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A Computer Program for the Calculation of Geomagnetic Field Changes due to an Inclined Rectangular Fault in a Half Space

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Abstract

It has been reported that the geomagnetic changes were accompanied with seismic activities. To estimate the seismomagnetic effect, Sasai (1991) presented the analytical solution of piezomagnetic potential in case of a vertical faulting. We expanded Sasai's method to an inclined faulting with arbitrary dip angle and developed a FORTRAN program to calculate the geomagnetic field changes.

1. Introduction

We established an analytic form of seismomagnetic effect due to an inclined rectangular fault with uniform slip (Utsugi et al., in preparation). As the mathematical expression is somewhat complicated, we present the FORTRAN program MGCAL for the sake of user's convenience. The program allows us to calculate the geomagnetic field changes in the northward, eastward and downward components, as well as the total force.

2. Formulation of piezomagnetic potential

2.1. Piezomagnetic potential due to an inclined fault

In the present section, we show an expression of the piezomagnetic potential due to an inclined fault briefly. Sasai (1991) formulated the elementary piezomagnetic potential ω^k_{lm}, i.e. piezomagnetic potential due to a point dislocation source. ω^k_{lm} is given by the integral over the surface of magnetized region of the medium ;

$$\omega_{lm}^{k}(\boldsymbol{r}, \boldsymbol{\xi}) = C_k \iint_S \left[S_{lm}^{k}(\boldsymbol{r}', \boldsymbol{\xi}) \cdot \boldsymbol{n} \frac{1}{|\boldsymbol{r}-\boldsymbol{r}'|} + \tau_{lm}^{k}(\boldsymbol{r}', \boldsymbol{\xi}) \frac{\partial}{\partial n} \frac{1}{|\boldsymbol{r}-\boldsymbol{r}'|} \right] dS_{r'} \quad (1)$$

$$C_k = \frac{1}{2} \beta J_k \mu \frac{3\lambda+2\mu}{\lambda+\mu}, \quad (2)$$

where $\boldsymbol{\xi}$ and $\boldsymbol{r}$ denote source point and observation point, respectively. τ_{lm}^{k} is the k-th component of displacement vector produced by point dislocation source of type (l, m). S_{lm}^{k} is the stress-induced magnetization vector. λ and μ are the Lamé constants, β is the stress sensitivity, J_k is the k-th component of initial magnetization of crustal rock, and C_k is the k-th component of seismomagnetic moment produced by the piezomagnetic effect.

For the finite fault, we can obtain the piezomagnetic potential as the following integral over the fault plain Σ ;

$$W^{k}(\boldsymbol{r}) = \iint_{\Sigma} \Delta u_l(\boldsymbol{\xi}) \cdot \omega_{lm}^{k}(\boldsymbol{r}, \boldsymbol{\xi}) \cdot \nu_m(\boldsymbol{\xi}) d\Sigma_{\xi}, \quad (3)$$

where W^k indicates the piezomagnetic potential produced by k-th component of initial magnetization of crustal rock, Δu_l is the dislocation vector (its l-th component) and ν_m is a unit vector normal to the fault plain (its m-th component).

For an inclined rectangular fault (length L, width W, depth d and dip-angle δ) with uniform slip (U_1, U_2, U_3) (Fig. 1), eq. (3) can be written in the following form ;

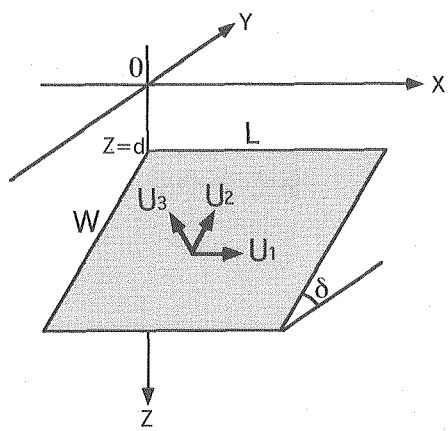

Fig. 1. Geometry of the fault model. Positive U_1, U_2 and U_3 with $0 < \delta < \pi/2$ indicate left-lateral slip, thrusting slip and tensile opening, respectively.

$$W^k(\boldsymbol{r}) = U_1 \cdot S^k(\boldsymbol{r}) + U_2 \cdot D^k(\boldsymbol{r}) + U_3 \cdot T^k(\boldsymbol{r}) \quad (4)$$

where S^k, D^k and T^k indicate the piezomagnetic potentials due to strike-slip, dip-slip and tensile opening faulting, respectively. These potentials can be written by the integral of ω^k_{lm} over the fault plain (Utsugi et al., in preparation).

2.2. *Earth model*

We assume the earth as a homogeneous and isotropic elastic half-space having a uniformly magnetized upper layer with a constant piezomagnetic stress sensitivity. We also assume the observation point is outside the medium.

We introduce a Cartesian coordinate as shown in Fig. 2, where X, Y and Z axes are directed east, north and downward, respectively. A point above the left edge of the fault is taken to be the origin of the coordinate as shown in Fig. 2. X' and Y' are parallel and perpendicular axes to the strike direction of the fault.

A semi-infinite elastic medium occupies $Z \geq 0$ and magnetized region is limited within a layer $0 \leq Z \leq H$, where H is the depth of the Curie point isotherm. Then we have to calculate ω^k_{lm} of eq. (1) over the free-surface (S_0), the fault plain (Σ) and the plain $Z = H(S_H)$. Therefore, W^k of eq. (3) can be written by the summation of the contributions from S_0, Σ and S_H. As W^k

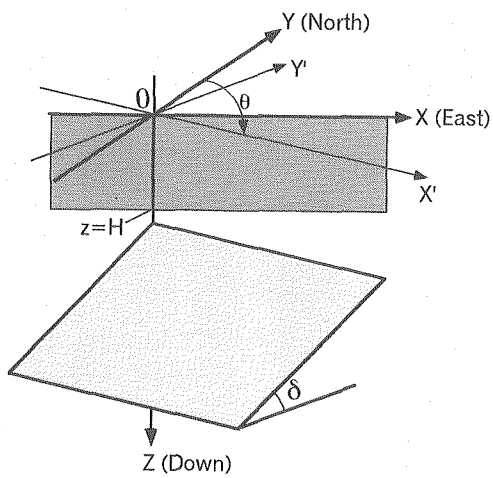

Fig. 2. Coordinate system. X, Y and Z axis direct eastward, northward and downward, respectively. θ and H mean strike-angle and depth of Curie point isotherm, rspectively.

depends on the fault depth, we write W^k as the following form;

$$W^k = W^k_{S_0+\Sigma} + W^k_{H0} + \begin{cases} W^k_{HI} & (d + W \sin\delta > H) \\ W^k_{HII} & (d < H) \end{cases}$$

For this earth model, we can obtain the analytical solution of W^k as well as S^k, D^k and T^k. The geomagnetic changes can be obtained by differentiating W^k with respect to X, Y and Z. The analytical solution of geomagnetic changes are listed in Utsugi et al. (in preparation). As these solutions become singular when dip angle $\delta = \pi/2$ (i.e. vertical fault), we cannot calculate geomagnetic changes. In this case, we should use the solution for vertical faulting presented by Sasai (1991).

