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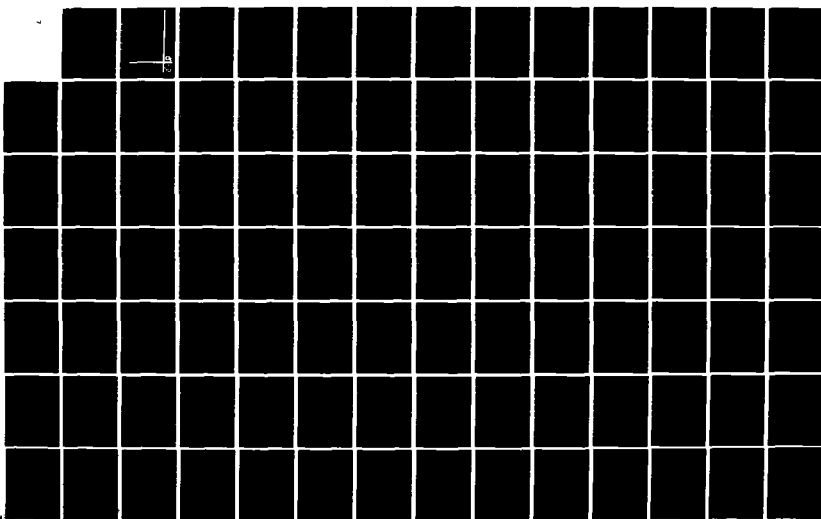
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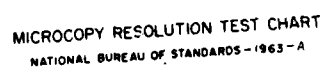
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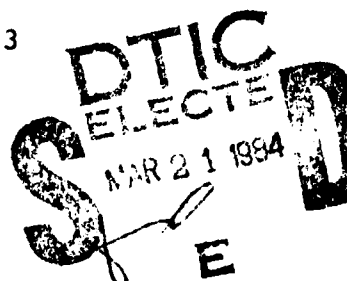
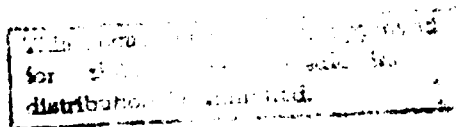
A SPECIAL RESEARCH PROBLEM

Presented to
The Faculty of the School of Civil Engineering
Georgia Institute of Technology

by
Dana Kevin Eddy

In Partial Fulfillment
of the Requirements for the Degree of
Master of Science in Civil Engineering

August 1983



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GEORGIA INSTITUTE OF TECHNOLOGY
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A very
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Report
R D Barksdale

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ABSTRACT

This report presents four geotechnical engineering programs for use on personal computing systems. An Apple II-Plus operating with DOS 3.3 Applesoft language was used. The programs include the solution of the signpost problem, the cantilevered sheet pile problem, the slope stability problem, and the flexible pavement design program.

Each chapter is independent and does not rely upon theories or data presented in other chapters. A chapter outlines the theory used and also presents a users guide, a program list, and verification of the program by hand calculation.

This report assimilates the product a practicing engineer would expect to receive when procuring software services.

CHAPTER I

INTRODUCTION

Micro-computers are rapidly becoming the work-horse of the small business and engineering world. All types of businesses are finding the micro-computer an invaluable tool. Uses range from cost accounting to word processing to an engineering calculating machine. The key advantages of personal computers over previous methods are its easy access, speed, reliability, and accuracy.

Engineering firms whose availability to main frame computing facilities have been limited by economics or demographics can now acquire personal computers and software for a fraction of the capital outlay. Software can be designed to fit the precise needs of the firm whereas firms used to cater their needs around an established software base. This is especially advantageous to specialized firms whose services demand repetitive engineering problems. Rather than expending labor on iterative problem solving, a personal computer matched with properly designed software can now provide engineering solutions at a fraction of the cost.

The introduction of the personal computer into the engineering firm provides a domino effect. The time which was once expended on iterative problem solving can now be devoted to more productive activity such as consideration of more complex problems and bidding strategy. Accordingly, the small engineering firm can now bid more jobs, accomplish more work and subsequently, increase the firm's net worth. It is becoming commonplace for short and long-range business plans to include the purchase and use of personal computers.

The personal computer is a godsend to the geotechnical engineer. Due to the nature of soil, the engineer is constantly dealing with lower and upper bounds of possible problem solutions. Unlike concrete and steel, soil has variable engineering properties and cannot be relied upon to perform in a consistent manner; consequently, the engineer must consider several possible combinations of soil behavior in order to provide a safe design. Once the soil characteristics have been normalized, the engineer uses mechanics of particulate matter to best approximate the response and behavior of soil acted upon by external forces and natural phenomena such as flow of water through the medium under a hydrostatic head.

At this point, the personal computer comes into play. The computer will calculate quantities and values according to a predetermined sequence. If the same input variables

are used, the computer will calculate identical values and quantities. The engineer then varies the input variables according to his evaluation of the possible conditions that may exist for a particular problem. The output will then represent a range of expected behavior of which the engineer will use for his design. Problems such as calculating the required penetration of a cantilevered wall can take up to four hours to calculate. This time represents several calculation iterations with one particular set of soil data. If no math errors were made, one possible bounding answer would be established. The same procedures would be repeated to establish another bound. Two trial boundary conditions have been established, but what if intermediate values are not linearly related to the boundary values? The prudent engineer would make intermediate value calculations. The time involved can be enormous. The personal computer can calculate iterative problems in a fraction of the time required to hand calculate the problems and without the math errors associated with hand calculations.

The scope of this special report is to program several iterative problems of interest to geotechnical engineers. The programs includes the calculation of the required depth of a vertical post subjected to lateral loads (SIGNPOST 1), the required penetration of a cantilevered wall (CANTWALL 1), and the design of flexible pavement (AASHTO 1). Additionally,

a slope stability program was translated and modified by the author (BISHOP 1).

No report of this nature would be complete without a warning about the ignorant use of computing software. Two major problems, separate or combined, can render the software and subsequent solutions totally useless. The user must understand the problem that the software is presumed to solve. In general, there are several methods or algorithms that can be used to solve engineering problems, but each method is best suited for a particular variation; furthermore, the solutions can significantly vary from one method to another. This is particularly evident with dynamic pile driving formulas. The user must understand the use and limitations of the program software. Although the user may understand the problem and its methods of solution, an erroneous entry or a program option inadvertently exercised can invalidate the computed solution. The solution should be scrutinized against past experience and sound engineering judgment. As a final check, a hand calculation of the final solution should be made. If the user allows the computer to perform the iterations and hand checks the final iteration, the user can be assured as to the validity of the computed solution.

It is the author's intent to convey a concise description of the software's use and limitations. It would behoove the

user to become completely familiar with the text prior to basing an engineering design on the calculated solutions. This is imperative where the possible loss of life is involved.

CHAPTER II

SIGNPOST PROBLEM

2.1 Problem Definition

The computer program "SIGNPOST 1" calculates the minimum safe embedment of a cantilevered pole subjected to lateral overturning loads. Figure 2.1 defines the input variables and general geometry of the problem. Plastic theory is utilized, thus considerable deflections are anticipated. All loads are laterally applied to the pole; overturning moments are resisted by passive earth pressure.

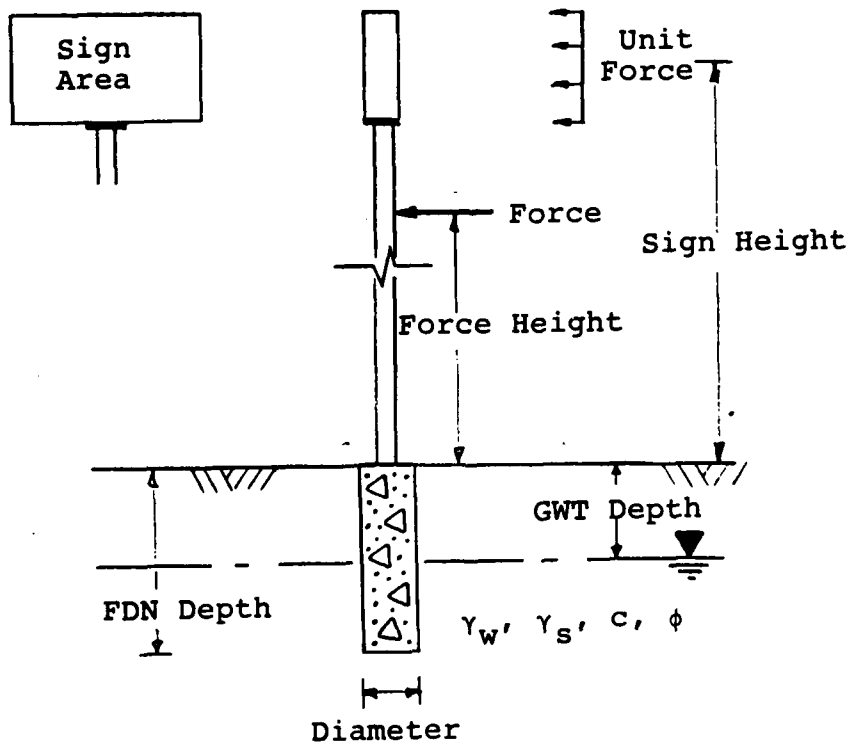


Figure 2.1. General Problem Definition.

2.2 Background Theory

Development of the laterally loaded cantilevered pole problem was initiated by J. F. Seiler in cooperation with the American Wood-Preservers' Association in the early 1930's [1]. Seiler correctly diagrammed the earth pressures about the embedded pole (Figure 2.2).

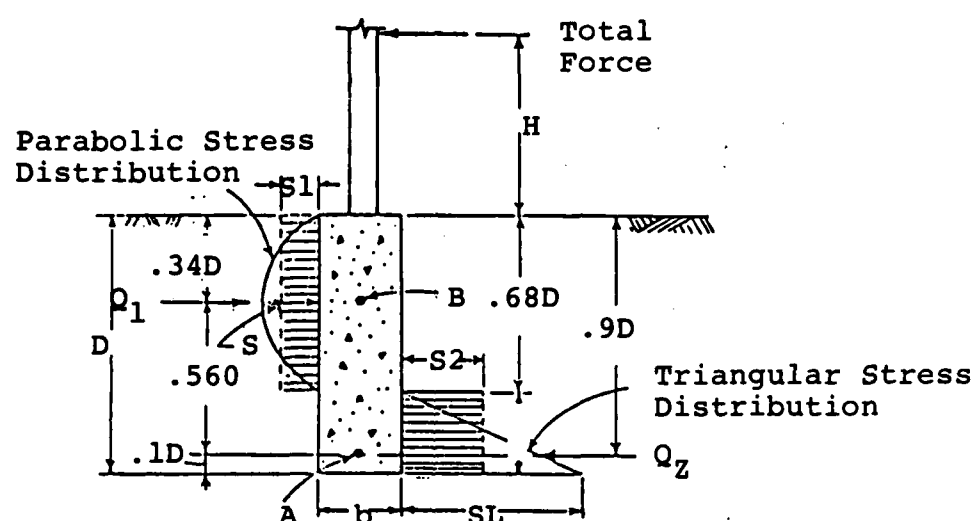


Figure 2.2. Stress Distribution on Foundation [3].

Seiler's objective was to classify embedment depths for particular timber pole classes, as industrial demand was increasing and the association felt an economic need existed for the correlation between pole class and required embedment. Timber poles are classified according to the strength in bending; Class 1 being the strongest, Class 6 the weakest in bending.

Seiler began his research on the premise that a particular pole class was best suited for a particular soil type. The most economic use of timber coupled with decreased labor of excavation lead to the conclusion that if a proper pole was used, it would develop its full bending strength just prior to soil failure. This conclusion is rational and warrants further investigation. Seiler, like many engineers, was unclear of the definition of soil failure. Although he properly perceived the earth pressure diagrams, Seiler's analysis focused on pole rotation when laterally loaded and ignored the soil pressures mobilized by the pole rotation.

A majority of the equations developed by this premise are contingent upon the angle of rotation the pole would undergo when laterally loaded. Although indirectly, Seiler was alluding to plastic theory, but allowed his stress analysis to go beyond the stress which would cause plastic failure. His analysis never made its debut in the engineering literature. Seiler adequately described the earth pressures and respective depths about the embedded pole.

In the early 1940's, Professor P. C. Rutledge was requested to devise a system by which embedment depths for signposts could be estimated. In association with the Outdoor Advertising Association of America, Professor Rutledge devised the nomograph as presented in Figure 2.3 [2].

SOIL TYPE DETERMINES ALLOWABLE STRESS, S.

Soil Type	Allowable Stress, S (lbs. per sq. ft.)
VERY SOFT	300
POOR	400 - 500
AVERAGE	600 - 1000
GOOD	1500 - 2500
VERY HARD	3000 - 4500

P = MAXIMUM LOAD ON POST IN POUNDS

C = COEFFICIENT OF POST STABILITY

S_a AND P REQUIRED TO DETERMINE C AND B

S_a = ALLOWABLE AVE. SOIL STRESS IN LBS. PER SQ. FT.

H = HEIGHT OF LOAD P ABOVE GROUND SURFACE IN FT.

L = DEPTH COEFFICIENT

b = WIDTH OF EMBEDDED SECTION OF POST IN

REQUIRED DEPTH OF EMBEDMENT IN FT.

DIAGRAM OF DIMENSIONS & LOADING CONDITIONS

SOLUTION FOR COEFFICIENT OF POST STABILITY

$$C = \frac{P}{S_1} = \frac{2.37D + 2.64H}{bD^2}$$

$$L = \frac{C}{b} = \frac{2.37D + 2.64H}{D^2}$$

CHART FOR EMBEDMENT OF POSTS WITH OVERTURNING LOADS BASED ON 1/2" MOTION AT GROUND SURFACE

OUTDOOR ADVERTISING ASSOCIATION OF AMERICA, INC. Chicago, Illinois

$$\frac{\text{MAXIMUM STRESS IN POST}}{\frac{P(H + 0.34D)}{\text{SECTION MODULUS}}} =$$

H = HEIGHT OF LOAD P
ABOVE GROUND SURFACE IN FT.

B - WIDTH OF EMBEDDED SECTION OF POST IN

C-Coefficient of Post Stability

P = MAXIMUM LOAD ON POST IN POUNDS

ALLOWABLE AVE.
SOIL STRESS IN
LBS. PER SQ. FT.

FOR SANDY &
GRAVELLY SOILS
FOR SILTS & CLAYS

50

b

a

AND P	DETERMINE	C AND b	DETERMINE
REQUIRED C		REQUIRED L	
TO USE CONNECT KNOWN VALUES BY STRAIGHT LINES			

SOIL TYPE DETERMINES ALLOWABLE STRESS. S.

AND P	DETERMINE	C AND b	DETERMINE
REQUIRED C		REQUIRED L	

REQUIRED DEPTH OF
EMBEDMENT OF POST

CHART FOR

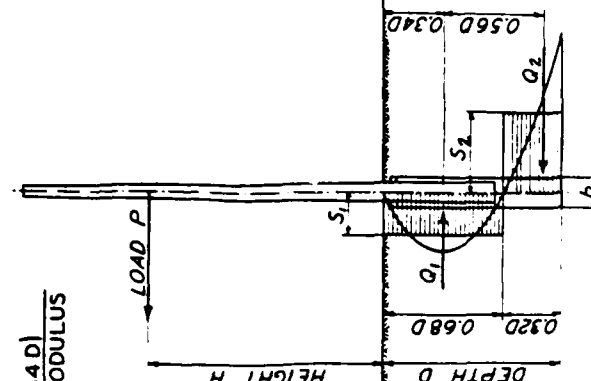
**EMBEDMENT OF POSTS
WITH OVERTURNING LOADS
BASED ON 1/2" MOTION AT GROUND SURFACE**
**OUTDOOR ADVERTISING ASSOCIATION
OF AMERICA, INC.**
Chicago, Illinois

DIAGRAM OF DIMENSIONS & LOADING CONDITIONS

SOLUTION FOR COEFFICIENT

OF POST STABILITY

$$C = \frac{C_D}{S_1} = \frac{2.37 D + 2.64 H}{S_1}$$



The basis of this nomograph was the earth pressure stress distribution as presented by J. F. Seiler (Fig. 2.2). By summing forces horizontally and summing moments about Q_1 , Rutledge developed the equation:

$$\frac{P}{S_1} = \frac{D^2 B}{2.37D + 2.64H}$$

and solving for D in the quadratic equation:

$$S_1 B D^2 - 2.37 P D - 2.64 P H = 0$$

$$D = \frac{2.37P + \sqrt{(2.37P)^2 + 4 \times 2.64 P S_1 B}}{2 S_1 B}$$

where,

D = embedment depth (ft)

P = lateral load (#)

S_1 = average passive soil pressure (#/ft²)

H = height of P above grade (ft)

B = diameter (ft)

S_1 is dependent upon depth as it is the passive soil resistance at .34D; thus, the above equation must be iterated.

To calculate a safe embedment depth, the soil pressure depths presented by Seiler and later used by Professor Rutledge were corroborated by Professors W. L. Shilts,

L. D. Graves, G. F. Driscoll of Notre Dame University and by Dr. J. O. Osterberg of Northwest University [2].

Due to the limited ability to test soils, and the lack of standardized soil classification, Rutledge devised a testing device which could be used to determine the in-situ average soil pressure (S_1) [2]. It consisted of a 1- $\frac{1}{2}$ " hand auger which after being rotated into the soil would be pulled up. The force required to pull out the auger was correlated to S_1 (Figure 2.3). A scale for cohesionless soils and a scale for silts and clays are provided. The nomograph is limited to embedment depths of 10', post diameters of 6" to 24" and a load height of 24'. The above equation must be used for any parameters beyond these boundaries.

In 1957, D. Patterson, being dissatisfied with Rutledges' soil test method, modified the nomograph to include five general soil type categories; i.e., very soft, poor soil, average soil, good soil, and very hard soil [2]. To augment this general classification, the following table was also provided:

Table 2.1. Generalized Soil Classifications.

Clay, in lumps, dry	Poor soil
Clay, damp, plastic	Poor soil
Clay and gravel, dry	Average soil
Clay, gravel and sand, dry	Average soil
Earth, loose, perfectly dry	Average soil
Earth, packed, perfectly dry	Average soil
Earth, loose, slightly moist	Average soil
Earth, packed, more moist	Very hard soil
Earth, soft flowing mud	Very soft soil
Earth, soft mud, packed	Poor soil
Gravel, one inch and under, dry	Good soil
Gravel, two and one-half inches and under, dry	Average soil
Sand, clean and dry	Average soil
Sand, river, dry	Average soil

Patterson contended that in the absence of better soil data the above table would yield satisfactory embedment depths.

In an effort to refine the soil data input, D. L. Ivey and L. Hawkins [3] applied Rankine's formula for passive soil resistance:

$$P_p = \gamma z N_{\phi} + 2c \sqrt{N_{\phi}}$$

$$N_{\phi} = \tan^2 (45^\circ + \phi/2)$$

With this formula, S_1 can be calculated using soil strength data, C and ϕ ; furthermore, introduction of a ground water table with subsequent bouyant forces can be accounted for.

Ivey and Hawkins extended the design process to include checking the lower stresses (S_2 & SL) against the allowable stresses calculated by Rankine formula. This is especially critical when the ground water table is at or near 0.68D as the lower allowable stresses will be reduced. Ivey and Hawkins recommended applying a safety factor to the design by dividing the ultimate passive resistance by a factor of safety prior to checking the working stresses (S_1 , S_2 , and SL).

2.3 Programming Rationale

The ultimate purpose of "SIGNPOST 1" is to provide the user a design depth capable of resisting a specified lateral load. The "Rutledge" method is used as modified by Ivey and Hawkins as described in Section 2.2. The program is user oriented in that all input is prompted by clear, concise questions displayed on the monitor prior to the appropriate input command. Output format is intended to provide easy identification of the calculated solutions and supplemented by intermediate values calculated during the program routine. The flow chart, Figure 2.4, is provided as a skeleton of basic routines and conditionals as well as the general sequence of events performed between the input of the problem parameters and the printed output.

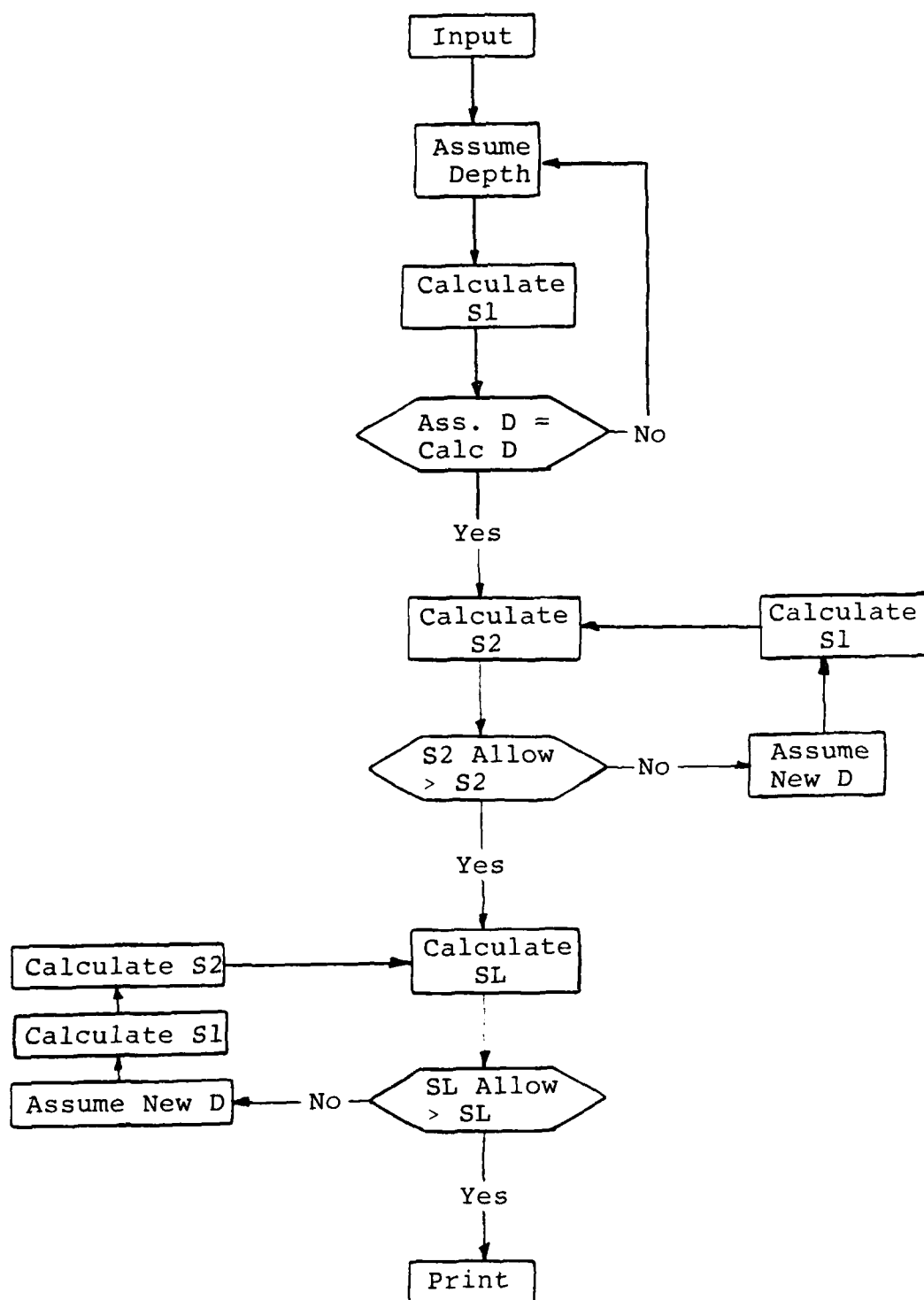


Figure 2.4 Simplified SIGNPOST1 Flow Chart.

2.4 Program Use and Limitations

2.4.1 General

"SIGNPOST 1" was programmed on an Apple II-Plus with 64K random access memory. The disk operating system was version 3.3 (DOS 3.3). Prior to using this program, the user should be familiar with the system control features of the Apple II-Plus. Namely, the user needs to know how to LOAD, RUN and use the return key; all other commands and options are integrated into the program.

As with any computer run, the user should have reviewed the required input parameters and have them available (preferably in order of response) prior to running the program. If more than one set of input parameters are to be used, it is recommended that a table be set up to prevent erroneous input and reduce input time.

2.4.2 Input

The following is a list of input parameters for SIGNPOST 1:

- a) number of runs
- b) angle of internal friction (degrees)
- c) cohesion (PSF)
- d) wet soil weight (PCF)
- e) saturated soil weight (PCF)
- f) wind pressure (PSF) (see Fig. 2.5)
- g) height to sign centroid (ft)
- h) sign area (SF)
- i) post load (#)
- j) ground water table depth (ft)
- k) number of diameters

RECOMMENDED MINIMUM DESIGN WIND PRESSURES
(Pounds per Square Foot)
(Based upon data obtained from U.S. WEATHER BUREAU and
AMERICAN STANDARD BUILDING REQUIREMENTS
A58.1-1945)

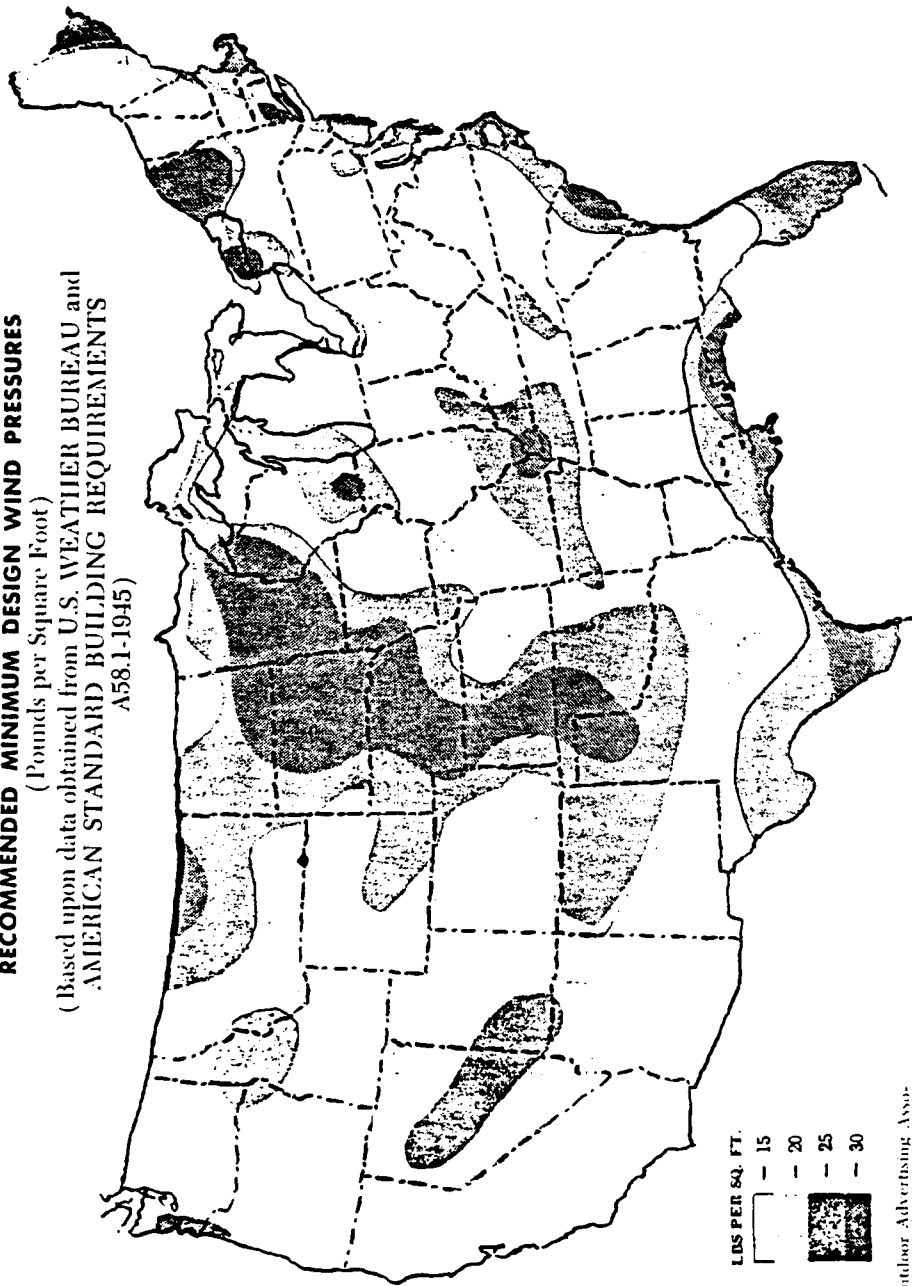


Figure 2.5. Recommended Minimum Design Wind Pressures[2].

- k₁) diameter #1 (ft)
- k₂) diameter #2 (ft)
- k_i) diameter #i (ft)
- l) safety factor
- m) depth calculation tolerance
- n) passive coefficient of earth pressure*

*Note: This quantity can be input or the program can calculate the passive coefficient of earth pressure at the option of the user.

2.4.3 Apple II Start Up

A brief discussion of the steps required to run a program on the Apple II-Plus will be provided here.

- a) Plug the computer and the monitor into any 110v, 60 Hz, power outlet.
- b) Turn the computer on by flipping the switch located on left back side to the on position. Hit the "reset" key to stop the disc drive from turning.
- c) Turn the monitor on by pulling out the brightness control.
- d) Insert the system master diskette into disk drive #1.
- e) Type PR#6.
- f) After the disk drive stops (light off) and the blinking cursor appears, remove the system master diskette.
- g) Insert the slave diskette with the program to be run into the disk drive.

If the user is unsure about this procedure, refer to the operation manuals provided with the computer.

If a printer is attached to the computer type RUN SIGNPOST 1. Include a space between RUN and SIGNPOST and a space between SIGNPOST and 1. Type the return key. If a printer is not available, the user must type LOAD SIGNPOST 1. Once the flashing cursor appears, type DEL 1080, 1080. This will delete a DOS command which switches the output to the printer. Type RUN.

2.4.4 Program Use

An introduction will begin; the last line will be the first user question. See Section 2.7 for listing of all introductory statements, user prompting questions, user option questions, and output.

Each run is associated with a particular set of input data. Within each run the user may specify up to a maximum of ten diameters for which a required embedment depth will be calculated. Refer to Section 2.7 for an example. This allows the user to observe the change in required depth associated with a change in post diameter without having to repetitiously input the bulk of the input data.

SIGNPOST 1 allows the user to input an additional load on the post (see Figure 2.1). Rutledge's depth equation was modified to include an additional load and moment arm.

$$D = \frac{2.37(P+P_1) + \sqrt{(2.37(P+P_1))^2 + 4 \times 2.64(PH+P_1H_1)S_1B}}{2S_1B}$$

A practical use of this feature involves considering wind pressure against wide portions of the cantilevered post. The user must input force and height (Figure 2.1). If no force is to be included, the user should input zero for both force and height.

SIGNPOST 1 provides the user the option to input the coefficient of passive earth pressure or the program can calculate the coefficient. Rankine's formula is used.

$$K_p = N_\phi = \tan^2(45 - \phi/2)$$

The user may know from experience the value of the coefficient K_p and may want to input it rather than have it calculated. The computer will ask the user which option the user desires. If the user responds to input the coefficient, the computer will respond with the question, "What is KP?" The user should at that time input the desired coefficient of passive earth pressure.

All data must be input in units of degrees, pounds, and feet. In order to change the units, the unit weight of water must be changed in line 5030 from 62.4 PCF to whatever units are to be input. The output will be in terms of the new unit, but the print statement will still print out degrees, PCF, etc. behind the variables and solutions.

2.4.5 Output

Refer to Figure 2.2 for interpretation of the output data. S is the maximum pressure of the parabolic stress distribution on the upper $2/3$ of the embedded post. S_1 is the average pressure of the parabolic stress distribution. S_2 is calculated from S_1 and represents an average stress on the lower $1/3$ of the embedded post. S_2 is compared to S_2 ALLOW to insure that it is less. S_2 ALLOW is calculated from Rankine's formula of earth pressure. SL is the maximum pressure mobilized at the bottom of the embedded post. SL is a function of S_2 , thus a function of S_1 . SL ALLOW is calculated by Rankine's formula of earth pressure but unlike S_2 ALLOW, the safety factor is taken to be one. Ivey and Hawkins [3] contends that due to local plastic failure at the butt of the post, the stress would distribute upward; thus, the ultimate pressure versus the safe pressure should be used for comparison.

Following the output of the calculated data, a list of the input data will follow. This list will serve as a verification of proper data input as well as a record of data used to produce the calculated output.

2.5 Program List

```

5  SPEED= 150
10  PRINT "          *****"
11  PRINT "          *SIGNPOST*"
12  PRINT "          *****"
13  PRINT
14  PRINT
15  PRINT
20  PRINT "DANA K. EDDY, 578-80-8378"
22  PRINT "GA. INSTITUTE OF TECHNOLOGY"
24  PRINT "SCHOOL OF CIVIL ENGINEERING"
26  PRINT "DEPARTMENT OF GEOTECHNICAL ENGINEERING"
30  PRINT
31  PRINT
32  PRINT
35  PRINT "SYSTEM HARDWARE: APPLE II PLUS (64K)"
37  PRINT "SYSTEM HARDWARE: DOS 3.3, APPLESOFT BASIC LANGUAGE"
39  PRINT "PROGRAM DATE: APRIL, 1983"
42  PRINT
43  PRINT
44  PRINT
45  PRINT
50  PRINT "SIGNPOST ESTIMATES THE MINIMUM EMBEDMENT DEPTH OF A SINGLE CANT
    ILEVERED POST FOUNDATION.  THE CLASSICAL APPLICATION IS A SIGN OR MAR
    QUE SUBJECTED TO WIND LOADS."
51  PRINT
52  PRINT
53  PRINT
100  SPEED= 255
320  PRINT "HOW MANY PROBLEM SETS DO YOU WANT TO RUN?  THE USER MAY INPUT
    SEVERAL POST DIAMETERS PER PROBLEM SET."
330  INPUT N
331  PRINT
332  PRINT
340  DIM A(N,28)
350  FOR I = 1 TO N
360  PRINT "WHAT IS THE ANGLE OF INTERNAL FRICTION OF THE SOIL FOR RUN #"I
    "? (DEGREES)"
370  INPUT A(I,1)
380  PRINT "WHAT IS THE COHESION OF THE SOIL FOR RUN #"I"? (PSF)"
390  INPUT A(I,2)
400  PRINT "WHAT IS THE WET WEIGHT OF THE SOIL FOR RUN #"I"? (PCF)"
410  INPUT A(I,3)
420  PRINT "WHAT IS THE SATURATED WEIGHT OF THE SOIL FOR RUN #"I"? (PCF)"
430  INPUT A(I,4)
440  PRINT "WHAT IS THE WIND PRESSURE AGAINST THE SIGN FOR RUN #"I"? (PSF)
    "
450  INPUT A(I,5)

```

```

460 PRINT "WHAT IS THE HEIGHT ABOVE GRADE TO THE CENTROID OF THE SIGN FOR
    RUN #"I"? (FEET)"
470 INPUT A(I,6)
480 PRINT "WHAT IS THE AREA OF THE SIGN FOR RUN #"I"? (SF)"
490 INPUT A(I,7)
500 PRINT "WHAT IS THE LOAD ON THE POST FOR RUN #"I"? (POUNDS)"
510 INPUT A(I,8)
520 PRINT "WHAT IS THE HEIGHT ABOVE GRADE OF THE POST LOAD FOR RUN #"I"?
    (FEET)"
530 INPUT A(I,9)
540 PRINT "WHAT IS THE DEPTH BELOW GRADE OF THE GROUND WATER TABLE FOR RU
    N #"I"? (FEET)"
550 INPUT A(I,10)
560 PRINT "HOW MANY POST HOLE DIAMETERS DO YOU WANT TO INPUT FOR RUN #"I"
    ?"
570 INPUT A(I,11)
580 FOR J = 1 TO A(I,11)
590 PRINT "WHAT IS DIAMETER #"J" (FEET)"
600 J = J + 12
610 INPUT A(I,J)
620 J = J - 12
630 NEXT J
640 PRINT "WHAT IS THE SAFETY FACTOR FOR RUN #"I"?"
650 INPUT A(I,12)
651 PRINT "INPUT THE TOLERANCE FOR DEPTH CALCULATION. (RECOMMEND .5 - 1.
    0 FT)"
652 INPUT TL
650 PRINT "DO YOU WANT TO INPUT THE COEFFICIENT OF PASSIVE EARTH PRESSURE
    (KP) ,(YES), OR HAVE SIGNPOST CALCULATE KP FOR YOU (NO) ?"
670 INPUT B$:X = ASC(B$): IF X < 84 GOTO 700
680 PRINT "WHAT IS KP?"
690 INPUT A(I,28)
695 GOTO 710
700 A(I,28) = ( TAN ((45 + A(I,1) / 2) * .01745)) ^ 2
710 A(I,11) = A(I,11) + 12
720 FOR K = 13 TO A(I,11)
730 A(I,21) = 20
740 Z = .34 * A(I,21)
750 GOSUB 5000
760 A(I,22) = PS
770 A(I,23) = .6667 * A(I,22)
780 GOSUB 6000
790 IF D < A(I,21) GOTO 820
800 A(I,21) = A(I,21) + TL
810 GOTO 740
820 IF D > A(I,21) - TL GOTO 850
830 A(I,21) = A(I,21) - TL
831 Z = .34 * A(I,21)
832 GOSUB 5000:A(I,22) = PS

```

```

833 A(I,23) = .6667 * A(I,22): GOSUB 6000
834 GOTO 820
850 A(I,24) = A(I,23) / ((.28 * A(I,21) / (A(I,6) + .34 * A(I,21))) + .5)
860 Z = .68 * A(I,21)
870 GOSUB 5000
880 A(I,25) = PS
890 IF A(I,25) > A(I,24) GOTO 960
900 A(I,21) = A(I,21) + TL
910 Z = .34 * A(I,21)
920 GOSUB 5000
930 A(I,22) = PS
940 A(I,23) = .6667 * A(I,22)
950 GOTO 850
960 A(I,26) = 2 * A(I,24)
970 Z = A(I,21)
980 GOSUB 5000
990 A(I,27) = PS * A(I,12)
1000 IF A(I,27) > A(I,26) GOTO 1080
1010 A(I,21) = A(I,21) + TL
1020 Z = .34 * A(I,21)
1030 GOSUB 5000
1040 A(I,22) = PS
1050 A(I,23) = .6667 * A(I,22)
1060 A(I,24) = A(I,23) / ((.28 * A(I,21) / (A(I,6) + .34 * A(I,21))) + .5)
1070 GOTO 960
1080 L$ = CHR$(4): PRINT L$;"PR#1": FOR L = 1 TO N
1091 K = K - 12
1098 PRINT "/////////////////////////////////"
1099 PRINT "/////////////////////////////////"
1090 PRINT "OUTPUT FOR DIAMETER #"K" ,RUN #"I"."
1091 PRINT "/////////////////////////////////"
1092 PRINT
1093 PRINT
1100 K = K + 12
1110 PRINT "DIAMETER ="A(I,K)" FEET    ", "DEPTH ="A(I,21)" FEET"
1111 PRINT
1120 PRINT "S ="A(I,22)" PSF    ", "S1 ="A(I,23)" PSF"
1121 PRINT
1130 PRINT "S2 ="A(I,24)" PSF", "S2 ALLOW ="A(I,25)" PSF"
1131 PRINT
1140 PRINT "SL ="A(I,26)" PSF", "SL ALLOW ="A(I,27)" PSF (ULTIMATE)"
1141 PRINT
1142 PRINT
1150 NEXT K
1158 PRINT "*****"
1159 PRINT "*****"
1160 PRINT "INPUT FOR RUN #"I"."
1161 PRINT "*****"
1162 PRINT

```

```

1170 PRINT "ANGLE OF INTERNAL FRICTION ="A(I,1)" DEGREES"
1171 PRINT
1180 PRINT "COHESION ="A(I,2)" PSF"
1181 PRINT
1190 PRINT "KP ="A(I,28)
1191 PRINT
1200 PRINT "WET WEIGHT OF SOIL ="A(I,3)" PCF"
1201 PRINT
1210 PRINT "SATURATED WEIGHT OF SOIL ="A(I,4)" PCF"
1211 PRINT
1220 PRINT "WIND PRESSURE ="A(I,5)" PSF"
1221 PRINT
1230 PRINT "HEIGHT OF SIGN CENTROID ="A(I,6)" FEET"
1231 PRINT
1240 PRINT "AREA OF SIGN ="A(I,7)" SF"
1241 PRINT
1250 PRINT "LOAD ON POST ="A(I,8)" #"
1251 PRINT
1260 PRINT "HEIGHT OF POST LOAD ="A(I,9)" FEET"
1261 PRINT
1270 PRINT "DEPTH OF GWT ="A(I,10)" FEET"
1271 PRINT
1280 PRINT "SAFETY FACTOR ="A(I,12)
1281 PRINT
1284 PRINT "TOLERANCE =+/-"TL" FEET"
1285 PRINT L$;"PR#0"
1286 PRINT
1287 PRINT
1290 NEXT I
1300 END
5000 IF Z > A(I,10) GOTO 5030
5010 PS = ((A(I,3) * Z * A(I,28)) + (2 * A(I,2) * A(I,28) ^ .5)) / A(I,12)

5020 RETURN
5030 PS = ((A(I,3) * A(I,10) * A(I,28)) + (2 * A(I,2) * A(I,28) ^ .5) + ((
A(I,4) - 62.4) * (Z - A(I,10)) * A(I,28))) / A(I,12)
5040 RETURN
5000 D = 1.18 * ((A(I,5) * A(I,7)) + A(I,8)) / A(I,K) / A(I,23) + ((1.16 +
((A(I,5) * A(I,7)) + A(I,8)) / A(I,K) / A(I,23)) ^ 2 + (A(I,5) + A(I,
7) * A(I,6) + A(I,8) * A(I,9)) * 2.63 / A(I,K) / A(I,23)) ^ .5
6010 RETURN

```

2.6 Variable List (SIGNPOST 1)

Input

N = # of runs
A(I,1) = Phi angle
A(I,2) = Cohesion
A(I,3) = Wet soil weight
A(I,4) = Saturated soil weight
A(I,5) = Wind pressure
A(I,6) = Height of sign centroid
A(I,7) = Sign area
A(I,8) = Post load
A(I,9) = Load height
A(I,10) = GWT depth
A(I,11) = # of diameters
A(I,12) = Safety factor
A(I,J) = Diameter
A(I,28) = Passive earth pressure coefficient
TL = Tolerance

Flow Control

X = Question input

Counters

I = Run #
J = Diameter #
K = Output

Miscellaneous

Z = Depth
PS = Earth Pressure
A(I,22) = S
A(I,23) = S1
A(I,24) = S2
A(I,25) = S2 allowable
A(I,26) = SL
A(I,27) = SL allowable (ultimate)

2.7 Program Verification

 SIGNPOST

DANA K. EDDY, 578-80-8378
 GA. INSTITUTE OF TECHNOLOGY
 SCHOOL OF CIVIL ENGINEERING
 DEPARTMENT OF GEOTECHNICAL ENGINEERING
 DR. RICHARD D. BARKSDALE, ADVISOR

SYSTEM HARDWARE: APPLE II PLUS (64K)
 SYSTEM SOFTWARE: DOS 3.3, APPLESOFT BASIC LANGUAGE
 PROGRAM DATE: APRIL, 1983

SIGNPOST ESTIMATES THE MINIMUM EMBEDMENT DEPTH OF A SINGLE CANTILEVERED POST FOUNDATION. THE CLASSICAL APPLICATION IS A SIGN OR MARQUE SUBJECTED TO WIND LOADS.

HOW MANY PROBLEM SETS DO YOU WANT TO RUN? THE USER MAY INPUT SEVERAL POST PARAMETERS PER PROBLEM SET.

71

WHAT IS THE ANGLE OF INTERNAL FRICTION OF THE SOIL FOR RUN #1? (DEGREES)

728

WHAT IS THE COHESION OF THE SOIL FOR RUN #1? (PSF)

7200

WHAT IS THE WET WEIGHT OF THE SOIL FOR RUN #1? (PCF)

7110

WHAT IS THE SATURATED WEIGHT OF THE SOIL FOR RUN #1? (PCF)

7122.4

WHAT IS THE WIND PRESSURE AGAINST THE SIGN FOR RUN #1? (PSF)

740

WHAT IS THE HEIGHT ABOVE GRADE TO THE CENTROID OF THE SIGN FOR RUN #1? (FEET)

7107.5

WHAT IS THE AREA OF THE SIGN FOR RUN #1? (SF)

7450

WHAT IS THE LOAD ON THE POST FOR RUN #1? (POUNDS)

71000

WHAT IS THE HEIGHT ABOVE GRADE OF THE POST LOAD FOR RUN #1? (FEET)

750

WHAT IS THE DEPTH BELOW GRADE OF THE GROUND WATER TABLE FOR RUN #1? (FEET)

715

HOW MANY POST HOLE DIAMETERS DO YOU WANT TO INPUT FOR RUN #1?

?3

WHAT IS DIAMETER #1 (FEET)

?2.0

WHAT IS DIAMETER #2 (FEET)

?2.5

WHAT IS DIAMETER #3 (FEET)

?3.0

WHAT IS THE SAFETY FACTOR FOR RUN #1?

?2

INPUT THE TOLERANCE FOR DEPTH CALCULATION. (RECOMMEND .5 - 1.0 FT)

?1.5

DO YOU WANT TO INPUT THE COEFFICIENT OF PASSIVE EARTH PRESSURE (KP) (YES), OR HAVE SIGNPOST CALCULATE KP FOR YOU (NO) ?

?NO

////////////////////////////////////

////////////////////////////////////

OUTPUT FOR DIAMETER #1 ,RUN #1.

////////////////////////////////////

DIAMETER =2 FEET

DEPTH =45.5 FEET

S =2654.82639 PSF

S1 =1769.97275 PSF

S2 =2932.34826 PSF

S2 ALLOW =3939.17206 PSF

SL =5864.69651 PSF

SL ALLOW =10295.936 PSF (ULTIMATE)

////////////////////////////////////

////////////////////////////////////

OUTPUT FOR DIAMETER #2 ,RUN #1.

