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SLOPE STABILITY SOFTWARE USAGE IN CANADA

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ABSTRACT

During the past few years there has been a considerable increase in the usage of slope stability computer programs in Canada. Programs have been used as a tool by the geotechnical engineer

a) for the design stage of excavations and embankments,

b) at the remedial stage after a failure has occurred, and

c) in detailed research studies for case histories.

The object of this paper is to present the status of slope stability computer program usage in Canada and outline the requirements for satisfactory slope stability software.

A comprehensive slope stability program has been developed at the University of Saskatchewan, Saskatoon, Canada, over the past ten years (Fredlund, 1974, 1975; Fredlund and Naderi, 1975; Krahn and Fredlund, 1976). The program has been distributed and used by universities, engineering consulting firms and government agencies. Many of the things learned during this period are summarized herein. In addition, a survey was conducted of most of the universities in Canada to ascertain the present status of slope stability computer program usage. Although the survey pertains only to Canada, the findings may be relevant to other countries.

STATUS OF SLOPE STABILITY COMPUTER PROGRAM USAGE AT CANADIAN UNIVERSITIES

Some of the results of the survey of the universities are presented in Table I. The following points can be made based on the based of the complete survey.

1) Most universities in Canada have one or more slope stability computer programs available for their usage.

2) Most computer programs have been developed either by a graduate student or a staff member to solve for the factor of safety by one of the methods of slices. The programs serve an immediate need but are generally not comprehensive and suitable for distribution.

3) The programs are generally in an "ad hoc" state with poor documentation. As a result they are not distributed outside of the University. As well, they are often in "cold storage."

4) The programs are generally used by one university staff member for some teaching (graduate and/or undergraduate) and a limited amount of consulting. However, most universities still do not make significant usage of a slope stability computer package as a teaching tool in soil mechanics. Generally, programs are used at either the undergraduate or graduate level but not both.

5) There are only a couple of slope stability programs developed that are well-documented and distributed on a routine basis by Canadian universities.

6) Universities appear to be slow, in general, to seek out and use computer programs they have not written.

7) Few universities are presently involved in the development of new slope stability software. The main reasons appear to be the widespread emphasis on the finite element method and the shortage of financial assistance for software development.

8) The most commonly available computer programs are for the Simplified Bishop method and the Morgenstern-Price method. Several universities have developed small computer programs for the Simplified Bishop method.

9) At many universities there seems to be little emphasis on the possible uses of slope stability software. This appears to be

TABLE I

SLOPE STABILITY COMPUTER PROGRAM USAGE IN CANADA

UNIVERSITY	METHOD OF ANALYSIS*	WRITTEN AT UNIVERSITY	DOCUMENTED & DISTRIBUTED	USAGE **		
				TEACHING	CONSULTING	RESEARCH
1	B	No	No	1	1	1
2	-	-	-	-	-	-
3	B,MP	B (No) MP (Yes)	B (No) MP (Yes)	0	2	2
4	F, B, JR	Yes	No	1	1	1
5	B, MP	B (Yes) MP (No)	No	1	1	1
6	B	No	No	1	1	0
7	F, B, S, C, JS, JR, MP	Yes	Yes	2	2	2
8	B	No	No	1	1	1
9	B, MP	No	No	2	1	2
10	B, JR, MP	B (Yes) Others (No)	B (Yes)	1	1	2
11	F, B, JR	JR (Yes) Others (No)	No	1	1	2
12	B	Yes	No	0	0	1
13	F, B, MP	No	No	2	2	1
14	B	Yes	Yes	1	1	1

* F - Fellenius or Ordinary
B - Simplified Bishop
S - Spencer
C - Corps of Engineers
JS - Janbu's Simplified
JR - Janbu's Rigorous
MP - Morgenstern-Price

** 0 - No usage
1 - Limited usage
2 - Considerable Usage

mainly due to limited usage of programs.

10) Very little consideration is given to 3-dimensional slope stability analyses and computer programs.

