Copy 3

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1972/49

A COMPUTER PROGRAM FOR CALCULATION OF GRAVITY AND MAGNETIC CURVES FOR TWO-DIMENSIONAL BODIES OF ARBITRARY CROSS-SECTIONS

by

J.E. Haigh, P.C. Pollard and J.P. Williams

Record No. 1972/49

A COMPUTER PROGRAM FOR CALCULATION OF GRAVITY AND MAGNETIC CURVES FOR TWO-DIMENSIONAL BODIES OF ARBITRARY CROSS-SECTION

by J.E. HAIGH, P.C. POLLARD and J.P. WILLIAMS

CONTENTS

ILLUSTRATIONS

SUMMARY

Computer programs are described for calculation of gravity and magnetic anomalies over bodies of arbitrary cross-section and infinite strike length. The traverse direction is assumed to be at right angles to the strike of the body. Paper tape is used as the input medium and the profiles are plotted directly on a graph plotter.

1. INTRODUCTION

Many magnetic and gravity anomalies are caused by bodies which have strike lengths very much greater than their thickness and which can be approximated by a two-dimensional model. In many cases a simple dyke or cylindrical model can be used to give a reasonable approximation to the body. A closer fit to the observed anomaly can often be achieved, however, by a change in the two-dimensional shape of the body.

In the past this could be achieved only by tedious and time consuming methods that involve integrating machines (Olbrich, 1966) or graticules (Millet, 1967). Consequently, officers of the Bureau of Mineral Resources have written FORTRAN programs MAGSIM and GRAVSIM to simulate respectively magnetic and gravity anomalies for two-dimensional bodies of arbitrary cross-section.

Both programs add the anomalies due to small infinite prisms and slabs, with interchangeable subroutines for paper tape input and plotted output. Up to 10 different values of magnetic susceptibility contrast and remanent magnetization (MAGSIM) or density contrast (GRAVSIM) can be specified for each model, so that extremely complicated cross-sections can be built up. The output of both programs is a plotted profile. The vertical scale of the profile may be specified or, if left out, will be computed to give a reasonable amplitude to the anomaly.

A flow chart for GRAVSIM is shown in Appendix 5, and is identical to the one that could be drawn for MAGSIM except for changes in the formulae and the plotting instructions. Listings of MAGSIM and subroutine MAGSLAB are given in Appendix 6, and GRAVSIM and subroutine GRAVSLAB in Appendix 7; subroutines SHAPER, CURVER, and SCALEFIT, which are common to both programs, are listed in Appendix 8.

The programs were originally designed by J.E. Haigh and J.P. Williams but left uncompleted in October 1969. At this stage the mathematics for GRAVSIM had been worked out. The work was revised in October and November 1970 by P.C. Pollard. Several amendments were made to the program and, in addition, the mathematics for a magnetic prism was developed and GRAVSIM adapted to produce MAGSIM.

2. DERIVATION OF MAGSIM

The co-ordinate system is shown in Figure 1. The direction of the traverse is along the X-axis, which makes an angle α with magnetic north, the strike of the bodies being along the Y-axis. The Z-axis is positive downwards.

Consider a square prism of magnetic susceptibility χ with sides 2b and extending to infinity in both the negative and positive y directions as shown in Figure 2. The equation for the magnetic intensity H of this prism at the origin is given in Appendix 1. The equations for a semi-infinite slab are given in Appendix 2.

If $\underset{\sim}{F}$ is the Earth's field having inclination i, the components along the co-ordinate axes are,

$$F_X = F \cos i \cos \alpha$$

$$F_Y = -F \cos i \sin \alpha$$

$$F_Z = F \sin i$$

If remanent magnetization is present it can be allowed for by incorporating it in the calculation of the dipole moment per unit volume $\underset{\sim}{M}$, also known as the magnetization. If the magnitude of remanent magnetization is R, and the inclination and declination with respect to magnetic north are θ and ϕ respectively, the components of $\underset{\sim}{M}$ in the x and z directions produced by induction and remanence combined are

$$M_x = \chi F_X + R \cos \theta \cos (\phi - \alpha)$$

$$M_z = \chi F_z + R \sin \theta$$

The anomaly for an individual prism or slab is calculated by using M_x and M_z in equations (A1.1), (A2.1), or (A2.2). By adding up the anomalies for individual prisms and slabs, extremely complicated models can be built up, as shown in Section 7.

