DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

In Situ Geomechanics of Crystalline and Sedimentary Rocks

Part VI: An Update on Two BASIC Computer Programs for the Determination of In Situ Stresses Using the CSIRO Hollow Inclusion Stress Cell and the USBM Borehole Deformation Gage

By

Henri S. Swolfs[1] and Philip S. Powers[1]

Open-File Report 85-509

1985

[1]U.S. Geological Survey
Denver, Colorado

IN SITU GEOMECHANICS OF CRYSTALLINE AND SEDIMENTARY ROCKS

PART VI: AN UPDATE ON TWO BASIC COMPUTER PROGRAMS FOR THE DETERMINATION OF IN SITU STRESSES USING THE CSIRO HOLLOW INCLUSION STRESS CELL AND THE USBM BOREHOLE DEFORMATION GAGE

By Henri S. Swolfs and Philip S. Powers

PREFACE

This report is the sixth of a series summarizing the results of the U.S. Geological Survey's research program in geomechanics aimed at investigating and assessing the potential of crystalline and sedimentary rock masses as geological repositories of nuclear waste. The first five parts of this series of reports are referenced below:

Savage, W. Z., and Swolfs, H. S., 1980, the long-term deformation and time-temperature correspondence of viscoelastic rock--an alternative theoretical approach, Pt. 1 of In situ geomechanics of crystalline and sedimentary rocks: U.S. Geological Survey Open-File Report 80-708, 21 p.

Smith, W. K., 1982, Two BASIC computer programs for the determination of in situ stresses using the CSIRO hollow incluion stress cell and the USBM borehole deformation gage [Pt. 2 of In situ geomechanics of crystalline and sedimentary rocks): U.S. Geological Survey Open-File Report 82-489,40 p.

Swolfs, H. S., 1982, First experiences with the C.S.I.R.O. hollow-inclusion stress cell, Pt. 3 of In situ geomechanics of crystalline and sedimentary rocks: U.S. Geological Survey Open-File report 82-990, 20 p.

Nichols, T. C., 1983, Continued field testing of the modified U.S. Geological Survey 3-D borehole stress probe, Pt. 4 of In situ geomechanics of crystalline and sedimentary rocks: U.S. Geological Survey Open-File Report 83-750, 11 p.

Savage, W. Z., Powers, P. S., and Swolfs, H. S., 1984, RVT--A FORTRAN program for an exact elastic solution for tectonic and gravity stresses of crystalline and sedimentary rocks: U.S. Geological Survey Open-File Report 84-827, 12 p.

Published journal articles that report on the findings of this program are referenced below:

Swolfs, H. S., and Kibler, J. D., 1982, A note on the Goodman Jack: Rock Mechanics, v. 15, no. 2, p. 57-66.

Swolfs, H. S., 1983, Aspects of the size-strength relationship of unjointed rocks: Chapter 51 in Rock Mechanics--Theory-Experiment-Practice: 24th U.S. Symposium on Rock Mechanics, College Station, Texas, p. 501-510.

Swolfs, H. S., 1984, The triangular stress diagram-a graphical representation of crustal stress measurements: U. S. Geological Survey Professional Paper 1291, 19 p.

Swolfs, H. S., and Savage, W. Z., 1984, Site characterization studies of a volcanic cap rock, Chapter 39 in Rock Mechanics in Productivity and Protection: 25th U.S. Symposium on Rock Mechanics, Evanston, Illinois, p. 370-380.

CONTENTS

Part VI: An Update on Two BASIC Computer Programs for the Determination of In Situ Stresses Using the CSIRO Hollow Inclusion Stress Cell and the USBM Borehole Deformation Gage

INTRODUCTION

The determination of the state of stress in rock masses is one of the more important problems in geomechanics, both for the design of underground openings and for assessing the effects of external influences, such as heating by stored radioactive materials. A common technique of stress determination is the overcoring method: a small-diameter pilot hole is drilled in the rock mass; an instrument for measuring strain or deformation in several directions is placed in the pilot hole; and a larger coaxial annulus is then drilled around the instrumented hole to register the deformations. Because the instrumented specimen is now released from the ambient stress field, the resulting deformations and knowledge of the rock moduli give a measure of the amount of stress relieved.

Two instruments in common use today are the U.S. Bureau of Mines (USBM) borehole deformation gage (Merrill, 1967), and the Commonwealth Scientific and Industrial Reasearch Organization (CSIRO, Australia) hollow-inclusion stress cell (Worotnicki and Walton, 1976).

The USBM instrument measures the change in borehole diameter along three directions in a single plane perpendicular to the borehole axis. Measurements in three or more nonparallel boreholes are required for a complete three-dimensional stress determination. The CSIRO instrument uses three strain-gage rosettes mounted around the circumference of a hollow epoxy cylinder which is cemented to the borehole wall prior to overcoring. Because of the three-dimensional orientation of the nine strain gages, it is possible to obtain a complete stress determination in a single borehole. Rock-mass moduli can be measured with these instruments using specialized techniques (Fitzpatrick, 1962).

The mathematical solution for the stress components is complex (Panek, 1966) and a digital computer is required to facilitate the reduction of the field measurements. In the past, the usual procedure has been to manually record the data in the field, return to the office, and perform the data reduction using a FORTRAN program and a large mainframe computer. Recent advances in computer technology and the availability of desk-top microcomputers have made it possible to perform immediate data reduction onsite and, in addition, to record the instrument response in real time during the overcoring process. In the field, this capability allows the investigator to immediately analyze the data, to assess its quality, and to make decisions to either abandon a particular test or to conduct additional tests while the drilling crew is still onsite. Most microcomputers in common use are programmable in BASIC. This report updates two BASIC data-reduction programs, one for use with the USBM borehole deformation gage, and the other for the CSIRO hollow-inclusion stress cell. These specialized programs were originally developed by Smith (1982) and offer the following advantages over the previously available FORTRAN programs:

1. They can be run on a desk-top microcomputer which can be transported to the field site, allowing data analyses to be performed on site.

2. The programs are shorter, but more specialized, because the available built-in matrix routines in BASIC eliminate the need for many subroutines.

