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Record 1971/127

COMPUTER CALCULATION OF DISTANCES IN THE RANGE 0° - 160°

(Program EPICENT)

by

D.M. Finlayson and W.D. Parkinson

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CONTENTS

SUMMARY

This Record describes a computer program for calculating distances between points on the Earth's surface whose latitude and longitude are known to 0.1 min of arc. The distances must be in the angular range 0° to 160°. The method has application to seismic refraction studies.

1. INTRODUCTION

Seismic refraction studies require a number of parameters to be calculated from field data, one of which is the distance from the earthquake or shot-point to the seismic station. The computer program EPICENT described in this Record is designed to calculate these distances when the positions of the shot-points and seismic stations are known.

2. METHOD

The formulae used to calculate the distances are given in K.E. Bullen's textbook 'Introduction to the Theory of Seismology' (1947), and are summarized below.

Let the co-latitude and east longitude of two points on the Earth's surface be (Θ, ϕ) and (Θ', ϕ') respectively. Then the parameters A, B, C, D, E, G, H, and K are defined as follows:

$A = \sin\Theta\cos\phi$ $\quad B = \sin\Theta\sin\phi$ $\quad C = \cos\Theta$

$D = \sin\phi$ $\quad E = -\cos\phi$ $\quad G = \cos\Theta\cos\phi$

$H = \cos\Theta\sin\phi$ $\quad K = -\sin\Theta$

with corresponding (A', B'), etc., for the point $(\Theta' \phi')$

The distance (Δ) between the two points, measured as an angle subtended at the Earth's centre is given by:

$$\cos\Delta = AA' + BB' + CC' \qquad \text{.....(1)}$$

Various other relations are:

$$2(1-\cos\Delta) = (A - A')^2 + (B - B')^2 + (C - C')^2 \qquad \text{.....(2)}$$

$$2(1+\cos\Delta) = (A + A')^2 + (B + B')^2 + (C + C')^2 \qquad \text{.....(3)}$$

$$2 + 2\sin\Delta\sin Z = (A' - D)^2 + (B' - E)^2 + C'^2 \qquad \text{.....(4)}$$

$$2 + 2\sin\Delta\cos Z = (A' - G)^2 + (B - H)^2 + (C' - K)^2 \qquad \text{.....(5)}$$

where Z is the azimuth between the two points measured from north through east.

Bullen recommends that equation (2) be used for angular distances between 0° and 20° and equation (1) can be used between 20° and 160°; these are the equations used in the computer program.

The error in equation (1) varies from 0.05° at 1° distance to 0.007° at 20° distance.

The error in equation (2) is less than 0.01° in the range 20° to 160°.

3. USAGE

A listing of the Fortran IV program is given in Table 1 and the format of the input cards in Table 2. The latitudes and longitudes are required in degrees, minutes, and tenths of minutes. The distances are calculated from the first shot-point to four stations whose locations are punched on the first card. If further station distances are required, a flag is put in column 78 of the first card, and further station positions are indicated in the next card.

If distances are required from second and subsequent shots, the data are punched as indicated in Table 2.

On the last data card, a flag is put in column 79.

The form of the data printout is given in Table 3. The computed angular distances are converted to kilometre distances by assuming the mean radius of the earth to be 6378.388 km.