11) The integrated system software package LEASE (Simplified Bishop method) appears to be maintained on only a couple of university computer systems in Canada.

SLOPE STABILITY PROGRAM USAGE BY CONSULTING ENGINEERING FIRMS

The results of discussions with many of the consulting engineering firms in Canada can be summarized as follows:

1) There is a fairly extensive usage of slope stability software by large consulting engineering firms in Canada. Their usage has commenced during the past few years as a result of involvement in a large engineering project.

2) Up-keep of the programs and familiarity with their usage are problems that arise mainly due to the time lag between the usage of the program.

3) Small consulting engineering firms generally do not maintain their own slope stability software. They sometimes get assistance from larger consulting firms or utilize computer programs made available by software companies. Most often they attempt to manage without using computer programs.

4) The most commonly used methods are:

a) the Simplified Bishop method, and

b) the Morgenstern-Price method.

There is limited usage of:

a) the Ordinary method, and

b) Janbu's Rigorous method.

5) There has been a definite reduction in the usage of the

Ordinary or Fellenius method by geotechnical engineers during the past few years. At present, there is little use of this method in practice.

6) Consulting engineering firms desire to see more education at universities on the usage of slope stability programs.

7) Consulting engineering firms often have difficulty with the theory related to slope stability analyses. This is particularly true with respect to the relationship between the various methods of slices and the significance of each method. There is often confusion over the use of circular versus composite (or non circular) modes of failure and the information required for a complete slope stability study.

8) Few consulting engineering firms maintain 3-dimensional slope stability software. There is often confusion over whether a 2-dimensional or 3-dimensional analysis should be used.

9) Approximately one half of the consulting engineering firms have attempted to operate in cooperation with software companies. The working relationship has often proven to be somewhat unsatisfactory.

Numerous government agencies are presently in the process of gaining access to slope stability software. There seems to be an increased awareness of the usefulness of slope stability programs. Several government agencies have opted to use the large integrated systems such as ICES-LEASE (Hsiung and Christian, 1969) and GENESYS (Allwood, 1974).

ALGORITHM REQUIREMENTS OF A SLOPE STABILITY COMPUTER PACKAGE

A common complaint of slope stability computer programs is that they are too narrow in scope and not able to handle the wide range of problems encountered in practice. Some of the features related to the slope stability analysis that should be given consideration in developing or selecting software are:

1) <u>Types of Analyses</u> - The most common methods of slices are:

a. The Ordinary method. Other names given to this method are the Fellenius, Swedish Circle and Conventional method.

b. The Simplified Bishop method.

c. The Spencer method.

d. The Taylor Modified Swedish method or the Corps of Fngineers method. Both methods satisfy force equilibrium only and form a special case of Spencer's method.

e. Janbu's Simplified and Janbu's Rigorous methods.