3. Data input is greatly simplified by assigning the known (standard) orientation angles to the individual strain gages in the CSIRO instrument.

4. The programs work with any consistent set of units (English or SI).

CONTINUING DOCUMENTATION AND PROGRAM LISTINGS

Programs continually evolve even after a standard version has been released; this evolution includes the development of new capabilities, the detection and repair of errors, and application-oriented modifications. Here, we report on updated versions of programs that were originally developed on the Hewlett-Packard (HP) 9800 series microcomputers (Smith, 1982). With some modifications, the BASIC programs have been adapted for use on the Hewlett-Packard series 200 technical computers which are powerful standalone work-stations and instrument controllers.

The modifications are as follows:

1. The conversion of the programs USBM and CSIRO from the Hewlett-Packard 9845 BASIC to the Hewlett-Packard Series 200 BASIC 2.0 with an AP2.1 upgrade was straightforward and readily accomplished. The two major modifications were (a) to rename all simple variable names that were already in use as array variable names, and (b) to move the END statement so that it follows the final subroutine of the programs. The simple variable names that were renamed in both programs are K, J, and I; the variable K was replaced by K1, J by J1, and I by I1. The original END statement immediately preceding the final subroutine of the programs, was replaced by a REM statement and a GO TO statement that now direct the flow of the program to the new END statement immediately following the final subroutines.

2. Because BASIC 3.0 (or BASIC 2.0 plus AP2.1 upgrade) has built-in MAX and MIN functions, the 27 statements in the sort routine have been replaced by the 5 program lines suggested by Smith (1982, p. 18).

