50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NSF/RA-780360	2.	3. Recipient's Accession No. PB291589

4. Title and Subtitle
Program Rassuel - Reliability Analysis of Soil Slopes Under Earthquake Loading

5. Report Date
December 1978

6.

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8. Performing Organization Rept. No.
CE-78-6

9. Performing Organization Name and Address
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10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G) ENV7716185

12. Sponsoring Organization Name and Address
Applied Science and Research Applications (ASRA)
National Science Foundation
1800 G Street, N.W.
Washington, DC 20550

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

RASSUEL is a computer program developed to assess the reliability of soil slopes under earthquake loading. A pseudo-static slope stability analysis is performed. Significant uncertainties in material and seismic parameters are recognized and probabilistic tools are introduced for their description and amelioration. The safety of the slope is measured in terms of its probability of failure (p_f) rather than the customary factor of safety. The numerical values of p_f are obtained through a Monte Carlo simulation of failure. The program can accomodate three types of earthquake source--point source, line source, and area source. Included is a brief description of the program and its capabilities. The various functions and options available in the program are presented in the form of a flow chart. Guidelines for data preparation are given in Appendix A. To illustrate the output provided by the program, the latter was applied in a case study involving the determination of the probability of failure of a given slope during a certain seismic event. The earthquake source was assumed to be a fault (line source) of known geometry and distance from the site of the slope. The program was written for an IBM 3033 computer. Special provisions were made so that it can be easily adjusted for use on CDC hardware. The computer graphics option was written for a PRIME 500 computer. Subroutines required for use of the program as a PRIME 500 computer and for the computer graphics option are listed in Appendix B. Finally, a complete listing of the program is provided in Appendix C.

17. Document Analysis a. Descriptors

Earthquakes	Slopes	Loads (forces)	Computer programs
Soil dynamics	Soil erosion	Monte Carlo method	

b. Identifiers/Open-Ended Terms

PRIME 500 Computer	Earthquake loading
IBM 3033 Computer	Slope stability
RASSUEL computer program	Probability of failure

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21.
NTIS	20. Security Class (This Page)	22. Price A03 - A01

(See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

PROGRAM RASSUEL - RELIABILITY ANALYSIS OF SOIL SLOPES UNDER EARTHQUAKE LOADING

by

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Report No. CE-78-6

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Sponsored by the National Science Foundation (ASRA)
Grant No. ENV77-16185

December 1978

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ACKNOWLEDGEMENT

This is the second in a series of reports on a project under the general title "Reliability Analysis of Soil Slopes during Earthquakes". This study is sponsored by the Earthquake Hazard Mitigation Program of the National Science Foundation (ASRA) under Grant No. ENV77-16185. Dr. Michael Gaus is the program manager of this project of which the present author is the principal investigator.

The author wishes to thank the National Science Foundation for sponsoring this study. The following individuals have assisted in modifying, improving and expanding the initial version of this program: Messrs. R. Dyvik, C. Floess, J. Howland, G. Nadeau and F.P. Tolcser. Their assistance is gratefully acknowledged. Finally, special thanks are extended to Mrs. Betty Alix for typing this report.

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ABSTRACT

RASSUEL is a computer program developed to assess the "Reliability of Soil Slopes under Earthquake Loading". A pseudo-static slope stability analysis is performed. Significant uncertainties in material and seismic parameters are recognized and probabilistic tools are introduced for their description and amelioration. The safety of the slope is measured in terms of its probability of failure (p_f) rather than the customary factor of safety. The numerical values of p_f are obtained through a Monte Carlo simulation of failure. The program can accomodate three types of earthquake source, namely: (a) point source, (b) line source, and (c) area source.

A detailed presentation of the theoretical background of this program can be found in the first report of this series, RPI Report No. CE-78-5. The present document includes a brief description of the program and its capabilities. The various functions and options available in the program are presented in the form of a flow chart. Guidelines for data preparation are given in Appendix A.

Furthermore, to illustrate the output provided by the program, the latter was applied in a case study involving the determination of the probability of failure of a given slope during a certain seismic event. The earthquake source was assumed to be a fault (line source) of known geometry and distance from the site of the slope.

The program was written for an IBM 3033 computer. Special provisions were made so that it can be easily adjusted for use on CDC hardware.

The computer graphics option was written for a PRIME 500 computer. In Appendix B are listed the subroutines that are required for use of the program on a PRIME 500 computer and for the computer graphics option. Finally, a complete listing of the program is given in Appendix C.

1. PROGRAM 'RASSUEL'

1.1 Program Description

RASSUEL is a computer program which provides a reliability analysis of soil slopes under earthquake loading. The safety of the slope is measured in terms of its probability of failure p_f rather than the customary factor of safety. The numerical values of p_f are obtained through a Monte Carlo simulation of failure. A pseudo-static, limiting equilibrium stability analysis is performed. Failure surfaces are assumed to follow a logarithmic spiral of the form (Figure 1)

$$r = r_o e^{-\theta t}$$

where t is the tangent of the ϕ parameter of soil strength,

r_o is the initial radius of the log spiral, and

θ is the angle between r and r_o.

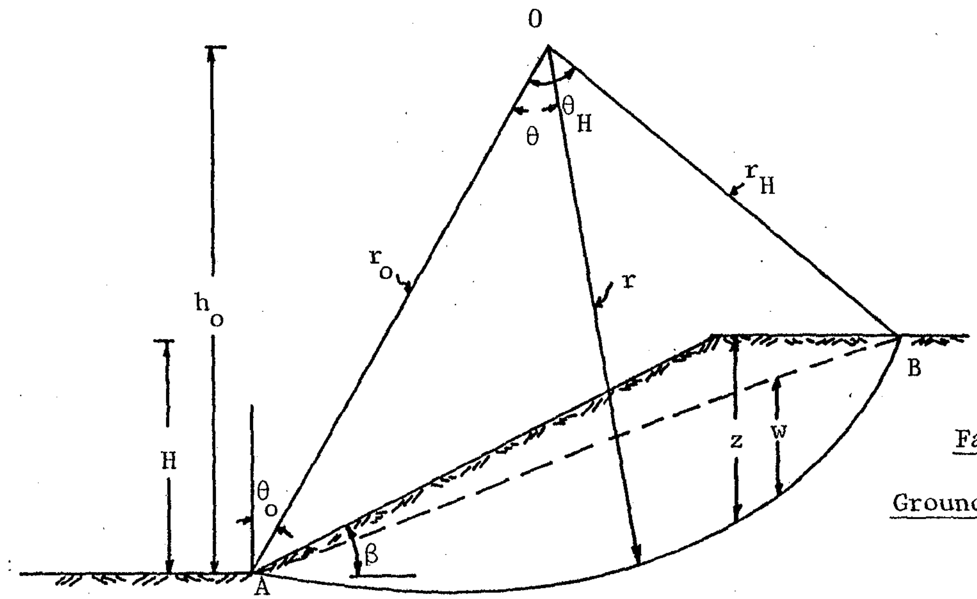
The geometry of the slope is defined in the program by means of its height H and angle β. The location of the water table is specified through the dimensionless pore pressure factor r_u defined as

$$r_u = \frac{u}{\gamma_m z}$$

where u is the pore pressure at the failure surface,

γ_m is the moist unit weight of the soil, and

z is the vertical distance from the failure surface to the boundary of the slope.



Failure Surface: $r = r_o e^{-\theta t}$

Ground Water Table: $w = r_u \cdot \frac{\gamma_m}{\gamma_w} \cdot z$

FIGURE 1. GEOMETRY OF SOIL SLOPE AND POTENTIAL FAILURE SURFACE

Soil strength is introduced through the two strength parameters, c and ϕ. Both c and ϕ are assumed to be independent random variables following a general beta distribution. This is expressed in the form

$$f(x) = c\ (x-a)^{\alpha}\ (b-x)^{\beta} \tag{1}$$

where α and β are the parameters of the beta distribution,

a and b are the minimum and maximum values of the strength parameters, respectively, and

c is a normalizing constant and is equal to

$$c = \frac{\Gamma(\alpha+\beta+2)}{\Gamma(\alpha+1)\Gamma(\beta+1)(b-a)^{\alpha+\beta+1}}$$

where

$\Gamma(\ )$ denotes the gamma function.

The center of the failure surface is defined through its polar coordinates h_o and θ_o (Figure 1). Both h_o and θ_o are also assumed to be random variables following a beta distribution. The limits and statistical values of h_o and θ_o can be specified by the user. If a zero (0) is read for the mean values of h_o and θ_o, the distributions of the two geometric parameters are taken to be symmetric within the following limits:

$$0 \leq h_o \leq 3H$$

$$\beta' - \frac{\pi}{3} \leq \theta_o \leq \beta' \tag{2}$$

where $\beta' = \frac{\pi}{2} - \beta$, and

H and β are the height and angle of the slope, respectively.

In such a case, the coefficient of variation of both h_o and θ_o is assumed to have a value equal to 35%.

The seismic load on a soil slope is expressed in terms of the maximum ground acceleration a_{max} assumed to be a (random) function of the earthquake magnitude. Three types of earthquake source can be examined by the program, namely: (a) point source (which models a known single earthquake source), (b) line source (which models a known fault), and (c) area source (which simulates an ill-defined seismic threat).

The attenuation relationship which is used to obtain the values of the maximum ground acceleration has the following form:

$$a_{max} = b_1 e^{b_2 m} (R+b_4)^{-b_3} \tag{3a}$$

where a_{max} is the maximum horizontal acceleration at the site of the slope,

m is the magnitude of the earthquake (random variable),

R is the distance between the earthquake source and the site of the slope, and

b_1, b_2, b_3, b_4 are regional parameters.

The option of using a probabilistic attenuation relationship is also available. This is derived by multiplying the maximum value of the ground acceleration a_{max}, given in Equation (3a), by a log-normally distributed random variable ε; i.e.,

$$a_{max} = b_1 e^{b_2 m} (R+b_4)^{-b_3} \varepsilon \tag{3b}$$

The mean value $(\bar{\varepsilon})$ and coefficient of variation (V_ε) of ε must be specified by the user.

The following two options are available for the frequency-magnitude relationship:

(1) Richter's log-linear relationship; i.e.,

$$\log n_m = am + b \tag{4a}$$

(b) A log-quadratic relationship expressed in the form

$$\log n_m = am^2 + bm + c \tag{4b}$$

where n_m is the number of earthquakes having a magnitude larger than m, and

a,b,c are regional constants.

1.2 Program Capabilities

RASSUEL is capable in providing both static and pseudo-static slope stability analyses. When it is used for a static analysis, the program can only account for the uncertainties around the exact location of the failure surface and for the variability in the numerical values of the soil's strength parameters. When a pseudo-static analysis is performed, the user must specify the type of the earthquake source (i.e., point, line or area source) and provide the necessary seismic parameters. Detailed information on the preparation of the data is given in Appendix A.