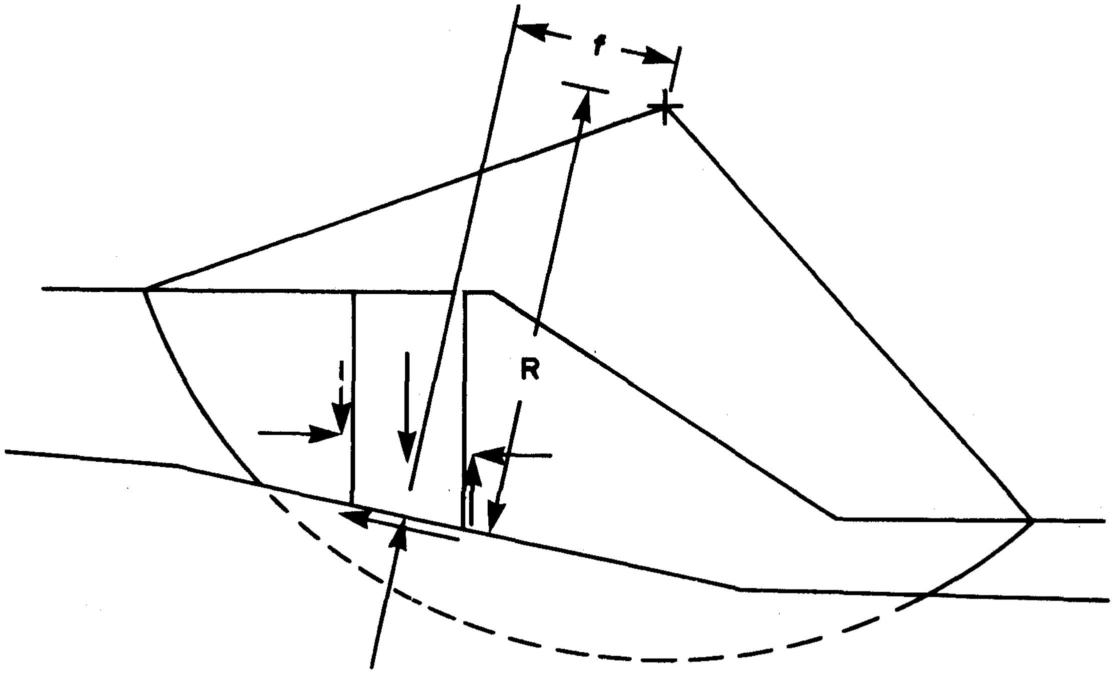
f. The Morgenstern-Price method.

Since all methods require essentially the same basic variables to be computed, there is little additional programming required to have more than one method of analysis in a program.

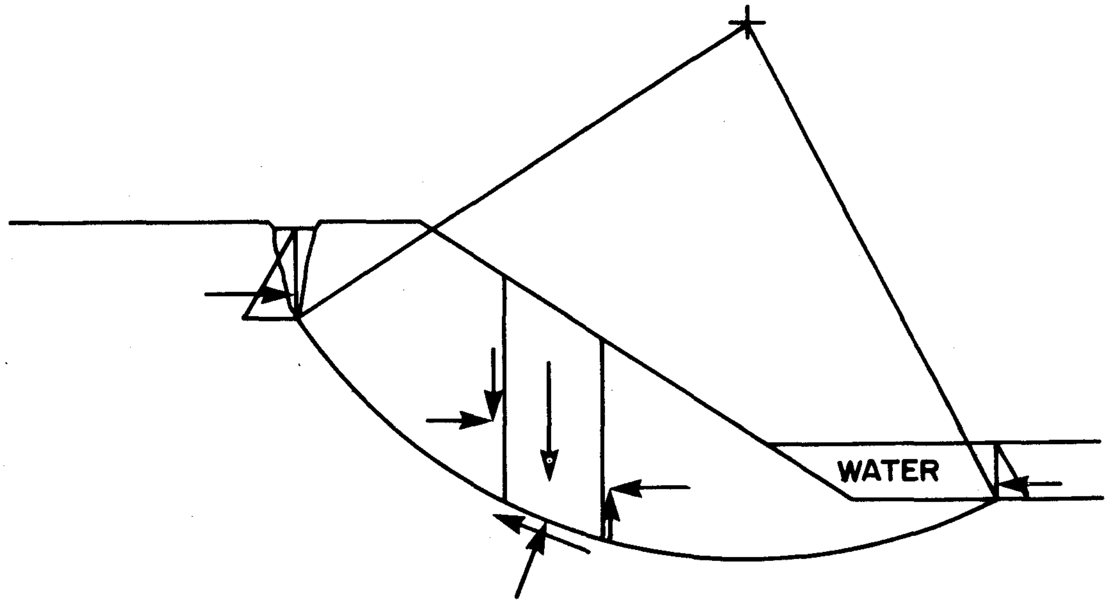
2) <u>Shape of Failure Surface</u> - Most slope stability computer programs will handle either a circular or composite (non circular) failure surface (Figure 1). Therefore, it may be necessary to maintain two programs to accommodate both cases. The composite failure surface should be capable of handling several soil types along the non circular portion of the failure surface (Figure 2a).

