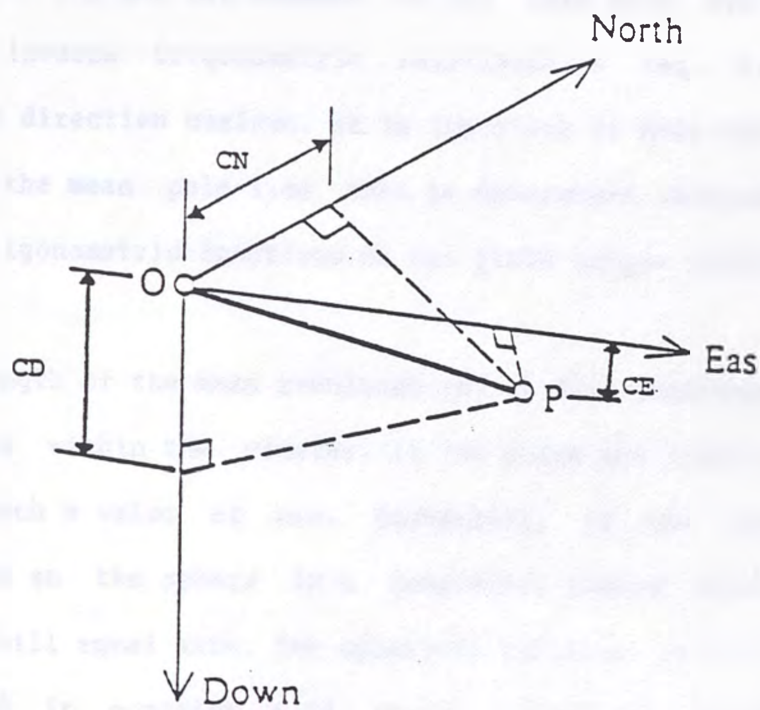


Figure 6-3

Illustration showing the physical significance of the direction cosines CN, CD, & CE.

The mean pole of a discontinuity cluster can be found through vector summation of the poles in the cluster. The mean direction cosines (designated by CNMN, CEMN, & CDMN) are equal to the summation of similar direction cosines, divided by the number of poles (N) in the cluster (eq. 6.4-6, Cheeney, 1983). The length of the resultant (R) of the mean cosines is given by equation 6.7; by definition, the magnitude of R can not be greater than one. However, because it is located on the reference sphere, the mean pole must have a unit length. The direction cosines of the mean pole (designated by LN, LE, & LD) must then be found by normalizing the mean cosines to a vector of unit length (eq. 6.8-10). The dip and dip azimuth of the mean pole are then found by applying inverse trigonometric relationships (eq. 6.11-13) to the normalized direction cosines. It is important to note that the quadrant in which the mean pole lies must be determined independently, as the inverse trigonometric functions do not yield unique solutions.

The length of the mean resultant (R) is also important as a measure of variance within the cluster. If the poles are tightly clustered, R will approach a value of one. Conversely, if the data points are distributed on the sphere in a completely random manner (no cluster exists) R will equal zero. The spherical variance (s^2) of the cluster as defined in equation 6.14 (Davis, 1986) will be used in a later section on the spherical normal distribution.

It is important to remember that the normal to a plane is an axis which may only be treated as a vector quantity in special cases. Data taken from steeply dipping discontinuity sets will typically plot in diametrically opposite clusters on the stereo net. If such data is analyzed in vectorial form, the length of the resultant would be near zero, and the summed direction cosines would indicate a horizontal mean. Treating the same data as axial in nature will indicate the true vertical orientation of the mean.

EQUATIONS USED IN THE DETERMINATION OF THE SPHERICAL MEAN

6.1 $$Y \text{ or } CN = -SIN(dip) * COS(azimuth)$$

6.2 $$X \text{ or } CE = -SIN(dip) * SIN(azimuth)$$

6.3 $$Z \text{ or } CD = COS(dip)$$

6.4 $$CNMN = \Sigma(CN)/N$$

6.5 $$CEMN = \Sigma(CE)/N$$

6.6 $$CDMN = \Sigma(CD)/N$$

6.7 $$R = \{(CNMN)^2 + (CEMN)^2 + (CDMN)^2\}^{.5}$$

6.8 $$LN = CNMN/R$$

6.9 $$LE = CEMN/R$$

6.10 $$LD = CDMN/R$$

6.11 $$dip = ARCCOS(LD)$$

6.12 $$azimuth = ARCSIN\left\{\frac{-LE}{SIN(dip)}\right\}$$

6.13 $$azimuth = ARCCOS\left\{\frac{-LN}{SIN(dip)}\right\}$$

6.14 $$s^2 = (1 - R)$$

POTENTIAL DISTRIBUTIONS ON THE SPHERE

Prior to making statistical inference regarding discontinuity clusters, one must first define the potential distributions that may occur. There are four general classes of distributions that occur in spherical data (Mardia, 1972).

Uniform - No preferential direction exists.

Unimodal - Data points cluster about a single preferred direction.

Bimodal - Two modal clusters exist, the special case where the clusters exhibit both axial and radial symmetry is known as the Bipolar distribution.

Girdle - The data points are distributed in an elliptical pattern about a great circle. Geologic uses of the girdle distribution include petrofabric studies and the reconstruction of tectonic events.

As discussed in the previous section, discontinuity data is axial in nature rather than vectorial. Discontinuity clusters will therefore exhibit a bimodal distribution with axial symmetry. Each cluster observed in a lower hemisphere projection, will have a reflection in the upper hemisphere. While it is only necessary to determine a mean pole for the lower hemisphere cluster, it is essential that upper hemisphere points belonging to that cluster be included. If there is no preferred orientation in the data (no significant clusters exist) the data is assumed to exhibit a uniform distribution.

Assuming that the data consists of points clustered around a mean pole, a model must be selected to describe the shape of the cluster. Four potential models proposed in the literature are described below.

Bingham Distribution - This is a general distribution for three dimensional axial data, it is based on the extraction of eigenvectors from a concentration matrix. The Bingham distribution closely approximates other spherical distributions when the eigenvalue ratios mimic the assumptions made in arriving at those distributions (Mardia, 1972).

One Dimensional Normal Distribution - This assumes that the variation is normally distributed about the mean and occurs in either dip or azimuth, but not both. Proposed usage is for assessing the probability of planar failure along joint sets that trend approximately parallel to a pit wall (CANMET, 1977).

Two Dimensional Normal Distribution - This is appropriate for cases where there is a strong elongation along one of the primary axes (dip or dip azimuth). It is based on the assumption that the deviations along each axis exhibit independent normal distributions (CANMET,1977).

Spherical Normal Distribution - Also known as the Fisher Distribution. The data is assumed to show radial symmetry about the mean. Scatter is thus a function of angular deviation from the mean and a "concentration factor" that can be related to the spherical variance (Watson, 1966).

Even though it approximates a general solution, the Bingham distribution was not chosen for use in this project. The computational procedure required is non-trivial, particularly with regard to extracting the eigenvalues from a 3x3 matrix. This complexity allows the Bingham Distribution to model virtually any type of distribution found on a sphere. The previous assumptions in this project have defined discontinuity data as occurring in point clusters that exhibit axial symmetry, making this complexity unnecessary. In addition, the primary axes of the resultant cone of confidence are not limited with respect to orientation, thus giving the cone a direction as well as size and eccentricity. This greatly complicates the process of comparing populations modeled with a Bingham distribution. Finally, the original goal of this project was to create an uncomplicated system; the computational procedure for the Bingham distribution violates that goal.

The normal distributions, both one and two dimensional, are based on assumptions that render them inappropriate for analysis of discontinuity data. As stated above, the one dimensional normal distribution is an oversimplification intended for a single function. The two dimensional case is able to account for eccentricity in the data, with the directions of eccentricity constrained to the azimuthal and dip directions. This distribution is more relevant for girdle or non-axial bimodal data. Discontinuity data often plots in elliptical clusters, which would appear to indicate that the two dimensional normal distribution is an appropriate model. However, the equal-area projection accentuates eccentricity within the data, particularly for sets of steeply dipping planes, causing clusters that may be circular to appear elliptical.

THE SPHERICAL NORMAL DISTRIBUTION

The spherical normal or Fisher distribution was chosen for use in this project for several reasons. An extensive literature search did not yield any evidence that this distribution was inappropriate for discontinuity analysis. In the literature reviewed, illustrative examples involving discontinuity data most often used the Fisher distribution (Cheeney, 1983, CANMET, 1977, Mahtab, et al., 1972, Mardia, 1972). The cone of confidence generated by the Fisher distribution is radial in symmetry, thus facilitating comparisons between data sets. This is a distinct advantage over the Bingham and two dimensional normal distributions. In addition, the idea of a radial symmetry implied by the Fisher distribution is entirely consistent with the contouring methods currently in use. Therefore, it is not a major departure from the currently accepted methodology.

The Fisher distribution is applicable to clusters exhibiting a point maximum that is defined by the vectorial resultant (mean pole). The probability (P) of finding a pole at an angle between θ and $\theta + d\theta$ from the mean is given by equation 6.15, which is rotationally symmetric about the true mean (CANMET, 1977). The parameter k is called the concentration factor, and is generally unknown. A maximum likelihood estimate for k can be obtained by iterative solution of equation 6.16 (Watson, 1982). Direct solution of equation 6.17 provides a reasonable approximation of k for values of R greater than 0.65 (after Watson, 1982). Cheeney (1983) defines the cone of confidence as an angle (θ) about the mean pole (eq. 6.18). The confidence level (a) is the decimal equivalent of the level of significance (ie. for a 90% level of significance, a = .9). Physically, the cone of confidence implies that at the stated level of significance, one can be assured that the true mean is within the calculated angular deviation from the sample mean. The size of this cone is a function of R, and serves as an empirical indicator of the clusters' significance, relative to a random distribution of points. Although it is possible to perform spherical analysis by hand, using either a calculator or the Braitsch overlay (CANMET, 1977), the process is much more amenable to computer solution.

<u>EQUATIONS FOR THE FISHER DISTRIBUTION</u>

6.15 $$P(\theta) = \left(\frac{k}{4\pi \sinh k}\right) \exp(k \cos \theta)\, d\theta$$

6.16 $$R = \coth(k)(1/k)$$

6.17 $$k = 1/(1-R)$$

6.18 $$\theta = ARCCOS\{1 + Ln(\frac{1 - a}{N * R * k})\}$$

INTRODUCTION TO THE PROGRAM STAT

The program entitled "STAT" is designed to perform three dimensional (spherical) statistical analysis on discontinuity clusters. Using the Fisher distribution, STAT calculates a mean pole and cone of confidence for up to ten designated clusters. The required input is based upon operator delineation of clusters within the data. In order to deduce this information, the operator should use the program PLOT to prepare a stereographic projection of the data set. Before proceeding, an important caution must be noted; STAT will not distinguish between plane types. If the data set to be analyzed contains different plane types in the same vicinity, they should be separated using the program SEARCH.

CLUSTER DELINEATION

The main difficulty (physical and philosophical) with computer contouring methods regards determination of cluster locations. Various programs currently in use, including PATCH (Mahtab, et al., 1972) count points using a grid similar to the Denness, and then test the significance of concentration density in each cell. This methodology raises several major criticisms; the primary being that it completely ignores the interpretive abilities of the geologist making the measurements. Additionally, the existence of a dense cluster may establish statistical criteria that hinders the identification of clusters exhibiting significantly lower concentrations. Finally, using an arbitrarily located counting grid implies that not all locations on the sphere are accorded equal importance (see discussion of contouring methods). STAT avoids these problems by allowing the operator to define the clusters for study.

The input parameters for STAT establish the domain of each cluster on the reference sphere. The input includes an estimated center for each cluster (trial mean), measured in terms of dip and azimuth. For the data in figure 6-1, the cluster center dips approximately 50 degrees in a direction of 225 degrees. The Fisher distribution assumes radial symmetry about the mean pole; for consistency the cluster should also be circular. Therefore, the third piece of information entered will be the surmised radius of the cluster to be studied. After the cluster parameters are entered, STAT establishes their physical location using the equal-angle projection technique (eq. 6.19-21 after Goodman & Gen-hua Shi, 1985). With the cluster defined, STAT then checks the specified data file to determine which poles are located within the cluster (eq. 6.22-23). Due to the axial nature of the data, both the upper and lower hemisphere poles are examined. Those poles that fall within the cluster are then used to determine the orientation of the mean pole and the associated cone of confidence.

EQUATIONS FOR CLUSTER DELINEATION

6.19 $$\text{X-CENTER} = \frac{\text{COS(cluster dip)} * \text{SIN(cluster azimuth)}}{\text{SIN(cluster dip)} + \text{SIN(cluster angle)}}$$

6.20 $$\text{Y-CENTER} = \frac{\text{COS(cluster dip)} * \text{COS(cluster azimuth)}}{\text{SIN(cluster dip)} + \text{SIN(cluster angle)}}$$

6.21 $$\text{RADIUS} = \frac{\text{SIN(cluster angle)}}{\text{SIN(cluster dip)} + \text{SIN(cluster angle)}}$$

6.22 $$\text{X-COORD} = \text{SIN(azimuth - 180)} * \text{TAN}\{45 - \frac{(90 - \text{dip})}{2}\}$$

6.23 $$\text{Y-COORD} = \text{COS(azimuth - 180)} * \text{TAN}\{45 - \frac{(90 - \text{dip})}{2}\}$$

ADDITIONAL INFORMATION ON STAT

The delineation of clusters is the only complicated logic used in STAT, the rest of the program merely solves the previously discussed equations regarding location of the mean pole and the cone of confidence. The only remaining operator entry required is the level of significance (confidence level) to be used in calculation of the cone of confidence. Selection of an appropriate level of significance is dependent on the intended use of the results; it should be based on the human or monetary cost of an error. Because the selection of the confidence level can have a major effect on the results, it should be determined prior to analysis. Choosing a confidence level after initial analysis or comparing populations evaluated at different confidence levels gives the appearance of manipulating the data set.

There are three potential output destinations for the results of calculations: screen display, line printer or plotter. All three output devices will state the orientation of the plane associated with the mean pole and the related cone of confidence. The screen and line printer provide additional information that can be of great assistance in preliminary investigations. The additional output from these devices includes the input parameters and the number of planes in each designated cluster. In order to facilitate comparisons with the calculated mean plane, the input parameters for the cluster center are expressed in the output as a planar normal (ie. if a cluster center was input as 225, 80 it will appear in the output as 45, 10). This information serves as feedback regarding the effectiveness of cluster delineation. If the plotter output option is chosen, the equal-area projection of the mean poles is drawn onto a reference circle. Due to the limited space on the plot, no numeric information regarding the input data is included. Therefore, the plotter should only be used if one is confident that the proper cluster delineation has been selected.

PSEUDOCODE FOR STAT

```
Initialize execution
    set constants and format lines
    define functions (inverse cosine, inverse sin)
    accept name of file for analysis
         open communications to file as #2
         field the buffer
    enter cluster parameters
         enter the number of clusters for analysis
         for each cluster enter
              cluster center in dip, dip azimuth
              radius of cluster
              confidence level for calculations
```

```
    select output destination
          if screen or line printer jump to @
          open communications to plotter as #1
          accept plot parameters
               numbering for reference circle
                 pen types for circle, poles, labels
@   pause for preparation of output device
          display screen prompt, to continue
          display note on execution time

Statistical analysis of clusters
    count the data file
    perform the following tasks for each cluster
          sum up direction cosines for a cluster
               zero all parameters to be summed
               set check parameters (equal-angle)
                    find X,Y coordinates of cluster center
                    find radius of cluster
               Check all records in data file against cluster
                    find X,Y coordinates of pole (equal-angle)
                    check distance from cluster center
                         if less than radius then jump to *
                         switch to upper hemisphere
                              if greater than radius jump to +
*                   find direction cosines of pole
                         add to total
                         add one to number of poles in cluster
+                   read next record until loop is completed

         determine mean values and cone angle
              find length of the mean vector
              normalize direction cosines to unit radius
              adjust values to fall between 2 & -2 radians
              determine mean dip
              determine mean azimuth
              calculate cone angle for given conf. level

    repeat loop for additional clusters as necessary

Output
    display output on screen
    if hard copy option chosen write to line printer
    plotter drive
          select appropriate pen
          draw reference circle
          number reference circle
          select appropriate pen
          draw in poles for mean planes
               number poles, with number towards center of circle
          label upper corner of paper
               print headings
```

print mean dip, azimuth cone angle & conf. level

Closing sequence
close both communications channels
chain to main menu

RUNNING THE PROGRAM STAT

As previously mentioned, equal-area projection results in a considerable amount of angular distortion, particularly for steeply dipping planes. As a consequence, accurate delineation of cluster boundaries should be treated as a trial and error process. Preliminary runs on the data should be varied in two separate manners: moving the location of the cluster centers and changing the cluster radii. Altering the confidence level does not improve the estimate, it is merely an unethical manipulation of numbers.

After approximating a cluster center for the data in figure 6-1, the cluster radius was investigated, as shown in figure 6-4. The associated operator input is also included (figure 6-5). Altering the surmised radius can have both positive and negative effects on the results. As the cluster size decreases, so does the number of points included. This is beneficial if the most distant points can be considered irrelevant, because eliminating such points narrows the cone of confidence and more accurately defines the mean pole (sets 3 & 4). However, the radius should not be decreased to the point (set 5) where meaningful information is discarded. In set 8 the input parameters are limited to such a degree that the calculated mean plane differs significantly from previous trials. This ability to manipulate the data is both an advantage and disadvantage, in that it allows the operator to fully investigate the data set, but provides a temptation to elicit the desired results.

RESULTS OF CALCULATIONS ON FILENAME, B:BOTTOM

SET #	TRIAL AZIMUTH	TRIAL DIP	SET RADIUS	DATA POINTS	MEAN AZIMUTH	MEAN DIP	CONE ANGLE	CONF. LEVEL
1	45	40	16	33	43.34	39.34	1.36	90.00%
2	45	40	14	33	43.34	39.34	1.36	90.00%
3	45	40	12	32	43.67	38.96	1.24	90.00%
4	45	40	10	31	43.66	39.25	1.20	90.00%
5	45	40	8	29	43.63	39.76	1.10	90.00%
6	45	40	6	25	44.23	40.00	1.02	90.00%
7	45	40	4	17	44.27	40.20	0.99	90.00%
8	45	40	2	4	45.23	40.24	1.06	90.00%

Figure 6-4

Output from STAT illustrating the procedure for delineating the radius of a cluster (20% reduction).

```
HOW MANY CLUSTERS ARE TO BE ANALYZED (1 - 10) ? 8

INPUT DATA FOR CLUSTER NUMBER  1

ENTER AZIMUTHAL COORDINATE OF CLUSTER CENTER ? 225

ENTER DIP OF CLUSTER CENTER, MEASURED FROM THE OUTSIDE ? 50

ENTER RADIUS OF CLUSTER IN DEGREES ? 16

ENTER CONFIDENCE LEVEL FOR CALCULATIONS IN PERCENT ? 90

                         OUTPUT DESTINATIONS

                          1 - SCREEN ONLY
                          2 - LINE PRINTER
                          3 - PLOTTER

              SELECT ONE OF THE ABOVE CHOICES BY NUMBER ? 2

  READY LINE PRINTER, THEN HIT <CR> TO CONTINUE ?

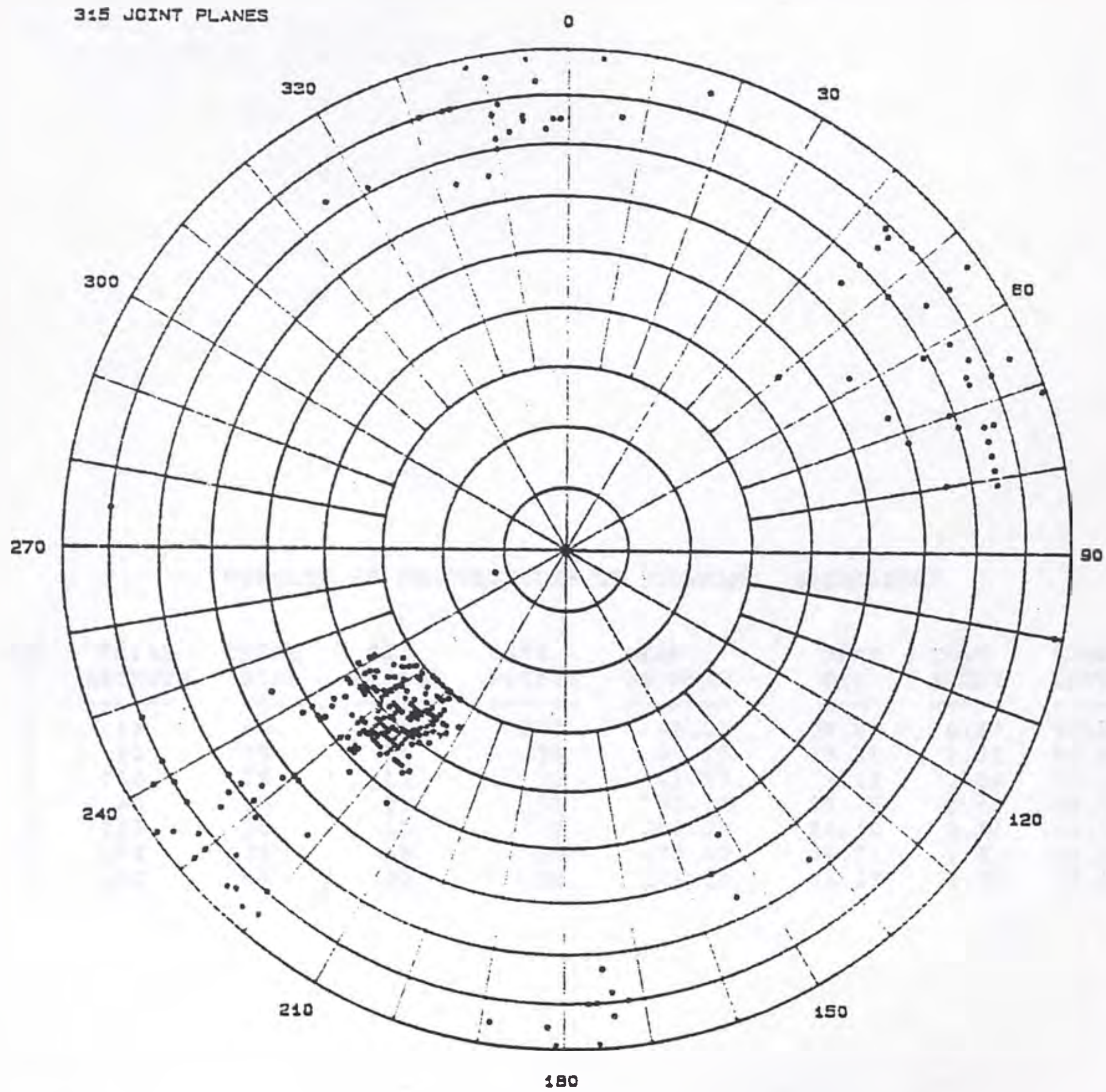


             ********EXECUTION MAY TAKE UP TO AN HOUR********
```

Figure 6-5

Operator input required to produce figure 6-4.

Determination of the mean poles for the compiled orientation data collected at Emerald Bay (figure 6-6) required a much more involved process. There is one obvious cluster in the third quadrant (azimuth = 225, dip = 45) with a radius of approximately 15 degrees. Clustering in other regions of the plot is less evident. There appear to be clusters of steeply dipping planes in both the N-S and NE-SW directions. Extensive preliminary investigations led to the input parameters and results shown in figure 6-7, which are plotted in figure 6-8. This data set may be viewed in two different ways. If one interprets the data as containing three distinct joint sets, then the cluster means are those designated 1, 4, & 7 in figures 6-7 & 6-8. Since this data set is a compilation of measurements taken on the entire site, a better interpretation may be that the primary orientations vary spatially. In such a case the mean poles for the NE-SW sets would be numbers 2 & 3, while numbers 5 & 6 would represent the N-S set. The tighter cone angles associated with the poles 2, 3, 5, & 6 would appear to indicate that there is some spatial trend in the orientation data.



COMPILATION OF DISCONTINUITY MEASUREMENTS
TAKEN FROM EMERALD BAY SLIDE

Figure 6-6

Compilation of discontinuity data collected at Emerald Bay (10% reduction).