The option is also available for a sorting of the results obtained during the Monte Carlo simulation. If a value IPRNT = 0 is specified in the data, a sorting routine is used and the values of the length of the failure surface (L), safety factor (SF), and safety margin (SM), determined during each iteration, are printed in ascending order. The statistical values (i.e., mean value and coefficient of variation) of the same quantities are provided in the program output even if a use of the sorting routine is not requested.

The possibility for the existance of an initial discontinuity inside the slope can be also considered by the program. This may be achieved by specifying a value for INIT equal to unity (INIT = 1). In this case, the initial discontinuity is assumed to start at the toe of the slope and have a length U modeled as a uniformly distributed random variable that can receive any value between zero and the total length L of the rupture surface $(0 \leq U \leq L)$.

The graphics capability of the program consists of a pictorial display of the boundary geometry of the slope and of a random sample of failure surfaces. This can be achieved by specifying a value for the parameter ITERM equal to two (ITERM = 2) as is shown in the section on data preparation (Appendix A). The graphics part of the program was written in the Dynagraphics Language supported by the Imlac graphics terminals which are a part of the Interactive Computer Graphics Center of Rensselaer Polytechnic Institute. The subroutines required to run the program on the Prime 500 computer and those necessary for the Graphics option are given in Appendix B.

In Figure 2 is shown the flow chart of the program. An explanation of the various symbols appearing in the flow chart is given in Table 1. The values of the cumulative beta distributions of HO, THETAO, PHI and C are generated on the basis of the information provided in the data. The value of the maximum ground acceleration ACC is found with the aid of the subroutine ACCEL in the case where Richter's log-linear frequency-magnitude relationship is used. If a log-quadratic frequency-magnitude relationship is specified, then the value of the ACC is determined in the NYACC subroutine.

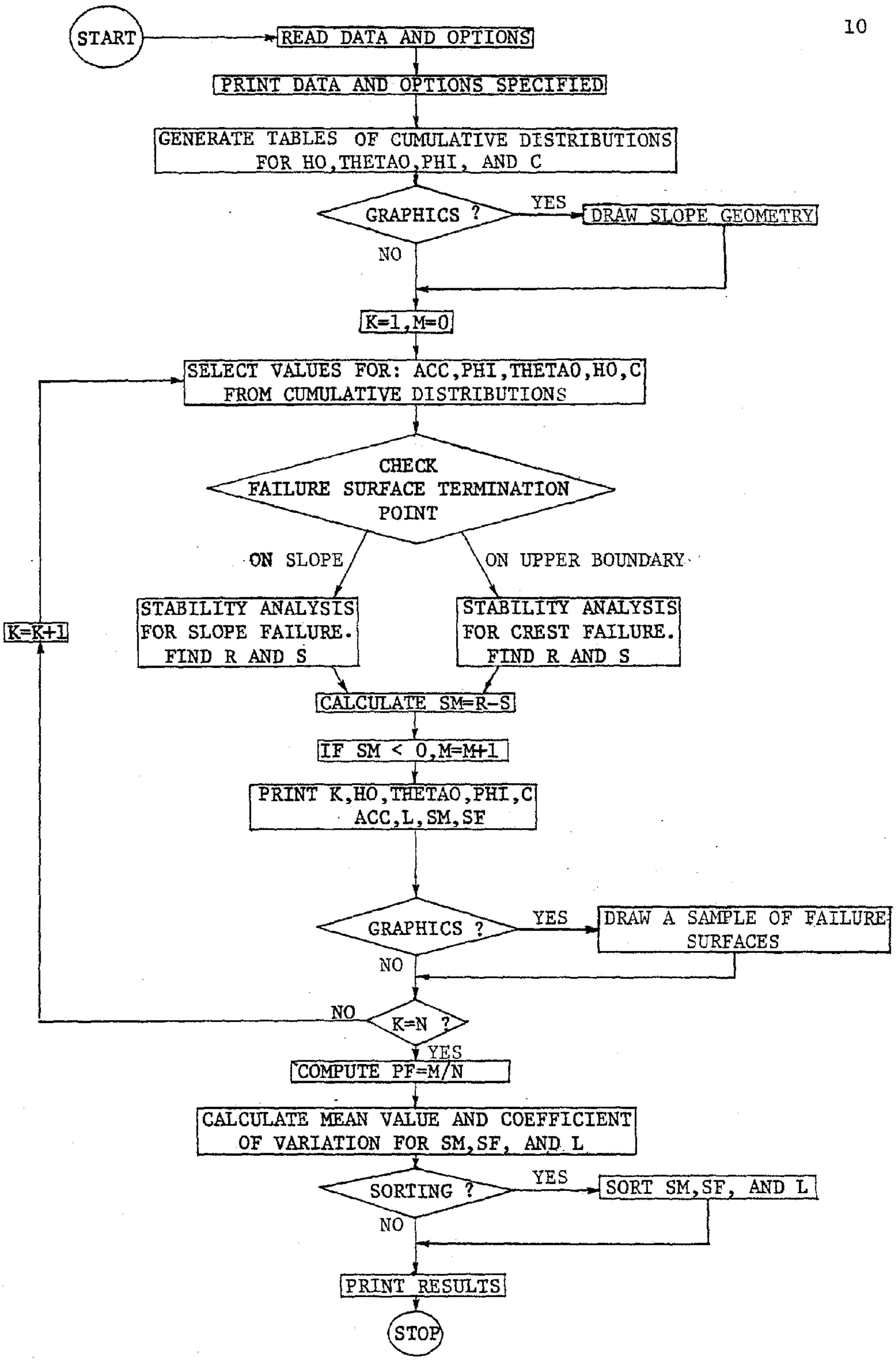


FIGURE 2 FLOW CHART FOR PROGRAM 'RASSUEL'

TABLE 1. GLOSSARY OF VARIABLES APPEARING IN THE FLOW CHART

ACC = Maximum ground acceleration

C = C-parameter of soil strength

HO = Vertical coordinates of the center of the failure surface

K = Iteration number

L = Length of potential failure surface

M = Counter for the number of failure surfaces

N = Total number of trials in the Monte Carlo simulation

PF = Probability of failure of the slope

PHI = ϕ-parameter of soil strength

R = Total resisting force along potential failure surface

S = Total driving force along potential failure surface

SF = Safety factor (=R/S)

SM = Safety margin (=R-S)

T = tan(ϕ)

THETAO = Angle between initial radius r_o and vertical direction

2. ILLUSTRATIVE EXAMPLE

The output provided by the program is shown in the following illustrative example:

In Table 2, are listed the data used for the example. Part (a) shows that a quasi-static stability analysis is requested. Part (b) gives the geometry of the soil slope, the unit weight of the material, the value of the pore pressure parameter, the number of iterations* requested for the Monte Carlo simulation and the statistical values of the two polar coordinates of the center of the failure surface (h_o and θ_o) and of the two strength parameters (ϕ and c). Part (c) lists the values of the two parameters (α and β) of the beta distribution for each of the four random variables (i.e., h_o, θ_o, ϕ and c). In Part (d) are given the specified earthquake data. This includes the type of attenuation relationship, the values of the regional seismic parameters, the statistical values of the error term ε (i.e., a probabilistic attenuation relationship is used) and the lower and upper limits of the earthquake magnitude. In this example, a line earthquake source (fault) is specified. This is shown schematically in Figure 3. It is assumed that the depth of the fault is equal to zero ($h = 0$), the orientation of the slope site with respect to the midpoint of the fault is 90° and the length of the fault is taken equal to 100 km (Figure 3).

The results obtained by the program are listed in Table 3. Part (a) shows the values of the various quantities for the first ten iterations

*For the purposes of this example, the number of iteration was specified as N = 10. For an actual case study, the number of iterations should be at least one thousand (N = 1,000).

of the program. The mean values and coefficients of variation of the length of the failure surface, safety factor, and safety margin are shown in Part (b). In Part (c) are listed the same quantities in an ascending order (as use of the sorting routine was requested). Part (d) gives the total number of failures and the numerical value of the probability of failure. From the ten iterations performed in this example, one unstable condition was generated. Thus, the probability of failure of the slope is 1/10. In Part (d) is also given the number of failures that correspond to each of the eight possible cases.

Finally, the computer graphics output for this example is given in Figure 4. This shows the specified profile of the soil slope and the ten failure surfaces that were generated during the Monte Carlo simulation.

a

```
QUASI-STATIC ANALYSIS
```

b

```
PROFILE PARAMETERS

  HEIGHT OF SLOPE = 40.50     SLOPE ANGLE =15.52
  UNIT WEIGHT SATURATED =125.00     UNIT WEIGHT MOIST =110.00     UNIT WEIGHT OF WATER = 62.40
  PORE PRESSURE PARAMETER =0.32
  NUMBER OF TRIALS =     10
  MIN VALUE OF HO      =    0.0   MAX VALUE OF HO      =  121.5   MEAN VALUE OF HO      =   60.8   COEF OF VAR = 0.35
  MIN VALUE OF THETAO =   14.5   MAX VALUE OF THETAO =   74.5   MEAN VALUE OF THETAO =   44.5   COEF OF VAR = 0.35
  MIN VALUE OF PHI     =   19.0   MAX VALUE OF PHI     =   41.0   MEAN VALUE OF PHI     =   26.3   COEF OF VAR = 0.20
  MIN VALUE OF C       =    0.0   MAX VALUE OF C       =  950.0   MEAN VALUE OF C       =  350.0   COEF OF VAR = 0.30
```

c

```
PARAMETERS FOR BETA DISTRIBUTIONS

  DISTRIBUTION OF HO              ALPHA =   2.5816     BETA =   2.5816
  DISTRIBUTION OF THETAO          ALPHA =   0.3567     BETA =   0.3567
  DISTRIBUTION OF PHI             ALPHA =  -0.0448     BETA =   0.9234
  DISTRIBUTION OF C               ALPHA =   5.6491     BETA =  10.3985
```

d

```
                                   EARTHQUAKE DATA

 REGIONAL PARAMETERS   PROBABILISTIC ATTENUATION RELATIONSHIP
        B              B1             B2            B3              B4              RADIAL DISTANCE
      1.500           1.2            1.15          1.00            0.0                   4.0
 NOTE:  QUADRATIC MAGNITUDE FREQ. RELATIONSHIP USED
     PARAMETERS B AND C ARE SET IN THE NIACC SUBROUTINE

 ERROR TERM PARAMETERS
                          MEAN VALUE                 COEFFICIENT OF VARIATION
                           1.64072                          0.60653

 BOUNDS FOR EARTHQUAKE MAGNITUDE
                          LOWER LIMIT                UPPER LIMIT
                             2.00                        7.00
```