4. COMMENTS

This computer program provides data accurate enough for many seismic refraction studies, but if higher accuracy is required at short distances (less than 1500 km), it is recommended that a more exact relation be used such as that incorporated in the Department of the Interior 'ROBBINS' program , in which accuracies of 2 cm are quoted. Plate 1 shows the difference between distances calculated by EPICENT and by the 'ROBBINS' programs. The 'ROBBINS' program description and computer card check are kept by BMR Regional Surveys Section.

```
      PROGRAM EPICENT                                                    1
C     PROGRAM COMPUTES EPICENTRAL DISTANCES IN DEGREES AND KILOMETERS.
C     LOCATIONS SHOULD BE QUOTED TO  0.1 MINUTES OF LATITUDE AND
C     LONGITUDE AND THE RESULTS ARE CALCULATED TO 0.1 KM.
C     DISTANCE SHOULD BE IN THE RANGE 0 - 180 DEGREES.
      TYPE REAL  LAEH,LGEH,LTH,LGH
      DIMENSION NOH(4),LT(4),LG(4)                                       2
   11 READ 30,LAE,LGE,(NOH(K),LT(K),LG(K),K=1,4),IND,LOT                 3
C     LAE,LGE ARE COORD OF QUAKE, LT,LG OF 4 STATIONS
C     IND=1 IF STATIONS ARE CONTINUED ON NEXT CARD
C     LOT=1 ON LAST CARD OF JOB
C     OUTPRINT  MANIPULATION
      LAED = LAE/1000
      LAEH = LAE - LAED*1000
      LAEH=LAEH/10.
      LGED = LGE/1000
      LGEH = LGE - LGED*1000
      LGEH=LGEH/10.
      IN1=1HN $ IN2=1HS $ IN3=1HE $ IN4=1HW
      IDIRC1 = IN1
      IDIRC2 = IN3
      IF(LAED.LT.0) IDIRC1 = IN2
      IF(LGED.LT.0) IDIRC2 = IN4
      IF(LAED.LT.0) LAED = -LAED
      IF(LGED.LT.0)LGED = -LGED
      IF(LAEH.LT.0) LAEH = -LAEH
      IF(LGEH.LT.0) LGEH = -LGEH
C     TO CONVERT TO RADIANS AND COMPUTE TRIG FCT
      RAE = RAD(LAE) $ RGE = RAD(LGE)                                    4
C     NOW CORRECT FOR ELLIPTICITY
      RAE=ATAN(0.993277*SIN(RAE)/COS(RAE))
      CPHE = COS(RAE) $ SPH = SIN(RAE)                                   5
      CLBE = COS(RGE) $ SLB = SIN(RGE)                                   6
C     PRINT QUAKE POSITION AND HEADING
      PRINT 90, LAED,LAEH,IDIRC1,LGED,LGEH,IDIRC2
      LINE = 0
      K=1 $ GO TO 10                                                     10
   12 READ 31,(NOH(K),LT(K),LG(K),K=1,4),IND,LOT                         11
      K = 1                                                      EPI
C     CALCULATION FOR EACH STATION
   10 RPH = RAD(LT(K)) $ RLB = RAD(LG(K))                                12
      RPH=ATAN(0.993277*SIN(RPH)/COS(RPH))
      CPH = COS(RPH) $ SPH = SIN(RPH)                                    13
      CLB = COS(RLB) $ SLB = SIN(RLB)                                    14
      CDEL = SPHE * SPH +CPHE*CPH*(CLB*CLBE + SLBE * SLB)               17
      SDEL = SQRT(1. - CDEL**2)                                          18
      D = ACOS(CDEL)* 57.29578                                           19
      IF(D.LE.20.0)15,4
   15 CDEL=(((CPHE*CLBE-CPH*CLB)**2)+((CPHE*SLBE-CPH*SLB)**2)+((SPHE-
     1SPH)**2))/2
      SDEL= SQRT(1. -CDEL**2)
      D=ACOS(CDEL)*57.29578
    4 CONTINUE
      DK=ACOS(CDEL)*6378.388
      CZ = (SPH - SPHE*CDEL)/(CPHE * SDEL)                               20
      SZ = CPH * (CLBE*SLB - SLBE* CLB) / SDEL                           21
```