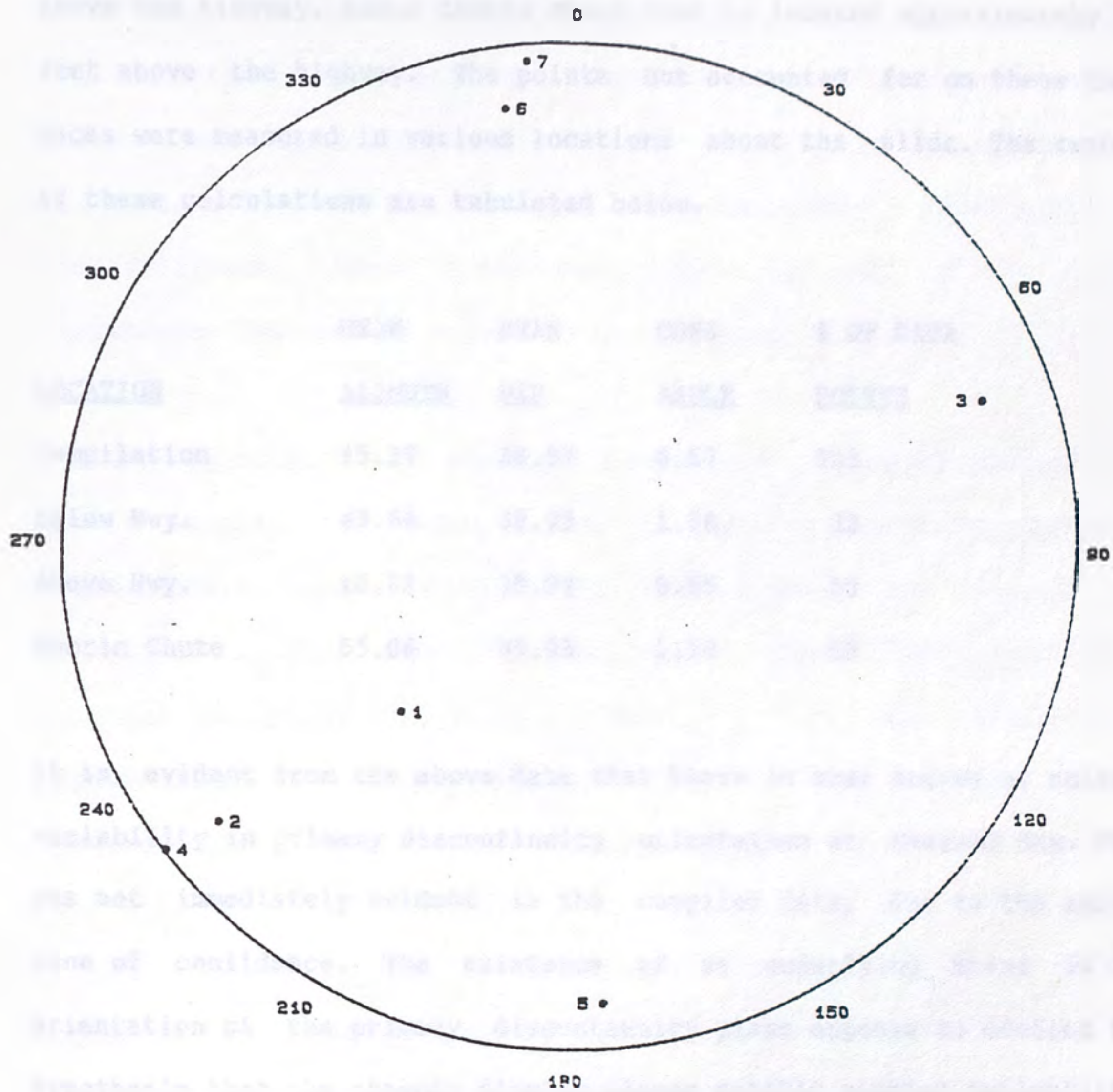
RESULTS OF CALCULATIONS ON FILENAME, B:EMRLDSRT

SET #	TRIAL AZIMUTH	TRIAL DIP	SET RADIUS	DATA POINTS	MEAN AZIMUTH	MEAN DIP	CONE ANGLE	CONF. LEVEL
1	45	40	15	203	45.27	38.97	0.67	90.00%
2	50	75	15	26	51.19	77.21	3.02	90.00%
3	250	75	15	20	249.58	75.19	2.86	90.00%
4	50	90	20	33	52.34	89.75	3.47	90.00%
5	355	80	10	9	355.68	80.10	2.81	90.00%
6	170	75	15	19	170.80	76.74	2.81	90.00%
7	170	90	20	29	174.12	86.23	3.55	90.00%

Figure 6-7

Line printer output of statistical analysis on designated clusters within the data plotted in figure 6-6 (20% reduction).

	MEAN AZIMUTH	MEAN DIP	CONE ANGLE	CONF. LEVEL
1.	45.27	38.97	0.67	90.00
2.	51.19	77.21	3.02	90.00
3.	249.58	75.19	2.86	90.00
4.	52.34	88.75	3.47	90.00
5.	355.88	80.10	2.81	90.00
6.	170.80	76.74	2.81	90.00
7.	174.12	86.23	3.55	90.00



LOCATION OF POTENTIAL MEAN POLES FOR THE COMPILED DATA MEASURED AT THE EMERALD BAY SLIDE

Figure 6-8

Plotter output of the results shown in figure 6-7 (10% reduction).

If the orientation of the steeply dipping planes is changing spatially, then the primary plane (1) should be subjected to a similar examination. This was investigated by comparing data measured at three large exposed faces on the slide; one below Highway 89, one immediately above the highway, and a debris chute that is located approximately 200 feet above the highway. The points not accounted for on these three faces were measured in various locations about the slide. The results of these calculations are tabulated below.

LOCATION	MEAN AZIMUTH	MEAN DIP	CONE ANGLE	# OF DATA POINTS
Compilation	45.27	38.97	0.67	203
Below Hwy.	43.66	39.25	1.20	33
Above Hwy.	40.67	35.94	0.95	53
Debris Chute	55.06	39.05	1.10	13

It is evident from the above data that there is some degree of spatial variability in primary discontinuity orientation at Emerald Bay. This was not immediately evident in the compiled data, due to the narrow cone of confidence. The existence of an underlying trend in the orientation of the primary discontinuity plane appears to confirm the hypothesis that the steeply dipping planes exhibit spatial variability.

CHAPTER 7 - STABILITY ASSESSMENT

In order to evaluate a discontinuous rock mass with respect to the stability of a free surface, an appropriate model must be developed. A model may be defined as a mathematical, graphical or physical representation, which simplifies description of the original system. The use of a particular model can only be justified if the underlying assumptions on which it is based are applicable to the field situation. The intricate, three dimensional nature of rock slides greatly complicates the task of selecting an appropriate model.

The emphasis of this study is to identify potential instabilities for a sloping free surface, rather than evaluate the mechanisms responsible for an existing slide. This mandates the selection of a general model that is not directed towards the failure mechanisms or material parameters present at a single site. After using the programs described in this chapter to identify potential instabilities, further evaluation using more complex models may be warranted.

POTENTIAL FAILURE MECHANISMS

The selection of a model must be based on the phenomena to be described, in this case the failure of a rock slope. Hoek & Bray (1981) have subdivided potential failure mechanisms into the following five general classifications:

Circular - The distinctive characteristic of this failure mechanism is that the failure plane is curvilinear in cross section. While circular failure is most often associated with cohesive soils, it is an important consideration in both weakly cemented and highly fractured rock units. As stated in chapter one, circular failures should be treated using standard soil mechanics techniques.

Ravelling - As the name suggests, this process involves the unravelling of intact rock from a slope as a result of weathering. Due to the small amount of material that is typically involved, ravelling is of limited importance as a mechanism for slope failure. The exception to this rule occurs when ravelling leads to massive failure by undercutting an overlying formation. Ravelling is influenced, rather than controlled by discontinuity patterns, as such it will not be covered in this undertaking.

Planar - Planar failure can be conceptually modelled as simple translational movement along an inclined plane. The conditions required for failure of a strictly planar nature are relatively uncommon, causing many engineers to treat it as a special case of wedge failure (Hoek & Bray, 1981).

Wedge - This is a form of translational movement where sliding occurs along the line of intersection between two discontinuities.

Toppling - Toppling occurs when there is a rotational component to failure, as opposed to strictly translational movement. This is the most complex and least understood mechanism of slope failure. It is also the most difficult to model, because the rotational movement of a block about its centroid often occurs in conjunction with translational movement.

In defining the above mechanisms, it was implicitly assumed that each occurs as a separate, distinct process. This is not always the case, as translational and rotational movements quite often appear in the same event. However, in order to produce a viable model it is commonly assumed that failure occurring in a given rock slope is controlled by a single mechanism.

BASIS FOR SELECTING A MODEL

The programs developed in this chapter are intended to provide a useful tool for reconnaissance level investigation of potential slope instability. The models used to describe translational and toppling failures are relatively simplistic in nature. This was done in order to minimize the number of required input parameters, as many of the variables affecting the stability of a rock slope are difficult, if not impossible to accurately quantify. The programs described in this chapter are limited to identification of potential instabilities. If further evaluation is warranted, a deterministic model such as limit equilibrium may be used to assess a factor of safety for a particular slope. However, unless accurate information is available, a more complicated model is worthless.

The models used in this project are based on the geometrical relationships between the discontinuities and a free surface. These planes delineate rigid blocks within the rock mass which may be examined for kinematic feasibility on the basis of their geometrical relationships. Kinematic analysis is concerned with the movement of an object, irrespective of the forces necessary to induce movement. If a particular block can be removed from the slope through the free surface without disturbing any adjacent blocks, it is said to be kinematically feasible. Geometric relationships are essentially scale independent, hence it is not necessary to specify block sizing prior to stability assessment. Identification of kinematically feasible blocks is essential to most models of rock slope stability, and is the primary objective of block theory (Goodman & Gen-hua Shi, 1985).

The only material parameter required for input in the selected models is the friction angle along the relevant discontinuities. The friction angle (ø) is defined within the Mohr-Coloumb strength criteria, as shown in figure 7-1. In conjunction with cohesion (c), it describes the relationship between shear and normal stresses acting on a discontinuity at failure. Unlike cohesion, the effects of the friction angle on stability are independent of contact area, therefore minimizing the need for spatial information on the discontinuities. Because cohesion is ignored, the results of a friction only analysis will tend to be conservative. In addition, minor variations in the friction angle typically will not greatly affect the analysis.

The friction angle can be determined empirically, or from laboratory and insitu testing. The testing procedures required to evaluate friction angle are both time consuming and expensive. The field friction angle is dependent on the surface roughness and the normal stress, this scale dependency greatly hinders accurate assessment of the true friction angle. Hence, in many instances, a conservative estimate of the friction angle based on comparison of field observation to published literature will be acceptable. The rock type found at Emerald Bay is a medium grain granodiorite, Barton (1973) gives values for the basic (residual) friction angle of granite as varying from 29 - 35 degrees. Since basic friction angle refers to laboratory tests performed on smooth diamond sawn faces, field values will be somewhat higher, possibly up to 72 degrees for rough undulating surfaces at low normal stress levels (Barton, 1973). In order to err on the conservative side, an estimated friction angle of 32 degrees will be used to describe the discontinuities at Emerald Bay.

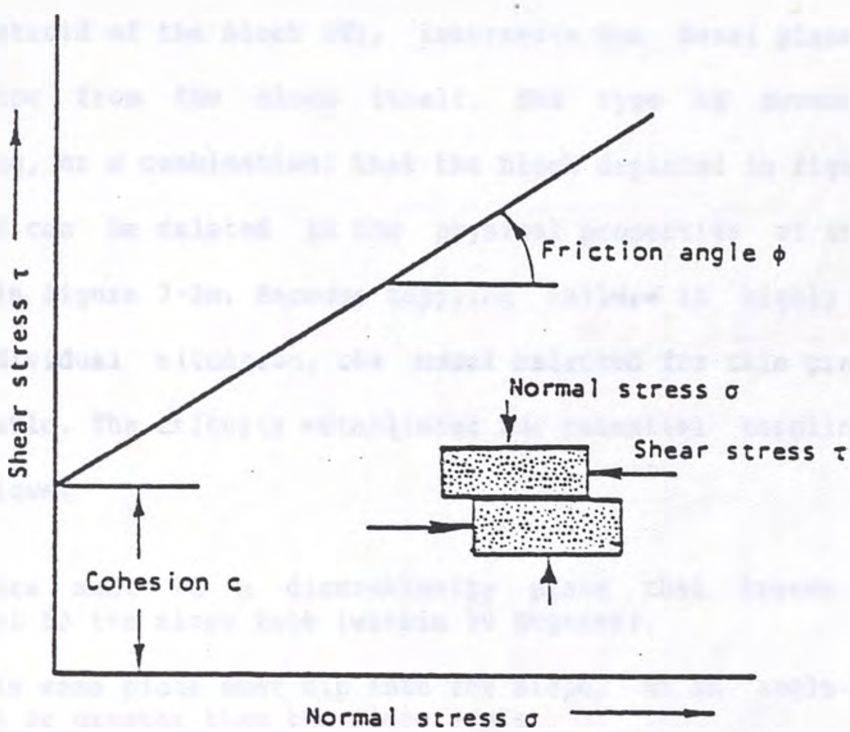


Figure 7-1

Mohr-Coloumb strength criteria, illustrating the relationship between shear and normal stresses at failure (Hoek & Bray, 1981).

TOPPLING FAILURE

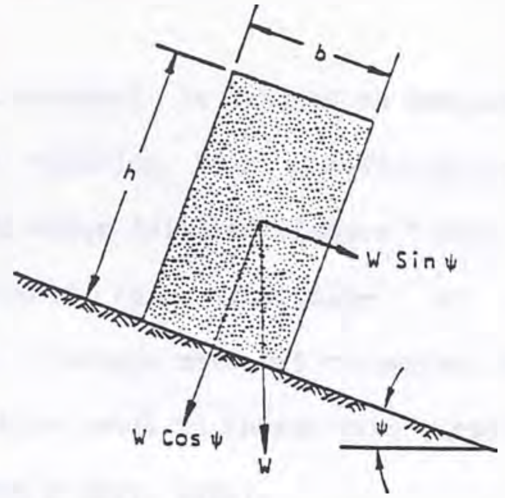
Toppling failure is an extremely complex phenomena. Only in recent years have serious attempts been made to quantify the parameters causing such failure. An idealized toppling model employing a rectangular block on an inclined plane, is shown in figure 7-2a. Toppling occurs when the vector resultant of the forces acting through the centroid of the block (W), intersects the basal plane at a point downslope from the block itself. The type of movement (sliding, toppling, or a combination) that the block depicted in figure 7-2a will undergo can be related to the physical properties of the system, as shown in figure 7-2b. Because toppling failure is highly dependent on the individual situation, the model selected for this project is very simplistic. The criteria established for potential toppling failure is as follows:

1) There must be a discontinuity plane that trends essentially parallel to the slope face (within 20 degrees).

2) This same plane must dip into the slope, at an angle that is the same as or greater than the slope angle.

In the absence of a discontinuity plane meeting these criteria, the potential for toppling failure is low (Watters, R. J., personal communication). The existence of a plane meeting the criteria merely indicates that further evaluation is in order.

a)



b)

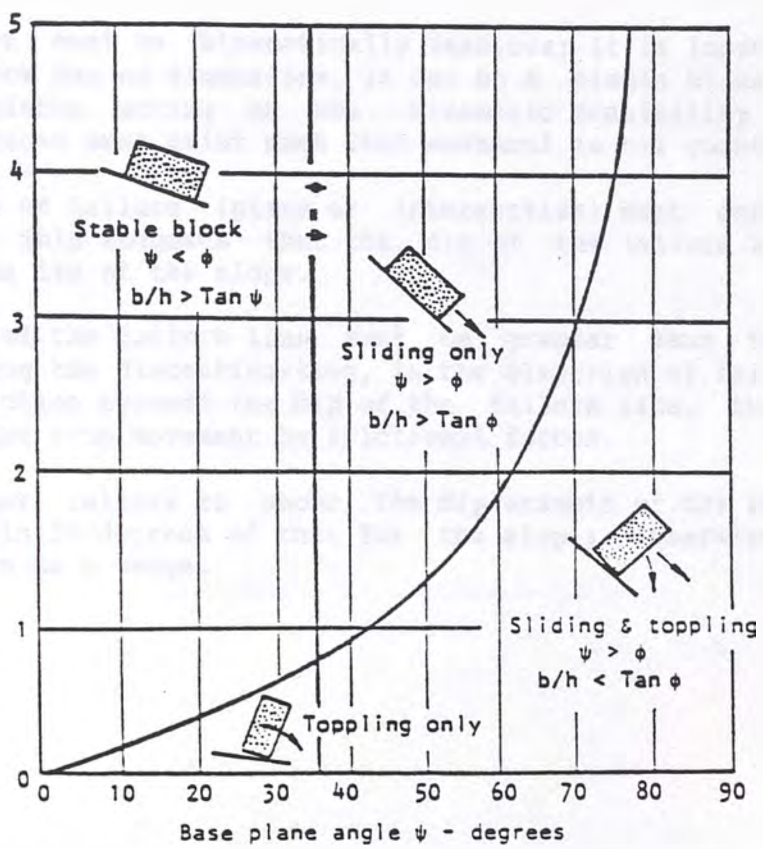


Figure 7-2

a) Geometry of a block on an inclined plane. b) Type of movement, related to physical state of the block (Hoek & Bray,1981).

SIMPLE TRANSLATIONAL FAILURE

Translational movement is defined as movement along a linear path, in the absence of rotation. This classification includes both planar (figure 7-3a) and wedge failures (figure 7-3b). The model used in this analysis is designed for simplicity; it relies on geometric relationships and a single material parameter, the friction angle. The criteria used in this model to investigate slope failure are listed as follows (after Hoek & Bray, 1981).

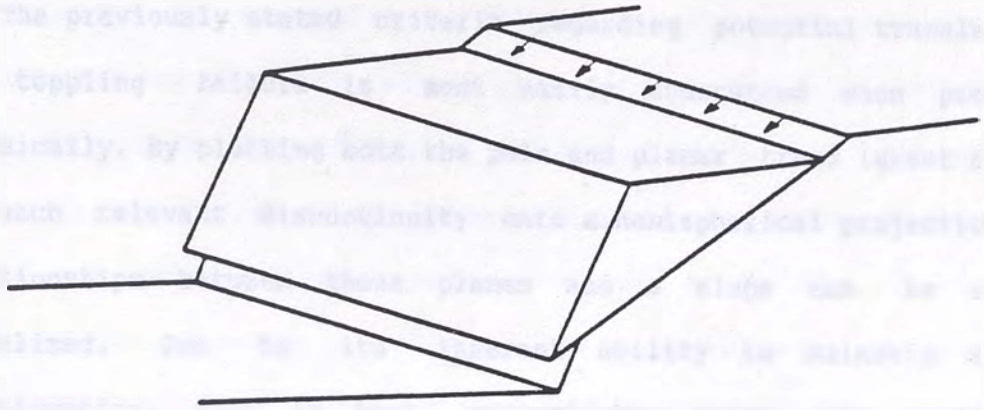
1) The block must be kinematically feasible; it is important to note that the block has no dimensions, it can be a single block or a group of rigid blocks acting as one. Kinematic feasibility implies that release surfaces must exist such that movement is not constrained.

2) The line of failure (plane or intersection) must daylight in the slope face. This suggests that the dip of the failure line, must be less than the dip of the slope.

3) The dip of the failure line must be greater than the angle of friction along the discontinuities, in the direction of failure. If the angle of friction exceeds the dip of the failure line, the block will be constrained from movement by frictional forces.

4) For planar failure to occur, the dip azimuth of the failure plane must be within 20 degrees of that for the slope; otherwise, the block can only move as a wedge.

a)



b)

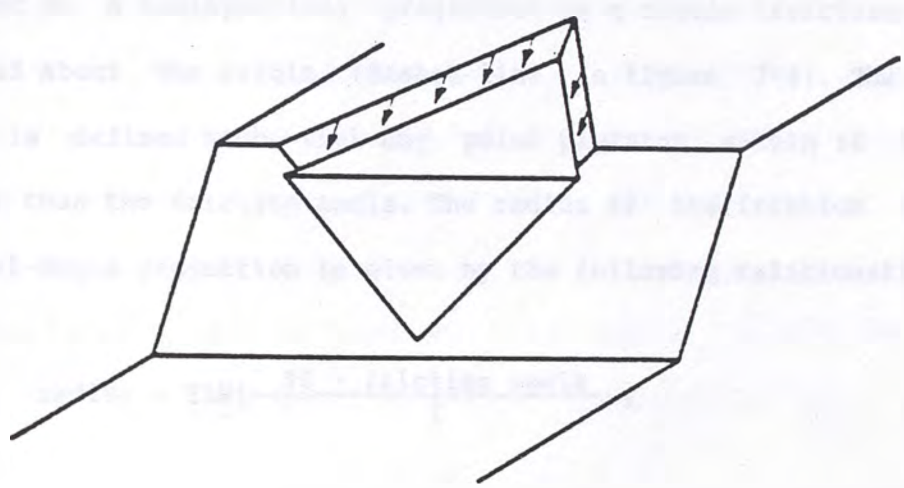


Figure 7-3

Block diagrams depicting: a) planar failure b) wedge failure (after CANMET, 1977).

GRAPHIC ANALYSIS OF STABILITY

The previously stated criteria regarding potential translational and toppling failure is most easily understood when presented graphically. By plotting both the pole and planar trace (great circle) of each relevant discontinuity onto a hemispherical projection, the relationships between these planes and a slope can be readily visualized. Due to its inherent ability to maintain angular relationships, this is best accomplished using the equal-angle projection technique.

In order to analyze a slope with respect to translational failure, the friction angle must be considered. The friction angle can be depicted on a hemispherical projection as a circle (friction circle), centered about the origin (dashed line in figure 7-4). The friction circle is defined such that any point plotting within it has a dip greater than the friction angle. The radius of the friction circle on an equal-angle projection is given by the following relationship:

$$\text{radius} = \text{TAN}\left\{\frac{90 - \text{friction angle}}{2}\right\}$$

In order to illustrate the process for identifying potential instabilities, an arbitrarily selected slope face and friction angle are presented in figure 7-4. Any point that plots outside of the slopes' great circle will have a shallower dip than the slope face; while those plotting inside the friction circle will have a dip exceeding the friction angle. Therefore, all points within the crescent shaped area defined by the friction circle and the slope face satisfy the criteria for translational failure. If the great circles of two discontinuities intersect within this region, there is potential for wedge failure in the direction of the intersection. Potential for planar failure exists if the trace of a great circle passes within this region and strikes within 20 degrees of the slope face. The criteria outlined for potential toppling failure is met if a discontinuity pole plots NE of the slope face, and within 20 degrees of the slopes' line of maximum dip.

Figure 7-5 shows arbitrarily chosen discontinuity planes along with a slope face and friction circle identical to that depicted in figure 7-4. There are three potential instabilities that can be identified in this figure. Plane #1 passes through the region of potential instability and strikes within 20 degrees of the slope face, thus satisfying the criteria for planar failure. The intersection of planes one and two falls in this same region, indicating a potential wedge failure. Finally, pole #4 plots NE of the line of maximum dip for the slope, which indicates that potential for toppling exists.

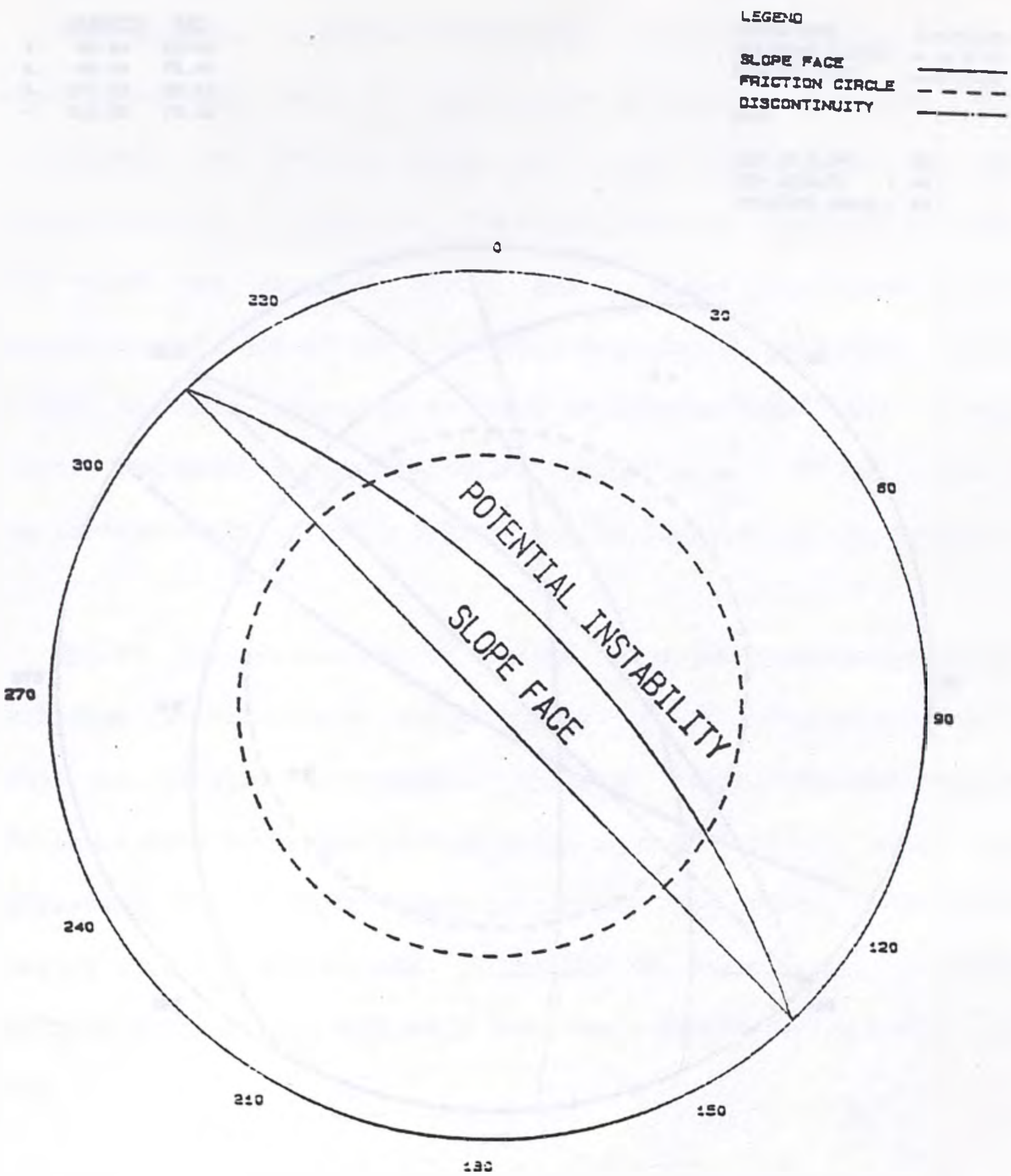


Figure 7-4

Reference circle illustrating the failure area delineated by the slope face, and friction circle.