3. DERIVATION OF GRAVSIM

The co-ordinate system and geometry are the same as for MAGSIM. The gravitational effects of a horizontal prism of square cross-section and of a horizontal semi-infinite slab are given in Appendices 3 and 4 respectively. The density contrast is ρ and G is the universal gravitation constant in cgs units.

4. SECTION PREPARATION

The section to be simulated should be drawn at a scale such that it will fit on a sheet 12 inches wide and up to 20 inches deep. The scale of the section is then the horizontal scale (HSCALE) which must be defined on the data card. The section is divided into 1/10" x 1/10" squares (1/10" square graph paper is ideal) and the density contrast (GRAVSIM) or the magnetic susceptibility contrast and remanent magnetism (MAGSIM) for each square is defined, as shown under (c) in Plates 1-3. To avoid the tedium of drawing the initial cross-section, the character x acts as a repetition indicato and causes repetition of the preceding (i.e. left hand) character until a non-blank character is encountered. Note that blank frames encountered without a repetition indicator will cause a zero value in those frames.

A semi-infinite slab to the left hand side of the section is indicated by a character in the first column, or by a character in any of columns 2 to 120 preceded immediately by a minus sign. Likewise a semi-infinite slab to the right hand side is indicated by a character in the last (or 121st) column or by a character in any of columns 2 to 120 followed immediately by a plus sign. The printed output, both directly from the typewriter and via the computer line printer, should be used only for verification of the original drawn section, because the vertical scale is exaggerated by the difference between the line to line and column to column spacing.

5. PAPER TAPE DATA INPUT

The normal rules for paper tape input apply (see CSIRO Technical Note No. 20). The normal format is:

At least 12 inches of blank tape, 6 inches of runout (07B), new line (02B), *DOC, charge code, NAMETAPE, NC new line (02B), 6 inches of runout, model data. Suggested NAMETAPE designations are MAGDATA for MAGSIM and GRAVITY for GRAVSIM.

The model is represented by the numerals 0-9 with the indicators described in the previous section, each numeral being ascribed specific values on a data card, as discussed in Section 6.

The carriage return character (02B) acts as a new line indicator which, within the computer, fills the current line of the array with blank characters, and increments to the next line of the array. Note that each line of the array is computed before going to the next, so that only one line of array storage is required. Runout (07B) and delete (77B) characters are ignored. The end of record is signified by NEXTCHAR being returned negative (physical end of tape), or by encounter of the character (76B). More than one model may be placed on a tape. After the character (76B) there must be a new line character to start the new model. This will be ignored only if it is followed immediately by a runout (07B) or delete (77B) character, so it is normal to separate models by a few inches of runout.

6. PUNCHED CARD DATA INPUT

(A) MAGSIM

The input consists of the following -

Card (1) (a) the codenumber under 2A8, an arbitrary alphanumeric name up to 16 characters in length, which is printed on both the line printer and the plotter and is the only identification linking the two outputs.

(b) the scale of the model (HSCALE) ft/inch under F4. It should be noted that equations (A1.1) etc. are independent of scale for a given model.

(c) ALPHA, the angle between the traverse direction and magnetic north in degrees between 0^o and 360^o under F4. If ALPHA is between 0^o and 180^o the profile will be plotted with the easternmost end to the right. If ALPHA is between 180^o and 360^o the profile will be plotted with the westernmost end to the right. If ALPHA is between 90^o and 270^o the profile will be plotted with the southernmost end to the right.

(d) H, the magnitude of the Earth's field in gammas under F6.

(e) HINC, the inclination of the Earth's field in degrees under F4. HINC must be negative for the southern magnetic hemisphere.

(f) ITAB, the tabulator setting on the typewriter which is used to shift the input characters on each line to the right by the amount specified in ITAB, under I3.

(g) SCALEX, SCALEXN, SCALEZ, and SCALET, the scale in gammas/inch of the profiles respectively for the horizontal anomalies along the traverse and along magnetic north, the vertical anomaly and the total anomaly, under 4F7. If any of these parameters is left blank a scale will be computed to give a reasonable amplitude for the anomaly. The scales computed will be of the form 1, 2, 5 x 10^n gammas/inch.

(h) IX, IXN, IZ, IT under 4I1, if equal to 1 will prevent the plotting of the curves for horizontal anomalies along the traverse and parallel to magnetic north, and the vertical and total anomalies, respectively.