TABLE 1: Program Listing, Program EPICENT

```
      AZ = ATAN2(SZ,CZ) * 57.29578                                    221
      IF(AZ.LT.0.) AZ = AZ + 360.                                     225
C     OUTPRINT  MANIPULATION
      LTD = LT(K)/1000
      LTM = LT(K)-LTD*1000
      LTM=LTM/10.
      LGD = LG(K)/1000
      LGM = LG(K)-LGD*1000
      LGM=LGM/10.
      IDIRN1 = IN1
      IDIRN2 = IN3
      IF(LTD.LT.0) IDIRN1 = IN2
      IF(LGD.LT.0) IDIRN2 = IN4
      IF(LTD.LT.0) LTD = - LTD
      IF(LGD .LT.0)LGD = -LGD
      IF(LTM.LT.0) LTM = - LTM
      IF(LGM.LT.0) LGM = - LGM
      IF (LINE.LE.28) GO TO 14
      PRINT 50, LAED,LAEM,IDIRC1,LGED,LGEM,IDIRC2
      LINE = 0
C     PRINT RESULTS FOR ONE STATION
   14 PRINT 51, NOM(K),D,AZ,DK,CZ,SZ,CDEL,LTD,LTM,IDIRN1,LGD,LGM,IDIRN2
      LINE = LINE + 1
      IF((K.GE.4).OR.(LT(K+1).EQ.0.AND.LG(K+1).EQ.0)) GO TO 1
      K = K+1 $ GO TO 10                                              26
    1 IF(IND.EQ.0) GO TO 13                                           27
      K=1 $ GO TO 12                                                  28
   13 IF(LOT.EQ.0) GO TO 11                                           29
      STOP                                                            30
   50 FORMAT (1141  QUAKE AT,6X,I2,1X,F4.1,A1,2X,I3,1X,F4.1,A1,///,42H S
     1TATION   DEGREES    AZIMUTH   KILOMETERS,17X,
     250HCOS Z      SIN Z        COS DEL       STATION COORDS )
   51 FORMAT (1H0,2X,A3,3F12.2,15X,3F10.6,6X,I2,1X,F4.1,A1,2X,I3,F5.1,A1
     1)
   30 FORMAT(I6,I7,4(A3,I6,I7),2I1)
   31 FORMAT(13X,4(A3,I6,I7),2I1)
      END                                                             36
```

TABLE 1 (continued)

```
      FUNCTION RAD(L)                                    R    1
C     TO CONVERT DEG MIN TO RADIANS                      R
      LA = L                                             R    2
      IF(L.LT.0) LA = - L                                R    3
      LD = LA/1000
      LM = LA - LD*1000
      RAD =.0174533*LD + .0000291*LM
      IF(L.LT.0) RAD =-RAD                               R    7
      E N D                                              R    8
```

TABLE 1 (continued)

ESIRC DATA SHEET

PROGRAM	NAME	JOB	DATE	PAGE NO.
EPICENT				

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 COMMENT

First central location	Subsidiary locations			Indicator for data on next card.
-31587 116125	PAL-26000 116000	PAM-24000 117000	PAN-25143 113291	PØA-28311 116433 1
	PQA-64321 152422	XXT-58416 102103	XYT-03591 126666	YPA-14041 152229 1
	QAC 03400 105192	BAC 14216 94312	DØI 32490 82511	TSR-04305 103492
Second central location				
-24042 136611	STX-41337 224136	STY-51440 106041	TUX-30221 72418	EEC-11402 194040 1
	DXY 36151 123191			

Station name: ST — Latitude: -51°44.0' — Longitude: 106°04.1'

Indicator for last data card.

TABLE 2: Input Data Format

QUAKE AT 31 42.7S 116 23.9E

STATION	DEGREES	AZIMUTH	KILOMETERS	COS Z	SIN Z	COS DEL	STATION COORDS
MUN	0.31	210.36	34.33	-0.862873	-0.505420	0.999986	31 58.7S 116 12.9E
TAR	1.55	161.38	173.10	-0.947676	0.319234	0.999632	33 11.3S 116 99.0E
CRH	2.74	161.02	304.76	-0.945652	0.325181	0.998859	34 18.2S 117 28.0E
SXC	2.55	79.99	283.90	0.174992	0.984641	0.999010	31 13.9S 119 19.4E