3) <u>Number of Stratigraphic Units</u> - The program should accommodate numerous lines delineating complex geometrics or stratigraphy. Approximately ten lines delineating soil types with at least ten points per line are generally satisfactory. The program should also be able to handle soil layers that bend backwards. Examples of this case are a soil layer that pinches out (Figure 2b) or zones of an earthfill dam that are discontinuous.

4) <u>Partial Submergence</u> - The calculations for the effect of partial submergence are handled independently of the soil layers (Figure 1b). The filling of water in a tension crack is also a situation that is handled similar to partial submergence.



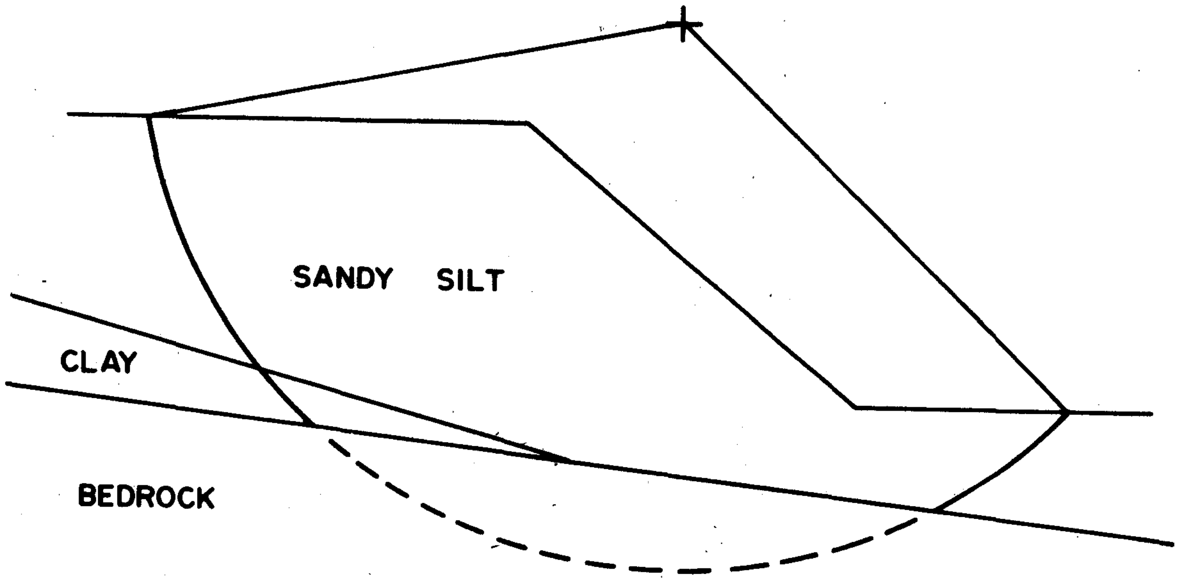
a) Composite failure surface



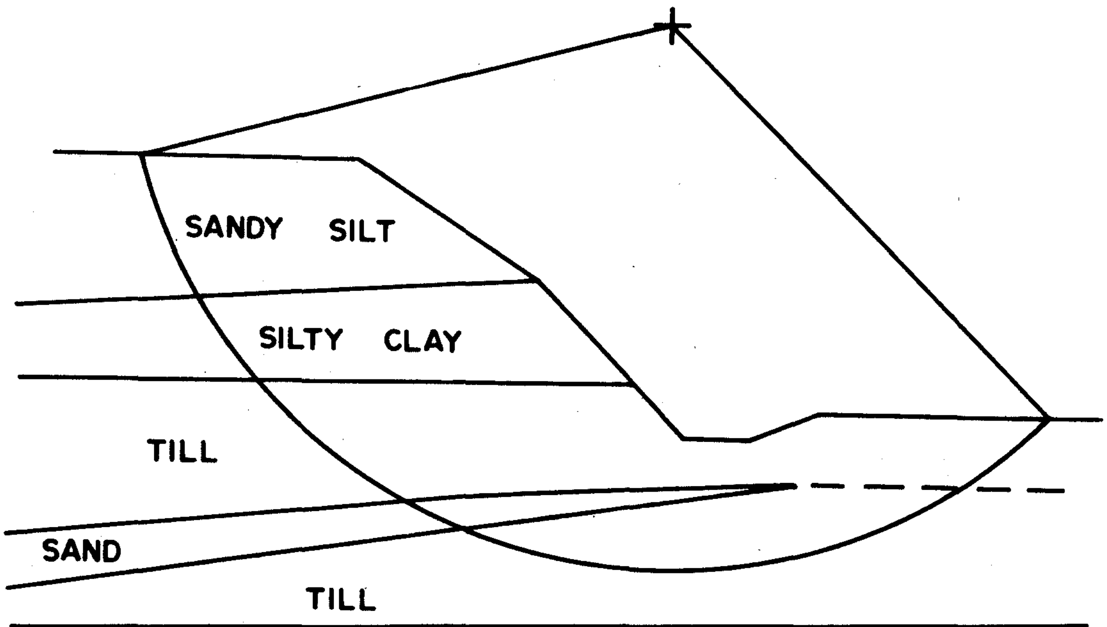
b) Partial submergence and tension cracks

Figure 1

TYPICAL SURFACE GEOMETRIES AND FAILURE SURFACES



a) Multiple soil types on composite surface



b) Sand lens pinching out

Figure 2

TYPICAL STRATIGRAPHIC AND SOIL CONDITIONS

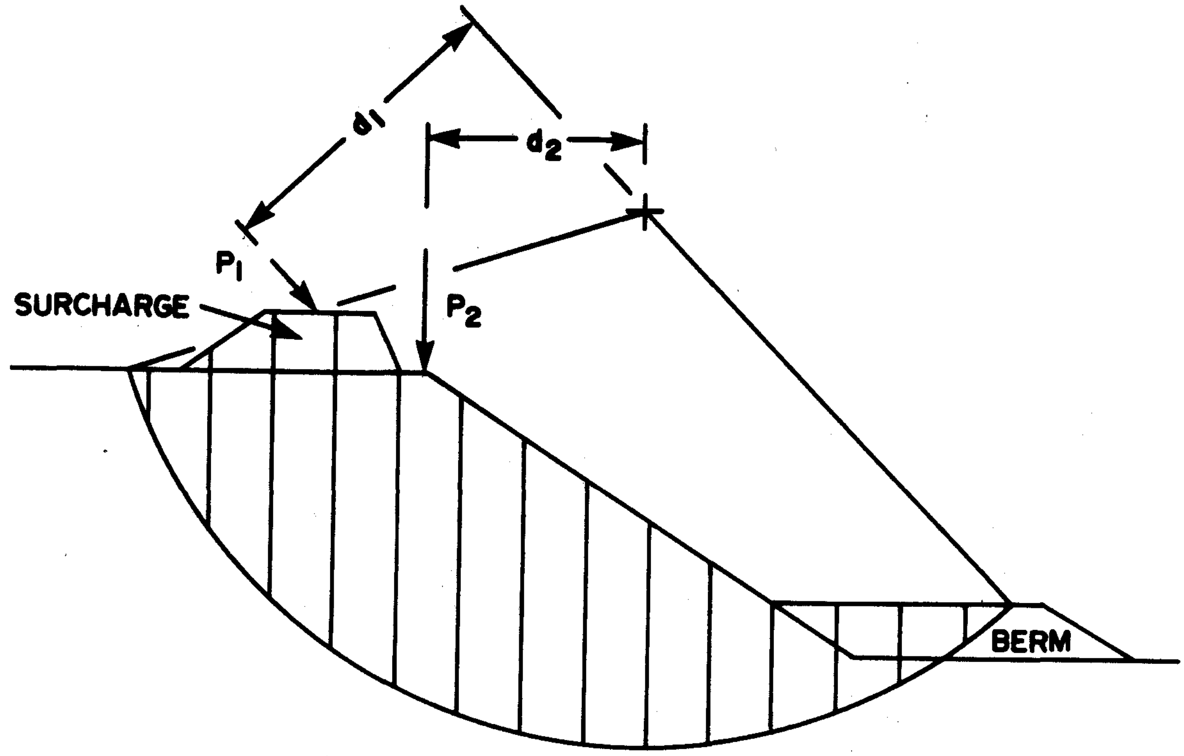
5) Surcharging and Berming - These are examples of a pressure being applied over a specified region (Figure 3a). These loadings are usually handled as a soil type. When this is done, the force from the surcharge or berm affects the computation of the normal force at the base of each slice.