Card (2) The 10 magnetic susceptibilities, CHI, in cgs units multiplied by 10^6 under 10F6, corresponding to the numerals 0-9.

Card (3) The 10 values of remanent magnetization, RM, in gammas, under 10F6, corresponding to the numerals 0-9.

Card (4) The 10 values of PHI, the declination of remanent magnetization with respect to magnetic north in degrees, under 10F5, corresponding to the numerals 0-9.

Card (5) The 10 values of THETA, the inclination of remanent magnetization in degrees under 10F5, corresponding to the numerals 0-9.

Blank cards are required for (3), (4), and (5) if there is no remanent magnetization.

(B) GRAVSIM

Only one card is required for each model, the input parameters being as follows:

(1) The codenumber, an arbitrary alphanumeric name up to 16 characters in length, which is printed on both the line printer and plotter and is the only identification linking the two outputs.

(2) The horizontal scale (HSCALE) ft/inch.

(3) The ten density contrasts corresponding to the numerals 0-9.

(4) ITAB, the tabulator setting on the typewriter which is used to shift the input characters on each line to the right by the amount specified in ITAB.

(5) SCALE, an arbitrary vertical scale may be specified, or if the parameter is left blank, a scale will be computed to give a reasonable amplitude to the anomaly. The scales computed will be of the form 1, 2, 5 x 10^n milligal/inch.

The format for the above parameters is (2A8, F4, 10(F5.2), I3, F7).

7. DISCUSSION

The use of paper tape as the input medium for these programs avoids the tedious computation of coordinates normally associated with simulation programs. Because of the representation of the cross-section as a number of thin horizontal prisms and slabs, the programs are most efficient for small sections but are quite reasonable even for large sections. A step by step routine for use of the program is given in Section 8.

Two examples of the use of GRAVSIM are shown in Plates 1 and 2. Plate 1 shows the simulation of the gravity anomaly for a simple semi-infinite slab 1/20 mile (264 feet) thick with the profile plotted at ½ mile per inch. Note that the same profile could be plotted at say 264 feet per inch by specifying this scale and making the input section one inch thick instead of 1/10 inch.

Plate 2 shows a comparison of the gravity profile computed using GRAVSIM with that computed by a hand integrator (Olbrich, 1966). The example comes from the Rum Jungle East area, NT (Trav. 120 S) and is taken from Plate 7 of Williams (1970). Note the exaggeration of the vertical scale on the line printer representation of the section. The agreement between the profile computed by the hand integrator and that from the program is good. The small discrepancy above 110W is attributed to the step effect inherent in the programs.

An example of the use of MAGSIM is given in Plate 3. This shows the vertical field anomaly for a semi-infinite prism 10 depth units deep and 20 depth units wide. The inclination of the Earth's field is 60°. The corresponding curve for the southern hemisphere could be produced by setting the inclination equal to -60°. The magnitude of the Earth's field is 50 000 gammas, the magnetic susceptibility is 1500 x 10^{-6} cgs units, the traverse direction is 45° from magnetic north, and remanent magnetization is not included. The three other magnetic curves were blocked off in this example but can be plotted out as required (see (h) under MAGSIM Card 1, in Section 6).

Both MAGSIM and GRAVSIM produce a plotted output which is 14" long and which extends for 1" before and beyond the end points of the 12" input (see Plate 3). The computation for this extension assumes blanks beyond the input data except in the case where repetition characters are used (see Section 4).

8. SUMMARIZED ROUTINE FOR USE OF THE PROGRAMS

(1) Draw the cross-section on 1/10" square graph paper and define the boundaries by the numerals 0-9.

(2) Type the tape header (Section 4) and the model data. A single tabulation setting may be used to increase the convenience of typing the section. The value of the setting is defined as ITAB.

(3) Each model must be separated by a new line character (02_B) followed by at least one runout character (07B).

(4) The first line of the typed section is assumed to be at the surface. Multiple new line characters may be used at the start of the model to increase the depth to the first line.

(5) Prepare the punched card data input as explained in Section 6. Data cards for extra models are placed consecutively in the deck. Only one end of file card is required and is the second last card in the deck followed by an EOD card.