3. Program

3.1. Design of the program

The program MGCAL is designed for the analytical calculation of geomagnetic field changes due to an inclined rectangular fault. This program consists of a main program and 14 subroutines. The complete source list is given in Appendix.

The main program MGCAL calls subroutine CALCON1 and PIEZ. CALCON1 calculates seismomagnetic moment and constants with respect to medium included in S^k, D^k and T^k. The geomagnetic changes are calculated by subroutine PIEZ. This subroutine calls subroutine DIFCOEF which calculate the geomagnetic changes in the coordinate system (X', Y', Z) (Fig. 2). These geomagnetic changes are transformed in the coordinate system (X, Y, Z) in subroutine PIEZ. The subroutine DIFCOEF calls following subroutines;

DERIV Calculate constants which are needed to calculate geomagnetic changes.

STRIKE_0, DIP_0, TENSILE_0 Calculate geomagnetic changes produced by free-surface and fault plain due to strike, dip and tensile-opening faulting ($S_0+\Sigma$).

STRIKE_H0, DIP_H0, TENSILE_H0 Calculate geomagnetic changes produced by Curie surface due to strike, dip and tensile-opening faulting (H0).

STRIKE_H, DIP_H, TENSILE_H Calculate geomagnetic changes produced by Curie surface due to strike, dip and tensile-opening faulting (HI+HII).

3.2. *Process*

In our program, we can chose the calculation point: the grid point or arbitrary point. Prior to execution of this program, we have to make a parameter file. The format of the parameter file is as follows;

Calculation at grid points;	Calculation at arbitrary points;
IFLG	IFLG
NDX NDY XX0 YY0	NUMB
DX DY	U1 U2 U3 FL FW DPT STR DIP
Z	POI AMU CMZ GMINC GMDEC HH
U1 U2 U3 FL FW DPT STR DIP	BETA
POI AMU CMZ GMINC GMDEC HH	X Y Z
BETA	

The meaning of these parameters are described in Table 1 and 2. When our program is executed, firstly we have to chose the calculation point:
"CALCULATE AT GRID POINTS OR ARBITRARY POINTS?"
"TYPE GRID POINTS=1 OR ARBITRARY POINTS=2"

Next, the parameter file name and output file name are requested:

"PARAMETER FILE NAME IS=?"
"OUTPUT FILE NAME IS=?"

Then the output file is made: geomagnetic field changes are output with the coordinate of calculation point. The parameter "IFLG" is prepared for choice of geomagnetic field components (eastward-, northward-, downward-component or total force) (see Table 1).

Table 1. The roles of input parameter IFLG.

IFLG	Designates output values.
=1	Output eastward component of geomagnetic field change.
=2	Output northward component of geomagnetic field change.
=3	Output downward component of geomagnetic field change.
=4	Output total force of geomagnetic field change.

Table 2. The meaning of input parameters.

In the case of the calculation at grid points:

NDX, NDY		Grid number.
DX, DY		Sample interval of X and Y axis.
XX0, YY0		Coordinate of start point of grid.
Z	(km)	Z-coordinate of observation points ($Z \leq 0$).

In the case of the calculation at arbitrary points:

NUMB		Number of arbitrary points.
X, Y, Z	(km)	Coordinates of observation points.

Fault parameters and medium parameters:

U1, U2, U3	(m)	Components of the displacement vector (U_1, U_2, U_3).
FL, FW	(km)	Fault length L and width W.
STR	(degree)	Strike angle of the fault θ.
DIP	(degree)	Dip angle of the fault δ ($0 \leq \delta < \pi/2$).
DPT	(km)	Depth of the upper boundary of the fault d.

POI		Poisson ratio.
AMU	(cgs)	Lamé constant μ.
CMZ	(A/m)	Initial magnetization of crustal rock $\|\boldsymbol{J}\|$.
GMDEC	(degree)	Magnetic declination.
GMINC	(degree)	Magnetic inclination.
HH	(km)	Depth of the Curie point isotherm H.
BETA	(bar^{-1})	Stress sensitivity β.

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References

Sasai Y., 1991. Tectonomagnetic modeling on the basis of the linear piezomagnetic effect. Bull. Earth. Res. Inst., Univ. Tokyo, **66**, 585-722.