QUAKE AT 31 40.3S 116 23.9E

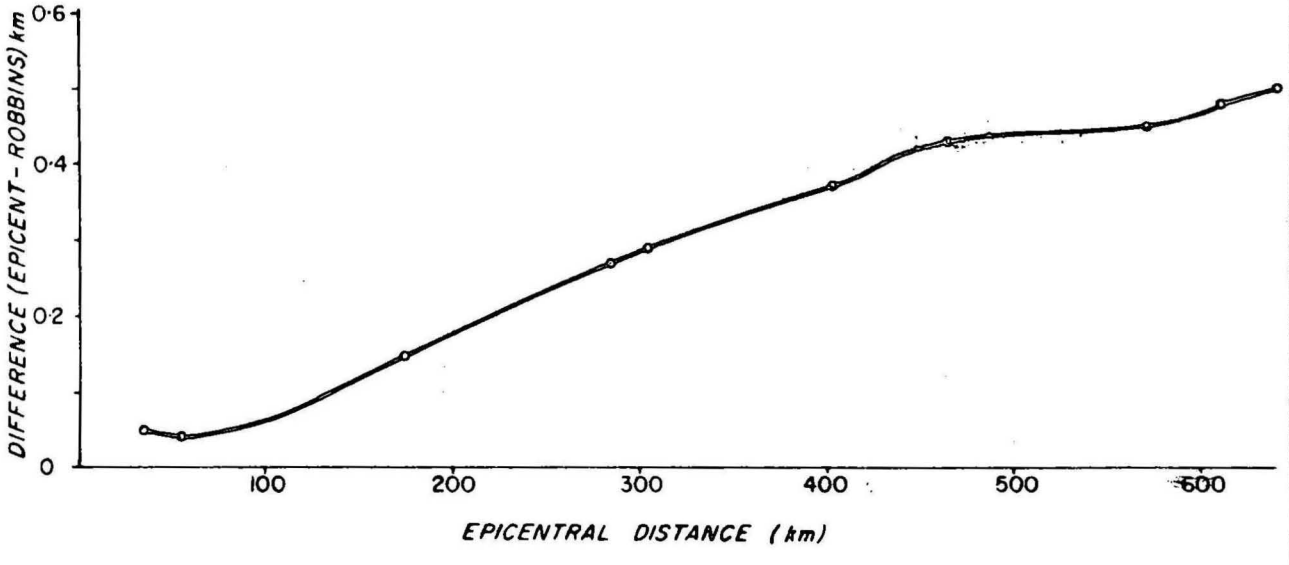
STATION	DEGREES	AZIMUTH	KILOMETERS	COS Z	SIN Z	COS DEL	STATION COORDS
MUN	0.34	206.99	38.23	-0.891060	-0.453884	0.999982	31 58.7S 116 12.9E
MTB	1.98	168.71	142.67	-0.980633	0.195856	0.999750	32 55.9S 116 41.4E
MBR	3.10	159.70	349.64	-0.937980	0.346960	0.998532	34 35.1S 117 41.8E
SXC	2.54	80.93	283.16	0.159375	0.987218	0.999015	31 13.9S 119 19.4E

QUAKE AT 31 45.1S 116 23.9E

STATION	DEGREES	AZIMUTH	KILOMETERS	COS Z	SIN Z	COS DEL	STATION COORDS
MUN	0.27	214.57	30.58	-0.823449	-0.567392	0.999989	31 58.7S 116 12.5E
BSB	2.04	161.92	227.53	-0.950159	0.312072	0.999364	33 41.8S 117 9.4E
PIB	1.02	200.74	113.03	-0.935199	-0.354121	0.999843	32 42.2S 115 57.9E
SXC	2.56	79.97	284.71	0.189685	0.981845	0.999004	31 13.9S 119 19.4E

TABLE 3: Output Data Format

PLATE 1



DIFFERENCE BETWEEN

EPICENT AND ROBBINS

EPICENTRAL DISTANCE COMPUTATIONS

G 96 – 430 A