////////////////////////////////////

DIAMETER =2.5 FEET

DEPTH =41.5 FEET

S =2480.34245 PSF

S1 =1653.64431 PSF

S2 =2776.66116 PSF

S2 ALLOW =3713.35364 PSF

SL =5553.32233 PSF

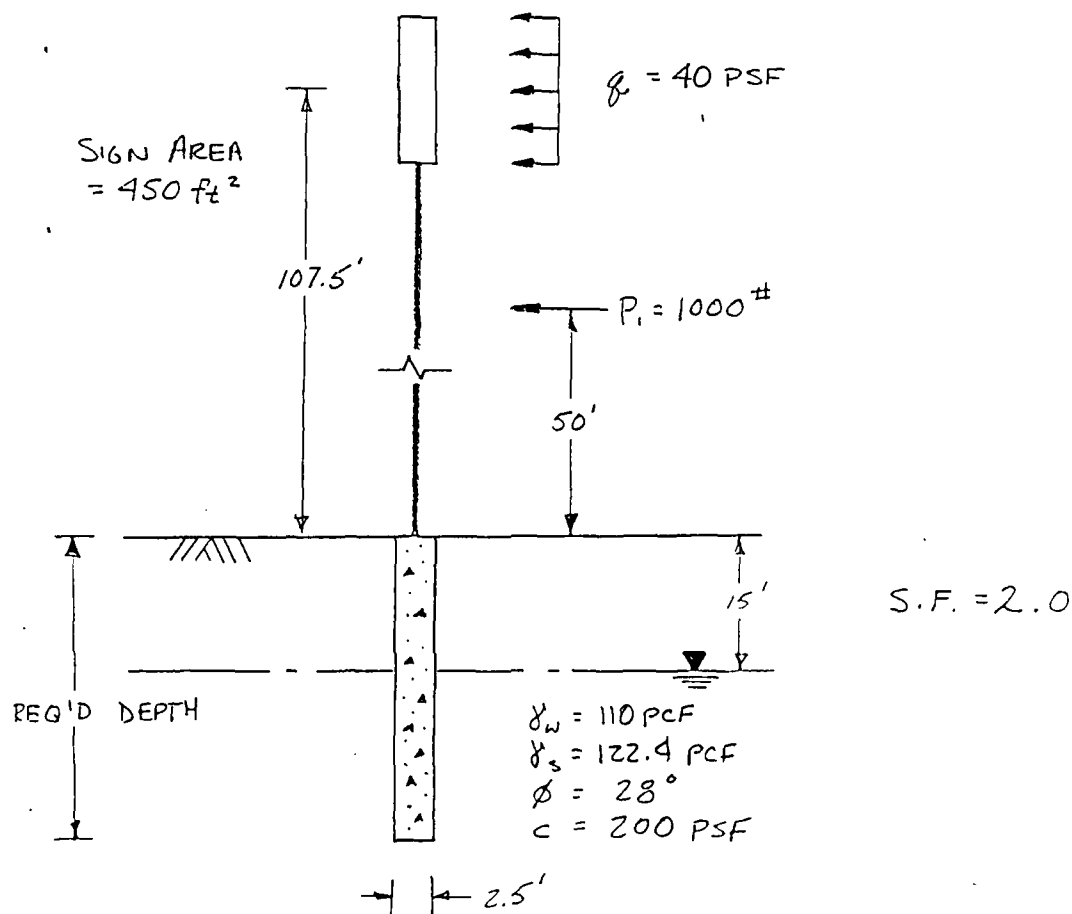
SL ALLOW =9631.76239 PSF (ULTIMATE)

////////////////////////////////////
 ////////////////////////////////////
 OUTPUT FOR DIAMETER #3 , RUN #1.
 ////////////////////////////////////

DIAMETER =3 FEET	DEPTH =38.5 FEET
S =2325.09187 PSF	S1 =1550.13875 PSF
S2 =2630.05603 PSF	S2 ALLOW =3543.98878 PSF
SL =5260.11206 PSF	SL ALLOW =9133.6322 PSF (ULTIMATE)

 INPUT FOR RUN #1.

ANGLE OF INTERNAL FRICTION =28 DEGREES
 COHESION =200 PSF
 KP =2.76738995
 WET WEIGHT OF SOIL =110 PCF
 SATURATED WEIGHT OF SOIL =122.4 PCF
 WIND PRESSURE =40 PSF
 HEIGHT OF SIGN CENTROID =107.5 FEET
 AREA OF SIGN =450 SF
 LOAD ON POST =1000 #
 HEIGHT OF POST LOAD =50 FEET
 DEPTH OF GWT =15 FEET
 SAFETY FACTOR =2
 TOLERANCE =+/- .5 FEET



$$k_p = \tan^2(45 + \phi/2) = \tan^2(45 + 28/2)$$

$$= \underline{\underline{2.77}}$$

FOR $z \leq 15'$

$$P_p = (\gamma_w(z) k_p + 2c \sqrt{k_p}) / SF$$

FOR $z \geq 15'$

$$P_p = [\gamma_w(GWT) + (\gamma_s - \gamma_{u20})(z - GWT)] k_p + 2c \sqrt{k_p} / SF$$

ASSUME $D = 41.5'$

CALCULATE S @ $z = .34 D = .34 (41.5') = 14.11'$

$$S = p_p = (110 (14.11') 2.77 + 2 (200) \sqrt{2.77}) / 2$$

$$= 2482.5 \text{ \#/ft}^2$$

CALCULATE S_1

$$S_1 = \frac{2}{3} S = \frac{2}{3} (2482.5)$$

$$= 1655.0 \text{ \#/ft}^2$$

CALCULATE D

$$D = \frac{1.18 (P + P_i)}{b S_1} + \sqrt{\left(\frac{1.18 (P + P_i)}{b S_1} \right)^2 + \frac{((P \cdot H) + (P_i \cdot H_i)) \cdot 2.63}{b S_1}}$$

$$P = 450 \text{ ft}^2 \cdot 40 \text{ \#/ft}^2 = 18,000.0 \text{ \#}$$

$$D = \frac{1.18 (1000 + 18,000)}{(2.5) 1655} +$$

$$\sqrt{\left(\frac{1.18 (1000 + 18,000)}{(2.5) 1655} \right)^2 + \frac{((18,000 \cdot 107.5) + (1000 \cdot 50)) \cdot 2.63}{(2.5) 1655}}$$

$$= 5.419 + \sqrt{29.363 + 1261.76}$$

$$= \underline{\underline{41.35'}} \approx \underline{\underline{41.5'}} \quad \text{OK}$$

CHECK SZ & SL

$$\begin{aligned} S1/SZ &= \frac{.28D}{H + .34D} + \frac{1}{2} \\ &= \frac{.28(41.35')}{107.5 + .34(41.35)} + \frac{1}{2} \\ &= .595 \end{aligned}$$

$$\begin{aligned} SZ &= S1 / .595 \\ &= 1655 / .595 \\ &= \underline{2780.4 \text{ \#/ft}^2} \quad \checkmark \end{aligned}$$

$$SZ_{ALLOW} = P_p @ Z = .68D = 28.12'$$

$$\begin{aligned} SZ_{ALLOW} &= \left[\frac{(110(15) + (122.4 - 62.4)(28.12 - 15))}{\sqrt{2.77}} + 2(200) \right] / 2 \\ &= \underline{3708.4 \text{ \#/ft}^2} \quad \checkmark \end{aligned}$$

$$\underline{SZ < SZ_{ALLOW}}$$

$$\begin{aligned} SL &= 2(SZ) = 2(2780.4) \\ &= \underline{5560.8 \text{ \#/ft}^2} \quad \checkmark \end{aligned}$$

$$SL_{ALLOW} = P_p (ULTIMATE, SF=1) @ Z = D = 41.35'$$

$$\begin{aligned} SL_{ALLOW} &= \frac{(110(15) + (122.4 - 62.4)(41.35 - 15))}{2(200)\sqrt{2.77}} + 2(200) \\ &= \underline{9615.6 \text{ \#/ft}^2} \quad \checkmark \end{aligned}$$

$$\underline{SL < SL_{ALLOW}}$$

$$\underline{\underline{REQUIRED \text{ DEPTH} = 41.35'}}$$

2.8 References

1. Seiler, J. F., "Effect of Depth of Embedment on Pole Stability," Wood Preserving News, Vol. 10, No. 11, Nov. 1932.
2. Patterson, Donald, How to Design Pole-Type Buildings, American Wood Preservers Institute, 1957.
3. Ivey, D. L. and Hawkins, L., "Signboard Footings to Resist Wind Loads," Civil Engineering, ASCE, Dec. 1966.

Recommended Reading

1. Foundation Depths for Self-Supporting Poles Subjected to Transverse Loads, Lieut. Comdr. James R. Griffith, U. S. Navy, 1939.
2. A Report of Field and Laboratory Tests on the Stability of Posts Against Lateral Loads, W. L. Shilts, L. D. Graves, G. G. Driscoll, Notre Dame University, 1948.
3. Engineering Design Manual, Outdoor Advertising Association of America, 1955.
4. Saghera, S. S., "Embedment Depth for Nonconstrained and Constrained Poles or Posts," Civil Engineering, ASCE, May 1973.

CHAPTER III

CANTILEVERED WALL

3.1 Problem Definition

CANTWALL 1 calculates the required embedment depth of a cantilevered wall. Although cantilevered wall heights are limited by structural constraints due to high bending moments in the wall, CANTWALL 1 can calculate the theoretical penetration depth required to support any height of wall. The limitations of wall height are discussed in more detail in Section 3.4. As depicted in Figure 3.1, the vertical wall penetrates through two soils. The soil characteristics are specified in terms of angle of internal friction, cohesion, saturated, and wet unit weight. A friction angle for the soil-wall interface must also be specified. The ground water table can be specified to exist anywhere from the top of Soil #1 to any depth below grade.

CANTWALL 1 satisfies the static summation of horizontal forces and moments.

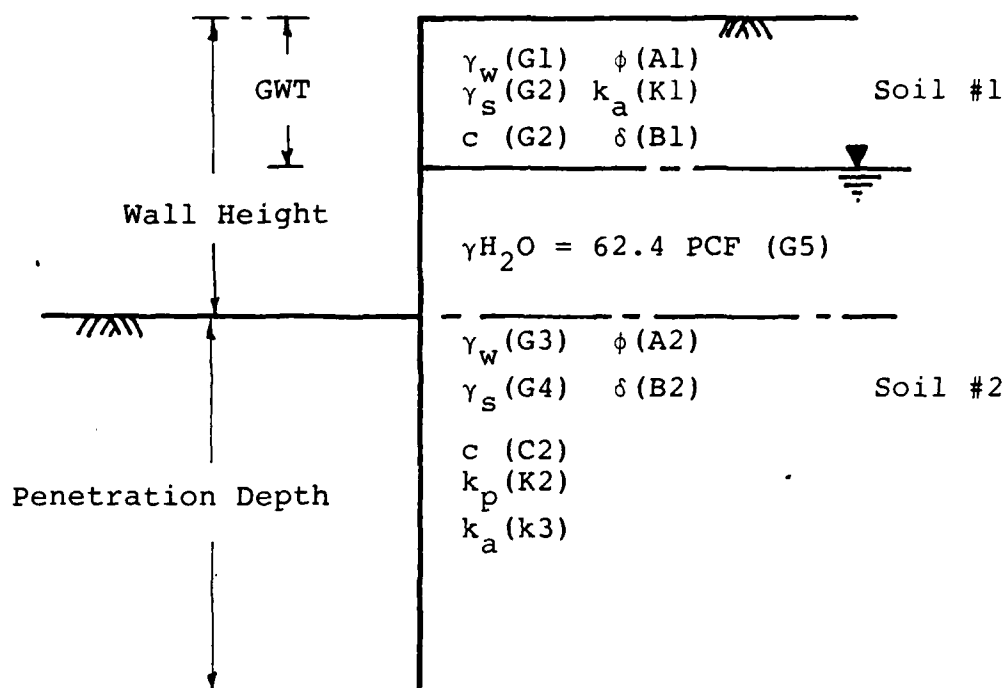


Figure 3.1. General Problem Diagram Cantilevered Wall.

3.2 Background Theory

3.2.1 General Definition

A cantilevered sheetpile wall depends upon its embedment depth to develop resistance against the overturning effect of a soil backfill. Cantilevered walls develop their strength through passive pressure in the lower soil thus counteracting the active earth pressure in the backfill. These walls do not depend upon an anchor in the backfill for support.

As depicted in Figure 3.2(A), cantilevered walls rotate about a point in the lower soil [1].

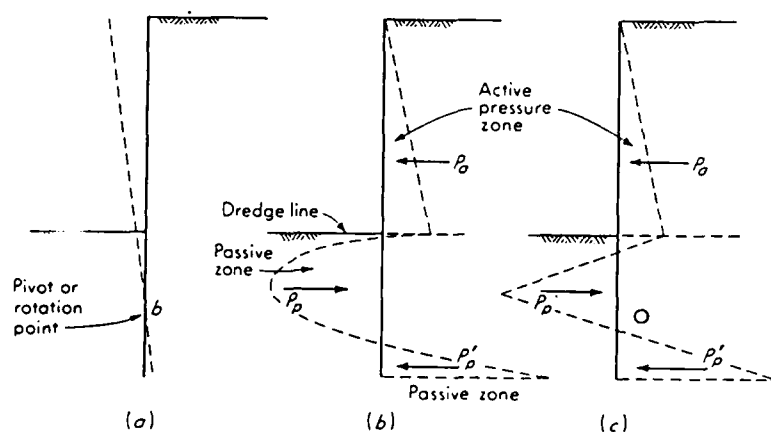


Figure 3.2 (a) Assumed elastic line of the sheetpiling; (b) probable and as obtained in finite-element solution qualitative soil-pressure distribution; (c) simplified pressure diagram for computational purposes (granular soil and no water as shown). [1]

Through model testing and field experience, the earth pressures mobilized as the wall rotates are shown in Figure 3.2 (b) [1]. For ease of calculation, these pressures have been simplified, Figure 3.2 (c).

The classic solution of the cantilevered wall involves assuming a trial embedment depth and varying the passive pressures in the lower soil until the summation of horizontal forces approximate zero. Moments are summed about the point of zero shear (Point o, Figure 3.2 (c)) in the lower soil. If the net moment indicates the wall will overturn, a deeper depth is assumed until a safe condition is calculated.

Two methods for applying a safety factor have been used. The passive pressures in the lower soil can be reduced by a factor, or the calculated depth increased by 20% to 40% [2].

Although there are other methods, the Rankine theory of earth pressure is used to calculate the coefficients of earth pressure.

$$k_a = \frac{\sin^2(\alpha + \phi)}{\sin^2 \alpha \sin(\alpha - \delta) \left[1 + \sqrt{\frac{\sin(\phi + \delta) \sin(\phi - \beta)}{\sin(\alpha - \delta) \sin(\alpha + \beta)}} \right]^2}$$

$$k_p = \frac{\sin^2(\alpha - \phi)}{\sin^2 \alpha \sin(\alpha + \delta) \left[1 - \sqrt{\frac{\sin(\phi + \delta) \sin(\phi + \beta)}{\sin(\alpha + \delta) \sin(\alpha + \beta)}} \right]^2}$$

where,

α = wall inclination from horizontal

β = backfill inclination from horizontal

δ = wall-soil friction angle

ϕ = angle of internal friction

Similarly, the Rankine equations for plastic soil behavior are used to calculate the active and passive states [3].

$$\sigma_a = \gamma Z k_a - 2c \sqrt{k_a}$$

$$\sigma_p = \gamma Z k_p + 2c \sqrt{k_p}$$

where,

38

σ_a = active earth pressure

σ_p = passive earth pressure

γ = unit soil weight

z = soil depth

C = cohesion

Effective stresses are considered using bouyant soil weights in the above equations. Water pressure is superimposed on the earth pressures when the soil is saturated.

In cohesive soils, tension cracks will develop when the soil is allowed to expand. This is the case in active pressure zones. The backfill, or soil #1 as referred to in this text, is an active zone. The depth of these tension cracks are calculated as [3]:

$$z_o = \frac{2c}{\gamma} \sqrt{k_p}$$

where,

z_o = tension crack depth

γ = soil unit weight

c = cohesion

k_p = passive coefficient

Any water that may accumulate in the tension cracks is considered in the computation of the active force in the backfill. Figure 3.3(A) illustrates the active pressures mobilized behind the wall for cohesive soils. The cohesive

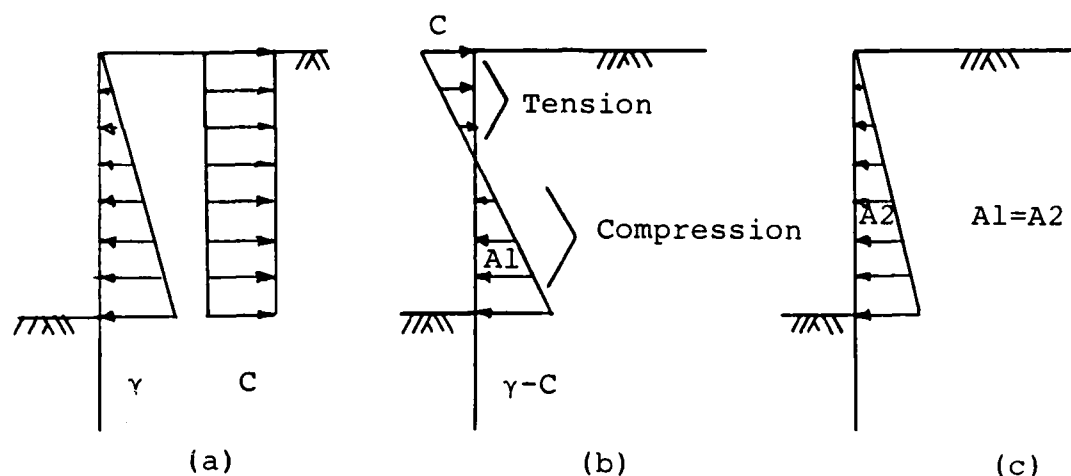


Figure 3.3. Equivalent Active Pressure.
 (a) Separate Rankine Pressure Distribution
 (b) Combined Pressure Diagram
 (c) Equivalent Active Force

component of the soil tends to counteract the active force mobilized by the soil weight. In certain cases when the backfill has a high cohesion ($C = 1000 - 2000$ PSF), the net active pressure is equal to or less than zero; consequently, the soil can theoretically stand unsupported. This premise is time dependent as changes in water content and time can alter the available cohesion in soil.

3.2.2 Equivalent Active Force

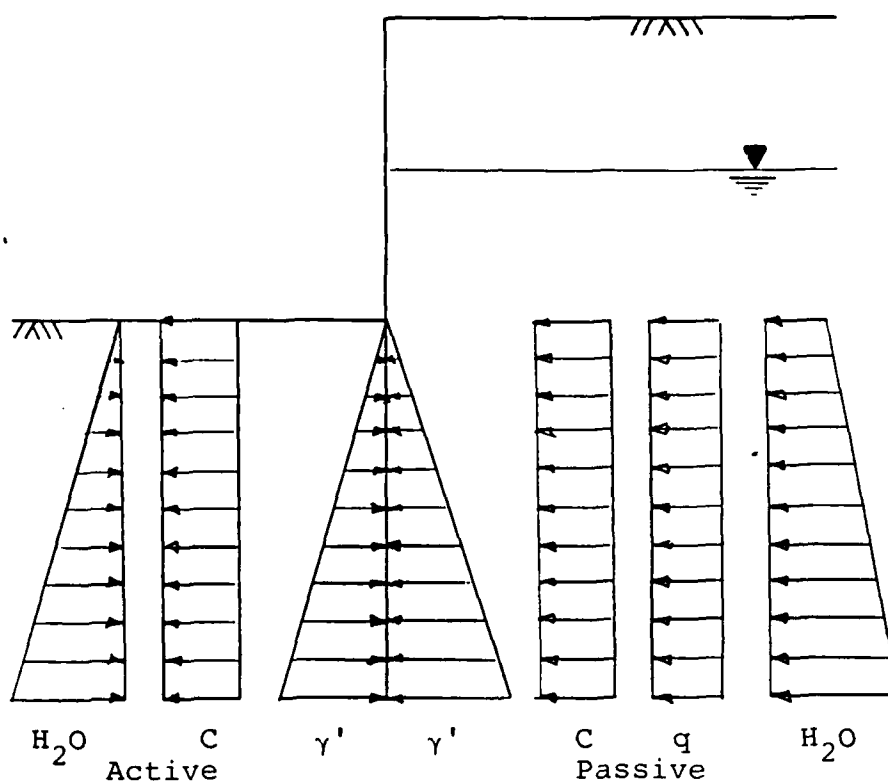
In cases where a net positive active force exists in the cohesive backfill, an equivalent active force may be used. Figure 3.3 (b) illustrates this condition. For computation the positive active force (A_1) is used. The negative cohesive active force is ignored. Force A_1

is distributed along the entire height of the wall (A2). Figure 3.3 (c) illustrates the final pressure distribution of the equivalent active force concept. In addition to disregarding the negative cohesive force and its contribution to moment, the equivalent active force method increases the lever arm distance thus increasing the overturning moment and ultimately the required penetration.

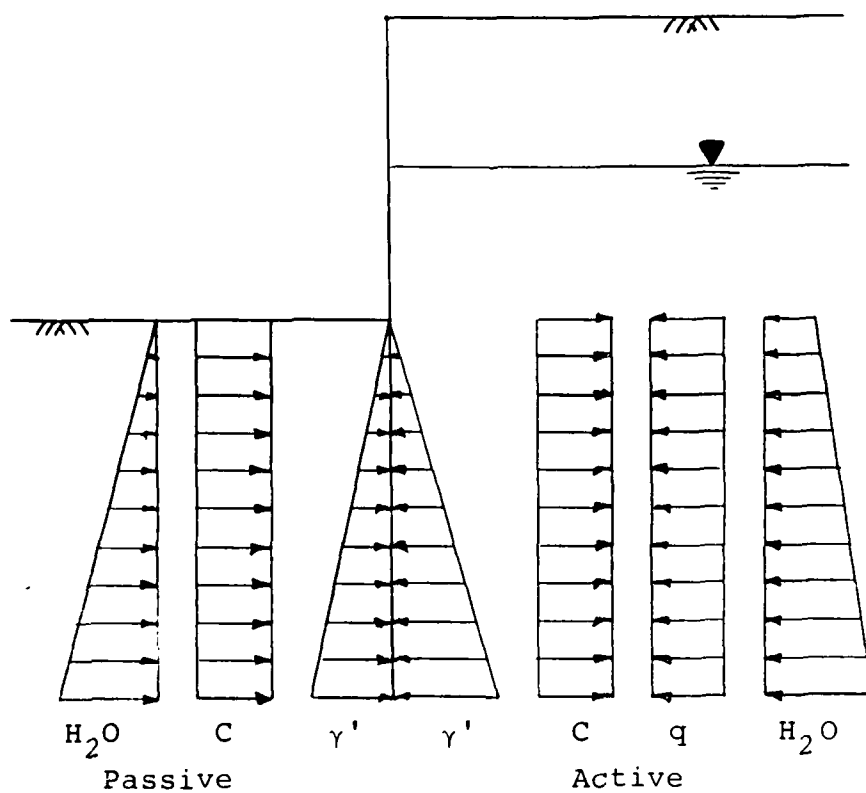
3.2.3 Pressure Calculation, Soil #2

To complete the soil pressure in the lower soil (Soil #2), active and passive pressures are calculated for each side of the embedded wall. Figure 3.4 illustrates the various components of the earth pressures. As previously mentioned, a factor of safety can be applied by reducing the passive pressures. The active pressure of one side is subtracted from the passive pressure of the other side. The resulting combined pressure diagrams are shown in Figure 3.5. In general, a granular, noncohesive soil will have a pressure diagram similar to Figure 3.5 (b); conversely, a cohesive soil will have a combined pressure diagram similar to Figure 3.5 (a). P_2 represents the pressure at the soil interface and will be discussed in more detail in Section 3.4.

The pressure against the embedded depth of wall is varied by altering Line L1 which is drawn from the lower right hand side pressure diagram up to an arbitrary point on the left hand side pressure diagram. The actual pressure

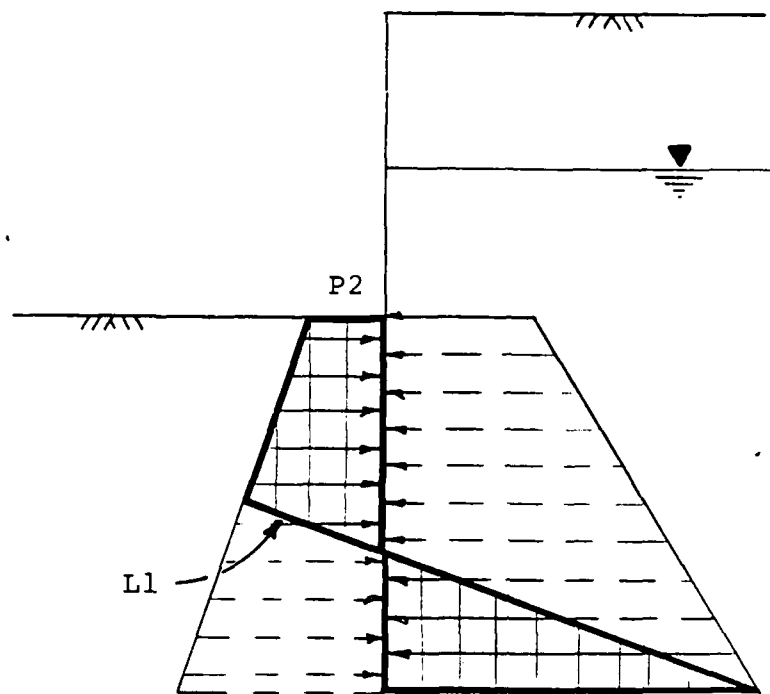


(a) Right Side Pressure Considerations.

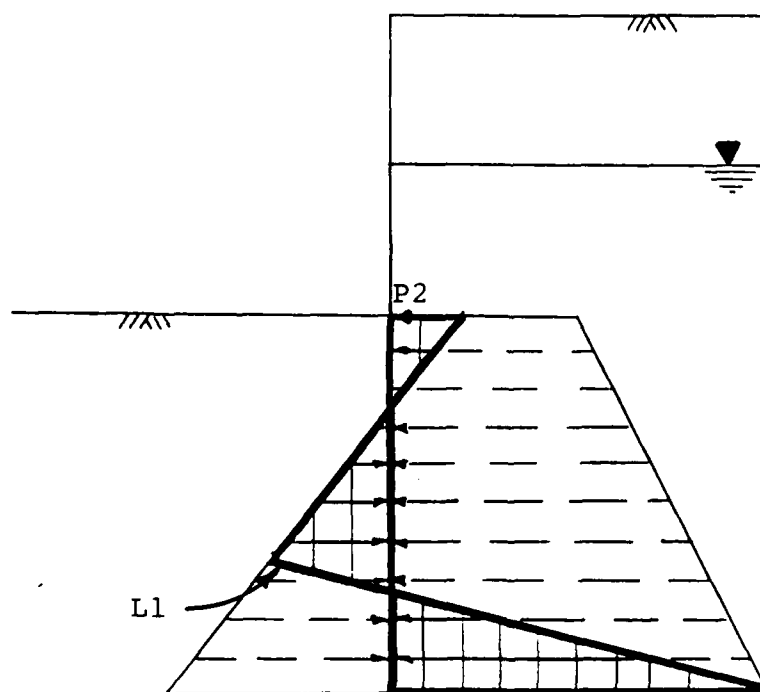


(b) Left Side Pressure Considerations.

Figure 3.4. Earth Pressures in Soil #2.



(a) Combined Pressure Diagram ($-P2$)



(b) Combined Pressure Diagram ($+P2$)

Figure 3.5. Combined Earth Pressures.

distribution is approximated as in Figure 3.2. Line L1 is varied until the summation of horizontal forces approaches zero. Although the active forces in soil #1 is emitted from the diagram, the forces are considered in the summation of forces and moments. Moments are summed about the point where the line crosses the embedded wall. The net moment indicates whether the assumed depth needs to be increased or decreased. The entire sequence is repeated for a new depth until static equilibrium is achieved.

3.3 Programming Rationale

3.3.1 Program Flow

The program flow is executed similar to a manual calculation. As depicted in Figure 3.6, the problem necessitated four main branches. Each branch is contingent upon the location of the ground water table. If the water table is in soil #1, the program will iterate within one branch exclusively. This is typically true if the water table is specified to be deeper than the originally assumed wall penetration and the calculated wall penetration. The program must iterate between branches when the water table is within the embedded wall depth.

As previously defined, the pressures in soil #2 are varied until static equilibrium is achieved. The pressures in soil #1 do not change during iterations; therefore, the program minimizes the number of times the pressures are calculated. To vary soil #2 pressures, the depth to

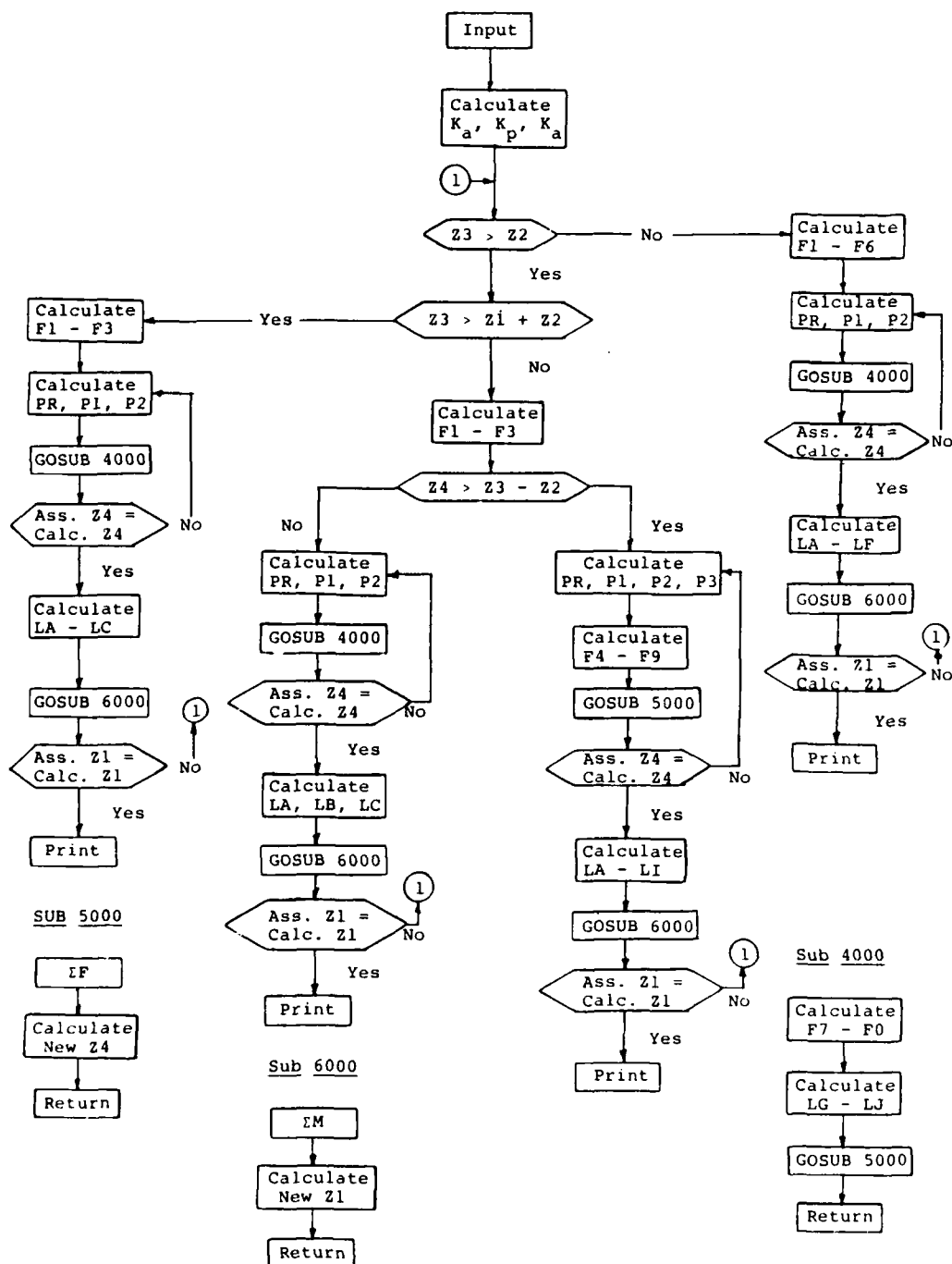


Figure 3.6. CANTWALL Flow Chart.

the maximum pressure on the left hand side of the combined pressure diagram is increased or decreased depending upon the previously calculated net horizontal force. If the net sum of horizontal forces is positive (to the left), the depth of maximum left side pressure is increased thus increasing the negative pressure (left side pressure to the right). As described in Section 3.4, the depth to the maximum pressure is defined as Z_4 .

3.3.2 Iteration by Slope-Intercept

To reduce the number of iterations required to balance horizontal forces, a slope intercept method was employed which would increase or decrease Z_4 toward a projected new Z_4 which corresponds to a net summation of horizontal forces of zero. Figure 3.7 illustrates this slope-intercept concept.

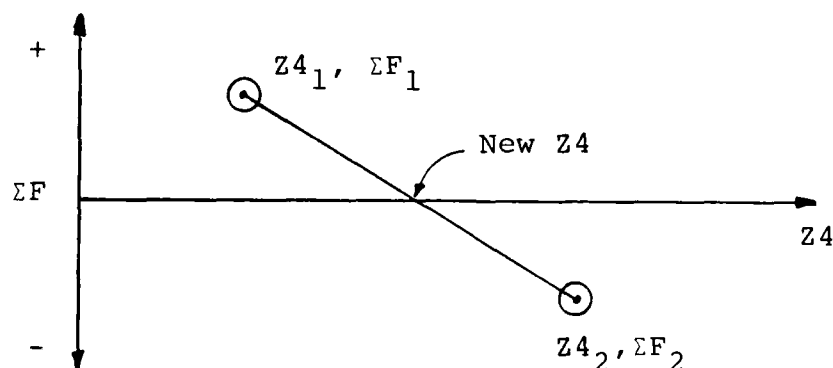


Figure 3.7. Slope-Intercept Search Method.

After using the above routine, it was found that only three iterations were required to balance the horizontal forces of the system. This indicates a linear relationship between the summation of horizontal forces and Z4. The same method is used for establishing the best new embedment depth (Z1) compared against the summation of moments. The program iterates up to 15 times prior to balancing the moments; thus, Z1 is not linearly related to the summation of moments.

3.3.3 Sign Convention

To simplify calculations, the sign convention was established such that all forces to the right are negative and forces to the left are positive. Counterclockwise moments are positive; therefore, all lever arms are positive except the lever arm associated with the lower right hand side force in soil #2. This lever arm is negative because the summation of moments is about point 0 (Figure 3.2c) and as previously mentioned, forces to the left are positive.

Subroutines are used as much as possible to reduce repetitious program lines. The calculation of pressures in soil #2, the summation of forces (5000), and the summation of moments (6000) are the main subroutines.

3.4 Program Use and Limitations

3.4.1 Input

CANTWALL 1 is a user-oriented program. All input and options are prompted by statements and questions which instruct the user that a particular input is necessary. As with all programs, the user should be familiar with the input variables prior to beginning the run. This will prevent inputting incorrect or mistaken variables. A sample of the prompting questions are presented in Section 3.7. The user must input the following variables (refer to Figure 3.1):

- a) number of runs
- b) wet weight, soil #1
- c) saturated weight, soil #1
- d) cohesion, soil #1
- e) Phi angle, soil #1
- f) wall-soil friction angle, soil #1 (see Table 3.1)
- g) wet weight, soil #2
- h) saturated weight, soil #2
- i) cohesion, soil #2
- j) Phi angle, soil #2
- k) wall-soil friction angle, soil #2 (see Table 3.1)
- l) wall height
- m) ground water table depth
- n) tolerance
- o) safety factor

Table 3.1. Friction Angles for Various Interface Materials
[2].

Interface Materials	Friction factor, $\tan \delta$	Friction angle, δ degrees
Mass concrete on the following foundation materials:		
Clean sound rock.....	0.70	35
Clean gravel, gravel-sand mixtures, coarse sand...	0.55 to 0.60	29 to 31
Clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel.....	0.45 to 0.55	24 to 29
Clean fine sand, silty or clayey fine to medium sand.....	0.35 to 0.45	19 to 24
Fine sandy silt, nonplastic silt.....	0.30 to 0.35	17 to 19
Very stiff and hard residual or preconsolidated clay.....	0.40 to 0.50	22 to 26
Medium stiff and stiff clay and silty clay.....	0.30 to 0.35	17 to 19
(Masonry on foundation materials has same friction factors.)		
Steel sheet piles against the following soils:		
Clean gravel, gravel-sand mixtures, well-graded rock fill with spalls.....	0.40	22
Clean sand, silty sand-gravel mixture, single size hard rock fill.....	0.30	17
Silty sand, gravel or sand mixed with silt or clay	0.25	14
Fine sandy silt, nonplastic silt.....	0.20	11
Formed concrete or concrete sheet piling against the following soils:		
Clean gravel, gravel-sand mixture, well-graded rock fill with spalls.....	0.40 to 0.50	22 to 26
Clean sand, silty sand-gravel mixture, single size hard rock fill.....	0.30 to 0.40	17 to 22
Silty sand, gravel or sand mixed with silt or clay	0.30	17
Fine sandy silt, nonplastic silt.....	0.25	14
Various structural materials:		
Masonry on masonry, igneous and metamorphic rocks:		
Dressed soft rock on dressed soft rock.....	0.70	35
Dressed hard rock on dressed soft rock.....	0.65	33
Dressed hard rock on dressed hard rock.....	0.55	29
Masonry on wood (cross grain).....	0.50	26
Steel on steel at sheet pile interlocks.....	0.30	17

- p) option, tension cracks in soil #1
- q) option, equivalent active force in soil #1
- r) option, input coefficient of earth pressure or calculate
- s) assumed penetration depth

3.4.2 Units

All input is in the units of feet, pounds, and degrees. The units may be altered by changing line 744 ($G5 = 62.4$) which establishes the unit weight of water as 62.4 PCF. Angles must be input in degrees. Although the units of the input variables may be changed, the print statement will label all output in the original units.

3.4.3 Repeat Runs

Each run is totally independent of the previous run; all input will be required again. This function saves time by eliminating the introductory statements and the system commands the user must execute to run the program.

Input variables b)-l) are self explanatory and are depicted in Figure 3.1. The depth of the ground water table is taken from the surface of soil #1.

3.4.4 Tolerance

The tolerance for depth calculation is recommended as 0.1 to 0.01. The tolerance is used during the summation of forces and moments routines. The tolerance is the maximum difference between a calculated depth and the new assumed depth. For force summations, Z4 is compared and for moment summations, Z1 is used.

3.4.5 Safety Factor

CANTWALL uses the safety factor to decrease the passive pressures in soil #2 prior to creating a combined pressure diagram. This method was previously described in Section 3.2. When specifying a soft cohesive soil for soil #2, it is recommended to use a safety factor of 1 as the resulting combined pressure diagrams will indicate wall instability. This is discussed in more detail later in this section.

3.4.6 Options

The user may exercise three options; i.e., specify tension cracks in soil #1, specify an equivalent active force in soil #1, and input the coefficients of earth pressure versus using the values calculated by the program.

The theoretical depth of tension cracks as described in Section 3.2 are used when this option is exercised. With this option, the force due to water pressure in the crack is included. The force is calculated from hydrostatic pressure for the calculated tension crack depth. The program checks the crack depth against the ground water table depth and the wall height. The crack depth can not exceed the wall height or the depth of the water table.

The equivalent active force option is calculated as described in Section 3.2 (Figure 3.3). Because the tensile effect of cohesion is ignored and the lever arm of the positive force is increased, the overall effect of exercising this option is to increase the required wall penetration.

The program allows the user to input the coefficients of earth pressure. If the user exercises this option, the program will not calculate the coefficients as defined in Section 3.2. The user will be required to input the active coefficient for soil #1 and the active and passive coefficient for soil #2. All input will be prompted by questions if the option is used.

3.4.7 Output

Printed output consists of a list of input variables and the required penetration depth. A supplementary data list is available giving the value of the variables used in the programs. After the required penetration depth is printed, the user is prompted by a question asking if the list of variables is desired. Figures 3.8 to 3.13 serve as a guide for interpreting the supplementary variables listing.

To locate the proper diagram, the user must know the ground water table depth (Z_3), the wall height (Z_2), and from the supplementary list, know the values of Z_1 , Z_4 , and P_2 . If Z_4 is less than Z_2 , Figures 3.8 or 3.9 apply; if P_2 is positive, Figure 3.9 applies. Table 3.2 is provided to easily identify the proper figure.

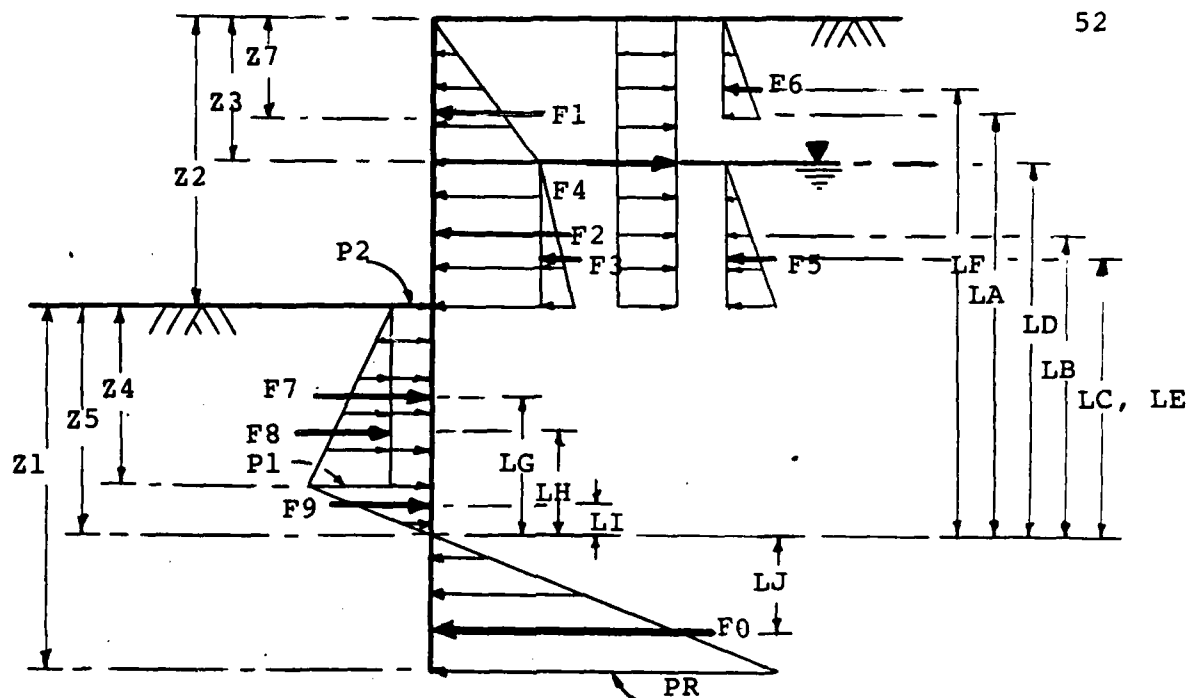


Figure 3.8. Forces and Lever Arms, GWT in Soil #1 (-P2).

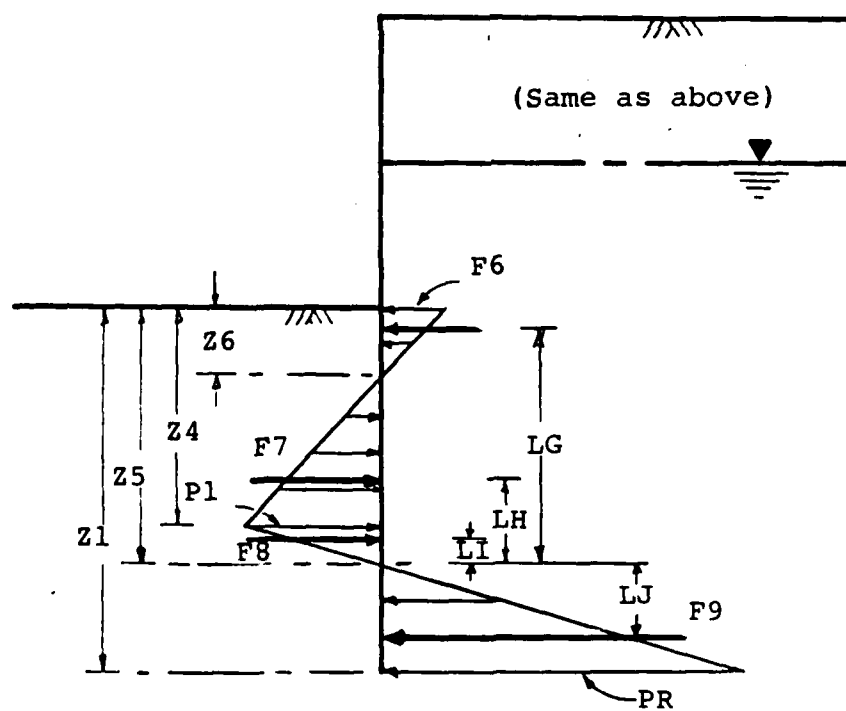


Figure 3.9. Forces and Lever Arms, GWT in Soil #1 (+P2).

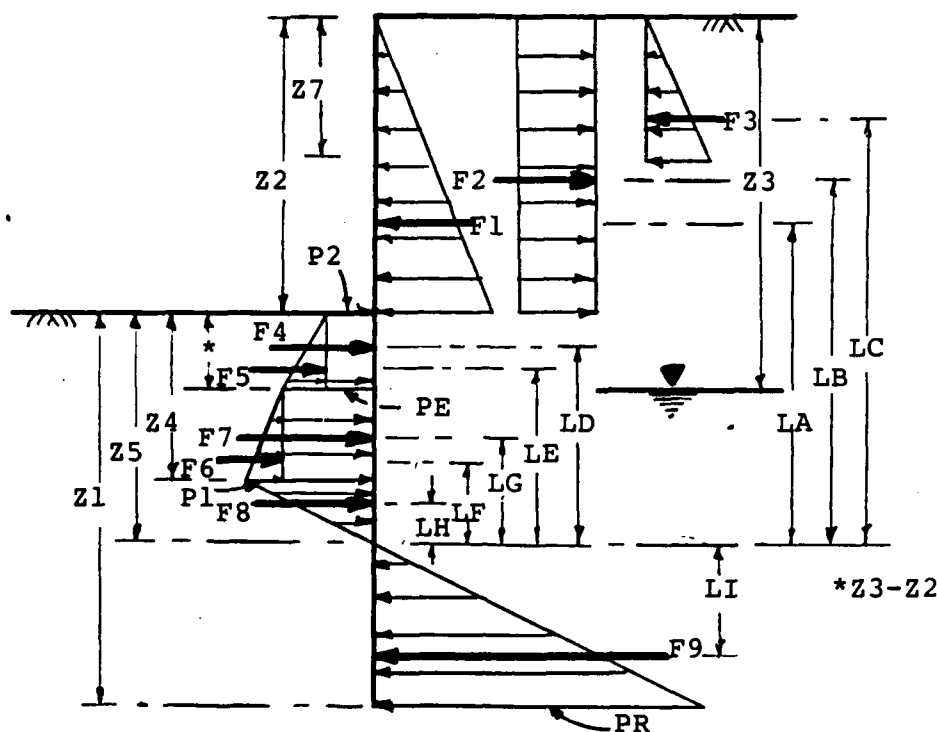


Figure 3.10. Forces and Lever Arms, GWT in Soil #2 (-P2)
($Z_3 < Z_4 + Z_2$).