Appendix

```
C
      PROGRAM MGCAL
C*************************************************************
C
C      GEOMAGNETIC FIELD CHANGE AT OUTSIDE THE MEDIUM
C          DUE TO AN INCLINED RECTANGULAR FAULT
C               IN A SEMIINFINITE MEDIUM
C             CODED BY M. UTSUGI....DEC 1996
C
C*************************************************************
C**** INPUT PARAMETERS
C     NDX,NDY     : GRID NUMBER (X,Y)
C     DX,DY       : SAMPLE INTERVAL (X,Y)
C     NUMB        : NUMBER OF ARBITRARY POINTS
C     Z           : Z-COORDINATE OF OBS. POINT
C
C     IFLG =1..OUTPUT EASTWARD 2..NORTHWARD 3..DOWNWARD COMPONENT
C          4..TOTAL FORCE OF GEOMAGNETIC FIELD CHANGE
C     U1,U2,U3    : DISLOCATION VECTOR(M)
C                         U1..STRIKE-SLIP
C                         U2..DIP-SLIP
C                         U3..TENSILE-OPENING
C     DIP,STR     : FAULT DIP AND STRIKE ANGLE (DEGREE)
C     FL,FW,DPT   : FAULT LENGTH, WIDTH AND DEPTH(KM)
C     POI,AMU     : POISSON RATIO AND LAME CONSTANT MU(CGS)
C     BETA        : STRESS SENSITIVITY
C     HH          : CURIE DEPTH(KM)
C     CMZ         : CRUSTAL MAGNETIZATION(A/M)
C     GMINC,GMDEC : GEOMAGNETIC INCLINATION AND DECRINATION(DEG.)
C***** OUTPUT VALUES
C     DMX,DMY,DMZ,DMF : EAST, NORTH, DOWNWARD COMPONENTS
C                       AND TOTAL FORCE OF GEOMAGNETIC
C                       FIELD CHANGE (NT)
C
      INTEGER I,J,K,INDX,NDX,NDY,NUMB,IFLG
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SITX(50),SITY(50),SITZ(50)
      CHARACTER*20 INFILE1,INFILE2
C
      WRITE(6,*) 'CALCULATE AT GRID POINTS OR ARBITRARY POINTS'
      WRITE(6,*) 'TYPE GRID POINTS=1 OR ARBITRARY POINTS=2'
      READ(5,*) INDX
      WRITE(6,*) 'PARAMETER FILE NAME=?'
      READ(5,*) INFILE1
      WRITE(6,*) 'OUTPUT FILE NAME=?'
      READ(5,*) INFILE2
C
      OPEN(10,FILE=INFILE1,STATUS='OLD')
      OPEN(20,FILE=INFILE2,STATUS='NEW')
      IF(INDX.EQ.1) GOTO 100
      IF(INDX.EQ.2) GOTO 200
C
  100 READ(10,*) IFLG
      READ(10,*) NDX,NDY
      READ(10,*) Z
      READ(10,*) DX,DY,XX0,YY0
      READ(10,*) U1,U2,U3,FL,FW,DPT,STR,DIP
      READ(10,*) POI,AMU,CMZ,GMINC,GMDEC,HH,BETA
      CLOSE(10)
      IF(Z.GT.0.D0) THEN
         WRITE(6,*) 'POSITIV Z CANNOT BE ACCEPTED IN THIS PROGRAM'
         GOTO 400
      ENDIF
      IF(DIP.EQ.90.D0) THEN
         WRITE(6,*) 'DIP=90 CANNOT BE ACCEPTED IN THIS PROGRAM'
         GOTO 400
      ENDIF
      STR=90.D0-STR
      CALL CALCON1(POI,AMU,BETA,CMZ,DIP,STR,GMINC,GMDEC)
C
      X=XX0
      DO 120 I=1,NDX+1
         Y=YY0
         DO 110 J=1,NDY+1
            CALL PIEZ(X,Y,Z,U1,U2,U3,DIP,STR,FL,FW,DPT,POI,
     &           AMU,BETA,HH,CMZ,GMINC,GMDEC,DMX,DMY,DMZ,DMF)
            IF(IFLG.EQ.1) WRITE(20,310) X,Y,DMX
            IF(IFLG.EQ.2) WRITE(20,310) X,Y,DMY
            IF(IFLG.EQ.3) WRITE(20,310) X,Y,DMZ
            IF(IFLG.EQ.4) WRITE(20,310) X,Y,DMF
            Y=Y+DY
  110    CONTINUE
         X=X+DX
  120 CONTINUE
      GOTO 300
C
  200 READ(10,*) IFLG
      READ(10,*) NUMB
      READ(10,*) U1,U2,U3,FL,FW,DPT,STR,DIP
      READ(10,*) POI,AMU,CMZ,GMINC,GMDEC,HH,BETA
      DO 210 K=1,NUMB
```

```
      READ(10,*) SITX(K),SITY(K),SITZ(K)
      IF(SITZ(K).GT.0.D0) THEN
         WRITE(6,*) 'POSITIV Z CANNOT BE ACCEPTED IN THIS PROGRAM'
         GOTO 400
      ENDIF
210   CONTINUE
      CLOSE(10)
      IF(DIP.EQ.90.D0) THEN
         WRITE(6,*) 'DIP=90 CANNOT BE ACCEPTED IN THIS PROGRAM'
         GOTO 400
      ENDIF
      STR=90.D0-STR
      CALL CALCON1(POI,AMU,BETA,CMZ,DIP,STR,GMINC,GMDEC)
C
      DO 220 K=1,NUMB
         X=SITX(K)
         Y=SITY(K)
         Z=SITZ(K)
         CALL PIEZ(X,Y,Z,U1,U2,U3,DIP,STR,FL,FW,DPT,POI,
     &        AMU,BETA,HH,CMZ,GMINC,GMDEC,DMX,DMY,DMZ,DMF)
         IF(IFLG.EQ.1) WRITE(20,310) X,Y,DMX
         IF(IFLG.EQ.2) WRITE(20,310) X,Y,DMY
         IF(IFLG.EQ.3) WRITE(20,310) X,Y,DMZ
         IF(IFLG.EQ.4) WRITE(20,310) X,Y,DMF
220   CONTINUE
300   CLOSE(20)
310   FORMAT(' ',F10.3,F10.3,F15.5)
400   STOP
      END
C
C
C
      SUBROUTINE PIEZ(X,Y,Z,U1,U2,U3,DIP,STR,FL,FW,DPT,POI,
     &          AMU,BETA,HH,CMZ,GMINC,GMDEC,DMX,DMY,DMZ,DMF)
      INTEGER I
      IMPLICIT REAL*8 (A-H,O-Z)
C
C************************************************************
C     CALCULATE EACH COMPONENT OF GEOMAGNETIC FIELD CHANGE
C************************************************************