6) External Line Loads - The program should accommodate several externally applied loads such as loadings due to a dragline or the restraint of a retaining wall. Line loads are treated differently than surcharges and berms in that they do not affect the normal force at the base of each slice (Figure 3a).

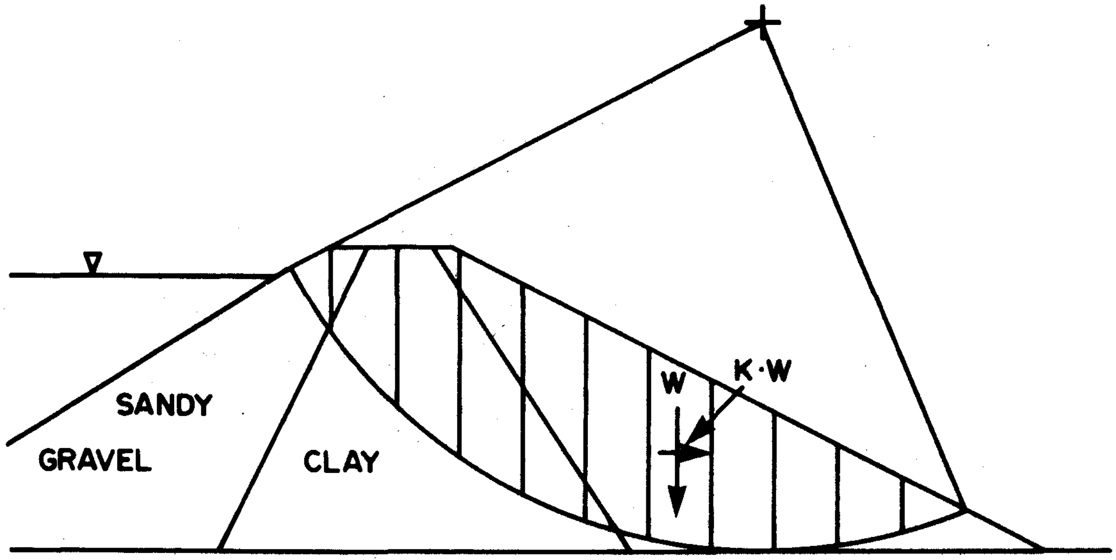
7) Earthquake Loading - The effects of accelerations related to earthquake and blasting operations are generally taken into account by applying a horizontal force through the centroid of each slice (Figure 3b). The magnitude of this force is expressed as a fraction of the slice weight.

8) Pore Water Pressures - Slope stability computer programs can be criticized for their lack of flexibility in handling different pore pressure conditions. Pore water pressure conditions can be subdivided into pressures that are dependent upon the soil stresses and those that are independent of soil stresses. The former category commonly pertains to the pore water pressures induced in the fill and foundation during the construction of an embankment. The pore pressure coefficient, r_u, specifies a linear relationship between pore water pressure and the overburden pressure. Hilf's analysis (1948) provides a non linear stress dependent procedure to specify pore water pressures in compacted fills. It is also possible to use a finite element numerical method along with "A and B" pore pressure parameters to describe the pore water pressures over a grid of locations superimposed upon the soil strata.