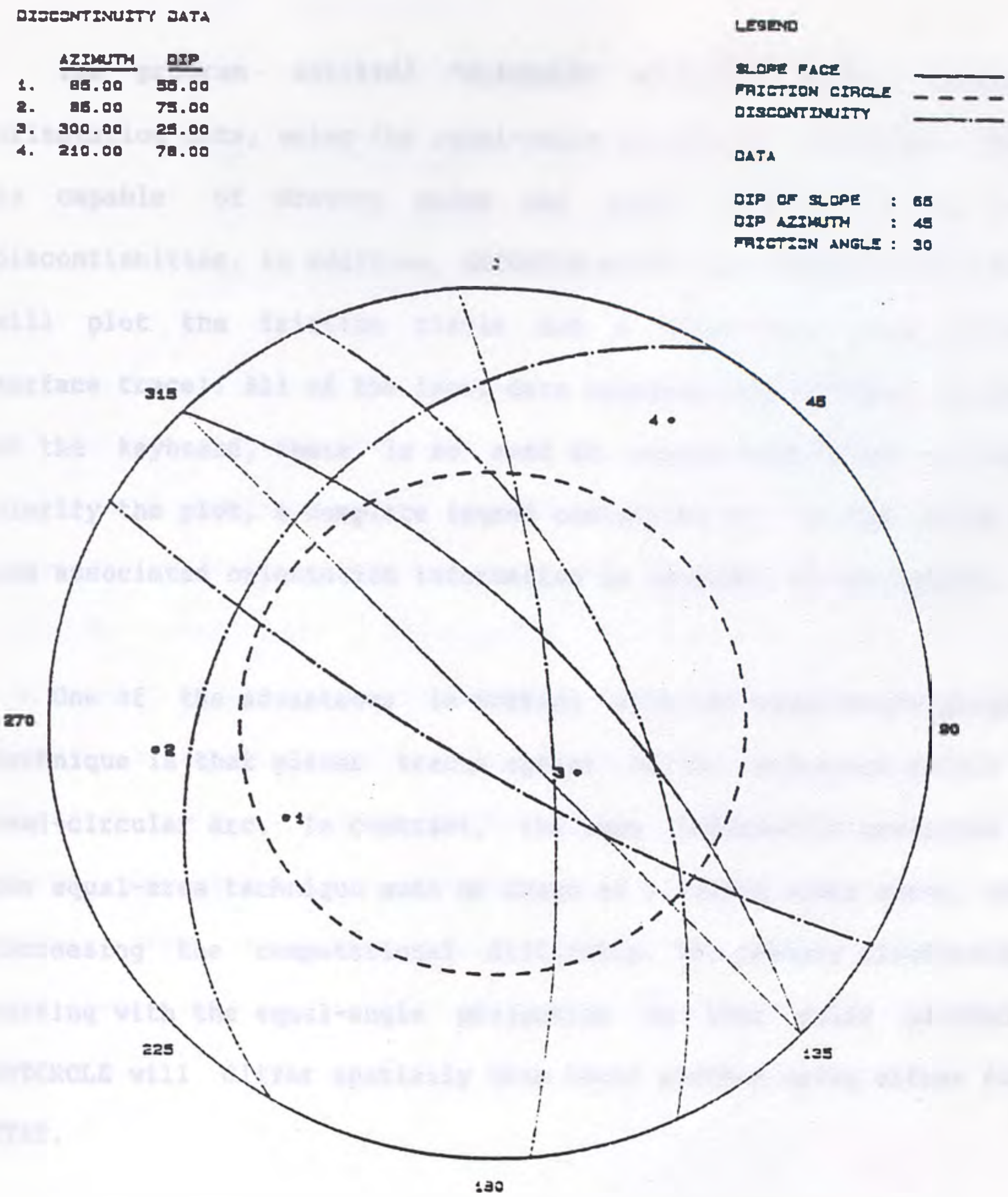


Figure 7-5

Illustrative example for potential failure mechanisms.

INTRODUCTION TO GRTCRCLE

The program entitled "GRTCRCLE" provides graphic display of orientation data, using the equal-angle projection technique. GRTCRCLE is capable of drawing poles and great circles for up to ten discontinuities. In addition, GRTCRCLE gives the operator options that will plot the friction circle and a slope face (great circle and surface trace). All of the input data required for GRTCRCLE is entered at the keyboard, there is no need to create data files. In order to clarify the plot, a complete legend containing all of the plane types and associated orientation information is included in the output.

One of the advantages in working with the equal-angle projection technique is that planar traces appear on the reference circle as a semi-circular arc. In contrast, the same information projected using the equal-area technique must be drawn as a fourth order curve, greatly increasing the computational difficulty. The primary disadvantage of working with the equal-angle projection is that poles plotted with GRTCRCLE will differ spatially from those plotted using either PLOT or STAT.

The critical points required to define a great circle on an equal-angle projection, are shown in figure 7-6. The X & Y coordinates of these points can be related to the dip (β) and dip azimuth (α) of the plane by the following relationships:

$$AX = \cos(\text{azimuth}) = -BX$$

$$AY = -\sin(\text{azimuth}) = -BY$$

$$MX = \sin(\text{azimuth}) * \tan\left(\frac{90 - dip}{2}\right)$$

$$MY = \cos(\text{azimuth}) * \tan\left(\frac{90 - dip}{2}\right)$$

$$CX = -\sin(\text{azimuth}) * \tan(dip)$$

$$CY = -\cos(\text{azimuth}) * \tan(dip)$$

For planes dipping less than 83 degrees GRTCRCLE calculates the location of points A, B, & C, and uses the Hewlett-Packard plotters' internal arc function (arc relative) to draw an arc from point A to point B, using point C as a center. For dips approaching 90 degrees, the radius of the great circle goes to infinity. Unfortunately, the plotter will not recognize any radius beyond a certain length, therefore any plane dipping steeper than 83 degrees will be represented on the plot by a linear approximation (the line A-M-B). When the plane being plotted represents a free surface, the surface trace (A-B) is also drawn in order to help differentiate it from the discontinuity planes.

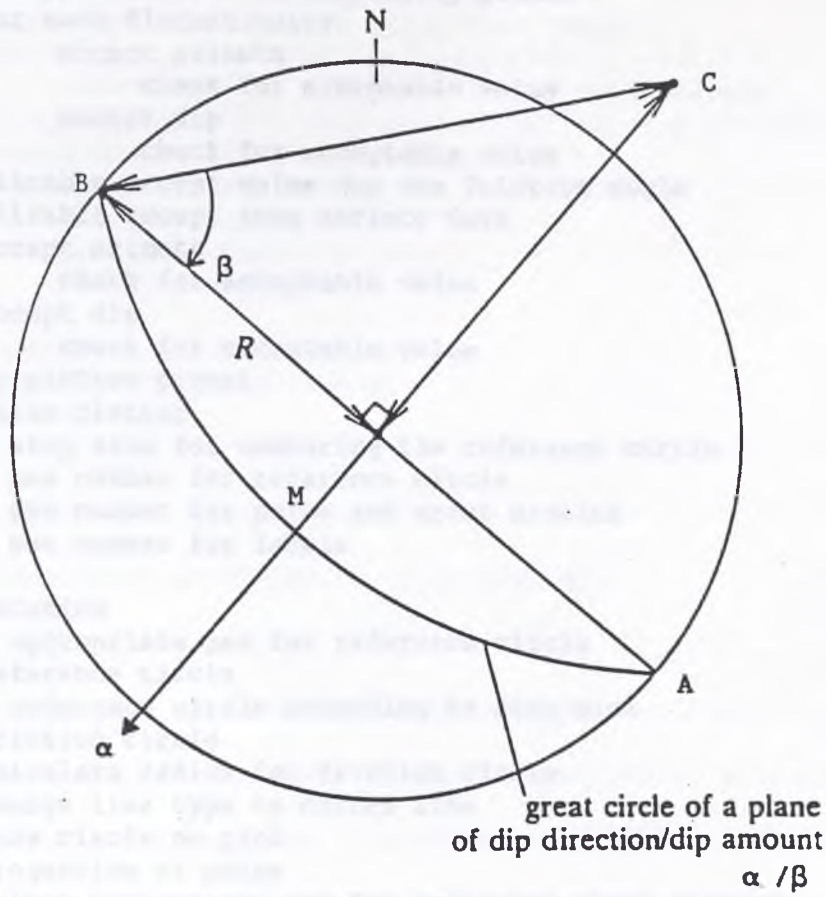


Figure 7-6

Geometry for defining the great circle of a plane with dip azimuth = α and dip = β (after Priest, 1985).

PSEUDOCODE FOR GRTCRCLE

```
Initialization procedure
    define functions and enter constants
    set input parameters
        offer choices regarding type of data for entry
```

```
          set flags for later use
     input discontinuity data
          accept number of discontinuity planes
          for each discontinuity
               accept azimuth
                    check for acceptable value
               accept dip
                    check for acceptable value
     if applicable accept value for the friction angle
     if applicable accept free surface data
          accept azimuth
               check for acceptable value
          accept dip
               check for acceptable value
     display plotter prompt
     initialize plotter
     accept step size for numbering the reference circle
     accept pen number for reference circle
     accept pen number for poles and great circles
     accept pen number for labels
Program execution
     select appropriate pen for reference circle
     draw reference circle
     number reference circle according to step size
     draw friction circle
          calculate radius for friction circle
          change line type to dotted line
          draw circle on plot
     draw projection of poles
          select appropriate pen for poles and great circles
          for each discontinuity plane
               calculate X & Y coordinates for each pole
               draw circles for poles
               number poles, with numbers toward inside of plot
     draw great circles
          change line type to dotted line
          for each discontinuity
               locate center of great circle
               locate line of maximum dip
               locate intersections with reference circle
               if dip > 83 perform a linear approximation A-M-B
                    else   draw   arc   between   intersections   through
                         line of maximum dip
          if free surface is not desired jump to *
               change line type to solid
               locate center and intersections as above
               draw straight line and arc between intersections
               if dip > 83 perform a linear approximation A-M-B
                    else   draw   arc   between   intersections   through
                         line of maximum dip
*    labeling routine
          select appropriate pen for labels
```

```
        print headings in upper left hand corner
        for each discontinuity
             print number, azimuth & dip
        print headings in upper right hand corner
        where appropriate show line types for
             discontinuity, friction circle, free surface
        if applicable print data on free surface and friction
        accept number of lines for title
        for number of lines input
             change character size
             accept character string
             center and print

Closing sequence
    close communications to plotter
    chain to main menu
```

GRAPHICAL ASSESSMENT OF STABILITY AT EMERALD BAY

The information required for a stability assessment includes the friction angle, slope orientation, and discontinuity orientations. As stated earlier in this chapter, the discontinuities at Emerald Bay were assigned a friction angle of 32 degrees. The slope orientation however, should not be evaluated as a single value. The strike of the highway varies from 285 - 327 degrees as it passes through the slide area, the corresponding slope will dip in a direction between 15 and 57 degrees. However, a dip azimuth of 45 degrees is appropriate for the bulk of the slide mass. After benching was completed in 1957, the average slope angle along the center of the slide mass was 32 degrees (Mc Cauley, 1971). Mc Cauley noted that the physical boundaries of the slide were essentially unchanged since 1957 and there is no evidence to indicate that the overall slope has changed since then. Locally, the slope exhibits rather large variations in dip, in particular, many of the benches are cut at angles of 55-60 degrees.

In chapter 6 the mean discontinuity planes encountered at Emerald Bay were analyzed using the program STAT. The results indicate the existence of 3 mean planes for the entire data set, and 7 additional local means. For the purpose of preliminary investigation, all 10 mean discontinuity planes were plotted using GRTCRCLE, along with several slopes spanning the range of relevant values. The resultant plot was so cluttered that it was very difficult to interpret. This was alleviated by plotting only those planes that contained significant information, as shown in figure 7-7 (associated operator input is shown in figure 7-8). It is immediately apparent that a highway cut dipping to the NE will have potential for planar failure along discontinuity set #1, for any slopes steeper than 39 degrees. There is also potential for toppling (see pole 3) for some highway alignments within the specified range. The overall slope dips 32 degrees in an direction of 45 degrees, indicating that failure will not involve the entire slope, but only localized regions.

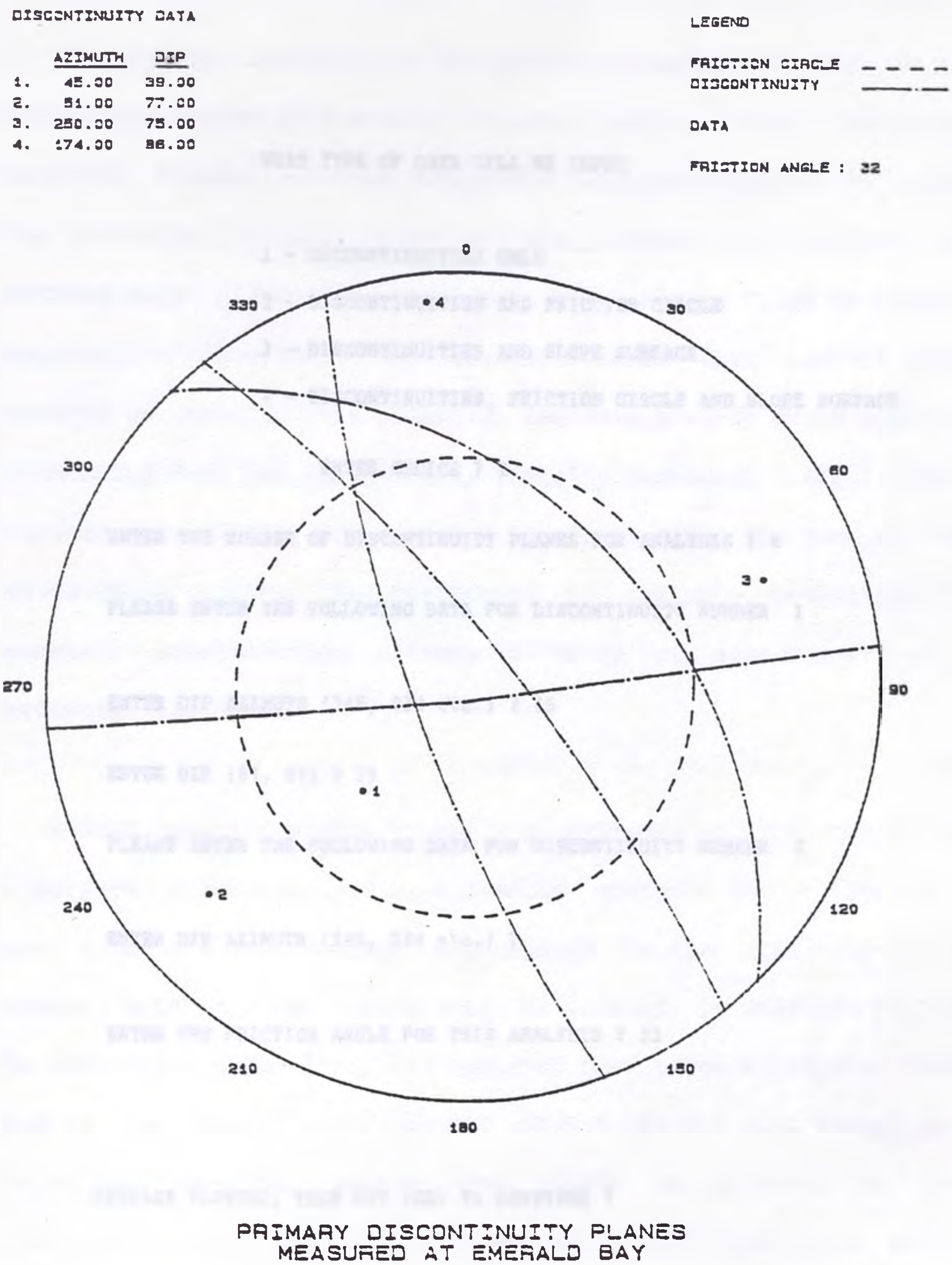


Figure 7-7

Equal-area projection of the significant discontinuity planes measured at Emerald Bay (10% reduction).

```
WHAT TYPE OF DATA WILL BE INPUT

1 - DISCONTINUITIES ONLY
2 - DISCONTINUITIES AND FRICTION CIRCLE
3 - DISCONTINUITIES AND SLOPE SURFACE
4 - DISCONTINUITIES, FRICTION CIRCLE AND SLOPE SURFACE

ENTER CHOICE ? 2

ENTER THE NUMBER OF DISCONTINUITY PLANES FOR ANALYSIS ? 4

PLEASE ENTER THE FOLLOWING DATA FOR DISCONTINUITY NUMBER  1

ENTER DIP AZIMUTH (345, 034 etc.) ? 45

ENTER DIP (87, 07) ? 39

PLEASE ENTER THE FOLLOWING DATA FOR DISCONTINUITY NUMBER  2

ENTER DIP AZIMUTH (345, 034 etc.) ?

ENTER THE FRICTION ANGLE FOR THIS ANALYSIS ? 32


PREPARE PLOTTER, THEN HIT <CR> TO CONTINUE ?
```

Figure 7-8

Operator input required to produce the plot in figure 7-7.

VECTORIAL ANALYSIS OF STABILITY

The primary advantage of the previous graphic analysis, is that it depicts the system in a manner allowing simple visual interpretation; there are however, several drawbacks. Program execution is relatively time consuming, it takes five to ten minutes to complete a plot. GRTCRCLE only allows for the input of a single friction angle, thus complicating description of discontinuities that exhibit different strength parameters. The potential for interpretive error also exists, as GRTCRCLE does not specifically identify potential instabilities, but presents the data for operator interpretation. The program "STABLE" solves these problems by performing an analytic evaluation of the geometric relationships between a group of discontinuities, and a particular slope face.

STABLE uses the simple criteria established earlier in this chapter to perform a friction only, kinematic analysis for a specific slope face. Since all calculations are related to the stability of a free surface, data for the slope must be entered, in addition to that for the discontinuities. Also, the operator must input a friction angle for each of the discontinuity planes entered (STABLE will accept up to 10 discontinuities). The output from STABLE is produced on the line printer in tabular form, and includes all of the input data, along with analyses for kinematically feasible toppling, planar, and wedge failure.

The analysis for planar and toppling failures is very straightforward. For toppling failure STABLE merely checks each discontinuity to see if it fits the failure criteria, and then assigns a yes or no answer. The analysis for planar failure proceeds in much the same manner, each discontinuity is checked to see if it daylights in the design slope and strikes parallel to the slope. In the process of performing this task, STABLE compares all potential failure planes to find the shallowest; for the given orientation, this value then defines the steepest slope that may be cut without daylighting a potential failure plane. Conversely, if none of the discontinuity planes meet the planar failure criteria for a slope of the given orientation, a statement to that effect is included in the output.

Wedge failure involves a somewhat more complex analysis, as it entails defining the line of intersection for each possible combination of discontinuity planes. The direction cosines for the pole of each discontinuity are first determined by using equations 6.1-3 (chapter 6). The line of intersection between two planes is parallel to the cross product of the planar normals (poles). The direction cosines (X,Y,Z) of the cross product are related to the direction cosines of poles 1 & 2 by the following equations:

```
X = (CN(1) * CD(2)) - (CN(2) * CD(1))
Y = (CE(2) * CD(1)) - (CN(1) * CD(2))
Z = (CE(1) * CN(2)) - (CE(2) * CN(1))
```

After the direction cosines (X,Y,Z) are found, they must be normalized by the resultant (R), so that the line of intersection contacts the reference sphere. The trend and plunge of the line of intersection can then be determined from the following relationships:

$$R = (X^2 + Y^2 + Z^2)^{.5}$$

$$\text{plunge} = \text{ARCSIN}(Z/R)$$

$$\text{trend} = \text{ARCCOS}\left(\frac{Y}{R * \text{plunge}}\right)$$

$$\text{trend} = \text{ARCSIN}\left(\frac{X}{R * \text{plunge}}\right)$$

As previously noted in chapter 6, the inverse trigonometric functions do not yield a unique solution, consequently the quadrant of the trend must be determined independently. There will be two possible intersections for each pair of planes (ie. 1 & 2, 2 & 1), hence the plane dipping into the upper hemisphere is discarded.

The wedge stability assessment performed by STABLE is very similar to that for planar failure. If the two discontinuities involved have different friction angles, the smaller value is used in order to assure a conservative result. Potential instability exists when the line of intersection dips steeper than the friction angle, shallower than the slope face, and trends within 90 degrees of the slope azimuth. This analysis locates potential instabilities, however it does not identify the slope angle that would prevent such a wedge from daylighting.

In the analysis of planar failure, any slope cut steeper than the discontinuity exhibiting the lowest angle above the friction angle is termed kinematically feasible. Unfortunately, this is not true for wedge analysis. Figure 7-9 illustrates a hypothetical line of intersection passing from the origin to point I. For a slope dipping in the direction α, the steepest possible dip that prevents intersection OI from daylighting is β. In order to find β, it is necessary to define the radius of the great circle (r) which corresponds to an azimuth of α and passes through point I. This radius is equal to the distance from point A to the center of the great circle (CX & CY), The center of a circle can be located from two points known to be on its circumference (A & I). The process for calculating β is given by the following relationships, where X, Y, & Z are the normalized direction cosines of the line OI (after Goodman & Gen-hua Shi, 1985):

$$AX = COS(\alpha)$$

$$AY = -SIN(\alpha)$$

$$CX = \frac{(-AY * Z)}{(X * AY) - (AX * Y)}$$

$$CY = \frac{(AX * Z)}{(X * AY) - (AX * Y)}$$

$$r = \{(CX - AX)^2 + (CY - AY)^2\}^{.5}$$

$$\beta = ARCCOS(1/r)$$

For a plane dipping in the direction α , any slope steeper than β will allow the line of intersection OI to daylight. STABLE reports the maximum slope for a free surface dipping in the direction α, that prevents the daylighting of any intersections that are steeper than the friction angle.

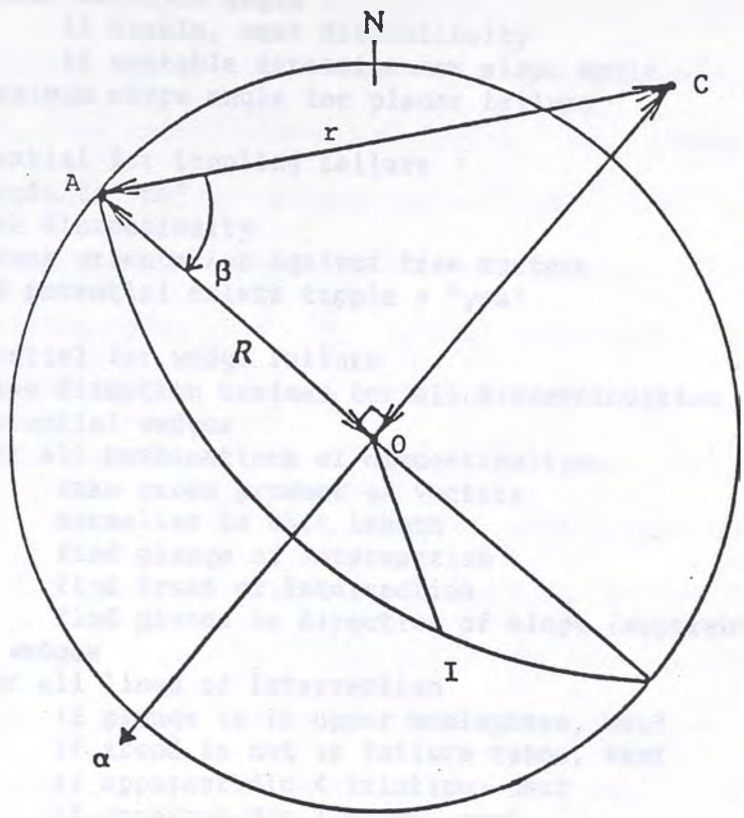


Figure 7-9

Illustration showing the points necessary to find the apparent dip of a line of intersection on a slope face.

PSEUDOCODE FOR STABLE

```
Initialize execution
    set constants
    accept number of discontinuities
         for each plane accept orientation and friction angle
    accept orientation of the free surface
    accept title for the output
    display prompt to prepare line printer
```

```
Assess potential for planar failure
    for each discontinuity
         check orientation against free surface
              if > 20 difference, next discontinuity
         check friction angle
              if stable, next discontinuity
              if unstable determine max slope angle
    find maximum slope angle for planar failure

Assess potential for toppling failure
    set topple to "no"
    for each discontinuity
         check orientation against free surface
         if potential exists topple = "yes"

Assess potential for wedge failure
    determine direction cosines for all discontinuities
    find potential wedges
         for all combinations of discontinuities
              take cross product of vectors
              normalize to unit length
              find plunge of intersection
              find trend of intersection
              find plunge in direction of slope (apparent dip)
    assess wedges
         for all lines of intersection
              if plunge is in upper hemisphere, next
              if trend is not in failure range, next
              if apparent dip < friction, next
              if apparent dip > slope, next
                   max slope = apparent dip

Print results
         print title
         print planar information
              for each discontinuity print
                   data, potential for failure, max slope
              print overall max slope and controlling plane
         print wedge information
              for all potential wedges print
                   planes involved, friction, plunge, trend
                        potential for failure, max slope
              print overall max slope and controlling planes
         print yes or no for potential topple
```

USE OF STABLE ON THE EMERALD BAY DATA

Due to the nature of the discontinuity data at Emerald Bay, STABLE does not provide any new information that was not found through the use of GRTCRCLE. The output shown in figure 7-10 reiterates the results shown in figure 7-7. Any slopes cut steeper than 39 degrees will produce kinematically feasible failure planes, while potential for toppling exists when the dip azimuth approaches 57 degrees. The operator input required to produce figure 7-10 is shown in figure 7-11; the execution time after data entry and prior to printing was 6 seconds. In order to fully investigate this slope, further runs were made using different orientations, as shown in figure 7-12 & 7-13. It was found that overall, the slope is stable with respect to translational failure, but that further investigation of toppling is warranted. Local variations in slope angle may result in planar failure where the dip exceeds 39 degrees, and wedge failure where it exceeds 43 degrees.