C****** INPUT ******
C     X,Y,Z        : COORDINATE OF OBS. POINT
C     U1,U2,U3     : DISLOCATION VECTOR
C     DIP,STR      : FAULT DIP AND STRIKE ANGLE
C     FL,FW,DPT    : FAULT LENGTH, WIDTH AND DEPTH OF BURIAL
C     POI,AMU      : POISSON RATIO AND LAME CONSTANT MU
C     BETA         : STRESS SENSITIVITY
C     HH           : CURIE DEPTH
C     CMZ          : CRUSTAL MAGNETIZATION
C     GMINC,GMDEC : GEOMAGNETIC INCLINATION AND DECRINATION
C****** OUTPUT ******
C     DMX,DMY,DMZ,DMF : EAST, NORTH, DOWNWARD COMPONENTS
C                       AND TOTAL FORCE OF GEOMAGNETIC
C                       FIELD CHANGE
C
      COMMON /C0/ SD,CD,TD,SED
      DIMENSION DM0(3)
      DATA PI/3.14159265358979D0/
      P18=PI/180.D0
C-----------------------------------------
C         COORDINATE TRANSFORM
C-----------------------------------------
      XT=X*DCOS(STR*P18)+Y*DSIN(STR*P18)
      YT=X*DSIN(STR*P18)-Y*DCOS(STR*P18)
      ZT=Z
C-------
      DD1=DPT-ZT
      DD2=DPT-2.D0*HH+ZT
      DD3=DPT+2.D0*HH-ZT
C
      P1=YT*CD-DD1*SD
      P2=YT*CD-DD2*SD
      P3=YT*CD-DD3*SD
      Q1=YT*SD+DD1*CD
      Q2=YT*SD+DD2*CD
      Q3=YT*SD+DD3*CD
      QD=YT*SD+(DPT-HH)*CD
C
      FW2=(HH-DPT)/SD
      BDPT=DPT+FW*SD
      ZH=ZT-HH
C
      DO 100 I=1,3
         JDRV=I
         CALL DIFCOEF(XT,ZT,P1,P2,P3,Q1,Q2,Q3,QD,U1,U2,U3,
     &        FL,FW,DPT,FW2,BDPT,HH,JDRV,DM)
         DM0(I)=DM
100   CONTINUE
      DMX0=DM0(1)
      DMY0=DM0(2)
      DMZ0=DM0(3)
```

```
C-------------------------------------------
C       CALCULATE EACH COMPONENT OF
C        GEOMAGNETIC FIELD CHANGE
C-------------------------------------------
      DMX=-DMX0*DCOS(STR*P18)-DMY0*DSIN(STR*P18)
      DMY=-DMX0*DSIN(STR*P18)+DMY0*DCOS(STR*P18)
      DMZ=-DMZ0
      DMF=DMX*DCOS(GMINC*P18)*DSIN(GMDEC*P18)
     &     +DMY*DCOS(GMINC*P18)*DCOS(GMDEC*P18)
     &     +DMZ*DSIN(GMINC*P18)
      RETURN
      END
C
C
C
      SUBROUTINE DIFCOEF(XT,ZT,P1,P2,P3,Q1,Q2,Q3,QD,U1,U2,U3,
     &          FL,FW,DPT,FW2,BDPT,HH,JDRV,DM)
      INTEGER I,J,K,JDRV
      IMPLICIT REAL*8 (A-H,O-Z)
C
C*************************************************************
C           CALCULATE DIFFERENTIAL COEFFICIENT
C              OF PIEZOMAGNETIC POTENTIAL
C*************************************************************
C****** INPUT ******
C     XT,ZT     : TRANSFORMED COORDINATE OF OBS. POINT
C     P1,P2,P3  : Y-COORDINATE OF OBS. POINT IN FAULT SYSTEM
C     Q1,Q2,Q3  : Z-COORDINATE OF OBS. POINT IN FAULT SYSTEM
C     U1,U2,U3  : DISLOCATION VECTOR
C     FL,FW,DPT : FAULT LENGTH, WIDTH AND FAULT DEPTH
C     BDPT      : DEPTH OF BOTTOM OF FAULT
C     HH        : CURIE DEPTH
C     JDRV =1..OUTPUT XT-DERIVATION
C          =2..       YT-DERIVATION
C          =3..       ZT-DERIVATION OF PIEZOMAGNETIC POTENTIAL
C****** OUTPUT ******
C     DM : DIFFERENTIAL COEFFICIENT OF PIEZOMAGNETIC POTENTIAL
C
      COMMON /C0/ SD,CD,TD,SED
      DIMENSION DIF0(4),DIFH0(4),DIFH(4)
      DATA F0/0.D0/
C
      K=1
      ZH=ZT-HH
      DO 200 I=1,2
         IF(I.EQ.1) XI=XT
         IF(I.EQ.2) XI=XT-FL
         DO 100 J=1,2
            IF(J.EQ.1) THEN
               ET1=P1
               ET3=P3
            ELSEIF(J.EQ.2) THEN
               ET1=P1-FW
               ET3=P3-FW
            ENDIF
C
            SGN=1.D0
            CALL DERIV(XI,ET3,Q3,QD,ZH,HH,SGN,JDRV)
            IF(U1.NE.F0) CALL STRIKE_H0(HH,SH0)
            IF(U2.NE.F0) CALL DIP_H0(HH,DH0)
            IF(U3.NE.F0) CALL TENSILE_H0(HH,TH0)
            DIFH0(K)=U1*SH0+U2*DH0+U3*TH0
            CALL DERIV(XI,ET1,Q1,QD,ZH,HH,SGN,JDRV)
            IF(U1.NE.F0) CALL STRIKE_0(HH,S0)
            IF(U2.NE.F0) CALL DIP_0(HH,D0)
            IF(U3.NE.F0) CALL TENSILE_0(HH,T0)
            DIF0(K)=U1*S0+U2*D0+U3*T0
C
            IF(DPT.GT.HH) THEN
               IF(U1.NE.F0) CALL STRIKE_H(SGN,HH,SH)
               IF(U2.NE.F0) CALL DIP_H(SGN,HH,DH)
               IF(U3.NE.F0) CALL TENSILE_H(SGN,HH,TH)
               DIFH(K)=U1*SH+U2*DH+U3*TH
               GOTO 30
            ENDIF
            IF(DPT.LT.HH.AND.BDPT.LT.HH) GOTO 10
            IF(DPT.LT.HH.AND.BDPT.GT.HH) GOTO 20
C
 10         IF(J.EQ.1) ET2=P2
            IF(J.EQ.2) ET2=P2-FW
            SGN=-1.D0
            CALL DERIV(XI,ET2,Q2,QD,ZH,HH,SGN,JDRV)
            IF(U1.NE.F0) CALL STRIKE_H(SGN,HH,SH)