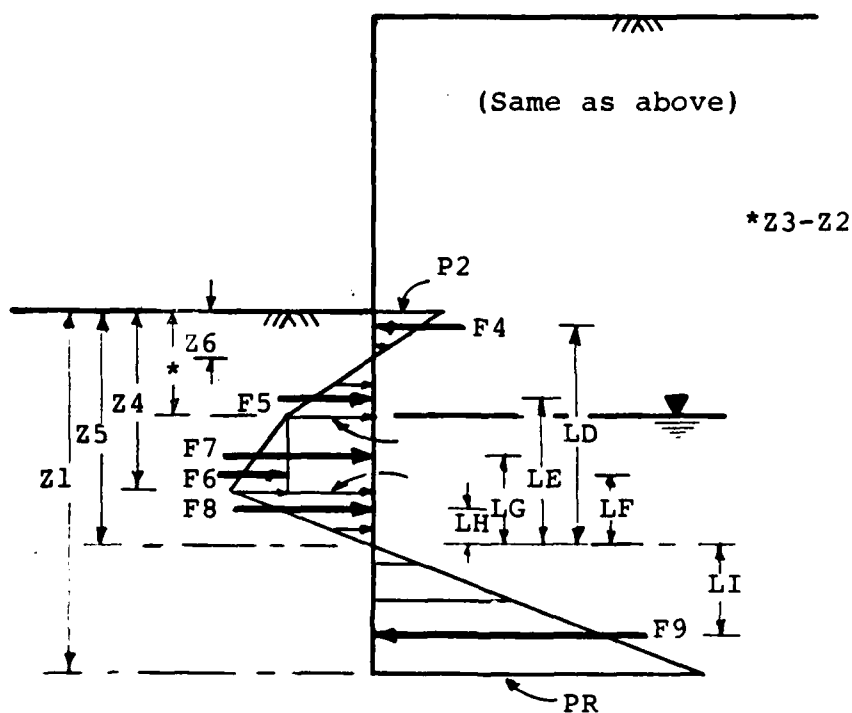


Figure 3.11. Forces and Lever Arms, GWT in Soil #2 (+P2)
($Z_3 < Z_4 + Z_2$).

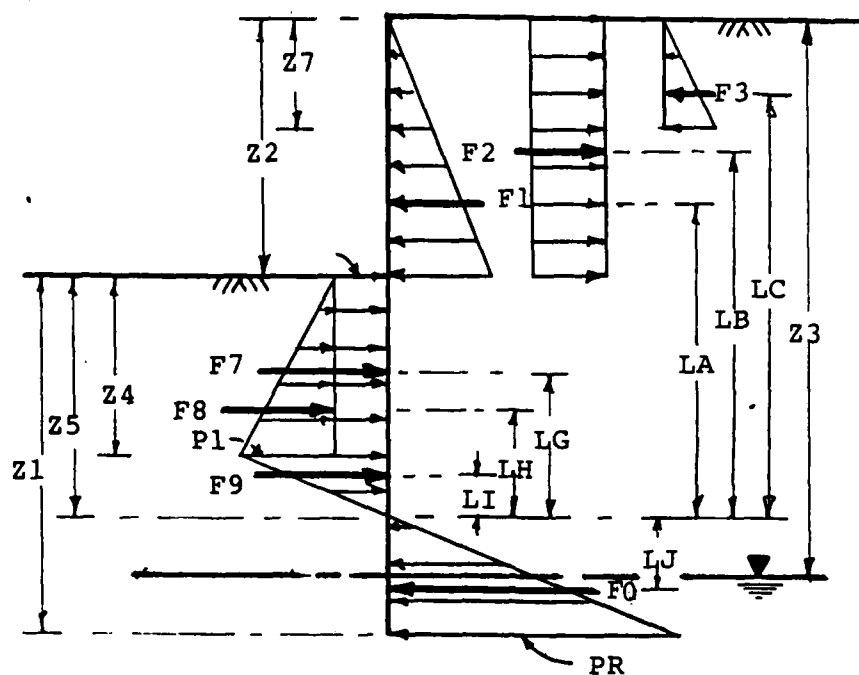


Figure 3.12. Forces and Lever Arms, GWT in Soil #2 (-P2)
($Z_3 > Z_4 + Z_2$).

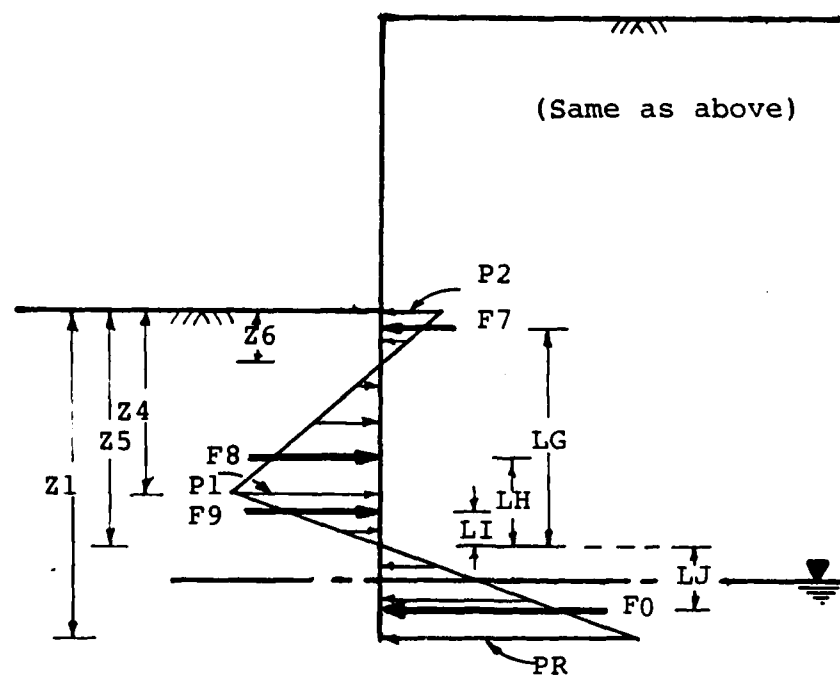


Figure 3.13. Forces and Lever Arms, GWT in Soil #2 (+P2)
($Z_3 > Z_4 + Z_2$).

Table 3.2. Figure Identification.

GWT Depth	Figure	
	+P2	-P2
$Z3 < Z2$	3.9	3.8
$Z2 < Z3 < Z4 + Z2$	3.11	3.10
$Z4 + Z2 < Z3 < Z1$	3.13	3.12
$Z3 > Z1$ (soil #2)	3.9	3.8
$Z3 > Z1$ (soil #1)	3.11	3.10

A separate figure is not included for $Z3 > Z1$ because the correlation of data to the figures is identical to those already shown. When $Z3 > Z1$ use the forces and lever arms of Figures 3.8 and 3.9 for soil #2; similarly, use Figures 3.10 and 3.11 for soil #1. Forces and lever arms consistently correspond to each other; i.e., LA is always the lever arm for $F1$, LE is the lever arm for $F5$, and LJ is the lever arm for $F0$.

CANTWALL will many times calculate a lever arm that is not used but will be printed in the supplementary list. As long as the corresponding force is zero, the user can summarize that the particular force and lever arm was not a part of the calculation.

In the first problem in Section 3.7, the supplementary data list indicates $FG = 0\#$ and $LF = 24.23$ ft. Referring to Figure 3.8, the user finds that $F6$ is the water pressure

due to tension cracks and that since $FG = 0\#$, tension cracks were not specified and that although LF was calculated, it did not affect the summation of forces or moments.

3.4.8 Error Warning

CANTWALL uses warnings to prevent the user from specifying problem parameters that can yield incorrect solutions. The warning, "Assumed depth must be increased" followed by the prompting statement, "Input assumed depth" will be printed on the monitor when Z_4 exceeds Z_1 . Referring to Figure 3.8, it is evident that Z_4 cannot be greater than Z_1 as the combined pressure diagram will not reflect the actual pressure distribution of Figure 3.2(b). The user must input a new depth, preferably two to three times greater than originally assumed. Input an estimated depth according to Table 3.3.

Table 3.3. Recommended Assumed Wall Depths.

N(Sand)	Clay	(Cu, PSF)	Depth (SF = 1)
0 - 4	Soft	(250- 500)	2.0H
5 - 10	Firm	(500 - 1000)	1.5H
11 - 30	Stiff	(1000 - 1500)	1.25H
31 - 50	Very Stiff	(1500 - 2000)	1.H
50+	Hard	(>2000)	.25 H

Although the number of moment iterations may be reduced in half by specifying a depth close to the required depth, it will many times reduce actual user time by inputting a seemingly large assumed depth. Doing so, the warning will not appear and the program will iterate the required depth in a relatively short time.

When the condition:

$$4c - q < 0$$

where,

q = surcharge on soil #2

c = cohesion of soil #2

is satisfied the passive pressure below the dredge line is always less than the active pressure (Figure 3.14). Therefore, an equilibrium condition cannot be achieved no matter how deep the sheet piling is driven below the dredge line. This condition may occur in soft and very soft clays typically having undrained shear strengths less than about 500 psf.

The program identifies this condition when P_1 is calculated as a positive number (see Figure 3.8). Upon identification of this condition, the statement "*Warning* Computed Wall Instability" is printed on the monitor. The user is given the option to end the program or to re-enter the input variables. The first correction would be to reduce the safety factor to one. If the program successfully runs,

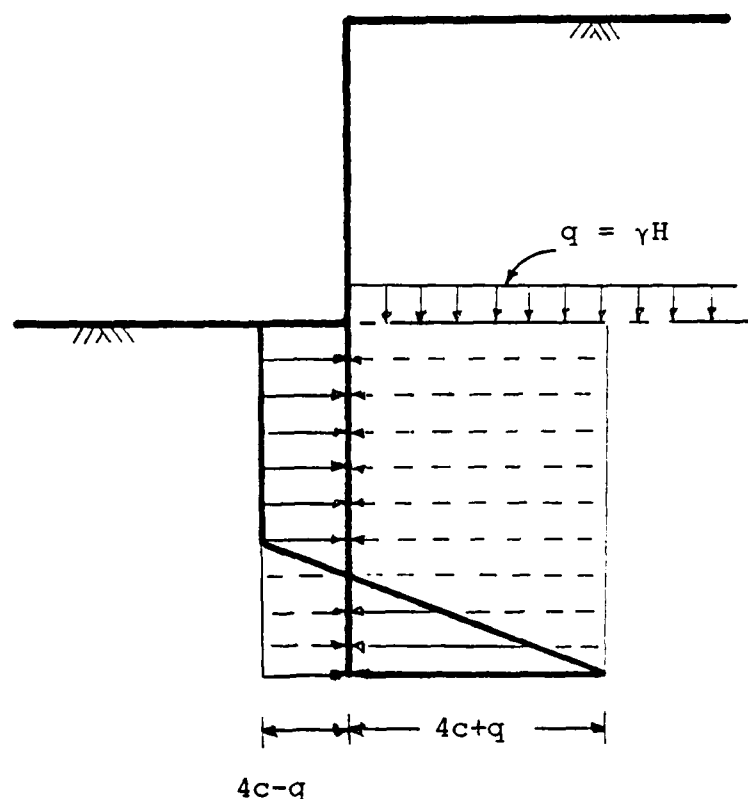


Figure 3.14. Quick, Undrained Loading in Cohesive Soil.

increase the depth by 20% to 40% [2]. The second correction should be to decrease the wall height thus decreasing the value of "q." If all else fails, the user must change the soil conditions in soil #2 or abort the design completely.

The final warning advises the user that soil #1 is in tension and does not mobilize an active force on the wall. This will occur when soil #1 is specified to have large cohesive characteristics. As described in Section 3.2, this phenomena occurs when the cohesive effects of the soil are great enough to allow the soil to stand

unsupported to a height equal to or greater than the specified wall height.

The only way to avoid this condition is to increase the wall height thus increasing the active force on the wall due to soil weight, or decrease the cohesive characteristic of the soil.

3.4.9 Limitations

The limitations of CANTWALL relate primarily to the physical description of the conditions. The most severe limitation is not being capable to specify a surcharge load on the backfill (soil #1). Many practical applications would warrant a surcharge. If a surcharge exists, the user can decrease the cohesion in soil #1 and soil #2 by an appropriate amount such that the net effect on the wall is the same. Since the cohesion creates a rectangular pressure diagram as does a surcharge, this could be done.

A negative cohesion may be input to simulate a surcharge in a cohesionless backfill. The user must convert the surcharge to a proper value of cohesion by the following analogy:

$$\sigma_a^{c'} = -2c' \sqrt{ka} \quad \text{cohesion}$$

$$\sigma_a^q = q \quad ka \quad \text{surcharge}$$

$$\therefore c' = -q\sqrt{ka}/2$$

where,

σ_a^c = active earth pressure due to cohesion

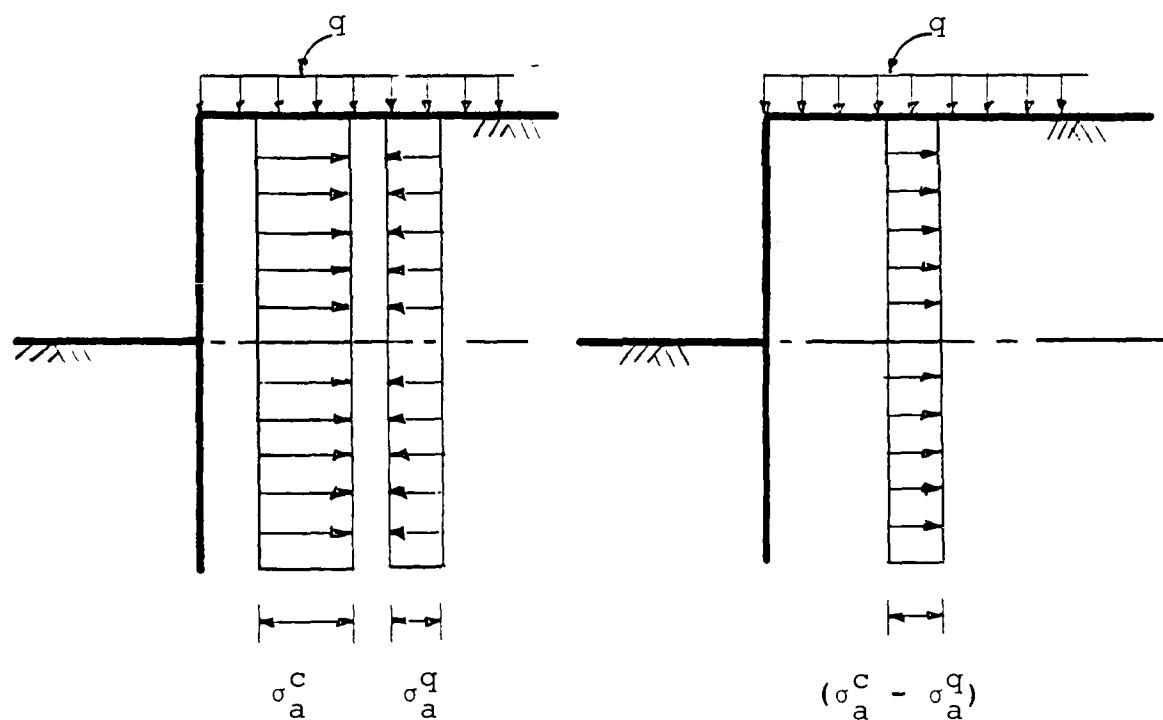
σ_a^q = active earth pressure due to surcharge

c' = equivalent cohesion

q = surcharge

k_a = active earth pressure coefficient

In a cohesive soil, the equivalent cohesion is added to the cohesion of soil #1 and soil #2. The user must maintain a consistent sign convention. See Figure 3.15.



(a) Active pressures due to cohesion and surcharge

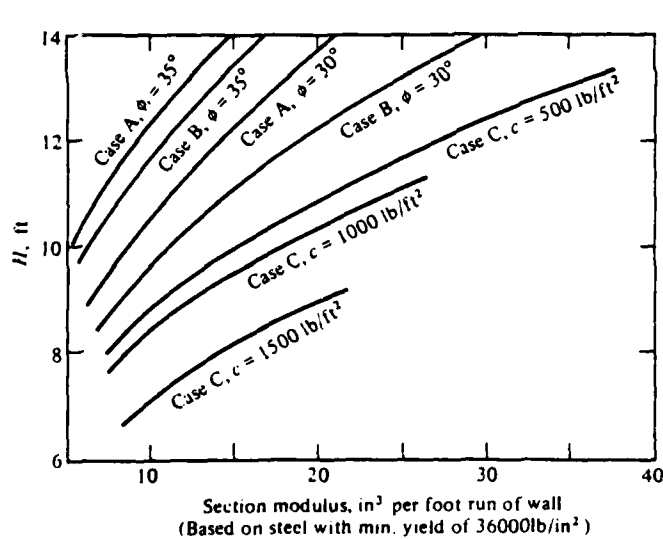
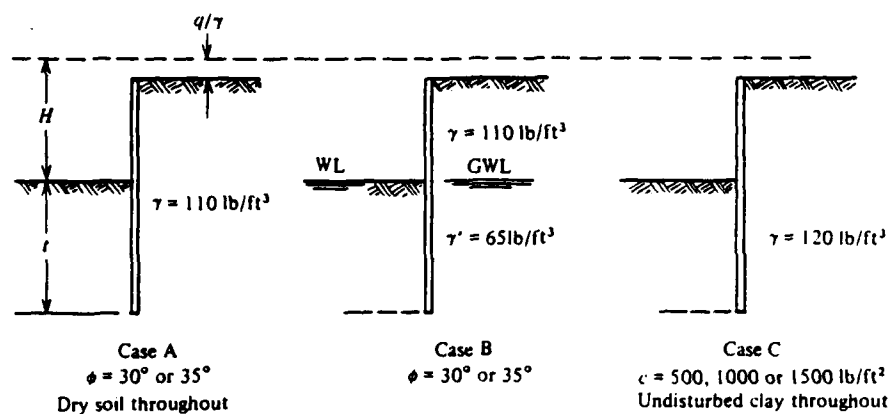
(b) Equivalent cohesion

Figure 3.15. Surcharge Represented by Equivalent Cohesion in a Cohesive Soil.

Another limitation is the predetermination of soil layers. Although the user may easily specify a homogeneous condition, the user is limited to two soil types separated at a predetermined depth. Engineering judgment is the only guide in this case.

The calculated method used in this program assumes a rigid wall and therefore no effects of moment redistribution attributed to wall flexibility are considered.

The final limitation is contingent upon the fact that any cantilevered structure is limited in length or depth by the large bending moments developed under load. In general, heights exceeding 15 to 20 ft are infeasible. Construction materials with section moduli high enough to withstand the bending moments become uneconomical compared to the cost of material used in alternate construction techniques such as anchored walls [1]. This is an engineering decision. The supplementary data list contains the necessary data to calculate the bending moments in the wall. Figure 3.16 provides an insight into the section moduli required to resist loads imposed under three cases.



q is surcharge in lb/ft²

	Values of t/H	
Case A	$\phi = 30^\circ$	1.0
	$\phi = 35^\circ$	1.0
Case B	$\phi = 30^\circ$	1.35
	$\phi = 35^\circ$	1.15
Case C	$c = 500$ lb/ft ²	*
	$c = 1000$ lb/ft ²	1.0
	$c = 1500$ lb/ft ²	1.0

* $t/H = 1.5$ when $H = 7.5'$
 $= 2.3$ when $H = 9.5'$

Figure 3.16. Cantilevered Walls [5].

3.5 Program List

```

5  SPEED= 150
10 PRINT "          *****"
11 PRINT "          *CANTWALL*"
12 PRINT "          *****"
13 PRINT : PRINT : PRINT
20 PRINT " DANA K. EDDY"
22 PRINT " 6A. INSTITUTE OF TECHNOLOGY"
24 PRINT " SCHOOL OF CIVIL ENGINEERING"
26 PRINT " DEPARTMENT OF GEOTECHNICAL ENGINEERING"
30 PRINT : PRINT : PRINT
35 PRINT " SYSTEM HARDWARE: APPLE II PLUS (64K)"
36 PRINT " SYSTEM SOFTWARE: DOS 3.3, APPLESOFT BASIC LANGUAGE"
37 PRINT " PROGRAM DATE: MAY, 1983"
40 PRINT : PRINT : PRINT : PRINT
45 PRINT " CANTWALL ESTIMATES THE EMBEDMENT DEPTH OF A CANTILEVERED WALL.
    THE FREE EARTH SUPPORT METHOD IS USED. THE WALL IS ASSUMED RIGID."
50 PRINT : PRINT : PRINT : PRINT : PRINT : PRINT
55 SPEED= 255
470 PRINT "HOW MANY PROBLEM SETS DO YOU WANT TO RUN?"
480 INPUT Q
485 DIM A(88): DIM B(88)
486 DIM C(88): DIM D(88)
490 FOR R = 1 TO Q
491 PRINT : PRINT
495 AD = 0
500 PRINT "WHAT IS THE WET WEIGHT OF SOIL #1? (PCF)"
510 INPUT G1
511 PRINT : PRINT
520 PRINT "WHAT IS THE SATURATED WEIGHT OF SOIL #1? (PCF)"
530 INPUT G2
531 PRINT : PRINT
534 PRINT "WHAT IS THE COHESION OF SOIL #1? (PSF)"
538 INPUT C1
539 PRINT : PRINT
542 PRINT "WHAT IS THE ANGLE OF INTERNAL FRICTION FOR SOIL #1? (DEGREES)"

546 INPUT A1
547 PRINT : PRINT
550 PRINT "WHAT IS THE FRICTION ANGLE BETWEEN THE WALL AND SOIL #1? (DEGR
    EES)"
554 INPUT B1
555 PRINT : PRINT
558 PRINT "WHAT IS THE WET WEIGHT OF SOIL #2? (PCF)"
562 INPUT G3

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```

563 PRINT : PRINT
566 PRINT "WHAT IS THE SATURATED WEIGHT OF SOIL #2? (PCF)"
570 INPUT G4
571 PRINT : PRINT
574 PRINT "WHAT IS THE COHESION OF SOIL #2? (PSF)"
578 INPUT C2
579 PRINT : PRINT
582 PRINT "WHAT IS THE ANGLE OF INTERNAL FRICTION FOR SOIL #2? (DEGREES)"

586 INPUT A2
587 PRINT : PRINT
590 PRINT "WHAT IS THE FRICTION ANGLE FOR THE WALL AND SOIL #2? (DEGREES)"
    "

595 INPUT B2
596 PRINT : PRINT
600 PRINT "WHAT IS THE HEIGHT OF THE WALL? (FEET)"
605 INPUT Z2
606 PRINT : PRINT
610 PRINT "WHAT IS THE DEPTH OF THE GROUND WATER TABLE? (FEET)"
615 INPUT Z3
616 PRINT : PRINT
620 PRINT "WHAT IS THE TOLERANCE FOR DEPTH CALCULATION (PERCENT, RECD .1
    - .01)?"
625 INPUT TL
626 PRINT : PRINT
630 PRINT "WHAT IS THE SAFETY FACTOR"
635 INPUT SF
636 PRINT : PRINT
640 PRINT "DO YOU WANT TENSION CRACKS WITH WATER PRESSURE TO BE CONSIDERE
    D IN SOIL #1? (YES OR NO)"
645 INPUT A$:X = ASC(A$): IF X < 84 GOTO 671
646 IF X < 84 GOTO 671
647 PRINT : PRINT
650 Z7 = 2 * C1 / G1
655 IF Z7 < Z3 GOTO 665
660 Z7 = Z2
665 IF Z7 < Z2 GOTO 671
670 Z7 = Z2
671 PRINT : PRINT : PRINT "DO YOU WANT TO USE AN EQUIVALENT ACTIVE FORCE
    IN SOIL #1? (YES OR NO)"
672 INPUT C$:W = ASC(C$)
673 PRINT : PRINT
675 PRINT "DO YOU WANT TO INPUT THE COEFFICIENTS OF EARTH PRESSURE (YES)
    OR HAVE THEM CALCULATED FOR YOU (NO)?"
680 INPUT B$:X = ASC(B$): IF X < 84 GOTO 725
681 IF X < 84 GOTO 725
682 PRINT : PRINT : PRINT
685 PRINT "WHAT IS K ACTIVE FOR SOIL #1?"
690 INPUT K1
691 PRINT

```

```

695 PRINT "WHAT IS K PASSIVE FOR SOIL #2?"
700 INPUT K2
701 PRINT
705 PRINT "WHAT IS K ACTIVE FOR SOIL #2?"
710 INPUT K3
715 GOTO 744
725 RA = .01745
730 K1 = ( SIN (1.571 + A1 * RA)) ^ 2 / SIN (1.571 - B1 * RA) / (1 + ( SIN
      ((A1 + B1) * RA) * SIN (A1 * RA) / SIN (1.571 - B1 * RA)) ^ .5) ^ 2
735 K2 = ( SIN (1.571 - A2 * RA)) ^ 2 / SIN (1.571 + B2 * RA) / (1 - ( SIN
      ((A2 + B2) * RA) * SIN (A2 * RA) / SIN (1.571 - B2 * RA)) ^ .5) ^ 2
740 K3 = ( SIN (1.571 + A2 * RA)) ^ 2 / SIN (1.571 - B2 * RA) / (1 + ( SIN
      ((A2 + B2) * RA) * SIN (A2 * RA) / SIN (1.571 - B2 * RA)) ^ .5) ^ 2
744 G5 = 62.4
745 PRINT : PRINT
746 IF Z3 > Z2 GOTO 747: Z8 = 2 * C1 * K1 ^ .5 * Z2 / ((G1 * Z3 + (G2 - G5
      ) * (Z2 - Z3)) * K1): IF Z8 < Z2 GOTO 750: GOTO 748
747 Z8 = 2 * C1 / (G1 * K1 ^ .5): IF Z8 < Z2 GOTO 760
748 PRINT "SOIL #1 IS IN TENSION, REEVALUATE THE COHESION OF SOIL #1 OR T
      HE HEIGHT OF THE WALL. TYPE (1) TO RESTART THE PROGRAM."
749 INPUT AB: GOTO 491
750 PRINT "INPUT ASSUMED DEPTH OF WALL PENETRATION (REFER TO USERS' MANUA
      L)."
752 INPUT Z1
753 PRINT : PRINT
754 N = 1
770 Z4 = .72 * Z1: GOTO 774
771 PRINT "ASSUMED DEPTH MUST BE INCREASED": PRINT : PRINT
772 AZ = 0: GOTO 760
774 F1 = 0: F2 = 0: F3 = 0: F4 = 0: F5 = 0: F6 = 0: F7 = 0: F8 = 0: F9 = 0: F0 = 0:
      LA = 0: LB = 0: LC = 0: LD = 0: LE = 0: LF = 0: LG = 0: LH = 0: LI = 0: LJ = 0
775 H = 1
780 IF Z3 > Z2 GOTO 930
781 IF H < 84 GOTO 785
782 F1 = ((G1 * Z3 + (G2 - G5) * (Z2 - Z3)) * K1 - 2 * C1 * K1 ^ .5) + (Z3
      - 2 * C1 * K1 ^ .5 * Z2 / (G1 * Z3 + (G2 - G5) * (Z2 - Z3)) / K1) /
      2
783 GOTO 805
795 F1 = G1 * Z3 ^ 2 * K1 / 2
796 F2 = G1 * Z3 * K1 * (Z2 - Z3)
795 F3 = (G1 * Z3 + (G2 - G5) * (Z2 - Z3) - G1 * Z3) * K1 * (Z2 - Z3) / 2
800 F4 = - 2 * C1 * K1 ^ .5 * Z2
805 F5 = G5 * (Z2 - Z3) ^ 2 / 2
810 F6 = G5 * Z7 ^ 2 / 2
815 FA = F1 + F2 + F3 + F4 + F5 + F6

```

```

816 IF FA > 0 GOTO 845
817 PRINT "*** WARNING **      THE NET ACTIVE FORCE AGAINST THE WALL IN SOI
    L #1 IS NEGATIVE."
818 PRINT : PRINT
819 PRINT "TO RESTART THE PROGRAM TYPE (1); TO EXERCISE SOIL #1 ACTIVE OP
    TIONS TYPE (2)."
```

820 INPUT AA: IF AA = 1 GOTO 491: GOTO 636

821 GOTO 636

845 Z = Z1

850 GOSUB 6200

855 Z = Z4

860 GOSUB 6100

865 P1 = PL

866 GOSUB 6800

867 IF AD = 1 GOTO 491

870 Z = 0

875 GOSUB 6100

880 P2 = PL

885 GOSUB 4000

886 IF AZ = 1 GOTO 771

887 IF M = 1 GOTO 894

890 IF TL > = ABS (100 * (Z4 - C(M)) / Z4) GOTO 896

894 M = M + 1

895 GOTO 855

896 IF W < 84 GOTO 900

897 LA = Z5 + Z2 / 3

898 GOTO 917

900 LA = Z5 + Z2 - 2 * Z3 / 3

910 LB = Z5 + (Z2 - Z3) / 2

915 LC = Z5 + (Z2 - Z3) / 3

916 LD = Z5 + Z2 / 2

917 LE = Z5 + (Z2 - Z3) / 3

918 LF = Z5 + Z2 - 2 * Z7 / 3

920 GOSUB 6000

921 IF N = 1 GOTO 923

922 IF TL > = ABS (100 * (Z1 - A(N)) / Z1) GOTO 3000

923 N = N + 1

925 GOTO 770

930 IF Z3 > Z2 + Z1 GOTO 2331

931 IF W < 84 GOTO 935

932 $F1 = (Z2 * G1 + K1 - 2 * C1 * K1 \wedge .5) + (Z2 - 2 * C1 / (G1 + K1 \wedge .5)) / 2$

933 GOTO 945

935 $F1 = G1 + Z2 \wedge 2 * K1 / 2$

940 $F2 = - 2 * C1 * K1 \wedge .5 * Z2$

945 $F3 = G5 + Z7 \wedge 2 / 2$

950 FA = F1 + F2 + F3

951 IF FA > 0 GOTO 965

952 PRINT "*** WARNING ** THE NET ACTIVE FORCE AGAINST THE WALL IN SOI
 L #1 IS NEGATIVE."

```

953 PRINT : PRINT
954 PRINT " TO RESTART THE PROGRAM TYPE (1); TO EXERCISE SOIL #1 ACTIVE O
PTIONS TYPE (2). "
955 INPUT AB: IF AB = 1 GOTO 491: GOTO 636
956 GOTO 636
965 IF Z4 < = Z3 - Z2 GOTO 2010
970 Z = Z1
975 GOSUB 6400
980 Z = Z4
985 GOSUB 6300
990 P1 = PL
991 GOSUB 6800
992 IF AD = 1 GOTO 491
995 Z5 = Z1 - (PR * (Z4 - Z1) / (P1 - PR))
1000 Z = Z3 - Z2
1005 GOSUB 6300
1010 P3 = PL
1015 Z = 0
1020 GOSUB 6700
1025 P2 = PL
1030 IF P2 > 0 GOTO 1120
1035 F4 = P2 * (Z3 - Z2)
1040 F5 = (P3 - P2) * (Z3 - Z2) / 2
1045 F6 = (P1 - P3) * (Z4 - Z3 + Z2) / 2
1050 F7 = P3 * (Z4 - Z3 + Z2)
1055 F8 = P1 * (Z5 - Z4) / 2
1060 F9 = PR * (Z1 - Z5) / 2
1065 GOSUB 5000
1066 IF AZ = 1 GOTO 771
1067 IF M = 1 GOTO 1074
1070 IF TL > = ABS (100 * (Z4 - C(M)) / Z4) GOTO 1080
1074 M = M + 1
1075 GOTO 980
1080 LA = Z5 + Z2 / 3
1081 IF W > 84 GOTO 1086
1085 LB = Z5 + Z2 / 2
1086 LC = Z5 + Z2 - 2 * Z7 / 3
1087 LD = Z5 - (Z3 - Z2) / 2
1088 LE = Z5 - 2 * (Z3 - Z2) / 3
1089 LF = Z5 - (Z3 - Z2 + 2 * Z4) / 3
1090 LG = Z5 - (Z3 - Z2 + Z4) / 2
1091 LH = 2 * (Z5 - Z4) / 3
1095 LI = - 2 * (Z1 - Z5) / 3
1110 GOSUB 6000
1111 IF N = 1 GOTO 1113
1112 IF TL > = ABS (100 * (Z1 - A(N)) / Z1) GOTO 3000
1113 N = N + 1
1115 GOTO 770
1120 Z6 = (Z3 - Z2) * P2 / (P2 - P3)
1122 IF Z6 > (Z3 - Z2) GOTO 1200

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```

1125 F4 = P2 * Z6 / 2
1130 F5 = P3 * (Z3 - Z2 - Z6) / 2
1135 F6 = (P1 - P3) * (Z4 - Z3 + Z2) / 2
1140 F7 = P3 * (Z4 - Z3 + Z2)
1145 F8 = P1 * (Z5 - Z4) / 2
1150 F9 = PR * (Z1 - Z5) / 2
1155 GOSUB 5000
1156 IF AZ = 1 GOTO 771
1157 IF M = 1 GOTO 1164
1160 IF TL > = ABS (100 * (Z4 - C(M)) / Z4) GOTO 1170
1164 M = M + 1
1165 GOTO 980
1170 LA = Z5 + Z2 / 3
1171 IF W > 84 GOTO 1173
1172 LB = Z5 + Z2 / 2
1173 LC = Z5 + Z2 - 2 * Z7 / 3
1174 LD = Z5 - Z6 / 3
1175 LE = Z5 - (Z6 + 2 * Z3 - 2 * Z2) / 3
1180 LF = Z5 - 2 * (Z4 - Z3 + Z2) / 3
1185 LG = Z5 - (Z4 - Z3 + Z2) / 2
1190 LH = (2 * Z5 + Z4) / 3
1195 LI = - 2 * (Z1 - Z5) / 3
1197 GOTO 2000
1200 F4 = P3 * (Z3 - Z2)
1205 F5 = (P2 - P3) * (Z3 - Z2) / 2
1210 F6 = P3 * (Z6 - Z3 + Z2) / 2
1215 F7 = P1 * (Z4 - Z6) / 2
1220 F8 = P1 * (Z5 - Z4) / 2
1225 F9 = PR * (Z1 - Z5) / 2
1230 GOSUB 5000
1232 IF AZ = 1 GOTO 771
1235 IF TL > = ABS (100 * (Z4 - C(M)) / Z4) GOTO 1250
1240 M = M + 1
1245 GOTO 980
1250 LA = Z5 + Z2 / 3
1255 IF W > 84 GOTO 1265
1260 LB = Z5 + Z2 / 2
1265 LC = Z5 + Z2 - 2 * Z7 / 3
1270 LD = Z5 - (Z3 - Z2) / 2
1275 LE = Z5 - (Z3 - Z2) / 3
1280 LF = Z5 + (2 * Z2 - 2 * Z3 - Z6) / 3
1285 LG = Z5 - 2 * (Z4 - Z6) / 3
1290 LH = 2 * (Z5 - Z4) / 3
1295 LI = - 2 * (Z1 - Z5) / 3
1300 GOSUB 6000
1305 IF N = 1 GOTO 1315
1310 IF TL > = ABS (100 * (Z1 - C(N)) / Z1) GOTO 3000
1315 N = N + 1
1320 GOTO 770
2000 GOSUB 6000

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```

2001 IF N = 1 GOTO 2003
2002 IF TL > = ABS (100 * (Z1 - A(N)) / Z1) GOTO 3000
2003 N = N + 1
2005 GOTO 770
2010 Z = Z1
2015 GOSUB 6400
2020 Z = Z4
2025 GOSUB 6700
2030 P1 = PL
2031 GOSUB 6800
2032 IF AD = 1 GOTO 491
2035 Z = 0
2040 GOSUB 6700
2045 P2 = PL
2050 GOSUB 4000
2051 IF AZ = 1 GOTO 771
2052 IF M = 1 GOTO 2059
2055 IF TL > = ABS (100 * (Z4 - C(M)) / Z4) GOTO 2065
2059 M = M + 1
2060 GOTO 2020
2065 LA = Z5 + Z2 / 3
2066 IF W > 84 GOTO 2075
2070 LB = Z5 + Z2 / 2
2075 LC = Z5 + Z2 - 2 * Z7 / 3
2085 GOSUB 6000
2086 IF N = 1 GOTO 2088
2087 IF TL > = ABS (100 * (Z1 - A(N)) / Z1) GOTO 3000
2088 N = N + 1
2090 GOTO 770
2331 IF W < 84 GOTO 2335
2332 F1 = (Z2 * G1 * K1 - 2 * C1 * K1 ^ .5) * (Z2 - 2 * C1 / (G1 * K1 ^ .5)
    ) / 2
2333 GOTO 2345
2335 F1 = G1 * Z2 ^ 2 * K1 / 2
2340 F2 = - 2 * C1 * K1 ^ .5 * Z2
2345 F3 = G5 * Z7 ^ 2 / 2
2350 FA = F1 + F2 + F3
2351 IF FA > 0 GOTO 2365
2352 PRINT "** WARNING **      THE NET ACTIVE FORCE AGAINST THE WALL IN SO
    IL #1 IS NEGATIVE."
2353 PRINT : PRINT
2354 PRINT "TO RESTART THE PROGRAM TYPE (1); TO EXERCISE SOIL #1 ACTIVE O
    PTIONS TYPR (2). "
2355 INPUT AC: IF AC = 1 GOTO 491: GOTO 636
2356 GOTO 636
2365 Z = Z1
2370 GOSUB 6600
2375 Z = Z4
2380 GOSUB 6500
2385 P1 = PL

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2386 GOSUB 6300
2387 IF AD = 1 GOTO 491
2390 Z = 0
2395 GOSUB 6500
2400 P2 = PL
2405 GOSUB 4000
2406 IF AZ = 1 GOTO 771
2407 IF M = 1 GOTO 2414
2410 IF TL > = ABS (100 * (Z4 - C(M)) / Z4) GOTO 2420
2414 M = M + 1
2415 GOTO 2375
2420 LA = Z5 + Z2 / 3
2421 IF W > 84 GOTO 2430
2425 LB = Z5 + Z2 / 2
2430 LC = Z5 + Z2 - 2 * Z7 / 3
2440 GOSUB 6000
2441 IF N = 1 GOTO 2443
2442 IF TL > = ABS (100 * (Z1 - A(N)) / Z1) GOTO 3000
2443 N = N + 1
2445 GOTO 770
3000 L$ = CHR$ (4): PRINT L$;"PR#1"
3008 PRINT "*****": PRINT "*****"
3010 PRINT "INPUT DATA"
3011 PRINT "*****": PRINT "*****"
3012 PRINT : PRINT
3020 PRINT "WET UNIT WEIGHT, SOIL #1 ="G1" PCF."
3021 PRINT
3030 PRINT "SATURATED UNIT WEIGHT, SOIL #1 ="G2" PCF."
3031 PRINT
3040 PRINT "COHESION, SOIL #1 ="C1" PSF."
3041 PRINT
3050 PRINT "ANGLE OF INTERNAL FRICTION, SOIL #1 ="A1" DEGREES."
3051 PRINT
3060 PRINT "FRICTION ANGLE, SOIL #1 ="B1" DEGREES."
3061 PRINT
3070 PRINT "WET UNIT WEIGHT, SOIL #2 ="G3" PCF."
3071 PRINT
3080 PRINT "SATURATED UNIT WEIGHT, SOIL #2 ="G4" PCF."
3081 PRINT
3090 PRINT "COHESION, SOIL #2 ="C2" PSF."
3091 PRINT
3100 PRINT "ANGLE OF INTERNAL FRICTION, SOIL #2 ="A2" DEGREES."
3101 PRINT
3110 PRINT "FRICTION ANGLE, SOIL #2 ="B2" DEGREES."
3111 PRINT
3120 PRINT "WALL HEIGHT ="Z2" FEET."
3121 PRINT
3130 PRINT " GROUND WATER DEPTH ="Z3" FEET."
3131 PRINT
3133 PRINT "ACTIVE K, SOIL #1 ="K1

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3134 PRINT
3135 PRINT "PASSIVE K, SOIL #2 ="K2
3136 PRINT
3137 PRINT "ACTIVE K, SOIL #2 ="K3
3138 PRINT
3140 PRINT "TOLERANCE ="TL" PERCENT."
3141 PRINT
3150 PRINT "SAFETY FACTOR ="SF"."
3151 PRINT : PRINT
3158 PRINT "*****": PRINT "*****"
3160 PRINT "OUTPUT DATA"
3161 PRINT "*****": PRINT "*****"
3162 PRINT : PRINT
3165 ZZ = Z1 * 100
3166 ZZ = INT (ZZ)
3167 ZZ = ZZ / 100
3170 PRINT "REQUIRED WALL PENETRATION ="ZZ" FEET."
3171 PRINT : PRINT
3180 PRINT L$;"PR#0"
3190 PRINT : PRINT : PRINT "DO YOU WANT SUPPLEMENTARY DATA?"
3200 INPUT C$:X = ASC (C$): IF X < 84 GOTO 3520
3210 L$ = CHR$ (4): PRINT L$;"PR#1"
3218 PRINT
3219 PRINT "*****"
3220 PRINT "SUPPLEMENTARY DATA"
3221 PRINT "*****"
3222 PRINT : PRINT
3225 PRINT "Z1 ="Z1" FEET."
3230 PRINT "Z4 ="Z4" FEET."
3240 PRINT "Z5 ="Z5" FEET."
3250 PRINT "Z6 ="Z6" FEET."
3260 PRINT "Z7 ="Z7" FT."
3270 PRINT "P1 ="P1" PSF."
3280 PRINT "P2 ="P2" PSF."
3290 PRINT "P3 ="P3" PSF."
3300 PRINT "P4 ="P4" PSF."
3400 PRINT "PR ="PR" PSF."
3405 PRINT "F1 ="F1"#.      ", "LA ="LA"FT."
3410 PRINT "F2 ="F2"#.      ", "LB ="LB"FT."
3415 PRINT "F3 ="F3"#.      ", "LC ="LC"FT."
3420 PRINT "F4 ="F4"#.      ", "LD ="LD"FT."
3425 PRINT "F5 ="F5"#.      ", "LE ="LE"FT."
3430 PRINT "F6 ="F6"#.      ", "LF ="LF"FT."
3435 PRINT "F7 ="F7"#.      ", "LG ="LG"FT."
3440 PRINT "F8 ="F8"#.      ", "LH ="LH"FT."
3445 PRINT "F9 ="F9"#.      ", "LI ="LI"FT."
3450 PRINT "F0 ="F0"#.      ", "LJ ="LJ"FT."
3460 PRINT "FT ="FT"#.      ", "HT ="HT"FT-#."
3500 PRINT L$;"PR#0"
3505 HOME

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3510 NEXT R
3520 PRINT "THANK YOU FOR USING CANTWALL."
3521 PRINT
3522 PRINT "BYE-BYE"
3523 END
4000 Z5 = Z1 - (PR * (Z4 - Z1) / (P1 - PR))
4005 IF P2 >= 0 GOTO 4040
4010 F7 = P2 * Z4
4015 F8 = (P1 - P2) * Z4 / 2
4020 F9 = P1 * (Z5 - Z4) / 2
4025 F0 = PR * (Z1 - Z5) / 2
4026 LG = Z5 - Z4 / 2
4027 LH = Z5 - 2 * Z4 / 3
4028 LI = 2 * (Z5 - Z4) / 3
4029 LJ = - 2 * (Z1 - Z5) / 3
4030 GOSUB 5000
4035 RETURN
4040 Z6 = - P2 * Z4 / (P1 - P2)
4045 F7 = P2 * Z6 / 2
4050 F8 = P1 * (Z4 - Z6) / 2
4055 F9 = P1 * (Z5 - Z4) / 2
4060 F0 = PR * (Z1 - Z5) / 2
4061 LG = Z5 - Z6 / 3
4062 LH = Z5 - (2 * Z4 + Z6) / 3
4063 LI = 2 * (Z5 - Z4) / 3
4064 LJ = - 2 * (Z1 - Z5) / 3
4065 GOSUB 5000
4070 RETURN
5000 FT = F1 + F2 + F3 + F4 + F5 + F6 + F7 + F8 + F9 + F0
5005 OCM) = Z4
5010 OCM) = FT
5015 IF M >= 2 GOTO 5055
5020 IF OCM) < 0 GOTO 5040
5025 Z4 = Z4 + 2
5035 RETURN
5040 Z4 = Z4 - 2
5050 RETURN
5055 Z4 = OCM) - 1 - OCM) - 1 * (OCM) - OCM) - 1 / (OCM) - OCM) - 1
5056 IF Z4 <= Z1 THEN 5065
5060 AZ = 1
5065 RETURN
6000 MT = F1 * LA + F2 * LB + F3 * LC + F4 * LD + F5 * LE + F6 * LF + F7 *
    LG + F8 * LH + F9 * LI + F0 * LJ
6001 PRINT "I AM COMPUTING, PLEASE BE PATIENT.": PRINT : PRINT
6005 BKN) = Z1
6010 BKN) = MT
6015 IF N >= 2 GOTO 6055
6020 IF BKN) < 0 GOTO 6040
6025 Z1 = Z1 + 2
6035 RETURN

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6040 Z1 = Z1 - 2
6050 RETURN
6055 Z1 = A(N - 1) - B(N - 1) * (A(N) - A(N - 1)) / (B(N) - B(N - 1))
6070 RETURN
6100 PL = - ((G4 - G5) * Z * K2 + 2 * C2 * K2 ^ .5 + G5 * Z) / SF + (G4 -
        G5) * Z * K3 + (G1 * Z3 + (G2 - G5) * (Z2 - Z3)) * K3 + G5 * (Z2 - Z3
        + Z) - 2 * C2 * K3 ^ .5
6105 RETURN
6200 PR = ((G4 - G5) * Z * K2 + 2 * C2 * K2 ^ .5 + (G1 * Z3 + (G2 - G5) *
        (Z2 - Z3)) * K2 + G5 * (Z2 - Z3 + Z)) / SF + 2 * C2 * K3 ^ .5 - (G4 -
        G5) * Z * K3 - G5 * Z
6205 RETURN
6300 PL = - (2 * C2 * K2 ^ .5 + G3 * (Z3 - Z2) * K2 + G5 * (Z - Z3 + Z2) +
        (G4 - G5) * (Z - Z3 + Z2) * K2) / SF + G3 * (Z3 - Z2) * K3 - 2 * C2 *
        K3 ^ .5 + G5 * (Z - Z3 + Z2) + (G4 - G5) * (Z - Z3 + Z2) * K3 + G1 *
        Z2 * K3
6305 RETURN
6400 PR = (G3 * (Z3 - Z2) * K2 + 2 * C2 * K2 ^ .5 + G1 * Z2 * K2 + (G4 - G
        5) * (Z - Z3 + Z2) * K2 + G5 * (Z - Z3 + Z2)) / SF + 2 * C2 * K3 ^ .5
        - G3 * (Z3 - Z2) * K3 - (G4 - G5) * (Z - Z3 + Z2) * K3 - G5 * (Z - Z
        3 + Z2)
6405 RETURN
6500 PL = - (G3 * Z * K2 + 2 * C2 * K2 ^ .5) / SF + G3 * Z * K3 - 2 * C2 *
        K3 ^ .5 + G1 * Z2 * K3
6505 RETURN
6600 PR = (G3 * Z * K2 + 2 * C2 * K2 ^ .5 + G1 * Z2 * K2) / SF + 2 * C2 *
        K3 ^ .5 - G3 * Z * K3
6605 RETURN
6700 PL = - (G3 * Z * K2 + 2 * C2 * K2 ^ .5) / SF + G3 * Z * K3 - 2 * C2 *
        K3 ^ .5 + G1 * Z2 * K3
6705 RETURN
6800 IF P1 < 0 GOTO 6835
6805 PRINT : PRINT
6810 PRINT "** WARNING **   COMPUTED WALL INSTABILITY (SEE USERS' MANUAL)
        "
6815 PRINT : PRINT
6820 PRINT "TO RESTART THE PROGRAM TYPE (1); TO END THE PROGRAM TYPE (2)"
6825 INPUT AD: IF AD = 1 GOTO 6835
6830 END
6835 RETURN

```

3.6 Variable List (CANTWALL 1)

Input

Q = # of runs
G1 = Wet weight, soil #1
G2 = Saturated weight, soil #2
C1 = Cohesion, soil #1
A1 = Phi angle, soil #1
B1 = Delta angle, soil #1
G3 = Wet weight, soil #2
G4 = Saturated weight, soil #2
C2 = Cohesion, soil #2
A2 = Phi angle, soil #2
B2 = Delta angle, soil #2
Z2 = Wall height
Z3 = Depth to GWT
TL = Tolerance
SF = Safety factor
K1 = Active earth pressure coefficient, soil #1
K2 = Passive earth pressure coefficient, soil #2
K3 = Active earth pressure coefficient, soil #2

Flow Control

AZ = Z4 > Z1
X = Question input
W = Equivalent active force in soil #1

AB = Restart or end program

AA = Restart or end program

AC = Restart or end program

AD = Restart or end program

Counters

R = Run number

N = Moment iterations

M = Force iterations

Miscellaneous

Z1 = Wall penetration depth

Z4 = Pressure depth in soil #2

Z5 = Pressure depth in soil #2

Z6 = Pressure depth in soil #2

Z7 = Tension crack depth in soil #1

Z8 = Tension depth in soil #1

Z = Depth

G5 = Unit weight of water, 62.4 pcf

F1-F0 = Forces

LA-LJ = Lever arms

FA = Σ forces in soil #1

FT = Σ forces, total

MT = Σ moments

C(M) = Z4

D(M) = FT

A(N) = Z1

B(N) = MT

P1-P3 = Soil pressures, soil #2

PR = Soil pressure, soil #2

3.7 Problem Verification

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3.7.1 Problem #1

HOW MANY PROBLEM SETS DO YOU WANT TO RUN?
?3

WHAT IS THE WET WEIGHT OF SOIL #1? (PCF)
?110

WHAT IS THE SATURATED WEIGHT OF SOIL #1? (PCF)
?122.4

WHAT IS THE COHESION OF SOIL #1? (PSF)
?200

WHAT IS THE ANGLE OF INTERNAL FRICTION FOR SOIL #1? (DEGREES)
?30

WHAT IS THE FRICTION ANGLE BETWEEN THE WALL AND SOIL #1? (DEGREES)
?15

WHAT IS THE WET WEIGHT OF SOIL #2? (PCF)
?110

WHAT IS THE SATURATED WEIGHT OF SOIL #2? (PCF)
?122.4

WHAT IS THE COHESION OF SOIL #2? (PSF)
?600

WHAT IS THE ANGLE OF INTERNAL FRICTION FOR SOIL #2? (DEGREES)
?30

WHAT IS THE FRICTION ANGLE FOR THE WALL AND SOIL #2? (DEGREES)
?15

WHAT IS THE HEIGHT OF THE WALL? (FEET)
?20

WHAT IS THE DEPTH OF THE GROUND WATER TABLE? (FEET)
?10

WHAT IS THE TOLERANCE FOR DEPTH CALCULATION (PERCENT, REC'D .1 - .01)?
?.05

WHAT IS THE SAFETY FACTOR
?1

DO YOU WANT TENSION CRACKS WITH WATER PRESSURE TO BE CONSIDERED IN SOIL #1? (YES
OR NO)
?N

DO YOU WANT TO USE AN EQUIVALENT ACTIVE FORCE IN SOIL #1? (YES OR NO)
?N

DO YOU WANT TO INPUT THE COEFFICIENTS OF EARTH PRESSURE (YES) OR HAVE THEM CALCU-
LATED FOR YOU (NO)?
?N

INPUT ASSUMED DEPTH OF WALL PENETRATION (REFER TO USERS' MANUAL).
?100

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

INPUT DATA

WET UNIT WEIGHT, SOIL #1 =110 PCF.