PRIMARY DISCONTINUITY SETS AT EMERALD BAY

SLOPE ORIENTATION

DIP AZIMUTH: 57
DIP : 32

KINEMATIC ANALYSIS OF PLANAR FAILURE ALONG DISCONTINUITES

#	DIP AZIMUTH	DIP	FRICTION ANGLE	POTENTIAL FOR PLANAR FAILURE
1.	45	39	32	NO
2.	51	77	32	NO
3.	250	75	32	NO
4.	174	86	32	NO

AT SLOPE ANGLES STEEPER THAN 39.00, A POTENTIAL FAILURE PLANE WILL DAYLIGHT IN THE FACE OF A SLOPE WITH THE GIVEN ORIENTATION

KINEMATIC ANALYSIS OF DISCONTINUITY INTERSECTIONS

PLANES INVOLVED	PLUNGE	TREND	DAYLIGHTS IN DESIGN SLOPE	DAYLIGHTS IF THE SLOPE IS CUT STEEPER THAN
1 & 3	15.91	335.62	NO	90.00
2 & 1	5.93	322.38	NO	90.00
2 & 3	33.49	329.79	NO	85.80
3 & 4	74.99	248.88	NO	90.00
4 & 1	31.26	86.43	NO	90.00
4 & 2	71.82	96.30	NO	75.75

AT SLOPE ANGLES STEEPER THAN 75.75, A POTENTIAL WEDGE FAILURE WILL DAYLIGHT IN THE FACE OF A SLOPE WITH THE GIVEN ORIENTATION

ANALYSIS OF POTENTIAL TOPPLING FAILURE

BASIC CRITERIA INDICATES THAT POTENTIAL FOR TOPPLING EXISTS

Figure 7-10

Results of the program STABLE, on the Emerald Bay data for a dip azimuth of 57 degrees (20% reduction from original).

```
ENTER THE NUMBER OF DISCONTINUITY PLANES FOR ANALYSIS ? 4

PLEASE ENTER THE FOLLOWING DATA FOR DISCONTINUITY NUMBER  1


ENTER DIP AZIMUTH (345, 034 etc.) ? 45

ENTER DIP (87, 07) ? 39

ENTER THE FRICTION ANGLE ALONG THIS PLANE ? 32

PLEASE ENTER THE FOLLOWING DATA FOR DISCONTINUITY NUMBER  2


ENTER DIP AZIMUTH (345, 034 etc.) ? 32

PLEASE ENTER THE FOLLOWING DATA FOR THE FREE SURFACE


ENTER DIP AZIMUTH (345, 034 etc.) ? 57

ENTER DIP (87, 07) ? 32

ENTER A TITLE OF UP TO 60 CHARACTERS FOR THE PRINTOUT
? PRIMARY DISCONTINUITY SETS AT EMERALD BAY


READY THE LINE PRINTER, HIT <CR> TO CONTINUE ?
```

Figure 7-11

Operator input required to produce Figure 7-10.

EMERALD BAY

SLOPE ORIENTATION

DIP AZIMUTH: 15
DIP : 32

KINEMATIC ANALYSIS OF PLANAR FAILURE ALONG DISCONTINUITES

#	DIP AZIMUTH	DIP	FRICTION ANGLE	POTENTIAL FOR PLANAR FAILURE
1.	45	39	32	NO
2.	51	77	32	NO
3.	250	75	32	NO
4.	174	86	32	NO

THE GIVEN SLOPE IS STABLE WITH RESPECT TO PLANAR FAILURE

KINEMATIC ANALYSIS OF DISCONTINUITY INTERSECTIONS

PLANES INVOLVED	PLUNGE	TREND	DAYLIGHTS IN DESIGN SLOPE	DAYLIGHTS IF THE SLOPE IS CUT STEEPER THAN
1 & 3	15.91	335.62	NO	90.00
2 & 1	5.93	322.38	NO	90.00
2 & 3	33.49	329.79	NO	43.21
3 & 4	74.99	248.88	NO	90.00
4 & 1	31.26	86.43	NO	90.00
4 & 2	71.82	96.30	NO	87.16

AT SLOPE ANGLES STEEPER THAN 43.21, A POTENTIAL WEDGE FAILURE WILL DAYLIGHT IN THE FACE OF A SLOPE WITH THE GIVEN ORIENTATION

ANALYSIS OF POTENTIAL TOPPLING FAILURE

BASIC CRITERIA INDICATES THAT POTENTIAL FOR TOPPLING IS LOW

Figure 7-12

Results of the program STABLE, on the Emerald Bay data for a dip azimuth of 15 degrees (20% reduction).

MEAN ORIENTATION OF HIGHWAY 89

SLOPE ORIENTATION

DIP AZIMUTH: 45
DIP : 32

KINEMATIC ANALYSIS OF PLANAR FAILURE ALONG DISCONTINUITES

#	DIP AZIMUTH	DIP	FRICTION ANGLE	POTENTIAL FOR PLANAR FAILURE
1.	45	39	32	NO
2.	51	77	32	NO
3.	250	75	32	NO
4.	174	86	32	NO

AT SLOPE ANGLES STEEPER THAN 39.00, A POTENTIAL FAILURE PLANE WILL DAYLIGHT IN THE FACE OF A SLOPE WITH THE GIVEN ORIENTATION

KINEMATIC ANALYSIS OF DISCONTINUITY INTERSECTIONS

PLANES INVOLVED	PLUNGE	TREND	DAYLIGHTS IN DESIGN SLOPE	DAYLIGHTS IF THE SLOPE IS CUT STEEPER THAN
1 & 3	15.91	335.62	NO	90.00
2 & 1	5.93	322.38	NO	90.00
2 & 3	33.49	329.79	NO	68.91
3 & 4	74.99	248.88	NO	90.00
4 & 1	31.26	86.43	NO	90.00
4 & 2	71.82	96.30	NO	78.40

AT SLOPE ANGLES STEEPER THAN 68.91, A POTENTIAL WEDGE FAILURE WILL DAYLIGHT IN THE FACE OF A SLOPE WITH THE GIVEN ORIENTATION

ANALYSIS OF POTENTIAL TOPPLING FAILURE

BASIC CRITERIA INDICATES THAT POTENTIAL FOR TOPPLING IS LOW

Figure 7-13

Results of the program STABLE, on the Emerald Bay data for a dip azimuth of 45 degrees (20% reduction).

CHAPTER 8 - PROGRAM CONTROL AND SUMMARIZATION

The previous chapters have described a system for handling data concerning discontinuous rock masses. The many tasks outlined in the preceding chapters are performed by separate programs within this system. Loading these programs individually, each time a different task is to be accomplished is a cumbersome and inefficient procedure. This chapter begins by describing a program that handles the function of loading the desired program from a common menu. Secondly, a short summary of the programs described in the previous chapters is provided, along with some hints on potential modifications that may be made in order to tailor a program for a specific usage. This thesis is then concluded with a short synopsis of additional work that could be done in order to expand on the original topic.

LINKING THE PROGRAMS

The programs described in chapters three through seven are linked together by a separate program entitled "MENU". This program produces a screen display showing all of the tasks that may be performed by the programs in this system (figure 8-1). After the operator selects an option, a short description of the selected program is displayed along with a continue/abort option (figure 8-2). The "continue" option causes the appropriate program to be loaded and run, while the "abort" option clears the screen and re-displays the menu options. When program execution is complete, control is passed back to MENU until the "exit to DOS" option is chosen. Every time control is passed from one program to another, all variables are erased from memory. This maximizes available RAM and eliminates any possibility of an error due to pre-defined variables. Chaining the programs together in this manner simplifies using this system by eliminating the need to load programs individually. Further simplification may be obtained by creating an auto-execute file (Microsoft, 1982) to load MENU directly from either a system "boot" or a single command, such as "begin".

```
THE FOLLOWING OPTIONS ARE AVAILABLE

 1 - ENTER DISCONTINUITY DATA INTO A FILE
 2 - OBTAIN HARD COPY OF A DATA FILE
 3 - EDIT AN EXISTING DATA FILE
 4 - SORT AN EXISTING DATA FILE
 5 - CREATE A SUB-FILE
 6 - DRAW A STEREO NET
 7 - PLOT POLES ON AN EQUAL-AREA NET
 8 - DETERMINE MEAN POLES
 9 - PLOT GREAT CIRCLES
10 - CALCULATE WEDGE INTERSECTIONS
11 - PLOT UP TO 10 LABELED POLES
12 - EXIT TO DOS

   ENTER DESIRED CHOICE ?
```

Figure 8-1

Screen display from the program MENU.

```
You are now entering the program entitled PLOT, this program
will plot discontinuity poles contained in an existing data
file, onto an equal-area projection. If you wish to continue,
type `yes' in response to the prompt ?
```

Figure 8-2

Sample of an individual program description along with the continue/abort option.

Pseudocode for MENU

```
Initialization
    close all files and communications channels
    turn function displays off
#   clear the screen

Link programs
    display all available options
    prompt operator to select an option
         if exit to DOS is selected jump to *
              display individual program description
              offer continue/abort option
              if abort jump to #
                   else chain to selected program

* Closing procedure
    close all files and communications channels
    exit MENU
    return to DOS
```

SUMMARY OF PROGRAMS

In the previous chapters ten computer programs have been described, each of which performs a different function concerning the analysis of a discontinuous rock mass. A short description of each of these programs is given below:

MENU - Links the system together and provides a means of moving from one program to another without using "load" commands.

CREATE - Provides a user friendly means of entering discontinuity data into a file.

PRINT - Produces formatted hard copy output of a data file, using the line printer.

EDIT - Allows the correction or deletion of records within an existing data file.

SORT - Places an existing data file into ascending order, based on plane type, dip azimuth, and dip.

SEARCH - Allows the creation of a sub-file by extracting those records from a data file that meet specified criteria, and placing them into a separate file.

PLOT - Reads a data file and plots the discontinuity poles on a polar equal-area projection; joints are represented by dots, faults by triangles, and bedding by squares.

STAT - Determines the mean plane and associated cone of confidence using the Spherical Normal distribution for operator defined discontinuity clusters within a data set; output can be sent to the screen, line printer, or plotter.

GRTCRCLE - Uses the equal-angle projection technique to plot a friction circle, slope traces, and great circles for up to ten discontinuities. Data is entered directly from the keyboard, rather than from a data file.

STABLE - Finds the directions of all possible wedge intersections for up to ten discontinuities and identifies those that are kinematically feasible for a given slope face. All data is entered directly from the keyboard.

The programs listed above were all designed such that they are readily adaptable to specific tasks. The programs are written in a modular style with each module fully described by remark statements, additionally the variable names are consistent throughout the system; these features allow modules to be linked together in order to facilitate a specific task. For example, option 6 on the menu shown in figure 8-1 is "draw a stereo net", however none of the programs developed in the preceding chapters were specifically intended for this task. The program NET, which draws stereo nets was created from the program PLOT simply by removing the data input modules and inserting the additional equations necessary to describe both equatorial and equal-angle projections. Additionally, minor modifications to PLOT also resulted in a program entitled POLE, which was written for a specific project that required labeling of individual discontinuity poles. These two examples are give merely to illustrate the inherent flexibility of this system to anyone familiar with structured programming in the BASIC language.

POTENTIAL FURTHER WORK

The work done in this thesis could be expanded upon in several different directions. The most obvious course would be to further address the statistical analysis of discontinuity clusters. This subject, which was discussed in chapter 6 is sufficiently broad as to warrant an entire thesis. In this project it was assumed that the Spherical Normal distribution was appropriate to describe the angular distribution of planar discontinuities about their mean. A possible course of investigation would be to assess the validity of this assumption with respect to the other potential distributions that could be employed (Bingham, Two-Dimensional Normal, etc.). Secondly, it was implicitly assumed that the mean plane was an appropriate indicator of the system properties . It is conceivable that discontinuity measurements may be more accurately modeled by a skewed distribution than by a normal distribution. If this is true, then use of the mean plane would not be appropriate for design purposes. Subsequent work in this area could further characterize the distribution of discontinuity planes in space.

Another potential area for further exploration would be the use of spatial data in the analytic procedure. The data handling system allows for input of measurements regarding feature spacing, area of exposure, and surface roughness, but does not utilize this information, except as potential search keys. Discontinuity spacing could be analyzed statistically to arrive at an average value for similar features. In three dimensions, this would define an average block size evaluated at a given level of significance. The block size and geometry (esp. with respect to toppling) could then be used as input for a deterministic model, allowing calculation of a factor of safety (limit equilibrium) or stress distributions (block theory). The area of exposure is indicative of persistance. Use of this parameter would allow discontinuity measurements to be weighted, such that large exposures are accorded more significance in calculations than small ones. Finally, values of surface roughness could be used as input into a model relating friction angle to surface roughness, such as that devised by Ladanyi and Archambault (1970).

In conclusion, the purpose of this project was to create a flexible system that was readily adaptable to specific applications. Further work using this system as a basis would indicate that the project was a success.

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APPENDIX A - THE EMERALD BAY LANDSLIDE

PHYSIOGRAPHIC SETTING

The orientation data used for examples in this project was collected from a large rock slide located in the Lake Tahoe Basin, El Dorado County, California (figure 1-1). The slide intersects State Highway 89 at the head of Emerald Bay, which is approximately 9 miles North of U.S. Highway 50 (figure A-1). The area affected by the slide extends upward from Highway 89 to an elevation of over 600 feet above the roadway. Debris from the slide is dispersed below the highway and into the bay. The present physical boundaries of the slide are essentially unchanged since benching was completed in 1956.

The geologic evolution of the Sierra Nevada Mountains and Lake Tahoe Basin is covered in detail by several authors (Burnett, 1977; Loomis, 1983; Mc Cauley, 1971) and will not be reiterated here. However, two factors are significant to slope stability at Emerald Bay and consequently need to be mentioned. There are two principal joint sets prevalent in the eastern Sierra Nevada batholith that cross pluton boundaries and hence are regional in scope (Bateman & Wahrhaftig, 1966). These steeply dipping joints are almost at right angles to each other and generally strike northwest and northeast, respectively. Joint sets fitting this general description were found during field investigations at Emerald Bay and play a significant role in the stability of the rock mass. Secondly, natural slopes in the slide vicinity were oversteepened as a result of Pleistocene glaciation that also stripped the surficial soils and exposed the underlying plutonic rocks (Burnett, 1971).

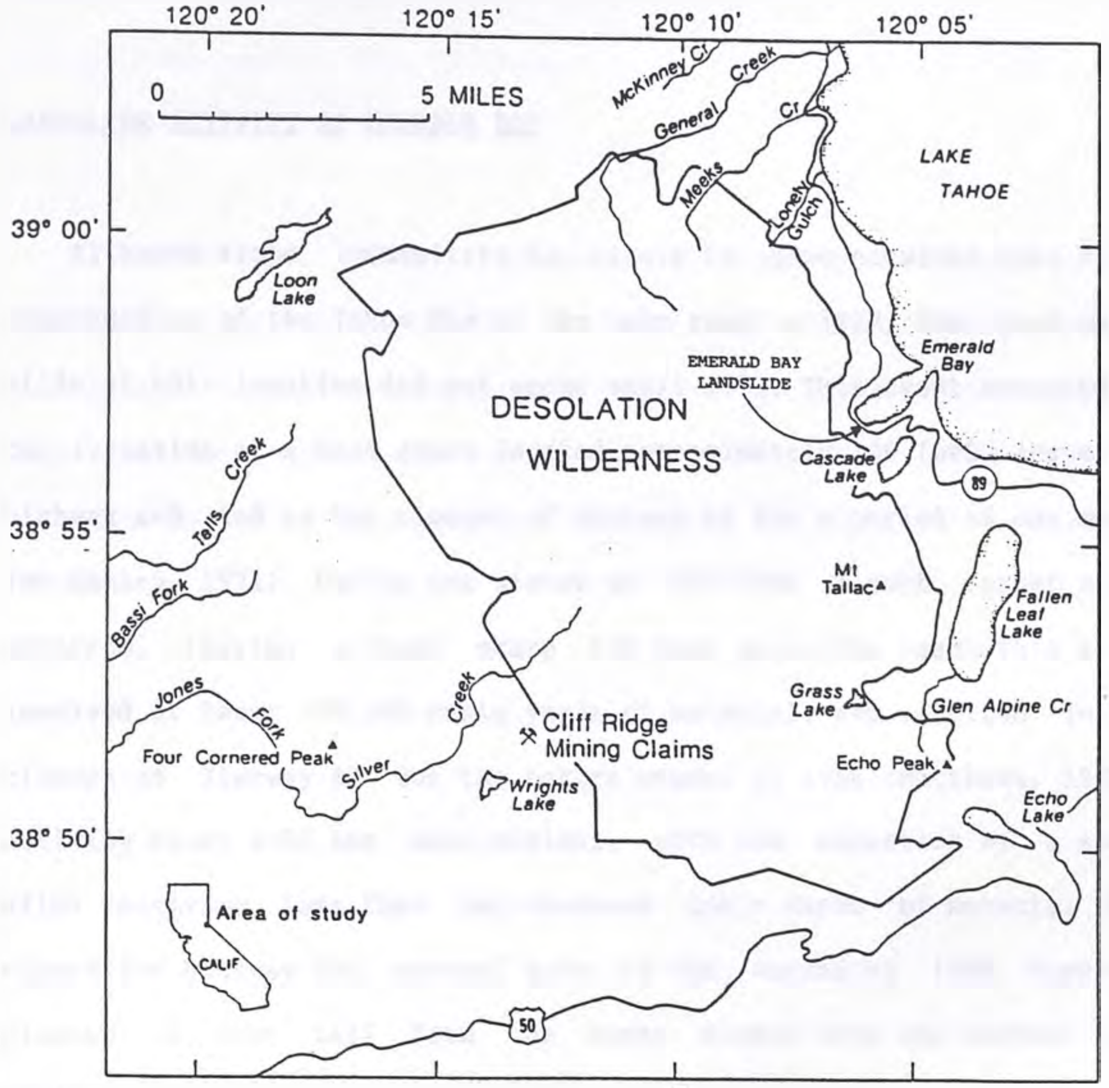

Figure A-1

Index map for Emerald Bay Landslide (after Armstrong et. al., 1983).

The plutonic rocks exposed at Emerald Bay belong to the Dicks Lake Granodiorite, which comprises the bulk of the Cretaceous Eagle Lake Sequence. The Dicks Lake Formation consists of a medium to coarse grained hornblende-biotite granodiorite that is exposed over a five square mile region southwest of Emerald Bay (Loomis, 1983).

LANDSLIDE ACTIVITY AT EMERALD BAY

Although slope instability is likely to have occurred ever since construction of the Tahoe Rim of the Lake road in 1913, the first major slide at this location did not occur until 1953. This event resulted in the formation of a head scarp located approximately 300 feet above the highway and led to the closure of Highway 89 for a period of one month (Mc Cauley, 1971). During the winter of 1955-1956 a much larger slide occurred, leaving a head scarp 600 feet above the road. This slide involved at least 200,000 cubic yards of material, and resulted in the closure of Highway 89 for the entire summer of 1956 (Matthews, 1968). Activity since 1956 has been minimal, with the exception of a small slide involving less than ten thousand cubic yards of material that closed the highway for several days in the spring of 1986. However, cleanup of rock fall from the upper slopes onto the highway is a regular occurrence.

REMEDIAL ACTION

Cleanup of the 1953 and 1956 slides was accomplished by benching the landslide and moving extraneous material downslope from the highway (Mc Cauley, 1971). Due to the strict environmental laws currently in effect for the Lake Tahoe Basin, this procedure is no longer feasible; any material removed from the slope or highway must be disposed of outside the basin.

Mc Cauley (1971) discusses several potential methods for mitigating the hazard at this locality. The proposed solutions included re-routing the highway, a tunnel, rock sheds, and catchment areas among others. These solutions would not only be expensive but would involve considerable environmental and visual impact in this sensitive, scenic region.