            IF(U2.NE.F0) CALL DIP_H(SGN,HH,DH)
            IF(U3.NE.F0) CALL TENSILE_H(SGN,HH,TH)
            DIFH(K)=U1*SH+U2*DH+U3*TH
            GOTO 30
C
 20         IF(J.EQ.1) THEN
               ET1=P1-FW2
               ET2=P2
```

```
274             ELSEIF(J.EQ.2) THEN
275                ET1=P1-FW
276                ET2=P2-FW2
277             ENDIF
278             SGN=1.D0
279             CALL DERIV(XI,ET1,Q1,QD,ZH,HH,SGN,JDRV)
280             IF(U1.NE.F0) CALL STRIKE_H(SGN,HH,SH1)
281             IF(U2.NE.F0) CALL DIP_H(SGN,HH,DH1)
282             IF(U3.NE.F0) CALL TENSILE_H(SGN,HH,TH1)
283             SGN=-1.D0
284             CALL DERIV(XI,ET2,Q2,QD,ZH,HH,SGN,JDRV)
285             IF(U1.NE.F0) CALL STRIKE_H(SGN,HH,SH2)
286             IF(U2.NE.F0) CALL DIP_H(SGN,HH,DH2)
287             IF(U3.NE.F0) CALL TENSILE_H(SGN,HH,TH2)
288             DIFH(K)=U1*(SH1+SH2)+U2*(DH1+DH2)+U3*(TH1+TH2)
289  30         K=K+1
290  100     CONTINUE
291  200  CONTINUE
292       DM0=DIF0(1)-DIF0(2)-DIF0(3)+DIF0(4)
293       DMH0=DIFH0(1)-DIFH0(2)-DIFH0(3)+DIFH0(4)
294       DMH=DIFH(1)-DIFH(2)-DIFH(3)+DIFH(4)
295       DM=DM0+DMH0+DMH
296       RETURN DM
297       END
298 C
299 C
300 C
301       SUBROUTINE CALCON1(POI,AMU,BETA,CMZ,DIP,STR,GMINC,GMDEC)
302       IMPLICIT REAL*8 (A-H,O-Z)
303 C
304 C*************************************************************
305 C       CALCLATE MEDIUM CONSTANTS, FALUT-DIP CONSTANTS
306 C               AND SEISMOMAGNETIC MOMENT
307 C*************************************************************
308 C****** INPUT ******
309 C     POI,AMU     : POISSON RATIO AND LAME CONSTANT MU
310 C     BETA        : STRESS SENSITIVITY
311 C     CMZ         : CRUSTAL MAGNETIZATION
312 C     DIP,STR     : FAULT DIP AND STRIKE ANGLE
313 C     GMINC,GMDEC : GEOMAGNETIC INCLINATION AND DECRINATION
314 C
315       COMMON /C0/ SD,CD,TD,SED
316      &     /C1/ AL,AL1,AL2,AL3,AL4,AL5,AL6,CX,CY,CZ
317       DATA PI/3.141592653589793D0/
318 C
319       P18=PI/180.D0
320       SD=DSIN(DIP*P18)
321       CD=DCOS(DIP*P18)
322       TD=DTAN(DIP*P18)
323       SED=1.D0/CD
324 C------  AL : MEDIUM CONSTANT ALPHA     ------
325 C------       =(LAMBDA+MU)/(LAMBDA+2MU) ------
326       AL=1.D0/(2.D0*(1.D0-POI))
327       ALL=4.D0*AL-1.D0
328       AL1=3.D0*AL/ALL
329       AL2=12.D0*AL/ALL
330       AL3=AL*(2.D0*AL+1.D0)/ALL
331       AL4=AL*(2.D0*AL-5.D0)/ALL
332       AL5=2.D0*AL*(1.D0-AL)/ALL
333       AL6=6.D0*(AL*AL)/ALL
334 C------ SMM : SEISMOMAGNETIC MOMENT ------
335       SMM=CMZ*BETA*AMU*(1.D0+POI)
336       C0=0.5D0*SMM*1.D-7
337       CX=C0*DCOS(GMINC*P18)*DSIN((STR+GMDEC)*P18)
338       CY=-C0*DCOS(GMINC*P18)*DCOS((STR+GMDEC)*P18)
339       CZ=C0*DSIN(GMINC*P18)
340       RETURN
341       END
342 C
343 C
344 C
345       SUBROUTINE CALCON2(XI,ET,QQ,CC)
346       IMPLICIT REAL*8 (A-H,O-Z)
347 C
348 C*************************************************************
349 C          CALCULATE STATION GEOMETRY CONSTANTS
350 C*************************************************************
351 C****** INPUT ******
352 C     XI,ET,QQ : COORDINATES OF OBS. POINT IN FAULT SYSTEM
353 C     CC       : SGN*(QQ*COS(DIP)-ET*SIN(DIP))
354 C
355       COMMON /PRM/ R,R3,RX,RE,RC,RRX,RRE,RRC,RX2,RE2,RC2,
356      &     TRX,TRE,TRC,R3X2,R3E2,R3C2
357       R=DSQRT(XI*XI+ET*ET+QQ*QQ)
358       R3=R*R*R
359 C
360       RX=R+XI
361       RE=R+ET
362       RC=R+CC
363 C
364       RRX=R*RX
```

```
      RRE=R*RE
      RRC=R*RC
C
      RX2=RX*RX
      RE2=RE*RE
      RC2=RC*RC
C
      TRX=2.D0*R+XI
      TRE=2.D0*R+ET
      TRC=2.D0*R+CC
      R3X2=R3*RX2
      R3E2=R3*RE2
      R3C2=R3*RC2
      RETURN
      END
C
C
C
      SUBROUTINE DERIV(XI,ET,QQ,QD,ZH,HH,SGN,JDRV)
      INTEGER LT,JDRV
      IMPLICIT REAL*8 (A-H,O-Z)
C
C**************************************************************
C        CALCULATE DIFFERENTIAL COEFFICIENT OF
C                ELEMENTARY FUNCTIONS
C**************************************************************
C****** INPUT ******
C     XI,ET,QQ : COORDINATES OF OBS. POINT IN FAULT SYSTEM
C     GD       : YT*SIN(DIP)+(DPT-HH)*COS(DIP)
C     ZH       : ZT-HH
C     HH       : CURIE DEPTH
C     JDRV =1..CALCULATE XT-DERIVATE
C          =2..          YT-DERIVATE
C          =3..          ZT-DERIVATE OF ELEMENTARY FUNCTIONS
C
      COMMON /C0/ SD,CD,TD,SED