SATURATED UNIT WEIGHT, SOIL #1 =122.4 PCF.

COHESION, SOIL #1 =200 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #1 =30 DEGREES.

FRICTION ANGLE, SOIL #1 =15 DEGREES.

WET UNIT WEIGHT, SOIL #2 =110 PCF.

SATURATED UNIT WEIGHT, SOIL #2 =122.4 PCF.

COHESION, SOIL #2 =600 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #2 =30 DEGREES.

FRICTION ANGLE, SOIL #2 =15 DEGREES.

WALL HEIGHT =20 FEET.

GROUND WATER DEPTH =10 FEET.

ACTIVE K, SOIL #1 =.301403678

PASSIVE K, SOIL #2 =4.97549393

ACTIVE K, SOIL #2 =.301403678

TOLERANCE =.05 PERCENT.

SAFETY FACTOR =1.

 OUTPUT DATA

REQUIRED WALL PENETRATION =5.21 FEET.

DO YOU WANT SUPPLEMENTARY DATA?
 Y

 SUPPLEMENTARY DATA

Z1 =5.21371744 FEET.

Z4 =3.99707472 FEET.

Z5 =4.23195843 FEET.

Z6 =0 FEET.

Z7 =0 FT.

P1 =-3320.07579 PSF.

P2 =-2199.1145 PSF.

P3 =0 PSF.

P4 =0 PSF.

PR =13880.0615 PSF.

F1 =1657.72023#.

F2 =3315.44046#.

F3 =904.211035#.

F4 =-4392.01951#.

F5 =3120#.

F6 =0#.

F7 =-8790.02499#.

F8 =-2240.283#.

F9 =-399.915853#.

F0 =6814.87162#.

FT =-1.71661377E-05#.

LA =17.5652918FT.

LB =9.23195843FT.

LC =7.56529176FT.

LD =14.2319584FT.

LE =7.56529176FT.

LF =24.2319584FT.

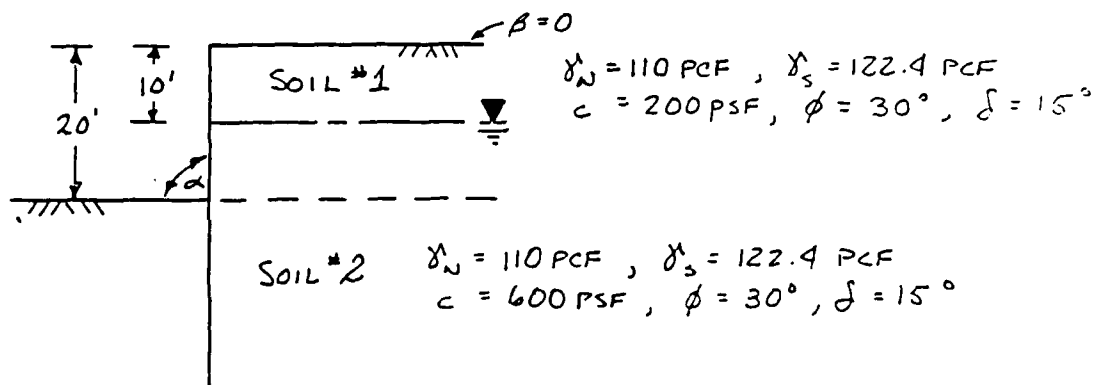
LG =2.23342107FT.

LH =1.56724195FT.

LI =.156589137FT.

LJ =-.654643747FT.

MT =-1.62272716FT-#.



$$k_a^1 = \frac{\sin^2(\alpha + \phi)}{\sin^2 \alpha \sin(\alpha - \delta) \left[1 + \sqrt{\frac{\sin(\phi + \delta) \sin(\phi - \beta)}{\sin(\alpha - \delta) \sin(\alpha + \beta)}} \right]^2}$$

$$= \frac{\sin^2(90^\circ + 30^\circ)}{\sin^2(90) \sin(90 - 15) \left[1 + \sqrt{\frac{\sin(30 + 15) \sin(30 - 0)}{\sin(90 - 15) \sin(90 + 0)}} \right]^2}$$

$$= \underline{\underline{.3014}}$$

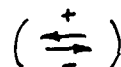
$$k_p^2 = \frac{\sin^2(\alpha - \phi)}{\sin^2 \alpha \sin(\alpha + \delta) \left[1 - \sqrt{\frac{\sin(\phi + \delta) \sin(\phi + \beta)}{\sin(\alpha + \delta) \sin(\alpha + \beta)}} \right]^2}$$

$$= \frac{\sin^2(90 - 30)}{\sin^2(90) \sin(90 + 15) \left[1 - \sqrt{\frac{\sin(30 + 15) \sin(30 + 0)}{\sin(90 + 15) \sin(90 + 0)}} \right]^2}$$

$$= \underline{\underline{4.974}}$$

$$k_a' = k_a^2 = \underline{\underline{.3014}}$$

REFER TO FIGURE



82

$$F1 = k_a' \gamma' (GWT)^2 / 2 = .3014 (110 \text{ PCF}) (10')^2 / 2 = \underline{1657.7}^\#$$

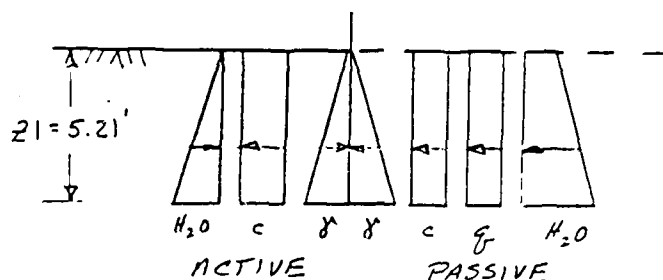
$$F2 = k_a' \gamma' (GWT) (H - GWT) = .3014 (110) (10') (20' - 10') = \underline{3315.4}^\#$$

$$F3 = k_a' \gamma' (H - GWT)^2 / 2 = .3014 (122.4 - 62.4) (20' - 10')^2 / 2 = \underline{904.2}^\#$$

$$F4 = -2c \sqrt{k_a'} H = -2 (200 \text{ PSF}) \sqrt{.3014} (20') = \underline{-4392.0}^\#$$

$$F5 = \gamma_{H_2O} (H - GWT)^2 / 2 = 62.4 (20' - 10')^2 / 2 = \underline{3120}^\#$$

COMPOSITE PRESSURE @ $z1 = 5.21'$ ($S.F. = 1.0$)



RIGHT SIDE (PASSIVE)

$$p_r = \gamma' (z1) k_p' = (122.4 - 62.4) 5.21' (4.974) = \underline{1554.9}^\# / \text{ft}^2$$

$$p_c = 2c \sqrt{k_p'} = 2 (600 \text{ PSF}) \sqrt{4.974} = \underline{2676.3}^\# / \text{ft}^2$$

$$p_s = [GWT (\gamma') - (H - GWT) (\gamma)] k_p' = (10' (122.4 - 62.4) + (20 - 10) (110)) 4.974 = \underline{8455.8}^\# / \text{ft}^2$$

$$p_{H_2O} = (z1 + (H - GWT)) \gamma_{H_2O} = (5.21' + 20' - 10') 62.4 = \underline{949.1}^\# / \text{ft}^2$$

$$\Sigma p_r = 13636.1^\# / \text{ft}^2$$

LEFT SIDE (ACTIVE)

$$p_a = -\gamma' (z1) k_a = (122.4 - 62.4) (5.21') (.3014) = \underline{-904.2}^\# / \text{ft}^2$$

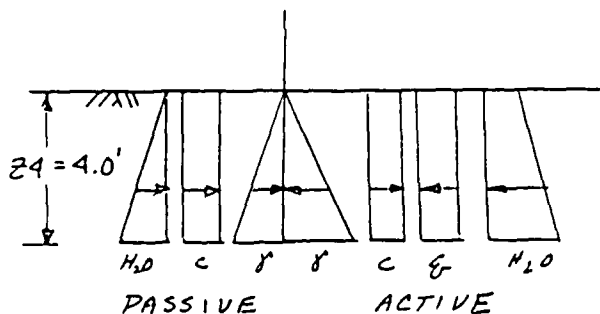
$$p_c = +2c \sqrt{k_a} = 2 (600) \sqrt{.3014} = \underline{658.8}^\# / \text{ft}^2$$

$$p_{H_2O} = -\gamma_{H_2O} z1 = 62.4 (5.21') = \underline{-325.1}^\# / \text{ft}^2$$

$$\Sigma p_a = 239.5^\# / \text{ft}^2$$

$$\begin{aligned}
 PR &= \sum p_r + \sum p_a \\
 &= 13636.1 + 239.5 \\
 &= \underline{\underline{13875.6 \text{ #/ft}^2}} \quad \checkmark
 \end{aligned}$$

COMPOSITE PRESSURE @ $z = z_4 = 4.0'$



LEFT SIDE (PASSIVE)

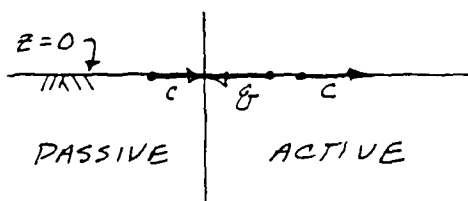
$$\begin{aligned}
 p_r &= -\gamma' (z_4) k_p = (122.4 - 62.4) (4.0') (4.974) = \underline{\underline{-1193.8 \text{ #/ft}^2}} \\
 p_c &= -2c \sqrt{k_p} = -2(600) \sqrt{4.974} = \underline{\underline{-2676.3 \text{ #/ft}^2}} \\
 p_{H_2O} &= -\gamma_{H_2O} z_4 = 62.4 \cdot 4.0' = \underline{\underline{-249.6 \text{ #/ft}^2}} \\
 \sum p_a &= \underline{\underline{-4119.7 \text{ #/ft}^2}}
 \end{aligned}$$

RIGHT SIDE (ACTIVE)

$$\begin{aligned}
 p_r &= \gamma' (z_4) k_a = (122.4 - 62.4) (4.0') (0.3014) = \underline{\underline{72.34 \text{ #/ft}^2}} \\
 p_c &= -2c \sqrt{k_a} = -2(600) \sqrt{0.3014} = \underline{\underline{-658.8 \text{ #/ft}^2}} \\
 p_s &= [6WT(\gamma') + (H - 6WT)(\gamma)] k_a \\
 &= [10'(60) + (20' - 10')(110)] = \underline{\underline{512.4 \text{ #/ft}^2}} \\
 p_{H_2O} &= (z_4 + (H - 6WT)) \gamma_{H_2O} = (4.0' + 20' - 10') 62.4 = \underline{\underline{873.6 \text{ #/ft}^2}} \\
 \sum p_r &= \underline{\underline{799.54 \text{ #/ft}^2}}
 \end{aligned}$$

$$\begin{aligned}
 P_1 &= \sum p_e + \sum p_r \\
 &= \underline{\underline{-3320.2 \text{ #/ft}^2}}
 \end{aligned}$$

COMPOSITE PRESSURE @ $z = 0$



LEFT SIDE (PASSIVE)

$$p_e = -2c \sqrt{K_p} = -2(600) \sqrt{4.974} = \underline{\underline{-2676.3 \text{ #/ft}^2}}$$

RIGHT SIDE (ACTIVE)

$$p_e = -2c \sqrt{K_a} = -2(600) \sqrt{.3014} = \underline{\underline{-658.8 \text{ #/ft}^2}}$$

$$p_f = [6WT(\gamma') + (H - 6WT)\gamma] K_a =$$

$$= (10(122.4 - 62.4) + (20' - 10')(110)) \cdot .3014 = \underline{\underline{512.4 \text{ #/ft}^2}}$$

$$p_{H_2O} = (H - 6WT)\gamma_{H_2O} = (20' - 10') 62.4 = \underline{\underline{624 \text{ #/ft}^2}}$$

$$\sum p_r = \underline{\underline{477.6 \text{ #/ft}^2}}$$

$$P_2 = \sum p_e + \sum p_r$$

$$= \underline{\underline{-2198.7 \text{ #/ft}^2}}$$

REFER TO FIGURE $\left(\begin{smallmatrix} + \\ \rightleftharpoons \end{smallmatrix} \right)$

CALCULATE Z5

$$\frac{X-X_1}{Y-Y_1} = \frac{X_2-X_1}{Y_2-Y_1} \quad \left(\begin{array}{l} X = \text{PRESSURE} \\ Y = \text{DEPTH} \end{array} \right)$$

$$\frac{0 - (-3320.2)}{Z5 - 4.0'} = \frac{13875.6 - (-3320.2)}{5.21' - 4.0'}$$

$$\underline{Z5 = 4.234'}$$

CALCULATE F7 - Fφ

$$F7 = P2(Z4) = -2198.7(4.0') = \underline{-8794.8^\#}$$

$$F8 = \frac{1}{2}(P1 - P2)(Z4) = \frac{1}{2}(-3320.2 - 2198.7)(4.0') = \underline{-2243.0^\#} \quad \checkmark$$

$$F9 = \frac{1}{2}P1(Z5 - Z4) = \frac{1}{2}(-3320.2)(4.234 - 4.0) = \underline{-388.5^\#} \quad \checkmark$$

$$F\phi = \frac{1}{2}PR(Z1 - Z5) = \frac{1}{2}(13875.6)(5.21 - 4.234) = \underline{6771.3^\#} \quad \checkmark$$

$$ZF \rightarrow +$$

$$ZF = F1 + F2 + F3 + F4 + F5 + F7 + F8 + F9 + F\phi$$

$$= 1657.7 + 3315.4 + 904.2 - 4392.0 + 3120 \\ - 8794.8 - 2243.0 - 388.5 + 6771.3$$

$$= \underline{\underline{-49.7^\#}} \approx 0 \quad \checkmark$$

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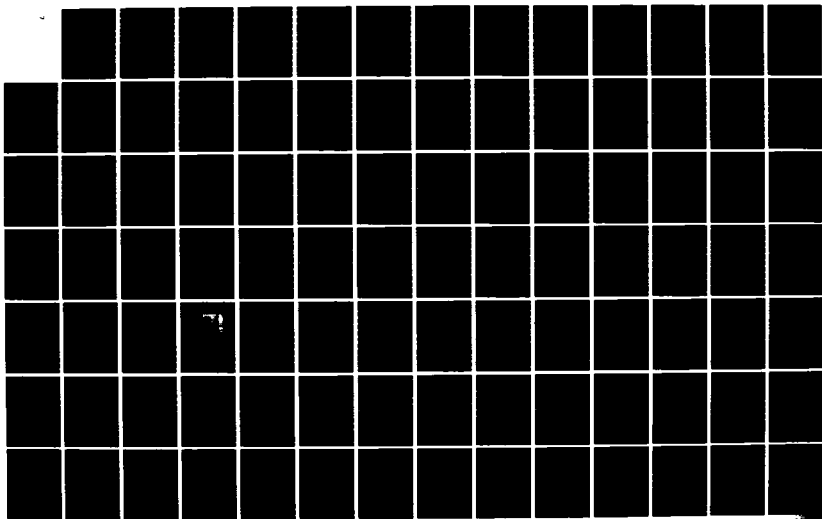
COMPUTER APPLICATIONS TO GEOTECHNICAL ENGINEERING(U)
AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH
D K EDDY AUG 83 AFIT/CI/NR-83-86T

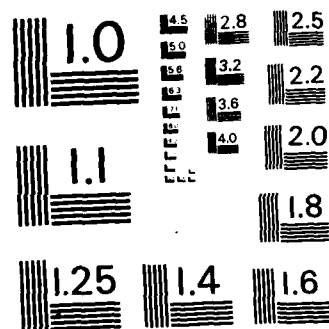
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F/G 13/2

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVER ARMS (REFER TO FIGURE)

<u>FORCE</u>	<u>LEVER ARM</u>	
F1	$LA = \frac{1}{3}(10') + 10' + 4.23' = 17.56'$	✓
F2	$LB = \frac{1}{2}(10') + 4.23' = 9.23'$	✓
F3	$LC = \frac{1}{3}(10') + 4.23' = 7.56'$	✓
F4	$LD = \frac{1}{2}(20') + 4.23' = 14.23'$	✓
F5	$LE = \frac{1}{3}(10') + 4.23' = 7.56'$	✓
F7	$LG = \frac{1}{2}(4') + (4.23' - 4') = 2.23'$	✓
F8	$LH = \frac{1}{3}(4') + (4.23' - 4') = 1.56'$	✓
F9	$LI = \frac{2}{3}(4.23' - 4') = .153'$	✓
F0	$LJ = \frac{2}{3}(5.21' - 4.23') = -.653'$	✓ *

(* LJ IS NEGATIVE FOR ΣM)

$\Sigma M \curvearrowright @ 25$

$$\begin{aligned}
 \Sigma M &= F1(LA) + F2(LB) + F3(LC) + F4(LD) + F5(LE) \\
 &\quad + F7(LG) + F8(LH) + F9(LI) + F0(LJ) \\
 &= 1657.7(17.56) + 3315.4(9.23) + 904.2(7.56) \\
 &\quad - 4392.0(14.23) + 3120(7.56) - 8794.8(2.23) \\
 &\quad - 2243.0(1.56) - 388.5(.153) + 6771.3(-.653) \\
 &= \underline{42.56 \text{ Ft} \cdot \#} \approx 0
 \end{aligned}$$

REQUIRED DEPTH = 5.21'

3.7.2 Problem #2

.

INPUT DATA

NET UNIT WEIGHT, SOIL #1 =110 PCF.

SATURATED UNIT WEIGHT, SOIL #1 =122.4 PCF.

COHESION, SOIL #1 =0 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #1 =32 DEGREES.

FRICTION ANGLE, SOIL #1 =14 DEGREES.

NET UNIT WEIGHT, SOIL #2 =100 PCF.

SATURATED UNIT WEIGHT, SOIL #2 =112.4 PCF.

COHESION, SOIL #2 =1000 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #2 =28 DEGREES.

FRICTION ANGLE, SOIL #2 =15 DEGREES.

WALL HEIGHT =20 FEET.

GROUND WATER DEPTH =23 FEET.

ACTIVE K, SOIL #1 =.28006464

PASSIVE K, SOIL #2 =4.48311107

ACTIVE K, SOIL #2 =.325042267

TOLERANCE =.05 PERCENT.

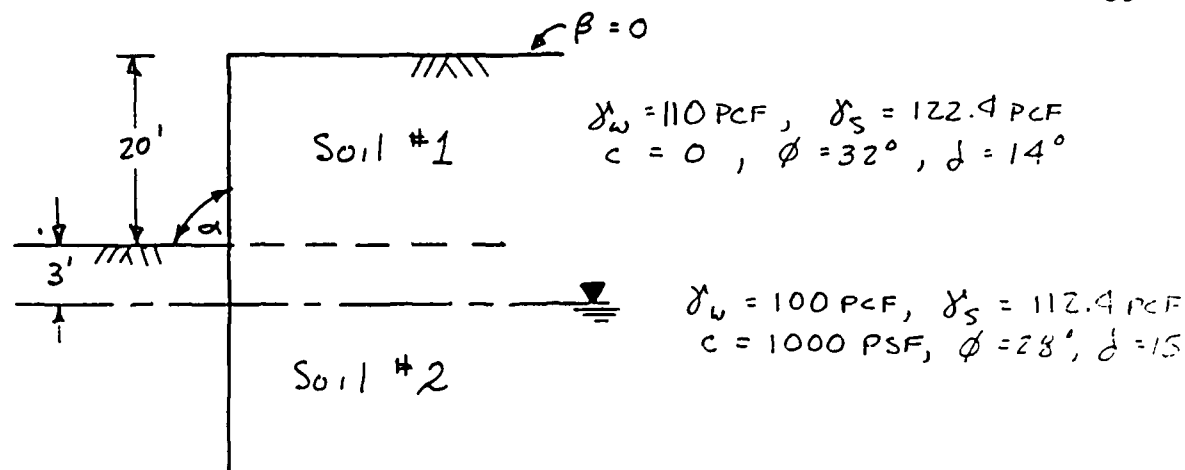
SAFETY FACTOR =1.

OUTPUT DATA

REQUIRED WALL PENETRATION =6.15 FEET.

SUPPLEMENTARY DATA

Z1 =6.15013255 FEET.	
Z4 =3.67646922 FEET.	
Z5 =4.32224836 FEET.	
Z6 =0 FEET.	
Z7 =0 FT.	
P1 =-6047.88918 PSF.	
P2 =-4659.82826 PSF.	
P3 =-5907.2489 PSF.	
P4 =0 PSF.	
PR =17140.5978 PSF.	
F1 =6161.42208#.	LA =10.988915FT.
F2 =0#.	LB =14.3222484FT.
F3 =0#.	LC =24.3222484FT.
F4 =-13979.4848#.	LD =2.82224836FT.
F5 =-1871.13096#.	LE =2.32224836FT.
F6 =-47.5694097#.	LF =.871268881FT.
F7 =-3996.07207#.	LG =.984013751FT.
F8 =-1952.80034#.	LH =.430519429FT.
F9 =15685.6354#.	LI =-1.22015468FT.
F0 =0#.	LJ =0FT.
FT =-4.57763672E-05#.	MT =-44.7207518FT-#.



$$k'_a = .28$$

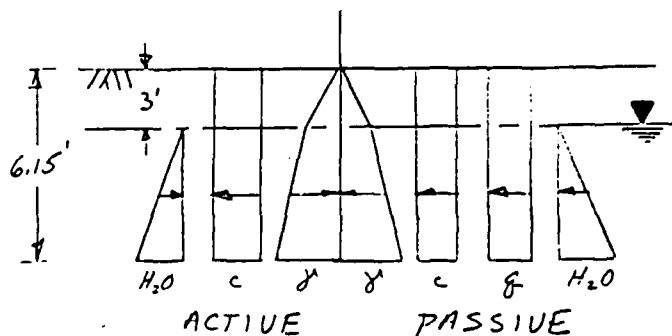
$$k_p = 4.483$$

$$k_a = .325$$

REFER TO FIGURE $(\rightarrow^+)$

$$F1 = \gamma_w H^2 / 2 k'_a = 110 \text{ PCF} \cdot (20')^2 / 2 \cdot .28 = 6160 \text{ #}$$

COMPOSITE PRESSURE @ $z = 6.15'$



RIGHT SIDE (PASSIVE)

$$P_x = [(\gamma_w \cdot 6 \text{ WT}) + (\gamma_s - \gamma_{H_2O})(21 - 6 \text{ WT})] k_p$$

$$= [(100 \cdot 3') + (112.4 - 62.4)(6.15 - 3)] 4.483 = 2050.97 \text{ #/ft}^2$$

$$p_c = 2c \sqrt{K_p} = 2(1000) \sqrt{4.483} = \underline{4234.62 \text{ #/ft}^2}$$

$$p_g = H \gamma_w K_p = 20'(110)(4.483) = \underline{9862.6 \text{ #/ft}^2}$$

$$p_{H_2O} = \gamma_{H_2O} (z1 - 6WT) = 62.4(6.15 - 3) = \underline{196.56 \text{ #/ft}^2}$$

$$\Sigma p_r = \underline{16344.75 \text{ #/ft}^2}$$

LEFT SIDE (ACTIVE)

$$p_r = -[(\gamma_w \cdot 6WT) + (\gamma_s - \gamma_{H_2O})(z1 - 6WT)] K_a$$

$$= -[(100 \cdot 3) + (112.4 - 62.4)(6.15 - 3)] \cdot 0.325 = \underline{-148.69 \text{ #/ft}^2}$$

$$p_c = 2c \sqrt{K_a} = 2(1000) \sqrt{0.325} = \underline{1140.18 \text{ #/ft}^2}$$

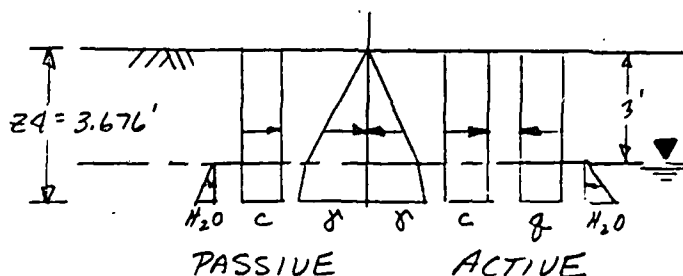
$$p_{H_2O} = -\gamma_{H_2O} (z1 - 6WT) = -62.4(6.15 - 3) = \underline{-196.56 \text{ #/ft}^2}$$

$$\Sigma p_e = \underline{794.93 \text{ #/ft}^2}$$

$$PR = \Sigma p_e + \Sigma p_r$$

$$= \underline{17139.68 \text{ #/ft}^2} \quad \checkmark$$

COMPOSITE PRESSURE @ $z = z4 = 3.676'$



LEFT SIDE (PASSIVE)

$$p_r = -[(\gamma_w \cdot 6WT) + (\gamma_s - \gamma_{H_2O})(z - 6WT)] K_p$$

$$= -[(100 \cdot 3) + (50)(3.676 - 3)] 4.483 = \underline{-1496.42 \text{ #/ft}^2}$$

$$p_c = -2c \sqrt{K_p} = -2(1000) \sqrt{4.483} = -4234.6 \text{ #/ft}^2$$

$$p_{H_2O} = -\gamma_{H_2O} (z - \text{GWT}) = -62.4 (3.676 - 3) = -42.18 \text{ #/ft}^2$$

$$\Sigma p_e = -5773.2 \text{ #/ft}^2$$

RIGHT SIDE (ACTIVE)

$$p_p = [(\gamma_w \cdot \text{GWT}) + (\gamma_s - \gamma_{H_2O}) (z - \text{GWT})] K_a = [(100 \cdot 3) + (50)(3.676 - 3)] \cdot 0.325 = 108.48 \text{ #/ft}^2$$

$$p_c = -2c \sqrt{K_a} = -2(1000) \sqrt{0.325} = -1140.2 \text{ #/ft}^2$$

$$p_q = \gamma' H K_a = 110(20') \cdot 0.325 = 715.0 \text{ #/ft}^2$$

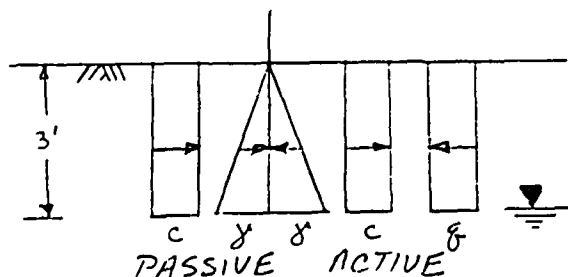
$$p_{H_2O} = \gamma_{H_2O} (z - \text{GWT}) = 42.18 \text{ #/ft}^2$$

$$\Sigma p_r = -274.54 \text{ #/ft}^2$$

$$P1 = \Sigma p_r + \Sigma p_e$$

$$= -6047.74 \text{ #/ft}^2 \quad \checkmark$$

COMPOSITE PRESSURE @ $z = \text{GWT} (3')$



LEFT SIDE (PASSIVE)

$$p_p = -\gamma_w (\text{GWT}) K_p = -100(3') \cdot 4.483 = -1344.9 \text{ #/ft}^2$$

$$p_c = -2c \sqrt{K_p} = -2(1000) \sqrt{4.483} = -4234.6 \text{ #/ft}^2$$

$$\Sigma p_e = -5579.5 \text{ #/ft}^2$$

RIGHT SIDE (ACTIVE)

$$p_r = \gamma_w (GWT) k_a = 100(3) \cdot 325 = \underline{97.5} \text{ #/ft}^2$$

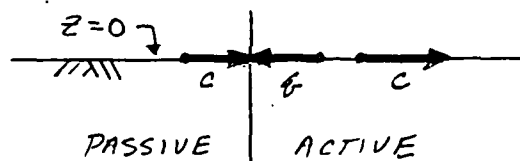
$$p_c = -2c \sqrt{k_a} = -2(1000) \sqrt{.375} = \underline{-1140.2} \text{ #/ft}^2$$

$$p_f = \gamma_w H k_a = 110(20') \cdot 325 = \underline{715.0} \text{ #/ft}^2$$

$$\Sigma p_r = \underline{-327.67} \text{ #/ft}^2$$

$$P3 = \Sigma p_r + \Sigma p_c$$

$$= \underline{-5907.2} \text{ #/ft}^2 \quad \checkmark$$

COMPOSITE PRESSURE @ z = 0LEFT SIDE (PASSIVE)

$$p_c = -2c \sqrt{k_p} = -2(1000) \sqrt{4.483} = \underline{-4234.6} \text{ #/ft}^2$$

RIGHT SIDE (ACTIVE)

$$p_c = -2c \sqrt{k_a} = -2(1000) \sqrt{.325} = \underline{-1140.2} \text{ #/ft}^2$$

$$p_f = \gamma_w H k_a = 110(20') \cdot 325 = \underline{715.0} \text{ #/ft}^2$$

$$\Sigma p_r = \underline{-425.2} \text{ #/ft}^2$$

$$P2 = \Sigma p_c + \Sigma p_r$$

$$= \underline{-4659.8} \text{ #/ft}^2 \quad \checkmark$$

CALCULATE $F_4 - F_9$ (SEE FIGURE) $z_5 = 4.321$

$$F_4 = P_2(6WT) = -4659.8(3') = \underline{-13979.4}^{\#} \quad \checkmark$$

$$F_5 = \frac{1}{2}(P_3 - P_2)(6WT) = \frac{1}{2}(-5907.2 - 4659.8)(3) = \underline{-1871.1}^{\#} \quad \checkmark$$

$$F_6 = \frac{1}{2}(P_1 - P_3)(24-6WT) = \frac{1}{2}(6047.4 - 5907.2)(3.676-3) = \underline{-47.4}^{\#} \quad \checkmark$$

$$F_7 = P_3(24-6WT) = -5907.2(3.676-3) = \underline{-3993.3}^{\#} \quad \checkmark$$

$$F_8 = \frac{1}{2}P_1(z_5 - z_4) = \frac{1}{2}(-6047.4)(4.321 - 3.676) = \underline{-1950.3}^{\#} \quad \checkmark$$

$$F_9 = \frac{1}{2}P_R(z_1 - z_5) = \frac{1}{2}(17139.68)(6.15 - 4.321) = \underline{15674.0}^{\#} \quad \checkmark$$

$$\Sigma F \quad \leftarrow +$$

$$\Sigma F = F_1 + F_4 + F_5 + F_6 + F_7 + F_8 + F_9$$

$$= 6160 - 13979.4 - 1871.1 - 47.4 - 3993.3 - 1950.3 + 15674$$

$$= \underline{-7.5} \approx 0 \quad \checkmark$$

LEVER ARM

FORCE

LEVER ARM

F_1	$LA = 4.321' + \frac{1}{3}(20') = 10.99'$	$\checkmark$
F_4	$LD = 4.321' - \frac{1}{2}(3') = 2.82'$	$\checkmark$
F_5	$LE = 4.321' - \frac{2}{3}(3') = 2.32'$	$\checkmark$
F_6	$LF = (4.321 - 3.676) + \frac{1}{3}(3.676 - 3) = .87'$	$\checkmark$
F_7	$LG = (4.321 - 3.676) + \frac{1}{2}(3.676 - 3) = .993'$	$\checkmark$
F_8	$LH = \frac{2}{3}(4.321 - 3.676) = .43'$	$\checkmark$
F_9	$LI = \frac{2}{3}(6.15 - 4.321) = -1.22'$	$\checkmark$

$$\Sigma M \quad \curvearrowright \quad @ \ z5$$

$$\Sigma M = F1(LA) + F4(LD) + F5(LE) + F6(LF) + F7(LL) + F8(LH) + F9(LI)$$

$$= 6160(10.99) - 13979.4(7.82) - 1871.1(2.32) - 47.4(.87) - 3993.3(.983) - 1950.3(.43) + 15674(-1.22)$$

$$= \underline{7.9 \text{ Ft} \cdot \#} \approx 0 \quad \checkmark$$

$$\underline{\underline{\text{REQUIRED DEPTH} = 6.15'}}$$

3.7.3 Problem #3

INPUT DATA

WET UNIT WEIGHT, SOIL #1 =110 PCF.

SATURATED UNIT WEIGHT, SOIL #1 =122.4 PCF.

COHESION, SOIL #1 =0 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #1 =32 DEGREES.

FRICTION ANGLE, SOIL #1 =15 DEGREES.

WET UNIT WEIGHT, SOIL #2 =100 PCF.

SATURATED UNIT WEIGHT, SOIL #2 =112.4 PCF.

COHESION, SOIL #2 =1000 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #2 =28 DEGREES.

FRICTION ANGLE, SOIL #2 =15 DEGREES.

WALL HEIGHT =20 FEET.

GROUND WATER DEPTH =60 FEET.

ACTIVE K, SOIL #1 =.279048023

PASSIVE K, SOIL #2 =4.48311107

ACTIVE K, SOIL #2 =.325042267

TOLERANCE =.05 PERCENT.

SAFETY FACTOR =1.

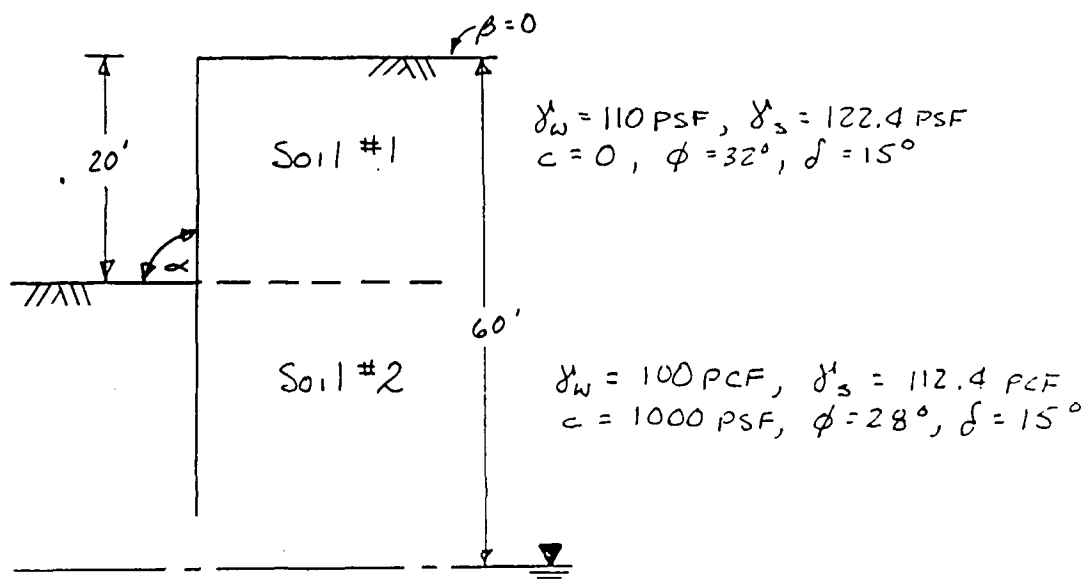
 OUTPUT DATA

REQUIRED WALL PENETRATION =6.1 FEET.

 SUPPLEMENTARY DATA

Z1 =6.10066258 FEET.
 Z4 =3.69574902 FEET.
 Z5 =4.31743173 FEET.
 Z6 =6.07054895 FEET.
 Z7 =0 FT.
 P1 =-6196.54613 PSF.
 P2 =-4659.82826 PSF.
 P3 =-21292.1035 PSF.
 P4 =0 PSF.
 PR =17774.4774 PSF.
 F1 =6139.0565#.
 F2 =0#.
 F3 =0#.
 F4 =0#.
 F5 =0#.
 F6 =0#.
 F7 =-17221.5557#.
 F8 =-2839.66178#.
 F9 =-1926.1428#.
 F0 =15848.3038#.
 FT =3.81469727E-06#.

LA =10.9840984FT.
 LB =14.3174317FT.
 LC =24.3174317FT.
 LD =0FT.
 LE =0FT.
 LF =0FT.
 LG =2.46955722FT.
 LH =1.85359905FT.
 LI =.414455141FT.
 LJ =-1.18884349FT.
 MT =-.663588911FT-#.



$$k_a' = .279$$

$$k_p' = 4.483$$

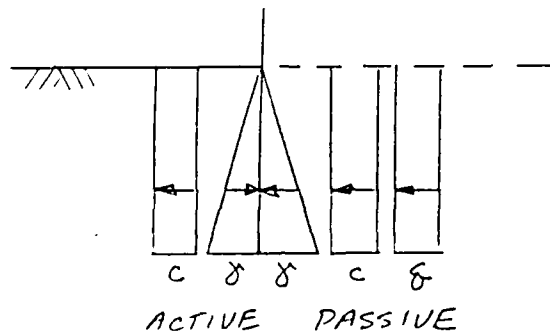
$$k_a' = .325$$

VERIFIED COMPUTER CALCULATION

REFER TO FIGURE

$$F_1 = \gamma H^2 / 2 k_a' = 110 \text{ PCF} (20')^2 / 2 (.279) = \underline{6138}^\# \quad \checkmark$$

COMPOSITE PRESSURE @ $z_1 = 6.1'$ (S.F. = 1)



RIGHT SIDE (PASSIVE)

$$p_s = \gamma(z_1) k_p = 100 \text{ PCF} (6.1') (4.483) = \underline{2734.6 \text{ #/ft}^2}$$

$$p_c = 2c \sqrt{k_p} = 2(1000) \sqrt{4.483} = \underline{4234.6 \text{ #/ft}^2}$$

$$p_g = \gamma_H k_p = 20' (110 \text{ PCF}) (4.483) = \underline{9862.6 \text{ #/ft}^2}$$

$$\Sigma p_r = \underline{16831.8 \text{ #/ft}^2}$$

LEFT SIDE (ACTIVE)

$$p_s = -\gamma(z_1) k_a = -100 \text{ PCF} (6.1') .325 = \underline{-198.25 \text{ #/ft}^2}$$

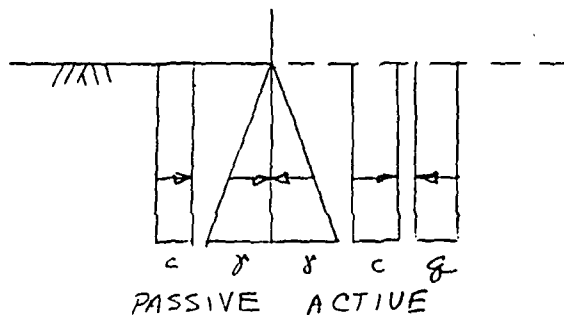
$$p_c = 2c \sqrt{k_a} = 2(1000) \sqrt{.325} = \underline{1140.17 \text{ #/ft}^2}$$

$$\Sigma p_e = \underline{941.92 \text{ #/ft}^2}$$

$$PR = \Sigma p_e + \Sigma p_r$$

$$= \underline{\underline{17773.72 \text{ #/ft}^2}}$$

COMPOSITE PRESSURE @ $z = z_4 = 3.696'$

LEFT SIDE (PASSIVE)

$$p_s = -\gamma(z_4) k_p = -100 (3.696) 4.483 = \underline{-1656.9 \text{ #/ft}^2}$$

$$p_c = -2c \sqrt{k_p} = -2(1000) \sqrt{4.483} = \underline{-4234.6 \text{ #/ft}^2}$$

$$\Sigma p_e = \underline{-5891.5 \text{ #/ft}^2}$$

RIGHT SIDE (ACTIVE)

$$p_r' = \gamma (z_4) k_a = 100 (3.696) (.325) = \underline{120.12 \text{ #/ft}^2}$$

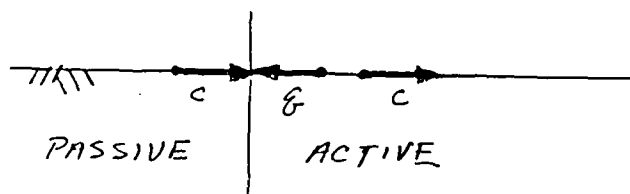
$$p_c = -2c \sqrt{k_a} = -2 (1000) \sqrt{.325} = \underline{-1140.2 \text{ #/ft}^2}$$

$$p_g = \gamma H k_a = 110 (20') .325 = \underline{715.0 \text{ #/ft}^2}$$

$$\Sigma p_r = \underline{-305 \text{ #/ft}^2}$$

$$P1 = \Sigma p_r + \Sigma p_c$$

$$= \underline{-6196.6 \text{ #/ft}^2}$$

COMPOSITE PRESSURE @ z = 0LEFT SIDE (PASSIVE)

$$p_c = -2c \sqrt{k_p} = \underline{-4234.6 \text{ #/ft}^2}$$

RIGHT SIDE (ACTIVE)

$$p_g = \gamma H k_a = \underline{715.0 \text{ #/ft}^2}$$

$$p_c = -2c \sqrt{k_a} = \underline{-1140.2 \text{ #/ft}^2}$$

$$P2 = \Sigma p_c - \Sigma p_r$$

$$= \underline{-4659.8 \text{ #/ft}^2}$$

REFER TO FIGURE $\left(\begin{smallmatrix} + \\ \leftarrow \\ - \end{smallmatrix} \right)$ $z5 = 4.317'$

CALCULATE $F7 - F\phi$

$$F7 = P2(z4) = -4659.8^{\#}/F_t^2 (3.696') = -17222.6^{\#}$$

$$F8 = \frac{1}{2}(P1 - P2)(z4) = \frac{1}{2}(6196.6 - 4659.8)(3.696) = -2840.0^{\#}$$

$$F9 = \frac{1}{2}(P1)(z5 - z4) = \frac{1}{2}(-6196.6)(4.317 - 3.696) = -1924.0^{\#}$$

$$F\phi = \frac{1}{2}PR(z1 - z5) = \frac{1}{2}(17773.72)(6.1 - 4.317) = 15845.3^{\#}$$

$\Sigma F \leftarrow +$

$$\Sigma F = F1 + F7 + F8 + F9 + F\phi$$

$$= 6138 - 17222.6 - 2840.0 - 1924.0 + 15845.3$$

$$= -3.3^{\#} \approx 0$$

LEVER ARMS

FORCE LEVER ARM

F1	LA = 4.317' + $\frac{1}{3}(20')$ = 10.98'	✓
F7	LG = $\frac{1}{2}(3.696) + (4.317 - 3.696)$ = 2.47'	✓
F8	LH = $\frac{1}{3}(3.696) + (4.317 - 3.696)$ = 1.85'	✓
F9	LI = $\frac{2}{3}(4.317 - 3.696)$ = .414'	✓
F ϕ	LJ = $-\frac{2}{3}(6.1 - 4.317)$ = -1.189'	✓

$\Sigma M \curvearrowright$

$$\Sigma M = F1(LA) + F7(LG) + F8(LH) + F9(LI) + F\phi(LJ)$$

$$= 6138(10.98) - 17222.6(2.47) - 2840(1.85) - 1924(.414) - 15845.3(1.189)$$

$$= -35.2 F_t^{\#} \approx 0$$

REQUIRED DEPTH = 6.1'

3.8 References

1. Bowles, J. E., Foundation Analysis and Design, McGraw-Hill Co., New York, 1982.
2. NAVFAC (1982), "Design Manual: Foundations and Earth Structures," DM-7.2, Department of the Navy, Alexandria, Virginia, pp. 7.2-95.
3. Terzaghi, K., Theoretical Soil Mechanics, John Wiley & Sons, New York, 1943.
4. Winterkorn, H. F., and Fang, H., Foundation Engineering Handbook, Van Nostrand Reinhold Co., New York, 1975.