Definitions of program variables and program operation remain as described by Smith (1982). Memory requirements to run these upgraded programs on the HP 200 series computers are 24K bytes for USBM and 16K bytes for CSIRO.

```
10     REM ***                  PROGRAM LISTING FOR USBM
20     REM ***
30     REM *** ************************************************************ *
40     REM ***
50     REM *** A PROGRAM FOR THE CALCULATION OF STRESS COMPONENTS, PRINCIPAL
60     REM *** STRESSES, AND THEIR STANDARD DEVIATIONS FROM SETS OF READINGS
70     REM *** FROM THE u.s. bureau of mines borehole deformation gage IN
80     REM *** THREE OR MORE NON-PARALLEL BOREHOLES.
90     REM ***
100    REM *** PROGRAM MODIFIED FROM USBM BY WILLIAM K. SMITH BY P. POWERS
110    REM *** JUNE 7, 1985.
120    REM *** PROGRAM WILL RUN WITH THE HP-9836 WITH BASIC 3.0, OR BASIC
130    REM *** 2.0 WITH THE AP2_1 EXTENSION.
140    REM ***
150    REM *** LITTLE OR NO MODIFICATION WAS REQUIRED TO RUN THE PROGRAM ON
160    REM *** THE HP-9836.  ONE SIGNIFICANT MODIFICATION WAS THAT THE HP-9836
170    REM *** DOES NOT DIFFERENTIATE BETWEEN ARRAY NAMES AND SIMPLE VARIABLE
180    REM *** NAMES THAT ARE THE SAME, THEREBY PRODUCING AN ERROR.  NEW SIMPLE
190    REM *** VARIABLES HAVE BEEN INTRODUCED INTO THIS PROGRAM TO COMPENSATE
200    REM *** FOR THIS DIFFERENCE (i.e., VARIABLE 'I' WAS CHANGED TO 'I1').
210    REM ***
220    REM *** ********************** REFERENCES ******************************* *
230    REM ***
240    REM *** PANEK, LOUIS A., 1966, Calculation of the average ground stress
250    REM ***      components from measurements of the diametral deformation of
260    REM ***      a drill hole: U.S. Bureau of Mines Rept. of Inv. 6732, 41 p.;
270    REM ***      or ASTM S.T.P. 402, p. 106-132.
280    REM *** SMITH, WILLIAM K., 1982, Two BASIC computer programs for the
290    REM ***      determination of in-situ stresses using the CSIRO hollow
300    REM ***      inclusion gage and the USBM borehole deformation gage:
310    REM ***      U.S. Geological Survey Open-File Rept. 82-489, 40 p.
320    REM ***
330    REM *** ************************************************************ *
340    REM ***
350    REM *** COORDINATE SYSTEM:
360    REM ***      X-AXIS IS POSITIVE EAST
370    REM ***      Y-AXIS IS POSITIVE NORTH
380    REM ***      Z-AXIS IS POSITIVE UP
390    REM ***
400    REM ***      H1-AXIS IS HORIZONTAL TO THE RIGHT WHEN LOOKING INTO THE HOLE
410    REM ***      H2-AXIS COINCIDES WITH THE BOREHOLE AXIS
420    REM ***      H3-AXIS IS IN A VERTICAL PLANE, POINTS GENERALLY UPWARD
430    REM ***
440    REM *** BEARINGS ARE IN DEGREES CLOCKWISE FROM NORTH (AZIMUTH).
450    REM *** INCLINATIONS ARE IN DEGREES FROM THE HORIZONTAL, POSITIVE UPWARD.
460    REM *** BEARING OF A VERTICAL HOLE IS 90 DEGREES COUNTER-CLOCKWISE FROM
470    REM *** THE AZIMUTH OF H1-AXIS, AS DETERMINED FROM THE ORIENTATION OF THE
480    REM *** SETTING TOOL.
490    REM ***
500    REM *** *********************** UNITS *****************************
510    REM ***
520    REM ***                                              YOUNG'S
530    REM ***    CALIB. FACTOR           DIAMETER     MODULUS     STRESS
540    REM *** --------------------       --------     -------     ------
550    REM *** MICRO-IN/MICROSTRAIN        INCHES      10^6PSI       PSI
560    REM *** MICRO-M/MICROSTRAIN         METERS        GPa         KPa
570    REM ***
580    REM *** ************************************************************
590    OPTION BASE 1
600    PRINTER IS 1
```

```
610    R1=57.29578
620    DIM A(6,6),B(6,1),C(6,6),F(50,4),G(6,1),H(3),I(3,3),J(50,6),K(50,9)
630    DIM O(50,7),P(3,3),S(3,3),T(3),U(50),V(6),X(3,3),Y(3,3),Z(3,3)
640    REM *** define measurement angles for each channel
650    T(1)=90
660    T(2)=150
670    T(3)=30
680    REM *** read calibration factors for each channel
690    PRINT "Enter calibration factors for channels 1-3 in"
700    PRINT "micro-length per microstrain"
710    INPUT H(1),H(2),H(3)
720    K9=1
730    M=2
740    M=M-1
750    PRINT CHR$(12)
760    PRINT "Enter bearing, inclination, and diameter of borehole."