The steady state seepage situation, which is independent of the soil stresses, is commonly handled by converting the phreatic line of a flow net into an approximate piezometric line for a soil strata. It is also possible to specify the water pressures as a seepage body force acting through the centroid of each slice. If greater



a) Examples of external loads, berms and surcharges



b) Earthquake loading

Figure 3

TYPICAL EXTERNAL LOADS AND EARTHQUAKE LOADING sophistication and accuracy are desired, a grid of pore water pressures can be superimposed over the soil strata. The pore water pressures can be determined by:

a) sketching a flow net, or

b) using a finite difference or finite element seepage computer program.

An interpolation procedure is used to compute the pore water pressures at the base of each slice.

An embankment placed over insitu soil with hydrostatic or steady state seepage conditions is a situation where the pore water pressures required in the slope stability analysis are a combination of the stress dependent and stress independent cases (Figure 4).

9) Grid Search - Numerous search routines have been devised to locate the center of minimum factor of safety. However, none of the procedures are completely "fool proof" when dealing with problems with complex geometrics. For this reason many geotechnical engineers are reluctant to use such a search. The more reliable procedure is to define the x and y-coordinates of a grid and specify several radii ranging between two y-coordinates for each center. The plot of the minimum factors of safety at each point in the grid reveals the location of one or more minimums.

Most computer programs for non circular failure surfaces do not allow a rapid search for the situation of minimum factor of safety.

ADDITIONAL FACTORS PERTINENT TO SLOPE STABILITY PROGRAMS

There are several factors pertaining to programming and distribution that contribute to making a software package satisfactory (Schiffman and Jubenville, 1976). The most important factors with respect to slope stability programs are:

1) Portability - Portability is generally ensured when Basic Fortran is used that is consistent with the minimum standards