APPENDIX B - PROGRAM LISTINGS

NOTE

The following pages contain program listings for all of the programs described in this thesis. The programs are presented in the same order as they appeared in the text. The listings are in small size type so that they could be presented in the same format as they appear on a screen listing.

```
10 REM *****************************************************
20 REM *                    MENU                          *
30 REM *  THIS PROGRAM LINKS ALL OF THE OTHER PROGRAMS    *
40 REM *  INCLUDED IN THIS DISCONTINUITY ANALYSIS SYSTEM  *
50 REM *****************************************************
60 KEY OFF
70 CLS
80 CLOSE
90 PRINT:PRINT
100 PRINT TAB(21);"THE FOLLOWING OPTIONS ARE AVAILABLE"
110 PRINT:PRINT
120 PRINT TAB(20);" 1 - ENTER DISCONTINUITY DATA INTO A FILE"
130 PRINT TAB(20);" 2 - OBTAIN HARD COPY OF A DATA FILE"
140 PRINT TAB(20);" 3 - EDIT AN EXISTING DATA FILE"
150 PRINT TAB(20);" 4 - SORT AN EXISTING DATA FILE"
160 PRINT TAB(20);" 5 - CREATE A SUB-FILE"
170 PRINT TAB(20);" 6 - DRAW A STEREO NET"
180 PRINT TAB(20);" 7 - PLOT POLES ON AN EQUAL-AREA NET"
190 PRINT TAB(20);" 8 - DETERMINE MEAN POLES"
200 PRINT TAB(20);" 9 - PLOT GREAT CIRCLES"
210 PRINT TAB(20);"10 - CALCULATE WEDGE INTERSECTIONS"
220 PRINT TAB(20);"11 - PLOT UP TO 10 LABELED POLES"
230 PRINT TAB(20);"12 - EXIT TO DOS"
240 PRINT:PRINT
250 INPUT "                    ENTER DESIRED CHOICE ";SELECT
260 IF SELECT >= 1 AND SELECT <= 12 GOTO 280
270 BEEP:CLS:PRINT:PRINT TAB(25);"******INVALID CHOICE******":GOTO 90
280 CLS:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
290 ON SELECT GOTO 300,350,400,450,490,540,580,630,680,730,790,850
300 PRINT "You are now entering the program entitled CREATE, this program"
310 PRINT "will allow you to create a data file containing discontinuity"
320 PRINT "data. If you wish to continue, type `yes' in response to the "
330 INPUT "prompt";A$
340 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "CREATE" ELSE GOTO 70
350 PRINT "You are now entering the program entitled PRINT, this program"
360 PRINT "will allow you to obtain hard copy output of an existing data"
370 PRINT "file. If you wish to continue, type `yes' in response to the "
380 INPUT "prompt";A$
390 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "PRINT" ELSE GOTO 70
400 PRINT "You are now entering the program entitled EDIT, this program"
410 PRINT "will allow you correct errrors within an existing data file."
420 PRINT "If you wish to continue, type `yes' in response to the "
430 INPUT "prompt";A$
440 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "EDIT" ELSE GOTO 70
450 PRINT "You are now entering the program entitled SORT, this program"
460 PRINT "allows you to sort an existing data file into ascending order."
470 INPUT "If you wish to continue, type `yes' in response to the prompt ";A$
480 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "SORT" ELSE GOTO 70
490 PRINT "You are now entering the program entitled SEARCH, this program"
500 PRINT "will create a sub-file from an existing data file, based on ."
510 PRINT "operator entered search parameters. If you wish to continue,"
520 INPUT "type `yes' in response to the prompt ";A$
530 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "SEARCH"  ELSE GOTO 70
```

```
540 PRINT "You are now entering the program entitled NET, this program"
550 PRINT "will draw a stereo net to the operators desired specifications."
560 INPUT "If you wish to continue, type `yes' in response to the prompt ";A$
570 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "NET" ELSE GOTO 70
580 PRINT "You are now entering the program entitled PLOT, this program"
590 PRINT "will plot discontinuity poles contained in an existing data "
600 PRINT "file, onto an equal-area projection. If you wish to continue,"
610 INPUT "type `yes' in response to the prompt ";A$
620 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "PLOT"  ELSE GOTO 70
630 PRINT "You are now entering the program entitled STAT, this program"
640 PRINT "uses operator defined clusters, in order to locate the mean"
650 PRINT "poles for an existing data file. If you wish to continue,"
660 INPUT "type `yes' in response to the prompt ";A$
670 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "STAT"  ELSE GOTO 70
680 PRINT "You are now entering the program entitled GRTCRCLE, this program"
690 PRINT "draws great circles for planar features, in response to data "
700 PRINT "entered at the keyboard. If you wish to continue, type `yes' in "
710 INPUT "response to the prompt ";A$
720 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "GRTCRCLE"  ELSE GOTO 70
730 PRINT "You are now entering the program entitled STABLE, this program"
740 PRINT "calculates kinematically possible wedge and planar failures for "
750 PRINT "a given system. Data on slope and discontinuity orientations is"
760 PRINT "entered from the keyboard. If you wish to continue, type `yes'"
770 INPUT "in response to the prompt";A$
780 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "STABLE"  ELSE GOTO 70
790 PRINT "You are now entering the program entitled POLE, this program will"
800 PRINT "plot numbered and labeled poles for planes entered at the keyboard,"
810 PRINT "using the equal area projection. The discontinuity data is entered"
820 PRINT "from the keyboard. If you wish to continue, type `yes' in response"
830 INPUT "to the prompt ";A$
840 IF A$ = "yes" OR A$ ="YES" THEN CHAIN "POLE" ELSE GOTO 70
850 CLOSE
860 SYSTEM
```

```
10 REM *****************************************************
20 REM *                 CREATE                            *
30 REM *  THIS PROGRAM INTERACTIVELY CREATES A DATA FILE    *
40 REM *****************************************************
50 CLS
60 PRINT:PRINT
70 GOSUB 2000
80 FOR I% = 1 TO 10000
90 GOSUB 1000
100 NEXT I%
110 REM
120 REM ********SET LAST RECORD TO ZERO AS A FLAG ********
130 AZIMUTH = 0:DIP = 0: INFILL$ = "":SPACING$ = "": AREA$ = ""
140 RC = 0:COMMENT$ = "": COMMENT2$ = "" .
150 GOSUB 4000
160 NUM% = REC% - 1
170 CLOSE 1
180 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
190 PRINT"     ";NUM%;" RECORDS HAVE NOW BEEN SAVED ON DISK IN FILE ";FILENAME$
200 PRINT:PRINT:PRINT
210 INPUT " HIT <CR> TO RETURN TO THE MAIN MENU ";Z$
220 CHAIN "MENU"
1000 REM
1010 REM ****THIS ROUTINE ALLOWS KEYBOARD INPUT OF DATA****
1020 CLS
1030 PRINT:PRINT:PRINT:PRINT
1040 PRINT "  PLEASE ENTER THE DATA FOR RECORD NUMBER ";I%;" AS REQUESTED. "
1050 PRINT:PRINT
1060 INPUT" ENTER PLANE TYPE (1,2 or 3, 0 to quit) ";PLANETYPE$
1070 IF PLANETYPE$ = "0" THEN I% = 10000:RETURN
1080 IF PLANETYPE$ = "1" OR PLANETYPE$ = "2" OR PLANETYPE$ = "3" THEN 1110
1090 BEEP:PRINT:PRINT:PRINT "  ERROR IN PLANE TYPE, RE-ENTER"
1100 GOTO 1050
1110 PRINT
1120 INPUT "  ENTER DIP AZIMUTH (345, 034 etc.) ";AZIMUTH
1130 IF AZIMUTH <=360 AND AZIMUTH >= 0 THEN 1160
1140 BEEP:PRINT:PRINT:PRINT "  INVALID DIP AZIMUTH, RE-ENTER"
1150 GOTO 1110
1160 PRINT
1170 INPUT "  ENTER DIP (87, 07) ";DIP
1180 IF DIP <= 90 AND DIP >= 0 THEN 1210
1190 BEEP:PRINT:PRINT:PRINT "  INVALID DIP, RE-ENTER"
1200 GOTO 1160
1210 IF CHOICE$ = "YES" OR CHOICE$ = "yes" GOTO 1250
1220 INFILL$ = "":SPACING$ = "": AREA$ = ""
1230 RC = 0:COMMENT$ = "": COMMENT2$ = ""
1240 GOTO 1550
1250 PRINT
1260 INPUT "  ENTER TYPE OF  INFILLING (IRONSTAIN) ";INFILL$
1270 IF LEN(INFILL$) < 10 THEN 1300
1280 BEEP:PRINT:PRINT"  STRING IS TOO LONG, RE-ENTER"
1290 GOTO 1250
1300 PRINT
```

```
1310 INPUT "  ENTER FEATURE SPACING (20 FT) ";SPACING$
1320 IF LEN(SPACING$) < 9 THEN 1350
1330 BEEP:PRINT:PRINT"  STRING IS TOO LONG, RE-ENTER"
1340 GOTO 1300
1350 PRINT
1360 INPUT "  ENTER AREA OF EXPOSURE (100 SQFT) ";AREA$
1370 IF LEN(AREA$) < 9 THEN 1400
1380 BEEP:PRINT:PRINT"  STRING IS TOO LONG, RE-ENTER"
1390 GOTO 1350
1400 PRINT
1410 INPUT"  ENTER THE SURFACE ROUGHNESS COEFFICIENT (1 - 9) ";RC
1420 IF RC < 1 OR RC > 9 THEN 1430 ELSE 1450
1430 BEEP:PRINT:PRINT "  THE ROUGHNESS COEFFICENT MUST BE BETWEEN 1 AND 9"
1440 GOTO 1400
1450 PRINT
1460 INPUT "  ENTER THE FIRST CHARCTER STRING ";COMMENT$
1470 IF LEN(COMMENT$) < 15 THEN 1490
1480 BEEP:PRINT:PRINT"  STRING IS TOO LONG, RE-ENTER":GOTO 1450
1490 PRINT
1500 PRINT "  NOW ENTER THE REMAINDER"
1510 INPUT COMMENT2$
1520 IF LEN(COMMENT2$) < 61 THEN 1550
1530 BEEP:PRINT:PRINT"  STRING IS TOO LONG, RE-ENTER"
1540 GOTO 1490
1550 GOSUB 4000
1560 REC% = REC% + 1
1570 RETURN
2000 REM
2010 REM ******THIS ROUTINE ALLOWS INPUT OF INITIALIZATION PARAMETERS******
2020 PRINT:PRINT
2030 PRINT TAB(15);"1 - OPEN A NEW FILE"
2040 PRINT TAB(15);"2 - ADD RECORDS TO AN EXISTING FILE"
2050 PRINT:PRINT
2060 INPUT "                  ENTER CHOICE ";NEWFILE
2070 IF NEWFILE = 1 OR NEWFILE = 2 GOTO 2090
2080 BEEP:PRINT:PRINT:PRINT TAB(15);"******INVALID CHOICE******":GOTO 2020
2090 PRINT:PRINT:PRINT:PRINT:PRINT
2100 INPUT " ENTER FILE NAME WITH DRIVE SPECIFICATION (B:FILENAME) ";FILENAME$
2110 OPEN "R",#1,FILENAME$,106
2120 FIELD  #1, 1 AS F1$,2 AS F2$,2 AS F3$,9 AS F4$,8 AS F5$,8 AS F6$,2 AS F7$,14
AS F8$,60 AS F9$
2130 REC% = 1
2140 IF NEWFILE = 2 THEN GOSUB 3000
2150 PRINT:PRINT:PRINT:PRINT:PRINT
2160 INPUT " WILL THERE BE DATA OTHER THAN PLANE TYPE AND ORIENTATION ";CHOICE$
2170 RETURN
3000 REM
3010 REM ********THIS ROUTINE FINDS THE END OF AN EXISTING FILE********
3020 FOR T% = 1 TO 10000
3030 GOSUB 5000
3040 IF PLANETYPE$ = "0" GOTO 3070
3050 REC% = REC% + 1
3060 NEXT T%
```

```
3070 RETURN
4000 REM
4010 REM **THIS ROUTINE WRITES RECORD NUMBER REC% TO THE SPECIFIED DATA FILE**
4020 REM
4030 LSET F1$ = PLANETYPE$
4040 RSET F2$ = MKI$(AZIMUTH)
4050 RSET F3$ = MKI$(DIP)
4060 LSET F4$ = INFILL$
4070 LSET F5$ = SPACING$
4080 LSET F6$ = AREA$
4090 RSET F7$ = MKI$(RC)
4100 LSET F8$ = COMMENT$
4110 LSET F9$ = COMMENT2$
4120 PUT #1, REC%
4130 RETURN
5000 REM
5010 REM ****THIS ROUTINE READS RECORD # REC% FROM THE SPECIFIED DATA FILE****
5020 GET #1,REC%
5030 PLANETYPE$ = F1$
5040 AZIMUTH = CVI(F2$)
5050 DIP = CVI(F3$)
5060 INFILL$ = F4$
5070 SPACING$ = F5$
5080 AREA$ = F6$
5090 RC = CVI(F7$)
5100 COMMENT$ = F8$
5110 COMMENT2$ = F9$
5120 RETURN
```

```
10 REM *********************************************************
20 REM *                    PRINT                              *
30 REM *  THIS PROGRAM PROVIDES HARD COPY OUTPUT OF ANY FILE  *
40 REM *********************************************************
50 REM
60 REM ********THIS SECTION CONTROLS PROGRAM EXECUTION********
70 REM
80 CLS
90 PRINT:PRINT:PRINT:PRINT:PRINT
100 INPUT " ENTER FILE NAME WITH DRIVE SPECIFICATION (B:FILENAME) ";FILENAME$
110 OPEN "R",#1,FILENAME$,106
120 FIELD #1, 1 AS F1$,2 AS F2$,2 AS F3$,9 AS F4$,8 AS F5$,8  AS F6$,2  AS F7$,14
AS F8$,60 AS F9$
130 GOSUB 5000
140 GOSUB 3000
150 IF PLANETYPE$ ="0" THEN PRINT:PRINT " THE SPECIFIED FILE IS EMPTY":GOTO 180
160 GOSUB 4000
170 GOSUB 1000
180 CLOSE 1
190 CHAIN "MENU"
1000 REM
1010 REM ********THIS ROUTINE CONTROLS PRINTING********
1020 REM
1030 Z$ = PLANETYPE$
1040 WHILE Z$ = "1" OR Z$ ="2" OR Z$ = "3"
1050 GOSUB 2000
1060 WEND
1070 IF CR = 2 GOTO 1100 ELSE IF PAGELEN <48 GOTO 1110
1080 PRINT:PRINT:PRINT
1090 INPUT "  READY PRINTER, THEN HIT <CR> TO CONTINUE ";CONTINUE$:GOTO 1110
1100 IF PAGELEN >47  THEN FOR I = 1 TO (66 - PAGELEN):LPRINT:NEXT I
1110 LPRINT:LPRINT:LPRINT
1120 NUM = REC% - 1
1130 IF FAULT = 0 THEN CK = CK + 1:GOTO 1150
1140 LPRINT USING FORMAT2$;FAULT;TOTAL4$
1150 IF JOINT = 0 THEN CK = CK + 1:GOTO 1170
1160 LPRINT USING FORMAT2$;JOINT;TOTAL2$
1170 IF BEDDING = 0 THEN CK = CK + 1:GOTO 1190
1180 LPRINT USING FORMAT2$;BEDDING;TOTAL3$
1190 IF CK >= 2  GOTO 1210
1200 LPRINT USING FORMAT2$;NUM;TOTAL1$
1210 RETURN
2000 REM
2010 REM ********THIS ROUTINE WRITES THE BODY OF THE REPORT********
2020 REM
2030 LPRINT TAB(B);HEAD$
2040 LPRINT
2050 LPRINT HEAD1$
2060 LPRINT HEAD2$
2070 LPRINT HEAD3$
2080 PAGELEN = 5
2090 WHILE PAGELEN <= 51
2100 LPRINT USING FORMAT$;TYPE$,AZIMUTH,DIP,INFILL$,SPACING$,AREA$,RC$,COMMENT$
```

```
2110 IF COMMENT2$ = CHECK$ THEN GOTO 2140
2120 LPRINT TAB(9);"*     ";COMMENT2$
2130 PAGELEN = PAGELEN + 1
2140 PAGELEN = PAGELEN + 1
2150 REC% = REC% + 1
2160 GOSUB 3000
2170 IF PLANETYPE$ = Z$ AND PAGELEN <= 51 THEN TYPE$ = " ":GOTO 2200
2180 Z$ = PLANETYPE$
2190 IF PLANETYPE$ = "0" THEN RETURN
2200 WEND
2210 IF CR = 3 GOTO 2230
2220 FOR I = 1 TO 14:LPRINT:NEXT I:GOTO 2250
2230 PRINT:PRINT:PRINT
2240 INPUT " READY PRINTER, THEN HIT <CR> TO CONTINUE ";CONTINUE$
2250 RETURN
3000 REM
3010 REM ****THIS ROUTINE READS RECORD # REC% FROM THE SPECIFIED DATA FILE****
3020 GET #1,REC%
3030 PLANETYPE$ = F1$
3040 AZIMUTH = CVI(F2$)
3050 DIP = CVI(F3$)
3060 INFILL$ = F4$
3070 SPACING$ = F5$
3080 AREA$ = F6$
3090 RC = CVI(F7$)
3100 COMMENT$ = F8$
3110 COMMENT2$ = F9$
3120 IF RC = 0 THEN RC$ = "" ELSE RC$ = STR$(RC)
3130 IF PLANETYPE$ = "1" THEN JOINT = JOINT + 1:TYPE$ = "JOINT":GOTO 3160
3140 IF PLANETYPE$ = "2" THEN BEDDING = BEDDING + 1:TYPE$ = "BEDDING":GOTO 3160
3150 IF PLANETYPE$ = "3" THEN FAULT = FAULT + 1: TYPE$ = "FAULT"
3160 RETURN
4000 REM
4010 REM ******THIS ROUTINE INPUTS AND CENTERS A GENERAL HEADING******
4020 REM
4030 PRINT:PRINT:PRINT
4040 PRINT " ENTER A PAGE TITLE OF UP TO 60 CHARACTERS "
4050 PRINT
4060 PRINT " NOTE: Inclusion of a comma in the title will cause an error"
4070 PRINT " unless the entire statement is enclosed by quotation marks"
4080 PRINT:INPUT HEAD$
4090 IF LEN(HEAD$) <=60 GOTO 4120
4100 BEEP:PRINT:PRINT" TITLE CAN NOT BE LONGER THAN 60 CHARACTERS, RE-ENTER"
4110 GOTO 4000
4120 B = FNC(HEAD$)
4130  PRINT:PRINT:PRINT
4140 INPUT " ARE YOU USING SINGLE SHEETS OF PAPER (YES or NO) ";PAPER$
4150 IF LEFT$(PAPER$,1) = "N" OR LEFT$(PAPER$,1) = "n" THEN CR =2:GOTO 4170
4160  IF  LEFT$(PAPER$,1)  =  "Y"  OR  LEFT$(PAPER$,1)  =  "y"  THEN  CR = 3 ELSE
PRINT:PRINT," ******INVALID CHOICE******":GOTO 4130
4170 PRINT:PRINT:PRINT
4180 INPUT " READY PRINTER AND THEN HIT <CR> TO BEGIN ";START$
4190 RETURN
```

```
5000 REM
5010 REM **THIS SECTION CONTAINS FORMAT STATEMENTS AND INITIALIZES VARIABLES**
5020 REM
5030 FORMAT$ = "      \      \ ###   ##  \          \  \         \\          \ \\   \
     \"
5040 FORMAT2$ = "       #####  \                                                 \
5050 TOTAL1$ = "TOTAL PLANES WERE RECORDED"
5060 TOTAL2$ = "JOINT PLANES WERE RECORDED"
5070 TOTAL3$ = "BEDDING PLANES WERE RECORDED"
5080 TOTAL4$ = "FAULT PLANES WERE RECORDED"
5090 HEAD1$ = "    PLANE   DIP          TYPE OF    FEATURE    AREA OF"
5100 HEAD2$  = "         TYPE       DIR   DIP  INFILLING   SPACING   EXPOSURE  Rc
COMMENT"
5110 HEAD3$ = "         ----    ---    ---   ---------   -------    --------   --
-------"
5120 JOINT = 0: BEDDING = 0: FAULT = 0
5130 REC% = 1:CHECK$ = SPACE$(60):CK = 0
5140 DEF FNC(A$) = (40 -(LEN(A$)/2))
5150 RETURN
```

```
10 REM **********************************************************
20 REM *                    EDIT                                *
30 REM *  THIS PROGRAM ALLOWS EDITNG OF EXISTING DATA FILES      *
40 REM **********************************************************
50 CLS
60 PRINT:PRINT:PRINT:PRINT:PRINT
70 INPUT " ENTER FILE FOR EDITING WITH DRIVE SPEC (B:FILENAME) ";FILENAME$
80 OPEN "R",#1,FILENAME$,106
90 FIELD #1, 1 AS F1$,2 AS F2$,2 AS F3$,9 AS F4$,8 AS F5$,8 AS F6$,2 AS F7$,14 AS
F8$,60 AS F9$
100 FORMAT$ ="####  \\  ###   ##   \   \  \  \     \ \\   \
  \"
110 PRINT:PRINT
120 PRINT" COUNTING THE DATA FILE, EXECUTION WILL BEGIN SHORTLY"
130 GOSUB 7000
140 REC% = 1
150 GOSUB 5000
160 GOSUB 1000
170 GOSUB 6000
180 CLOSE
190 CHAIN "MENU"
1000 REM
1010 REM ********THIS ROUTINE ALLOWS VIEWING OF THE DATA FILE********
1020 CLS
1030 PRINT
1040 PRINT "REC#  TYPE  AZMTH  DIP  INFILL  SPACING   AREA   RC   COMMENT
"
1050 PRINT "----  ----  -----  ---  ------  -------   ----   --   -------"
1060 FOR I% = 1 TO 15
1070                              PRINT                              USING
FORMAT$;REC%,PLANETYPE$,AZIMUTH,DIP,INFILL$,SPACING$,AREA$,RC$,COMMENT$
1080 IF PLANETYPE$ = "0" THEN I% = 15:GOTO 1110
1090 REC% = REC% + 1
1100 GOSUB 5000
1110 NEXT I%
1120 PRINT
1130 PRINT TAB(10); "1. END EDITING SESSION"
1140 PRINT TAB(10); "2. EDIT FILES"
1150 IF PLANETYPE$ = "0" GOTO 1170
1160 PRINT TAB(10); "3. CONTINUE BROWSING"
1170 PRINT
1180 INPUT "          ENTER CHOICE ";CK
1190 ON CK GOTO 1210,1220,1020
1200 BEEP:PRINT:PRINT TAB(10);"******INVALID CHOICE******":PRINT:GOTO 1130
1210 RETURN
1220 GOSUB 2000
1230 CLS
1240 PRINT:PRINT:PRINT:PRINT:PRINT
1250 PRINT TAB(10); "1. CONTINUE BROWSING FILE"
1260 PRINT TAB(10); "2. END EDITING SESSION"
1270 PRINT:INPUT "          ENTER CHOICE ";CH
1280 IF CH = 1 GOTO 1020 ELSE IF CH = 2 GOTO 1300
1290 BEEP:PRINT:PRINT TAB(10);"******INVALID CHOICE******":PRINT:GOTO 1240
```

```
1300 PRINT
1310 RETURN
2000 REM
2010 REM ********THIS ROUTINE DISPLAYS INDIVIDUAL RECORDS FOR EDITING********
2020 PRINT
2030 INPUT " ENTER RECORD NUMBER FOR EDITING ";REC%
2040 CLS:PRINT:PRINT:PRINT
2050 GOSUB 5000
2060 PRINT TAB(5);"EDITING RECORD NUMBER ";REC%
2070 PRINT
2080 PRINT TAB(5);"1. PLANE TYPE          : ";PLANETYPE$
2090 PRINT TAB(5);"2. DIP AZIMUTH         : ";AZIMUTH
2100 PRINT TAB(5);"3. DIP                 : ";DIP
2110 PRINT TAB(5);"4. INFILLING           : ";INFILL$
2120 PRINT TAB(5);"5. FEATURE SPACING     : ";SPACING$