e

```
 MODEL USED ... LINE SOURCE
 DEPTH=  0.0     ORIENTATION= 90.0     LENGTH OF FAULT= 100.0
```

TABLE 2. PROGRAM OUTPUT SHOWING THE DATA USED IN THE EXAMPLE

RESULTS CALCULATED

a

ITERATION	CASE	HO	THETAO	PHI	C	ACCELERATION	LENGTH	SAFETY MARGIN	SAFETY FACTOR
1	8	64.6	50.88	23.9	237.6	0.000	134.2	51241.2	1.764
2	8	92.0	40.20	39.2	237.6	0.005	76.7	28315.7	4.018
3	8	82.7	47.96	20.7	519.8	0.000	163.9	97301.9	1.974
4	8	71.1	59.45	37.0	176.5	0.000	167.5	136753.3	2.397
5	5	65.5	64.16	31.7	378.0	0.000	205.5	24823.6	1.088
6	5	90.3	58.42	32.3	412.5	0.009	208.3	49691.7	1.194
7	8	41.0	67.74	32.3	210.5	0.022	159.2	129053.3	2.201
8	5	52.2	70.60	22.9	365.6	0.000	267.8	-6239.8	0.987
9	8	82.8	47.21	24.2	405.3	0.000	147.4	80069.2	2.076
10	8	79.9	52.68	39.4	396.0	0.000	130.6	107216.8	3.301

b

MEAN VALUE OF LENGTH = 166.1 COEF OF VARIATION = 0.313
MEAN VALUE OF SAFETY FACTOR = 2.10 COEF OF VARIATION = 0.461
MEAN VALUE OF SAFETY MARGIN = 69822.6 COEF OF VARIATION = 0.684

c

PRINT VALUES OF LENGTH , SAFETY MARGIN, AND SAFETY FACTOR IN ASCENDING ORDER

TRIAL	LENGTH	SAFETY MARGIN	SF
1	76.7	-6239.8	0.99
2	130.6	24823.6	1.09
3	134.2	28315.7	1.19
4	147.4	49691.7	1.76
5	159.2	51241.2	1.97
6	163.9	80069.2	2.08
7	167.5	97301.9	2.20
8	205.5	107216.8	2.40
9	208.3	129053.3	3.30
10	267.8	136753.3	4.02

d

NUMBER OF FAILURES = 1

PROBABILITY OF FAILURE =0.1000

NUMBER OF FAILURE SURFACES IN CASE 1 = 0
NUMBER OF FAILURE SURFACES IN CASE 2 = 0
NUMBER OF FAILURE SURFACES IN CASE 3 = 0
NUMBER OF FAILURE SURFACES IN CASE 4 = 0
NUMBER OF FAILURE SURFACES IN CASE 5 = 3
NUMBER OF FAILURE SURFACES IN CASE 6 = 0
NUMBER OF FAILURE SURFACES IN CASE 7 = 0
NUMBER OF FAILURE SURFACES IN CASE 8 = 7

TABLE 3. PROGRAM OUTPUT SHOWING THE RESULTS FOUND IN THE EXAMPLE

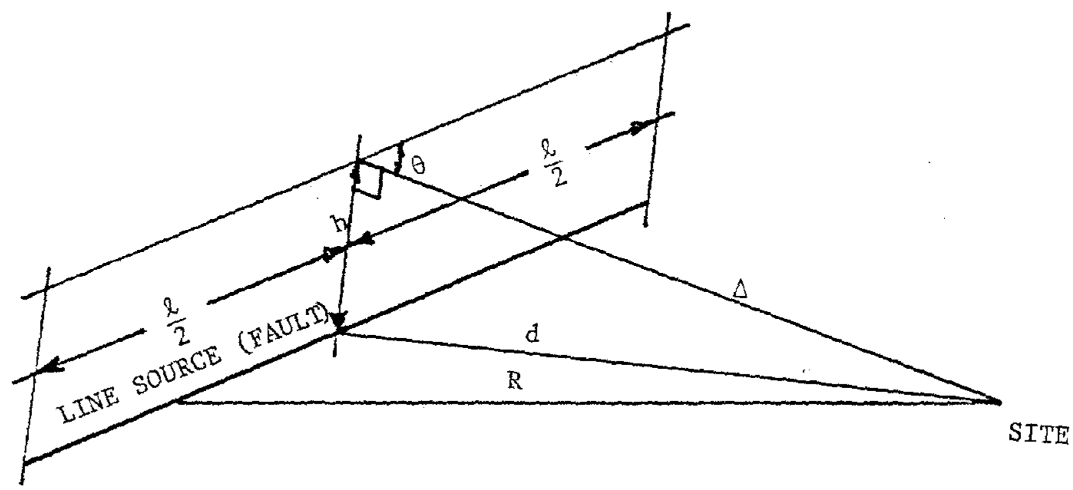


FIGURE 3. SCHEMATIC REPRESENTATION OF THE LINE SOURCE (FAULT) USED IN THE ILLUSTRATIVE EXAMPLE (perspective)

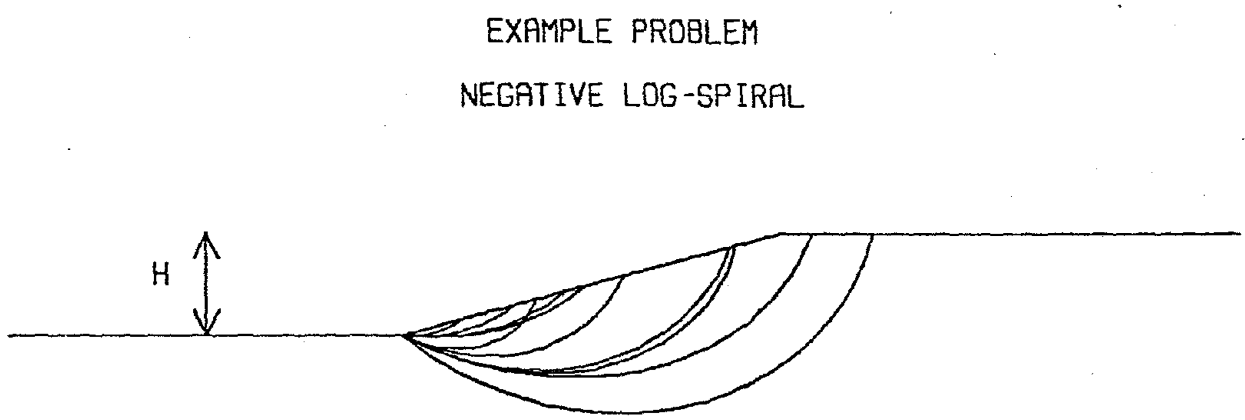


FIGURE 4. COMPUTER GRAPHICS OUTPUT OF ILLUSTRATIVE EXAMPLE

APPENDIX A: DATA PREPARATION

```
C        USE CONSISTENT UNITS
C
C   FIRST CARD
C     IPRNT = 0       FULL SORTING OF LENGTHS, SAFETY FACTORS, SAFETY MARGINS
C     IPRNT = 1       NO SORTING
C     IPRNT           SORTING REGULATOR
C     IATTN = 0       DETERMINISTIC ATTENUATION RELATIONSHIP
C     IATTN = 1       PROBABILISTIC ATTENUATION RELATIONSHIP
C     IATTN           ATTENUATION RELATIONSHIP REGULATOR
C     IDYN = 0        STATIC ANALYSIS
C     IDYN = 1        QUASI-STATIC ANALYSIS
C     IDYN            ANALYSIS REGULATOR
C     ISOUR = 0       POINT SOURCE MODEL
C     ISOUR = 1       AREA SOURCE MODEL
C     ISOUR = 2       LINE SOURCE MODEL
C     ISOUR           SOURCE REGULATOR
C     ISEIS = 0   LINEAR MAGNITUDE-FREQ. RELATIONSHIP
C           = 1   QUADRATIC RELATIONSHIP
C     ISEIS       SELECTS MAGNITUDE-FREQ RELATIONSHIP FOR QUASI-STATIC ANALYSIS
C     ITERM = 0   BATCH JOB
C     ITERM = 1   TERMINAL JOB
C     ITERM = 2   GRAPHIC TERMINAL JOB
C     ITERM       SWITCH FOR TERMINAL TYPE
C                 NOTE: FOR GRAPHICS OUTPUT THE ACCOMPANYING GRAPHICS SUB-
C                 ROUTINES MUST BE USED  AND LINES 333  AND 570
C                 MUST BE CHANGED
C 431 FORMAT(4I1)
C
C   SECOND CARD
C     H               HEIGHT OF SLOPE
C     BETA            SLOPE ANGLE (DEGREES)
C  41 FORMAT(F10.5,F10.5)
C
C   THIRD CARD
C     UWS             SATURATED UNIT WEIGHT
C     UWM             MOIST UNIT WEIGHT
C     UWW             UNIT WEIGHT OF WATER
C  42 FORMAT(F10.5,F10.5,F10.5)
C
C   FOURTH CARD
C     RU              PORE PRESSURE PARAMETER
C 421 FORMAT(F10.5)
C
C   FIFTH CARD
C     ISEED           SEED NUMBER NEEDED BY RANDOM NUMBER GENERATOR GGUB
C     N               NUMBER OF TRIALS  IN THE MONTE CARLO SIMULATION
C  43 FORMAT(I10,I10)
C
C   SIXTH CARD
C     AHO             MIN. VALUE OF THE RANDOM VARIABLE HO
C     BHO             MAX. VALUE OF THE RANDOM VARIABLE HO
C     MEANHO          MEAN VALUE OF THE RANDOM VARIABLE HO
C     CVARHO          COEF. OF VARIATION OF THE RANDOM VARIABLE HO
C      NOTE: DEFAULT VALUES ARE ASSUMED IF THE MEAN VALUE = 0.0
C  44 FORMAT(F10.5,F10.5,F10.5,F10.5)
C
C   SEVENTH CARD
C     ATO             MIN. VALUE OF THE RANDOM VARIABLE THETAO (DEGREES)
```

```
C     BTO                MAX. VALUE OF THE RANDOM VARIABLE THETAO (DEGREES)
C     MEANTO             MEAN VALUE OF THE RANDOM VARIABLE THETAC (DEGREES)
C     CVARTO             COEF. OF VARIATION OF THE RANDOM VARIABLE THETAO
C      NOTE: DEFAULT VALUES ARE ASSUMED IF THE MEAN VALUE = 0.0
C  45 FORMAT(F10.5,F10.5,F10.5,F10.5)
C
C   EIGHT CARD
C     AP                 MIN. VALUE OF THE STRENGTH PARAMETER PHI (DEGREES)
C     BP                 MAX. VALUE OF THE STRENGTH PARAMETER PHI (DEGREES)
C     MEANP              MEAN VALUE OF PHI (DEGREES)
C     CVARP              COEF. OF VARIATION OF PHI
C     NOTE: POINT VALUES MAY BE USED BY SETTING THE COEF. OF VAR. =0.0
C  46 FORMAT(F10.5,F10.5,F10.5,F10.5)
C
C   NINTH CARD
C     AC                 MIN. VALUE OF THE STRENGTH PARAMETER C
C     BC                 MAX. VALUE OF THE STRENGTH PARAMETER C
C     MEANC              MEAN VALUE OF C
C     CVARC              COEF. OF VARIATION OF C
C     NOTE: POINT VALUES MAY BE USED BY SETTING THE COEF. OF VAR. =0.0
C  47 FORMAT(F10.5,F10.5,F10.5,F10.5)
C
C   THE TENTH,ELEVENTH, AND TWELVETH CARDS ARE USED IN THE
C   GENERATION OF RANDOM MAXIMUM EARTHQUAKE ACCELERATIONS
C
C   TENTH CARD
C     MO                 EARTHQUAKE MAGNITUDE LOWER BOUND
C     M1                 EARTHQUAKE MAGNITUDE UPPER BOUND
C     RR                 RADIAL DISTANCE FROM SOURCE TO SITE(KILOMETERS)  ,ISOUR=0
C                        OR RADIUS OF THE AREA SOURCE ,ISOUR=1
C                        OR DIST TO THE MIDDLE OF THE LINE SOURCE ,ISOUR=2
C     AEQ                ANGLE BETWEEN ACCELERATION VECTOR AND HORIZONTAL
C  48 FORMAT(F10.5,F10.5,F10.5,F10.5,F10.5)
C
C   ELEVENTH CARD
C     DEPTH              DEPTH OF THE AREA SOURCE OR LINE SOURCE
C     THETA              ORIENTATION OF LINE SOURCE
C     XLEN               LENGTH OF THE LINE SOURCE
C 441 FORMAT(3F10.5)
C
C   TWELVETH CARD
C     BBETA,B1,B2,B3,B4    REGIONAL ATTENUATION COEFFICIENTS
C      NOTE: IF(ISEIS.EQ.1) B(BBETA) AND C ARE TO BE SET WITHIN
C            THE NYACC SUBROUTINE
C  49 FORMAT(F10.5,F10.5,F10.5,F10.5,F10.5)
C
C   THIRTEENTH CARD
C     EPSM               MEAN VALUE OF ERROR TERM
C     EPSCV              COEF. OF VARIATION OF ERROR TERM
C 491 FORMAT(F10.5,F10.5)
C
C
```