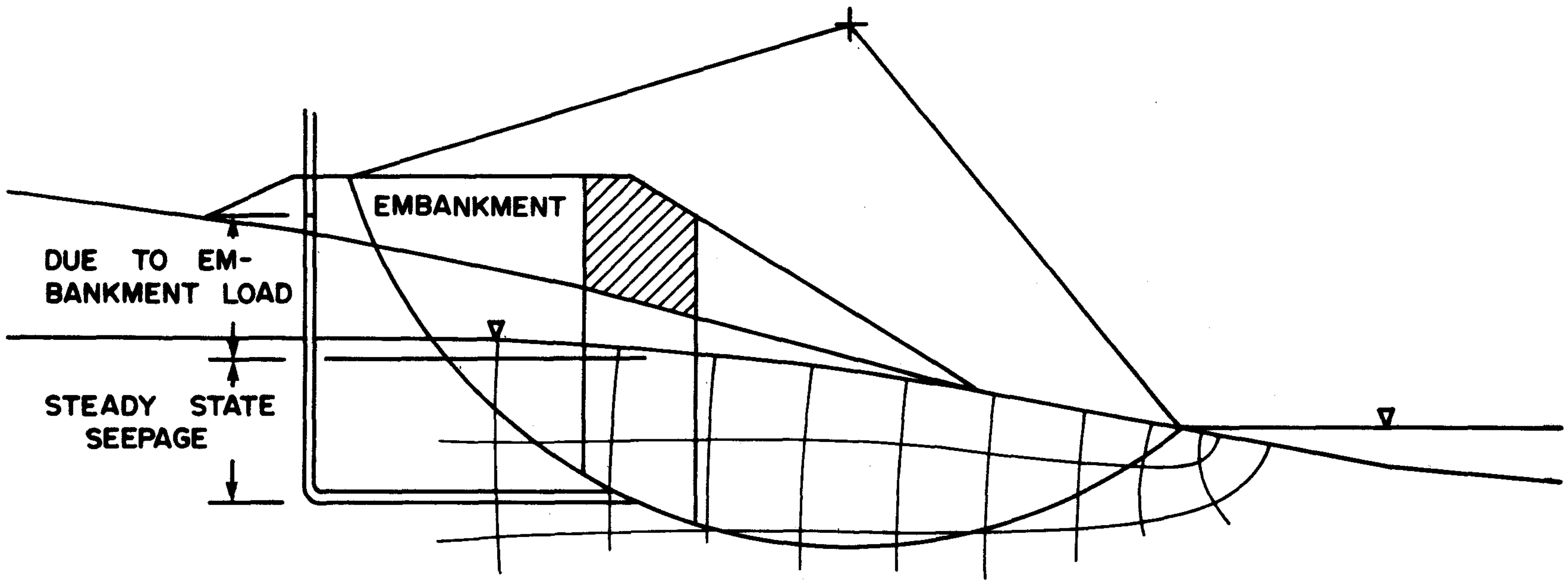


Figure 4

TYPICAL PORE WATER PRESSURE DUE TO STRESS DEPENDENT AND STRESS INDEPENDENT SOURCES established by national and international committees for the software community. The International Organization for Standards (i.e., ISO) and the American National Standards Institute (1966) publish software standards (i.e., ANSI) for the FORTRAN language.

2) Usability - In order for a program to be usable by another person, the program must be properly documented. In addition, it should be user-oriented with respect to data input and the amount of data output.

3) Credibility - Credibility pertains to the verification of the program to perform as advertised. First, the code should correctly execute the algorithms and second, there should be "benchmark" examples available that accurately reflect a high percentage of the coding.

4) Maintainability - Some errors are generally encountered in computer programs and there must be an organized procedure to implement program fixes for all users. As well, there should be a feedback system for modifications to enhance the program.

5) Education - An education effort is generally required to assist the engineering profession in the use of the slope stability software, theory and application.

6) Consultation - There must be a system whereby the user can receive decisive advice on the operation of the program.

SUMMARY

The survey of Canadian universities reveals that there is limited use of slope stability computer programs for undergraduate and graduate teaching. Consulting engineering firms feel that more education on the relationship between the various methods of slices, on available software and its application to practical problems, would be beneficial. The most commonly used procedures are the Simplified Bishop method for circular failure surfaces and the Morgenstern-Price method for non circular failure surfaces.

The geotechnical engineer should consider several computer system factors and slope stability analysis factors prior to selecting or developing one or more slope stability programs.

REFERENCES

Allwood, R. J., (1974), "GENESYS: Machine-Independent Software Sharing," Structural Mechanics Computer Programs (Edited by W. Pilkey, K. Saczalski and H. Schaeffer), University Press of Virginia, Charlottesville, Virginia, pp. 1073-1083.

American National Standards Institute, (1966), "American National Standard Basic FORTRAN," United States of American Standards Institute, X3.10-1966.

Fredlund, D. G., (1974), "Slope Stability Analysis (SLOPE), User's Manual CD-4," Publication of the Transportation and Geotechnical Group, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Fredlund, D. G., (1975), "A Comprehensive and Flexible Slope Stability Program," Presented at the Roads and Transportation Association of Canada, Calgary, Alberta, Canada.

Fredlund, D. G., and Naderi, F., (1975), "Slope Stability Analysis (SLOPE) Appendices, Manual CD-5," Publication of the Transportation and Geotechnical Group, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Hilf, J. W., (1948), "Estimating Construction Pore Pressures in Rolled Earth Dams," Second International Conference on Soil Mechanics and Foundation Engineering, Rotterdam, 3, pp. 234-240.

Krahn, J., and Fredlund, D. G., (1976), "Evaluation of the University of Saskatchewan Slope Stability Program," Presented at the Roads and Transportation Association of Canada, Quebec City, Quebec, Canada.

Schiffman, R. L., and Jubenville, D. M., (1976), "Software Coordination in Geotechnical Engineering," Numerical Methods in Geomechanics, (edited by C. S. Desai), American Society of Civil Engineers, 2, pp. 1228-1240.