2130 PRINT TAB(5);"6. AREA OF EXPOSURE    : ";AREA$
2140 PRINT TAB(5);"7. ROUGHNESS COEF      : ";RC$
2150 PRINT TAB(5);"8. FIRST COMMENT       : ";COMMENT$
2160 PRINT TAB(5);"9. SECOND COMMENT      : ";COMMENT2$
2170 PRINT
2180 PRINT TAB(5);"D. DELETE THIS RECORD "
2190 PRINT TAB(5);"S. SAVE THIS RECORD AS SHOWN"
2200 PRINT
2210 INPUT " ENTER FIELD FOR EDITING (1-9) OR ACTION DESIRED (D or S) ";CHOICE$
2220 IF VAL(CHOICE$)>0 AND VAL(CHOICE$)< 10 GOTO 2250
2230 IF  CHOICE$ = "S" OR CHOICE$ = "s" GOTO 2300
  ELSE IF CHOICE$ = "D" OR CHOICE$ = "d" GOTO 2290
2240 BEEP:PRINT:PRINT"  INVALID CHOICE":GOTO 2060
2250 GOSUB 3000
2260 PRINT:PRINT
2270 PRINT TAB(5);"EDITED RECORD NUMBER ";REC%
2280 GOTO 2070
2290 PLANETYPE$ = "*"
2300 GOSUB 4000
2310 PRINT:PRINT
2320 INPUT " DO YOU WISH TO EDIT ADDITIONAL RECORDS ";CHECK$
2330 IF CHECK$ = "YES" OR CHECK$ = "yes" GOTO 2020
2340 IF CHECK$ = "no" OR CHECK$ = "NO" GOTO 2360
2350 BEEP:PRINT:PRINT TAB(10);"******INVALID CHOICE******":PRINT:GOTO 2310
2360 RETURN
3000 REM
3010 REM ****THIS ROUTINE ALLOWS KEYBOARD INPUT OF DATA****
3020 PRINT:PRINT
3030 ON VAL(CHOICE$) GOTO 3040,3080,3130,3170,3220,3270,3330,3380,3440
3040 INPUT " ENTER PLANE TYPE (1,2, or 3) ";PLANETYPE$
3050 IF PLANETYPE$ = "1" OR PLANETYPE$ = "2" OR PLANETYPE$ = "3" THEN 4010
3060 BEEP:PRINT:PRINT:PRINT "  ERROR IN PLANE TYPE, RE-ENTER"
3070 PRINT:GOTO 3040
3080 INPUT "  ENTER DIP AZIMUTH (345, 034 etc.) ";AZIMUTH
3090 IF AZIMUTH <=360 AND AZIMUTH >= 0 THEN 4010
3100 BEEP:PRINT:PRINT:PRINT " INVALID DIP AZIMUTH, RE-ENTER"
3110 GOTO 3070
3120 PRINT:PRINT
```

```
3130 INPUT "  ENTER DIP (87, 07) ";DIP
3140 IF DIP <= 90 AND DIP >= 0 THEN 4010
3150 BEEP:PRINT:PRINT:PRINT " INVALID DIP, RE-ENTER"
3160 GOTO 3120
3170 PRINT:PRINT
3180 INPUT "  ENTER TYPE OF  INFILLING (IRONSTAIN) ";INFILL$
3190 IF LEN(INFILL$) < 10 THEN 4010
3200 BEEP:PRINT:PRINT"  STRING IS TOO LONG, RE-ENTER"
3210 GOTO 3170
3220 PRINT:PRINT
3230 INPUT "  ENTER FEATURE SPACING (20 FT) ";SPACING$
3240 IF LEN(SPACING$) < 9 THEN 4010
3250 BEEP:PRINT:PRINT"  STRING IS TOO LONG, RE-ENTER"
3260 GOTO 3220
3270 PRINT:PRINT
3280 INPUT  "  ENTER AREA OF EXPOSURE (100 SQFT) ";AREA$
3290 IF LEN(AREA$) < 9 THEN 4010
3300 BEEP:PRINT:PRINT"  STRING IS TOO LONG, RE-ENTER"
3310 GOTO 3270
3320 PRINT:PRINT
3330 INPUT"  ENTER THE SURFACE ROUGHNESS COEFFICIENT (1 - 9) ";RC
3340 IF RC < 1 OR RC > 9 THEN 3350 ELSE 3370
3350 BEEP:PRINT:PRINT "  THE ROUGHNESS COEFFICENT MUST BE BETWEEN 1 AND 9"
3360 GOTO 3320
3370 RC$ = STR$(RC):GOTO 4010
3380 PRINT
3390 INPUT "  ENTER THE FIRST COMMENT ";COMMENT$
3400 IF LEN(COMMENT$) < 15 THEN 4010
3410 BEEP:PRINT:PRINT"  STRING IS TOO LONG, RE-ENTER"
3420 GOTO 3380
3430 PRINT:PRINT
3440 PRINT "  ENTER THE SECOND COMMENT ";COMMENT2$
3450 INPUT COMMENT2$
3460 IF LEN(COMMENT2$) < 61 THEN 3490
3470 BEEP:PRINT:PRINT"  STRING IS TOO LONG, RE-ENTER"
3480 GOTO 3430
3490 RETURN
4000 REM
4010 REM **THIS ROUTINE WRITES RECORD NUMBER REC% TO THE SPECIFIED DATA FILE**
4020 REM
4030 LSET F1$ = PLANETYPE$
4040 RSET F2$ = MKI$(AZIMUTH)
4050 RSET F3$ = MKI$(DIP)
4060 LSET F4$ = INFILL$
4070 LSET F5$ = SPACING$
4080 LSET F6$ = AREA$
4090 RSET F7$ = MKI$(RC)
4100 LSET F8$ = COMMENT$
4110 LSET F9$ = COMMENT2$
4120 PUT #1, REC%
4130 RETURN
5000 REM
5010 REM ****THIS ROUTINE READS RECORD # REC% FROM THE SPECIFIED DATA FILE****
```

```
5020 GET #1,REC%
5030 PLANETYPE$ = F1$
5040 AZIMUTH = CVI(F2$)
5050 DIP = CVI(F3$)
5060 INFILL$ = F4$
5070 SPACING$ = F5$
5080 AREA$ = F6$
5090 RC = CVI(F7$)
5100 COMMENT$ = F8$
5110 COMMENT2$ = F9$
5120 IF RC = 0 THEN RC$ = "" ELSE RC$ = STR$(RC)
5130 RETURN
6000 REM
6010 REM *******THIS ROUTINE REMOVES THE DELETED RECORDS FROM THE FILE******
6020 CLS
6030 PRINT:PRINT:PRINT:PRINT:PRINT
6040 PRINT"  PACKING THE FILE, THIS MAY TAKE SEVERAL MINUTES"
6050 FOR REC% = 1 TO NUM%
6060 GOSUB 5000
6070 IF PLANETYPE$ = "0" THEN RETURN
6080 IF PLANETYPE$ <> "*" GOTO 6180
6090 TEMP% = REC%
6100 FOR I% = TEMP% TO NUM%
6110 REC% = I% + 1
6120 GOSUB 5000
6130 REC% = I%
6140 GOSUB 4000
6150 IF PLANETYPE$ = "0" GOTO 6170
6160 NEXT I%
6170 REC% = TEMP% - 1
6180 NEXT REC%
7000 REM
7010 REM *******THIS ROUTINE COUNTS THE DATA SET********
7020 REC% = 1
7030 GOSUB 5000
7040 IF PLANETYPE$ <> "0" GOTO 7060
7050 BEEP:PRINT:PRINT " DATA FILE IS EMPTY":GOTO 180
7060 FOR J% = 1 TO 10000
7070 GOSUB 5000
7080 IF PLANETYPE$ = "0" GOTO 7110
7090 REC% = REC% + 1
7100 NEXT J%
7110 NUM% = REC%
7120 RETURN
```

```
10 REM **********************************************************************
20 REM *                                SORT                                *
30 REM * THIS PROGRAM SORTS A DATA FILE BY PLANETYPE, DIP AZIMUTH AND DIP *
40 REM **********************************************************************
50 DIM SRT$(2000), COUNT(2000)
60 CLS
70 GOSUB 4000
80 TIME$ = "00:00:00"
90 GOSUB 3000
100 NUM% = REC% - 1
110 GOSUB 1000
120 GOSUB 2000
130 CLOSE
140 EXECUTE$ = TIME$
150 GOSUB 5000
160 PRINT:PRINT
170 INPUT "          HIT <CR> TO RETURN TO THE MAIN MENU ";Z$
180 CHAIN "MENU"
1000 REM
1010 REM ********THIS ROUTINE PERFORMS A SHELL-METZNER TYPE SORT********
1020 M% = NUM%
1030 M% = INT(M%/2)
1040 IF M% = 0 THEN RETURN
1050 K% = NUM% - M%
1060 J% = 1
1070 I% = J%
1080 L% = I% + M%
1090 IF SRT$(I%) <= SRT$(L%) THEN 1140
1100    SWAP SRT$(I%), SRT$(L%)
1110    SWAP COUNT(I%), COUNT(L%)
1120 I% = I% - M%
1130 IF I%> 0 THEN 1080
1140 J% = J% + 1
1150 IF J% > K% THEN 1030
1160 GOTO 1070
2000 REM
2010 REM ********THIS ROUTINE MOVES RECORDS TO TEMPFILE, IN ORDER********
2020 REC% = 0
2030 TOTAL% = NUM% + 1
2040 FOR F% = 1 TO NUM%
2050 REC% = COUNT(F%): GOSUB 7000
2060 REC% = F%: GOSUB 6000
2070 NEXT F%
2080 REC% = TOTAL%
2090 GOSUB 7000
2100 GOSUB 6000
2110 RETURN
3000 REM
3010 REM *********THIS ROUTINE LOADS THE SORT PARAMETERS INTO AN ARRAY*******
3020 REM
3030 FOR REC% = 1 TO 2000
3040 GOSUB 7000
3050 IF PLANETYPE$ = "0" THEN 100
```

```
3060 Z1$ = STR$(AZIMUTH):Z2$ = STR$(DIP)
3070 WHILE LEN(Z1$) < 4:Z1$ = " " +Z1$:WEND'FORCES DATA INTO THE PROPER COLUMNS
3080 WHILE LEN(Z2$) < 3:Z2$ = " " +Z2$:WEND
3090 SRT$(REC%) = PLANETYPE$ + Z1$ + Z2$
3100 COUNT(REC%) = REC%
3110 NEXT REC%
3120 RETURN
4000 REM
4010 REM *******THIS ROUTINE OPENS THE REQUIRED FILES********
4020 PRINT:PRINT:PRINT:PRINT:PRINT
4030 PRINT TAB(24);"********CAUTION********":PRINT:PRINT
4040 PRINT "         THERE MUST BE SUFFICIENT STORAGE AVAILABLE FOR A FILE"
4050 PRINT "                 OF THE SAME LENGTH AS THE SORT FILE"
4060 PRINT:PRINT
4070 INPUT "         DO YOU WISH TO CONTINUE (YES or NO) ";CONTINUE$
4080 IF CONTINUE$ = "NO" OR CONTINUE$ = "no" GOTO 180
4090 CLS
4100 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
4110 INPUT " ENTER FILE TO BE SORTED, WITH DRIVE SPECIFICATION
(B:FILENAME)";FILENAME$
4120 PRINT:PRINT:PRINT
4130 INPUT " ENTER NAME FOR SORTED FILE, WITH DRIVE SPECIFICATION
(B:FILENAME)";SORTFILE$
4140 OPEN "R",#1,FILENAME$,106
4150 FIELD #1, 1 AS F1$,2 AS F2$,2 AS F3$,9 AS F4$,8 AS F5$,8 AS F6$,2 AS F7$,14
AS F8$,60 AS F9$
4160 OPEN "R",#2,SORTFILE$,106
4170 FIELD #2, 1 AS Q1$,2 AS Q2$,2 AS Q3$,9 AS Q4$,8 AS Q5$,8 AS Q6$,2 AS Q7$,14
AS Q8$,60 AS Q9$
4180 CLS
4190 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
4200 PRINT TAB(15);"******SORT IS IN PROGRESS*******"
4210 PRINT:PRINT
4220 PRINT TAB(15);" THIS MAY TAKE SEVERAL MINUTES"
4230 RETURN
5000 REM
5010 REM ******THIS ROUTINE ALLOWS DESTRUCTION OF THE UNSORTED FILE******
5020 CLS
5030 PRINT:PRINT:PRINT:PRINT
5040 PRINT TAB(15);"1 - SAVE BOTH FILES"
5050 PRINT TAB(15);"2 - DESTROY THE UNSORTED FILE"
5060 PRINT
5070 INPUT"              ENTER CHOICE ";DESTROY
5080 IF DESTROY = 1 OR DESTROY = 2 GOTO 5100
5090 BEEP:PRINT:PRINT TAB(15);"********INVALID CHOICE********":GOTO 5030
5100 IF DESTROY = 1 GOTO 5200
5110 KILL FILENAME$
5120 PRINT:PRINT:PRINT
5130 PRINT TAB(15);"1 - STORE SORTED FILE AS ";SORTFILE$
5140 PRINT TAB(15);"2 - STORE SORTED FILE AS ";FILENAME$
5150 PRINT
5160 INPUT"              ENTER CHOICE ";CHOICE
5170 IF CHOICE = 1 OR CHOICE = 2 GOTO 5190
```

```
5180 BEEP:PRINT:PRINT TAB(15);"********INVALID CHOICE********":GOTO 5120
5190 IF CHOICE = 2 THEN NAME SORTFILE$ AS FILENAME$
5200 CLS
5210 PRINT:PRINT:PRINT:PRINT
5220 IF DESTROY = 1 OR CHOICE = 1 GOTO 5250
5230 PRINT TAB(10);"THE SORTED FILE IS STORED AS ";FILENAME$
5240 GOTO 5260
5250 PRINT TAB(10);"THE SORTED FILE IS STORED AS ";SORTFILE$
5260 PRINT:PRINT
5270 PRINT TAB(10);"NUMBER OF RECORDS SORTED :  ";NUM%
5280 PRINT:PRINT
5290 PRINT TAB(10);"EXECUTION TIME OF SORT   :  ";EXECUTE$
5300 RETURN
6000 REM
6010 REM **THIS ROUTINE WRITES RECORD NUMBER REC% TO THE SPECIFIED DATA FILE**
6020 LSET Q1$ = PLANETYPE$
6030 RSET Q2$ = MKI$(AZIMUTH)
6040 RSET Q3$ = MKI$(DIP)
6050 LSET Q4$ = INFILL$
6060 LSET Q5$ = SPACING$
6070 LSET Q6$ = AREA$
6080 RSET Q7$ = MKI$(RC)
6090 LSET Q8$ = COMMENT$
6100 LSET Q9$ = COMMENT2$
6110 PUT #2, REC%
6120 RETURN
7000 REM
7010 REM ***THIS ROUTINE READS RECORD # REC% FROM THE SPECIFIED DATA FILE***
7020 GET #1,REC%
7030 PLANETYPE$ = F1$
7040 AZIMUTH = CVI(F2$)
7050 DIP = CVI(F3$)
7060 INFILL$ = F4$
7070 SPACING$ = F5$
7080 AREA$ = F6$
7090 RC = CVI(F7$)
7100 COMMENT$ = F8$
7110 COMMENT2$ = F9$
7120 RETURN
```

```
10 REM ************************************************************************
20 REM *                           SEARCH                                     *
30 REM *   THIS PROGRAM INTERACTIVELY CREATES A SUBFILE ON SPECIFIC KEYS      *
40 REM ************************************************************************
50 CLS
60 SREC% = 1:REC% = 1:DIM SEARCH$(11)
70 GOSUB 1000
80 GOSUB 4000
90 IF PLANETYPE$ <> "0" GOTO 110
100 BEEP: PRINT" INVALID FILE CHOICE":GOTO 140
110 GOSUB 2000
120 GOSUB 3000
130 GOSUB 5000
140 CLS
150 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
160 INPUT "   EXECUTION COMPLETE, HIT <CR> TO RETURN TO THE MAIN MENU ";Z$
170 CHAIN "MENU"
1000 REM
1010 REM ********THIS ROUTINE OPENS THE ORIGINAL AND SUBFILES********
1020 CLS
1030 PRINT:PRINT:PRINT:PRINT:PRINT
1040 PRINT TAB(25);"******CAUTION*****"
1050 PRINT
1060 PRINT" BE SURE THAT THERE IS ENOUGH DISK SPACE AVAILABLE FOR TWO FILES"
1070 PRINT:PRINT
1080 INPUT" DO YOU WISH TO CONTINUE (YES or NO) ";CONTINUE$
1090 IF CONTINUE$ = "NO" OR CONTINUE$ = "no" GOTO 140
1100 PRINT:PRINT:PRINT
1110  INPUT "  ENTER  ORIGINAL  FILE  NAME WITH DRIVE SPECIFICATION (B:FILENAME)
";FILENAME$
1120 OPEN "R",#1,FILENAME$,106
1130 FIELD #1, 1 AS F1$,2 AS F2$,2 AS F3$,9 AS F4$,8 AS F5$,8 AS F6$,2  AS F7$,14
AS F8$,60 AS F9$
1140 PRINT:PRINT:PRINT
1150  INPUT "  ENTER  TITLE  FOR  SUBFILE  WITH DRIVE SPECIFICATION (B:FILENAME)
";SUBFILE$
1160 OPEN "R",#2,SUBFILE$,106
1170 FIELD #2, 1 AS Q1$,2 AS Q2$,2 AS Q3$,9 AS Q4$,8 AS Q5$,8 AS Q6$,2  AS Q7$,14
AS Q8$,60 AS Q9$
1180 RETURN
2000 REM
2010 REM ********THIS ROUTINE ALLOWS ENTRY OF THE SEARCH PARAMETERS********
2020 FOR J% = 1 TO 11:SEARCH$(J%) = "":NEXT J%
2030 CLS
2040 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
2050 PRINT TAB(5);"ONLY THE DESIRED SEARCH PARAMETERS NEED BE ENTERED"
2060 PRINT
2070 PRINT TAB(15);" 1. PLANE TYPE               :  ";SEARCH$(1)
2080 PRINT TAB(15);" 2. DIP AZIMUTH              :  ";SEARCH$(2);HYPH1$;SEARCH$(3)
2090 PRINT TAB(15);" 3. DIP                      :  ";SEARCH$(4);HYPH2$;SEARCH$(5)
2100 PRINT TAB(15);" 4. INFILLING MATERIAL       :  ";SEARCH$(6)
2110 PRINT TAB(15);" 5. FEATURE SPACING          :  ";SEARCH$(7);HYPH4$;SEARCH$(11)
2120 PRINT TAB(15);" 6. AREA OF EXPOSURE         :  ";SEARCH$(8)
```

```
2130 PRINT TAB(15);" 7. ROUGHNESS COEFFICIENT :  ";SEARCH$(9);HYPH3$;SEARCH$(10)
2140 PRINT TAB(15);" 8. BEGIN SEARCH "
2150 PRINT TAB(15);" 9. RETURN TO MAIN MENU"
2160 PRINT
2170 INPUT "                   ENTER DESIRED ACTION (1-9) ";CHOICE%
2180 IF CHOICE% >= 1 AND CHOICE% <= 9 GOTO 2200
2190 CLS:BEEP:PRINT:PRINT TAB(8);" INVALID CHOICE RE-ENTER":GOTO 2040
2200 ON CHOICE% GOTO 2210,2240,2300,2360,2390,2450,2480,2540,2550
2210 PRINT:PRINT
2220 INPUT " ENTER PLANE TYPE FOR SEARCH (1,2 or 3) ";SEARCH$(1)
2230 GOTO 2030
2240 PRINT:PRINT
2250 INPUT " ENTER MINIMUM DIP AZIMUTH FOR SEARCH ";SEARCH$(2)
2260 PRINT:PRINT
2270 INPUT " ENTER MAXIMUM DIP AZIMUTH FOR SEARCH ";SEARCH$(3)
2280 HYPH1$ = " - "
2290 GOTO 2030
2300 PRINT:PRINT
2310 INPUT " ENTER MINIMUM DIP FOR SEARCH ";SEARCH$(4)
2320 PRINT:PRINT
2330 INPUT " ENTER MAXIMUM DIP FOR SEARCH ";SEARCH$(5)
2340 HYPH2$ = " - "
2350 GOTO 2030
2360 PRINT:PRINT
2370 INPUT " ENTER INFILLING TYPE FOR SEARCH ";SEARCH$(6)
2380 GOTO 2030
2390 PRINT:PRINT
2400 INPUT." ENTER MINIMUM FEATURE SPACING FOR SEARCH ";SEARCH$(7)
2410 PRINT:PRINT
2420 INPUT " ENTER MAXIMUM FEATURE SPACING FOR SEARCH ";SEARCH$(11)
2430 HYPH4$ = " - "
2440 GOTO 2030
2450 PRINT:PRINT
2460 INPUT " ENTER MINIMUM AREA OF EXPOSURE FOR SEARCH ";SEARCH$(8)
2470 GOTO 2030
2480 PRINT:PRINT
2490 INPUT " ENTER MINIMUM ROUGHNESS COEFFICIENT FOR SEARCH ";SEARCH$(9)
2500 PRINT:PRINT
2510 INPUT " ENTER MAXIMUM ROUGHNESS COEFFICIENT FOR SEARCH ";SEARCH$(10)
2520 HYPH3$ = " - "
2530 GOTO 2030
2540 RETURN
2550 GOTO 140
3000 REM
3010 REM ********THIS ROUTINE SEARCHS AND CREATES THE SUB-FILE********
3020 WHILE PLANETYPE$ = "1" OR PLANETYPE$ = "2" OR PLANETYPE$ = "3"
3030 IF SEARCH$(1) = "" GOTO 3050
3040 IF SEARCH$(1) <> PLANETYPE$ GOTO 3190
3050 IF SEARCH$(2) = "" AND SEARCH$(3) = "" GOTO 3070
3060 IF AZIMUTH < VAL(SEARCH$(2)) OR AZIMUTH  > VAL(SEARCH$(3)) GOTO 3190
3070 IF SEARCH$(4) = "" AND SEARCH$(5) = "" GOTO 3090
3080 IF DIP < VAL(SEARCH$(4)) OR DIP  > VAL(SEARCH$(5)) GOTO 3190
3090 IF SEARCH$(6) = "" GOTO 3120
```

```
3100 T% = LEN(SEARCH$(6))
3110 IF LEFT$(SEARCH$(6),T%) <> LEFT$(INFILL$,T%) GOTO 3190
3120 IF SEARCH$(7) = "" AND SEARCH$(11) = "" GOTO 3140
3130 IF  VAL(SPACING$) < VAL(SEARCH$(7)) OR VAL(SPACING$) > SEARCH$(11))
  GOTO 3190
3140 IF SEARCH$(8) = "" GOTO 3160
3150 IF VAL(AREA$) < VAL(SEARCH$(8)) GOTO 3190
3160 IF SEARCH$(9) = "" AND SEARCH$(10) = "" GOTO 3180
3170 IF RC < VAL(SEARCH$(9)) OR RC > SEARCH$(10)) GOTO 3190
3180 GOSUB 5000
3190 REC% = REC% + 1
3200 GOSUB 4000
3210 WEND
3220 RETURN
4000 REM
4010 REM ****THIS ROUTINE READS RECORD # REC% FROM THE SPECIFIED DATA FILE****
4020 GET #1,REC%
4030 PLANETYPE$ = F1$
4040 AZIMUTH = CVI(F2$)
4050 DIP = CVI(F3$)
4060 INFILL$ = F4$
4070 SPACING$ = F5$
4080 AREA$ = F6$
4090 RC = CVI(F7$)
4100 COMMENT$ = F8$
4110 COMMENT2$ = F9$
4120 RETURN
5000 REM
5010 REM **THIS ROUTINE WRITES RECORD NUMBER SREC% TO THE SPECIFIED DATA FILE**
5020 LSET Q1$ = PLANETYPE$
5030 RSET Q2$ = MKI$(AZIMUTH)
5040 RSET Q3$ = MKI$(DIP)
5050 LSET Q4$ = INFILL$
5060 LSET Q5$ = SPACING$
5070 LSET Q6$ = AREA$
5080 RSET Q7$ = MKI$(RC)
5090 LSET Q8$ = COMMENT$
5100 LSET Q9$ = COMMENT2$
5110 PUT #2, SREC%
5120 SREC% = SREC% + 1
5130 RETURN
```

```
10 REM ******************************************************
20 REM *                PLOT                               *
30 REM *  THIS PROGRAM PLOTS PLANE NORMALS ON THE LOWER     *
40 REM *  HEMISPHERE OF AN EQUAL AREA STEREO-NET            *
50 REM ******************************************************
60 RADIAN = 3.1415926#/180:ROOT2 = SQR(2):SWITCH% = 0:STEP2% = 90
70 REC% = 1:JOINT% = 0:FAULT% = 0:BED% = 0
80 LAB$(1) = "JOINT PLANES":LAB$(2) = "FAULT PLANES":LAB$(3) = "BEDDING PLANES"
90 GOSUB 1000
100 GOSUB 2000
110 N1=INT(90/STEP1% +.00001)
120 N2=INT(90/STEP2% +.00001)
130 N=N1
140 G=STEP2%
150 H=400
160 D=STEP1%
170 GOSUB 3000
180 IF NET%=1 THEN 280
190 GOSUB 4000
200 GOSUB 5000
210 PRINT #1,"SP",PEN2%,";"
220 N=N2
230 G=STEP1%
240 H=STEP1%
250 D=STEP2%
260 GOSUB 4000
270 GOSUB 5000
280 GOSUB 6000
290 GOSUB 8000
300 GOSUB 9000
310 CLOSE
320 CLS
330 PRINT:PRINT:PRINT:PRINT:PRINT
340 INPUT " EXECUTION COMPLETE, HIT <CR> TO RETURN TO THE MAIN MENU ";Z$
350 CHAIN "MENU"
1000 REM
1010 REM ******THIS ROUTINE OPENS COMMUNICATIONS AND SETS PLOT PARAMETERS******
1020 CLS
1030 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
1040 INPUT "        READY PLOTTER, THEN HIT RETURN TO BEGIN EXECUTION ";BEGIN$
1050 CLS
1060 REM *****  PLOTTER COMMUNICATION COMMMANDS  *****
1070 OPEN "COM1:9600,S,7,1,RS,CS65535,DS,CD" AS #1
1080 PRINT #1,"IN;RO90;IP;IW;IP3754,5130,6754,8130;SC",0,1,0,1,";"
1090 PRINT:PRINT:PRINT:PRINT
1100 INPUT " ENTER FILE NAME WITH DRIVE SPECIFICATION (B:FILENAME) ";FILENAME$
1110 OPEN "R",#2,FILENAME$,106
1120 FIELD #2, 1 AS F1$,2 AS F2$,2 AS F3$,9 AS F4$,8 AS F5$,8 AS F6$,2  AS F7$,14
AS F8$,60 AS F9$
1130 PRINT
1140 PRINT:PRINT TAB(10);"1 - DRAW LABELED REFERENCE CIRCLE ONLY"
1150 PRINT:PRINT TAB(10);"2 - DRAW COMPLETE POLAR STEREO-NET"
1160 PRINT:INPUT "                ENTER CHOICE ";NET%
```

```
1170 PRINT:PRINT
1180 INPUT" ENTER STEP SIZE FOR REFERENCE CIRCLE DIVISIONS IN DEGREES ";STEP1%
1190 PRINT:PRINT
1200 INPUT " ENTER PEN NUMBER FOR THE REFERENCE CIRCLE (1 - 6) ";PEN1%
1210 PRINT #1,"SP",PEN1%,";"
1220 PRINT:PRINT
1230 IF NET% = 1 GOTO 1280
1240 INPUT" ENTER STEP FOR REFERENCE CIRCLE SUB-DIVISIONS IN DEGREES ";STEP2%
1250 PRINT:PRINT
1260 INPUT " ENTER PEN NUMBER FOR THE SMALL CIRCLES (1 - 6) ";PEN2%
1270 PRINT:PRINT
1280 INPUT " ENTER PEN NUMBER FOR THE POLES (1 - 6) ";PEN3%
1290 PRINT:PRINT
1300 INPUT " ENTER PEN NUMBER FOR THE LABELS (1 - 6) ";PEN4%
1310 RETURN
2000 REM
2010 REM ********DRAW REFERENCE CIRCLE********
2020 PRINT #1,"PA",0,0,";"