CHAPTER IV

SLOPE STABILITY

4.1 Problem Definition

The program, BISHOP1, calculates the stability of earth slopes. The Bishop method of slices is used (Bishop, 1955). The slope is assumed to fail in a well defined circular arc. The earth mass is assumed to remain in a solid state at the time of failure. See Figure 4.1 for the generalized geometry of the problem. A reservoir or pool may be specified.

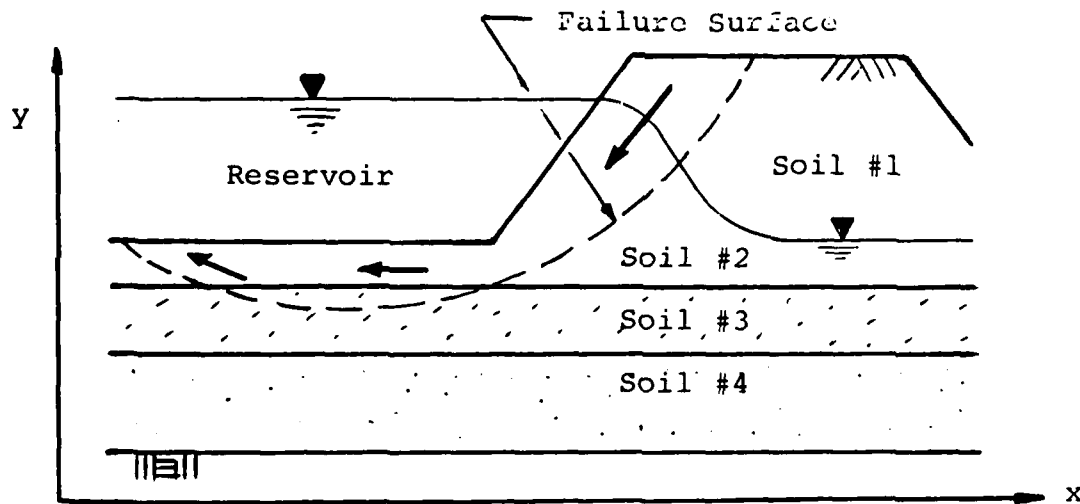


Figure 4.1. General Problem Definition.

4.2 Background Theory

4.2.1 General

A landslide is the failure of a soil mass beneath a slope [1]. A slide involves the downward and outward movement of the soil mass. Slides occur at various rates. Some slides are sudden and provide no warning; conversely, other slides fail slowly producing cracks and other visible signs of impending failure. The safety of the earth mass against failure is termed its stability [2]. The stability of earth masses must be considered whenever the possible failure of a slope may damage a structure or cause harm to individuals.

Slope failure occurs when the shear strength of the soil is exceeded by the shear stresses distributed over a finite continuous surface. Among the major factors which influence slope stability are: failure plane geometry, non-homogeneity of soil layers, tension cracks, dynamic loading or earthquakes, and seepage flow [4].

4.2.2 Limit Equilibrium Analysis

The limit equilibrium analysis of slope stability is composed of several methods varying in complexity and applicability to particular conditions. The ultimate solution of a limit equilibrium analysis is the determination of a factor of safety. "The factor of safety is that factor by which the shear strength parameters may be reduced in order to bring the slope into a state of limiting equilibrium

along a given slip surface" [5]. This definition implies a uniform state of stresses along a given failure plane.

Classes of analysis within the limit equilibrium analysis include the Culmann method (straight line failure plane), Bishop's method (circular arc failure plane), the logarithmic failure plane method, and the irregular failure plane method (Janbu, 1954). Each method introduces an additional degree of complexity; subsequently, the resulting factor of safety is hoped to reflect the actual conditions better than its predecessor [4].

4.2.3 Bishop's Method

The slice method, as originally proposed by Fellenius (1927), is the basis of Bishop's method of slope stability analysis. Bishop's method assumes a circular failure surface. Circles' centers and radii are varied until the minimum factor of safety is calculated. Figure 4.2 illustrates the safety factor contours created by iteratively solving the stability analysis. The circle center is the minimum factor of safety of the slope.

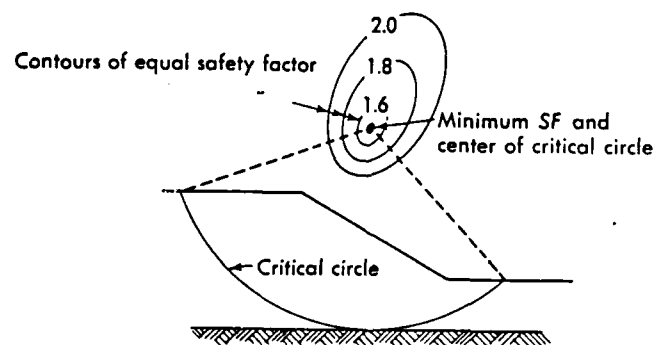


Figure 4.2. Slope Stability Safety Factor Contours [2].

For each slice, the forces are evaluated according to the limit equilibrium of the slice. Figure 4.3 illustrates the forces considered to act on a slice.

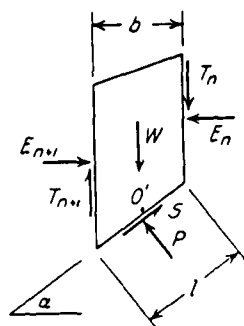


Figure 4.3. Forces Acting on a Single Slice [1].

where,

b = slice width

α = slice inclination

P = normal force on slice bottom

W = slice weight

S = shear force on slice bottom

E_n = normal force on slice side

T_n = shear force on slice side

The equilibrium of the entire soil mass is evaluated by summing the forces acting on all the slices. Because the factor of safety appears on both sides of the limiting

equilibrium equation, iterations are required for each failure surface. The equation is as follows:

$$F = \frac{\Sigma (Cb + P \tan \phi) \sec \alpha}{1 + \frac{\tan \phi \tan \alpha}{F}} \frac{\Sigma W \sin \alpha}{\Sigma W \sin \alpha}$$

where,

ϕ = angle of internal friction

C = cohesion

α = slice inclination

F = factor of safety

The user can find the derivation of this equation in reference 5, p. 161.

Earthquake forces treated as equivalent static forces are added as additional driving forces. The force, F, is calculated by accelerating the slice mass.

$$F = ma$$

$$m = \frac{W}{g}$$

$$a = k_{eq}$$

therefore,

$$F = k_{eq} W$$

where,

F = earthquake force

m = slice mass

W = slice weight

g = acceleration of gravity

k_{eq} = seismic coefficient

The earthquake force may reduce the normal force acting on the bottom of the slice [3].

4.3 Program Use and Limitations

4.3.1 General

BISHOP1 was translated into Applesoft Basic Language by the author. The original slope stability program was programmed in TRS-80 Basic language and was presented in reference 3 by Cross. Since the author did not program the software, the programming rationale for selection of particular program flow paths is not presented. During translation of the program, all print and input statements were modified; additionally, the program was altered to calculate a rapid drawdown without repetitive data input.

The program is user oriented. All input is prompted by brief, concise statements and questions. As with any program, the user should be familiar with the associated theory, required input data, and the sequence of input. The user is urged to tabulate *and check* the input data prior to running the program.

4.3.2 Data Input

As depicted in Figure 4.4, the geometry of the physical conditions is specified by a series of point and line numbers. The user should graphically display the problem using an appropriate scale such that the entire problem is in the first quadrant. Points on the top soil line must be numbered

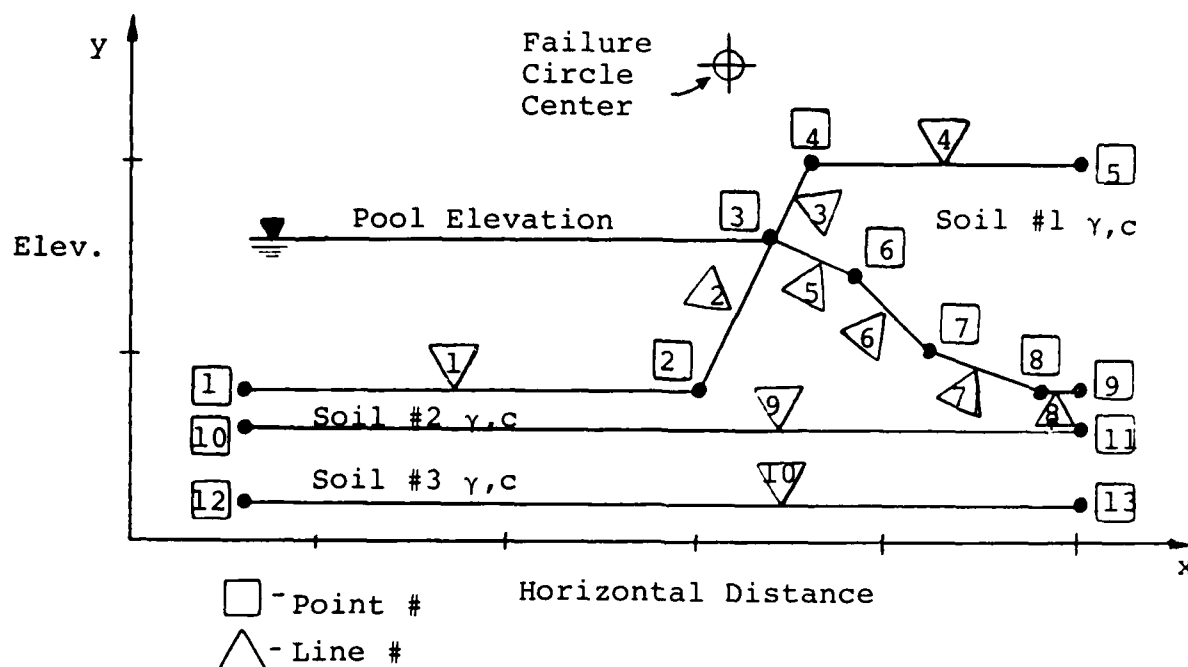


Figure 4.4. Input Parameters for Slope Stability Analysis.

from left to right. The user must insure that the extreme left points are outside of the specified failure circle; similarly, the extreme right points must be outside the failure circle. Below the top soil line, points may be numbered at random, but the interpretation of output data is simplified by maintaining a left-to-right numbering order. Point numbers are specified by their x and y coordinates.

Lines are specified by the left and right point numbers. Vertical lines are not permitted. If a vertical line is

required, the user may slope the line by an insignificant amount; i.e., .01. Interpretation of the output data is simplified by maintaining a consistent left-to-right numbering order, but it is not required.

Soil types are specified by number. While inputting line data, the user must specify which soil is beneath the particular line. Soil physical properties are input as the angle of internal friction, cohesion, the unit weight, and an indication if the soil is saturated (0 = yes, 1 = no). Saturation implies the soil is below the groundwater table; this is the method used to specify groundwater table location.

The failure circle is specified by inputting the x and y coordinates of the circle center and the radius.

The pool or reservoir is specified by the pool surface elevation and the extreme left and right x-coordinates of the line defining the pool water level. The piezometric surface within the soil mass is identified by indicating a saturated soil while inputting the soil data; therefore, the phreatic surface is a series of lines with a wet soil above and a saturated soil beneath.

Any units may be used but must be consistent; i.e., feet, pounds, and degrees.

The sequence of input is as follows:

- a) problem heading
- b) pool elevation

- c) extreme left x-coordinate of pool
- d) extreme right x-coordinate of pool
- e) water unit weight
- f) earthquake seismic coefficient, k_{eq}
- g) total number of points to be specified for all lines (see Section 4.3.5, Limitations). Note that the pool water level does not have line points associated with it.
- h) point #1, x-coordinate
- i) point #1, y-coordinate
- j) point #i, x-coordinate
- k) point #i, y-coordinate
- l) number of lines (see Section 4.3.5)
- m) left point, line #1
- n) right point, line #1
- o) soil beneath line #1
- p) left point, line #i
- q) right point, line #i
- r) soil beneath line #i
- s) number of soil types (see Section 4.3.5)
- t) unit weight, soil #1
- u) cohesion, soil #1
- v) phi angle, soil #1
- w) is soil saturated, 0 = yes, 1 = no
- x) unit weight, soil #i
- y) cohesion, soil #i

- z) phi angle, soil #i
- aa) is soil saturated, 0 = yes, 1 = no
- bb) minimum number of slices to be used (see Section 4.3.3)
- cc) x-coordinate of circle center
- dd) y-coordinate of circle center
- ee) failure circle radius
- ff) drawdown option (see Section 4.3.3)

See Section 4.5 for a printout of the above statements and associated input for an example problem. As previously mentioned, the user should create a table of input parameters prior to running BISHOP1. Example Problem #1 has approximately one hundred input variables.

4.3.3 Options

BISHOP1 can calculate a rapid drawdown condition without repetitive input of the problems physical geometry. This option is prompted by a question after the initial input of data and again following the output of calculated data. If the user desires to calculate the safety factor for only a drawdown condition, a pool elevation of 0 should be input. The rapid drawdown option sets the pool elevation equal to zero and does not affect the phreatic surface.

In most design studies, both the steady state and rapid drawdown conditions are analyzed. To analyze both cases, first calculate the steady state safety factor by specifying a pool elevation. At the completion of this analysis, the computer asks if a rapid drawdown analysis is desired. At

that time, specify a rapid drawdown condition and calculate the slope stability. This sequence provides the most information with the least required user input.

A minimum number of slices can be specified (the computer may use more slices in some instances). The original program automatically sets the minimum number of slices at 10 [3]. The program was modified to allow the user to specify a minimum number. The maximum number is set at 25 slices due to the memory constraints of the hardware. The author has successfully used 25 slices, but in approximately 50% of the cases, an "Out of Memory" error was encountered. The number of slices specified is contingent on the number of points, lines, and soil types input; the user must use trial and error to best suit the minimum number of slices to the physical geometry of the particular problem. The author never encountered an "Out of Memory" error when 10 slices were specified. Fewer than 10 slices should not be used for most problems.

The key advantage of BISHOP1 is the user option to specify various failure circles without re-entering physical geometry data. At the end of each run, the user is prompted to define another failure circle. After defining the new circle, the program repeats the stability analysis using the physical geometry data previously input. The rapid drawdown option is used concurrently with the above option. As depicted in Figure 3.2, the user can manually "search"

for the minimum factor of safety by establishing contours based on successive runs.

4.3.4 Output

Output of calculated data is composed of three general types. The first is automatically printed at the end of each run and consists of the calculated factor of safety, circle definition, and earthquake loading factor. The second section of output is at the option of the user. When specified, a "formal printout" of all input data will be printed. When successive runs are made while searching out the minimum factor of safety, the "formal printout" should not be specified until after the last run. The "formal printout" is used to document the output data, thus enabling the user to identify a particular series of circle definitions and factors of safety to a particular problem.

The third option is a list of variables calculated during a particular stability analysis. Each diagnostic list will be different for each circle definition or physical geometry. The diagnostic option creates a list of slices and the corresponding weights, inclinations, cohesions, widths, effective weights, phi angles, and lever arms (X) used in the stability analysis. Additionally, the factor of safety iterations are listed and the net force required to provide a factor of safety equal to one. See Section 4.5 for a printout of the diagnostic list.

4.3.5 Limitations

The number of points, lines, soil types, and number of slices are limited. To avoid program errors, the user must not specify more variables than allowed by Table 4.1.

Table 4.1. Input Limitations.

Parameter	Maximum
Points	20
Lines	20
Soil types	5
Slices	25*

*Refer to Section 4.3.3.

The physical geometry of the problem must be specified completely within the first quadrant. No negative values of x and y coordinates are allowed. No vertical lines may be specified. As previously discussed, offsetting the x-coordinate of a vertical line by an insignificant amount will suffice to avoid this limitation.

A slope must be specified to move up and out away from the coordinate origin as depicted in Figure 4.1. Erroneous slope stabilities were calculated when this rule was not followed. By rotating the slope geometry 180° such that the embankment sloped up and out away from the origin, a

correct factor of safety was obtained. This limitation was not mentioned by Cross in his presentation [3].

A limitation of BISHOP1 is the lack of a search routine which would yield a minimum factor of safety without user intervention. Main frame computing facilities have programs available to perform this task; for example, ICES LEASE I. Once again, this ability is dependent upon memory requirements beyond the capacity of most personal computers.

4.3.6 Warnings

In Section 4.3.2, the user was advised to ensure that the extreme left and right points were outside the failure circle. If the user ignored this, the warning, "Circle exceeds top line end points" will be printed. The user will then be prompted to input another failure circle. If the failure circle previously specified must be used, the point x-coordinates must be altered such that the failure circle is within the extreme left or right points. The user must restart the program to redefine the problem.

When the user defines a circle with a radius not large enough to intercept the slope the warning, "Circle does not intercept slope" will be printed. The user will be prompted to define a new failure circle. Input of physical geometry is not required. See Section 4.5 for an example of this warning.

The final warning advises the user that more than ten iterations are required to calculate the factor of safety.

No user intervention is required as the program will continue to iterate the factor of safety. If the warning continues to appear, the preset iteration tolerance may be changed by altering line 3860. The preset tolerance is .005. If the user is experiencing repetitive warnings, try changing .005 to .01 to avoid this problem. More than ten iterations were never required to calculate the factor of safety during verification of this program.

4.4 Program List

```

5  SPEED= 150
10 PRINT "*****"
15 PRINT "***SIMPLIFIED BISHOP SLOPE**"
20 PRINT "** STABILITY ANALYSIS **"
25 PRINT "*****"
27 PRINT : PRINT : PRINT : PRINT :
30 PRINT " DANA K. EDDY, 578-80-8378"
35 PRINT " GEORGIA INSTITUTE OF TECHNOLOGY"
40 PRINT " DEPT. OF CIVIL ENGINEERING"
45 PRINT " GEOTECHNICAL ENGINEERING DIV."
47 PRINT : PRINT : PRINT
50 PRINT " PROGRAM DATE: JUNE 1983"
55 PRINT " SYSTEM HARDWARE: APPLE II PLUS,64K"
60 PRINT " SYSTEM SOFTWARE: DOS 3.3, APPLESOFT"
62 PRINT : PRINT : PRINT
65 PRINT " THIS PROGRAM CALCULATES THE FACTOR OF SAFETY OF AN EARTH SLOP
    E AGAINST A CIRCULAR FAILURE. THE SIMPLIFIED BISHOP SLOPE STABILITY
    ANALYSIS IS USED."
67 PRINT : PRINT : PRINT
70 SPEED= 255
140 DIM P(20,2),L(20,3),S2(5,4),A(50),F(50,14),Z(50,8)
155 PI = 3.14159
160 J6 = 0
170 REM ***INPUT PROGRAM VARIABLES***
180 PRINT "PROBLEM HEADING"
190 INPUT H$
195 PRINT
200 PRINT "SUBMERGENCE ELEVATION (0 IF NO SUBMERGENCE)"
210 INPUT S0
215 PRINT
220 PRINT "FROM X-COORDINATE"
230 INPUT S6
235 PRINT
240 PRINT "TO X-COORDINATE"
250 INPUT S7
255 PRINT
260 PRINT "WATER UNIT WEIGHT"
270 INPUT W0
275 PRINT
280 PRINT "EARTHQUAKE LOADING FACTOR"
290 INPUT E1
295 PRINT : PRINT
300 PRINT "NUMBER OF POINTS"
310 INPUT P1
315 PRINT
320 FOR I = 1 TO P1
330 PRINT "POINT #"I
340 PRINT "X-COORDINATE"
350 INPUT P(I,1)
355 PRINT

```

```
360 PRINT "Y-COORDINATE"
370 INPUT P(1,2)
375 PRINT
380 NEXT I
385 PRINT
390 PRINT "NUMBER OF LINES"
400 INPUT L1
405 PRINT
410 FOR I = 1 TO L1
420 PRINT "LINE #"I
425 PRINT
430 PRINT "LEFT POINT"
440 INPUT L(1,1)
445 PRINT
450 PRINT "RIGHT POINT"
460 INPUT L(1,2)
465 PRINT
470 PRINT "SOIL BENEATH LINE #"I
480 INPUT L(1,3)
485 PRINT
490 NEXT I
495 PRINT : PRINT
500 PRINT "NUMBER OF SOIL TYPES"
510 INPUT S1
515 PRINT
520 FOR I = 1 TO S1
530 PRINT "SOIL #"I
535 PRINT
540 PRINT "UNIT WEIGHT"
550 INPUT S2(1,1)
555 PRINT
560 PRINT "COHESION"
570 INPUT S2(1,2)
575 PRINT
580 PRINT "PHI ANGLE"
590 INPUT S2(1,3)
595 PRINT
600 PRINT "IS SOIL SATURATED, 0=YES, 1=NO ?"
610 INPUT S2(1,4)
615 PRINT
620 NEXT I
625 PRINT : PRINT
627 PRINT "SPECIFY THE MINIMUM NUMBER OF SLICES TO BE USED (MAX = 25). "
628 INPUT S3
629 PRINT : PRINT
630 REM
640 F3 = 0
650 PRINT "FAILURE CIRCLE DEFINITION"
655 PRINT : PRINT
660 PRINT "X-COORDINATE OF CENTER"
```

```

670 INPUT X
675 PRINT
680 PRINT "Y-COORDINATE OF CENTER"
690 INPUT Y
695 PRINT
700 PRINT "CIRCLE RADIUS"
710 INPUT R
712 PRINT : PRINT
713 PRINT "FOR A RAPID DRAWDOWN TYPE (0), FOR SUBMERGENCE ELEVATION AS PR
EVIOUSLY SPECIFIED TYPE (1)"
714 INPUT ZZ: IF ZZ = 1 THEN 716
715 S0 = 0
716 PRINT : PRINT
720 REM **CHECK, CIRCLE EXCEEDS TO LINE END POINTS**
730 U1 = P1
740 FOR I = 2 TO P1
750 IF P(I,1) < P(I - 1,1) AND U1 = P1 THEN 770
760 GOTO 780
770 U1 = I - 1
780 NEXT I
790 J1 = R * R - (P(1,2) - Y) ^ 2
800 J2 = R * R - (P(U1,2) - Y) ^ 2
810 IF J1 < = 0 THEN 830
820 IF J1 > 0 AND P(1,1) > X - SQR (J1) THEN 860
830 IF J2 < = 0 THEN 850
840 IF J2 > 0 AND P(U1,1) < X + SQR (J2) THEN 860
850 GOTO 880
860 PRINT "* CIRCLE EXCEEDS TOP LINE END POINTS *"
870 GOTO 4380
880 REM **DEFINE INTERSECTION OF CIRCLE WITH LINES**
890 FOR I = 1 TO L1
900 X1 = P(L(I,1),1)
910 Y1 = P(L(I,1),2)
920 X2 = P(L(I,2),1)
930 Y2 = P(L(I,2),2)
940 IF X2 = X1 THEN 960
950 GOTO 970
960 S = 9.99E + 10
970 IF X2 < > X1 THEN 990
980 GOTO 1000
990 S = (Y2 - Y1) / (X2 - X1)
1000 IF ABS (S) < 1.0E - 5 THEN 1150
1010 C1 = X1 - Y1 / S
1020 C2 = 1 / S ^ 2 + 1
1030 C3 = 2 * C1 / S - 2 * X / S - 2 * Y
1040 C4 = C1 ^ 2 - 2 * X * C1 + X ^ 2 + Y ^ 2 - R ^ 2
1050 C5 = C3 ^ 2 - 4 * C2 * C4
1060 IF C5 < 0 THEN 1080
1070 GOTO 1090
1080 Z(I,1) = 0

```

```

1090 IF C5 < 0 THEN 1630
1100 Q1 = ( - C3 + SQR (C5)) / (2 * C2)
1110 Q2 = ( - C3 - SQR (C5)) / (2 * C2)
1120 Q3 = Q1 / S + C1
1130 Q4 = Q2 / S + C1
1140 GOTO 1240
1150 C5 = R ^ 2 - (Y - Y1) ^ 2
1160 IF C5 < 0 THEN 1180
1170 GOTO 1190
1180 Z(I,1) = 0
1190 IF C5 < 0 THEN 1630
1200 Q3 = X + SQR (C5)
1210 Q4 = X - SQR (C5)
1220 Q1 = Y1
1230 Q2 = Y1
1240 J1 = 0
1250 J2 = 0
1260 IF ABS (S) < = 9.99E + 9 AND Q3 = > X1 AND Q3 < = X2 THEN 1290
1270 GOTO 1290
1280 J1 = 1
1290 IF ABS (S) < = 9.99E + 9 AND Q4 = > X1 AND Q4 < = X2 THEN 1310
1300 GOTO 1320
1310 J2 = 1
1320 IF S < - 9.99E + 9 AND Q1 > = Y2 AND Q1 < = Y1 THEN 1340
1330 GOTO 1350
1340 J1 = 1
1350 IF S < - 9.99E + 9 AND Q2 > = Y2 AND Q2 < = Y1 THEN 1370
1360 GOTO 1380
1370 J2 = 1
1380 IF S > 9.99E + 9 AND Q1 > = Y1 AND Q1 < = Y2 THEN 1400
1390 GOTO 1410
1400 J1 = 1
1410 IF S > 9.99E + 9 AND Q2 > = Y1 AND Q2 < = Y2 THEN 1430
1420 GOTO 1440
1430 J2 = 1
1440 Z(I,1) = J1 + J2
1450 IF J1 = 1 THEN 1470
1460 GOTO 1480
1470 Z(I,2) = Q3
1480 IF J1 = 1 THEN 1500
1490 GOTO 1510
1500 Z(I,3) = Q1
1510 IF J1 = 0 AND J2 = 1 THEN 1530
1520 GOTO 1540
1530 Z(I,2) = Q4
1540 IF J1 = 0 AND J2 = 1 THEN 1560
1550 GOTO 1570
1560 Z(I,3) = Q2
1570 IF J1 = 1 AND J2 = 1 THEN 1590
1580 GOTO 1600

```

```

1590 Z(I,4) = Q4
1600 IF J1 = 1 AND J2 = 1 THEN 1620
1610 GOTO 1630
1620 Z(I,5) = Q2
1630 NEXT I
1640 X4 = 0
1650 X5 = 9.99E + 20
1660 I1 = 1
1670 FOR I = 1 TO L1
1680 IF Z(I,1) = > 1 THEN 1700
1690 GOTO 1710
1700 A(I1) = Z(I,2)
1710 IF Z(I,1) = > 1 THEN 1730
1720 GOTO 1740
1730 I1 = I1 + 1
1740 IF Z(I,1) = 2 THEN 1760
1750 GOTO 1770
1760 A(I1) = Z(I,4)
1770 IF Z(I,1) = 2 THEN 1790
1780 GOTO 1800
1790 I1 = I1 + 1
1800 NEXT I
1810 IF I1 = 1 THEN 1830
1820 GOTO 1840
1830 PRINT "CIRCLE DOES NOT INTERCEPT SLOPE"
1840 IF I1 = 1 THEN 4380
1850 REM **SET UP OF SLICE ARRAY**
1860 FOR I = 1 TO I1 - 1
1870 IF A(I) > X4 THEN 1890
1880 GOTO 1900
1890 X4 = A(I)
1900 IF A(I) < X5 THEN 1920
1910 GOTO 1930
1920 X5 = A(I)
1930 NEXT I
1940 FOR I = 1 TO P1
1950 IF P(I,1) < X4 AND P(I,1) > X5 THEN 1970
1960 GOTO 1980
1970 A(I1) = P(I,1)
1980 IF P(I,1) < X4 AND P(I,1) > X5 THEN 2000
1990 GOTO 2010
2000 I1 = I1 + 1
2010 NEXT I
2020 I1 = I1 - 1
2030 FOR I = 1 TO I1
2040 FOR J = 1 TO I1 - 1
2050 IF A(J + 1) > A(J) THEN 2090
2060 J1 = A(J + 1)
2070 A(J + 1) = A(J)
2080 A(J) = J1

```

```

2090 NEXT J
2100 NEXT I
2110 U1 = 0
2120 FOR I = 1 TO I1 - 1
2130 IF A(I) < A(I + 1) THEN 2150
2140 GOTO 2190
2150 U1 = U1 + 1
2160 IF A(I) < A(I + 1) THEN 2180
2170 GOTO 2190
2180 A(U1) = A(I)
2190 NEXT I
2200 U1 = U1 + 1
2210 A(U1) = A(I1)
2220 I1 = U1
2230 REM **DEFINE SLICE BOUNDARIES**
2240 Q1 = A(I1) - A(1)
2250 Q2 = Q1 / S9
2260 U1 = I1
2270 FOR I = 1 TO U1 - 1
2280 Q3 = A(I + 1) - A(I)
2290 Q4 = INT (Q3 / Q2) + 1
2300 C1 = Q3 / Q4
2310 C2 = A(I)
2320 FOR J = 1 TO Q4
2330 IF J < Q4 THEN 2350
2340 GOTO 2360
2350 I1 = I1 + 1
2360 IF J < Q4 THEN 2380
2370 GOTO 2390
2380 A(I1) = C2 + C1
2390 IF J < Q4 THEN 2410
2400 GOTO 2420
2410 C2 = C2 + C1
2420 NEXT J
2430 NEXT I
2440 FOR I = 1 TO I1
2450 FOR J = 1 TO I1 - 1
2460 IF A(J + 1) > A(J) THEN 2500
2470 J1 = A(J + 1)
2480 A(J + 1) = A(J)
2490 A(J) = J1
2500 NEXT J
2510 NEXT I
2520 REM **DEFINE SOIL PARAMETERS FOR EACH SLICE**
2530 F1 = I1 - 1
2540 FOR I = 1 TO F1
2550 F(I,4) = A(I + 1) - A(I)
2560 X6 = F(I,4)
2570 F(I,7) = (A(I + 1) + A(I)) / 2
2580 X3 = F(I,7)

```

```

2590 Y1 = Y - SQR (R ^ 2 - (A(I) - X) ^ 2)
2600 Y2 = Y - SQR (R ^ 2 - (A(I + 1) - X) ^ 2)
2610 A5 = ATN (ABS (Y2 - Y1) / F(I,4))
2620 IF Y2 < Y1 THEN 2640
2630 GOTO 2650
2640 A5 = - A5
2650 F(I,2) = A5
2660 IF A5 = 0 THEN 2680
2670 GOTO 2690
2680 F(I,2) = 1.0E - 5
2690 Y3 = Y - SQR (R ^ 2 - (X3 - X) ^ 2)
2700 I4 = 0
2710 FOR J = 1 TO L1
2720 L5 = L(J,1)
2730 L6 = L(J,2)
2740 IF P(L5,2) < = Y3 AND P(L6,2) < = Y3 THEN 2840
2750 IF P(L5,1) < X3 AND P(L6,1) < X3 THEN 2840
2760 IF P(L5,1) > X3 AND P(L6,1) > X3 THEN 2840
2770 Y6 = P(L5,2) + (P(L5,2) - P(L6,2)) / (P(L5,1) - P(L6,1)) * (X3 - P(L5,1))
2780 IF Y6 < = Y3 THEN 2840
2790 I4 = I4 + 1
2800 Z(I4,1) = Y6
2810 Z(I4,2) = L(J,3)
2820 W = 0
2830 E = 0
2840 NEXT J
2850 IF I4 = 1 THEN 2970
2860 FOR J = 1 TO I4
2870 FOR J1 = 1 TO I4 - 1
2880 IF Z(J1,1) = > Z(J1 + 1,1) THEN 2950
2890 L5 = Z(J1,1)
2900 L6 = Z(J1,2)
2910 Z(J1,1) = Z(J1 + 1,1)
2920 Z(J1,2) = Z(J1 + 1,2)
2930 Z(J1 + 1,1) = L5
2940 Z(J1 + 1,2) = L6
2950 NEXT J1
2960 NEXT J
2970 I4 = I4 + 1
2980 Z(I4,1) = Y3
2990 FOR J1 = 1 TO I4 - 1
3000 IF I = 1 AND J1 = 1 AND X3 = > S6 THEN 3020
3010 GOTO 3030
3020 I6 = S0 - Y1
3030 IF I = F1 AND J1 = 1 AND X3 = > S6 AND X3 < = S7 THEN 3050
3040 GOTO 3060
3050 J6 = S0 - Y2
3060 W = W + (Z(J1,1) - Z(J1 + 1,1)) * X6 + S2(Z(J1,2),1)
3070 IF Z(J1,1) < S0 AND X3 = > S6 AND X3 < = S7 THEN 3090

```

```

3080 GOTO 3100
3090 W = W + (S0 - Z(J1,1)) * X6 * W0
3100 IF S2(Z(J1,2),4) > 0.95 THEN 3120
3110 GOTO 3130
3120 E4 = S2(Z(J1,2),1)
3130 IF S2(Z(J1,2),4) < 0.95 THEN 3150
3140 GOTO 3160
3150 E4 = S2(Z(J1,2),1) - W0
3160 E = E + (Z(J1,1) - Z(J1 + 1,1)) * X6 * E4
3170 NEXT J1
3180 F(I,1) = W
3190 F(I,5) = E
3200 F(I,3) = S2(Z(I4 - 1,2),2)
3210 F(I,6) = 2 * PI * (S2(Z(I4 - 1,2),3) / 360)
3220 NEXT I
3230 IF F9 = 0 THEN 3360
3235 L$ = CHR$(4): PRINT L$;"PR#1"
3240 PRINT "SLICE   HEIGHT   INCLINATION   COHESION   WIDTH   EFF WEIGH
T   PHI       X"
3241 PRINT
3280 O = 360 / (2 * PI)
3290 FOR I = 1 TO F1
3300 POKE 36,3: PRINT I;: POKE 36,7: PRINT F(I,1);: POKE 36,19: PRINT F(I
,2) * O;: POKE 36,34: PRINT F(I,3);: POKE 36,41: PRINT F(I,4);: POKE
36,53: PRINT F(I,5);: POKE 36,65: PRINT F(I,6) * O;: POKE 36,69: PRINT
F(I,7)
3340 NEXT I
3350 PRINT L$;"PR#0"
3360 O = 0
3370 FOR I = 1 TO F1
3380 O = O + F(I,1) * SIN ( ABS (F(I,2))) * (F(I,2) / ABS (F(I,2)))
3390 O = O + E1 * F(I,1) * COS ( ABS (F(I,2)))
3400 NEXT I
3410 IF I6 > 0 THEN 3430
3420 GOTO 3440
3430 I7 = W0 * I6 * I6 * (R - I6 / 3) / (2 * R)
3440 IF I6 > 0 THEN 3460
3450 GOTO 3470
3460 O = O - SGN (O) * I7
3470 IF I6 > 0 AND F9 = 1 THEN 3485
3480 GOTO 3510
3485 L$ = CHR$(4): PRINT L$;"PR#1"
3487 PRINT : PRINT
3490 PRINT "DRIVING FORCE COUNTER BALANCE OF "I7"#."
3495 PRINT : PRINT
3500 PRINT L$;"PR#0"
3510 IF J6 > 0 THEN 3530
3520 GOTO 3540
3530 I7 = W0 * J6 * J6 * (R - J6 / 3) / (2 * R)
3540 IF J6 > 0 THEN 3560

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```

3550 GOTO 3570
3560 D = D + SGN (D) * 17
3570 IF J6 > 0 AND F9 = 1 THEN 3585
3580 GOTO 3610
3585 L$ = CHR$ (4): PRINT L$;"PR#1"
3587 PRINT : PRINT
3590 PRINT "DRIVING FORCE INCREASE OF "I7"#."
3595 PRINT : PRINT
3600 PRINT L$;"PR#0"
3610 REM **ITERATIVE SOLUTION FOR FACTOR OF SAFETY**
3620 F0 = 1
3630 R4 = 0
3640 I6 = 0
3650 FOR I = 1 TO F1
3660 R1 = F(I,3) * F(I,4) + F(I,5) * TAN (F(I,6))
3670 R2 = 1 / COS ( ABS (F(I,2)))
3680 R3 = 1 + TAN (F(I,6)) * TAN (F(I,2)) / F0
3690 R4 = R4 + R1 * (R2 / R3)
3700 NEXT I
3710 F2 = R4 / D
3720 I6 = I6 + 1
3730 IF F9 = 1 THEN 3750
3740 GOTO 3820
3750 IF I6 = 1 THEN 3765
3760 GOTO 3775
3765 L$ = CHR$ (4): PRINT L$;"PR#1"
3770 PRINT "ITERATION","INITIAL","CALCULATED"
3775 L$ = CHR$ (4): PRINT L$;"PR#1"
3780 PRINT TAB( 5)I6,F0,F2
3800 PRINT L$;"PR#0"
3820 IF I6 > 10 THEN 3840
3830 GOTO 3850
3840 PRINT "WILL NOT CLOSE"
3850 IF I6 > 10 THEN 3970
3860 IF ABS ( ABS (F0) - ABS (F2)) < 0.005 THEN 3910
3870 F0 = ABS (F2)
3880 R4 = 0
3890 GOTO 3650
3895 PRINT : PRINT
3910 L$ = CHR$ (4): PRINT L$;"PR #1": PRINT : PRINT
3915 PRINT H$
3916 PRINT "*****"
3920 PRINT "FACTOR OF SAFETY = "F2;" AT X ="X;" Y ="Y;" RADIUS ="R
3935 PRINT
3940 PRINT "EARTHQUAKE LOADING FACTOR ="E1
3955 PRINT : PRINT
3960 PRINT L$;"PR#0"
3965 HOME
3970 PRINT "DO YOU WANT A FORMAL PRINTOUT (Y OR N)?"
3980 INPUT A$

```

```

3885 PRINT : PRINT
3990 IF A$ = "N" THEN 4320
4005 L$ = CHR$(4): PRINT L$;"PR#1"
4007 PRINT H$
4008 PRINT : PRINT
4010 PRINT "WATER UNIT WEIGHT ="W0;" EARTHQUAKE LOADING FACTOR ="E1
4020 PRINT "SUBMERGENCE ELEV ="S0;" FROM X="S6;" TO X="S7
4030 PRINT
4040 PRINT "POINT","X-COORDINATE","Y-COORDINATE"
4050 FOR I = 1 TO P1
4060 PRINT I,P(I,1),P(I,2)
4070 NEXT I
4080 PRINT : PRINT
4090 PRINT "LINE";" LEFT PT";" RIGHT PT";" SOIL"
4100 FOR I = 1 TO L1
4110 POKE 36,2: PRINT I;: POKE 36,10: PRINT L(I,1);: POKE 36,19: PRINT L(
I,2);: POKE 36,27: PRINT L(I,3)
4120 NEXT I
4130 PRINT : PRINT
4140 PRINT "SOIL";" UNIT WEIGHT";" COHESION";" PHI";" SAT'D"
4150 FOR I = 1 TO S1
4160 POKE 36,2: PRINT I;: POKE 36,10: PRINT S2(I,1);: POKE 36,21: PRINT S
2(I,2);: POKE 36,30: PRINT S2(I,3);: POKE 36,37: PRINT S2(I,4)
4170 NEXT I
4180 PRINT : PRINT
4190 PRINT "CIRCLE: X="X;" Y="Y;" RADIUS ="R;" FACTOR OF SAFETY ="F2
4200 PRINT : PRINT
4210 PRINT L$;"PR#0"
4215 HOME
4320 PRINT "DO YOU WANT A DIAGNOSTIC RUN (Y OR N)?"
4330 INPUT A$
4332 PRINT : PRINT
4340 IF A$ = "Y" THEN 4360
4350 GOTO 4370
4360 F9 = 1
4370 IF A$ = "Y" THEN 720
4380 PRINT "DO YOU WANT TO DEFINE ANOTHER FAILURE CIRCLE (Y OR N)?"
4390 INPUT A$
4391 PRINT : PRINT
4400 IF A$ = "Y" THEN 630
4410 PRINT "BYE-BYE"

```

4.5 Program Verification

4.5.1 Problem #1

SIMPLIFIED BISHOP SLOPE
** STABILITY ANALYSIS **

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PROGRAM DATE: JUNE 1983
SYSTEM HARDWARE: APPLE II PLUS, 64K
SYSTEM SOFTWARE: DOS 3.3, APPLESOFT

THIS PROGRAM CALCULATES THE FACTOR OF SAFETY OF AN EARTH SLOPE AGAINST A CIRCULAR FAILURE. THE SIMPLIFIED BISHOP SLOPE STABILITY ANALYSIS IS USED.

PROBLEM HEADING
?AN EXAMPLE PROBLEM

SUBMERGENCE ELEVATION (0 IF NO SUBMERGENCE)
?1040

FROM X-COORDINATE
?0

TO X-COORDINATE
?132

WATER UNIT WEIGHT
?62.4

EARTHQUAKE LOADING FACTOR
?0

NUMBER OF POINTS
?13

POINT #1
X-COORDINATE
?0

Y-COORDINATE
?1020

POINT #2
X-COORDINATE
7100

Y-COORDINATE
71020

POINT #3
X-COORDINATE
7132

Y-COORDINATE
71040

POINT #4
X-COORDINATE
7162.5

Y-COORDINATE
71045

POINT #5
X-COORDINATE
7172.5

Y-COORDINATE
71045

POINT #6
X-COORDINATE
7235

Y-COORDINATE
71020

POINT #7
X-COORDINATE
70

Y-COORDINATE
71000

POINT #8
X-COORDINATE
7300

Y-COORDINATE
71000

POINT #9
X-COORDINATE
7138

Y-COORDINATE
71035

POINT #10
X-COORDINATE
7150

Y-COORDINATE
71030

POINT #11
X-COORDINATE
7161

Y-COORDINATE
71027.5

POINT #12
X-COORDINATE
7168

Y-COORDINATE
71025

POINT #13
X-COORDINATE
7171

Y-COORDINATE
71020

NUMBER OF LINES
713

LINE #1

LEFT POINT
71

RIGHT POINT
72

SOIL BENEATH LINE #1
73

LINE #2

LEFT POINT
72

RIGHT POINT
73

SOIL BENEATH LINE #2
72

LINE #3

LEFT POINT
73

RIGHT POINT
74

SOIL BENEATH LINE #3
71

LINE #4

LEFT POINT
74

RIGHT POINT
75

SOIL BENEATH LINE #4
71

LINE #5

LEFT POINT
75

RIGHT POINT
76

SOIL BENEATH LINE #5
71

LINE #6

LEFT POINT
73

RIGHT POINT
79

SOIL BENEATH LINE #6
72

LINE #7

LEFT POINT

?9

RIGHT POINT

?10

SOIL BENEATH LINE #7

?2

LINE #8

LEFT POINT

?10

RIGHT POINT

?11

SOIL BENEATH LINE #8

?2

LINE #9

LEFT POINT

?11

RIGHT POINT

?12

SOIL BENEATH LINE #9

?2

LINE #10

LEFT POINT

?12

RIGHT POINT

?13

SOIL BENEATH LINE #10

?2

LINE #11

LEFT POINT

?2

RIGHT POINT

?13

SOIL BENEATH LINE #11

?3

LINE #12

LEFT POINT
713

RIGHT POINT
76

SOIL BENEATH LINE #12
73

LINE #13

LEFT POINT
77

RIGHT POINT
78

SOIL BENEATH LINE #13
74

NUMBER OF SOIL TYPES
74

SOIL #1

UNIT WEIGHT
7115

COHESION
7200

PHI ANGLE
726

IS SOIL SATURATED, 0=YES, 1=NO ?
71

SOIL #2

UNIT WEIGHT
7117

COHESION
7200

PHI ANGLE
726

IS SOIL SATURATED, 0=YES, 1=NO ?
70

SOIL #3

UNIT WEIGHT

?120

COHESION

?100

PHI ANGLE

?28

IS SOIL SATURATED, 0=YES, 1=NO ?