770    PRINT "Young's modulus (in mega-stress), and poisson's ratio"
780    B1=0
790    I1=0
800    D1=0
810    E1=0
820    P1=0
830    INPUT B1,I1,D1,E1,P1
840    IF B1=999 THEN 1340
850    B1=B1/R1
860    I1=I1/R1
870    E=E1*1.0E+6
880    L1=COS(B1)
890    M1=-SIN(B1)
900    N1=0
910    L2=SIN(B1)*COS(I1)
920    M2=COS(B1)*COS(I1)
930    N2=SIN(I1)
940    L3=-SIN(B1)*SIN(I1)
950    M3=-COS(B1)*SIN(I1)
960    N3=COS(I1)
970    PRINT CHR$(12)
980    PRINT "Enter channel no. and microstrain reading"
990    PRINT "Enter '999,999' to terminate readings for this borehole"
1000   INPUT C1,U(M)
1010   M=M+1
1020   IF C1=999 THEN 760
1030   A1=T(C1)/R1
1040   O(M-1,1)=U(M-1)
1050   U(M-1)=U(M-1)*1.0E-6*H(C1)
1060   O(M-1,2)=C1
1070   O(M-1,3)=B1*R1
1080   O(M-1,4)=I1*R1
1090   O(M-1,5)=D1
1100   O(M-1,6)=E1
1110   O(M-1,7)=P1
1120   K(M-1,1)=L1
1130   K(M-1,2)=L2
1140   K(M-1,3)=L3
1150   K(M-1,4)=M1
1160   K(M-1,5)=M2
1170   K(M-1,6)=M3
1180   K(M-1,7)=N1
1190   K(M-1,8)=N2
1200   K(M-1,9)=N3
```

```
1210  F(M-1,1)=(D1*(1+2*COS(2*A1))*(1-P1*P1)+D1*P1*P1)/E
1220  F(M-1,2)=-D1*P1/E
1230  F(M-1,3)=(D1*(1-2*COS(2*A1))*(1-P1*P1)+D1*P1*P1)/E
1240  F(M-1,4)=D1*4*SIN(2*A1)*(1-P1*P1)/E
1250  J(M-1,1)=F(M-1,1)*L1*L1+F(M-1,2)*L2*L2+F(M-1,3)*L3*L3+F(M-1,4)*L1*L3
1260  J(M-1,2)=F(M-1,1)*M1*M1+F(M-1,2)*M2*M2+F(M-1,3)*M3*M3+F(M-1,4)*M1*M3
1270  J(M-1,3)=F(M-1,1)*N1*N1+F(M-1,2)*N2*N2+F(M-1,3)*N3*N3+F(M-1,4)*N1*N3
1280  J(M-1,4)=2*F(M-1,1)*L1*M1+2*F(M-1,2)*L2*M2+2*F(M-1,3)*L3*M3+F(M-1,4)*(L1*M
3+L3*M1)
1290  J(M-1,5)=2*F(M-1,1)*M1*N1+2*F(M-1,2)*M2*N2+2*F(M-1,3)*M3*N3+F(M-1,4)*(M1*N
3+M3*N1)
1300  J(M-1,6)=2*F(M-1,1)*N1*L1+2*F(M-1,2)*N2*L2+2*F(M-1,3)*N3*L3+F(M-1,4)*(N1*L
3+N3*L1)
1310  IF K9=2 THEN 1430
1320  PRINT CHR$(12)
1330  GOTO 980
1340  M=M-1
1350  PRINTER IS 701
1360  PRINT
1370  PRINT "*U.S. BUREAU OF MINES BOREHOLE DEFORMATION GAGE DATA REDUCTION*"
1380  PRINT
1390  PRINT "number of deformation measurements = ";M
1400  PRINT
1410  PRINT " MICRO-              ******* BOREHOLE *******"
1420  PRINT " STRAIN   DEFORMATION  CH   BEARING  INCL.  DIAMETER   E     PR"
1430  FOR K1=1 TO M
1440    PRINT USING 1460;O(K1,1),U(K1),O(K1,2),O(K1,3),O(K1,4),O(K1,5),O(K1,6),O
(K1,7)
1450  NEXT K1
1460  IMAGE S6D,5X,S.6D,4X,D,3X,3D.D,3X,S2D.D,3X,D.4D,3X,2D.2D,3X,.3D
1470  PRINT
1480  PRINT "                    Channel  Angle   Calib. factor"
1490  FOR K1=1 TO 3
1500    PRINT USING 1520:K1,T(K1),H(K1)
1510  NEXT K1
1520  IMAGE 20X,D,5X,3D.D,5X,3D.3D
1530  PRINT
1540  REM ***  CLEAR A(I,J1) and G(J1) ARRAYS
1550  FOR J1=1 TO 6
1560    G(J1,1)=0
1570    FOR I1=1 TO 6
1580      A(I1,J1)=0
1590    NEXT I1
1600  NEXT J1
1610  REM *** COMPUTE [A] AND [G] ARRAYS
1620  FOR K1=1 TO M
1630    FOR J1=1 TO 6
1640      G(J1,1)=G(J1,1)+U(K1)*J(K1,J1)
1650      FOR I1=1 TO 6
1660        A(I1,J1)=A(I1,J1)+J(K1,I1)*J(K1,J1)
1670      NEXT I1
1680    NEXT J1
1690  NEXT K1
1700  MAT C= INV(A)
1710  MAT B= C*G
1720  REM *** compute statistical parameters
1730  IF K9=2 THEN 1950
1740  S1=0
1750  FOR K1=1 TO M
1760    S1=S1+U(K1)*U(K1)
```

```
1770  NEXT K1
1780  S2=B(1,1)*G(1,1)+B(2,1)*G(2,1)+B(3,1)*G(3,1)+B(4,1)*G(4,1)+B(5,1)*G(5,1)+B
(6,1)*G(6,1)
1790  S3=S1-S2
1800  R2=1-S3/S1
1810  R=SQR(R2)
1820  S4=SQR(S3/(M-6))
1830  PRINT USING 1890:S1
1840  PRINT USING 1900:S2
1850  PRINT USING 1910:S3
1860  PRINT USING 1920:S4
1870  PRINT USING 1930:R2
1880  PRINT USING 1940:R
1890  IMAGE "DEFORMATION SUM OF SQUARES = ".D.4DE
1900  IMAGE " [B].[G] =                    ".D.4DE
1910  IMAGE " RESIDUAL SUM OF SQUARES =    ".D.4DE
1920  IMAGE " STD. DEV. OF FITTED DATA =   ".D.4DE
1930  IMAGE " GOODNESS OF FIT (R**2) =     ".D.5D
1940  IMAGE " CORRELATION COEFFICIENT =    ".D.5D
1950  FOR I1=1 TO 6
1960    V(I1)=S4*SQR(C(I1,I1))
1970  NEXT I1
1980  IF K9=2 THEN 2880
1990  PRINT
2000  PRINT "STRESS COMPONENTS       STD. DEV."
2010  PRINT USING 2020:B(2,1),V(2)
2020  IMAGE "    NORMAL N-S = ",S6D, 4X, 5D
2030  PRINT USING 2040:B(1,1),V(1)
2040  IMAGE "    NORMAL E-W = ",S6D, 4X, 5D
2050  PRINT USING 2060:B(3,1),V(3)
2060  IMAGE "    NORMAL VER = ",S6D, 4X, 5D
2070  PRINT USING 2080:B(4,1),V(4)