2030 PRINT #1,"CI,1,1;"
2040 PRINT #1,"PU;"
2050 RETURN
3000 REM
3010 REM ********WRITE DEGREES ON REFERENCE CIRCLE********
3020 PRINT #1,"SR1.6,2;"
3030 E=1.06:SET1 = .32:SET2 = .015
3040 IF D < 10 THEN D = 10
3050 FOR I% = 0 TO 360 - D STEP D
3060 X1 = E * SIN(I% * RADIAN)
3070 Y1 = E * COS(I% * RADIAN)
3080 PRINT #1,"PA"
3090 PRINT #1,USING"####.######";X1-SET1,Y1-SET2
3100 PRINT #1,";"
3110 PRINT #1,"LB",I%,CHR$(3)
3120 SET1 = .35:SET2 = .012
3130 NEXT I%
3140 RETURN
4000 REM
4010 REM ********DRAW CIRCLES OF POLAR NET********
4020 FOR I=1 TO N-1
4030 IF I*D-INT(I*D/H+.000001)*H=0 THEN 4080
4040 RADIUS! = ROOT2*SIN((I*D/2)*RADIAN)
4050 RADIUS! = INT(RADIUS! * 1000000!)/1000000!
4060 PRINT #1,"PA",0,0,";"
4070 PRINT #1,"CI";RADIUS!;"1;"
4080 NEXT I
4090 RETURN
5000 REM
5010 REM ********DRAW RADIUS LINES OF POLAR NET********
5020 SWITCH% = SWITCH% + 1
5030 E=ROOT2*SIN(G/2*RADIAN)
5040 FOR I=1 TO N*4
5050 X1=COS(I*D*RADIAN)
5060 Y1=SIN(I*D*RADIAN)
```

```
5070 X0 = 0:Y0 = 0
5080 IF SWITCH% = 1 GOTO 5100
5090 IF I*D-INT(I*D/H+.000001)*H=0 THEN 5190 ELSE GOTO 5110
5100 IF STEP1% >= 20 OR I/3 = INT(I/3)  GOTO 5130
5110 X0=E*X1
5120 Y0=E*Y1
5130 PRINT #1,"PA"
5140 PRINT #1,USING"####.######";X0,Y0
5150 PRINT #1,";PD;"
5160 PRINT #1,"PA"
5170 PRINT #1,USING"####.######";X1,Y1
5180 PRINT #1,";PU;"
5190 NEXT I
5200 RETURN
6000 REM
6010 REM ********DRAW PROJECTION OF POLES********
6020 PRINT #1,"SP",PEN3%,";"
6030 GOSUB 7000
6040 IF PLANETYPE$ = "0" GOTO 6710
6050 RADIUS = ROOT2 * SIN(DIP/2*RADIAN)
6060 Y0 = RADIUS * COS(AZIMUTH * RADIAN)
6070 X0 = RADIUS * SIN(AZIMUTH * RADIAN)
6080 X0=-X0
6090 Y0=-Y0
6100 ON VAL(PLANETYPE$) GOTO 6120,6210,6460
6110 REM
6120 REM ********DRAW POLE AS A CIRCLE (JOINT)********
6130 PRINT #1,"PA"
6140 PRINT #1,USING"####.######";X0,Y0
6150 PRINT #1,";CI,.004,10;"
6160 PRINT #1,"PU"
6170 JOINT% = JOINT% + 1
6180 GOTO 6690
6190 REM
6200 REM ********DRAW POLE AS A TRIANGLE (FAULT)********
6210 FOR I% = 1 TO 3
6220 PRINT #1, "PA"
6230 PRINT #1,USING"####.######";X0,Y0+.006
6240 PRINT #1,";PD;"
6250 PRINT #1,"PA"
6260 PRINT #1,USING"####.######";X0-.006,Y0-.006
6270 PRINT #1,"PA"
6280 PRINT #1,USING"####.######";X0+.006,Y0-.006
6290 PRINT #1,"PA"
6300 PRINT #1,USING"####.######";X0,Y0+.006
6310 PRINT #1, "PA"
6320 PRINT #1,USING"####.######";X0,Y0+.003
6330 PRINT #1,";PD;"
6340 PRINT #1,"PA"
6350 PRINT #1,USING"####.######";X0-.003,Y0-.003
6360 PRINT #1,"PA"
6370 PRINT #1,USING"####.######";X0+.003,Y0-.003
6380 PRINT #1,"PA"
```

```
6390 PRINT #1,USING"####.######";X0,Y0+.003
6400 NEXT I%
6410 PRINT #1,"PU;"
6420 FAULT% = FAULT%  + 1
6430 GOTO 6690
6440 REM
6450 REM ********DRAW POLE AS A SQUARE (BEDDING)********
6460 FOR I% = 1 TO 3
6470 PRINT #1, "PA"
6480 PRINT #1,USING "####.######";X0,Y0 + .006
6490 PRINT #1,";PD;"
6500 PRINT #1,"PA"
6510 PRINT #1,USING"####.######";X0-.005,Y0+.005
6520 PRINT #1,"PA"
6530 PRINT #1,USING"####.######";X0-.005,Y0-.005
6540 PRINT #1,"PA"
6550 PRINT #1,USING"####.######";X0+.005,Y0-.005
6560 PRINT #1,"PA"
6570 PRINT #1,USING"####.######";X0+.005,Y0+.005
6580 PRINT #1,"PA"
6590 PRINT #1,USING"####.######";X0-.002,Y0+.002
6600 PRINT #1,"PA"
6610 PRINT #1,USING"####.######";X0-.002,Y0-.002
6620 PRINT #1,"PA"
6630 PRINT #1,USING"####.######";X0+.002,Y0-.002
6640 PRINT #1,"PA"
6650 PRINT #1,USING"####.######";X0+.002,Y0+.002
6660 NEXT I%
6670 PRINT #1,"PU;"
6680 BED% = BED% + 1
6690 REC% = REC% + 1
6700 GOTO 6030
6710 RETURN
7000 REM
7010 REM ****THIS ROUTINE READS RECORD # REC% FROM THE SPECIFIED DATA FILE****
7020 GET #2,REC%
7030 PLANETYPE$ = F1$
7040 AZIMUTH = CVI(F2$)
7050 DIP = CVI(F3$)
7060 INFILL$ = F4$
7070 SPACING$ = F5$
7080 AREA$ = F6$
7090 RC = CVI(F7$)
7100 COMMENT$ = F8$
7110 COMMENT2$ = F9$
7120 RETURN
8000 REM
8010 REM ******THIS ROUTINE ALLOWS LABELING OF THE NET*******
8020 T = 1.3:B = 1.05
8030 CT$(1) = STR$(JOINT%):CT$(2) = STR$(FAULT%):CT$(3) = STR$(BED%)
8040 PRINT #1, "SP",PEN4%,";"
8050 REM ******THIS SECTION PRINTS TOTALS******
8060 PRINT #1,"SR1.6,2;"
```

```
8070 FOR L% = 1 TO 3
8080 K% = 4 - L%
8090 PRINT #1, "PA-1",B";"
8100 IF VAL(CT$(K%)) = 0 GOTO 8140
8110 WHILE LEN(CT$(K%)) <4 : CT$(K%) = " " + CT$(K%):WEND
8120 PRINT #1, "LB";CT$(K%);" ";LAB$(K%) + CHR$(3)
8130 B = B + .05
8140 NEXT L%
8150 CLS
8160 REM ******THIS SECTION ALLOWS INPUT OF LABELS BELOW THE NET******
8170 PRINT:PRINT:PRINT:PRINT
8180 PRINT " THERE IS ROOM FOR 4 LINES OF 60 CHARACTERS EACH"
8190 PRINT "    EACH LINE WILL BE AUTOMATICALLY CENTERED"
8200 PRINT:PRINT
8210 INPUT " HOW MANY LINES OF TEXT WILL BE ENTERED ";CNT%
8220 PRINT #1, "SR2.6,3.1;"
8230 FOR J% = 1 TO CNT%
8240 PRINT:PRINT
8250 A$ = " "
8260 PRINT " ENTER LINE ";J%
8270 PRINT:INPUT A$
8280 PRINT #1, "PA0",-T";"
8290 PRINT #1, "CP";-LEN(A$)/2;"-.5,LB";A$;+ CHR$(3)
8300 T = T + .05
8310 NEXT J%
8320 RETURN
9000 REM
9010 REM ********WRITE ADDITIONAL INFORMATION ON PLOT********
9020 CLS
9030 PRINT:PRINT:PRINT
9040 INPUT " DO YOU WISH TO ADD ADDITIONAL INFORMATION ON TO THE PLOT ";K$
9050 IF K$="NO" OR K$ = "no" GOTO 9220
9060 PRINT:PRINT:PRINT
9070 PRINT " FIRST, USE THE PLOTTER CURSOR CONTROLS TO MOVE THE PEN"
9080 PRINT " TO THE LOCATION FOR THE DESIRED CHARACTER STRING. THEN:"
9090 PRINT:PRINT
9100 PRINT " CHARCTER SIZE MUST BE ENTERED AS WIDTH AND HEIGHT"
9110 PRINT " THE SIZE OF THE STEREO-NET LABELS IS (1.6,2) AND THE BOTTOM"
9120 INPUT " LABELS ARE (2.6,3.1). ENTER (WIDTH,HEIGHT) ";O$,P$
9130 PRINT
9140 PRINT " ENTER THE DESIRED CHARACTER STRING ?"
9150 INPUT Q$
9160 PRINT#1, "SR";O$,P$,";LB";Q$;+ CHR$(3)
9170 PRINT
9180 INPUT " DO YOU WISH TO ENTER MORE INFORMATION ";R$
9190 IF R$="NO" OR R$ = "no" GOTO 9220
9200 PRINT:PRINT
9210 GOTO 9070
9220 RETURN
9230 REM
9240 REM THIS LINE CAN BE USED IN PLACE OF LINE 1050 TO SCALE THE PLOT
9250 REM ONTO SIZE B PAPER THE PLOTTER ITSELF MUST ALSO BE ADJUSTED
9260 PRINT #1,"IN;RO90;IP;IW;IP5200,8100,9600,12500;SC",0,1,0,1,";"
```

```
10 REM ****************************************************
20 REM *                    STAT                          *
30 REM *    THIS PROGRAM PROVIDES STATISTICAL INFORMATION  *
40 REM *              ON PLANE ORIENTATIONS               *
50 REM ****************************************************
60 GOSUB 10000
70 GOSUB 1000
80 GOSUB 2000
90 GOSUB 5000
100 FOR K% = 1 TO CLSTR%
110 GOSUB 3000
120 GOSUB 4000
130 NEXT K%
140 ON CONTROL% GOSUB 7000,8000,9000
150 CLOSE
160 PRINT:PRINT:PRINT
170 INPUT " EXECUTION IS COMPLETE, HIT <CR> TO RETURN TO THE MAIN MENU ";Z$
180 CHAIN "MENU"
1000 REM
1010 REM ********THIS ROUTINE OPENS FILE AND INPUTS CLUSTER PARAMETERS********
1020 CLS
1030 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
1040 INPUT " ENTER FILE NAME WITH DRIVE SPECIFICATION (B:FILENAME)";FILENAME$
1050 OPEN "R",#2,FILENAME$,106
1060 FIELD  #2, 1 AS F1$,2 AS F2$,2 AS F3$,9 AS F4$,8 AS F5$,8 AS F6$,2 AS F7$,14
AS F8$,60 AS F9$
1070 PRINT:PRINT
1080 INPUT " HOW MANY CLUSTERS ARE TO BE ANALYZED (1 - 10) ";CLSTR%
1090 IF CLSTR% >= 1 AND CLSTR% <= 10 GOTO 1110
1100 BEEP:PRINT:PRINT "       ********INVALID CHOICE*******":GOTO 1070
1110 FOR I% = 1 TO CLSTR%
1120 CLS
1130 PRINT:PRINT:PRINT:PRINT
1140 PRINT " INPUT DATA FOR CLUSTER NUMBER ";I%
1150 PRINT:PRINT
1160 INPUT " ENTER AZIMUTHAL COORDINATE OF CLUSTER CENTER ";AZI(I%)
1170 PRINT:PRINT
1180 INPUT " ENTER DIP OF CLUSTER CENTER, MEASURED FROM THE OUTSIDE ";DIPP(I%)
1190 PRINT:PRINT
1200 INPUT " ENTER RADIUS OF CLUSTER IN DEGREES ";RAD(I%)
1210 PRINT:PRINT
1220 INPUT " ENTER CONFIDENCE LEVEL FOR CALCULATIONS IN PERCENT ";CONLEV(I%)
1230 IF CONLEV(I%) > 0 AND CONLEV(I%) < 100 GOTO 1250
1240 BEEP:PRINT:PRINT " CONFIDENCE LEVEL MUST BE > 0 AND <100 ":GOTO 1210
1250 LEVEL(I%) = CONLEV(I%)/100
1260 NEXT I%
1270 RETURN
2000 REM
2010 REM ******THIS ROUTINE SETS OUTPUT PARAMETERS******
2020 CLS
2030 PRINT:PRINT:PRINT:PRINT:PRINT
2040 PRINT:PRINT TAB(28);"OUTPUT DESTINATIONS":PRINT
2050 PRINT:PRINT TAB(30);"1 - SCREEN ONLY"
```

```
2060 PRINT:PRINT TAB(30);"2 - LINE PRINTER"
2070 PRINT:PRINT TAB(30);"3 - PLOTTER"
2080 PRINT:PRINT:PRINT:PRINT
2090 INPUT "                    SELECT ONE OF THE ABOVE CHOICES BY NUMBER ";
 CONTROL%
2100 ON CONTROL%  GOTO 2300,2280,2120
2110 BEEP:PRINT:PRINT"       ********INVALID PARAMETER********":GOTO 2030
2120 PRINT:PRINT
2130 INPUT " PREPARE PLOTTER, THEN HIT <CR> TO CONTINUE ";ZZ$
2140 CLS
2150 REM *****  PLOTTER COMMUNICATION COMMMANDS  *****
2160 OPEN "COM1:9600,S,7,1,RS,CS65535,DS,CD" AS #1
2170 PRINT #1,"IN;RO90;IP;IW;IP3754,5130,6754,8130;SC",0,1,0,1,";"
2180 PRINT:PRINT:PRINT:PRINT
2190 INPUT" ENTER STEP SIZE FOR REFERENCE CIRCLE DIVISIONS IN DEGREES ";STEP1%
2200 PRINT:PRINT
2210 INPUT " ENTER PEN NUMBER FOR THE REFERENCE CIRCLE (1 - 6) ";PEN1%
2220 PRINT:PRINT
2230 INPUT " ENTER PEN NUMBER FOR THE POLES (1 - 6) ";PEN3%
2240 PRINT:PRINT
2250 INPUT " ENTER PEN NUMBER FOR THE LABELS (1 - 6) ";PEN4%
2260 PRINT #1,"SP",PEN1%,";"
2270 GOTO 2300
2280 PRINT:PRINT
2290 INPUT " READY LINE PRINTER, THEN HIT <CR> TO CONTINUE ";Z$
2300 CLS
2310 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
2320 PRINT TAB(15);FORM1$
2330 RETURN
3000 REM
3010 REM ******THIS ROUTINE ROTATES THE DATA SET TO THE CLUSTER CENTER******
3020 CN = 0:CE = 0:CD = 0:R = 0:LN = 0:LE = 0:LD = 0:CNT%(K%) = 0
3030 REM **** THIS SECTION SETS THE CENTER AND RADIUS OF THE CLUSTER ****
3040 TEM1 = DIPP(K%) * RADIAN:TEM2 = RAD(K%) * RADIAN
3050 RCENTER = COS(TEM1)/(SIN(TEM1) + COS(TEM2))
3060 XC = RCENTER * SIN(AZI(K%) * RADIAN)
3070 YC = RCENTER * COS(AZI(K%) * RADIAN)
3080 RADC = SIN(TEM2)/(SIN(TEM1) + COS(TEM2))
3090 REM **** THIS SECTION CHECKS DATA FILE AGAINST THE CLUSTER PARAMETRS****
3100 FOR REC% = 1 TO NUM%
3110 GOSUB 6000
3120 IF  AZIMUTH < 180 THEN NORMAZ = (AZIMUTH + 180)
 ELSE NORMAZ = (AZIMUTH - 180)
3130 XP = (SIN(NORMAZ * RADIAN)) * (TAN((45 - (90 - DIP)/2) * RADIAN))
3140 YP = (COS(NORMAZ * RADIAN)) * (TAN((45 - (90 - DIP)/2) * RADIAN))
3150 RCHECK = SQR(((XP - XC)^2) + ((YP - YC)^2))
3160 IF RCHECK <= RADC GOTO 3250
3170 IF DIPP(K%) - RAD(K%) >= 0 GOTO 3310
3180 CK1 =  ABS(NORMAZ - AZI(K%))
3190 IF CK1 <= 90 OR CK1 >= 270  GOTO 3310
3200 XP = -XP:YP = -YP
3210 RCHECK = SQR(((XP - XC)^2) + ((YP - YC)^2))
3220 IF RCHECK > RADC GOTO 3310
```

```
3230 AZIMUTH = NORMAZ
3240 DIP = 180 - DIP
3250 INC = DIP * RADIAN
3260 AZ = AZIMUTH * RADIAN
3270 CN = CN + (-SIN(INC) * COS(AZ))
3280 CE = CE + (-SIN(INC) * SIN(AZ))
3290 CD = CD + COS(INC)
3300 CNT%(K%) = CNT%(K%) + 1
3310 NEXT REC%
3320 RETURN
4000 REM
4010 REM ****THIS ROUTINE PERFORMS STATISTICAL ANALYSIS ON DESIRED CLUSTER****
4020 IF CNT%(K%) = 0 GOTO 4300
4030 CNMN = CN/CNT%(K%)
4040 CDMN = CD/CNT%(K%)
4050 CEMN = CE/CNT%(K%)
4060 R = SQR(CNMN * CNMN + CDMN * CDMN + CEMN * CEMN)
4070 LN = CNMN/R
4080 LE = CEMN/R
4090 LD = CDMN/R
4100 IF R < 1 THEN K = 1/(1-R) ELSE K =1D+16
4110 TRIAL3 = FNARCCOS(LD)
4120 TEMPA = LN/-SIN(TRIAL3)
4130 TEMPB = LE/-SIN(TRIAL3)
4140 IF TEMPA > 1 THEN ADJUST = -2 ELSE ADJUST = 2
4150 WHILE TEMPA > 1 :TEMPA = TEMPA + ADJUST:WEND
4160 WHILE TEMPA < -1 :TEMPA = TEMPA + ADJUST:WEND
4170 IF TEMPB > 1 THEN ADJUST = -2 ELSE ADJUST = 2
4180 WHILE TEMPB < -1 :TEMPB = TEMPB + ADJUST:WEND
4190 WHILE TEMPB > 1 :TEMPB = TEMPB + ADJUST:WEND
4200 TRIAL1 = INT(FNARCCOS(TEMPA) * 100 /RADIAN)/100
4210 TRIAL2 = INT(FNARCSIN(TEMPB) * 100 /RADIAN)/100
4220 MEANDIP(K%) = INT(TRIAL3 * 100/RADIAN)/100
4230 IF  TEMPB >= 0 THEN MEANAZ(K%) = TRIAL1 ELSE
     MEANAZ(K%) = 360 - TRIAL1
4240 IF MEANDIP(K%) <= 90 GOTO 4270
4250 MEANDIP(K%) = 180 - MEANDIP(K%)
4260 IF  MEANAZ(K%) >= 180 THEN MEANAZ(K%) = MEANAZ(K%) - 180 ELSE
     MEANAZ(K%) = MEANAZ(K%) + 180
4270 TEMPC = LOG(1 - LEVEL(K%))/(CNT%(K%) * R * K)
4280 TEMPD = FNARCCOS(1 + TEMPC)
4290 CONEANGLE(K%) = INT(TEMPD * 100/RADIAN)/100
4300 RETURN
5000 REM
5010 REM ********THIS ROUTINE COUNTS THE DATA SET********
5020 REC% = 1
5030 GOSUB 6000
5040 IF PLANETYPE$ <> "0" GOTO 5060
5050 BEEP:PRINT:PRINT " DATA FILE IS EMPTY":GOTO 150
5060 FOR J% = 1 TO 2000
5070 GOSUB 6000
5080 IF PLANETYPE$ = "0" GOTO 5110
5090 REC% = REC% + 1
```

```
5100 NEXT J%
5110 NUM% = REC% - 1
5120 RETURN
6000 REM
6010 REM ****THIS ROUTINE READS RECORD # REC% FROM THE SPECIFIED DATA FILE****
6020 GET #2,REC%
6030 PLANETYPE$ = F1$
6040 AZIMUTH = CVI(F2$)
6050 DIP = CVI(F3$)
6060 INFILL$ = F4$
6070 SPACING$ = F5$
6080 AREA$ = F6$
6090 RC = CVI(F7$)
6100 COMMENT$ = F8$
6110 COMMENT2$ = F9$
6120 RETURN
7000 REM
7010 REM ******THIS ROUTINE PRODUCES A SCREEN DISPLAY OF THE RESULTS******
7020 CLS
7030 PRINT:PRINT:PRINT
7040 PRINT TAB(15);FORM2$;FILENAME$
7050 PRINT:PRINT
7060 PRINT FORM3$
7070 PRINT FORM4$
7080 PRINT FORM5$
7090 FOR T% = 1 TO CLSTR%
7100 DIPM(T%) = 90 - DIPP(T%)
7110 IF AZI(T%) >= 180 THEN AZIM(T%) = AZI(T%) - 180
  ELSE AZIM(T%) = AZI(T%) + 180
7120 IF CNT%(T%) > 0 GOTO 7170
7130 PRINT USING FORM7$;T%;AZIM(T%);DIPM(T%);RAD(T%);CNT%(T%)
7140 PRINT TAB(7);FORM8$
7150 PRINT
7160 GOTO 7180
7170                                    PRINT                                    USING
FORM6$;T%;AZIM(T%);DIPM(T%);RAD(T%);CNT%(T%);MEANAZ(T%);MEANDIP(T%);CONEANGLE(T%-
);CONLEV(T%);"%"
7180 NEXT T%
7190 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
7200 RETURN
8000 REM
8010 REM ******THIS ROUTINE PRODUCES HARD COPY OUTPUT OF THE RESULTS******
8020 GOSUB 7000
8030 LPRINT TAB(15);FORM2$;FILENAME$
8040 LPRINT:LPRINT
8050 LPRINT FORM3$
8060 LPRINT FORM4$
8070 LPRINT FORM5$
8080 FOR T% = 1 TO CLSTR%
8090 IF CNT%(T%) = 0 GOTO 8110
8100  LPRINT   USING   FORM6$;T%;AZIM(T%);DIPM(T%);RAD(T%);CNT%(T%);MEANAZ(T%);
MEANDIP(T%);CONEANGLE(T%);CONLEV(T%);"%"
8110 NEXT T%
```

```
8120 RETURN
9000 REM
9010 REM ********PLOTTER DRIVE********
9020 GOSUB 7000
9030 REM
9040 REM ********DRAW REFERENCE CIRCLE WITH DEGREES ON PERIMETER********
9050 PRINT #1,"PA",0,0,";"
9060 PRINT #1,"CI,1,1;"
9070 PRINT #1,"PU;"
9080 PRINT #1,"SR1.6,2;"
9090 IF STEP1% < 10 THEN D = 10 ELSE D = STEP1%
9100 FOR I% = 0 TO 360 - D STEP D
9110 X1 = E * SIN(I% * RADIAN)
9120 Y1 = E * COS(I% * RADIAN)
9130 PRINT #1,"PA"
9140 PRINT #1,USING"####.######";X1-SET1,Y1-SET2
9150 PRINT #1,";"
9160 PRINT #1,"LB",I%,CHR$(3)
9170 SET1 = .35:SET2 = .012
9180 NEXT I%
9190 REM
9200 REM ********DRAW PROJECTION OF POLES********
9210 PRINT #1,"SP",PEN3%,";"
9220 FOR Q% = 1 TO CLSTR%
9230 IF CNT%(Q%) = 0 GOTO 9340
9240 RADIUS = ROOT2 * SIN(MEANDIP(Q%)/2*RADIAN)
9250 Y0 = -RADIUS * COS(MEANAZ(Q%) * RADIAN)
9260 X0 = -RADIUS * SIN(MEANAZ(Q%) * RADIAN)
9270 PRINT #1,"PA"
9280 PRINT #1,USING"####.######";X0,Y0
9290 PRINT #1,";CI,.006,10;"
9300 PRINT #1,";CI,.003,10;"
9310 PRINT #1,"PU"
9320 IF MEANAZ(Q%) <= 180 THEN SET4% = 0 ELSE SET4% = -3
9330 PRINT #1,"CP",SET4%,"-.25,LB";Q%;+ CHR$(3)
9340 NEXT Q%
9350 REM
9360 REM ******THIS SECTION LABELS THE PLOT*******
9370 PRINT #1, "SP",PEN4%,";"
9380 PRINT #1, "PA-1.1",B + .05 ";"
9390 PRINT #1, "LB";PLOT1$;+ CHR$(3)
9400 PRINT #1, "PA-1.1",B ";"
9410 PRINT #1, "LB";PLOT2$;+ CHR$(3)
9420 B = B - .01
9430 PRINT #1, "PA-1.1",B ";"
9440 PRINT #1, "LB";PLOT3$;+ CHR$(3)
9450 FOR L% = 1 TO CLSTR%
9460 IF CNT%(L%) = 0 GOTO 9520
9470 B = B - .05
9480 PRINT #1, "PA-1.1",B";"
9490 PRINT #1, "LB"
9500 PRINT #1,USING OUTPT$;L%,MEANAZ(L%),MEANDIP(L%),CONEANGLE(L%),CONLEV(L%),
9510 PRINT #1, + CHR$(3)
```

```
9520 NEXT L%
9530 PRINT:PRINT
9540 INPUT "  HIT RETURN <CR> TO CONTINUE ";CONTINUE$
9550 CLS
9560 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
9570 PRINT "  THERE IS ROOM FOR 4 LINES CONTAINING UP TO 60 CHARACTERS"
9580 PRINT "            EACH LINE WILL BE AUTOMATICALLY CENTERED"
9590 PRINT:PRINT
9600 INPUT " HOW MANY LINES OF TEXT WILL BE ENTERED ";CNT%
9610 PRINT #1, "SR2.6,3.1;"
9620 FOR J% = 1 TO CNT%
9630 PRINT:PRINT
9640 G$ = " "
9650 PRINT " ENTER LINE ";J%
9660 PRINT:INPUT G$
9670 PRINT #1, "PA0",-T";"
9680 PRINT #1, "CP";-LEN(G$)/2;"-.5,LB";G$;+ CHR$(3)
9690 T = T + .05
9700 NEXT J%
9710 RETURN
10000 REM
10010 REM *******THIS ROUTINE DEFINES FUNCTIONS AND CONSTANTS*******
10020 DEF FNARCSIN(X) = ATN(X/SQR(1-X*X))
10030 DEF FNARCCOS(X) = 1.570796 - ATN(X/SQR(1-X*X))
10040 E=1.06:SET1 = .32:SET2 = .015:T = 1.3:B = 1.5
10050 RADIAN = 3.1415926#/180:ROOT2 = SQR(2)
10060 FORM1$ = "********EXECUTION MAY TAKE UP TO AN HOUR********"
10070 FORM2$ = "RESULTS OF CALCULATIONS ON FILENAME, "
10080 FORM3$  = "SET   TRIAL   TRIAL    SET     DATA     MEAN         MEAN   CONE
  CONF."
10090 FORM4$ = " #   AZIMUTH   DIP    RADIUS   POINTS   AZIMUTH      DIP    ANGLE
 LEVEL"
10100 FORM5$ = "--   ------   ---    ------   ------   -------      ---    -----
 -----"
10110 FORM6$ ="##    ###      ##      ###     #####     ###.##     ##.##    ##.##
 ##.##l"
10120 FORM7$ ="##    ###      ##      ###     #####"
10130 FORM8$ = "*****NO DATA POINTS WERE FOUND IN THE CLUSTER DEFINED ABOVE*****"
10140 PLOT1$ = "         MEAN    MEAN  CONE   CONF."
10150 PLOT2$ = "     AZIMUTH   DIP   ANGLE  LEVEL"
10160 PLOT3$ = "     _______   ___   _____  _____"
10170 OUTPT$ = "##.  ###.##   ##.##  ##.##  ##.##"
10180 RETURN
```

```
10 REM ****************************************************************
20 REM *                      GRTCRCLE                                *
30 REM *   THIS PROGRAM PLOTS THE GREAT CIRCLES FOR DISCONTINUITY     *
40 REM *          PLANES, FREE SURFACE AND FRICTION CIRCLE            *