?0

SOIL #4

UNIT WEIGHT

?150

COHESION

?10000

PHI ANGLE

?45

IS SOIL SATURATED, 0=YES, 1=NO ?

?0

SPECIFY THE MINIMUM NUMBER OF SLICES TO BE USED (MAX = 25).

?10

FAILURE CIRCLE DEFINITION

X-COORDINATE OF CENTER

?108.7

Y-COORDINATE OF CENTER

?1100.8

CIRCLE RADIUS

?81.0

FOR A RAPID DRAWDOWN TYPE (0), FOR SUBMERGENCE ELEVATION AS PREVIOUSLY SPECIFIED
TYPE (1)

?1

AN EXAMPLE PROBLEM

FACTOR OF SAFETY = 2.64016612 AT X =108.7 Y =1100.8 RADIUS =81

EARTHQUAKE LOADING FACTOR =0

DO YOU WANT A FORMAL PRINTOUT (Y OR N)?
?Y

AN EXAMPLE PROBLEM

WATER UNIT WEIGHT =62.4 EARTHQUAKE LOADING FACTOR =0
SUBMERGENCE ELEV =1040 FROM X=0 TO X=132

POINT	X-COORDINATE	Y-COORDINATE
1	0	1020
2	100	1020
3	132	1040
4	162.5	1045
5	172.5	1045
6	235	1020
7	0	1000
8	300	1000
9	138	1035
10	150	1030
11	161	1027.5
12	168	1025
13	171	1020

LINE	LEFT PT	RIGHT PT	SOIL
1	1	2	3
2	2	3	2
3	3	4	1
4	4	5	1
5	5	6	1
6	3	9	2
7	9	10	2
8	10	11	2
9	11	12	2
10	12	13	2
11	2	13	3
12	13	6	3
13	7	8	4

SOIL	UNIT WEIGHT	COHESION	PHI	SAT'D
1	115	200	26	1
2	117	200	26	0
3	120	100	28	0
4	150	10000	45	0

CIRCLE: X=108.7 Y=1100.8 RADIUS =81 FACTOR OF SAFETY =2.64016612

DO YOU WANT A DIAGNOSTIC RUN (Y OR N)?
Y

SLICE	HEIGHT	INCLINATION	COHESION	WIDTH	EFF WEIGHT	PHI	X
1	3419.83601	-4.96581439	200	2.64388013	137.423009	26	101.688478
2	15437.8547	-2.01358368	100	5.68858236	1185.89153	28	105.855709
3	16542.1386	2.01358368	100	5.68858236	2290.17546	28	111.544291
4	10617.9847	6.11577104	200	5.87047255	3387.01816	26	117.323819
5	11212.2684	10.3152172	200	5.87047255	4291.56704	26	123.194291
6	11499.2192	14.5718242	200	5.87047255	5052.69402	26	129.064764
7	11408.9623	18.9619938	200	6	6425.16599	26	135
8	9484.07119	23.3014683	200	5.43929673	6948.87283	26	140.719648
9	8372.38118	27.5671964	200	5.43929673	7483.64569	26	146.158945
10	1556.34339	30.1967314	200	1.12140656	1556.34339	26	149.439297
11	6689.7098	32.9750275	200	5.5	6689.7098	26	152.75
12	4794.2082	37.7555341	200	5.5	4794.2082	26	158.25
13	912.06297	40.9187278	200	1.5	912.06297	26	161.75
14	1399.49512	44.0393237	200	4.91422302	1399.49512	26	164.957112

DRIVING FORCE COUNTER BALANCE OF 11202.7945#.

ITERATION	INITIAL	CALCULATED
1	1	2.3702899
2	2.3702899	2.61883446
3	2.61883446	2.63872113
4	2.63872113	2.64016612

AN EXAMPLE PROBLEM

FACTOR OF SAFETY = 2.64016612 AT X =108.7 Y =1100.8 RADIUS =81

EARTHQUAKE LOADING FACTOR =0

DO YOU WANT A FORMAL PRINTOUT (Y OR N)?

?N

DO YOU WANT A DIAGNOSTIC RUN (Y OR N)?

?N

DO YOU WANT TO DEFINE ANOTHER FAILURE CIRCLE (Y OR N)?

?Y

FAILURE CIRCLE DEFINITION

X-COORDINATE OF CENTER

?108.7

Y-COORDINATE OF CENTER

?1100.8

CIRCLE RADIUS

?81.0

FOR A RAPID DRAWDOWN TYPE (0), FOR SUBMERGENCE ELEVATION AS PREVIOUSLY SPECIFIED
TYPE (1)

?0

AN EXAMPLE PROBLEM

FACTOR OF SAFETY = 1.45417058 AT X =108.7 Y =1100.8 RADIUS =81

EARTHQUAKE LOADING FACTOR =0

DO YOU WANT A FORMAL PRINTOUT (Y OR N)?

?Y

AN EXAMPLE PROBLEM

WATER UNIT WEIGHT =62.4 EARTHQUAKE LOADING FACTOR =0
 SUBMERGENCE ELEV =0 FROM X=0 TO X=132

POINT	X-COORDINATE	Y-COORDINATE
1	0	1020
2	100	1020
3	132	1040
4	162.5	1045
5	172.5	1045
6	235	1020
7	0	1000
8	300	1000
9	138	1035
10	150	1030
11	161	1027.5
12	168	1025
13	171	1020

LINE	LEFT PT	RIGHT PT	SOIL
1	1	2	3
2	2	3	2
3	3	4	1
4	4	5	1
5	5	6	1
6	3	9	2
7	9	10	2
8	10	11	2
9	11	12	2
10	12	13	2
11	2	13	3
12	13	6	3
13	7	8	4

SOIL	UNIT WEIGHT	COHESION	PHI	SAT'D
1	115	200	26	1
2	117	200	26	0
3	120	100	28	0
4	150	10000	45	0

CIRCLE: X=108.7 Y=1100.8 RADIUS =81 FACTOR OF SAFETY =1.45417058

DO YOU WANT A DIAGNOSTIC RUN (Y OR N)?
?Y

SLICE	HEIGHT	INCLINATION	COHESION	WIDTH	EFF HEIGHT	PHI	X
1	294.477875	-4.96581439	200	2.64388013	137.423009	26	101.689478
2	2538.26968	-2.01358368	100	5.68858236	1185.89153	28	105.855709
3	4904.59238	2.01358368	100	5.68858236	2290.17546	28	111.544291
4	7257.89607	6.11577104	200	5.87047255	3387.01816	26	117.323819
5	9196.21509	10.3152172	200	5.87047255	4291.56704	26	123.134291
6	10827.2015	14.5718242	200	5.87047255	5052.69402	26	123.064764
7	11408.9623	18.9619938	200	6	6425.16599	26	135
8	9484.07119	23.3014683	200	5.43929673	6948.87283	26	140.719648
9	8372.38118	27.5671964	200	5.43929673	7483.64569	26	146.158945
10	1556.34339	30.1967314	200	1.12140656	1556.34339	26	149.439297
11	6689.7098	32.9750275	200	5.5	6689.7098	26	152.75
12	4794.2082	37.7555341	200	5.5	4794.2082	26	158.25
13	912.06297	40.9187278	200	1.5	912.06297	26	161.75
14	1399.49512	44.0393237	200	4.91422302	1399.49512	26	164.957112

ITERATION	INITIAL	CALCULATED
1	1	1.38086936
2	1.38086936	1.44516603
3	1.44516603	1.45320706
4	1.45320706	1.45417058

AN EXAMPLE PROBLEM

FACTOR OF SAFETY = 1.45417058 AT X =108.7 Y =1100.8 RADIUS =81

EARTHQUAKE LOADING FACTOR =0

DO YOU WANT A FORMAL PRINTOUT (Y OR N)?
?N

DO YOU WANT A DIAGNOSTIC RUN (Y OR N)?
?N

DO YOU WANT TO DEFINE ANOTHER FAILURE CIRCLE (Y OR N)?
?Y

FAILURE CIRCLE DEFINITION

X-COORDINATE OF CENTER
?108.7

Y-COORDINATE OF CENTER
?1100.8

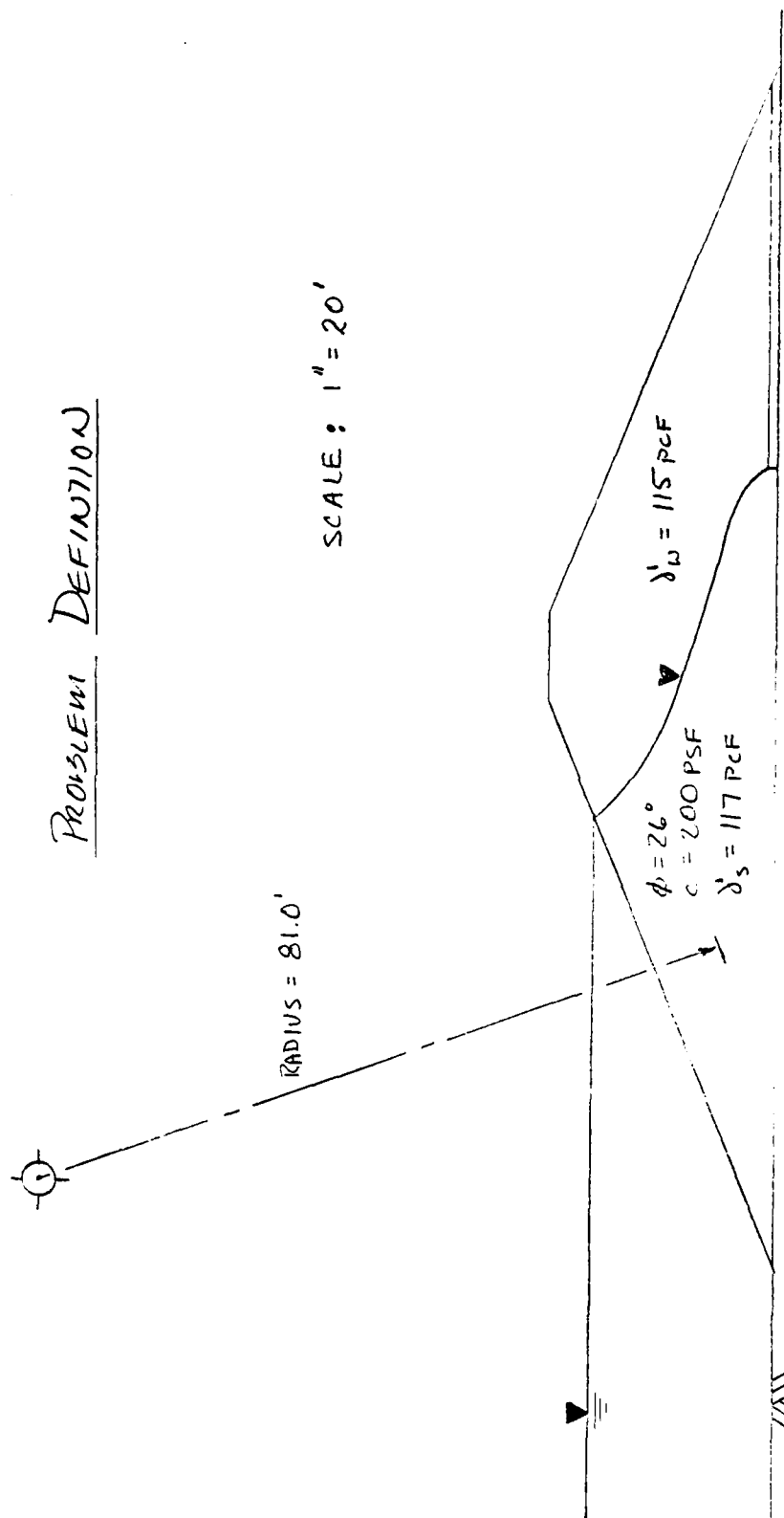
CIRCLE RADIUS
?40

FOR A RAPID DRAWDOWN TYPE (0), FOR SUBMERGENCE ELEVATION AS PREVIOUSLY SPECIFIED
TYPE (1)
?1

CIRCLE DOES NOT INTERCEPT SLOPE
DO YOU WANT TO DEFINE ANOTHER FAILURE CIRCLE (Y OR N)?
?N

BYE-BYE

PROBLEM DEFINITION



$\phi = 28^\circ$
 $c = 100 \text{ PSF}$
 $\gamma'_s = 120 \text{ PCF}$

~ ROCK ~

LINE	LEFT PT	RIGHT PT	SOIL BENEATH	142
1	1	2	3	
2	2	3	2	
3	3	4	1	
4	4	5	1	
5	5	6	1	
6	3	9	2	
7	9	10	2	
8	10	11	2	
9	11	12	2	
10	12	13	2	
11	2	13	3	
12	13	6	3	
13	7	8	4	

Soil	γ (pcf)	C (psf)	ϕ	SATURATED (1=No)
1	115	200	26	1
2	117	200	26	0
3	120	100	28	0
4 (ROCK)	150	10,000	45	0

FAILURE CIRCLE CENTER

$$X = 108.7' \quad Y = 1100.8' \quad \text{RADIUS} = 81'$$

FOR FULL POOL : ELEVATION = 1040'
FROM $X=0' \rightarrow X=132'$

OCS CYBER 730
GTICES LEASE I SF = 2.72

$$\Delta = 2.9\%$$

BISHOP 1 SF = 2.64

FOR RAPID DRAWDOWN :

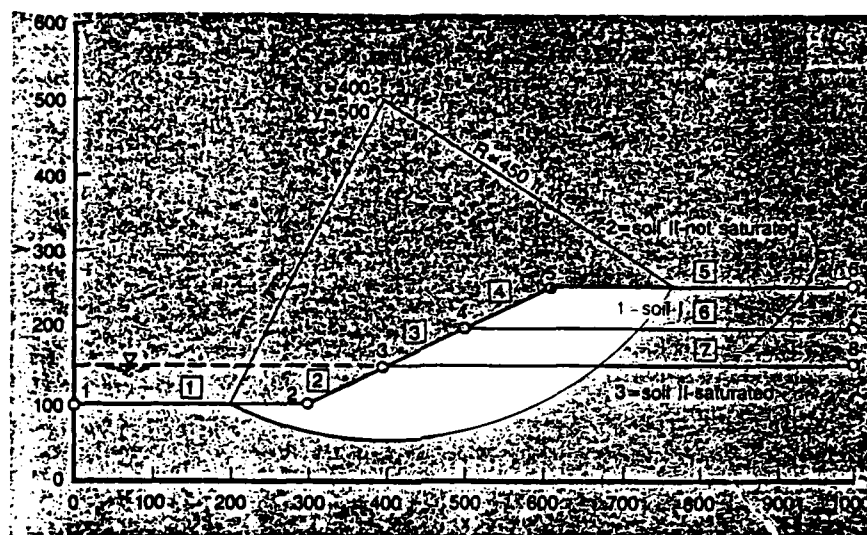
OCS CYBER 730
GTICES LEASE I SF = 1.42

$$\Delta = 2.1\%$$

BISHOP 1 SF = 1.45

4.5.2 Problem #2

Example Problem Presented by Cross [3].



Point	X	Y	Line	Left	Right	Soil	Soil	α	Cohesion	Phi	Saturated
1	0	100	1	1	2	3	1	127	2000	20	No
2	300	100	2	2	3	3	2	130	1000	33	No
3	400	150	3	3	4	2	3	130	1000	33	Yes
4	500	200	4	4	5	1					
5	800	250	5	5	6	1					
6	1000	250	6	4	7	2					
7	1000	200	7	3	8	3					
8	1000	150									

FACTOR OF SAFETY= 1.96 AT X= 400 Y= 500 R= 450
EARTHQUAKE= 0.05

DO YOU WISH A FORMAL PRINTOUT (Y OR N)?

SAMPLE SLOPE STABILITY PROBLEM

WATER UNIT WEIGHT= 62.40 EARTHQUAKE=0.05

SUBMERGENCE AT 150.00 FROM 0.0 TO 400.0

POINT	X-ORD	Y-ORD
1	0.00	100.00
2	300.00	100.00
3	400.00	150.00
4	500.00	200.00
5	600.00	250.00
6	1000.00	250.00
7	1000.00	200.00
8	1000.00	150.00

LINE	LEFT	RIGHT	SOIL
1	1	2	3
2	2	3	3
3	3	4	2
4	4	5	1
5	5	6	1
6	4	7	2
7	3	8	3

SOIL	UNIT WEIGHT	COHESION	PHI	SATURATED
1	127	2000	20	1
2	130	1000	33	1
3	130	1000	33	0

CIRCLE X-ORD Y-ORD RADIUS FACTOR OF SAFETY
400.0 500.0 450.0 1.96

DO YOU WISH A DIAGNOSTIC RUN (Y OR N)?

SLICE	WEIGHT	INCLINATION	COHESION	WIDTH	EFF WEIGHT	PHI	X
1	252536.4	-23.6	1000	23.1	45205.8	33.0	220.38
2	385318.3	-16.4	1000	53.1	114252.4	33.0	271.46
3	482338.9	-9.6	1000	50.0	189976.2	33.0	325.00
4	603232.6	-3.2	1000	50.0	293401.0	33.0	375.00
5	726732.6	3.2	1000	50.0	416901.0	33.0	425.00
6	852838.9	9.6	1000	50.0	560476.2	33.0	475.00
7	939262.7	16.2	1000	50.0	682516.4	33.0	525.00
8	982882.6	22.9	1000	50.0	781399.0	33.0	575.00
9	759268.3	29.4	1000	41.4	650306.4	33.0	620.71
10	617175.8	35.7	1000	41.4	576418.3	33.0	662.13
11	518439.1	43.6	1000	52.6	518439.1	33.0	709.13
12	131972.9	52.2	2000	38.8	131972.9	20.0	754.79

DRIVING FORCE COUNTER BALANCE OF 75111.11

ITERATION	INITIAL	CALCULATED
1	1.0000	1.8106
2	1.8106	1.9435
3	1.9435	1.9570
4	1.9570	1.9583

FACTOR OF SAFETY= 1.96 AT X= 400 Y= 500 R= 450
EARTHQUAKE= 0.05

Example Problem Calculated by BISHOP1.

(BISHOP1 is the slope stability program presented by Cross [3] translated into Applesoft)

SAMPLE SLOPE STABILITY PROBLEM

FACTOR OF SAFETY = 1.95830517 AT X =400 Y =500 RADIUS =450

EARTHQUAKE LOADING FACTOR =.05

SAMPLE SLOPE STABILITY PROBLEM

WATER UNIT WEIGHT =62.4 EARTHQUAKE LOADING FACTOR =.05

SUBMERGENCE ELEV =150 FROM X=0 TO X=400

POINT	X-COORDINATE	Y-COORDINATE
1	0	100
2	300	100
3	400	150
4	500	200
5	600	250
6	1000	250
7	1000	300
8	1000	150

LINE	LEFT PT	RIGHT PT	SOIL
1	1	2	3
2	2	3	3
3	3	4	2
4	4	5	1
5	5	6	1
6	4	7	2
7	3	8	3

SOIL	UNIT WEIGHT	COHESION	PHI	SAT'D
1	127	2000	30	1
2	130	1000	33	1
3	130	1000	33	0

CIRCLE: X=400 Y=500 RADIUS =450 FACTOR OF SAFETY =1.95830517

SLICE	WEIGHT	INCLINATION	COHESION	WIDTH	EFF WEIGHT	PHI	X
1	252536.452	-23.5767355	1000	53.0776408	45205.7908	33	220.383538
2	385318.321	-18.363501	1000	53.0776407	114252.363	33	273.46118
3	482338.898	-9.60948742	1000	50	189976.227	33	325
4	603232.626	-3.18968777	1000	50	283400.965	33	375
5	726732.626	3.18968777	1000	50	416900.965	33	425
6	852838.898	9.60948742	1000	50	560476.227	33	475
7	939262.679	16.1554181	1000	50	682516.593	33	525
8	982882.646	22.9295296	1000	50	781398.976	33	575
9	759268.279	29.4164975	1000	41.4213565	650306.432	33	620.710678
10	617175.754	35.6938236	1000	41.4213562	576418.317	33	662.132035
11	518439.062	43.5661001	1000	52.5674844	518439.062	33	709.126455
12	131972.89	52.2203924	2000	38.7555423	131972.89	30	754.767968

DRIVING FORCE COUNTER BALANCE OF 75111.1116#.

ITERATION	INITIAL	CALCULATED
1	1	1.81060871
2	1.81060871	1.94350336
3	1.94350336	1.95701339
4	1.95701339	1.95830517

SAMPLE SLOPE STABILITY PROBLEM

FACTOR OF SAFETY = 1.95830517 AT X =400 Y =500 RADIUS =450

EARTHQUAKE LOADING FACTOR =.05

Results

<u>Method</u>	<u>Factor of Safety</u>
Cross [3]	1.96
BISHOP 1	1.958

4.6 References

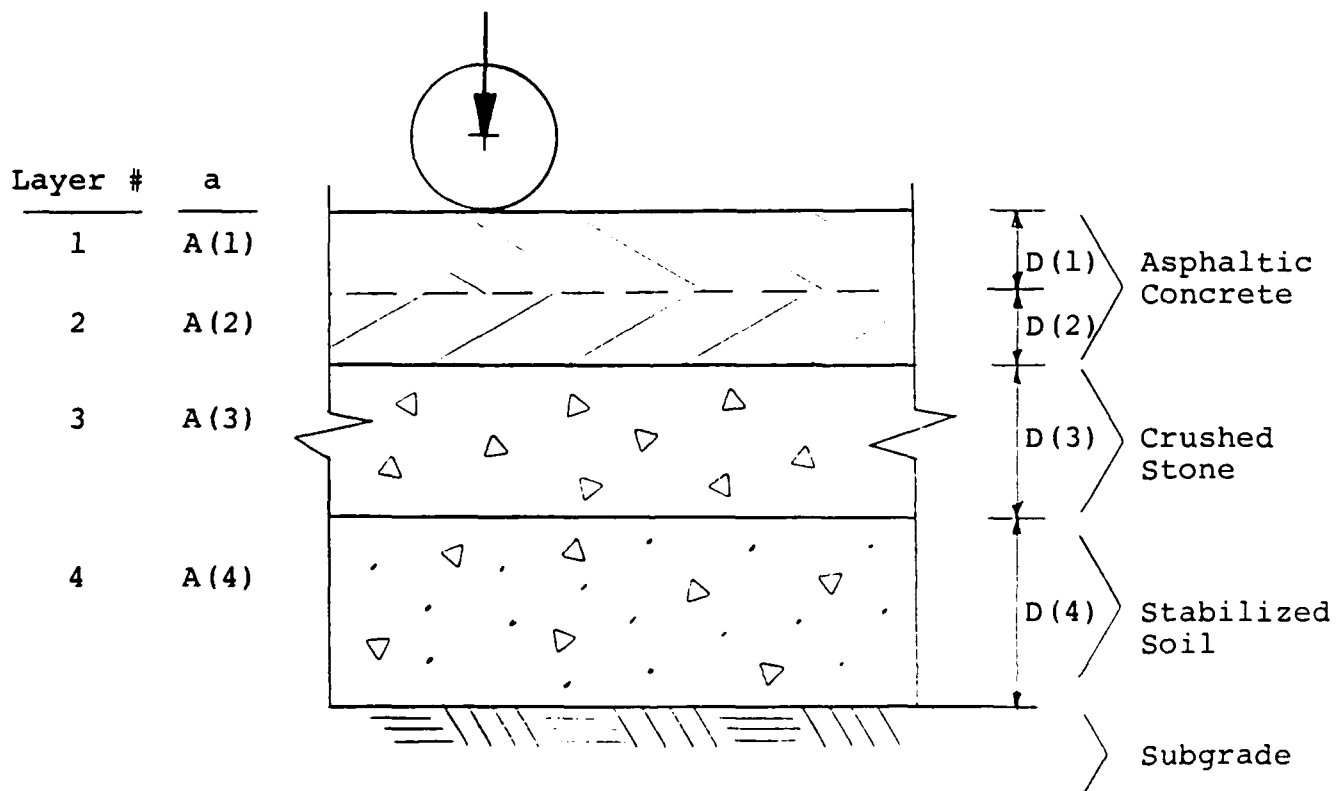
1. Terzaghi, K., and Peck, R. B., Soil Mechanics in Engineering Practice, John Wiley & Sons, New York, 1967.
2. Sowers, G. B., and Sowers, G. F., Introductory Soil Mechanics and Foundations, MacMillan Publishing Co., Inc., 1970.
3. Cross, J. P., "Slope Stability Program," Civil Engineering, ASCE, October, 1982, pp. 71-74.
4. Winterkorn, H. F., and Fang, H., "Foundation Engineering Handbook," Van Nostrand Reinhold Co., New York, 1975.
5. Schuster, R. L, and Krizek, R. J., "Landslides, Analysis and Control," Special Report 176, Transportation Research Board, Washington, D.C., 1978, pp. 155-164.

CHAPTER V

FLEXIBLE PAVEMENT DESIGN (AASHTO)

5.1 Problem Definition

AASHTO 1 is a computer program for the design of flexible pavements. AASHTO 1 is based on the design equations developed from the AASHO Road Test performed in 1958 by the American Association of State Highway Officials [1]. (See Figure 5.1.)



a - structural coefficient

D(i) - layer thickness

Figure 5.1. General Problem Definition.

AASHTO 1 is composed of two basic programs. The first program calculates the required thickness of a layer given the required design parameters and the characteristics of the other layers. The second program calculates the number of equivalent 18 kip wheel loads the pavement can endure over a projected 20-year service life. Both programs calculate the structural number.

5.2 Background Theory

5.2.1 General

The AASHO Road Test was performed in Illinois from 1958 through 1960. The test consisted of several pavement types constructed in a race track configuration. The pavements were subjected to various wheel loads and durations. So much data was collected that it took two years to produce the results and recommendations extrapolated from the test. The scope of the test was to produce a standardized design based on the useful service of a pavement versus theoretical structural design criteria. Rigid and flexible pavements were considered. This report deals only with flexible pavement design.

5.2.2 Flexible Pavement Construction

A flexible pavement consists of structural layers. The capacity of a layer to distribute load decreases from the top layer down to the subgrade. In general, a flexible pavement consists of a bituminous surface course, a base, and a subbase which in turn rests upon a soil subgrade.

The surface course is usually made of asphaltic concrete and is capable of distributing a wheel load to the base with a minimum amount of distortion or consolidation. By distributing the constant pressure of a wheel load such that the pressure is reduced at some finite depth, the base can be made up of a material which is less structurally capable than the surface course. This rationale applies to the subbase as well as the subgrade soil. From the AASHTO Road Test, minimum thicknesses for flexible pavement layers were established as follows [1]:

Surface Course	2 inches
Base Course	4 inches
Subbase Course	4 inches

In many cases a subbase course is not used and the base course rests directly on the subgrade soil.

5.2.3 AASHTO Design Considerations

The principal factors of the AASHTO pavement design are [2]:

- a) magnitude, method of application, and number of wheel loads
- b) function of pavement and base in transmitting the load to the subgrade
- c) measurement of the subgrades ability to support the transmitted load

5.2.3.1 Equivalent 18-kip Loads

The AASHTO design considers the number of equivalent 18-kip wheel loads (E-18's) applied to a pavement over a particular service life. Several methods of estimating this quantity have been established by various transportation and highway organizations. Methods range from traffic counters with load meters to extrapolating historic data. In many cases, organizations will expend more funds on collecting this data than can be rationalized for its intended purpose. Historic data will usually suffice as a means of projecting anticipated wheel loads. This is especially true when new interstates are being constructed as other factors will influence usage such as route direction, load limitations, city connections, and other regional limitations. Large amounts of data exist for equating given loads and load configurations to 18-kip single axle loads. Service organizations must adapt a method of calculating E-18's best suited for their region.

5.2.3.2 Soil Support

In the AASHTO Road Test, a soil support value of 3 was established to represent the subgrade soil used which was an A-6 soil [2]. Crushed stone with a California Bearing Ratio (CBR) of 200 was assigned a soil support value of 10.

The soil support value of various soils have been established by different service organizations. Figure 5.2 and Tables 5.1 through 5.4 represent a selected group of soil

Table 5.1. Maximum Recommended Soil Support Values [6].

Classification	Description	Upper Soil Support Value
A-1a	Largely gravel but can include sand and fines	6.5
A-1b	Gravelly sand or graded sand; may include fines	6
A-2-4	Sands, gravels with low plasticity silt fines	5
2-2-4	Micaceous silty sands	2.5 - 3.0
A-2-5	Sands, gravels with plastic silt fines	4
A-2-6	Sands, gravels with clay fines	4.0 - 5.0
A-2-7	Sands, gravels with highly plastic clay fines	4.0
A-3	Fine sands	4.5
A-4	Low compressibility silts	4.0
A-5	High compressibility silts, micaceous silts and micaceous sandy silts	2.5 - 3.5
A-6	Low to medium compressibility clays	3.5 - 4.5
A-7	High compressibility clays, silty clays and high volume change clays	3-4

Table 5.2. Soil Support Values [2].

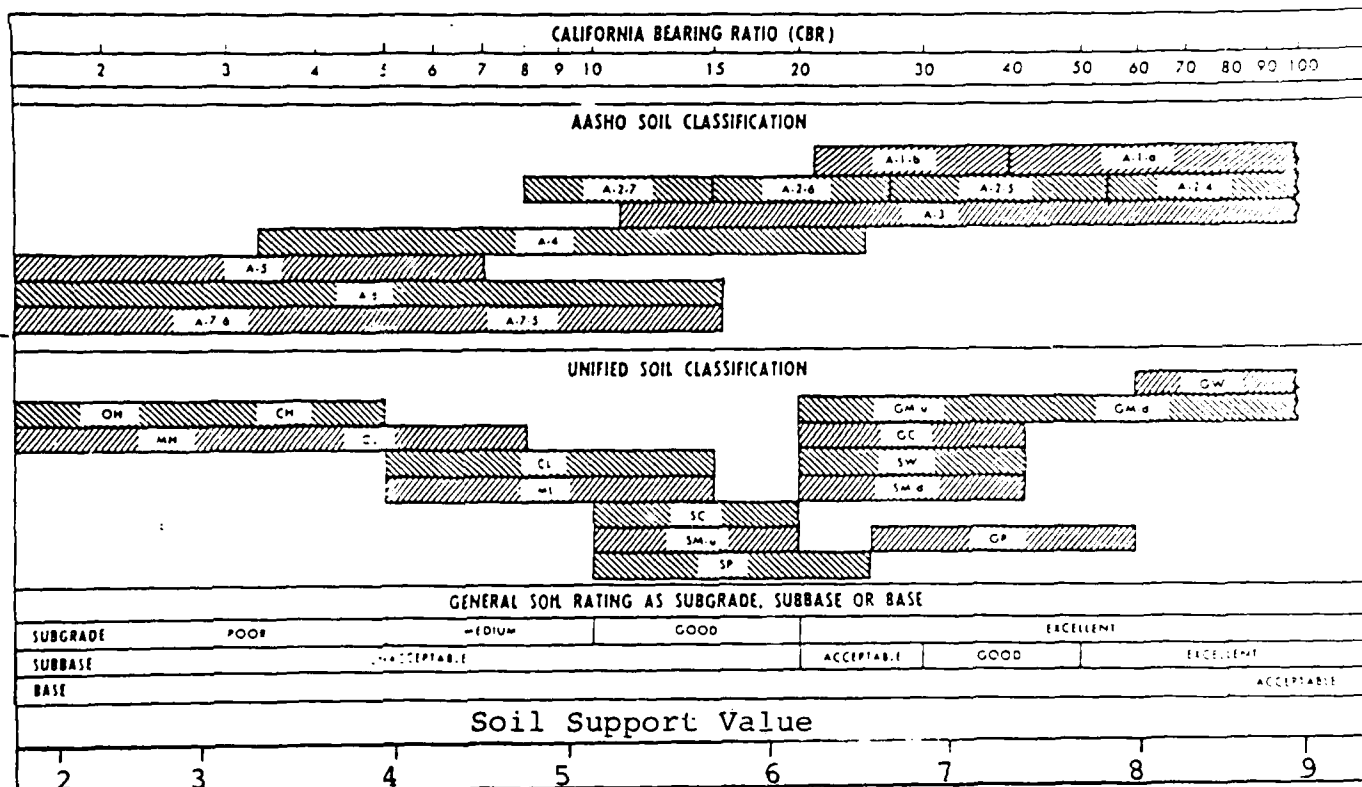


Table 5.3 Summary of Laboratory Test Results Repeatability Study, State of Utah [1].

Soil Type	Soil Support	Dynamic CBR	Static CBR	AASHTO 3-Point CBR	R-Value (240psi)*	R-Value (300psi)*
A-7-6	3.9	4.9	7.2	1.9	8.4	12.0
A-4-5	4.9	8.9	8.0	5.2	10.5	14.8
A-2-4	7.2	38.9	42.6	9.9	68.2	72.2
A-1-9	8.4	78.0	116.5	17.2	75.5	77.2

* Exudation pressure

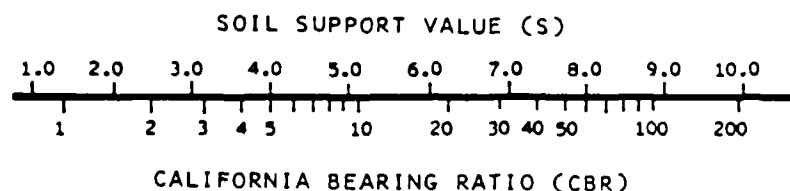


Figure 5.2. Soil Support Values [1].

Table 5.4. Soil Support Values [5].

RELATIONSHIPS BETWEEN SOIL TYPES AND BEARING VALUES*			
Type of Soil	Subgrade Strength	k-Value Range, psi	Soil Support Value (S.S.V.)
Silts and clays of high compressibility natural density (uncompacted)	Very low	50	1.7
Silts and clays of high compressibility natural Density (compacted)	Low	100	2.7
Fine grain soils in which silt and clay size particles predominate (compacted)	Medium	100 - 150	2.7 - 4.3
Poorly graded sands and soils that are predominantly sandy with moderate amounts of silts and clays (compacted)	High	150 - 220	4.3 - 6.0

support values based on widely varying soil characteristics. Each organization must adopt a means of evaluating the soil support values which best suit the soils encountered in a particular region.

5.2.3.3 Terminal Serviceability Index

A significant concept developed by the Road Test was the Terminal Serviceability Index (P_t). The P_t is a qualitative measure of the final condition of a pavement at the end of its design service life. The P_t scale is from total failure at 1.5 to outstanding at 5.0; 3.5 to 5.0 corresponds to poor to outstanding new construction, respectively. For design, a P_t of 2.5 applies to the minimum serviceability of an interstate highway; similarly, a P_t of 2.0 applies to secondary roads.

5.2.3.4 Regional Factors

In an effort to apply the general design equations developed via the Road Test to other regions, a regional factor was introduced such that environmental factors not encountered in Illinois could be incorporated into the design. The regional factor can incorporate the following parameters [1]:

- a) topography
- b) similarity to the Road Test location
- c) rainfall
- d) frost penetration
- e) temperature

- f) groundwater table
- g) subgrade type
- h) engineering judgment
- i) type of highway structure
- j) subsurface drainage

Figure 5.3 is a general guide for the selection of a regional factor. The scale varies from 0.5 to 4.8. The lowest values apply to permanently frozen or consistently dry roadbed materials. The upper values apply to severe frost heave conditions and other mechanisms which rapidly accelerate pavement deterioration. The value used for the road test was 1.0. AASHTO recommends the following as a crude guide.

Table 5.5. Regional Factors [1].

Condition	R value
Roadbed materials frozen to depth of 5 in. or more	0.2-1.0
Roadbed materials dry, summer and fall	0.3-1.5
Roadbed materials wet, spring thaw	4.0-5.0

Historical data of pavement performance in relation to the number of annual freeze-thaw cycles, steep grades with large volumes of heavy truck traffic, and areas of concentrated turning and stopping movements can be useful in evaluating an appropriate regional factor.

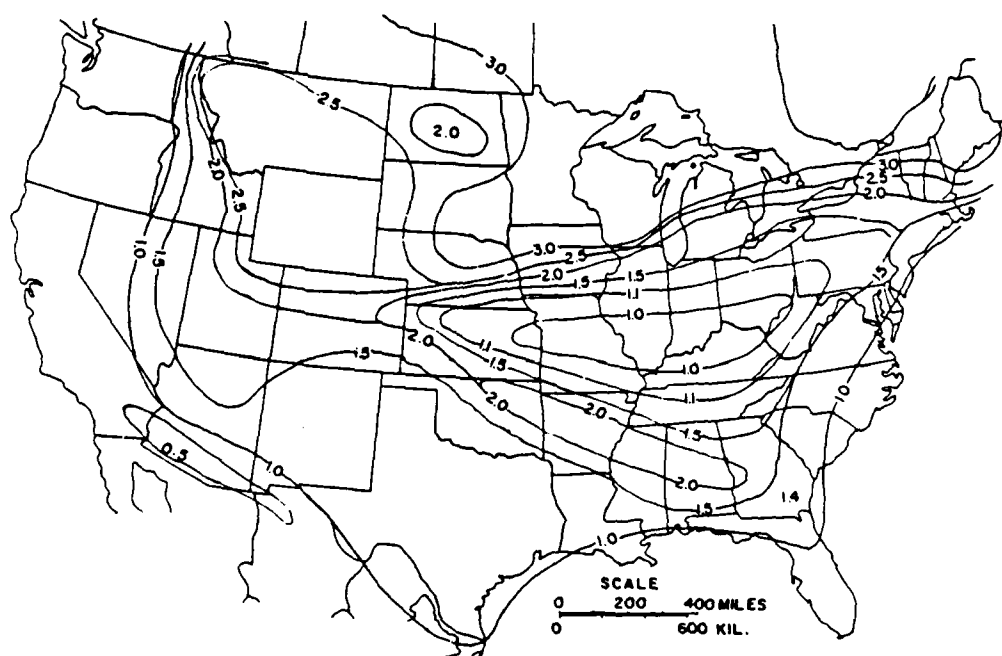


Figure 5.3. Generalized Regional Factors [4].

5.2.3.5 Structural Number

The E-18s, regional factor, soil support value, and terminal serviceability index represent various components influencing the design of a flexible pavement. To combine the above parameters into a value which could be translated into a pavement design, a structural number (SN) was introduced. The structural number is a value calculated from the above parameters and is the sum of the layer thicknesses multiplied by their appropriate structural coefficients.

$$SN = a_1 D_1 + a_2 D_2 + \dots + a_i D_i$$

where,

a_i = structural coefficient of layer i

D_i = thickness of layer i (inches)

The structural number is abstract but relates to the strength of the section.

5.2.3.6 Structural Coefficient

The structural coefficient is a measure of a layers ability to transmit load. As previously discussed, the surface course will have a higher structural coefficient than a layer less capable of distributing a load to a lower layer. Tables 5.6 through 5.9 relate structural coefficients to various construction materials. Many service organizations develop their own correlations to best suit their situation.

Table 5.6. Structural Coefficients [1].

Structural Layer Coefficients Proposed by AASHO Committee on Design,
October 12, 1961

Pavement Component	Coefficient ²
<i>Surface Course</i>	
Roadmix (low stability)	0.20
Plantmix (high stability)	0.44*
Sand Asphalt	0.40
<i>Base Course</i>	
Sandy Gravel	0.07 ³
Crushed Stone	0.14*
Cement-Treated (no soil-cement)	
Compressive strength @ 7 days	
650 psi or more ¹ (4.48MPa)	0.23 ²
400 to 650 psi (2.76 to 4.48MPa)	0.20
400 psi or less (2.76MPa)	0.15
Bituminous-Treated	
Coarse-Graded	0.34 ²
Sand Asphalt	0.30
Lime-Treated	0.15-0.30
<i>Subbase Course</i>	
Sandy Gravel	0.11*
Sand or Sandy-Clay	0.05-0.10

* Established from AASHO Road Test Data

¹ Compressive strength at 7 days.

² This value has been estimated from AASHO Road Test data, but not to the accuracy of those factors marked with an asterisk.

³ It is expected that each state will study these coefficients and make such changes as experience indicates necessary.

Table 5.7. Selected Structural Coefficients Used by Various Transportation Organizations in the AASHTO Interim Guide Design Method [6].

Pavement Component	Structural Coefficient			
	Fla.	Ga.	Md.	S.C.
I. Surface and Binder Course (a_1)				
Asphalt Concrete	(5) 0.2 - 0.4	(1) 0.44	0.44	0.44
Bituminous Surfacing	-	-	-	0.35
II. Base Course (a_2)				
Asphalt Concrete	(4) 0.21 - 0.30	0.30	0.28	0.34
Sand-Asphalt		0.12	0.28	0.20 - 0.25
Soil Cement	0.22	0.20	0.28	0.20
Graded Aggregate		0.18 ⁽²⁾	0.14	0.12 - 0.20
Cement Stabilized Graded Aggregate		0.22	0.22	0.34
Sand Aggregate	-	-	0.14	-
Sand-Clay CBR > 49	0.12	-	-	-
Limerock CBR > 80	0.15	-	-	-
Limerock Stabilized Base. CBR > 56	0.12	-	-	-
III. Subbase (a_3)				
Graded Aggregate		0.14	-	-
Topsoil or Sand-Clay		0.10	-	-
Gravel or Screenings	-	-	0.07	-
Soil Aggregate	-	-	-	0.08 - 0.12
Cement Stabilized Earth	-	-	-	0.15

1. Georgia uses a coefficient of 0.44 for surface and binder to a depth of 4.5 in. (110 mm).
2. When compacted to 100% of T-180 density.
3. Subbase coefficients are used in Georgia below a depth of 12 in. (300 mm).
4. The Florida DOT uses the following structural coefficients for different base mixes: (1) Type I, 500 lb. Marshall stability, $a_2 = 0.21$; (2) Type II, 750 lb. Marshall stability, $a_2 = 0.25$; (3) Type III, 1,000 lb. Marshall stability, $a_2 = 0.30$.
5. The Florida DOT uses the following structural coefficients for different surface mixes: Type S1, 1,000 lb. Marshall stability, $a_1 = 0.40$; Type S2, 1,000 lb. Marshall stability, $a_2 = 0.20$; and Type S3, 750 lb. Marshall stability, $a_1 = 0.30$.

Table 5.8. Pavement Coefficients for Flexible Section Design, Louisiana [1]

	Strength	Coefficient
I. <i>SURFACE COURSE</i>		
Asphaltic Concrete		
Types 1, 2 and 4 BC and WC	1000+	0.40
Types 3 WC	1800+	0.44
BC	1500+	0.43
II. <i>BASE COURSE</i>		
UNTREATED		
Sand Clay Gravel - Grade A	3.3-	0.08
Sand Clay Gravel - Grade B	3.5-	0.07
Shell and Sand - Shell	2.2-	0.10
CEMENT-TREATED		
Soil-Cement	300 psi+	0.15
Sand Clay Gravel - Grade B	500 psi+	0.18
Shell and Sand - Shell	500 psi+	0.18
Shell and Sand - Shell	650 psi+	0.23
LIME-TREATED		
Sand Shell	2.0-	0.12
Sand Clay Gravel - Grade B	2.0-	0.12
ASPHALT-TREATED		
Hot-Mix Base Course (Type 5A)	1200+	0.34
Hot-Mix Base Course (Type 5B)	800+	0.30
III. <i>SUBBASE COURSE</i>		
Lime-Treated Sand Clay Gravel - Grade B	2.0-	0.14
Shell and Sand-Shell	2.0-	0.14
Sand Clay Gravel - Grade B	3.5-	0.11
Lime-Treated Soil	3.5-	0.11
Old Gravel or Shell Roadbed (8" thickness) (200 mm)	-	0.11
Sand (R-Value)	55+	0.11
Suitable Material-A-6 (PI = 15-)	-	0.04

Table 5.9. Recommended AASHTO Interim Guide Structural Coefficients for Thickness Design [6].

Structural Layer	Class	Structural Coefficient	General Requirements
1. Surface and Binder Course (Weighted Avg.)			
Asphalt Concrete	1	0.48	> 6.0% AC; 2-4% Air Voids; > 1500 lb. Marshall Stability (1)
	2	0.44	> 4.8% AC; 2-6% Air Voids; > 1200 lb. Marshall Stability
	3	0.35	< 4.4% AC; 2-8% Air Voids; > 700 lb. Marshall Stability
Sand Asphalt	1	0.35	> 5.8% AC; <14% Air Voids; > 550 lb. Marshall Stability (1)
	2	0.27	< 4.8% AC; <18% Air Voids; > 400 lb. Marshall Stability
2. Base Course			
Crushed Stone (Untreated)	1	0.14	Well graded; 1-1/2 in. or greater top size; 3-8% fines; 100% T-180 compaction
Asphalt Concrete	1	0.34	> 5.8% AC; 2-4% Air Voids; > 1200 lb. Marshall Stability (1)
	2	0.28	< 4.8% AC; <8% Air Voids; > 1200 lb. Marshall Stability
Sand Asphalt	1	0.25	> 5.8% AC; 14% Air Voids; > 600 lb. Marshall Stability (1)
	2	0.17	< 4.5% AC; 18% Air Voids; > 350 lb. Marshall Stability
Sand Cement	1	0.24	> 600 psi, 7 day Compressive Strength
	2	0.18	> 400 psi, 7 day Compressive Strength
3. Inverted Structural Section - Experimental			
Unstabilized Sand Base		0.10 to 0.12	Clean, medium to coarse sand with less than 4 to 8 percent fines
Unstabilized sand - crushed stone blend		0.16	

NOTES: 1. Given Marshall Stabilities are for a 50 blow Mix Design

2. Structural section consisting of unstabilized clean sand or crushed stone placed between a sand-cement base and asphalt concrete surface course. Use structural coefficients for sand-cement base and asphalt concrete surface course given above.