2080  IMAGE "    SHEAR HOR =  ",S6D, 4X, 5D
2090  PRINT USING 2100:B(5,1),V(5)
2100  IMAGE "    SHEAR N-V =  ",S6D, 4X, 5D
2110  PRINT USING 2120:B(6,1),V(6)
2120  IMAGE "    SHEAR E-V =  ",S6D, 4X, 5D
2130  REM *** COMPUTE PRINCIPAL STRESSES AND ORIENTATIONS
2140  S(1,1)=B(1,1)
2150  S(2,1)=B(4,1)
2160  S(3,1)=B(6,1)
2170  S(1,2)=B(4,1)
2180  S(2,2)=B(2,1)
2190  S(3,2)=B(5,1)
2200  S(1,3)=B(6,1)
2210  S(2,3)=B(5,1)
2220  S(3,3)=B(3,1)
2230  REM *** COMPUTE INVARIANTS OF STRESS TENSOR
2240  I1=S(1,1)+S(2,2)+S(3,3)
2250  I2=S(1,1)*S(3,3)+S(2,2)*S(3,3)+S(1,1)*S(2,2)
2260  I4=S(2,3)^2+S(1,2)^2+S(1,3)^2
2270  I2=I2-I4
2280  MAT P= INV(S)
2290  I3=DET
2300  REM *** SOLVE CUBIC EQUATION BY TRIGONOMETRIC SUBSTITUTION
2310  Q1=-I1
2320  Q2=I2
2330  Q3=-I3
2340  Q4=(3*Q2-Q1*Q1)/3
2350  Q5=(2*Q1^3-9*Q1*Q2+27*Q3)/27
```

```
2360  Q6=-Q5/2/SQR(-Q4^3/27)
2370  Q7=ACS(Q6)/3
2380  X1=2*SQR(-Q4/3)*COS(Q7)
2390  X2=2*SQR(-Q4/3)*COS(Q7+120/R1)
2400  X3=2*SQR(-Q4/3)*COS(Q7+240/R1)
2410  Z(1,1)=X1-Q1/3
2420  Z(2,1)=X2-Q1/3
2430  Z(3,1)=X3-Q1/3
2440  REM  *** END OF CUBIC SOLUTION
2450  REM ***  SORT PRINCIPAL STRESSES
2460  Z1=MAX(Z(1,1),Z(2,1),Z(3,1))
2470  Z3=MIN(Z(1,1),Z(2,1),Z(3,1))
2480  Z(1,1)=Z1
2490  Z(2,1)=I1-Z1-Z3
2500  Z(3,1)=Z3
2510  REM *** END OF SORT
2520  REM *** COMPUTE DIRECTION COSINES OF PRINCIPAL STRESSES
2530  FOR N=1 TO 3
2540    MAT I= IDN
2550    MAT X= (Z(N,1))*I
2560    MAT Y= S-X
2570    N3=(Y(1,1)*Y(2,2)-Y(2,1) 2)/(Y(1,2)*Y(2,3)-Y(2,2)*Y(1,3))
2580    N2=-(Y(1,1)+Y(1,3)*N3)/Y(1,2)
2590    N4=SQR(1+N2*N2+N3*N3)
2600    P(1,N)=1/N4
2610    P(2,N)=N2/N4
2620    P(3,N)=N3/N4
2630    GOSUB 2970
2640    Z(N,2)=B5
2650    Z(N,3)=I5
2660  NEXT N
2670  REM *** RE-COMPUTE DIRECTION COSINES WITH RESPECT TO PRINCIPAL AXES
2680  REM *** TO COMPUTE STANDARD DEVIATIONS OF PRINCIPAL STRESSES
2690  FOR N=1 TO M
2700    L1=K(N,1)*P(1,1)+K(N,4)*P(2,1)+K(N,7)*P(3,1)
2710    M1=K(N,1)*P(1,2)+K(N,4)*P(2,2)+K(N,7)*P(3,2)
2720    N1=K(N,1)*P(1,3)+K(N,4)*P(2,3)+K(N,7)*P(3,3)
2730    L2=K(N,2)*P(1,1)+K(N,5)*P(2,1)+K(N,8)*P(3,1)
2740    M2=K(N,2)*P(1,2)+K(N,5)*P(2,2)+K(N,8)*P(3,2)
2750    N2=K(N,2)*P(1,3)+K(N,5)*P(2,3)+K(N,8)*P(3,3)
2760    L3=K(N,3)*P(1,1)+K(N,6)*P(2,1)+K(N,9)*P(3,1)
2770    M3=K(N,3)*P(1,2)+K(N,6)*P(2,2)+K(N,9)*P(3,2)
2780    N3=K(N,3)*P(1,3)+K(N,6)*P(2,3)+K(N,9)*P(3,3)
2790    J(N,1)=F(N,1)*L1*L1+F(N,2)*L2*L2+F(N,3)*L3*L3+F(N,4)*L1*L3
2800    J(N,2)=F(N,1)*M1*M1+F(N,2)*M2*M2+F(N,3)*M3*M3+F(N,4)*M1*M3
2810    J(N,3)=F(N,1)*N1*N1+F(N,2)*N2*N2+F(N,3)*N3*N3+F(N,4)*N1*N3
2820    J(N,4)=2*F(N,1)*L1*M1+2*F(N,2)*L2*M2+2*F(N,3)*L3*M3+F(N,4)*(L1*M3+L3*M1)
2830    J(N,5)=2*F(N,1)*M1*N1+2*F(N,2)*M2*N2+2*F(N,3)*M3*N3+F(N,4)*(M1*N3+M3*N1)
2840    J(N,6)=2*F(N,1)*N1*L1+2*F(N,2)*N2*L2+2*F(N,3)*N3*L3+F(N,4)*(N1*L3+N3*L1)
2850  NEXT N
2860  K9=2
2870  GOTO 1540
2880  PRINT
2890  PRINT " PRINCIPAL STRESSES"
2900  PRINT "     STRESS  STD. DEV.  BEARING  INCL."
2910  FOR N=1 TO 3
2920    PRINT USING 2940:B(N,1),V(N),Z(N,2),Z(N,3)
2930  NEXT N
2940  IMAGE 3X,SDDDDDD,4X,DDDDD,5X,DDD.D,3X,SDD.D
2950  REM     END
```

```
2960  GOTO 3210
2970  REM *** COMPUTE BEARINGS AND INCLINATIONS
2980  REM *** OF PRINCIPAL STESSES
2990  I5=90-ACS(P(3,N))*R1
3000  IF P(1,N)<>0 THEN 3090
3010  IF P(2,N)>0 THEN 3050
3020  IF P(2,N)<0 THEN 3070
3030  B5=999
3040  GOTO 3200
3050  B5=0
3060  GOTO 3200
3070  B5=180
3080  GOTO 3200
3090  B5=ATN(P(1,N)/P(2,N))*R1
3100  IF P(2,N)<0 THEN 3140
3110  IF P(1,N)>0 THEN 3150
3120  B5=360+B5
3130  GOTO 3150
3140  B5=180+B5
3150  IF I5<0 THEN 3180
3160  I5=-I5
3170  B5=180+B5
3180  IF B5<360 THEN 3200
3190  B5=B5-360
3200  RETURN
3210  END
```

```
10    REM ***                 PROGRAM LISTING FOR CSIRO
20    REM ***
30    REM *** ************************************************************
40    REM ***
50    REM *** A PROGRAM FOR THE CALCULATION OF STRESS COMPONENTS, PRINCIPAL
60    REM *** STRESSES, AND THEIR STANDARD DEVIATIONS FROM STRAIN READINGS FROM
70    REM *** THE csiro hollow inclusion stress cell IN A SINGLE BOREHOLE.
80    REM ***
90    REM *** PROGRAM MODIFIED FROM CSIRO BY WILLIAM K. SMITH BY P. POWERS
100   REM *** JUNE 6, 1985.