50 REM ****************************************************************
60 GOSUB 7000
65 GOSUB 1000
70 GOSUB 2000
80 GOSUB 3000
90 GOSUB 4000
100 GOSUB 5000
110 GOSUB 6000
120 CHAIN "MENU"
1000 REM
1010 REM ******THIS ROUTINE SETS INPUT PARAMETERS******
1020 CLS
1030 PRINT:PRINT:PRINT
1040 PRINT TAB(15)" WHAT TYPE OF DATA WILL BE INPUT":PRINT:PRINT
1050 PRINT:PRINT TAB(15) " 1 - DISCONTINUITIES ONLY"
1060 PRINT:PRINT TAB(15) " 2 - DISCONTINUITIES AND FRICTION CIRCLE"
1070 PRINT:PRINT TAB(15) " 3 - DISCONTINUITIES AND SLOPE SURFACE"
1080  PRINT:PRINT  TAB(15)  "  4  -  DISCONTINUITIES,  FRICTION  CIRCLE AND SLOPE
SURFACE"
1090 PRINT:PRINT
1100 INPUT "                    ENTER CHOICE ";CHOICE
1110 IF CHOICE >= 1 AND CHOICE <= 4 GOTO 1130
1120 BEEP: PRINT:PRINT:PRINT TAB(20);"******INVALID CHOICE******": GOTO 1030
1130 RETURN
2000 REM
2010 REM ******THIS ROUTINE ALLOWS KEYBOARD INPUT OF DATA******
2020 CLS
2030 PRINT:PRINT
2040 INPUT "  ENTER THE NUMBER OF DISCONTINUITY PLANES FOR ANALYSIS ";DISC%
2050 FOR I% = 1 TO DISC%
2060 CLS
2070 PRINT:PRINT
2080 PRINT "  PLEASE ENTER THE FOLLOWING DATA FOR DISCONTINUITY NUMBER ";I%;
2090 PRINT:PRINT
2100 PRINT:PRINT
2110 INPUT "  ENTER DIP AZIMUTH (345, 034 etc.) ";DISCAZ(I%)
2120 IF DISCAZ(I%) <=360 AND DISCAZ(I%) >= 0 THEN 2150
2130 BEEP:PRINT:PRINT:PRINT "  INVALID DIP AZIMUTH, RE-ENTER"
2140 GOTO 2100
2150 PRINT:PRINT
2160 INPUT "  ENTER DIP (87, 07) ";DISCDIP(I%)
2170 IF DISCDIP(I%) <= 90 AND DISCDIP(I%) >= 0 THEN 2200
2180 BEEP:PRINT:PRINT:PRINT "  INVALID DIP, RE-ENTER"
2190 GOTO 2150
2200 NEXT I%
2210 CLS
2220 PRINT:PRINT:PRINT
2230 IF CHOICE = 1 OR CHOICE = 3 GOTO 2290
2240 INPUT "  ENTER THE FRICTION ANGLE FOR THIS ANALYSIS ";FRICTION
```

```
2250 IF FRICTION <= 90 AND FRICTION >= 0 THEN 2280
2260 BEEP:PRINT:PRINT:PRINT "  INVALID FRICTION ANGLE, RE-ENTER"
2270 GOTO 2220
2280 PRINT:PRINT
2290 IF CHOICE = 1 OR CHOICE = 2 GOTO 2420
2300 PRINT " PLEASE ENTER THE FOLLOWING DATA FOR THE FREE SURFACE"
2310 PRINT:PRINT
2320 T% = DISC% + 1
2330 INPUT " ENTER DIP AZIMUTH (345, 034 etc.) ";DISCAZ(T%)
2340 IF DISCAZ(T%) <=360 AND DISCAZ(T%) >= 0 THEN 2370
2350 BEEP:PRINT:PRINT:PRINT "  INVALID DIP AZIMUTH, RE-ENTER"
2360 GOTO 2310
2370 PRINT:PRINT
2380 INPUT " ENTER DIP (87, 07) ";DISCDIP(T%)
2390 IF DISCDIP(T%) <= 90 AND DISCDIP(T%) >= 0 THEN 2420
2400 BEEP:PRINT:PRINT:PRINT " INVALID DIP, RE-ENTER"
2410 GOTO 2370
2420 CLS
2430 PRINT:PRINT:PRINT:PRINT
2440 INPUT" PREPARE PLOTTER, THEN HIT <CR> TO CONTINUE ";S$
2450 REM ***** PLOTTER COMMUNICATION COMMMANDS  *****
2460 OPEN "COM1:9600,S,7,1,RS,CS65535,DS,CD" AS #1
2470 PRINT #1,"IN;RO90;IP;IW;IP3754,5130,6754,8130;SC",0,1,0,1,";"
2480 PRINT:PRINT
2490 INPUT" ENTER STEP SIZE FOR REFERENCE CIRCLE DIVISIONS IN DEGREES ";STEP1%
2500 PRINT:PRINT
2510 INPUT " ENTER PEN NUMBER FOR THE REFERENCE CIRCLE (1 - 6) ";PEN1%
2520 PRINT:PRINT
2530 INPUT " ENTER PEN NUMBER FOR THE POLES (1 - 6) ";PEN3%
2540 PRINT:PRINT
2550 INPUT " ENTER PEN NUMBER FOR THE LABELS (1 - 6) ";PEN4%
2560 PRINT #1,"SP",PEN1%,";"
2570 RETURN
3000 REM
3010 REM ********DRAW REFERENCE CIRCLE WITH DEGREES ON PERIMETER********
3020 PRINT #1,"PA",0,0,";"
3030 PRINT #1,"CI,1,1;"
3040 PRINT #1,"PU;"
3050 PRINT #1,"SR1.6,2;"
3060 IF STEP1% < 10 THEN D = 10 ELSE D = STEP1%
3070 FOR I% = 0 TO 360 - D STEP D
3080 X1 = E * SIN(I% * RADIAN)
3090 Y1 = E * COS(I% * RADIAN)
3100 PRINT #1,"PA"
3110 PRINT #1,USING"####.######";X1-SET1,Y1-SET2
3120 PRINT #1,";"
3130 PRINT #1,"LB",I%,CHR$(3)
3140 SET1 = .35:SET2 = .012
3150 NEXT I%
3160 IF CHOICE = 1 OR CHOICE = 3 GOTO 3240
3170 REM ******DRAW FRICTION CIRCLE******
3180 RAD = TAN((90 - FRICTION) * RADIAN/2)
3190 PRINT #1,"LT2;"
```

```
3200 PRINT #1,"PA",0,0,";"
3210 PRINT #1,"CI",RAD,1,";"
3220 PRINT #1,"PU;"
3230 PRINT #1,"LT;"
3240 REM ********DRAW PROJECTION OF POLES********
3250 PRINT #1,"SP",PEN3%,";"
3260 FOR Q% = 1 TO DISC%
3270 RADIUS = TAN(DISCDIP(Q%)/2*RADIAN)
3280 Y0 = -RADIUS * COS(DISCAZ(Q%) * RADIAN)
3290 X0 = -RADIUS * SIN(DISCAZ(Q%) * RADIAN)
3300 PRINT #1,"PA"
3310 PRINT #1,USING"####.######";X0,Y0
3320 PRINT #1,";CI,.006,10;"
3330 PRINT #1,";CI,.003,10;"
3340 PRINT #1,"PU"
3350 IF DISCAZ(Q%) <= 180 THEN SET4% = 0 ELSE SET4% = -3
3360 PRINT #1,"CP",SET4%,"-.25,LB";Q%;+ CHR$(3)
3370 NEXT Q%
3380 RETURN
4000 REM
4010 REM******THIS ROUTINE DRAWS THE GREAT CIRCLES******
4020 IF CHOICE = 3 OR CHOICE = 4 THEN T% = DISC% + 1 ELSE T% = DISC%
4030 FOR G% = 1 TO T%
4040 TEM1 = DISCAZ(G%) * RADIAN
4050 TEM2 = (90 - DISCDIP(G%)) * RADIAN
4060 TEM3 = DISCDIP(G%) * RADIAN
4070 TEM4 = 90 - DISCDIP(G%)
4080 AX =  COS(TEM1)
4090 AY = -SIN(TEM1)
4100 MX =  SIN(TEM1) * TAN(TEM2/2)
4110 MY =  COS(TEM1) * TAN(TEM2/2)
4120 CX = -SIN(TEM1) * TAN(TEM3)
4130 CY = -COS(TEM1) * TAN(TEM3)
4140 DX = CX - MX
4150 DY = CY - MY
4160 IF G% = DISC% + 1 THEN PRINT #1,"LT;" ELSE PRINT #1,"LT4,10;"
4170 IF TEM4 >= 7 GOTO 4280
4180 PRINT #1,"PA"
4190 PRINT #1, USING"####.#####";AX,AY
4200 PRINT #1,"PD;"
4210 PRINT #1,"PA"
4220 PRINT #1, USING"#####.#####";MX,MY
4230 PRINT #1,";PA"
4240 PRINT #1, USING"#####.#####";-AX,-AY
4250 PRINT #1,";PU;"
4260 PRINT #1,"PA"
4270 GOTO  4390
4280 PRINT #1,"PA"
4290 PRINT #1, USING"####.#####";MX,MY
4300 PRINT #1,"PD"
4310 PRINT #1,"AR"
4320 PRINT #1, USING"#####.#####";DX,DY,TEM4,1
4330 PRINT #1,";PU;PA"
```

```
4340 PRINT #1, USING"####.#####";MX,MY
4350 PRINT #1,"PD;"
4360 PRINT #1,"AR"
4370 PRINT #1, USING"#####.#####";DX,DY,-TEM4,1
4380 PRINT #1,";PU;"
4390 IF G% < DISC% + 1 GOTO 4460
4400 PRINT #1,"PA"
4410 PRINT #1, USING"####.#####";AX,AY
4420 PRINT #1,"PD;"
4430 PRINT #1,"PA"
4440 PRINT #1, USING"#####.#####";-AX,-AY
4450 PRINT #1,";PU;"
4460 NEXT G%
4470 RETURN
5000 REM
5010 REM ******THIS ROUTINE LABELS THE PLOT*******
5020 PRINT #1, "SP",PEN4%,";"
5030 PRINT #1, "PA-1.1",B + .1 ";"
5040 PRINT #1, "LB";PLOT1$;+ CHR$(3)
5050 PRINT #1, "PA-1.1",B ";"
5060 PRINT #1, "LB";PLOT2$;+ CHR$(3)
5070 B = B - .01
5080 PRINT #1, "PA-1.1",B ";"
5090 PRINT #1, "LB";PLOT3$;+ CHR$(3)
5100 FOR L% = 1 TO DISC%
5110 B = B - .05
5120 PRINT #1, "PA-1.1",B";"
5130 PRINT #1, "LB"
5140 PRINT #1,USING OUTPT$;L%,DISCAZ(L%),DISCDIP(L%)
5150 PRINT #1, + CHR$(3)
5160 NEXT L%
5170 PRINT #1, "PA.5",F ";"
5180 PRINT #1, "LB";PLOT5$;+ CHR$(3):F = F - .1
5190 PRINT #1, "PA.5",F ";"
5200 IF CHOICE = 1 OR CHOICE = 2 GOTO 5230
5210 PRINT #1, "LB";PLOT9$;+ CHR$(3);"PR.05,0;PD;LT;PR.2,0;PU;":F = F - .05
5220 PRINT #1, "PA.5",F ";"
5230 IF CHOICE = 1 OR CHOICE = 3 GOTO 5260
5240 PRINT #1, "LB";PLOT10$;+ CHR$(3);"PR.05,0;PD;LT2;PR.2,0;PU":F = F - .05
5250 PRINT #1, "PA.5",F ";"
5260 PRINT #1, "LB";PLOT11$;+ CHR$(3);"PR.05,0;PD;LT4,10;PR.2,0;PU":F = F - .1
5270 PRINT #1, "PA.5",F ";"
5280 IF CHOICE = 1 GOTO 5400
5290 PRINT #1, "LB";PLOT12$;+ CHR$(3);:F = F - .1
5300 PRINT #1, "PA.5",F ";"
5310 IF CHOICE = 1 OR CHOICE = 2 GOTO 5370
5320 L% = DISC% + 1
5330 PRINT #1, "LB";PLOT7$;DISCDIP(L%);+ CHR$(3): F = F - .05
5340 PRINT #1, "PA.5",F ";"
5350 PRINT #1, "LB";PLOT6$;DISCAZ(L%);+ CHR$(3): F = F - .05
5360 PRINT #1, "PA.5",F ";"
5370 IF CHOICE = 1 OR CHOICE = 3 GOTO 5400
5380 PRINT #1, "LB";PLOT8$;FRICTION;+ CHR$(3):F = F - .05
```

```
5390 PRINT #1, "PA.5",F ";"
5400 RETURN
6000 REM
6010 REM ******THIS ROUTINE CENTERS A TITLE BELOW THE PLOT******
6020 CLS
6030 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
6040 PRINT "  THERE IS ROOM FOR 4 LINES CONTAINING UP TO 60 CHARACTERS"
6050 PRINT "            EACH LINE WILL BE AUTOMATICALLY CENTERED"
6060 PRINT:PRINT
6070 INPUT " HOW MANY LINES OF TEXT WILL BE ENTERED ";CNT%
6080 PRINT #1, "SR2.6,3.1;"
6090 FOR J% = 1 TO CNT%
6100 PRINT:PRINT
6110 G$ = " "
6120 PRINT " ENTER LINE ";J%
6130 PRINT:INPUT G$
6140 PRINT #1, "PA0",-T";"
6150 PRINT #1, "CP";-LEN(G$)/2;"-.5,LB";G$;+ CHR$(3)
6160 T = T + .05
6170 NEXT J%
6180 RETURN
7000 REM
7010 REM *******THIS ROUTINE DEFINES FUNCTIONS AND CONSTANTS*******
7020 RADIAN = 3.1415926#/180:ROOT2=SQR(2)
7030 E = 1.06:SET1 = .32:SET2 =.015:T = 1.3:B = 1.5:F = 1.6
7040 DEF FNARCSIN(X) = ATN(X/SQR(1-X*X))
7050 DEF FNARCCOS(X) = 1.570796 - ATN(X/SQR(1-X*X))
7060 PLOT1$ = " DISCONTINUITY DATA"
7070 PLOT2$ = "     AZIMUTH   DIP"
7080 PLOT3$ = "     ________  ___  "
7090 OUTPT$ = "##.  ###.##  ##.## "
7100 PLOT5$ = "  LEGEND"
7110 PLOT6$ = "  DIP AZIMUTH    :"
7120 PLOT7$ = "  DIP OF SLOPE   :"
7130 PLOT8$ = "  FRICTION ANGLE :"
7140 PLOT9$ = "  SLOPE FACE     "
7150 PLOT10$= "  FRICTION CIRCLE"
7160 PLOT11$= "  DISCONTINUITY  "
7170 PLOT12$= "  DATA  "
7180 RETURN
```

```
10 REM *************************************************
20 REM *                STABLE                         *
30 REM *  THIS PROGRAM ANALYTICALLY LOCATES             *
40 REM * KINEMATICALLY FEASIBLE FAILURE PLANES         *
50 REM *************************************************
60 GOSUB 7000
70 GOSUB 1000
80 GOSUB 2000
90 GOSUB 3000
100 GOSUB 4000
110 GOSUB 5000
120 GOSUB 6000
130 CHAIN "MENU"
1000 REM
1010 REM ******THIS ROUTINE ALLOWS KEYBOARD INPUT OF DATA******
1020 CLS
1030 PRINT:PRINT
1040 INPUT "  ENTER THE NUMBER OF DISCONTINUITY PLANES FOR ANALYSIS ";DISC%
1050 FOR I% = 1 TO DISC%
1060 CLS
1070 PRINT:PRINT
1080 PRINT "  PLEASE ENTER THE FOLLOWING DATA FOR DISCONTINUITY NUMBER ";I%;
1090 PRINT:PRINT
1100 PRINT:PRINT
1110 INPUT "  ENTER DIP AZIMUTH (345, 034 etc.) ";DISCAZ(I%)
1120 IF DISCAZ(I%) <=360 AND DISCAZ(I%) >= 0 THEN 1150
1130 BEEP:PRINT:PRINT:PRINT "  INVALID DIP AZIMUTH, RE-ENTER"
1140 GOTO 1100
1150 PRINT:PRINT
1160 INPUT "  ENTER DIP (87, 07) ";DISCDIP(I%)
1170 IF DISCDIP(I%) <= 90 AND DISCDIP(I%) >= 0 THEN 1200
1180 BEEP:PRINT:PRINT:PRINT "  INVALID DIP, RE-ENTER"
1190 GOTO 1150
1200 PRINT:PRINT
1210 INPUT "  ENTER THE FRICTION ANGLE ALONG THIS PLANE ";FRICTION(I%)
1220 IF FRICTION(I%) <= 90 AND FRICTION(I%) >= 0 THEN 1250
1230 BEEP:PRINT:PRINT:PRINT "  INVALID FRICTION ANGLE, RE-ENTER"
1240 GOTO 1200
1250 NEXT I%
1260 CLS
1270 PRINT:PRINT
1280 PRINT "  PLEASE ENTER THE FOLLOWING DATA FOR THE FREE SURFACE"
1290 PRINT:PRINT
1300 PRINT:PRINT
1310 T% = 1
1320 INPUT "  ENTER DIP AZIMUTH (345, 034 etc.) ";FREEAZ(T%)
1330 IF FREEAZ(T%) <=360 AND FREEAZ(T%) >= 0 THEN 1360
1340 BEEP:PRINT:PRINT:PRINT "  INVALID DIP AZIMUTH, RE-ENTER"
1350 GOTO 1300
1360 PRINT:PRINT
1370 INPUT "  ENTER DIP (87, 07) ";FREEDIP(T%)
1380 IF FREEDIP(T%) <= 90 AND FREEDIP(T%) >= 0 THEN 1410
1390 BEEP:PRINT:PRINT:PRINT "  INVALID DIP, RE-ENTER"
```

```
1400 CLS
1410 PRINT:PRINT
1420 PRINT " ENTER A TITLE OF UP TO 60 CHARACTERS FOR THE PRINTOUT"
1430 INPUT TITLE$
1440 PRINT:PRINT:PRINT
1450 INPUT " READY THE LINE PRINTER, HIT <CR> TO CONTINUE ";A$
1460 CLS
1470 FOR T = 1 TO 10:PRINT: NEXT T
1480 PRINT TAB(20);"******CALCULATION IN PROGRESS******"
1490 RETURN
2000 REM
2010 REM ******THIS ROUTINE LOADS THE DIRECTION COSINES INTO ARRAYS******
2020 FOR A% = 1 TO DISC%
2030 AZ(A%)  = DISCAZ(A%) * RADIAN
2040 INC(A%) = DISCDIP(A%) * RADIAN
2050 CN(A%)  = -SIN(INC(A%)) * COS(AZ(A%))
2060 CE(A%)  = -SIN(INC(A%)) * SIN(AZ(A%))
2070 CD(A%)  = COS(INC(A%))
2080 NEXT A%
2090 RETURN
3000 REM
3010 REM ******THIS ROUTINE ANALYZES THE POSSIBILITY OF PLANAR FAILURE******
3020 MAXPLANE = 90
3030 FOR J% = 1 TO DISC%
3040 CHECK(J%) = ABS(DISCAZ(J%) - FREEAZ(T%))
3050 IF CHECK(J%) > 20 AND CHECK(J%) < 340 THEN PLANESTAB$(J%) = " NO":
 GOTO 3100
3060 IF DISCDIP(J%) <= FRICTION(J%) THEN PLANESTAB$(J%) = " NO":GOTO 3100
3070 PLANEFAIL(J%) = DISCDIP(J%)
3080 IF  PLANEFAIL(J%) <FREEDIP(T%) THEN PLANESTAB$(J%) = "YES"
   ELSE PLANESTAB$(J%) = " NO"
3090 IF PLANEFAIL(J%) < MAXPLANE THEN MAXPLANE = PLANEFAIL(J%)
3100 NEXT J%
3110 RETURN
4000 REM
4010 REM ******THIS ROUTINE CHECKS FOR POTENTIAL TOPPLING FAILURE******
4020 TOPPLE$ = "NO"
4030 FOR J% = 1 TO DISC%
4040 CHECK(J%) = ABS(DISCAZ(J%) - FREEAZ(T%))
4050 IF CHECK(J%) < 160 OR CHECK(J%) > 200 GOTO 4070
4060 IF DISCDIP(J%) >= FREEDIP(T%) THEN TOPPLE$ = "YES"
4070 NEXT J%
4080 RETURN
5000 REM
5010 REM ******THIS ROUTINE PERFORMS SIMPLE WEDGE FAILURE ANALYSIS******
5020 X2 = COS(FREEAZ(T%) * RADIAN)
5030 Y2 = -SIN(FREEAZ(T%) * RADIAN)
5040 Z2 = 0
5050 FOR K% = 1 TO DISC%
5060 FOR L% = 1 TO DISC%
5070 IF L% = K% THEN CK$(K%,L%) = "SKIP":GOTO 5330
5080 X = (CN(K%) * CD(L%)) - (CN(L%) * CD(K%))
5090 Y = (CE(L%) * CD(K%)) - (CE(K%) * CD(L%))
```

```
5100 Z = (CE(K%) * CN(L%)) - (CE(L%) * CN(K%))
5110 R = SQR((X*X) + (Y*Y) + (Z*Z))
5120 X = X/R
5130 Y = Y/R
5140 Z = Z/R
5150 TRIAL3 = FNARCSIN(Z)
5160 IF TRIAL3 < 0 THEN CK$(K%,L%) = "SKIP":GOTO 5330
5170 TEMPA = Y/COS(TRIAL3)
5180 TEMPB = X/COS(TRIAL3)
5190 IF TEMPA > 1 THEN ADJUST = -2 ELSE ADJUST = 2
5200 WHILE TEMPA > 1 :TEMPA = TEMPA + ADJUST:WEND
5210 WHILE TEMPA < -1 :TEMPA = TEMPA + ADJUST:WEND
5220 IF TEMPB > 1 THEN ADJUST = -2 ELSE ADJUST = 2
5230 WHILE TEMPB < -1 :TEMPB = TEMPB + ADJUST:WEND
5240 WHILE TEMPB > 1 :TEMPB = TEMPB + ADJUST:WEND
5250 TRIAL1 = INT(FNARCCOS(TEMPA) * 100 /RADIAN)/100
5260 TRIAL2 = INT(FNARCSIN(TEMPB) * 100 /RADIAN)/100
5270 PLUNGE(K%,L%) = INT(TRIAL3 * 100/RADIAN)/100
5280 IF  TEMPB >= 0 THEN TREND(K%,L%) = TRIAL1
 ELSE TREND(K%,L%) = 360 - TRIAL1
5290 CX = (-Y2 * Z)/((X * Y2) - (X2 * Y))
5300 CY = (X2 * Z)/((X * Y2) - (X2 * Y))
5310 TEMP3 = SQR((CX - X2)^2 + (CY - Y2)^2)
5320 APRNTDIP(K%,L%) = FNARCCOS(1/TEMP3)/RADIAN
5330 NEXT L%
5340 NEXT K%
5350 REM ******THIS SECTION ANALYZES THE WEDGES FOR FAILURE******
5360 MAX = 90
5370 FOR K% = 1 TO DISC%
5380 FOR L% = 1 TO DISC%
5390 IF  FRICTION(K%) < FRICTION(L%) THEN FRIC(K%,L%) = FRICTION(K%)
  ELSE FRIC(K%,L%) = FRICTION(L%)
5400 CHECK = ABS(TREND(K%,L%) - FREEAZ(T%))
5410 IF CHECK >=90 AND CHECK <= 270 THEN WEDGESTAB$(K%,L%) = " NO":
  MAXWEDGE(K%,L%) = 90: GOTO 5460
5420 IF  PLUNGE(K%,L%) < = FRIC(K%,L%) THEN WEDGESTAB$(K%,L%) =" NO":
   MAXWEDGE(K%,L%) = 90:GOTO 5460
5430 MAXWEDGE(K%,L%) = APRNTDIP(K%,L%)
5440 IF MAXWEDGE(K%,L%) < FREEDIP(T%) THEN WEDGESTAB$(K%,L%) ="YES"
 ELSE WEDGESTAB$(K%,L%) = " NO"
5450 IF MAXWEDGE(K%,L%) < MAX THEN MAX = MAXWEDGE(K%,L%)
5460 NEXT L%
5470 NEXT K%
5480 RETURN
6000 REM
6010 REM ******THIS ROUTINE SENDS OUTPUT TO THE LINE PRINTER******
6020 LPRINT CHR$(27)+"!"+CHR$(152):LPRINT TITLE$:LPRINT CHR$(27)+"!"+CHR$(0)
6030 LPRINT:LPRINT
6040 LPRINT CHR$(27)+"!"+CHR$(152):LPRINT FORM1$:LPRINT CHR$(27)+"!"+CHR$(0)
6050 LPRINT USING FORM2$;FREEAZ(T%)
6060 LPRINT USING FORM3$;FREEDIP(T%)
6070 FOR I = 1 TO 4:LPRINT:NEXT I
6080 LPRINT CHR$(27)+"!"+CHR$(152):LPRINT FORM4$:LPRINT CHR$(27)+"!"+CHR$(0)
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```
6090 LPRINT FORM5$
6100 LPRINT FORM6$
6110 LPRINT FORM7$
6120 FOR A% = 1 TO DISC%
6130 LPRINT USING FORM8$;A%;DISCAZ(A%);DISCDIP(A%);FRICTION(A%);PLANESTAB$(A%)
6140 NEXT A%
6150 LPRINT:LPRINT
6160 IF MAXPLANE = 90 THEN LPRINT FORM11$:GOTO 6190
6170 LPRINT USING FORM9$;MAXPLANE
6180 LPRINT FORM10$
6190 FOR I = 1 TO 4:LPRINT:NEXT I
6200 LPRINT CHR$(27)+"!"+CHR$(152):LPRINT FORM12$:LPRINT CHR$(27)+"!"+CHR$(0)
6210 LPRINT FORM13$
6220 LPRINT FORM14$
6230 LPRINT FORM15$
6240 FOR K% = 1 TO DISC%
6250 FOR L% = 1 TO DISC%
6260 IF CK$(K%,L%) = "SKIP" GOTO 6280
6270                                   LPRINT                              USING
FORM16$;K%;L%;PLUNGE(K%,L%);TREND(K%,L%);WEDGESTAB$(K%,L%);MAXWEDGE(K%,L%)
6280 NEXT L%
6290 NEXT K%
6300 LPRINT:LPRINT
6310 IF MAX = 90  THEN LPRINT FORM18$:LPRINT FORM19$: GOTO 6340
6320 LPRINT USING FORM17$;MAX
6330 LPRINT FORM10$
6340 LPRINT:LPRINT
6350 LPRINT CHR$(27)+"!"+CHR$(152):LPRINT FORM20$:LPRINT CHR$(27)+"!"+CHR$(0)
6360 IF TOPPLE$ = "YES" THEN LPRINT FORM21$ ELSE LPRINT FORM22$
6370 RETURN
7000 REM
7010 REM ******THIS ROUTINE ESTABLISHES FUNCTIONS AND CONSTANTS******
7020 DEF FNARCSIN(X) = ATN(X/SQR(1-X*X))
7030 DEF FNARCCOS(X) = 1.570796 - ATN(X/SQR(1-X*X))
7040 RADIAN = 3.1415926#/180:ROOT2 = SQR(2)
7050 FORM1$ ="SLOPE ORIENTATION"
7060 FORM2$ ="DIP AZIMUTH: ###"
7070 FORM3$ ="DIP        :  ##"
7080 FORM4$ ="KINEMATIC ANALYSIS OF PLANAR FAILURE ALONG DISCONTINUITES"
7090 FORM5$ ="        DIP             FRICTION   POTENTIAL FOR "
7100 FORM6$ =" #    AZIMUTH     DIP     ANGLE     PLANAR FAILURE"
7110 FORM7$ ="---   --------    ---     -----     --------------"
7120 FORM8$ ="##.     ###        ##       ##          \ \       "
7130 FORM9$ ="AT SLOPE ANGLES STEEPER THAN ##.##, A POTENTIAL FAILURE PLANE"
7140 FORM10$="WILL DAYLIGHT IN THE FACE OF A SLOPE WITH THE GIVEN ORIENTATION"
7150 FORM11$="THE GIVEN SLOPE IS STABLE WITH RESPECT TO PLANAR FAILURE"
7160 FORM12$="KINEMATIC ANALYSIS OF DISCONTINUITY INTERSECTIONS"
7170 FORM13$="PLANES                          DAYLIGHTS IN   DAYLIGHTS IF THE SLOPE"
7180 FORM14$="INVOLVED   PLUNGE    TREND   DESIGN SLOPE   IS CUT STEEPER THAN"
7190 FORM15$="--------   ------    -----   ------------   -------------------"
7200 FORM16$="## _&##     ##.##    ###.##      \ \              ##.##"
7210 FORM17$="AT SLOPE ANGLES STEEPER THAN ##.##, A POTENTIAL WEDGE FAILURE"
7220 FORM18$="THE WEDGES FORMED BY DISCONTINUITY INTERSECTIONS WILL"
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7230 FORM19$="NOT DAYLIGHT IN A SLOPE OF THE GIVEN ORIENTATION"
7240 FORM20$="ANALYSIS OF POTENTIAL TOPPLING FAILURE"
7250 FORM21$="BASIC CRITERIA INDICATES THAT POTENTIAL FOR TOPPLING EXISTS"
7260 FORM22$="BASIC CRITERIA INDICATES THAT POTENTIAL FOR TOPPLING IS LOW"
7270 RETURN
```