     &     /PRM/ R,R3,RX,RE,RC,RRX,RRE,RRC,RX2,RE2,RC2,
     &     TRX,TRE,TRC,R3X2,R3E2,R3C2
     &     /MAIN/ W(9)
     &     /ELM1/ FLX,FLE,FLC,TAN,G(2)
     &     /ELM2/ A(3),B(3),D(3),E(3),F(3)
     &     /ELM3/ SX1,SY1,SZ1,DX1,DY1,DZ1,TX1,TY1,TZ1
      DATA F0,F1,EPS/0.D0,1.D0,1.D-6/
C
      YY=ET*CD+QQ*SD
      CC=SGN*(QQ*CD-ET*SD)
      CALL CALCON2(XI,ET,QQ,CC)
      IF(ABS(RE).GT.EPS) LT=1
      IF(ABS(RE).LE.EPS) LT=0
C
      AI0=F1/RRC
      IF(LT.EQ.1) AI0=AI0+SGN*SD/RRE
C=============================
C       X-DERIVATIVE
C=============================
      IF(JDRV.NE.1) GOTO 100
C-------------------------
C   ELEMENTARY FUNCTIONS
C        DIPOLES
C-------------------------
      TAN=F0
      FLE=F0
      FLX=F1/R
      FLC=XI/RRC
      G(1)=SGN*YY/RRC
      IF(LT.EQ.1) THEN
         TAN=TAN-QQ/RRE
         FLE=FLE+XI/RRE
         G(1)=G(1)+QQ/RRE
      ENDIF
      G(2)=FLC+SGN*SD*FLE
C
      W(1)=TD*(F1/RC-(XI*XI)/(R*RC2))+TD*TD*G(1)
      W(2)=-TD*XI*YY/(R*RC2)-SGN*TD*TD*G(2)
      W(3)=TD*G(2)
      W(4)=CD*(W(2)-SD*FLE)
      W(5)=CD*W(1)
      W(6)=-SD*G(1)
      W(7)=-SD*(W(2)-SD*FLE)
      W(8)=-SD*W(1)
      W(9)=SD*TD*G(1)
C-------------------------
C   ELEMENTARY FUNCTIONS
C   QUADRA AND OCTA POLES
C-------------------------
      IF(LT.EQ.1) THEN
         A(1)=F1/RRE-(XI*XI)*TRE/R3E2
         A(2)=-XI*CD/(R*RE2)-XI*YY*TRE/R3E2
         A(3)=SGN*XI*SD/(R*RE2)-XI*CC*TRE/R3E2
      ELSE
         DO 10 I=1,3
```

```
456            A(I)=F0
457  10      CONTINUE
458       ENDIF
459 C
460       B(1)=F1/RRC-(XI*XI)*TRC/R3C2
461       B(2)=-XI*YY*TRC/R3C2
462 C
463       D(1)=-XI/R3
464       D(2)=-YY/R3
465       D(3)=-CC/R3
466 C
467       E(1)=F0
468       E(2)=SGN*CC/R3
469       E(3)=-SGN*YY/R3
470       AI1=-XI*TRC/R3C2
471       F(2)=F0
472       IF(LT.EQ.1) THEN
473          E(1)=E(1)+XI*QQ*TRE/R3E2
474          E(2)=E(2)+SD/RRE-(XI*XI)*SD*TRE/R3E2
475          E(3)=E(3)+SGN*(CD/RRE-(XI*XI)*CD*TRE/R3E2)
476          AI1=AI1-SGN*XI*SD*TRE/R3E2
477          F(2)=F(2)-SGN*XI*SD/(R*RE2)
478       ENDIF
479       F(1)=XI*AI1+AI0
480       F(2)=F(2)+YY*SED*AI1
481       F(3)=B(1)+D(3)
482 C
483       SX1=QD*A(1)+ZH*F(1)*TD
484       SY1=QD*A(2)+ZH*F(2)*SD
485       SZ1=QD*A(3)+ZH*A(2)*SD
486       DX1=QD*D(1)+ZH*B(2)*SD
487       DY1=QD*D(2)-ZH*F(3)*SD
488       DZ1=QD*D(3)+ZH*D(2)*SD
489       TX1=QD*E(1)-ZH*(A(2)+SD*B(2))*TD
490       TY1=QD*(D(3)-SD*A(1))+ZH*(D(2)-TD*F(1))*SD
491       TZ1=QD*E(3)+ZH*E(2)*SD
492 C=================================
493 C       Y-DERIVATIVE
494 C=================================
495  100  IF(JDRV.NE.2) GOTO 200
496 C-------------------------
497 C   ELEMENTARY FUNCTIONS
498 C       DIPOLES
499 C-------------------------
500       TAN=-SGN*CC/RRX
501       FLE=F0
502       FLX=YY/RRX
503       FLC=YY/RRC
504       G(1)=-SGN*XI/RRC
505       IF(LT.EQ.1) THEN
506          TAN=TAN+XI*SD/RRE
507          FLE=FLE+CD/RE+YY/RRE
508          G(1)=G(1)-XI*SD/RRE
509       ENDIF
510       G(2)=FLC+SGN*FLE
511 C
512       W(1)=-TD*XI*YY/(R*RC2)+TD*TD*G(1)
513       W(2)=TD*(F1/RC-(YY*YY)/(R*RC2))-SGN*TD*TD*G(2)
514       W(3)=TD*G(2)
515       W(4)=CD*(W(2)-SD*FLE)
516       W(5)=CD*W(1)
517       W(6)=-SD*G(1)
518       W(7)=-SD*(W(2)-SD*FLE)
519       W(8)=-SD*W(1)
520       W(9)=SD*TD*G(1)
521 C-------------------------
522 C   ELEMENTARY FUNCTIONS
523 C   QUADRA AND OCTA POLES
524 C-------------------------
525       IF(LT.EQ.1) THEN
526          A(1)=-XI*CD/(R*RE2)-XI*YY*TRE/R3E2
527          A(2)=(SD*SD)/RE2-(YY*CD+SGN*CC*SD)/(R*RE2)
528      &        -YY*YY*TRE/R3E2
529          A(3)=SGN*SD*CD/RE2-(CC*CD-SGN*YY*SD)/(R*RE2)
530      &        -YY*CC*TRE/R3E2
531       ELSE
532          DO 110 I=1,3
533             A(I)=F0
534  110     CONTINUE
535       ENDIF
536 C
537       B(1)=-XI*YY*TRC/R3C2
538       B(2)=F1/RRC-(YY*YY)*TRC/R3C2
539 C
540       D(1)=-YY/R3
541       D(2)=F1/RRX-(YY*YY)*TRX/R3X2
542       D(3)=-YY*CC*TRX/R3X2
543 C
544       E(1)=F0
545       E(2)=SGN*YY*CC*TRX/R3X2
546       E(3)=SGN*(F1/RRX-(YY*YY)*TRX/R3X2)
```

```
      AI1=-YY*TRC/R3C2
      F(2)=SED*AI0
      IF(LT.EQ.1) THEN
         E(1)=E(1)-SD/RE2+SGN*CC/(R*RE2)+YY*QQ*TRE/R3E2
         E(2)=E(2)    -SD*(XI*CD/(R*RE2)+XI*YY*TRE/R3E2)
         E(3)=E(3)-SGN*CD*(XI*CD/(R*RE2)+XI*YY*TRE/R3E2)
         AI1=AI1-SGN*SD*(CD/(R*RE2)+YY*TRE/R3E2)