110   REM *** PROGRAM WILL RUN WITH THE HP-9836 WITH BASIC 3.0, OR BASIC
120   REM *** 2.0 WITH THE AP2_1 EXTENSION.
130   REM ***
140   REM *** LITTLE OR NO MODIFICATION WAS REQUIRED TO RUN THE PROGRAM ON
150   REM *** THE HP-9836.  ONE SIGNIFICANT MODIFICATION WAS THAT THE HP-9836
160   REM *** DOES NOT DIFFERENTIATE BETWEEN ARRAY NAMES AND SIMPLE VARIABLE
170   REM *** NAMES THAT ARE THE SAME, THEREBY PRODUCING AN ERROR.  NEW SIMPLE
180   REM *** VARIABLES HAVE BEEN INTRODUCED INTO THE PROGRAM TO COMPENSATE
190   REM *** FOR THIS DIFFERENCE (I.E. VARIABLE 'I' WAS CHANGED TO 'I1'.).
200   REM ***
210   REM *** ********************** REFERENCES *********************************
220   REM ***
230   REM *** PANEK, LOUIS A., 1966, Calculation of the average ground stress
240   REM ***      components from measurements of the diametral deformation of
250   REM ***      a drill hole: U.S. Bureau of Mines Rept. of Inv. 6732, 41 p.;
260   REM ***      or ASTM S.T.P. 402, p. 106-132.
270   REM *** WOROTNICKI, G., and WALTON, R., 1976, Triaxial "hollow inclusion"
280   REM ***      gauges for determination of rock stresses in situ: Common-
290   REM ***      wealth Sci. and Ind. Res. Org. (AUSTRALIA) Div., Applied
300   REM ***      Geomechanics Research Paper 275: or Proc. Symp. on Investiga-
310   REM ***      tion of stress in rock - Advances in stress measurement,
320   REM ***      Sydney, 1976, p. 1-8 (pre-print).
330   REM *** FIELD Manual for CSIRO hollow inclusion gauge (includes FORTRAN
340   REM ***      data reduction program).
350   REM *** SMITH, WILLIAM K., 1982, Two BASIC computer programs for the
360   REM ***      determination of in-situ stresses using the CSIRO hollow
370   REM ***      inclusion gage and the USBM borehole deformation gage:
380   REM ***      U.S. Geological Survey Open-File Rept. 82-489, 40 p.
390   REM ***
400   REM *** **************************************************************
410   REM ***
420   REM *** COORDINATE SYSTEMS:
430   REM ***    X-AXIS IS POSITIVE EAST
440   REM ***    Y-AXIS IS POSITIVE NORTH
450   REM ***    Z-AXIS IS POSITIVE UP
460   REM ***
470   REM ***    H1-AXIS IS HORIZONTAL TO THE RIGHT WHEN LOOKING INTO THE HOLE
480   REM ***    H2-AXIS COINCIDES WITH THE BOREHOLE AXIS.
490   REM ***    H3-AXIS IS IN A VERTICAL PLAN, POINTS GENERALLY UPWARD
500   REM ***
510   REM *** BEARINGS ARE IN DEGREES CLOCKWISE FROM THE NORTH (AZIMUTH).
520   REM *** INCLINATIONS ARE IN DEGREES FROM HORIZONTAL, POSITIVE UPWARD.
530   REM *** BEARING OF A VERTICAL HOLE IS 90 DEGREES COUNTER-CLOCKWISE
540   REM *** FROM THE AZIMUTH OF THE H1-AXIS, AS DETERMINED FROM THE
550   REM *** ORIENTATION OF THE SETTING TOOL.
560   REM *** UNITS FOR THE STRESS VALUES IN THE OUTPUT ARE SAME AS THOSE FOR
570   REM *** USED FOR YOUNG'S MODULUS IN THE INPUT.
580   REM *** ORIENTATION ANGLES ALPHA & BETA AND CORRECTION FACTORS K1-K4 ARE
590   REM *** INITIALIZED IN DATA STATEMENTS.
```

```
600   REM *** ALPHA AND BETA ANGLES WILL NOT CHANGE AS LONG AS STANDARD
610   REM *** INSTALLATION PROCEDURES ARE USED.  CORRECTION FACTORS MAY CHANGE
620   REM *** DEPENDING ON THE ROCK/EPOXY MODULUS RATIO.
630   REM ***
640   REM *** ****************************************************************
650   OPTION BASE 1
660   PRINTER IS 1
670   DIM A(6,6),B(6,1),C(6,6),D(9,2),E(9),F(9,6),G(6,1),I(3,3),J(9,6),K(9,9)
680   DIM P(3,3),S(3,3),T(9,2),U(9),V(6),X(3,3),Y(3,3),Z(3,3),H(9)
690   R1=57.29578
700   K9=1
710   PRINT "INPUT NUMBER OF STRAIN READINGS TO BE AVERAGED"
720   INPUT M
730   PRINT CHR$(12)
740   PRINT "INPUT ELASTIC MODULUS AND POISSON'S RATIO"
750   INPUT E1,P1
760   PRINT CHR$(12)
770   PRINT "INPUT BEARING AND INCLINATION OF BOREHOLE"
780   INPUT B2,I2
790   B1=B2/R1
800   I1=I2/R1
810   REM *** READ ORIENTATION ANGLES ALPHA AND BETA
820   REM *** AND CORRECTION FACTORS K1 THROUGH K4
830   FOR N=1 TO 9
840     READ D(N,1)
850   NEXT N
860   FOR N=1 TO 9
870     READ D(N,2)
880   NEXT N
890   READ K1,K2,K3,K4
900   DATA 322.9,300,300,163.6,163.6,180,82.9,60,60
910   DATA 0,90,45,45,135,90,0,90,45
920   DATA 1.12,1.13,1.08,0.91