APPENDIX B: SUBROUTINES REQUIRED FOR USE OF THE PROGRAM ON PRIME 500 AND FOR COMPUTER GRAPHICS

```
C***********************************************************************
C    THESE SUBROUTINES ARE REQUIRED FOR USE ON THE PRIME 500
C***********************************************************************
C    GGUB IS THE RANDOM NUMBER GENERATOR ON THE IBM 3033 (IMSL)
C    RND IS THE RAN # GEN. ON THE PRIME 500
      SUBROUTINE GGUB(ISEED,N,RN)
      DIMENSION RN(N)
      DO 1 I=1,N
1     RN(I)=RND(0)
      RETURN
      END
C
      FUNCTION TAN(X)
      TAN=SIN(X)/COS(X)
      RETURN
      END
C
      FUNCTION ARCOS(X)
      ARCOS=ATAN(SQRT(1.-X**2)/X)
      RETURN
      END
C***********************************************************************
C    THESE SUBROUTINES ARE REQUIRED FOR GRAPHICS
C***********************************************************************
C    THIS SUBROUTINE DRAWS THE SLOPE
      SUBROUTINE GRID(HX,BX)
C     DIMENSION ITIT(20)
      COMMON /GRAF/  H ,B,SL,XL,XORG,YORG,SCALE,RAD
      CALL GRESET
      CALL ENTGRA
      RAD=3.1416/180.
      SCALE=(HX/TAN(BX))/(3.75-.05*BX/RAD)
      B=BX
      H=HX/SCALE
      XORG=-5.0
      YORG=-3.5
C    DRAW THE SLOPE
C     CALL OPEN(1)
C     CALL SLINT(7)
      XL=H/TAN(B)
      SL=H/SIN(B)
      TL=XORG+9.5
      CALL MOVF(XORG,YORG)
      CALL MOVE(XORG,SL+YORG)
      CALL DRAW(SL+XORG,SL+YORG)
      CALL DRAW(SL+XORG+XL,SL+H+YORG)
      CALL DRAW(TL,SL+H+YORG)
C
      TX=SL/2.+XORG
      TY=SL+YORG
      CALL MOVE(TX,TY)
      CALL RDRAW(.1,.2)
      CALL MOVE(TX,TY)
      CALL RDRAW(-.1,.2)
      CALL MOVE(TX,TY)
      TY=TY+H
      CALL DRAW(TX,TY)
      CALL RDRAW(.1,-.2)
      CALL MOVE(TX,TY)
```

```
      CALL RDRAW(-.1,-.2)
      CALL MOVE(TX-.4,TY-H/2.)
      CALL TEXT(1,'H')
C
      CALL MOVE(TX+2.,TY+1.)
      CALL TEXT(19,'NEGATIVE LOG-SPIRAL')
      CALL MOVE(TX+1.5,TY+1.5)
C     CALL TEXT(40,ITIT)
C     CALL CLOSE
C     CALL DSPICT(1)
      CALL EXITGR
      RETURN
      END
      SUBROUTINE LOGSP(XI,YI,THO,RX,T)
C     DRAW THE LOG-SPIRAL
      DIMENSION XA(40),YA(40)
      COMMON /GRAF/ H,B,SL,XL,XORG,YORG,SCALE,RAD
C
      X=XI/SCALE+SL+XORG
      Y=YI/SCALE+SL+YORG
      RO=RX/SCALE
      XC=X
      YC=Y
      TH90=90.*RAD-THO
      CALL POLAR(TH90,RO,XX,YY)
      XO=YY
      YO=-XX
      TH=5.*RAD
      DO 10 I=1,40
      R=RO*EXP(TH*T)
      THH=TH-THO
      CALL POLAR(THH,R,X1,Y1)
      DX=Y1-YO
      DY=-(X1-XO)
      XCP=XC
      YCP=YC
      XC=XC+DX
      YC=YC+DY
      CALL CHECK(XCP,YCP,XC,YC,IERR)
      XA(I)=XC
      YA(I)=YC
      IF(IERR.NE.0)  WRITE(6,100) IERR
100   FORMAT('  IERR=',I5)
      IF(IERR) 999,5,20
5     YO=Y1
      XO=X1
10    TH=TH+5.*RAD
20    CONTINUE
      CALL ENTGRA
      CALL SLINT(6)
C     PLOT THE LOG-SPIRAL
      CALL MOVE(X,Y)
      DO 30 J=1,I
30    CALL DRAW(XA(J),YA(J))
      CALL EXITGR
999   RETURN
      END
C     THIS SUBROUTINE CALCULATES X AND Y GIVEN R AND THETA
      SUBROUTINE POLAR(TH,R,X,Y)
```

```
C***********************************************************************
      Y=R*SIN(TH)
      X=R*COS(TH)
      RETURN
      END
      SUBROUTINE CHECK(X0,Y0,X1,Y1,IERROR)
      COMMON /GRAF/ H,BETA,SL,XL,XORG,YORG,SCALE,RAD
      X0=X0-XORG
      Y0=Y0-YORG
      X1=X1-XORG
      Y1=Y1-YORG
      IERROR=0
C     CHECKS TO SEE IF BREAKS THE BOTTOM
      IF(X1.GT.SL) GO TO 1
C     IF ERROR IS LESS THAN ZERO, BAD SPIRAL
      IF(Y1.GT.SL) IERROR=-100
      GO TO 2
1     CONTINUE
C     CHECKS TO SEE IF BREAKS THE TOP
      XXL=SL+XL
      YL=SL+H
      IF(X1.LT.XXL) GO TO 3
      IF(Y1.LT.YL) GO TO 2
C     IF REACHES HERE THE CURVE GOES THROUGH THE TOP
      DELTA=(YL-Y0)/(Y1-Y0)
      X1=X0+DELTA*(X1-X0)
      Y1=YL
      IERROR=100
      GO TO 2
3     CONTINUE
C     THE CURVE IS SOMEWHERE UNDER OR ABOVE THE SLOPES
      SM=H/XL
      B=SL*(1-SM)
      Y=SM*X1+B
      IF(Y.GT.Y1) GO TO 2
      PM=(Y1-Y0)/(X1-X0)
      BB=Y0-PM*X0
      X=(B-BB)/(PM-SM)
      Y=PM*X+BB
C     CHECKS TO SEE IF THE INTERSECTION IS ON THE SLOPE
      IF(Y.GT.YL) GO TO 2
      IF(Y.LT.SL) GO TO 2
      Y1=Y
      X1=X
      IERROR=50
2     CONTINUE
      X0=X0+XORG
      Y0=Y0+YORG
      X1=X1+XORG
      Y1=Y1+YORG
      RETURN
      END
```