(6) Two EQUIP cards are required. These precede the program deck and are of the following form:

*EQUIP, 3 = (CC, NAMETAPE), TR

*EQUIP, 1 = PL

9. REFERENCES

GRANT, F.S., & WEST, G.F., 1965 - INTERPRETATION THEORY IN APPLIED GEOPHYSICS. McGraw-Hill, Inc. U.S.A., p. 213

MILLET, F.R., 1967 - A dot chart for calculation of gravitational and magnetic attraction of two-dimensional bodies. Mining Geophysics, Soc. of Expl. Geophysicists, Tulsa, Vol II, p. 645.

OLBRICH, W., 1966 - A vertical section integrator for the computation of gravity anomalies. Bur. Miner. Resour. Aust. Rec. 1966/23 (unpubl.).

WILLIAMS, J.P., 1970 - Geophysical investigation of the eastern margin of the Rum Jungle Complex, N.T. 1967. Bur. Miner. Resour. Aust. Rec. 1970/1 (unpubl.).

APPENDIX 1

DERIVATION OF THE MAGNETIC INTENSITY FOR A HORIZONTAL INFINITE PRISM

The magnetic intensity $\underset{\sim}{H}(\underset{\sim}{r})$ at a position $\underset{\sim}{r}$ due to volume V of material having magnetic moment per unit volume $\underset{\sim}{M}(\underset{\sim}{r}_0)$ is given by (Grant and West, 1965, p. 213)

$$\underset{\sim}{H}(\underset{\sim}{r}) = -\bar{\nabla} A(\underset{\sim}{r}) = -\bar{\nabla}\left[-\int_V \underset{\sim}{M}.\bar{\nabla}\left(\tfrac{1}{r}\right) d^3r\right]$$

where $A(\underset{\sim}{r})$ is the magnetic scalar potential.

Therefore, the magnetic intensity $\underset{\sim}{H}$ at the origin due to an infinite prism of square cross-section is :

$$\underset{\sim}{H} = -\underset{\sim}{n}_x \frac{\partial}{\partial x}\left\{\int_{x-b}^{x+b}\int_{-\infty}^{\infty}\int_{z}^{z+2b}\left(\frac{M_x x + M_y y + M_z z}{(x^2+y^2+z^2)^{3/2}}\right) dx\, dy\, dz\right\}$$
$$-\underset{\sim}{n}_y \frac{\partial}{\partial y}\left\{\int_{x-b}^{x+b}\int_{-\infty}^{\infty}\int_{z}^{z+2b}\left(\frac{M_x x + M_y y + M_z z}{(x^2+y^2+z^2)^{3/2}}\right) dx\, dy\, dz\right\}$$
$$-\underset{\sim}{n}_z \frac{\partial}{\partial z}\left\{\int_{x-b}^{x+b}\int_{-\infty}^{\infty}\int_{z}^{z+2b}\left(\frac{M_x x + M_y y + M_z z}{(x^2+y^2+z^2)^{3/2}}\right) dx\, dy\, dz\right\}$$

By symmetry $H_y = 0$. Therefore :

$$\underset{\sim}{H} = -\underset{\sim}{n}_x\left[\int_{-\infty}^{\infty}\int_{z}^{z+2b}\left(\frac{M_x x + M_y y + M_z z}{(x^2+y^2+z^2)^{3/2}}\right) dy\, dz\right]_{x-b}^{x+b}$$
$$-\underset{\sim}{n}_z\left[\int_{x-b}^{x+b}\int_{-\infty}^{\infty}\left(\frac{M_x x + M_y y + M_z z}{(x^2+y^2+z^2)^{3/2}}\right) dx\, dy\right]_{z}^{z+2b}$$

$$= -\underset{\sim}{n}_x\left[\int_{z}^{z+2b}\left(\frac{2M_x x}{x^2+z^2} + \frac{2M_z z}{x^2+z^2}\right) dz\right]_{x-b}^{x+b}$$
$$-\underset{\sim}{n}_z\left[\int_{x-b}^{x+b}\left(\frac{2M_x x}{x^2+z^2} + \frac{2M_z z}{x^2+z^2}\right) dx\right]_{z}^{z+2b}$$

$$= -\underset{\sim}{n}_x\left\{\left[2M_x \tan^{-1}\frac{z}{x} + M_z \log(x^2+z^2)\right]_z^{z+2b}\right\}_{x-b}^{x+b}$$
$$-\underset{\sim}{n}_z\left\{\left[2M_z \tan^{-1}\frac{x}{z} + M_x \log(x^2+z^2)\right]_{x-b}^{x+b}\right\}_{z}^{z+2b}$$