930   REM *** CONVERT ALPHA AND BETA TO RADIANS
940   MAT T= (1/R1)*D
950   PRINT CHR$(12)
960   PRINT "INPUT ";M;"GAGE NUMBERS AND CORRESPONDING MICROSTRAINS"
970   FOR N=1 TO M
980     INPUT H(N),E(N)
990     U(N)=E(N)*1.0E-6
1000  NEXT N
1010  PRINT CHR$(12)
1020  PRINTER IS 701
1030  PRINT "*** CSIRO HOLLOW INCLUSION STRESS CELL DATA REDUCTION ***"
1040  PRINT
1050  PRINT "              MICRO-"
1060  PRINT " GAGE NO.     STRAIN    ALPHA     BETA"
1070  FOR N=1 TO M
1080    PRINT USING 1090;H(N),E(N),D(H(N),1),D(H(N),2)
1090    IMAGE (4X,D,6X,S6D,5X,3D.D,4X,3D.D)
1100  NEXT N
1110  PRINT
1120  PRINT " BOREHOLE BEARING = ";B2;";          INCLINATION =    ";I2
1130  PRINT "     MODULUS =      ";E1;";      POISSON'S RATIO = ";P1
1140  PRINT
1150  L1=COS(B1)
1160  M1=-SIN(B1)
1170  N1=0
1180  L2=SIN(B1)*COS(I1)
1190  M2=COS(B1)*COS(I1)
```

```
1200  N2=SIN(I1)
1210  L3=-SIN(B1)*SIN(I1)
1220  M3=-COS(B1)*SIN(I1)
1230  N3=COS(I1)
1240  FOR N=1 TO M
1250    K(N,1)=L1
1260    K(N,2)=L2
1270    K(N,3)=L3
1280    K(N,4)=M1
1290    K(N,5)=M2
1300    K(N,6)=M3
1310    K(N,7)=N1
1320    K(N,8)=N2
1330    K(N,9)=N3
1340    F1=COS(2*T(H(N),1))
1350    F2=COS(2*T(H(N),2))
1360    F3=SIN(2*T(H(N),1))
1370    F4=SIN(2*T(H(N),2))
1380    F5=P1*P1
1390    F(N,1)=((1-F5)*F1*(1-F2)*K2+.5*(K1-P1)-.5*(K1+P1)*F2)/E1
1400    F(N,2)=(.5*(1-K4*P1)+.5*(1+K4*P1)*F2)/E1
1410    F(N,3)=((F5-1)*F1*(1-F2)*K2+.5*(K1-P1)-.5*(K1+P1)*F2)/E1
1420    F(N,4)=2*(1+P1)*COS(T(H(N),1))*F4*K3/E1
1430    F(N,5)=-2*(1+P1)*SIN(T(H(N),1))*F4*K3/E1
1440    F(N,6)=2*(F5-1)*F3*(1-F2)*K2/E1
1450  NEXT N
1460  FOR N=1 TO 9
1470    J(N,1)=F(N,1)*L1*L1+F(N,2)*L2*L2+F(N,3)*L3*L3+F(N,4)*L1*L2+F(N,5)*L2*L3+
F(N,6)*L1*L3
1480    J(N,2)=F(N,1)*M1*M1+F(N,2)*M2*M2+F(N,3)*M3*M3+F(N,4)*M1*M2+F(N,5)*M2*M3+
F(N,6)*M1*M3
1490    J(N,3)=F(N,1)*N1*N1+F(N,2)*N2*N2+F(N,3)*N3*N3+F(N,4)*N1*N2+F(N,5)*N2*N3+
F(N,6)*N1*N3
1500    J(N,4)=2*F(N,1)*L1*M1+2*F(N,2)*L2*M2+2*F(N,3)*L3*M3+F(N,4)*(L1*M2+L2*M1)
+F(N,5)*(L2*M3+L3*M2)+F(N,6)*(L1*M3+L3*M1)
1510    J(N,5)=2*F(N,1)*M1*N1+2*F(N,2)*M2*N2+2*F(N,3)*M3*N3+F(N,4)*(M1*N2+M2*N1)
+F(N,5)*(M2*N3+M3*N2)+F(N,6)*(M1*N3+M3*N1)
1520    J(N,6)=2*F(N,1)*L1*N1+2*F(N,2)*L2*N2+2*F(N,3)*L3*N3+F(N,4)*(L1*N2+L2*N1)
+F(N,5)*(L2*N3+L3*N2)+F(N,6)*(L1*N3+L3*N1)
1530  NEXT N
1540  REM *** CLEAR A(I,J) AND G(J) ARRAYS
1550  FOR J1=1 TO 6
1560    G(J1,1)=0
1570    FOR I1=1 TO 6
1580      A(I1,J1)=0
1590    NEXT I1
1600  NEXT J1
1610  REM *** COMPUTE [A] AND [G] ARRAYS
1620  FOR K1=1 TO M
1630    FOR J1=1 TO 6
1640      G(J1,1)=G(J1,1)+U(K1)*J(K1,J1)
1650      FOR I1=1 TO 6
1660        A(I1,J1)=A(I1,J1)+J(K1,I1)*J(K1,J1)
1670      NEXT I1
1680    NEXT J1
1690  NEXT K1
1700  MAT C= INV(A)
1710  MAT B= C*G
1720  REM *** COMPUTE STATISTICAL PARAMETERS
1730  IF K9=2 THEN 1950
```

```
1740  S1=0
1750  FOR K1=1 TO M
1760    S1=S1+U(K1)*U(K1)
1770  NEXT K1
1780  S2=B(1,1)*G(1,1)+B(2,1)*G(2,1)+B(3,1)*G(3,1)+B(4,1)*G(4,1)+B(5,1)*G(5,1)+B
(6,1)*G(6,1)
1790  S3=S1-S2
1800  R2=1-S3/S1
1810  R=SQR(R2)
1820  S4=SQR(S3/(M-6))
1830  PRINT USING 1890;S1
1840  PRINT USING 1900;S2
1850  PRINT USING 1910;S3
1860  PRINT USING 1920;S4
1870  PRINT USING 1930;R2
1880  PRINT USING 1940;R
1890  IMAGE " STRAIN SUM OF SQUARES    = ",D.4DE
1900  IMAGE " [B].[G]                  = ",D.4DE
1910  IMAGE " RESIDUAL SUM OF SQUARES = ",D.4DE
1920  IMAGE " STD. DEV OF FITTED DATA = ",D.4DE
1930  IMAGE " GOODNESS OF FIT (R**2)  = ",D.5D
1940  IMAGE " CORRELATION COEFFICIENT = ",D.5D
1950  FOR I1=1 TO 6
1960    V(I1)=S4*SQR(C(I1,I1))
1970  NEXT I1
1980  IF K9=2 THEN 2820
1990  PRINT
2000  PRINT " STRESS COMPONENTS       STD. DEV."
2010  PRINT USING 2020;B(2,1),V(2)
2020  IMAGE "     NORMAL N-S = ",S3D.2D,4X,3D.2D
2030  PRINT USING 2040;B(1,1),V(1)
2040  IMAGE "     NORMAL E-W = ",S3D.2D,4X,3D.2D
2050  PRINT USING 2060;B(3,1),V(3)
2060  IMAGE "     NORMAL VER = ",S3D.2D,4X,3D.2D
2070  PRINT USING 2080;B(4,1),V(4)
2080  IMAGE "     SHEAR HORZ = ",S3D.2D,4X,3D.2D
2090  PRINT USING 2100;B(5,1),V(5)
2100  IMAGE "     SHEAR  N-V = ",S3D.2D,4X,3D.2D
2110  PRINT USING 2120;B(6,1),V(6)
2120  IMAGE "     SHEAR  E-V = ",S3D.2D,4X,3D.2D