APPENDIX C: LISTING OF COMPUTER PROGRAM

```
C      ******************************************************************
C      *                                                                *
C      *                      PROGRAM RASSUEL                           *
C      *          RELIABILITY ANALYSIS OF A SOIL SLOPE                  *
C      *                UNDER EARTHQUAKE LOADING                        *
C      *                                                                *
C      ******************************************************************
C
C
C
C      THIS PROGRAM GIVES THE PROBABILITY OF FAILURE OF
C      A SOIL SLOPE BY MEANS OF A MONTE CARLO SIMULATION
C
C      RUPTURE SURFACE IS AN EXPONENTIAL CURVE OF THE
C      FORM R=RO*EXP(-THETA*T), WHERE RO IS A REFERENCE
C      VECTOR, T=TAN(PHI) IS THE STRENGTH PARAMETER OF
C      THE SOIL MATERIAL, AND THETA IS THE ANGLE BETWEEN
C      THE VECTORS R AND RO
C
C      THE SEQUENCE OF OPERATIONS LEADING TO THE
C      PROBABILITY OF FAILURE IS AS FOLLOWS
C            1. FIND RANDOMLY THE CENTER OF THE FAILURE SURFACE
C            2. GENERATE THE C AND T STRENGTH PARAMETERS
C               (T AND C ARE BETA DISTRIBUTED)
C            3. GENERATE THE MAXIMUM ACCELERATION AT THE SITE
C               USING A TRUNCATED EXPONENTIAL DISTRIBUTION
C            4. COMPUTE THE LENGTH OF THE RUPTURE SURFACE
C            5. GENERATE THE LENGTH XLU OF THE INITIAL DISCONTINUITY
C                   IF(INIT.NE.0), SET WITHIN THE PROGRAM (LINE172)
C            6. FIND THE RESISTING AND DRIVING FORCES ALONG THE
C               RUPTURE SURFACE
C            7. FIND THE PROBABILITY OF FAILURE
C
C
C
      REAL MEANHO,MEANTO,MEANP,MEANC,MEANT,MO,M1
      DIMENSION XLENGT(1001),SM(1001),SF(1001),RANDNO(1)
      DIMENSION HX(101),HF(101),THETAX(101),THETAF(101),
     *PHIX(101),PHIF(101),CX(101),CF(101),Z(1001)
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RC,UWW,UWM,UWS
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      EXTERNAL F1,F2,GAA,GBA,HAA,HBA,FTC ,SEARCH
      INTEGER CASE
      RAD=3.14159/180.
      SUML=0.
      SUML2=0.
      SUMSM=0.
      SUMSM2=0.
      SUMSF=0.
      SUMSF2=0.
      NOF=0
      II1=0
      II2=0
      II3=0
      II4=0
      II5=0
      II6=0
      II7=0
      II8=0
C
```

```
C        SET INIT=0 FOR NO DISCONTINUITY"
C
      INIT=0
C
C          READ IN DATA
C
      READ(5,431)IPRNT,IATTN ,IDYN ,ISOUR,ISEIS,ITERM
  431 FORMAT(6I1)
      READ(5,41)H,BETA
   41 FORMAT(F10.5,F10.5)
      READ(5,42)UWS,UWM,UWW
   42 FORMAT(F10.5,F10.5,F10.5)
      READ(5,421)RU
  421 FORMAT(F10.5)
      READ(5,43)ISEED,N
   43 FORMAT(I10,I10)
      READ(5,44)AHO,BHO,MEANHO,CVARHO
   44 FORMAT(F10.5,F10.5,F10.5,F10.5)
      READ(5,45)ATO,BTO,MEANTO,CVARTO
   45 FORMAT(F10.5,F10.5,F10.5,F10.5)
      READ(5,46)AP,BP,MEANP,CVARP
   46 FORMAT(F10.5,F10.5,F10.5,F10.5)
      READ(5,47)AC,BC,MEANC,CVARC
   47 FORMAT(F10.5,F10.5,F10.5,F10.5)
      READ(5,48)MO,M1,RR,AEQ
   48 FORMAT(4F10.5)
      READ(5,441) DEPTH,THETA,XLEN
  441 FORMAT(3F10.5)
      READ(5,49)BB,B1,B2,B3,B4
   49 FORMAT(5F10.5)
      READ(5,491) EPSM,EPSCV
  491 FORMAT(2F10.5)
C
C          PRINT OUT DATA
C
      WRITE(6,51)
   51 FORMAT('1',25X,'--2 DIMENSIONAL SLOPF STABILITY ANALYSIS--',/,
     *35X,'PROBABILITY OF FAILURE',/,
     *32X,'USING MONTE CARLO SIMULATION',///)
      IF(IDYN.EQ.0) WRITE(6,750)
  750 FORMAT(38X,'STATIC ANALYSIS',///)
      IF(IDYN.EQ.1) WRITE(6,751)
  751 FORMAT(35X,'QUASI-STATIC ANALYSIS',///)
      WRITE(6,52)
   52 FORMAT(2X,'PROFILE PARAMETERS',//)
      WRITE(6,61)H,BETA
   61 FORMAT(5X,'HEIGHT OF SLOPE =',F6.2,5X,'SLOPE ANGLE =',F5.2,/)
      WRITE(6,62)UWS,UWM,UWW
   62 FORMAT(5X,'UNIT WEIGHT SATURATED =',F6.2,5X,'UNIT WEIGHT',
     *' MOIST =',F6.2,5X,'UNIT WEIGHT OF WATER =',F6.2,/)
      WRITE(6,622)RU
  622 FORMAT(5X,'PORE PRESSURE PARAMETER =',F4.2,/)
      WRITE(6,63)N
   63 FORMAT(5X,'NUMBER OF TRIALS =',I6,/)
      IF(MEANHO.GT.0.) GO TO 71
      AHO=0.
      BHO=3.*H
      MEANHO=1.50*H
      CVARHO=0.35
      WRITE(6,73)
```

```
   73  FORMAT(5X,'*NOTE* - DEFAULT VALUE FOR HO')
   71  WRITE(6,64)AHO,BHO,MEANHO,CVARHO
    64 FORMAT(5X,'MIN VALUE OF HO      =',F7.1,3X,'MAX VALUE OF HO     ='
      *,F7.1,3X,'MEAN VALUE OF HO     =',F7.1,3X,'COEF OF VAR =',F5.2,/)
       IF(MEANTO.GT.0.) GO TO 72
       ATO=90.0-(BETA+60.0)
       BTO=90.0-BETA
       MEANTO=(ATO+BTO)/2.0
       CVARTO=0.35
       WRITE(6,74)
   74  FORMAT(5X,'*NOTE* - DEFAULT VALUE FOR THETAO')
   72  WRITE(6,65)ATO,BTO,MEANTO,CVARTO
    65 FORMAT(5X,'MIN VALUE OF THETAO =',F7.1,3X,'MAX VALUE OF THETAO ='
      *,F7.1,3X,'MEAN VALUE OF THETAO =',F7.1,3X,'COEF OF VAR =',F5.2,/)
       WRITE(6,66)AP,BP,MEANP,CVARP
    66 FORMAT(5X,'MIN VALUE OF PHI    =',F7.1,3X,'MAX VALUE OF PHI    ='
      *,F7.1,3X,'MEAN VALUE OF PHI    =',F7.1,3X,'COEF OF VAR =',F5.2,/)
       WRITE(6,67)AC,BC,MEANC,CVARC
    67 FORMAT(5X,'MIN VALUE OF C      =',F7.1,3X,'MAX VALUE OF C      ='
      *,F7.1,3X,'MEAN VALUE OF C      =',F7.1,3X,'COEF OF VAR =',F5.2,/)
       ATO=ATO*RAD
       BTO=BTO*RAD
       MEANTO=MEANTO*RAD
       BETA=BETA*RAD
       AEQ=AEQ*RAD
       THETA=THETA*RAD
       ISIID=ISEED
       WRITE(6,53)
    53 FORMAT(1X,//,2X,'PARAMETERS FOR BETA DISTRIBUTIONS',//)
C
C        GENERATE THE RANDOM VARIABLES HO,THETAO,T AND C
C
       CALL INBETA(AHO,BHO,MEANHO,CVARHO,HX,HF)
       WRITE(6,54)CALPHA,CBETA
    54 FORMAT(5X,'DISTRIBUTION OF HO           ',10X,'ALPHA =',F9.4,5X,
      *'BETA =',F9.4,/)
       CALL INBETA(ATO,BTO,MEANTO,CVARTO,THETAX,THETAF)
       WRITE(6,55)CALPHA,CBETA
    55 FORMAT(5X,'DISTRIBUTION OF THETAO       ',10X,'ALPHA =',F9.4,5X,
      *'BETA =',F9.4,/)
       IF(CVARP.EQ.0.) GO TO 112
       CALL INBETA(AP,BP,MEANP,CVARP,PHIX,PHIF)
       WRITE(6,56)CALPHA,CBETA
    56 FORMAT(5X,'DISTBIBUTION OF PHI          ',10X,'ALPHA =',F9.4,5X,
      *'BETA =',F9.4,/)
   112 IF(CVARC.EQ.0.) GO TO 113
       CALL INBETA(AC,BC,MEANC,CVARC,CX,CF)
       WRITE(6,57)CALPHA,CBETA
    57 FORMAT(5X,'DISTRIBUTION OF C            ',10X,'ALPHA =',F9.4,5X,
      *'BETA =',F9.4,/)
   113 IF(IDYN.EQ.0) GO TO 82
       IF(IATTN.EQ.0) GO TO 80
       CALL LGNRM(N,EPSM,EPSCV,Z)
   80  CONTINUE
       WRITE(6,611)
   611 FORMAT('-',5X,47X,'EARTHQUAKE DATA')
       IF(IATTN.EQ.0) WRITE (6,612)
   612 FORMAT('0',5X,'REGIONAL PARAMETERS   DETERMINISTIC ATTENUATION ',
      *'RELATIONSHIP')
       IF(IATTN.EQ.1) WRITE(6,625)
```

```
      625 FORMAT('0',5X,'REGIONAL PARAMETERS   PROBABILISTIC '
         *,'ATTENUATION RELATIONSHIP')
          WRITE(6,613)
      613 FORMAT('0',5X,9X,'B',16X,'B1',13X,'B2',14X,'B3',18X,'B4',16X
         *'RADIAL DISTANCE')
          WRITE(6,614) BB,B1,B2,B3,B4,RR
      614 FORMAT('0',5X,6X,F5.3,11X,F6.1,12X,F4.2,12X,F4.2,15X,F6.2
         *,16X,F8.1)
          IF(ISEIS.EQ.1) WRITE(6,619)
     619  FORMAT('        NOTE:  QUADRATIC MAGNITUDE FREQ. RELATIONSHIP USED'
         &,/,10X,'PARAMETERS B AND C ARE SET IN THE NYACC SUBROUTINE')
          IF(IATTN.EQ.0) GO TO 81
          WRITE(6,626)
      626 FORMAT('0',5X,'ERROR TERM PARAMETERS')
          WRITE(6,627)
      627 FORMAT('0',5X,34X,'MEAN VALUE',20X,'COEFFICIENT '