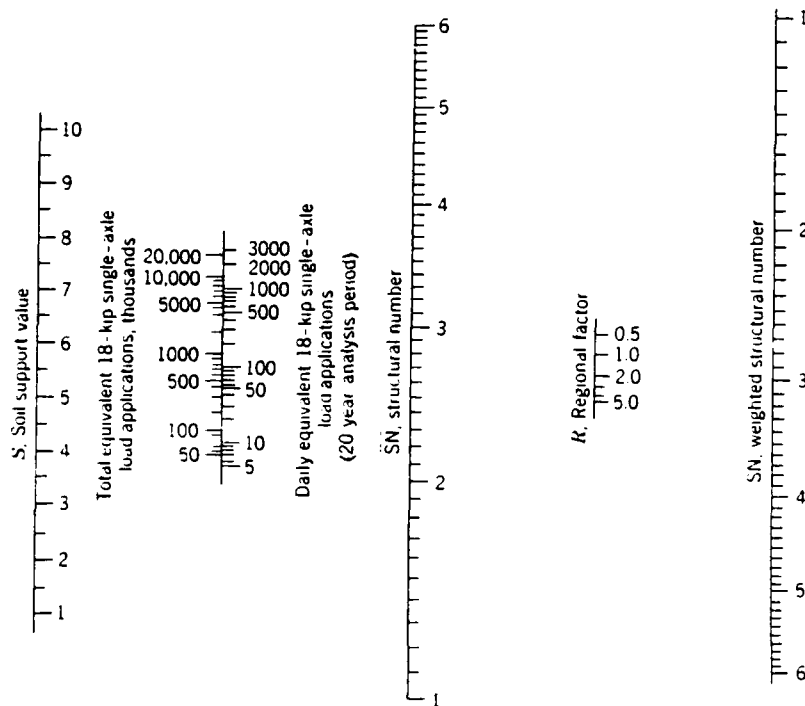
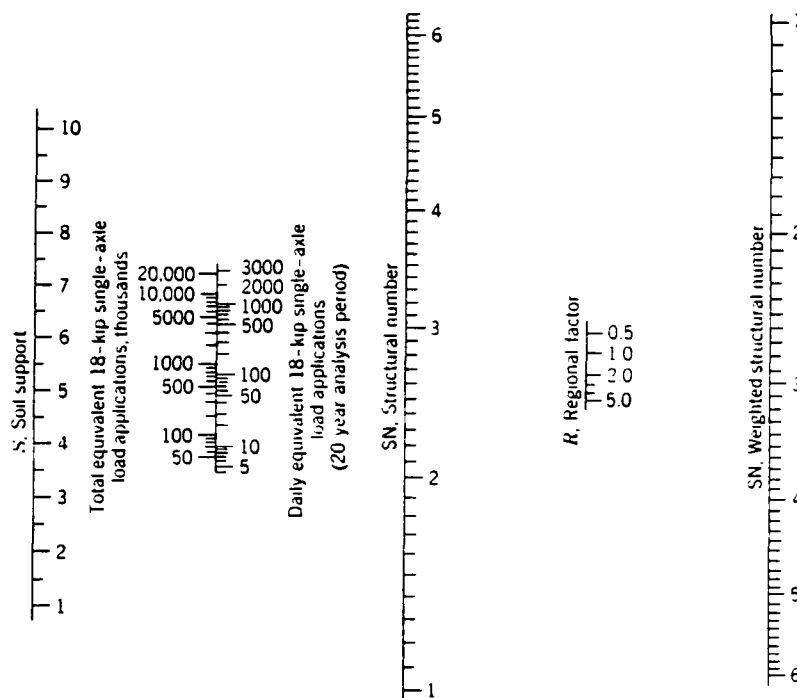


Figure 5.4. AASHTO Flexible Pavement Design Nomographs [3].

5.2.4 AASHTO Equation

The general equation developed by AASHTO is as follows:

$$\log W_{18} = 9.36 \log (SN+1) - .2 + \frac{\log [(4.2-P_t)/2.7]}{.4 + \frac{1094}{(SN+1)^{5.19}}} + \log \frac{1}{R} + .372 (S_i - 3.0)$$

where,

W_{18} = E-18's, single axle loads

SN = structural number

P_t = terminal serviceability index

R = regional factor

S_i = soil support value

(log = natural logarithm)

The structural number is calculated by iterative trials given W_{18} , P_t , R, and S_i .

Nomographs were developed for terminal serviceability indexes of 2.0 and 2.5 and are presented in Figure 5.4. After calculating SN with S_i and W_{18} , a weighted or design SN is calculated using the regional factor.

Figure 5.5 relates the variation of wheel load type to the structural number with all other parameters normalized to the road test; i.e., $S_i = 3.0$ and $R = 1.0$.

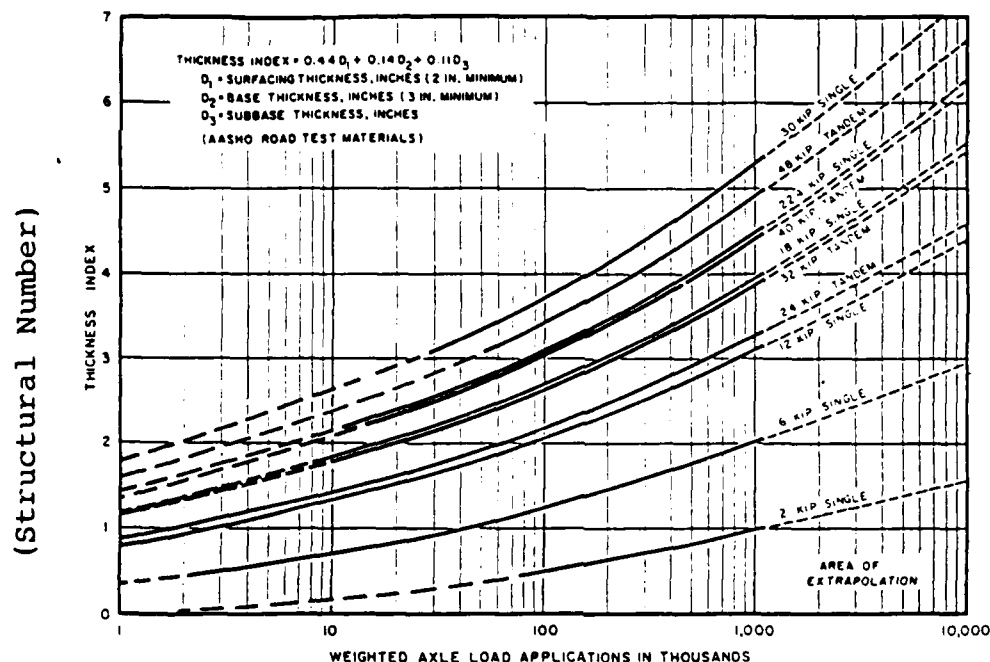


Figure 5.5. AASHO road test relationship between thickness index and axle loads at $p = 2.5$. [2].

5.3 Program Rationale

AASHTO 1 is designed to provide the user the ability to approach the design problem by two avenues. Given the regional factor, soil support value, and terminal serviceability index, the user can input the pavement layer characteristics and calculate the number of equivalent single axle 18-kip loads the pavement can expect to endure. Similarly, the program can calculate the required thickness of a layer given the regional factor, soil support value, terminal serviceability index, E-18's, and the characteristics of the other layers (see Figure 5.6).

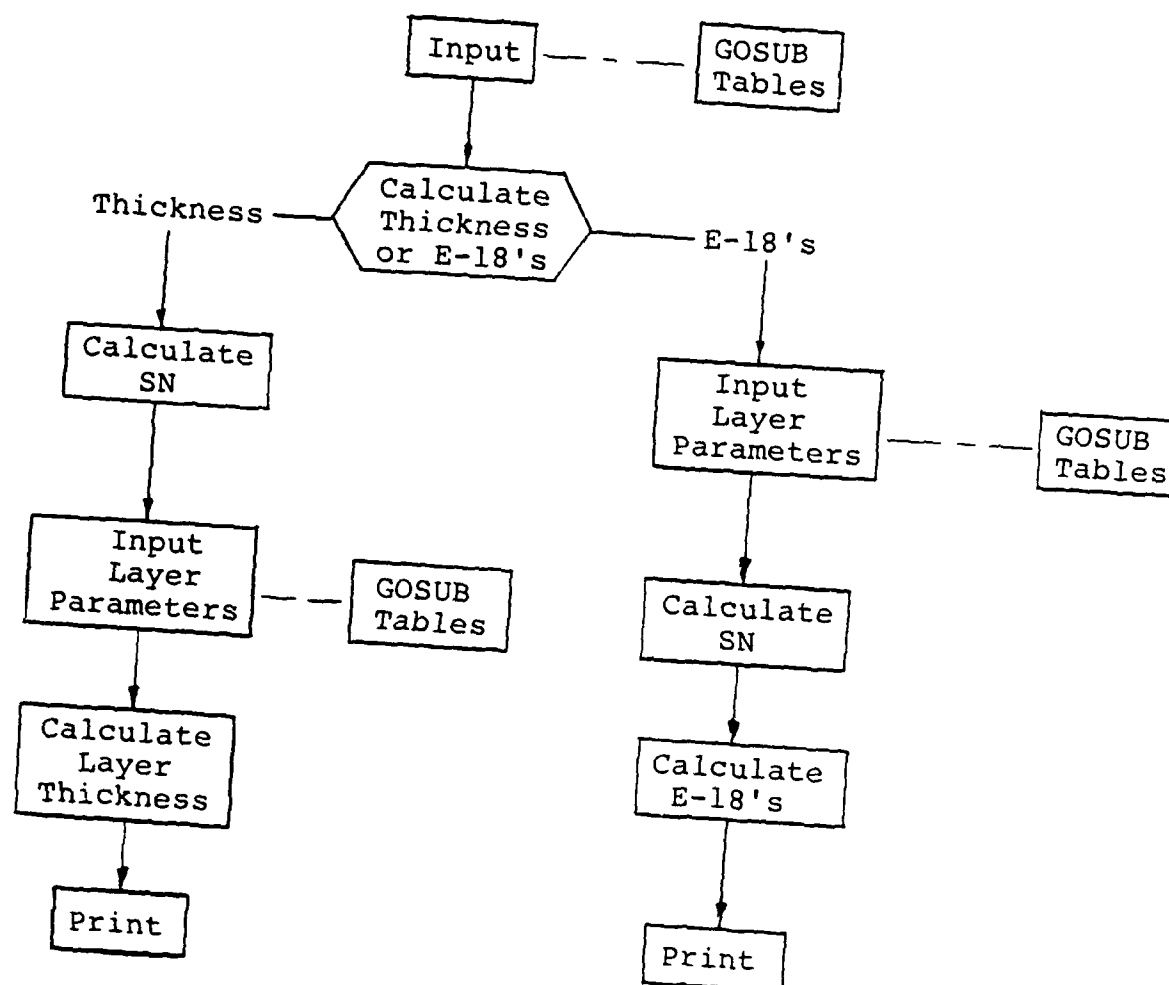


Figure 5.6. AASHTO 1 Flow Chart.

Originally, the author intended to create a matrix of possible layer thicknesses but due to the limited capacity of the miniature computer, this idea was aborted. The program was then designed to allow the user to quickly change thicknesses and structural coefficients in successive runs without inputting repetitive data.

The output was designed to resemble a layered system with input variables and other calculated data presented below the output. This format allows the user to correlate data from different runs with the maximum of ease.

5.4 Program Use and Limitations

5.4.1 General

AASHTO 1 is user oriented. Input is prompted by statements and questions which clearly identify the input requirements. As with any program, the user should have the input ready prior to running the program. If several runs are to be executed, the user should prepare a chart of required input variables. This method will eliminate most errors associated with mistaken or improper variable input.

5.4.2 Input

As previously mentioned, AASHTO 1 is composed of two parts. One portion of the program calculates a required thickness given all other data, and the second portion calculates the equivalent single axle 18-kip loadings. The user will be prompted to choose which option is to be run. The user must input the number of runs to be made with the

portion of the program previously specified. After the runs are completed, the user may then opt to run the alternate portion of the program or more runs of the same. Each time a new set of runs are specified, all input must be re-entered.

The following is a list of required input. The input differences between the two programs will be discussed later in this section.

- a) soil support value
- b) terminal serviceability index
- c) regional factor
- d) E-18's
- e) number of layers
- f) layer number for thickness calculation
- g) layer number
- h) structural coefficient
- i) layer thickness

When the user has specified an E-18 calculation, input d) and f) will be emitted; conversely, for a layer thickness calculation input i) will be emitted for the layer specified for thickness calculation. Although it is recommended to number the layers successively from #1 for the top layer to #i for the ith layer, this is not required. The user will find the output format suited to numbering layers in this fashion.

5.4.3 Options

AASHTO 1 provides the user with tables of typical values of soil support, terminal serviceability index, regional factor, E-18's, and structural coefficients. The user may access these charts by inputting 0 (zero) instead of the non-zero variable requested. After inputting 0, the chart will appear on the monitor. When the user is finished reviewing the chart, the user will again be prompted to input the required variable. The charts are derived from those presented in Section. 5.2.

As previously described, the user has the option of calculating a layer thickness or the number of equivalent single-axle 18-kip loads.

5.4.4 Limitations

The user is limited to specifying ten layers. This limitation is due to memory capacity. If the user requires more layers, there are no constraints in the program to prevent inputting more than ten. The user should not attempt to input more than ten layers. If an out-of-memory error results, the user must reduce the number of layers.

The inherent limitation of AASHTO 1 is the basis and validity of the AASHO Road Test equations. The user is urged to study reference #4 for an evaluation of the guide.

5.5 Program List

```

2  HOME
5  SPEED= 150
10 PRINT "          *****"
12 PRINT "          * AASHTO *"
14 PRINT "          *****"
16 PRINT : PRINT : PRINT
18 PRINT "DANA K. EDDY, 578-80-8378"
20 PRINT "GA. INSTITUTE OF TECHNOLOGY"
22 PRINT "SCHOOL OF CIVIL ENGINEERING"
24 PRINT "DEPARTMENT OF GEOTECHNICAL ENGINEERING"
26 PRINT : PRINT : PRINT
28 PRINT "SYSTEM HARDWARE: APPLE II PLUS (64K)"
30 PRINT "SYSTEM HARDWARE: DOS 3.3, APPLESOFT BASIC LANGUAGE"
32 PRINT "PROGRAM DATE: JULY, 1983"
34 PRINT : PRINT
36 PRINT : PRINT
38 PRINT "AASHTO IS BASED ON THE AASHTO INTERIM GUIDE FOR THE DESIGN OF F
    LEXIBLE PAVEMENT STRUCTURES, 1972."
39 PRINT : PRINT : PRINT "(PRESS THE SPACE BAR TO CONTINUE)"
40 POKE - 16388,0
41 CH = PEEK ( - 16384)
42 IF CH < > 160 GOTO 40
44 SPEED= 255
46 HOME
100 PRINT "USER INPUT QUESTIONS AND COMMANDS WHICH ARE FOLLOWED BY (*) AR
    E SUPPLEMENTED BY LISTS AND TABLES. TO ACCESS THE LIST OR TABLE TYPE
    (0) INSTEAD OF THE APPROPRIATE VALUE OF THE VARIABLE REQUESTED."
110 PRINT : PRINT
115 INPUT "PROBLEM HEADING ";H$
117 PRINT : PRINT
120 INPUT "TO CALCULATE THE THICKNESS OF A PARTICULAR LAYER, TYPE (1); TO
    CALCULATE THE MAXIMUM NUMBER OF EQUIVALENT 18-KIP LOADS, TYPE (2). "
    ;BB
130 PRINT : PRINT
140 INPUT "HOW MANY TRIALS DO YOU WANT TO RUN? ";Z
150 PRINT : PRINT
160 IF BB = 2 THEN 190
170 INPUT "WHAT IS THE CALCULATION TOLERANCE (REC'D; .01). ";TL
180 PRINT : PRINT
190 INPUT "SOIL SUPPORT VALUE (*) = ";SI
200 PRINT : PRINT
210 IF SI > 0 GOTO 240
220 GOSUB 2000
230 GOTO 190
240 INPUT "TERMINAL SERVICABILITY INDEX (*) = ";PT
250 PRINT : PRINT
260 IF PT > 0 GOTO 290
270 GOSUB 3000
280 GOTO 240
290 INPUT "REGIONAL FACTOR (*) = ";RI
300 PRINT : PRINT
310 IF RI > 0 GOTO 340
320 GOSUB 4000

```

```

330 GOTO 290
340 IF BB = 2 GOTO 1010
350 INPUT "# OF EQUIVALENT SINGLE AXLE 18-KIP WHEEL LOADS (*) = ";WI
352 PRINT : PRINT
355 IF WI > 0 GOTO 370
360 GOSUB 5000
365 GOTO 350
370 X = 4
375 XX = 1:YY = 0:ZZ = 0
380 A1 = LOG (WI) / 2.3026
390 A2 = .2
400 A3 = LOG ((4.2 - PT) / 2.7) / 2.3026
410 A4 = LOG (1 / RI) / 2.3026
420 A5 = .375 * (SI - 3.0)
430 AA = A1 + A2 - A4 - A5
440 AB = (4.065 * LOG (X) * (.4 * X ^ 5.19 + 1094) + A3 * X ^ 5.19) / (.4
      * X ^ 5.19 + 1094)
442 XX = XX + 1
444 IF XX > 500 GOTO 510
450 IF AB > = AA - TL / 2 AND AB < = AA + TL / 2 GOTO 510
460 IF AB < AA GOTO 490
470 IF YY = 0 GOTO 474
471 IF YY = 1 AND ZZ = 1 GOTO 474
472 TL = TL / 10
474 X = X - TL
476 ZZ = 1
480 GOTO 440
490 IF ZZ = 0 GOTO 494
491 IF ZZ = 1 AND YY = 1 GOTO 494
492 TL = TL / 10
494 X = X + TL
496 YY = 1
500 GOTO 440
510 SN = X - 1
512 NN = SN * 100
513 NN = INT (NN)
514 NN = NN / 100
520 FOR H = 1 TO 2
521 HOME
524 PRINT "/////////"
525 PRINT "TRIAL #"H
526 PRINT "/////////"
527 PRINT : PRINT
528 PRINT "STRUCTURAL NUMBER ="NN
529 PRINT : PRINT
530 INPUT "SPECIFY # OF LAYERS (MAX=10). ";N
540 PRINT : PRINT
550 INPUT "LAYER # FOR THICKNESS CALCULATION. ";L
560 PRINT : PRINT
570 FOR I = 1 TO N
575 PRINT "*****"

```

```

577 PRINT
580 INPUT "LAYER #. ";Y
590 PRINT : PRINT
600 INPUT "STRUCTURAL COEFFICIENT (*) = ";A(Y)
610 PRINT : PRINT
620 IF A(Y) > 0 GOTO 645
630 GOSUB 6000
640 GOTO 600
645 IF I = L GOTO 700
650 INPUT "LAYER THICKNESS (INCHES) = ";D(Y)
660 PRINT : PRINT
670 IF D(Y) > 0 GOTO 700
680 GOSUB 7000
690 GOTO 650
700 NEXT I
710 SC = 0
720 FOR I = 1 TO N
730 IF I = L GOTO 750
740 SC = SC + D(I) * A(I)
750 NEXT I
760 IF SC < SN GOTO 830
770 PRINT "** WARNING ** INPUT LAYERS SATISFY MINIMUM STRUCTURAL REQUIRE
MENTS."
780 PRINT : PRINT
790 INPUT "TYPE (1) TO REENTER VARIABLES, TYPE (2) TO END PROGRAM. ";DD
800 PRINT : PRINT
810 IF DD = 1 GOTO 520
820 GOTO 1490
830 D(L) = SN / A(L)
840 FOR I = 1 TO N
850 IF I = L GOTO 870
860 D(L) = D(L) - A(I) * D(I) / A(L)
870 NEXT I
880 D(L) = D(L) * 100
890 D(L) = INT (D(L))
900 D(L) = D(L) / 100
902 L$ = CHR$(4): PRINT L$;"PR# 1"
905 PRINT : PRINT : PRINT
906 PRINT "/////////////////////////////////////"
907 PRINT H$
908 PRINT "/////////////////////////////////////"
909 PRINT : PRINT
910 PRINT "TRIAL #"H
915 PRINT "*****"
920 PRINT : PRINT
930 PRINT "LAYER","STR/L COEFF.,""THICKNESS"
940 FOR I = 1 TO N
950 PRINT SPC(20);A(I);D(I)
960 NEXT I
980 PRINT
990 PRINT "STRUCTURAL NUMBER ="SN

```

```

992 PRINT
995 PRINT "EQUIVALENT SINGLE AXLE 18-KIP LOAD ="WI
997 PRINT : PRINT : PRINT
998 PRINT L$;"PR#0"
1000 NEXT H
1005 PRINT L$;"PR#0"
1006 GOTO 1370
1010 FOR H = 1 TO Z
1015 HOME
1016 PRINT "%%%%%%%%%"
1017 PRINT "TRIAL #"H
1018 PRINT "%%%%%%%%%"
1019 PRINT : PRINT
1020 INPUT "SPECIFY # OF LAYERS (MAX-10) ";N
1030 PRINT : PRINT
1040 FOR I = 1 TO N
1045 PRINT "*****"
1047 PRINT
1050 INPUT "LAYER # =";Y
1060 PRINT : PRINT
1070 INPUT "STRUCTURAL COEFFICIENT (*) =";A(Y)
1080 PRINT : PRINT
1090 IF A(Y) > 0 GOTO 1120
1100 GOSUB 6000
1110 GOTO 1070
1120 INPUT "LAYER THICKNESS (INCHES) = ";D(Y)
1130 PRINT : PRINT
1140 IF D(Y) > 0 GOTO 1161
1150 GOSUB 7000
1160 GOTO 1120
1161 NEXT I
1163 SN = 0
1165 FOR I = 1 TO N
1167 SN = SN + A(I) * D(I)
1169 NEXT I
1170 B2 = 9.36 * LOG (SN + 1) / 2.3026
1180 B3 = .2
1190 B4 = LOG ((4.2 - PT) / 2.7) / 2.3026
1200 B5 = .4 + 1094 / (SN + 1) ^ 5.19
1210 B6 = LOG (1 / RI) / 2.3026
1220 B7 = .372 * (SI - 3.0)
1230 B1 = B2 - B3 + B4 / B5 + B6 + B7
1240 WI = EXP (2.3026 * B1)
1250 WI = INT (WI)
1260 L$ = CHR$ (4): PRINT L$;"PR#1"
1261 PRINT : PRINT : PRINT
1262 PRINT "%%%%%%%%%"
1263 PRINT H$
1264 PRINT "%%%%%%%%%"
1265 PRINT : PRINT
1270 PRINT "TRIAL #"H

```

```

1272 PRINT "*****"
1280 PRINT
1285 PRINT "LAYER","STR'L COEFF. ","THICKNESS"
1290 FOR I = 1 TO N
1295 PRINT SPC( 3)I,A(I),D(I)
1300 NEXT I
1310 PRINT : PRINT
1320 PRINT "STRUCTURAL NUMBER ="SN
1330 PRINT
1340 PRINT "EQUIVALENT SINGLE AXLE 18-KIP LOADS ="WI
1350 PRINT L$;"PR#0"
1360 NEXT H
1370 L$ = CHR$( 4): PRINT L$;"PR#1"
1380 PRINT : PRINT
1390 PRINT "SOIL SUPPORT VALUE ="SI
1400 PRINT
1410 PRINT "TERMINAL SERVICEABILITY INDEX ="PT
1420 PRINT
1430 PRINT "REGIONAL FACTOR ="RI
1435 PRINT L$;"PR#0"
1440 INPUT "DO YOU WANT TO RUN ANY MORE TRIALS (0=NO, 1=YES)? ";Q1
1450 PRINT : PRINT
1460 IF Q1 = 0 GOTO 1490
1470 INPUT "FOR A LAYER THICKNESS CALCULATION, TYPE(1); FOR AN 18-KIP LOA
DING CALCULATION, TYPE(2). ";BB
1475 PRINT : PRINT
1480 GOTO 140
1490 HOME
1495 PRINT "THANK YOU FOR USING AASHTO"
1500 PRINT
1510 PRINT "BYE-BYE"
1520 END
2000 HOME
2101 PRINT TAB( 12)"SOIL SUPPORT VALUE"
2102 PRINT TAB( 17)"(AASHTO)"
2103 PRINT TAB( 12)"*****"
2104 PRINT
2105 PRINT " SOIL DYNAMIC STATIC AASHTO MODULUS"
2106 PRINT " SUPPORT CBR CBR 3 PT. MR"
2107 PRINT " VALUE PSI"
2108 PRINT
2109 PRINT TAB( 5)"8 ---- 60 --- 78 - 14.5 -- NA"
2110 PRINT TAB( 5)"7 ---- 35 --- 36 - 9.75 -- NA"
2111 PRINT TAB( 5)"6 ---- 17 --- 19 - 6.75 -- 9300"
2112 PRINT TAB( 5)"5 ---- 8 --- 11 - 4.5 -- 6400"
2113 PRINT TAB( 5)"4 ---- 5 --- 6 - 2.5 -- 4400"
2114 PRINT TAB( 5)"3 ---- 3 --- 2.8 - 1.25 -- 3000"
2115 PRINT TAB( 5)"2 ---- 1.5 --- 1.8 - 0.50 -- 2100"
2116 PRINT TAB( 5)"1 ---- 0.5 --- 0.5 - 0.25 -- NA"
2120 PRINT : PRINT : PRINT
2122 PRINT : PRINT
2130 IF C1 = 1 GOTO 2300

```

```

2200 PRINT "(TO CONTINUE LIST, PRESS SPACE BAR)"
2210 POKE - 16368,0:CJ = PEEK ( - 16384)
2215 IF CJ < > 160 GOTO 2210
2300 HOME
2301 PRINT TAB( 12)"SOIL SUPPORT VALUE"
2302 PRINT TAB( 17)"(GA DOT)"
2303 PRINT TAB( 12)"*****"
2304 PRINT
2305 PRINT TAB( 6)"REGION          SOIL SUPPORT VALUE"
2306 PRINT
2307 PRINT TAB( 7)"PIEDMONT          2.5-3.0"
2308 PRINT
2309 PRINT TAB( 7)"COASTAL PLAIN      4.0-5.0"
2310 PRINT
2311 PRINT TAB( 7)"VALLEY & RIDGE      2.5-3.0"
2320 PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT
      : PRINT
2322 IF C1 = 1 GOTO 2945
2325 PRINT "TO CONTINUE, PRESS SPACE BAR"
2330 POKE - 16368,0:CK = PEEK ( - 16384)
2335 IF CK < > 160 GOTO 2330
2900 IF C1 = 1 GOTO 2945
2920 HOME
2925 INPUT "DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)?" :C1
2930 IF C1 = 0 GOTO 2950
2935 L$ = CHR$(4): PRINT L$;"PR#1"
2940 GOTO 2101
2945 PRINT L$;"PR#0"
2950 C1 = 0
2955 RETURN
3000 HOME
3101 PRINT TAB( 4)"TERMINAL SERVICEABILITY INDEX, PT"
3102 PRINT TAB( 16)"(AASHTO)"
3103 PRINT TAB( 4)"*****"
3104 PRINT
3105 PRINT TAB( 4)"CLASSIFICATION          PT"
3106 PRINT
3107 PRINT TAB( 4)"PRIME ROUTES, MAJOR          2.5"
3108 PRINT TAB( 5)"ARTERIALS, EXPRESSWAYS"
3109 PRINT
3110 PRINT TAB( 4)"PRIME SECONDARY ROUTES,      2.25"
3111 PRINT TAB( 5)"IND. & COMM. STREETS"
3112 PRINT
3113 PRINT TAB( 4)"MINOR SECONDARY ROUTES,      2.0"
3114 PRINT TAB( 5)"RESIDENTIAL STREETS,"
3115 PRINT TAB( 5)"PARKING LOTS"
3116 PRINT
3117 PRINT TAB( 4)"FAILURE, DEFINED BY          1.5"
3118 PRINT TAB( 5)"AASHTO"
3200 PRINT : PRINT
3205 PRINT : PRINT

```

```

3207 IF D1 = 1 GOTO 3945
3210 PRINT "TO CONTINUE, PRESS SPACE BAR"
3220 POKE - 16368,0:D1 = PEEK ( - 16384)
3225 IF D1 < > 160 GOTO 3220
3230 HOME
3235 INPUT "DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)?" :D1
3240 IF D1 = 0 GOTO 3950
3935 L$ = CHR$(4): PRINT L$;"PR#1"
3940 GOTO 3101
3945 PRINT L$;"PR#0"
3950 D1 = 0
3955 RETURN
4000 HOME
4101 PRINT TAB( 6)"RECOMMENDED REGIONAL FACTORS"
4102 PRINT TAB( 15)"FOR GEORGIA"
4103 PRINT TAB( 6)"*****"
4104 PRINT
4105 PRINT TAB( 10)"AREA" FACTOR"
4106 PRINT
4107 PRINT TAB( 6)"COASTAL PLAINS" 1.4-1.7"
4108 PRINT TAB( 7)"-SAVANNAH" 1.7"
4109 PRINT
4110 PRINT TAB( 6)"PIEDMONT" 1.5-1.8"
4111 PRINT TAB( 7)"-ATLANTA" 1.8"
4112 PRINT TAB( 7)"-MACON" 1.6"
4113 PRINT TAB( 7)"-COLUMBUS" 1.8"
4114 PRINT TAB( 7)"-AUGUSTA" 1.5"
4115 PRINT
4116 PRINT TAB( 6)"VALLEY & RIDGE" 2.0-2.2"
4400 PRINT : PRINT : PRINT
4410 PRINT : PRINT
4415 IF E1 = 1 GOTO 4945
4420 PRINT "TO CONTINUE, PRESS SPACE BAR"
4430 POKE - 16368,0:E1 = PEEK ( - 16384)
4440 IF E1 < > 160 GOTO 4430
4445 HOME
4450 INPUT "DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)?" :E1
4455 IF E1 = 0 GOTO 4950
4460 L$ = CHR$(4): PRINT L$;"PR#1"
4465 GOTO 4101
4945 PRINT L$;"PR#0"
4950 E1 = 0
4955 RETURN
5000 HOME
5101 PRINT " EQUIVALENT SINGLE AXLE 18-KIP LOADS"
5102 PRINT TAB( 11)"20 YEAR DESIGN LIFE"
5103 PRINT " *****"
5104 PRINT
5105 PRINT " CLASS TYPE PUNT EQUIVALENT"
5106 PRINT TAB( 28)"18-KIP LOAD*"
5107 PRINT " LIGHT PARKING, CITY"
5108 PRINT TAB( 11)"STREET, RURAL 22000-420000"

```

```

5109 PRINT TAB( 11)"ROADS"
5110 PRINT
5111 PRINT " MEDIUM SECONDARY 420000-3000000"
5112 PRINT TAB( 11)"HIGHWAY"
5113 PRINT
5114 PRINT " HEAVY INTERSTATE 3000000-10000000"
5115 PRINT TAB( 11)"HIGHWAY"
5116 PRINT : PRINT
5117 PRINT
5118 PRINT TAB( 6)"* BASED ON 580.7 18-KIP LOADS PER"
5119 PRINT TAB( 7)"1000 TRUCKS"
5120 PRINT : PRINT
5125 IF F1 = 1 GOTO 5945
5130 PRINT "(TO CONTINUE, PRESS SPACE BAR)"
5140 POKE - 16368,0:F1 = PEEK ( - 16384)
5150 IF F1 < > 160 GOTO 5140
5160 HOME
5170 INPUT "DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)? ";F1
5180 IF F1 = 0 GOTO 5950
5190 L$ = CHR$(4): PRINT L$;"PR#1"
5200 GOTO 5101
5945 PRINT L$;"PR#0"
5950 F1 = 0
5955 RETURN
6000 HOME
6101 PRINT TAB( 5)"SELECTED STRUCTURAL COEFFICIENTS"
6102 PRINT TAB( 5)"*****"
6103 PRINT
6104 PRINT " PAVEMENT COMPONENT STR'L COEFF."
6105 PRINT TAB( 22)"FLA GA MD SC"
6106 PRINT " SURFACE COURSE"
6107 PRINT " ASPHALT CONCRETE .2-.4 .44* .44 .44"
6108 PRINT
6109 PRINT " BASE COURSE"
6110 PRINT " ASPHALT CONCRETE .2-.3 .30 .28 .34"
6111 PRINT " SAND-ASPHALT - .12 .28 .25"
6112 PRINT " SOIL-CEMENT .22 .20 .28 .20"
6113 PRINT " GRADED AGGREGATE - .18 .14 .15"
6114 PRINT " CEMENT STABILIZED - .22 .28 .34"
6115 PRINT " GRADED AGGREGATE"
6116 PRINT
6117 PRINT " SUBBASE"
6118 PRINT " GRADED AGGREGATE - .14 - -"
6119 PRINT " TOPSOIL OR SAND- - .10 - -"
6120 PRINT " CLAY"
6122 PRINT TAB( 8)"* MAXIMUM DEPTH OF 4.5 IN."
6200 PRINT
6202 IF G1 = 1 GOTO 6945
6205 PRINT "(TO CONTINUE, PRESS SPACE BAR)"
6210 POKE - 16368,0:G1 = PEEK ( - 16384)
6215 IF G1 < > 160 GOTO 6210

```

```
6220 HOME
6225 INPUT "DO YOU WANT LIST IN HARD COPY (0=NO, 1=YES)?" ;G1
6230 IF G1 = 0 GOTO 6950
6335 L$ = CHR$(4): PRINT L$;"PR#1"
6940 GOTO 6101
6945 PRINT L$;"PR#0"
6950 G1 = 0
6955 RETURN
```

5.6 Variable List (AASHTO 1)

Input

H\$ = Heading
Z = # of trials
TL = Tolerance
SI = Soil support value
PT = Terminal serviceability index
RI = Regional factor
WI = Equivalent 18-kip single axle loads
L = Layer # for calculation
Y = Layer #
A(Y) = Structural coefficient
D(Y) = Layer thickness
N = # of layers
D(L) = Layer thickness

Flow Control

BB = Calculate thickness of E-18's
XX = Calculate thickness of E-18's
YY = Calculate thickness of E-18's
ZZ = Calculate thickness of E-18's
Q1 = Table listing
C1 = Table listing
D1 = Table listing
E1 = Table listing
F1 = Table listing
G1 = Table listing

Counters

H = Run #

I = Layer #

Miscellaneous

X = Structural number + 1

AA = Intermediate equation values

AB = Intermediate equation values

NN = Rounded off structural number

SN = Structural number

SC = Structural number (with N-1 layers)

A(1)-A(5) = Intermediate equation values

B(1)-B(7) = Intermediate equation values

5.7 Program Verification

JRUN

```
*****
* AASHTO *
*****
```

DANA K. EDDY, 578-80-8378
GA. INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL ENGINEERING
DEPARTMENT OF GEOTECHNICAL ENGINEERING

SYSTEM HARDWARE: APPLE II PLUS (64K)
SYSTEM HARDWARE: DOS 3.3, APPLESOFT BASIC LANGUAGE
PROGRAM DATE: JULY, 1983

AASHTO IS BASED ON THE AASHTO INTERIM GUIDE FOR THE DESIGN OF FLEXIBLE PAVEMENT STRUCTURES, 1972.

(PRESS THE SPACE BAR TO CONTINUE)

USER INPUT QUESTIONS AND COMMANDS WHICH ARE FOLLOWED BY (*) ARE SUPPLEMENTED BY LISTS AND TABLES. TO ACCESS THE LIST OR TABLE TYPE (0) INSTEAD OF THE APPROPRIATE VALUE OF THE VARIABLE REQUESTED.

PROBLEM HEADING AN EXAMPLE PROBLEM

TO CALCULATE THE THICKNESS OF A PARTICULAR LAYER, TYPE (1); TO CALCULATE THE MAXIMUM NUMBER OF EQUIVALENT 18-KIP LOADS, TYPE (2). 1

HOW MANY TRIALS DO YOU WANT TO RUN? 1

WHAT IS THE CALCULATION TOLERANCE (REC'D: .01). .01

SOIL SUPPORT VALUE (*) = 0

SOIL SUPPORT VALUE
(AASHO)

SOIL SUPPORT VALUE	DYNAMIC CBR	STATIC CBR	AASHO 3 PT.	MODULUS MR PSI
--------------------------	----------------	---------------	----------------	----------------------

8	60	78	14.5	NA
7	35	38	9.75	NA
6	17	19	6.75	9300
5	8	11	4.5	8400
4	5	6	2.5	4400
3	3	2.8	1.25	3000
2	1.5	1.8	0.50	2100
1	0.5	0.5	0.25	NA

(TO CONTINUE LIST, PRESS SPACE BAR)

SOIL SUPPORT VALUE
(GA DOT)

REGION	SOIL SUPPORT VALUE
--------	--------------------

PIEDMONT	2.5-3.0
----------	---------

COASTAL PLAIN	4.0-5.0
---------------	---------

VALLEY & RIDGE	2.5-3.0
----------------	---------

TO CONTINUE, PRESS SPACE BAR

DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES) 0

SOIL SUPPORT VALUE (*) = 3

AD-A139 271

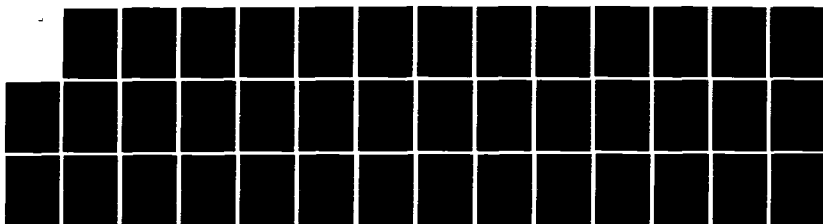
COMPUTER APPLICATIONS TO GEOTECHNICAL ENGINEERING(U)
AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH
D K EDDY AUG 83 AFIT/CI/NR-83-86T

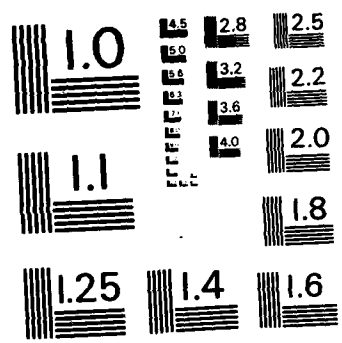
3/3

UNCLASSIFIED

F/G 13/2

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TERMINAL SERVICABILITY INDEX (*) = 0

TERMINAL SERVICEABILITY INDEX, PT
(AASHTO)

CLASSIFICATION	PT
PRIME ROUTES, MAJOR ARTERIALS, EXPRESSWAYS	2.5
PRIME SECONDARY ROUTES, IND. & COMM. STREETS	2.25
MINOR SECONDARY ROUTES, RESIDENTIAL STREETS, PARKING LOTS	2.0
FAILURE, DEFINED BY AASHTO	1.5

TO CONTINUE, PRESS SPACE BAR
DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)? 0
TERMINAL SERVICABILITY INDEX (*) = 2.5

REGIONAL FACTOR (*) = 0

RECOMMENDED REGIONAL FACTORS
FOR GEORGIA

AREA	FACTOR
COASTAL PLAINS	1.4-1.7
-SAVANNAH	1.7
PIEDMONT	1.5-1.8
-ATLANTA	1.8
-MACON	1.6
-COLUMBUS	1.8
-AUGUSTA	1.5
VALLEY & RIDGE	2.0-2.2

TO CONTINUE, PRESS SPACE BAR
 DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)? 0
 REGIONAL FACTOR (*) = 1.5

OF EQUIVALENT SINGLE AXLE 18-KIP WHEEL LOADS (*) = 0

EQUIVALENT SINGLE AXLE 18-KIP LOADS
 20 YEAR DESIGN LIFE

CLASS	TYPE PUMT	EQUIVALENT 18-KIP LOAD*
LIGHT	PARKING, CITY STREET, RURAL ROADS	22000-420000
MEDIUM	SECONDARY HIGHWAY	420000-3000000
HEAVY	INTERSTATE HIGHWAY	3000000-10000000

* BASED ON 500.7 18-KIP LOADS PER
 1000 TRUCKS

(TO CONTINUE, PRESS SPACE BAR)
 DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)? 0
 # OF EQUIVALENT SINGLE AXLE 18-KIP WHEEL LOADS (*) = 8500000

 TRIAL #1

STRUCTURAL NUMBER =5.71

SPECIFY # OF LAYERS (MAX=10). 3

LAYER # FOR THICKNESS CALCULATION. 1

LAYER #. 1

STRUCTURAL COEFFICIENT (*) = 0

SELECTED STRUCTURAL COEFFICIENTS

PAVEMENT COMPONENT	STR'L COEFF.			
	FLA	GA	MD	SC
SURFACE COURSE				
ASPHALT CONCRETE	.2-.4	.44*	.44	.44
BASE COURSE				
ASPHALT CONCRETE	.2-.3	.30	.28	.34
SAND-ASPHALT	-	.12	.28	.25
SOIL-CEMENT	.22	.20	.28	.20
GRADED AGGREGATE	-	.18	.14	.15
CEMENT STABILIZED	-	.22	.28	.34
GRADED AGGREGATE				
SUBBASE				
GRADED AGGREGATE	-	.14	-	-
TOPSOIL OR SAND-	-	.10	-	-
CLAY				

* MAXIMUM DEPTH OF 4.5 IN.

<TO CONTINUE, PRESS SPACE BAR>

DO YOU WANT LIST IN HARD COPY (0=NO, 1=YES)? 0

STRUCTURAL COEFFICIENT (*) = .44

LAYER #. 2

STRUCTURAL COEFFICIENT (*) = .14

LAYER THICKNESS (INCHES) = 12

LAYER #. 3

STRUCTURAL COEFFICIENT (*) = .11

LAYER THICKNESS (INCHES) = 13.5

////////////////////
 AN EXAMPLE PROBLEM
 //////////////////////

TRIAL #1

LAYER	STR'L COEFF.	THICKNESS
1	.44	5.8
2	.14	12
3	.11	13.5

STRUCTURAL NUMBER =5.71999994

EQUIVALENT SINGLE AXLE 18-KIP LOAD =8500000

SOIL SUPPORT VALUE =3

TERMINAL SERVICEABILITY INDEX =2.5

REGIONAL FACTOR =1.5

DO YOU WANT TO RUN ANY MORE TRIALS (0=NO, 1=YES)? 1

FOR A LAYER THICKNESS CALCULATION, TYPE(1); FOR AN 18-KIP LOADING CALCULATION, TYPE(2). 2

HOW MANY TRIALS DO YOU WANT TO RUN? 1

SOIL SUPPORT VALUE (*) = 3

TERMINAL SERVICEABILITY INDEX (*) = 2.5

REGIONAL FACTOR (*) = 1.5

/////////
TRIAL #1
/////////

SPECIFY # OF LAYERS (MAX=10) 3

LAYER # =1

STRUCTURAL COEFFICIENT (*) =.44

LAYER THICKNESS (INCHES) = 5.8

LAYER # =2

STRUCTURAL COEFFICIENT (*) =.14

LAYER THICKNESS (INCHES) = 12

LAYER # =3

STRUCTURAL COEFFICIENT (*) =.11

LAYER THICKNESS (INCHES) = 13.5

////////////////////////////////////
AN EXAMPLE PROBLEM
////////////////////////////////////

TRIAL #1

LAYER	STR'L COEFF.	THICKNESS
1	.44	5.8
2	.14	12
3	.11	13.5

STRUCTURAL NUMBER =5.717

EQUIVALENT SINGLE AXLE 18-KIP LOADS =8421531

SOIL SUPPORT VALUE =3

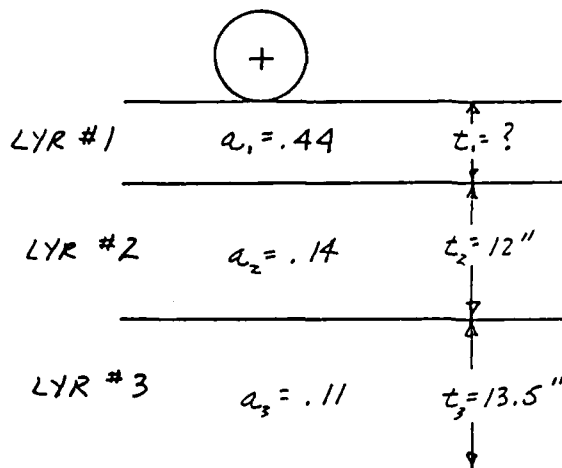
TERMINAL SERVICEABILITY INDEX =2.5

REGIONAL FACTOR =1.5

DO YOU WANT TO RUN ANY MORE TRIALS (0=NO, 1=YES)? 0

THANK YOU FOR USING AASHTO

BYE-BYE



SOIL SUPPORT VALUE = 3 (S_L)

TERMINAL SERVICEABILITY INDEX = 2.5 (P_t)

REGIONAL FACTOR = 1.5 (R)

$E-183 = 8,500,000$ (W_t)

$$\log W_t = 9.36 \log (SN+1) - .2 + \frac{G_t}{.4 + \frac{1094}{(SN+1)^{5.19}}} + \log \frac{1}{2}$$

$$+ .372 (S_L - 3.0)$$

$$G_t = \log \left(\frac{4.2 - P_t}{2.7} \right)$$

TRY SN = 5.0

$$\begin{aligned}\log(W_t) &= 9.36 \log(5+1) - .2 + \frac{\log\left(\frac{4.2-2.5}{2.7}\right)}{.4 + \frac{1094}{(5+1)^{5.19}}} \\ &\quad + \log \frac{1}{1.5} + .372(3 - 3.0) \\ &= 16.77 - .2 + \frac{-.46}{.500095} + (-.405) + 0 \\ &= 15.245\end{aligned}$$

$$W_t = 4,177,296 \quad (E-18\%)$$

TRY SN = 7.0

$$\begin{aligned}\log(W_t) &= 9.36 \log(7+1) - .2 + \frac{\log\left(\frac{4.2-2.5}{2.7}\right)}{.4 + \frac{1094}{(7+1)^{5.19}}} \\ &\quad + \log \frac{1}{1.5} + .372(3 - 3.0) \\ &= 19.46 - .2 + \frac{-.46}{.4225} - .405 \\ &= 17.766\end{aligned}$$

$$W_t = 51,971,997 \quad (E-18\%)$$

TRY SN = 6.0

$$\log(W_t) = 9.36(6+1) - .2 + \frac{-.46}{.4 + \frac{1094}{(6+1)^{5.19}}} - .405$$

$$= 18.21 - .2 - 1.034 - .405$$

$$= 16.571$$

$$W_t = 15,732,371 \quad (E-18s)$$

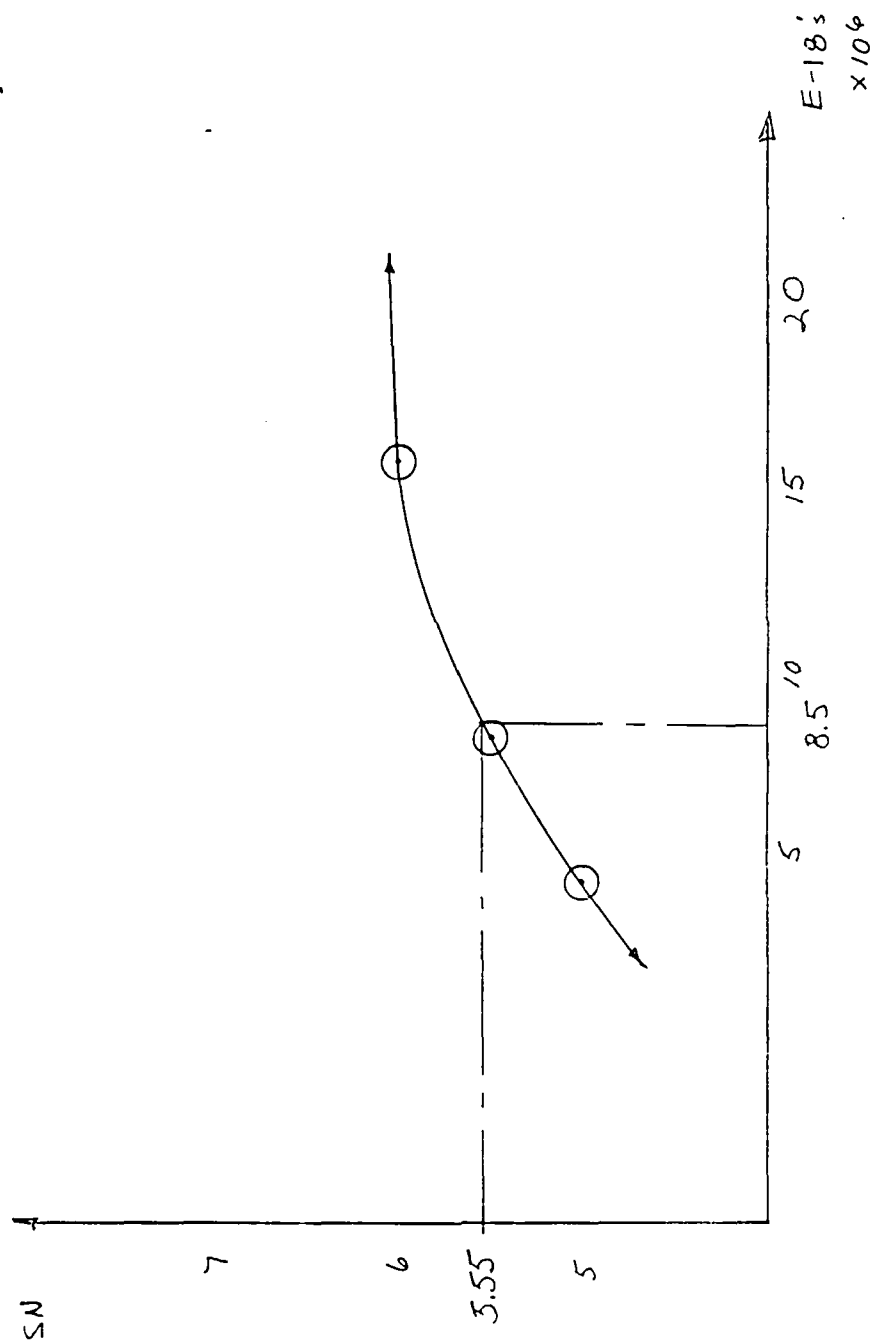
TRY SN = 5.5

$$\log(W_t) = 9.36 \log(5.5+1) - .2 + \frac{-.46}{.4 + \frac{1094}{(5.5+1)^{5.19}}} - .405$$

$$= 17.52 - .2 + -.992 - .405$$

$$= 15.922$$

$$W_t = 8,219,300 \quad (E-18s)$$



$$SN (HAND) = 5.55$$

$$SN (COMPUTER) = 5.72$$

* NOTE: DEVIATION DUE TO SIGNIFICANT FIGURES

$$SN = a_1(t_1) + a_2(t_2) + a_3(t_3)$$

$$t_1 = [SN - a_2(t_2) - a_3(t_3)] / a_1$$

$$= [5.55 - .14(12) - .11(13.5)] / .44$$

$$= 5.42" \quad (HAND \ SN) \quad \checkmark$$

$$t_1 = [5.72 - .14(12) - .11(13.5)] / .44$$

$$= 5.81" \quad (COMPUTER \ SN) \quad \checkmark$$

SECOND VERIFICATION PERFORMED BY
PROGRAM. USING CALCULATED THICKNESS,
CALCULATE E-18's.