2130  REM *** COMPUTE PRINCIPAL STRESSES AND ORIENTATIONS
2140  S(1,1)=B(1,1)
2150  S(2,1)=B(4,1)
2160  S(3,1)=B(6,1)
2170  S(1,2)=B(4,1)
2180  S(2,2)=B(2,1)
2190  S(3,2)=B(5,1)
2200  S(1,3)=B(6,1)
2210  S(2,3)=B(5,1)
2220  S(3,3)=B(3,1)
2230  REM *** COMPUTE INVARIANTS OF STRESS TENSOR
2240  I1=S(1,1)+S(2,2)+S(3,3)
2250  I2=S(1,1)*S(3,3)+S(2,2)*S(3,3)+S(1,1)*S(2,2)
2260  I4=S(2,3)^2+S(1,2)^2+S(1,3)^2
2270  I2=I2-I4
2280  MAT P= INV(S)
2290  I3=DET
2300  REM *** SOLVE CUBIC EQUATION BY TRIGONOMETRIC SUBSTITUTION
2310  Q1=-I1
2320  Q2=I2
```

```
2330  Q3=-I3
2340  Q4=(3*Q2-Q1*Q1)/3
2350  Q5=(2*Q1^3-9*Q1*Q2+27*Q3)/27
2360  Q6=-Q5/2/SQR(-Q4 3/27)
2370  Q7=ACS(Q6)/3
2380  X1=2*SQR(-Q4/3)*COS(Q7)
2390  X2=2*SQR(-Q4/3)*COS(Q7+120/R1)
2400  X3=2*SQR(-Q4/3)*COS(Q7+240/R1)
2410  Z(1,1)=X1-Q1/3
2420  Z(2,1)=X2-Q1/3
2430  Z(3,1)=X3-Q1/3
2440  REM *** END OF CUBIC SOLUTION
2450  REM *** SORT PRINCIPAL STRESSES
2460  Z1=MAX(Z(1,1),Z(2,1),Z(3,1))
2470  Z3=MIN(Z(1,1),Z(2,1),Z(3,1))
2480  Z(1,1)=Z1
2490  Z(2,1)=I1-Z1-Z3
2500  Z(3,1)=Z3
2510  REM *** END OF SORT
2520  REM *** COMPUTE DIRECTION COSINES OF PRINCIPAL STRESSES
2530  FOR N=1 TO 3
2540    MAT I= IDN
2550    MAT X= (Z(N,1))*I
2560    MAT Y= S-X
2570    N3=(Y(1,1)*Y(2,2)-Y(2,1) 2)/(Y(1,2)*Y(2,3)-Y(2,2)*Y(1,3))
2580    N2=-(Y(1,1)+Y(1,3)*N3)/Y(1,2)
2590    N4=SQR(1+N2*N2+N3*N3)
2600    P(1,N)=1/N4
2610    P(2,N)=N2/N4
2620    P(3,N)=N3/N4
2630    GOSUB 2910
2640    Z(N,2)=B5
2650    Z(N,3)=I5
2660  NEXT N
2670  REM *** RE-COMPUTE DIRECTION COSINES WITH RESPECT TO PRINCIPAL AXES
2680  REM *** TO COMPUTE STANDARD DEVIATIONS OF PRINCIPAL STRESSES
2690  FOR N=1 TO M
2700    L1=K(N,1)*P(1,1)+K(N,4)*P(2,1)+K(N,7)*P(3,1)
2710    M1=K(N,1)*P(1,2)+K(N,4)*P(2,2)+K(N,7)*P(3,2)
2720    N1=K(N,1)*P(1,3)+K(N,4)*P(2,3)+K(N,7)*P(3,3)
2730    L2=K(N,2)*P(1,1)+K(N,5)*P(2,1)+K(N,8)*P(3,1)
2740    M2=K(N,2)*P(1,2)+K(N,5)*P(2,2)+K(N,8)*P(3,2)
2750    N2=K(N,2)*P(1,3)+K(N,5)*P(2,3)+K(N,8)*P(3,3)
2760    L3=K(N,3)*P(1,1)+K(N,6)*P(2,1)+K(N,9)*P(3,1)
2770    M3=K(N,3)*P(1,2)+K(N,6)*P(2,2)+K(N,9)*P(3,2)
2780    N3=K(N,3)*P(1,3)+K(N,6)*P(2,3)+K(N,9)*P(3,3)
2790  NEXT N
2800  K9=2
2810  GOTO 1460
2820  PRINT
2830  PRINT " PRINCIPAL STRESSES"
2840  PRINT "    STRESS  STD. DEV.  BEARING  INCL."
2850  FOR N=1 TO 3
2860    PRINT USING 2880:B(N,1),V(N),Z(N,2),Z(N,3)
2870  NEXT N
2880  IMAGE 3X,S3D.2D,4X,2D.2D,5X,3D.D,3X,S2D.D
2890  REM  THE END
2900  GOTO 3150
2910  REM *** COMPUTE BEARINGS AND INCLINATIONS
2920  REM *** OF PRINCIPAL STRESSES
```

```
2930  I5=90-ACS(P(3,N))*R1
2940  IF P(1,N)<>0 THEN 3030
2950  IF P(2,N)>0 THEN 2990
2960  IF P(2,N)<0 THEN 3010
2970  B5=999
2980  GOTO 3140
2990  B5=0
3000  GOTO 3140
3010  B5=180
3020  GOTO 3140
3030  B5=ATN(P(1,N)/P(2,N))*R1
3040  IF P(2,N)<0 THEN 3080
3050  IF P(1,N)>0 THEN 3090
3060  B5=360+B5
3070  GOTO 3090
3080  B5=180+B5
3090  IF I5<0 THEN 3120
3100  I5=-I5
3110  B5=180+B5
3120  IF B5<360 THEN 3140
3130  B5=B5-360
3140  RETURN
3150  END
```

REFERENCES

Fitzpatrick, J., 1962, Biaxial device for determining the modulus of elasticity in stress-relief cores: U.S. Bureau of Mines Report of Investigations 7015, 38 p.

Merrill, R. H., 1967, Three-component borehole deformation gage for determining the stress in rock: U.S. Bureau of Mines Report of Investigations 7015, 38 p.

Panek, L. A., 1966, Calculation of the average ground stress components from measurements of the diametral deformation of a drill hole: American Society for Testing and Materials Special Technical Publication 402, p. 106-132.

Smith, W. K., 1982, Two BASIC computer programs for the determination of in situ stresses using the CSIRO hollow inclusion stress cell and the USBM borehole deformation gage [Part II of In situ geomechanics of crystalline and sedimentary rocks]: U.S. Geological Survey Open-File Report 82-489, 40 p.

Worotnicki, G., and Walton, R. J., 1976, Triaxial "hollow-inclusion" gauges for the determination of rock stresses in situ, in Investigation of stress in rock--Advances in stress measurement, International Society of Rock Mechanics Symposium, Sidney, Australia, National Conference Publication 76/4, Supplement, p. 1-8.