         *,'OF VARIATION')
          WRITE(6,628) EPSM,EPSCV
      628 FORMAT('0',5X,35X,F7.5,35X,F7.5)
       81 CONTINUE
          WRITE(6,615)
      615 FORMAT('0',5X, 'BOUNDS FOR EARTHQUAKE MAGNITUDE ')
          WRITE(6,616)
      616 FORMAT('0',5X,34X,'LOWER LIMIT',20X,'UPPER LIMIT')
          WRITE(6,617) MO,M1
      617 FORMAT('0',5X,9X,28X,F4.2,27X,F4.2)
          IF(ISOUR.EQ.0) GO TO 75
          IF(ISOUR.EQ.1) GO TO 86
          IF(ISOUR.EQ.2) WRITE(6,78)
      78  FORMAT('0',5X,'MODEL USED ... LINE SOURCE')
          OREN=THETA/RAD
          WRITE(6,84) DEPTH,OREN,XLEN
      84  FORMAT('0',5X,'DEPTH= ',F4.1,5X,'ORIENTATION= ',
         *F4.1,5X,'LENGTH OF FAULT= ',F5.1)
          GO TO 82
      86  WRITE(6,76)
      76  FORMAT('0',5X,'MODEL USED ... AREA SOURCE')
          WRITE(6,85) DEPTH
      85  FORMAT('0',5X,'DEPTH= ',F4.1)
          GO TO 82
      75  WRITE(6,77)
      77  FORMAT('0',5X,'MODEL USED ... POINT SOURCE')
       82 CONTINUE
C**GRAPHICS** IF(ITERM.GT.1) CALL GRID(H,BETA)
          DO 1 II=1,N
C
C            CHECK IF THE RUPTURE SURFACE TERMINATES AT THE SLOPE
C            OR AT THE HORIZONTAL BOUNDARY
C
          IF(IDYN.EQ.0) GO TO 83
          CALL ACCEL(MO,M1,BB,B1,B2,B3,B4,RR,N,AL,AU,ACC,ISOUR,ISEIS)
       83 CONTINUE
          IF(IATTN.EQ.0.OR.IDYN.EQ.0)   Z(II)=1.0
          MEANT=TAN(MEANP*RAD)
          IF(IDYN.EQ.0) ACC=0.
       31 IF(CVARP.GT.0.) CALL RANNO(PHIX,PHIF,PHI,ISIID)
          IF(CVARP.EQ.0.) PHI=MEANP
          CALL RANNO(THETAX,THETAF,THETAO,ISIID)
C    MAKE SURE THE FAILURE SURFACE IS BELOW THE SLOPE
          IF(PHI-THETAO/RAD.GT.BETA/RAD) GO TO 31
```

```
      CALL RANNO(HX,HF,HO,ISIID)
      IF(CVARC.GT.0.) CALL RANNO(CX,CF,C,ISIID)
      IF(CVARC.EQ.0.) C=MEANC
      T=-TAN(PHI*RAD)
      SNRV=Z(II)
      ACC=ACC*SNRV
      ACC=ACC/COS(AEQ)
      BETA1=90.*RAD-BETA-THETAO
      RO=HO/COS(THETAO)
      AB=(HO*TAN(THETAO)-H   /TAN(BETA))**2+(HO-H   )**2
      AB=SQRT(AB)
      DC=H/SIN(BETA)
      SS=(AB+DC+RO)/2.
      ZI=2.*ARCOS(SQRT(SS*(SS-DC)/(AB*RO)))
      CRIT=RO*EXP(ZI*T)-AB
      IF(CRIT.LE.0.) GO TO 2
C
C        COMPUTE THETAC,THETAH,THETAI,AND THETAS FOR A RUPTURE
C        SURFACE TERMINATING AT THE HORIZONTAL BOUNDARY OF THE SLOPE
C
      A=.01
      B=3.14
      CALL MRGFLS(F1,A,B,1.E-4,1.E-5,100,IFLAG)
      THETAH=(A+B)/2.
      XLENGT(II)=RO*SQRT(1.+1./T**2)*(-EXP(THETAH*T)+1.)
      SUML=SUML+XLENGT (II)
      SUML2=SUML2+XLENGT(II)**2
      THETAS=0.0
      IF(INIT.EQ.0) GO TO 1001
      CALL GGUB(ISEED,1,RANDNO)
      THETAS=RANDNO(1)*THETAH
 1001 XLU=RO*SQRT(1.+1./T**2)*(-EXP(THETAS*T)+1.)
      AA=0.
      BB=THETAH
      CALL MRGFLS(FTC,AA,BB,1.E-4,1.E-5,100,IFLAG)
      THETAC=(AA+BB)/2.
      THETAI=THETAO+ATAN(T)
      IF(THETAI.LT.0.) THETAI=0.
      GO TO 3
C
C        COMPUTE THETAH, THETAS, AND THETAI FOR A RUPTURE SURFACE
C        TERMINATING AT THE SLOPE
C
    2 A=.01
      B=3.14
      CALL MRGFLS(F2,A,B,1.E-4,1.E-5,100,IFLAG)
      THETAH=(A+B)/2.
      XLENGT(II)=RO*SQRT(1.+1./T**2)*(-EXP(THETAH*T)+1.)
C   SET A MINIMUM LENGTH FOR THE FAILURE SURFACES
      IF(XLENGT(II).LT.0.50*H/SIN(BETA)) GO TO 31
      SUML=SUML+XLENGT (II)
      SUML2=SUML2+XLENGT(II)**2
      THETAS=0.0
      IF(INIT.EQ.0) GO TO 1002
      CALL GGUB(ISEED,1,RANDNO)
      THETAS=RANDNO(1)*THETAH
 1002 XLU=RO*SQRT(1.+1./T**2)*(-EXP(THETAS*T)+1.)
      THETAI=THETAO+ATAN(T)
      IF(THETAI.LT.0.) THETAI=0.
      GO TO 707
```

```
C
C          CHECK FOR EXISTING CASE AND PERFORM INTEGRATIONS
C
       3 IF(THETAI.LT.THETAC.AND.THETAC.LT.THETAS) GO TO 701
         IF(THETAC.LT.THETAI.AND.THETAI.LT.THETAS) GO TO 702
         IF(THETAC.LT.THETAS.AND.THETAS.LT.THETAI) GO TO 703
         IF(THETAI.LT.THETAS.AND.THETAS.LT.THETAC) GO TO 704
         IF(THETAS.LT.THETAI.AND.THETAI.LT.THETAC) GO TO 705
         IF(THETAS.LT.THETAC.AND.THETAC.LT.THETAI) GO TO 706
C
C          CASE 1 IS FOR A TOP FAILURE WITH THETAI < THETAC < THETAS
C          CASE 2 IS FOR A TOP FAILURE WITH THETAC < THETAI < THETAS
C          CASE 3 IS FOR A TOP FAILURE WITH THETAC < THETAS < THETAI
C          CASE 4 IS FOR A TOP FAILURE WITH THETAI < THETAS < THETAC
C          CASE 5 IS FOR A TOP FAILURE WITH THETAS < THETAI < THETAC
C          CASE 6 IS FOR A TOP FAILURE WITH THETAS < THETAC < THETAI
C          CASE 7 IS FOR A SLOPE FAILURE WITH THETAI < THETAS
C          CASE 8 IS FOR A SLOPE FAILURE WITH THETAS < THETAI
C
     701 II1=II1+1
         CASE = 1
         CALL SIMP(GAA,0.     ,THETAI,8,RT0)
         CALL SIMP(GAA,THETAI,THETAC,8,RT1)
         CALL SIMP(GBA,THETAC,THETAS,8,RT2)
         CALL SIMP(GBA,THETAS,THETAH,8,RT3)
         R0=RT0*MEANT
         R1=RT1*MEANT
         R2=RT2*MEANT
         R3=RT3*ABS(T)
         CALL SIMP(HAA,0.     ,THETAI,8,S1)
         CALL SIMP(HAA,THETAI,THETAC,8,S2)
         CALL SIMP(HBA,THETAC,THETAH,8,S3)
         R=R1+R2+R3+C*(XLENGT(II)-XLU)-S1+R0
         S=S2+S3
         GO TO 401
     702 II2=II2+1
         CASE = 2
         CALL SIMP(GAA,0.     ,THETAC,8,RT0)
         CALL SIMP(GBA,THETAC,THETAI,8,RT1)
         CALL SIMP(GBA,THETAI,THETAS,8,RT2)
         CALL SIMP(GBA,THETAS,THETAH,8,RT3)
         R0=RT0*MEANT
         R1=RT1*MEANT
         R2=RT2*MEANT
         R3=RT3*ABS(T)
         CALL SIMP(HAA,0.     ,THETAC,8,S1)
         CALL SIMP(HBA,THETAC,THETAI,8,S2)
         CALL SIMP(HBA,THETAI,THETAH,8,S3)
         R=R2+R3+C*(XLENGT(II)-XLU)-S1-S2+R0+R1
         S=S3
         GO TO 401
     703 II3=II3+1
         CASE = 3
         CALL SIMP(GAA,0.     ,THETAC,8,RT0)
         CALL SIMP(GBA,THETAC,THETAS,8,RT1)
         CALL SIMP(GBA,THETAS,THETAI,8,RT2)
         CALL SIMP(GBA,THETAI,THETAH,8,RT3)
         R0=RT0*MEANT
         R1=RT1*MEANT
         R2=RT2*ABS(T)
```

```
      R3=RT3*ABS(T)
      CALL SIMP(HAA,0.    ,THETAC,8,S1)
      CALL SIMP(HBA,THETAC,THETAI,8,S2)
      CALL SIMP(HBA,THETAI,THETAH,8,S3)
      R=R3+C*(XLENGT(II)-XLU)-S1-S2+R0+R1+R2
      S=S3
      GO TO 401
  704 II4=II4+1
      CASE = 4
      CALL SIMP(GAA,0.    ,THETAI,8,RT0)
      CALL SIMP(GAA,THETAI,THETAS,8,RT1)
      CALL SIMP(GAA,THETAS,THETAC,8,RT2)
      CALL SIMP(GBA,THETAC,THETAH,8,RT3)
      R0=RT0*MEANT
      R1=RT1*MEANT
      R2=RT2*ABS(T)
      R3=RT3*ABS(T)
      CALL SIMP(HAA,0.    ,THETAI,8,S1)
      CALL SIMP(HAA,THETAI,THETAC,8,S2)
      CALL SIMP(HBA,THETAC,THETAH,8,S3)
      R=R1+R2+R3+C*(XLENGT(II)-XLU)-S1+R0
      S=S2+S3
      GO TO 401
  705 II5=II5+1
      CASE = 5
      CALL SIMP(GAA,0.    ,THETAS,8,RT0)
      CALL SIMP(GAA,THETAS,THETAI,8,RT1)
      CALL SIMP(GAA,THETAI,THETAC,8,RT2)
      CALL SIMP(GBA,THETAC,THETAH,8,RT3)
      R0=RT0*MEANT
      R1=RT1*ABS(T)
      R2=RT2*ABS(T)
      R3=RT3*ABS(T)
      CALL SIMP(HAA,0.    ,THETAI,8,S1)
      CALL SIMP(HAA,THETAI,THETAC,8,S2)
      CALL SIMP(HBA,THETAC,THETAH,8,S3)
      R=R2+R3+C*(XLENGT(II)-XLU)-S1
      S=S2+S3+R0+R1
      GO TO 401
  706 II6=II6+1
      CASE = 6
      CALL SIMP(GAA,0.    ,THETAS,8,RT0)
      CALL SIMP(GAA,THETAS,THETAC,8,RT1)
      CALL SIMP(GBA,THETAC,THETAI,8,RT2)
      CALL SIMP(GBA,THETAI,THETAH,8,RT3)
      R0=RT0*MEANT
      R1=RT1*ABS(T)
      R2=RT2*ABS(T)
      R3=RT3*ABS(T)
      CALL SIMP(HAA,0.    ,THETAC,8,S1)
      CALL SIMP(HBA,THETAC,THETAI,8,S2)