         F(2)=F(2)-SGN*SD*(CD/RE2+YY/(R*RE2))
      ENDIF
      F(1)=XI*AI1
      F(2)=F(2)+YY*SED*AI1
      F(3)=B(1)+D(3)
C
      SX1=QD*A(1)+ZH*F(1)*TD
      SY1=QD*A(2)+ZH*F(2)*SD
      SZ1=QD*A(3)+ZH*A(2)*SD
      DX1=QD*D(1)+ZH*B(2)*SD+SD/R
      DY1=QD*D(2)-ZH*F(3)*SD+SD*YY/RRX
      DZ1=QD*D(3)+ZH*D(2)*SD+SD*CC/RRX
      TX1=QD*E(1)-ZH*(A(2)+SD*B(2))*TD
      TY1=QD*(D(3)-SD*A(1))+ZH*(D(2)-TD*F(1))*SD
     &     +SD*CC/RRX
      TZ1=QD*E(3)+ZH*E(2)*SD+SD*SGN*YY/RRX
      IF(LT.EQ.1) THEN
         SX1=SX1+SD*XI/RRE
         SY1=SY1+SD*(CD/RE+YY/RRE)
         SZ1=SZ1-SD*(SGN*SD/RE-CC/RRE)
         TX1=TX1-SD*QQ/RRE
         TY1=TY1-SD*SD*XI/RRE
         TZ1=TZ1+SD*SGN*CD*XI/RRE
      ENDIF
C=============================
C       Z-DERIVATIVE
C=============================
 200  IF(JDRV.NE.3) GOTO 300
C--------------------------
C   ELEMENTARY FUNCTIONS
C        DIPOLES
C--------------------------
      TAN=-SGN*YY/RRX
      FLE=F0
      FLX=-CC/RRX
      FLC=-F1/R
      G(1)=F0
      G(2)=F0
      IF(LT.EQ.1) THEN
         TAN=TAN-SGN*XI*CD/RRE
         FLE=FLE+SGN*SD/RE-CC/RRE
         G(1)=G(1)+SGN*XI*CD/RRE
      ENDIF
      G(2)=FLC+SGN*FLE
C
      W(1)=TD*XI/RRC+TD*TD*G(1)
      W(2)=TD*YY/RRC-SGN*TD*TD*G(2)
      W(3)=TD*G(2)
      W(4)=CD*(W(2)-SD*FLE)
      W(5)=CD*W(1)
      W(6)=-SD*G(1)
      W(7)=-SD*(W(2)-SD*FLE)
      W(8)=-SD*W(1)
      W(9)=SD*TD*G(1)
C--------------------------
C   ELEMENTARY FUNCTIONS
C   QUADRA AND OCTA POLES
C--------------------------
      IF(LT.EQ.1) THEN
         A(1)=-XI*CD/(R*RE2)-XI*YY*TRE/R3E2
         A(2)=SD*SD/RE2-(YY*CD+SGN*CC*SD)/(R*RE2)
     &        -YY*YY*TRE/R3E2
         A(3)=SGN*SD*CD/RE2-(CC*CD-SGN*YY*SD)/(R*RE2)
     &        -YY*CC*TRE/R3E2
      ELSE
         DO 210 I=1,3
            A(I)=F0
 210     CONTINUE
      ENDIF
C
      B(1)=XI/R3
      B(2)=YY/R3
C
      D(1)=CC/R3
      D(2)=YY*CC*TRX/R3X2
      D(3)=-F1/RRX+(CC*CC)*TRX/R3X2
C
      E(1)=F0
      E(2)=SGN*(F1/RRX-(CC*CC)*TRX/R3X2)
      E(3)=SGN*YY*CC*TRX/R3X2
      AI1=F1/R3
      F(2)=F0
      IF(LT.EQ.1) THEN
         E(1)=E(1)+SGN*(CD/RE2+YY/(R*RE2))-QQ*CC*TRE/R3E2
```

```
          E(2)=E(2)+SD*(-SGN*XI*SD/(R*RE2)+XI*CC*TRE/R3E2)
          E(3)=E(3)+CD*(-XI*SD/(R*RE2)+SGN*XI*CC*TRE/R3E2)
          AI1=AI1-SD*(SD/(R*RE2)-SGN*CC*TRE/R3E2)
          F(2)=F(2)+SD*(-SD/RE2+SGN*CC/(R*RE2))
        ENDIF
        F(1)=XI*AI1
        F(2)=F(2)+SFD*YY*AI1
        F(3)=B(1)+D(3)
C
        SX1=QD*A(1)+ZH*F(1)*TD+XI*AI0*TD
        SY1=QD*A(2)+ZH*F(2)*SD+YY*AI0*TD
        SZ1=QD*A(3)+ZH*A(2)*SD
        DX1=QD*D(1)+ZH*B(2)*SD+SD*YY/RRC
        DY1=QD*D(2)-ZH*F(3)*SD-SD*(XI/RRC+CC/RRX)
        DZ1=QD*D(3)+ZH*D(2)*SD+SD*YY/RRX
        TX1=QD*E(1)-ZH*(A(2)+SD*B(2))*TD
     &      -SD*TD*YY/RRC
        TY1=QD*(D(3)-SD*A(1))+ZH*(D(2)-TD*F(1))*SD
     &      +SD*(YY/RRX-TD*XI*AI0)
        TZ1=QD*E(3)+ZH*E(2)*SD-SD*SGN*CC/RRX
        IF(LT.EQ.1) THEN
           SY1=SY1+SGN*SD*SD/RE
           SZ1=SZ1+SD*(CD/RE+YY/RRE)
           TX1=TX1-TD*(CD/RE+YY/RRE)
           TZ1=TZ1+SD*SD*XI/RRE
        ENDIF
C
300     RETURN
        END
C
C
C
        SUBROUTINE STRIKE_0(HH,S0)
        IMPLICIT REAL*8 (A-H,O-Z)
        COMMON /MAIN/ W(9)
     &      /C1/ AL,AL1,AL2,AL3,AL4,AL5,AL6,CX,CY,CZ
C
        SX=2.D0*W(1)
        SY=2.D0*W(2)
        SZ=2.D0*W(3)
        S0=CX*SX+CY*SY+CZ*SZ
        RETURN S0
        END
C
C
C
        SUBROUTINE STRIKE_H0(HH,SH0)
        IMPLICIT REAL*8 (A-H,O-Z)
        COMMON /C0/ SD,CD,TD,SED
     &      /C1/ AL,AL1,AL2,AL3,AL4,AL5,AL6,CX,CY,CZ
     &      /MAIN/ W(9)
     &      /ELM1/ FLX,FLE,FLC,TAN,G(2)
     &      /ELM2/ A(3),B(3),D(3),E(3),F(3)
     &      /ELM3/ SX1,SY1,SZ1,DX1,DY1,DZ1,TX1,TY1,TZ1
C
        SH0X=(-2.D0+AL3)*W(3)-AL1*TAN-AL5*G(1)
     &      -2.D0*AL3*HH*(A(1)*CD-F(1)*TD)
     &      -AL2*HH*F(1)*TD-AL5*SX1
C
        SH0Y=(-2.D0+AL3)*W(2)+AL3*FLE*SD+AL5*G(2)
     &      -2.D0*AL3*HH*(A(2)*CD-F(2)*SD)
     &      -AL2*HH*F(2)*SD-AL5*SY1
C
        SH0Z=-(2.D0+AL4)*W(3)-AL*FLE*CD
     &      -2.D0*AL*HH*(A(3)*CD-A(2)*SD)
     &      -AL2*HH*A(2)*SD+AL5*SZ1
C
        SH0=CX*SH0X+CY*SH0Y+CZ*SH0Z
        RETURN SH0
        END
C
C
C
        SUBROUTINE STRIKE_H(SGN,HH,SH)
        IMPLICIT REAL*8 (A-H,O-Z)
        COMMON /C0/ SD,CD,TD,SED
     &      /C1/ AL,AL1,AL2,AL3,AL4,AL5,AL6,CX,CY,CZ