INPUT	VS.	CALCULATED
8,500,000		8,421,531

5.8 Flexible Pavement Structure Design for Georgia

The following document details the requirements set forth by the Georgia Department of Transportation to divisional offices for the design of flexible pavements.

Flexible Pavement Structure Design for Georgia

Office of Road and Airport Design

Georgia Department of Transportation

District Design Personnel Conference

February 23, 1983

Table of ContentsPage No.

1	Pavement Structure Design Committee
1	Design Methods
2, 3	Procedure for Field Districts
4, 5	Instructions for AASHTO Interim Guides and Ultimate Strength
6	Sample Forms
7	Lane Distribution Factors
8	18^k Single Axle Equivalent Load Factors
9	Regional Factors
10, 11	Nomographs
12	Structure Layer Coefficient of Relative Strength
13, 14	Sample AASHTO Design Problem
15	Instructions for Ultimate Strength
16, 17	Ultimate Strength Design Charts
18-20	Ultimate Strength Sample Design Problem

Instructions for Using AASHTO Interim Guides for Pavement Structure Design
in Georgia - Blank form on page number 6

1. Project Number
2. County
3. Description: Describe the project giving length, termini, number of lanes, new or existing location, widening and resurfacing, overlay, or any other significant information.
4. Type of Adjoining Pavement: Metal surface, bituminous surface treatment, asphaltic concrete, or P.C. concrete.
5. Traffic Data: Derive the mean traffic in VPD for one direction during the design period. The design period for Interstate and Primary projects is 20 years and for Secondary and other projects the design period is 15 years.
6. Design Loading: Distribute the mean AADT for one direction into the highest design lane traffic with a division between trucks and other vehicles. Use a truck classification of multiple units and single units if available. Use estimated lane distribution factors if the project is a multi-lane facility (page 7).

Multiply the number of vehicles in each vehicle classification by an appropriate 18 kip single axle equivalent load (18^k S.A.E.L.) factor (page 8). The load factors may be derived as required for specific cases; i.e., a road leading to a pulpwood yard or a quarry.

Sum the daily 18^k S.A.E.L. and multiply by the number of days in the design period to derive the total design period loading.

7. Design Data: Set the design terminal serviceability (P_t) at 2.5 for Class III or higher projects and 2.0 for Class IV or less projects. The soil support value is furnished in the soil survey but if a soil survey is not conducted the soil support value may be estimated in conjunction with the district soils engineer and the soil laboratory at Forest Park. The regional factor is also given in the soil survey but may be estimated from the attached chart if a soil survey is not conducted.
8. Recommended Flexible Pavement Structure: Enter the respective monograph for terminal serviceability of 2.0 or 2.5 with the soil support value, 18^k single axle equivalent loads and the regional factor to find the required weighted structural number of the pavement structure to be designed. This weighted structural number is then matched by a design structural number which satisfies the equation $SN = a_1 d_1 + a_2 d_2 + a_3 d_3 + a_n d_n$ where a = structure layer coefficient and d = depth of each respective layer in inches. Engineering judgment and knowledge of local materials must be used to set depths and types of materials in the pavement structure; the district construction engineer, district materials engineer, or the state bituminous construction engineer should be consulted if required.

COMMITTEE ON ROADWAY PAVEMENT STRUCTURES

PROCEDURE FOR ESTABLISHING PAVEMENT STRUCTURE DESIGNS
FOR SECONDARY PROJECTS, AUTHORITY PROJECTS AND COUNTY CONTRACT PROJECTS

I. Secondary Projects

The procedure for making, processing, and reviewing these designs shall be as follows:

A. Projects Designed in District Offices

1. The Designs will generally be made for the District Engineer by his Design personnel in cooperation with the Assistant District Engineer, Pre-Construction and the District Materials Engineer.
2. The District Engineer shall transmit this design to the State Road and Airport Design Engineer listing the thickness and materials to be used in each layer of the pavement structure down through the subgrade stabilizer aggregate or select material, if these are required. The District Engineer shall also include information as to the availability of local materials used in the design, and the availability of alternate materials. This submission shall be made as early as possible in the plan development process.
3. The State Road and Airport Design Engineer shall check the design, reconcile any differences of opinion with the District Engineer and the State Materials and Research Engineer, and if the roadway is Class I or II, he shall submit the design to the Committee. If lower than Class II, the design need not be submitted to the Committee if concurred in by the State Road and Airport Design Engineer and the State Materials and Research Engineer.

4. After consideration by the Committee, the State Road and Airport Design Engineer shall inform the District Engineer that either the design is approved or that the Committee desires specific changes in the design, and that the approved or modified design may be used for the project plans.
5. If the District Engineer wishes to question modifications made by the Committee, he may do so through the State Road and Airport Design Engineer.

B. Projects Designed in the General Office

1. These designs shall be prepared in accord with policies of the Committee.
2. If these roadways are Class I or Class II, they shall be submitted to the Committee in regular manner.
3. If the roadway is lower than Class II, the design need not be submitted to the Committee if concurred in by the State Urban and Multi-Modal Design Engineer or the State Road and Airport Design Engineer (whichever has responsibility for the plans) and the State Materials and Research Engineer.

II. Authority Projects

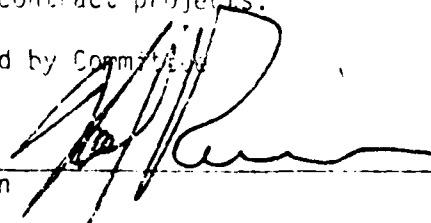
- A. When requested by the Director of Operations, the Committee will review and make recommendations concerning Authority Projects.

III. County Contract Projects

- A. When requested by the Director of Operations, the Committee will review and make recommendations concerning county contract projects.

Approved by Committee

Chairman



PAVEMENT STRUCTURE DESIGN COMMITTEE

1. Consists of:

State Highway Engineer - Chairman

State Materials and Research Engineer - Secretary

Director of Operations

Director of Pre-Construction

Director of Construction and
State Construction Engineer

State Road and Airport Design Engineer

State Urban and Multi-Modal Design Engineer

State Maintenance Engineer

Project Review Engineer

FHWA Representative

2. Reviews: All projects over 1000 VPD (future traffic) and any others requested.

3. Design Methods Approved:

(A) Flexible Pavement

(a) over 1000 VPD - AASHO Interim Guide

(b) under 1000 VPD - generally use ultimate strength

(B) Rigid Pavement AASHO Interim Guide

(C) Overlay

(1) Flexible over flexible

(a) AASHO structural coefficients assigned

(2) Flexible over rigid

(a) AASHO structural coefficients assigned

(b) Corps of Engineers

(c) layered elastic theory

(3) Rigid over flexible - AASHO Interim Guide

(4) Rigid over rigid

(a) Corps of Engineers

(b) AASHO Interim Guide

The percent over-under design should be computed by dividing the difference between the weighted structural number and the total SN and dividing by the weighted structural number. The percent over-under design should be limited to about fifteen percent.

Any additional pertinent information should be entered under "remarks". The submission of the form should follow T. D. Moreland's instructions of January 6, 1970.

(Based on AASHO Interim Guide for the Design of Flexible Pavement Structures)

Project: _____ County: _____

Description: _____

_____Type of Adjoining Pavement: _____ Beginning of Project: _____
End of Project: _____Traffic Data: 24 Hr. Truck Percentage _____
AADT Beginning of Design Period _____ VPD _____ Year _____
AADT End of Design Period _____ VPD _____ Year _____
Mean AADT (One Way) _____ VPD _____

Design Loading:

Design Lane Traffic

18^k Axle
Eq. Load

_____	x	_____	=	_____
_____	x	_____	=	_____
_____	x	_____	=	_____

Total Daily Loading = _____

Total Design Period Loading = _____

Design Data: Serviceability (P_t) _____

(From Soil Survey) Soil Support Value (S) _____ Regional Factor (R) _____

Recommended Flexible Pavement Structure:

Type of Material	Thickness	Coefficient	SN

Weighted Structural Value (SN) (From Nomograph) = _____ Total SN = _____

Actual Design Life (Years) _____ Percent Over-Under Design _____

Remarks: _____

Prepared By: _____ Date _____

Submitted By: _____ Date _____

Recommended _____ District Pre-Construction Engineer _____ Date _____

Approved _____ State Road Design Engineer _____ Date _____

Approved _____ Chairman, Committee on Roadway Pavement Structures _____ Date _____

Approved _____ Commissioner _____ Date _____

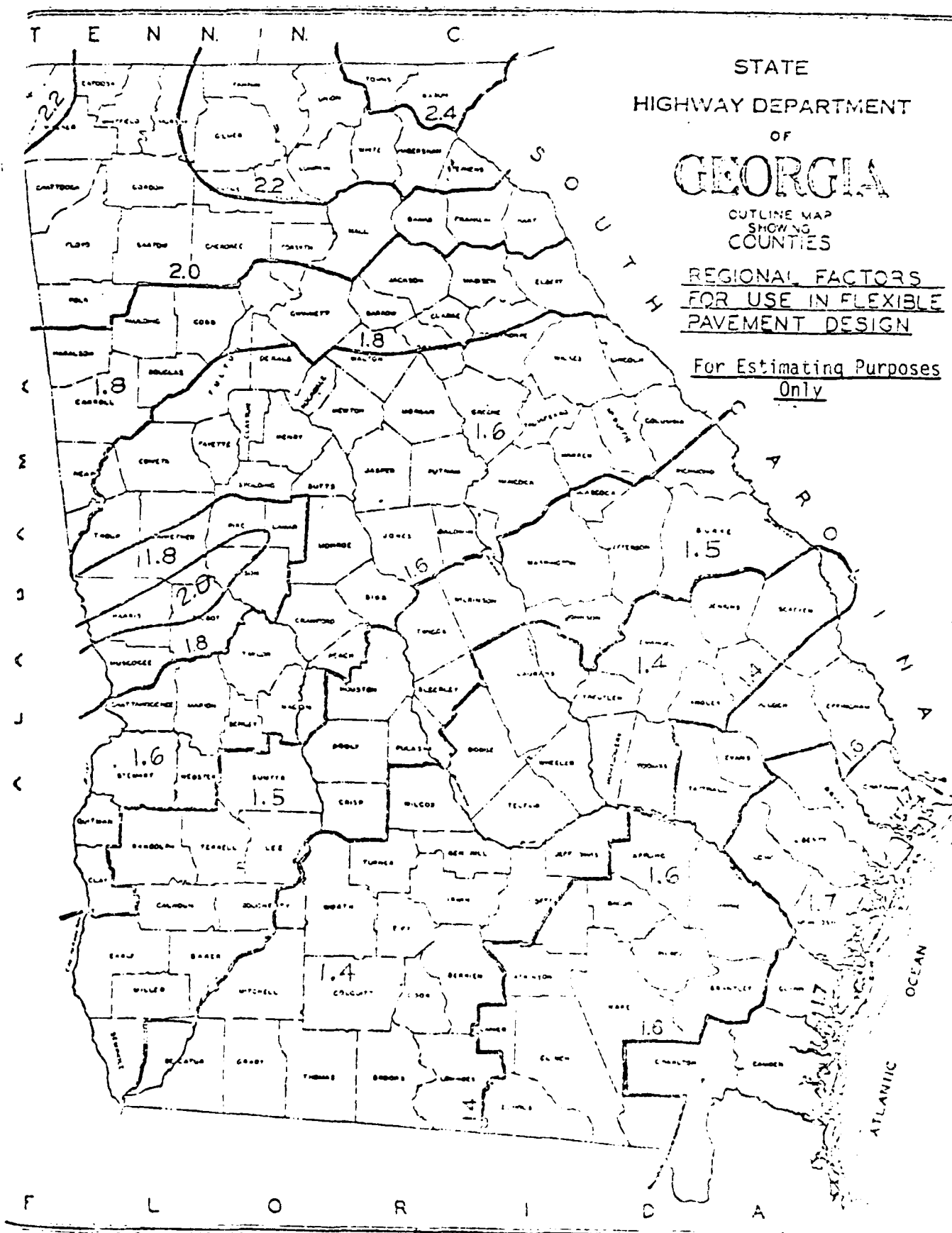
Table 4. Lane Distribution Factors.

FACILITY	Design Lane Distribution Factors - percent of One Way Trucks in the Heaviest Lane	
	Trucks	Other Vehicles
Four lane rural freeway	85-100	50-80
Four lane urban freeway	60-80	50-60
Six lane rural freeway	70	40-60
Six lane urban freeway	60	40-50
Four lane rural highway-free access	70-100	50-80
Four lane urban free access	60-80	50-60
Two lane highways and ramps	100	100

18^k Single Axle Equivalent Loads for Flexible Pavement

	Average 18 ^k S.A.E.L.
All Multiple Unit Trucks	1.4
5 Axle M.U. Trucks Only	1.7
4 Axle M.U. Trucks Only	1.1
3 Axle M.U. Trucks Only	0.9
All Single Unit Trucks	0.4
3 Axle S.U. Trucks Only	0.9
2 Axle S.U. Trucks Only	0.2

Facility	% M.U. Trucks	% S.U. Trucks	Average 18 ^k S.A.E.L. Flexible Pavement
Interstate Routes	100	0	1.4
	90	10	1.3
	80	20	1.2
Primary System Heavy State Routes	70	30	1.1
	60	40	1.0
	50	50	0.9
Medium State Routes	40	60	0.8
	30	70	0.7
	20	80	0.6
Light State Routes, Secondary System, City Streets	10	90	0.5
	0	100	0.4



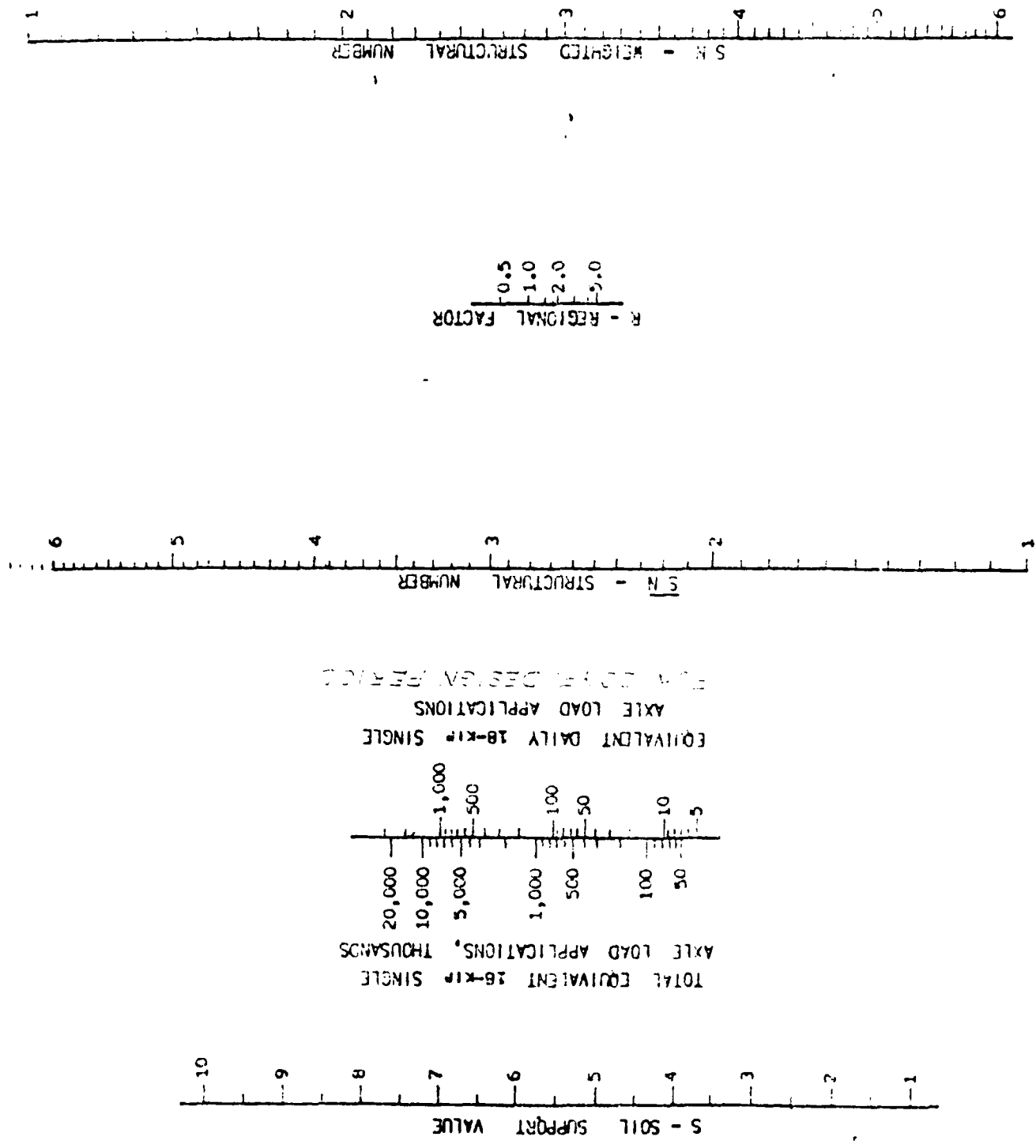


Figure 11-1 Design Chart for Flexible Pavements, $p_t = 2.5$

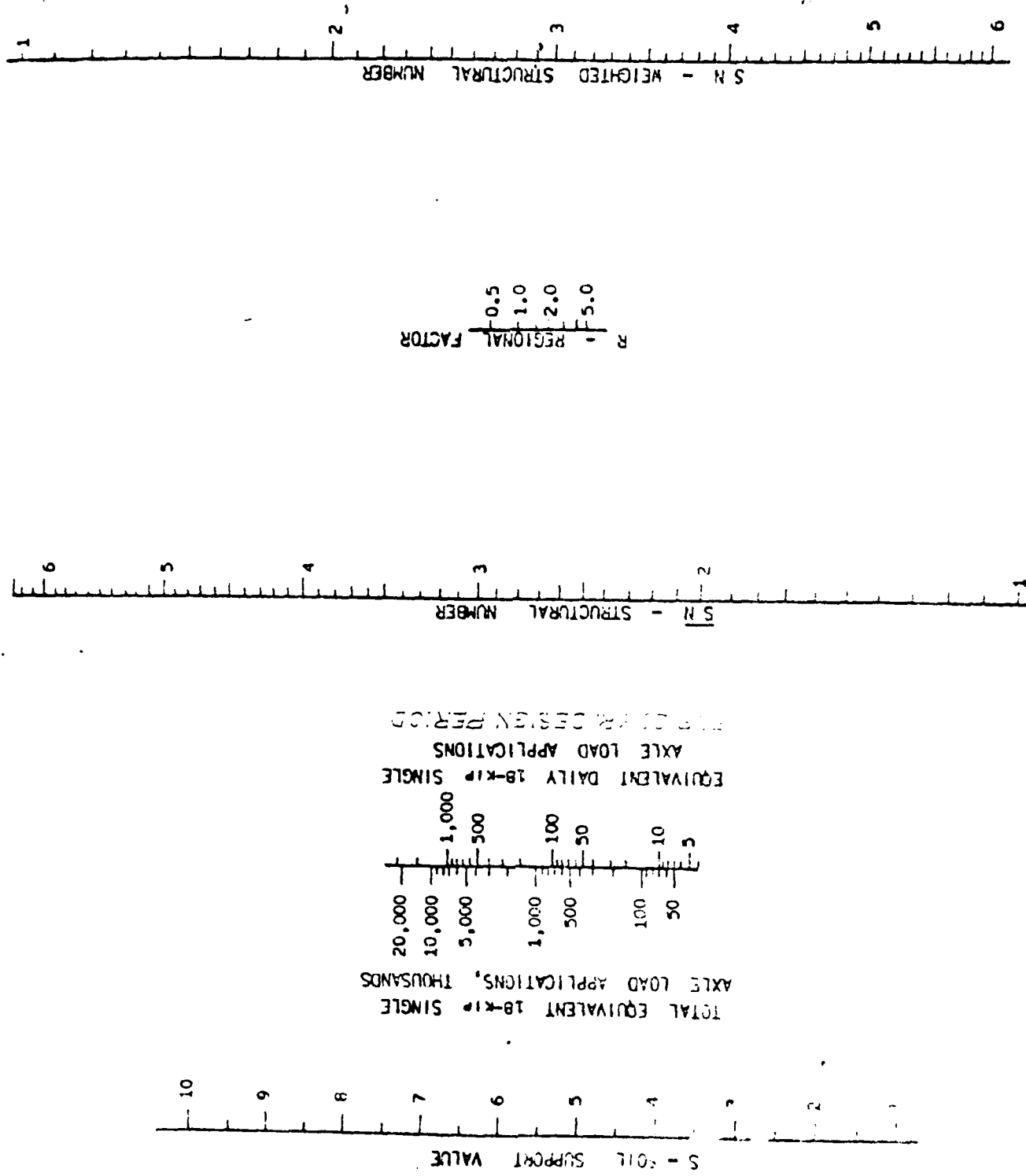


Figure 11-2 Design Chart for Flexible Pavements

STRUCTURAL COEFFICIENTS FOR
PAVEMENT DESIGN

APPLICABLE DEPTH BELOW
SURFACE, INCHES

I. <u>Surface Course</u> ¹	Coef. Per Inch	0-4½
Asphaltic Concrete Surfacing and Binder	0.44	
II. <u>Base Courses</u>		4½-12
Asphaltic Concrete	0.30	
Graded Aggregate and Crushed Limestone (Compacted to modified density)	0.18	
Graded Aggregate and Crushed Limestone (Compacted to standard density)	0.14	
Topsoil or Sand Clay Bases	0.10	
Topsoil or Sand Clay (stabilized with (150 lbs./sq. yd. x 6" stabilizer aggregate)	0.12	
Cement Stabilized Graded Aggregate	0.22	
Soil-Cement	0.20	
Sand Bituminous	0.12	
III. <u>Subbase Courses</u>		Below 12
Graded Aggregate or Crushed Limestone	0.14	
Topsoil or Sand Clay	0.10	
Sandy Gravel (Float material which fails graded aggregate)	0.11	
Crushed Aggregate Subbase	0.10	
IV. <u>Subgrade Courses</u>		
Class I Soil	0.05	
Class II Soil	0.02	

FLEXIBLE PAVEMENT DESIGN ANALYSIS

207

(Based on AASHO Interim Guide for the Design of Flexible Pavement Structures)

Project: _____ **County:** _____

Description: Two lane, from ~~~~~ to ~~~~~, new location, length = 5.0 miles.

Type of Adjoining Pavement: _____ **Beginning of Project:** asphaltic concrete
End of Project: asphaltic concrete

Traffic Data: 24 Hr. Truck Percentage 10%
 AADT Beginning of Design Period 400 VPD 1975 Year
 AADT End of Design Period 900 VPD 1990 Year
 Mean AADT (One Way) $(400+900) \times \frac{1}{2} \times \frac{1}{2} = 325$ VPD

Design Loading:

18^k Axle
Eq. Load

Design Lane Traffic

325 VPD x 10% Trucks x 100% Lane Dist. = 33 Trucks x 0.4 = 13

325 VPD x 90% Other veh. x 100% L.D. = 293 o.v. x 0.003 = 1

Total Daily Loading = 14

Total Design Period Loading = 14 x 365 x 15 years = 76650

Design Data: Serviceability (P_t) 2.0

(From Soil Survey) Soil Support Value (S) 3.0 Regional Factor (R) 1.8

Recommended Flexible Pavement Structure:

Type of Material	Thickness	Coefficient	SN
Asphaltic Concrete E	1"	0.44	0.66
Asphaltic Concrete A or B	2"	0.44	0.88
Graded Aggregate	6"	0.18	1.08

Weighted Structural Value (SN) (From Nomograph) = 2.8 Total SN = 2.62

Actual Design Life (Years) 11 Percent Over-Under Design $\frac{18}{2.8} = 6$

Remarks:

Prepared By _____

Recommended _____

Approved _____

Approved _____

State Road Design Engineer

Chairman, Committee on Roadway Pavement Structures

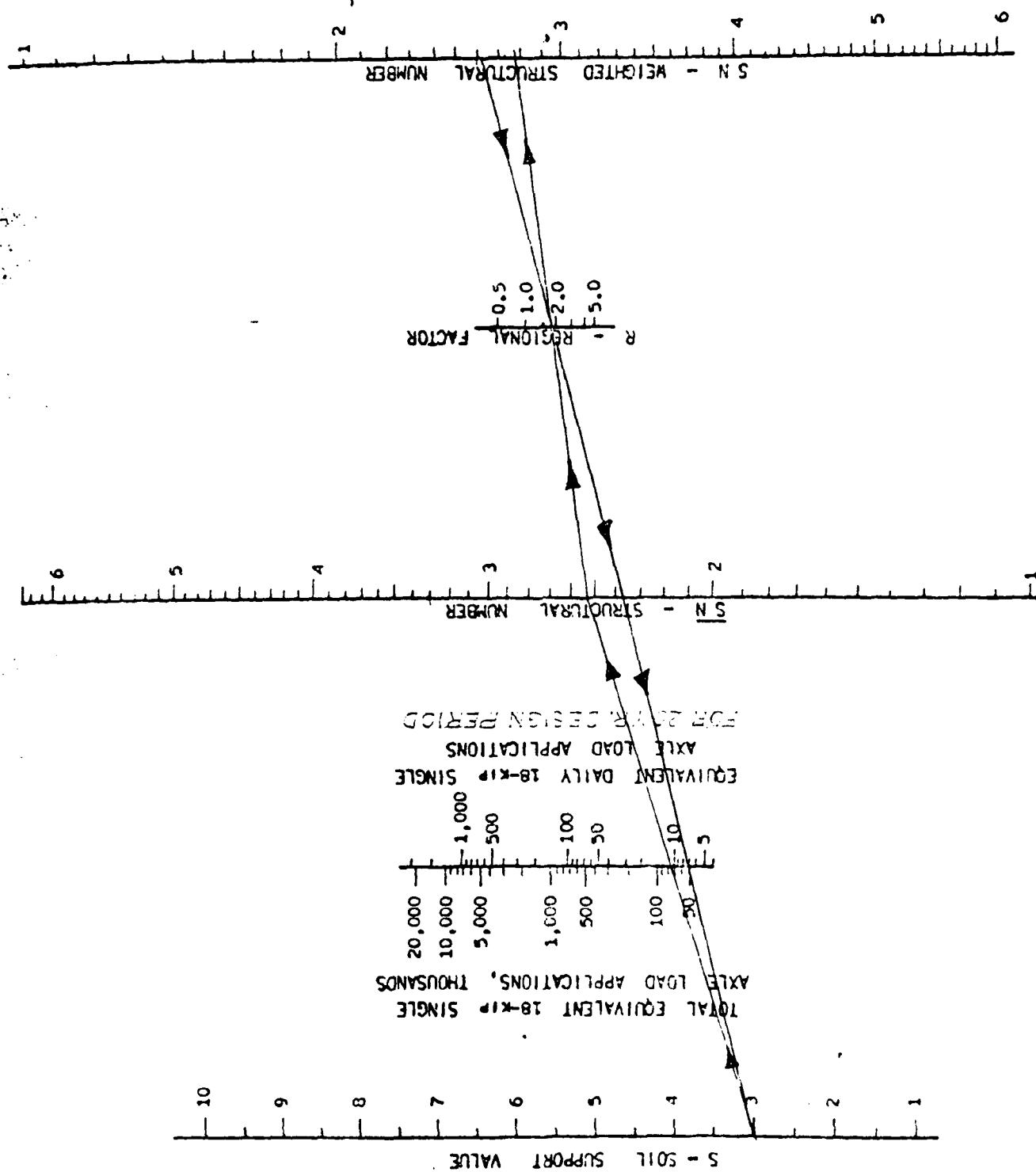


Figure II-2 Design Chart for Flexible Pavements, $p = 2.0$

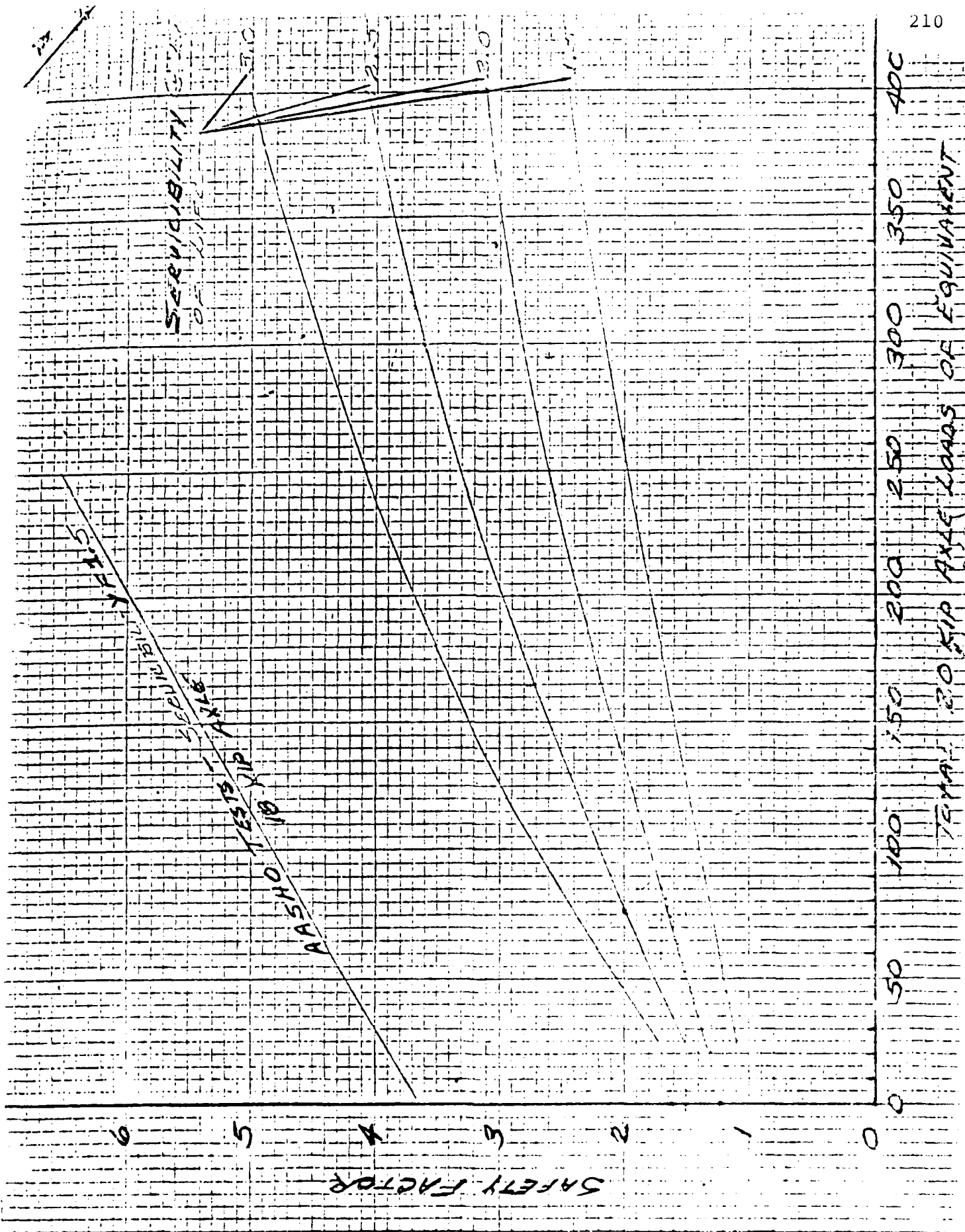
Instructions For Using Ultimate Strength Pavement Structure Design In Georgia

Personnel other than those assigned to the Materials and Testing Laboratory are not authorized to design pavement structures using ultimate strength methods. Ultimate strength is used when a thinner pavement section is obtained than using the AASHTO Interim Guides. This normally occurs at below 1000 VPD with 10% trucks.

The method is based on using a design criteria of preventing shear failure by limiting the imposed vertical stress on the subgrade to a safe limit below the bearing capacity of the subgrade.

The steps in design area as follows:

- 1) Determine total loading.
- 2) Obtain bearing capacity from the soils laboratory.
- 3) Determine the safety factor from page 19 .
- 4) Compute the safe bearing capacity = $\frac{\text{bearing capacity}}{\text{safety factor}}$.
- 5) Find total pavement thickness from page 20 .
- 6) Use engineering judgment and experience to set surface courses.



10 KIP, DUAL-
STABILIZED
CURVE
 $E/E_2 = 10$

NON-STABILIZED
10 KIP, DUAL-
BOUSSINESQ

BASE

BASE

Ultimate Strength Sample Problem

1. Total Loading - Assume same as page 13

Total Loading = 76,650 18^k S.A.E.L.

2. From soil survey - bearing capacity of subgrade soil = 31 psi

3. Set design terminal serviceability = 2.0

4. From page 19 - safety factor = 1.6

5. Allowable subgrade bearing capacity

= bearing capacity of subgrade soil $\div$ safety factor = 31 psi $\div$ 1.6 = 19 psi

6. From page 20 - a) depth required for stabilized base = 7 $\frac{1}{2}$ inches

use minimum design

1 $\frac{1}{2}$ " asphaltic concrete E

2" asphaltic concrete A or B

6" cement stabilized base

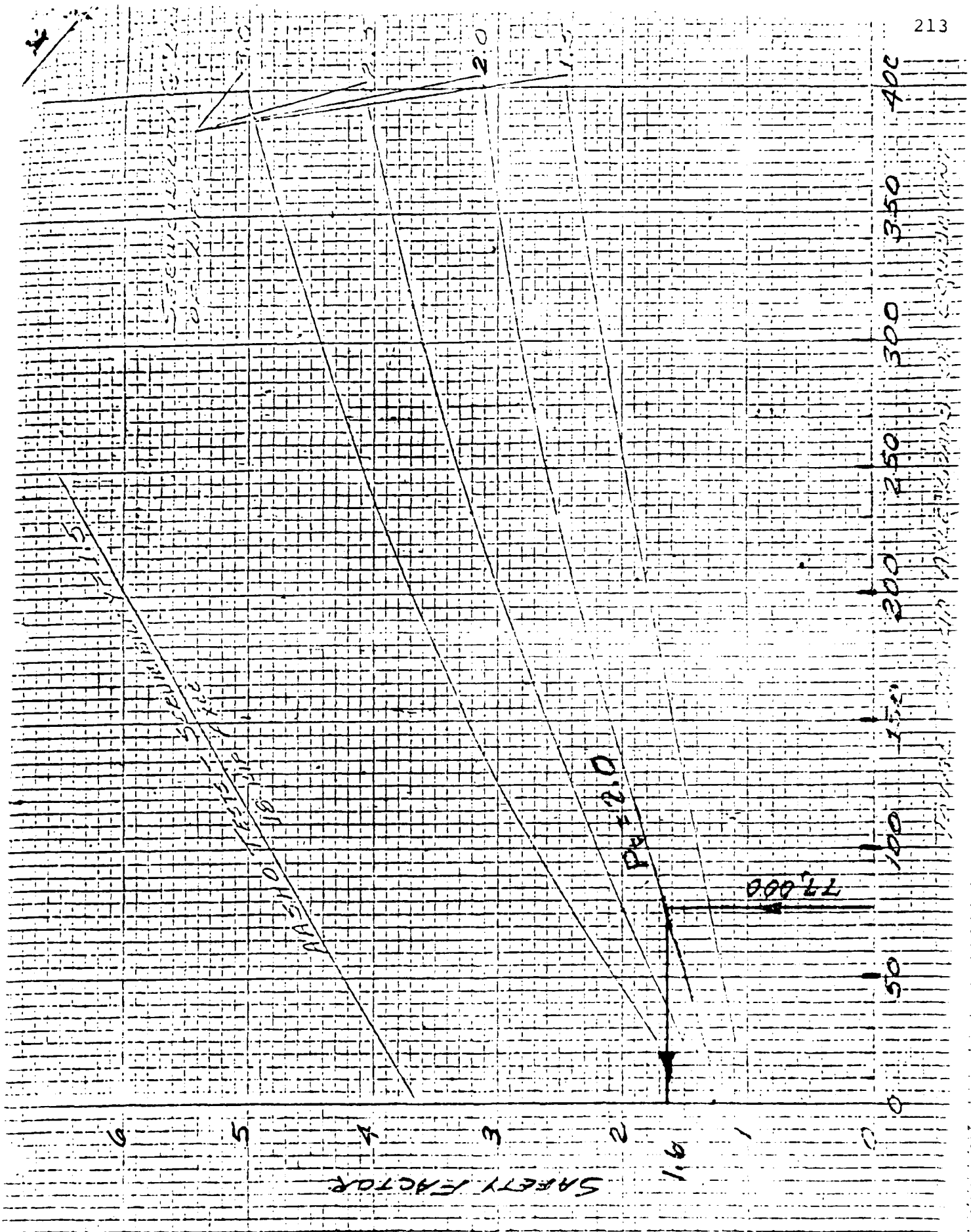
- b) depth required for non-stabilized base = 13 $\frac{1}{2}$ inches

use 1 $\frac{1}{2}$ " asphaltic concrete E

2" asphaltic concrete A or B

10" graded aggregate

- c) cement treated base with thin surfacing acceptable



5.9 References

1. AASHTO, "AASHTO Interim Guide for Design of Pavement Structures - 1972," Washington, D.C., 1972.
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5. Dixon, J. C., Knutson, M. J., and Riley, R. C., "Design of Pavements Using the AASHTO Design System," American Concrete Pavement Association, 1982.
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CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 Scope

6.1.1 General

This report presents four programs designed to solve specific engineering problems. The report organization is based on the theme of a service that would be provided an engineering client acquiring engineering software. Each program is supported with background theory, programming rationale, and a user's guide; additionally, a program list, example problems, and hand verified solutions have been included.

The programs include the solution of the embedded post subject to lateral loads above grade (SIGNPOST 1), the solution of the cantilevered sheet pile wall (CANTWALL 1), the limit equilibrium analysis of slope stability by the Bishop method (BISHOP 1), and the design of flexible pavement based on the AASHTO Interim Guide, 1972 (AASHTO 1).

6.1.2 Hardware

Programming was performed on an Apple II-Plus personal computer with 64K storage. The programming language was Applesoft Basic operating on DOS 3.3. The programs were

stored on 5¼" disks. Peripheral equipment included two disk drives, a green screen monitor, and a thermal printer.

6.2 Personal Computers in Engineering Practice

Personal computers (PC) have become quite economical and extremely popular in the last five years. Businesses of all types rely upon PC's for processing routine data, storage and retrieval, word processing, cost accounting, and repetitive problem solving.

When General Electric introduced the first main frame computer (MACH I) in the early 1950's, computation speed was approximately three calculations per second. MACH I required 1500 ft² of floor space, a considerable air conditioning system, and constant maintenance replacing vacuum tubes. Today's PC requires six square feet of desk space, standard environmental controls, and a minimal maintenance program. Computation speeds range up to hundreds of calculations per second. Although technological advances have drastically increased the speed of main frame computing facilities, the size remains a physical constraint. Many businesses rely upon hard wire connections through telephone lines to utilize main frame computers. Costs include installation and maintenance fees as well as charges assessed on compilation and computing time.

A construction cost estimating service provided by McGraw-Hill Information Systems charges \$300 to compile

a "quantity take off" for an average 20,000 ft², one floor office building. The cost of "time sharing" main frame computing facilities can be large and subsequently prohibitive for small businesses.

The principal advantage of the PC over main frame time sharing is its easy access and low relative cost. For accounting purposes, the purchase of a PC and software represent a one-time fixed cost. With exception of maintenance costs, the value of a PC is amortized through depreciation.

The absence of variable costs directly influence the cost of a service; consequently, bid prices or negotiated costs can be lower. Lower service costs directly influence the volume of services provided. Firms which utilize personal computers can maintain a sharp competitive edge.

As a result of increased personal computer use, the demand for software has become enormous. In response to this demand, hundreds of small software service companies have been formed. This is particularly evidenced by the advertisements in trade magazines and professional publications for software services. At this time, the demand appears to be almost limitless.

Many firms have been disappointed with the services provided when purchasing software packages. Although the actual programs are delivered as promised, the supporting documentation has left the user deserted and basically helpless. It is with this in mind that the author chose the

organization and theme of this report. The bulk of this text is devoted to educating the user about the programs use and limitations.

6.3 Program Applications

This section presents some classic applications for which the programs are best suited. Iteration of the background theory is avoided as each program is supported within its respective chapter. Typical applications of each Program are as follows:

6.3.1 SIGNPOST 1

- a) Highway signs and markers subjected to wind loads
- b) Pole-type buildings which resist wind loads through embedded post columns
- c) Commercial signs and billboards subjected to wind loads
- d) Utility poles (power and telephone) subjected to cable loads, guy wire loads, and wind loads

6.3.2 CANTWALL 1

- a) Shallow excavation (<15'-20') when surface deflections are tolerable
- b) Marine applications

6.3.3 BISHOP 1

- a) Earth dams
- b) Highway cuts and fills
- c) Slopes near or under structures
- d) Any slope whose failure can be approximated by a circular failure

6.3.4 AASHTO 1

- a) Flexible pavement design
- b) Analysis of existing pavement
- c) Economic feasibility study

6.4 Recommendations for Future Work

The ultimate goal is to produce a program capable of solving a problem given an endless spectrum of varying conditions and parameters. Additionally, a program should be foolproof. Experience proves these goals serve as sound guidance but are impossible to totally achieve. Man-hour and computer memory constraints force programming efforts to be concentrated around specific tasks with definable end goals.

As with any program, the programs presented in this report can be improved. The limitations listed in each chapter can best serve as a basis for improvement.

6.4.1 SIGNPOST 1

The amelioration of this program might include a routine to compare the post diameter to the foundation volume (as a function of the required depth). The volume of a wood pole or of concrete is directly related to cost. The user could make an economic judgment as to the best diameter and depth of a foundation.

6.4.2 CANTWALL 1

This program can be enhanced by providing the ability to specify a surcharge above the upper soil. Soil layering at the option of the user would be desirable. A major improvement would be a routine to calculate the bending moment in the wall considering moment distribution. This could be complemented with a section modulus selection.

6.4.3 BISHOP 1

Enrichment of BISHOP 1 could include a search routine in which the minimum factor of safety is calculated without user intervention. Another improvement would increase the maximum number of points, lines, and soil types the user can specify.

6.4.4 AASHTO 1

AASHTO 1 could be ameliorated by providing two types of economic analysis. The first analysis would contrast the use of alternate construction materials on a unit cost basis such as dollars per square yard of pavement. The second option would provide a life cycle cost analysis.

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