      CALL SIMP(HBA,THETAI,THETAH,8,S3)
      R=R3+C*(XLENGT(II)-XLU)-S1-S2+R0+R1+R2
      S=S3
      GO TO 401
  707 IF(THETAS.LT.THETAI) GO TO 708
      II7=II7+1
      CASE = 7
      CALL SIMP(GAA,0.    ,THETAI,8,RT0)
      CALL SIMP(GAA,THETAI,THETAS,8,RT1)
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      CALL SIMP(GAA,THETAS,THETAH,8,RT2)
      R0=RT0*MEANT
      R1=RT1*MEANT
      R2=RT2*ABS(T)
      CALL SIMP(HAA,0.     ,THETAI,8,S1)
      CALL SIMP(HAA,THETAI,THETAH,8,S2)
      R=R1+R2+C*(XLENGT(II)-XLU)-S1+R0
      S=S2
      GO TO 401
  708 II8=II8+1
      CASE=8
      CALL SIMP(GAA,0.     ,THETAS,8,RT0)
      CALL SIMP(GAA,THETAS,THETAI,8,RT1)
      CALL SIMP(GAA,THETAI,THETAH,8,RT2)
      R0=RT0*MEANT
      R1=RT1*ABS(T)
      R2=RT2*ABS(T)
      CALL SIMP(HAA,0.     ,THETAI,8,S1)
      CALL SIMP(HAA,THETAI,THETAH,8,S2)
      R=R2+C*(XLENGT(II)-XLU)-S1+R0+R1
      S=S2
  401 IF(R.GE.S) GO TO 21
      NOF=NOF+1
   21 SM(II)=(R-S)
      SUMSM=SUMSM+SM(II)
      SUMSM2=SUMSM2+SM(II)**2
      SF(II)=R/S
      SUMSF=SUMSF+SF(II)
      SUMSF2=SUMSF2+SF(II)**2
      PHI=ATAN(-T)/RAD
      PHETAO=THETAO/RAD
      IF(II.EQ.1) WRITE(6,58)
   58 FORMAT('1',2X,'RESULTS CALCULATED',///)
      IF(II.EQ.1) WRITE(6,620)
  620 FORMAT('-',5X,'ITERATION',4X,'CASE',4X,'HC',4X,'THETAC',4X,'PHI'
     *4X,'C',4X,'ACCELERATION',4X,'LENGTH',4X,'SAFETY MARGIN',4X,
     *'SAFETY FACTOR')
      WRITE(6,621) II,CASE,HC,PHETAO,PHI,C,ACC,XLENGT(II),SM(II),SF(II
  621 FORMAT(' ',8X,I4,8X,I1,4X,F5.1,3X,F5.2,3X,F4.1,2X,F5.1,4X,
     *F7.3,7X,F6.1,5X,F10.1,9X,F6.3)
C**GRAPHICS** IF(ITERM.GT.1.AND.II.LT.21) CALL LOGSP(0.,0.,THETAO,RO,T
    1 CONTINUE
C
C          COMPUTE THE MEANS AND COEFFICIENTS OF VARIATION OF
C          THE LENGTH OF THE FAILURE SURFACE,THE SAFETY MARGIN
C          AND THE SAFETY FACTOR
C
      XLMEAN=SUML/FLOAT(N)
      XLVAR=SUML2/FLOAT(N-1)-FLOAT(N)*XLMEAN**2/FLOAT(N-1)
      STDVL=SQRT(XLVAR)
      CVL=STDVL/XLMEAN
      SFMEAN=SUMSF/FLOAT(N)
      SFVAR=SUMSF2/FLOAT(N-1)-FLOAT(N)*SFMEAN**2/FLOAT(N-1)
      SFCVAR=SQRT(SFVAR)/SFMEAN
      SMMEAN=SUMSM/FLOAT(N)
      SMVAR=SUMSM2/FLOAT(N-1)-FLOAT(N)*SMMEAN**2/FLOAT(N-1)
      SMCVAR=SQRT(SMVAR)/SMMEAN
      WRITE(6,90)XLMEAN,CVL,SFMEAN,SFCVAR,SMMEAN,SMCVAR
   90 FORMAT('1',4X,'MEAN VALUE OF LENGTH         =',F12.1,5X,
     *'COEF OF VARIATION =',F8.3,/,5X,'MEAN VALUE OF SAFETY FACTOR ='
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     *F12.2,5X,'COEF OF VARIATION =',F8.3,/,5X,
     *'MEAN VALUE OF SAFETY MARGIN =',F12.1,5X,'COEF OF VARIATION =',
     *F8.3)
C
C        SORT THE LENGTHS, THE SAFETY FACTORS AND THE SAFETY MARGINS
C
      IF(IPRNT.EQ.1) GO TO 95
      CALL SORT(XLENGT,N)
      CALL SORT(SF,N)
      CALL SORT(SM,N)
      WRITE(6,91)
   91 FORMAT(1X,//,2X,'PRINT VALUES OF LENGTH       , SAFETY MARGIN,',
     *' AND SAFETY FACTOR IN ASCENDING ORDER',///,5X,'TRIAL',6X,
     *'LENGTH       ',5X,'SAFETY MARGIN',9X,'SF',/)
      DO 22 NNN=1,N
      WRITE(6,92)NNN,XLENGT(NNN),SM(NNN),SF(NNN)
   92 FORMAT(5X,I5,5X,F13.1,5X,F13.1,5X,F6.2)
   22 CONTINUE
C
C        COMPUTE PROBABILITY OF FAILURE
C
   95 PFAIL=NOF/FLOAT(N)
      WRITE(6,93)NOF,PFAIL
   93 FORMAT('1',34X,'NUMBER OF FAILURES     =',I5,//,
     *35X,'PROBABILITY OF FAILURE =',F6.4)
      WRITE(6,94)II1,II2,II3,II4,II5,II6,II7,II8
   94 FORMAT(10X,'NUMBER OF FAILURE SURFACES IN CASE 1 =',I5,/,
     1        10X,'NUMBER OF FAILURE SURFACES IN CASE 2 =',I5,/,
     2        10X,'NUMBER OF FAILURE SURFACES IN CASE 3 =',I5,/,
     3        10X,'NUMBER OF FAILURE SURFACES IN CASE 4 =',I5,/,
     4        10X,'NUMBER OF FAILURE SURFACES IN CASE 5 =',I5,/,
     5        10X,'NUMBER OF FAILURE SURFACES IN CASE 6 =',I5,/,
     6        10X,'NUMBER OF FAILURE SURFACES IN CASE 7 =',I5,/,
     6        10X,'NUMBER OF FAILURE SURFACES IN CASE 8 =',I5,/)
      STOP
      END
      FUNCTION F1(X)
C
C        F1 IS THE EQUATION FOR THETAH FOR FAILURE THROUGH TOP OF
C        SLOPE
C
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RO,UWW,UWM,UWS
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      F1=H+HO*COS(X-THETAO)*EXP(X*T)/COS(THETAO)-HO
      RETURN
      END
      FUNCTION F2(X)
C
C        F2 IS THE EQUATION FOR THETAH FOR FAILURE THROUGH THE SLOPE
C
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RO,UWW,UWM,UWS
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      F2=EXP(X*T)*COS(X-BETA-THETAO)-COS(BETA+THETAC)
      RETURN
      END
      FUNCTION FTC(X)
C
C        FTC IS THE EQUATION FOR THETAC
C
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RO,UWW,UWM,UWS
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     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      FTC=RO*TAN(BETA)*(SIN(THETAO)+SIN(X-THETAO)*EXP(X*T))-H
      RETURN
      END
      FUNCTION GAA(XX1)
C
C        GAA IS THE EQUATION FOR THE NORMAL FORCE FOR VALUES OF
C        THETA LESS THAN THETAC
C
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RO,UWW,UWM,UWS
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      Z1=RO/SIN(BETA1+THETAO)*(EXP(XX1*T)*SIN(BETA1+XX1)-SIN(BETA1))
      XTO=XX1-THETAO
      EPS=(TAN(XTO)-T)/(1.+T*TAN(XTO))
      EPS=ATAN(EPS)
      UWB=UWS-UWW
      W=RU*Z1*UWM/UWW
      ZW=Z1-W
      P1=UWM*ZW+UWB*W
      P2=RO*EXP(XX1*T)*SQRT(1.+T**2)*ABS(COS(EPS))
      DN=P1*COS(EPS)*P2
      DNEQ=P1*ACC*SIN(-(AEQ+EPS))*P2
      GAA=DN+DNEQ
      RETURN
      END
      FUNCTION GBA(XX3)
C
C        GBA IS THE EQUATION FOR THE NORMAL FORCE FOR VALUES OF
C        THETA GREATER THAN THETAC
C
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RO,UWW,UWM,UWS
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      Z1=RO/SIN(BETA1+THETAO)*(EXP(XX3*T)*SIN(BETA1+XX3)-SIN(BETA1))
      XTO=XX3-THETAO
      DZ=RO*TAN(BETA)*(SIN(XX3-THETAO)*EXP(XX3*T)-SIN(THETAC-THETAO)
     1*EXP(THETAC*T))
      Z=Z1-DZ
      EPS=(TAN(XTO)-T)/(1.+T*TAN(XTO))
      EPS=ATAN(EPS)
      UWB=UWS-UWW
      W=RU*Z*UWM/UWW
      ZW=Z-W
      P1=UWM*ZW+UWB*W
      P2=RO*EXP(XX3*T)*SQRT(1.+T**2)*ABS(COS(EPS))
      DN=P1*COS(EPS)*P2
      DNEQ=P1*ACC*SIN(-(AEQ+EPS)) *P2
      GBA=DN+DNEQ
      RETURN
      END
      FUNCTION HAA(XX5)
C
C        HAA IS THE EQUATION FOR THE TANGENTIAL FORCE FOR VALUES OF
C        THETA LESS THAN THETAC
C
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RO,UWW,UWM,UW
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      Z1=RO/SIN(BETA1+THETAO)*(EXP(XX5*T)*SIN(BETA1+XX5)-SIN(BETA1))
      XTO=XX5-THETAO
      EPS=(TAN(XTO)-T)/(1.+T*TAN(XTO))
      EPS=ATAN(EPS)
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      UWB=UWS-UWW
      W=RO*Z1*UWM/UWW
      ZW=Z1-W
      P1=UWM*ZW+UWS*W
      P2=RO*EXP(XX5*T)*SQRT(1.+T**2)*ABS(COS(EPS))
      DT=P1*SIN(EPS)*P2
      DTEQ=P1*ACC*COS(AEQ+EPS)*P2
      HAA=DT+DTEQ
      RETURN
      END
      FUNCTION HBA(XX7)
C
C        HBA IS THE EQUATION FOR THE TANGENTIAL FORCE FOR VALUES OF
C        THETA GREATER THAN THETAC
C
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RO,UWW,UWM,UW
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      Z1=RO/SIN(BETA1+THETAO)*(EXP(XX7*T)*SIN(BETA1+XX7)-SIN(BETA1))
      XTO=XX7-THETAO
      DZ=RO*TAN(BETA)*(SIN(XX7-THETAO)*EXP(XX7*T)-SIN(THETAC-THETAO)