     &      /MAIN/ W(9)
     &      /ELM1/ FLX,FLE,FLC,TAN,G(2)
     &      /ELM2/ A(3),B(3),D(3),E(3),F(3)
     &      /ELM3/ SX1,SY1,SZ1,DX1,DY1,DZ1,TX1,TY1,TZ1
C
        SHX1=-SGN*(AL3*W(2)+AL1*TAN+AL5*G(1))
        SHY1=-SGN*AL3*W(2)-AL5*G(2)
        SHZ1=AL4*W(3)+AL*FLE*CD
        IF(SGN.EQ.1.D0) THEN
           SHX2=AL5*SX1
           SHY2=AL5*SY1-AL3*SD*FLE
           SHZ2=-AL5*SZ1
        ELSEIF(SGN.EQ.-1.D0) THEN
           SHX2=-AL6*SX1
```

```
      SHY2=-AL6*SY1+(AL1-AL6)*FLE
      SHZ2=-AL6*SZ1
    ENDIF
    SHX=SHX1+SHX2
    SHY=SHY1+SHY2
    SHZ=SHZ1+SHZ2
C
    SH=CX*SHX+CY*SHY+CZ*SHZ
    RETURN SH
    END
C
C
C
    SUBROUTINE DIP_0(HH,D0)
    IMPLICIT REAL*8 (A-H,O-Z)
    COMMON /MAIN/ W(9)
   &     /C1/ AL,AL1,AL2,AL3,AL4,AL5,AL6,CX,CY,CZ
C
    DX=-2.D0*W(4)
    DY=2.D0*W(5)
    DZ=2.D0*W(6)
    D0=CX*DX+CY*DY+CZ*DZ
    RETURN D0
    END
C
C
C
    SUBROUTINE DIP_H0(HH,DH0)
    IMPLICIT REAL*8 (A-H,O-Z)
    COMMON /C0/ SD,CD,TD,SED
   &     /C1/ AL,AL1,AL2,AL3,AL4,AL5,AL6,CX,CY,CZ
   &     /MAIN/ W(9)
   &     /ELM1/ FLX,FLE,FLC,TAN,G(2)
   &     /ELM2/ A(3),B(3),D(3),E(3),F(3)
   &     /ELM3/ SX1,SY1,SZ1,DX1,DY1,DZ1,TX1,TY1,TZ1
C
    DH0X=(2.D0-AL3)*W(4)
   &     +AL5*(2.D0*SD*CD*FLE-(CD-SD*TD)*G(2))
   &     +2.D0*AL4*HH*(D(1)*CD-B(2)*SD)-AL2*HH*A(2)
   &     +AL5*DX1
C
    DH0Y=(-2.D0+AL3)*W(5)-AL*SD*FLX+AL3*CD*TAN
   &     -AL5*(CD+SD*TD)*G(1)
   &     +2.D0*AL3*HH*(D(2)*CD+F(3)*SD)+AL2*HH*F(1)*SD
   &     +AL5*DY1
C
    DH0Z=-(2.D0+AL4)*W(6)+AL*CD*FLX+AL3*TAN
   &     +2.D0*AL*HH*(D(3)*CD-D(2)*SD)-AL2*HH*A(1)*SD*CD
   &     -AL5*DZ1
C
    DH0=CX*DH0X+CY*DH0Y+CZ*DH0Z
    RETURN DH0
    END
C
C
C
    SUBROUTINE DIP_H(SGN,HH,DH)
    IMPLICIT REAL*8 (A-H,O-Z)
    COMMON /C0/ SD,CD,TD,SED
   &     /C1/ AL,AL1,AL2,AL3,AL4,AL5,AL6,CX,CY,CZ
   &     /MAIN/ W(9)
   &     /ELM1/ FLX,FLE,FLC,TAN,G(2)
   &     /ELM2/ A(3),B(3),D(3),E(3),F(3)
   &     /ELM3/ SX1,SY1,SZ1,DX1,DY1,DZ1,TX1,TY1,TZ1
C
    DHX1=SGN*AL3*W(4)
   &     -AL5*(2.D0*SD*CD*FLE-(CD-SD*TD)*G(2))
    DHY1=-SGN*AL3*W(5)+AL*FLX-SGN*AL3*CD*TAN
   &     +SGN*AL5*(CD-SD*TD)*G(1)
    DHZ1=SGN*AL4*W(6)-AL*CD*FLX-SGN*AL3*SD*TAN
    IF(SGN.EQ.1.D0) THEN
      DHX2=-AL5*DX1
      DHY2=-AL5*DY1
      DHZ2=AL5*DZ1
    ELSEIF(SGN.EQ.-1.D0) THEN
      DHX2=AL6*DX1
      DHY2=AL6*DY1
      DHZ2=AL6*DZ1
    ENDIF
    DHX=DHX1+DHX2
    DHY=DHY1+DHY2
    DHZ=DHZ1+DHZ2
C
    DH=CX*DHX+CY*DHY+CZ*DHZ
    RETURN DH
    END
C
C
C
    SUBROUTINE TENSILE_0(HH,T0)
    IMPLICIT REAL*8 (A-H,O-Z)
```

```
      COMMON /MAIN/ W(9)
     &     /C1/ AL,AL1,AL2,AL3,AL4,AL5,AL6,CX,CY,CZ
C
      TX=-2.D0*W(7)
      TY=2.D0*W(8)
      TZ=2.D0*W(9)
      T0=CX*TX+CY*TY+CZ*TZ
      RETURN T0
      END
C
C
C
      SUBROUTINE TENSILE_H0(HH,TH0)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /C0/ SD,CD,TD,SED
     &     /C1/ AL,AL1,AL2,AL3,AL4,AL5,AL6,CX,CY,CZ
     &     /MAIN/ W(9)
     &     /ELM1/ FLX,FLE,FLC,TAN,G(2)
     &     /ELM2/ A(3),B(3),D(3),E(3),F(3)
     &     /ELM3/ SX1,SY1,SZ1,DX1,DY1,DZ1,TX1,TY1,TZ1
C
      TH0X=(2.D0-AL3)*W(7)
     &     +2.D0*AL5*SD*FLC-AL*FLE
     &     +2.D0*AL4*HH*(E(1)*CD+(A(2)+SD*B(2))*TD)
     &     -(AL2-2.D0*AL6)*HH*A(3)+AL5*TX1
C
      TH0Y=(-2.D0+AL3)*W(8)
     &     -AL3*SD*TAN-AL*CD*FLX+2.D0*AL5*SD*G(1)
     &     -2.D0*AL*HH*((D(3)-A(1)*SD)*CD
     &                  -(D(2)-F(1)*TD)*SD)
     &     +(AL2-2.D0*AL6)*HH*F(1)*SD*TD-AL5*TY1
C
      TH0Z=-(2.D0+AL4)*W(9)
     &     +AL3*CD*TAN-AL*SD*FLX
     &     -AL3*HH*(E(3)*CD-E(2)*SD)+AL2*HH*A(1)*SD*SD
     &     -AL5*TZ1
C
      TH0=CX*TH0X+CY*TH0Y+CZ*TH0Z
      RETURN TH0
      END
C
C
C
      SUBROUTINE TENSILE_H(SGN,HH,TH)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /C0/ SD,CD,TD,SED
     &     /C1/ AL,AL1,AL2,AL3,AL4,AL5,AL6,CX,CY,CZ
     &     /MAIN/ W(9)
     &     /ELM1/ FLX,FLE,FLC,TAN,G(2)
     &     /ELM2/ A(3),B(3),D(3),E(3),F(3)
     &     /ELM3/ SX1,SY1,SZ1,DX1,DY1,DZ1,TX1,TY1,TZ1
C
      THX1=SGN*AL3*W(7)+SGN*AL*FLE-SGN*2.D0*AL5*SD*FLC
      THY1=SGN*AL3*W(8)+AL*CD*FLX-SGN*AL4*TAN
     &     -SGN*2.D0*AL5*G(1)
      THZ1=SGN*AL4*W(9)+AL*SD*FLX-SGN*AL3*CD*TAN
C
      IF(SGN.EQ.1) THEN
         THX2=-AL5*TX1
         THY2=-AL5*TY2
         THZ2=AL5*TZ1
      ELSE
         THX2=AL6*TX1
         THY2=AL6*TY2
         THZ2=AL6*TZ1
      ENDIF
      THZ=THZ1+THZ2
      TH=CZ*THZ
      RETURN TH
      END
```