     1*EXP(THETAC*T))
      Z=Z1-DZ
      EPS=(TAN(XTO)-T)/(1.+T*TAN(XTO))
      EPS=ATAN(EPS)
      UWB=UWS-UWW
      W=RU*Z*UWM/UWW
      ZW=Z-W
      P1=UWM*ZW+UWS*W
      P2=RO*EXP(XX7*T)*SQRT(1.+T**2)*ABS(COS(EPS))
      DT=P1*SIN(EPS)*P2
      DTEQ=P1*ACC*COS(AEQ+EPS)*P2
      HBA=DT+DTEQ
      RETURN
      END
      SUBROUTINE INBETA(A,B,MEAN,CVAR,X,F)
C
C        INBETA GENERATES BETA DISTRIBUTED RANDOM VARIABLES
C
      DIMENSION X(101),CR(101),BR(101),F(101)
      REAL MEAN
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RC,UWW,UWM,UW
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      XX=(MEAN-A)/(B-A)
      STDV=MEAN*CVAR
      VAR=STDV**2
      VV=VAR/(B-A)**2
      CALPHA=XX**2*(1.-XX)/VV-(1.+XX)
      CBETA=(CALPHA+1.)/XX-(CALPHA+2.)
      X(1)=A
      DX=(B-A)/99.
      CR(1)=0.
      BR(1)=0.
      DO29 I=2,100
      X(I)=X(I-1)+DX
      BR(I)=(X(I)-A)**CALPHA*(B-X(I))**CBETA
      CR(I)=BR(I)+CR(I-1)
   29 CONTINUE
      F(1)=0.
      DO30 J=2,100
      F(J)=(CR(J-1)+BR(J)/2.)/(CR(99)+BR(100)/2.)
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```
   30 CONTINUE
      RETURN
      END
      SUBROUTINE RANNO(X,F,RN,ISEED)
      DIMENSION X(101),F(101),RLN(1)
      CALL GGUB(ISEED,1,RLN(1))
      J=2
   21 IF(RLN(1).GT.F(J)) GO TO 22
      DF=F(J)-F(J-1)
      PF=RLN(1)-F(J-1)
      DP=PF/DF
      RN=X(J-1)+DP*(X(J)-X(J-1))
      GO TO 25
   22 J=J+1
      GO TO 21
   25 CONTINUE
      RETURN
      END
      SUBROUTINE ACCEL(ML,MU,BB,B1,B2,B3,B4,R,N,AL,AU,ANSWER,
     *ISOUR,ISEIS)
C
C        ACCEL GENERATES RANDOMLY THE MAXIMUM HORIZONTAL GROUND
C        ACCELERATION USING A TRUNCATED EXPONENTIAL DISTRIBUTION
C
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RC,UWW,UWM,UWS
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      REAL ML,MU


      CALL GGUB(ISEED,1,ANSWER)
      C1=1./(1.-EXP(-BB*(MU-ML)))
      RX=R
      IF(ISOUR.EQ.0) GO TO 111
      IF(ISOUR.EQ.2) GO TO 112
C   FIND THE DIST. FROM EQ TO SITE FOR AN AREA SOURCE
      CALL GGUB(ISEED,1,RAN)
      RX=SQRT(RAN)*RX
      RX=SQRT(RX**2.0+DEPTH**2.0)
      GO TO 111
C   FIND THE DIST. FROM EQ TO SITE FOR A LINE SOURCE
  112 CALL GGUB(ISEED,1,RN)
      X=RN*XLEN
      Z=X-XLEN/2.
      D=SQRT(DEPTH**2.+RX**2.)
      RX=-2.0*Z*D*COS(THETA)
      RX=ABS(Z)**2.+D**2.+RX
      RX=SQRT(RX)
C   IF(ISEIS.EQ.1) USE THE QUADRATIC MAGNITUDE-FREQ RELTAION
  111 RX=RX+B4
      IF(ISEIS.EQ.0) GO TO 113
      CALL NYACC(B1,B2,B3,RX,MU,ML,ISEED,ANSWER)
      GO TO 100
  113 ANSWER=(B1/RX**B3)*EXP(B2*(ML-1./BB*ALOG(1.-ANSWER/C1)))
  100 ANSWER=ANSWER/981.
      RETURN
      END
      SUBROUTINE SORT(JAN,ID)
C
C         THIS IS A BUBBLE SORT
C
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```
      REAL JAN(ID)
      K=0
    2 K=K+1
    1 IF(K+1.GT.ID) RETURN
      V=JAN(K+1)
      N=K
      IF(JAN(K) .LE.V) GO TO 2
      M=1
    4 IF(M.GT.N) GO TO 30
      J=(M+N)/2
      GO TO 10
   30 JAN(M)=V
      GO TO 1
   10 IF(V.LT.JAN(J)) GO TO 7
      M=J+1
      GO TO 4
    7 DO 20 I=J,N
      JAN(N-I+J+1)=JAN(N-I+J)
   20 CONTINUE
      N=J-1
      GO TO 4
      END
      SUBROUTINE MRGFLS(F,A,B,XTOL,FTOL,NTOL,IFLAG)
C
C        MRGFLS USES THE MODIFIED REGULA FALSI METHOD IN
C        THE SOLUTION OF NONLINEAR EQUATIONS
C
      IFLAG=0
      FA=F(A)
      SIGNFA=SIGN(1.,FA)
      FB=F(B)
C********CHECK FOR SIGN CHANGE
      IF(SIGNFA*FB.LE.0.) GO TO 5
      IFLAG=3
      WRITE(6,601) A,B
  601 FORMAT(1X,'***F(X) IS OF SAME SIGN AT THE TWO ENDPOINTS'
     1,3X,E15.7,3X,E15.7)
      RETURN
    5 W=A
      FW=FA
      DO20 N=1,NTOL
C********CHECK FOR SUFFICIENTLY SMALL INTERVAL
      IF(ABS(B-A)/2..LE.XTOL) RETURN
C********CHECK FOR SUFFICIENTLY SMALL FUNCTION VALUES
      IF(ABS(FW) .GT.FTOL) GO TO 9
      A=W
      B=W
      IFLAG=1
      RETURN
    9 W=(FA*B-FB*A)/(FA-FB)
      PREVFW=SIGN(1.,FW)
      FW=F (W)
C********CHANGE TO NEW INTERVAL
      IF(SIGNFA*FW.LT.0.) GO TO 10
      A=W
      FA=FW
      IF(FW*PREVFW.GT.0.) FB=FB/2.
      GO TO 20
   10 B=W
      FB=FW
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      IF(FW*PREVFW.GT.0.) FA=FA/2.
   20 CONTINUE
      IFLAG=2
      WRITE(6,620)NTOL
  620 FORMAT('***NO CONVERGENCE IN',I5,'ITERATIONS')
      RETURN
      END
      SUBROUTINE SIMP(F,A,B,N,S)
C
C        SIMP PERFORMS NUMERICAL INTEGRATION BY SIMPSONS RULE
C
      IF(A.EQ.B) GO TO 10
      H=(B-A)/FLOAT(N)
      HOV2=H/2.
      S=0.
      HALF=F(A+HOV2)
      NM1=N-1
      DO 2 I=1,NM1
      X=A+FLOAT(I)*H
      S=S+F(X)
    2 HALF=HALF+F(X+HOV2)
      S=(H/6.)*(F(A)+4.*HALF+2.*S+F(B))
      RETURN
   10 S=0.00
      RETURN
      END
      SUBROUTINE LGNRM(N,EPSM,EPSCV,Z)
C
C           LGNRM GENERATES LOGNORMALLY DISTRIBUTED RANDOM VARIABLES
C
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RO,UWW,UWM,UWS
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      DIMENSION Z(N)
      SDEPS=EPSCV*EPSM
      XBAR=ALOG(EPSM)-SDEPS**2/2.
      SDX=SQRT(ALOG(EPSCV**2+1.))
      CALL NORMAL(N,Z)
      DO 100 I=1,N
      SNDRN=Z(I)
      Z(I)=SNDRN*SDX+XBAR
      Z(I)=EXP(Z(I))
  100 CONTINUE
      RETURN
      END
      SUBROUTINE  NORMAL(N,Z)
C
C           NORMAL GENERATES STANDARD NORMAL RANDOM VARIABLES
C
      DIMENSION Z(N),X(330),PDF(330),CDF(330)
      COMMON H,HO,THETAO,T,BETA,BETA1,ISEED,CALPHA,CBETA,RO,UWW,UWM,UWS
     *,RU,THETAC,ACC,AEQ,GRAV,THETA,DEPTH,XLEN
      R=1./SQRT(2.*3.14159)
      DX=.025
      X(1)=-4.
      PDF(1)=0.
      CDF(1)=0.
      DO 10     I=2,320
      X(I)=FLOAT(I-1)*DX-4.
      PDF(I)=R*EXP(-(X(I)**2)/2.)
   10 CONTINUE
```

```
      DO 20 J=3,320,2
      CDF(J)=CDF(J-2)+(PDF(J-2)+4*PDF(J-1)+PDF(J))*DX/3.
   20 CONTINUE
      II=1
      DO 30  K=1,320,2
      CDF(II)=CDF(K)
      PDF(II)=PDF(K)
      X(II)=X(K)
      II=II+1
   30 CONTINUE
      CALL GGUB(ISEED,N,Z)
      DO 40  IJ=1,N
      URV=Z(IJ)
      ID=SEARCH(CDF,1,160,URV)
      Z(IJ)=X(ID)+(X(ID+1)-X(ID))*(URV-CDF(ID))/(CDF(ID+1
     *)-CDF(ID))
   40 CONTINUE
      RETURN
      END
      FUNCTION SEARCH(A,IBOT,ITOP,B)
C
C            SEARCH SCANS AN ARRAY FOR THE POSITION NUMBER OF
C            THE ARRAY ELEMENT DIRECTLY BELOW A DESIRED NUMBER
C
      DIMENSION  A(ITOP)
      L=IBOT
      M=ITOP
   10 CONTINUE
      IF(L.GT.M) GO TO  20
      IF(B.GE.A(M)) GO TO 60
      K=(L+M)/2
      IF(B.GE.A(K).AND.B.LT.A(K+1)) GO TO 40
      IF(B-A(K))  30,40,50
   30 CONTINUE
      M=K-1
      GO TO 10
   50 CONTINUE
      L=K+1
      GO TO 10
   20 CONTINUE
      K=0
      GO TO 40
   60 K=M
   40 CONTINUE
      SEARCH=K
      RETURN
      END
C
C   THIS SUBROUTINE PROVIDES A QUADRATIC MAGNITUDE-FREQ RELATION
C     LN(NM)=A+B*M+C*M**2
C          WHERE A,B,C, ARE REGIONAL CONSTANTS
C          AND NM IS THE # OF EQ'S EXCEEDING MAGNITUDE M
C
      SUBROUTINE NYACC(B1,B2,B3,R,M1,M0,ISEED,ANSWER)
      REAL M1,M0
C   THESE VALUES ARE FOR NY STATE
      B=0.203
      C=-0.182
      CON=B*(M1-M0)+C*(M1*M1-M0*M0)
      CON=1/(1-EXP(CON))
```

```
      CALL GGUB(ISEED,1,RND)
      CONST=-B*MO-C*MO*MO-ALOG(1.-RND/CON)
      CONST=-4.0*C*CONST
      A=B**2.+CONST
      M=(-B-SQRT(A))/(2*C)
      ANSWER=B1*EXP(B2*M)/R**B3
      RETURN
      END
ND OF FILE
```