$$= \underset{\sim}{n}_x \left\{ 2M_x \left(\tan^{-1}\frac{z}{x+b} - \tan^{-1}\frac{z+2b}{x+b} - \tan^{-1}\frac{z}{x-b} + \tan^{-1}\frac{z+2b}{x-b} \right) + M_z \log\left[\frac{\left((x+b)^2+z^2\right)\left((x-b)^2+(z+2b)^2\right)}{\left((x+b)^2+(z+2b)^2\right)\left((x-b)^2+z^2\right)} \right] \right\}$$

$$+ \underset{\sim}{n}_z \left\{ 2M_z \left(\tan^{-1}\frac{x-b}{z+2b} - \tan^{-1}\frac{x+b}{z+2b} - \tan^{-1}\frac{x-b}{z} + \tan^{-1}\frac{x+b}{z} \right) + M_x \log\left[\frac{\left((x+b)^2+z^2\right)\left((x-b)^2+(z+2b)^2\right)}{\left((x+b)^2+(z+2b)^2\right)\left((x-b)^2+z^2\right)} \right] \right\}$$

............(A1.1)

APPENDIX 2

DERIVATION OF THE MAGNETIC INTENSITY FOR A HORIZONTAL SEMI-INFINITE SLAB

The equation for a slab of thickness 2b extending to $(-\infty)$ in the x direction is obtained from equation (A1.1) by letting $(x - b)$ tend to $(-\infty)$. This gives,

$$\underset{\sim}{H} = \underset{\sim}{n}_x \left\{ 2M_x \left(\tan^{-1}\frac{z}{x+b} - \tan^{-1}\frac{z+2b}{x+b} \right) + M_z \log\left[\frac{(x+b)^2+z^2}{(x+b)^2+(z+2b)^2} \right] \right\}$$

$$+ \underset{\sim}{n}_z \left\{ 2M_z \left(\tan^{-1}\frac{x+b}{z} - \tan^{-1}\frac{x+b}{z+2b} \right) + M_x \log\left[\frac{(x+b)^2+z^2}{(x+b)^2+(z+2b)^2} \right] \right\}$$

..........(A2.1)

Similarly the equation for a slab of thickness 2b extending to $+\infty$ in the x direction is,

$$\underset{\sim}{H} = -\underset{\sim}{n}_x \left\{ 2M_x \left(\tan^{-1}\frac{z}{x-b} - \tan^{-1}\frac{z+2b}{x-b} \right) + M_z \log\left[\frac{(x-b)^2+z^2}{(x-b)^2+(z+2b)^2} \right] \right\}$$

$$- \underset{\sim}{n}_z \left\{ 2M_z \left(\tan^{-1}\frac{x-b}{z} - \tan^{-1}\frac{x-b}{z+2b} \right) + M_x \log\left[\frac{(x-b)^2+z^2}{(x-b)^2+(z+2b)^2} \right] \right\}$$

..........(A2.2)

APPENDIX 3

DERIVATION OF THE GRAVITY EFFECT OF A HORIZONTAL INFINITE PRISM

The vertical component of gravitational attraction of an infinite prism of square cross-section 2b is (Millet, 1967)

$$g_z = 2G\rho \int_{x-b}^{x+b} \int_{z}^{z+2b} \left(\frac{z}{x^2+z^2} \right) dx\, dz$$

$$= G\rho \left[\int_{x-b}^{x+b} \log (x^2+z^2)\, dx \right]_z^{z+2b}$$

$$= G\rho \left\{ \left[x \log (x^2+z^2) - 2x + 2z \tan^{-1} \frac{x}{z} \right]_{x-b}^{x+b} \right\}_z^{z+2b}$$

$$= G\rho \left\{ (x-b) \log \left(\frac{(x-b)^2+z^2}{(x-b)^2+(z+2b)^2} \right) - (x+b) \log \left(\frac{(x+b)^2+z^2}{(x+b)^2+(z+2b)^2} \right) \right.$$

$$+ 2(z+2b) \left[\tan^{-1} \left(\frac{x+b}{z+2b} \right) - \tan^{-1} \left(\frac{x-b}{z+2b} \right) \right]$$

$$+ 2z \left[\tan^{-1} \left(\frac{x-b}{z} \right) - \tan^{-1} \left(\frac{x+b}{z} \right) \right] \qquad \text{.........(A3.1)}$$

Using the relationship

$$\tan (A-B) = \frac{\tan A - \tan B}{1 + \tan A \tan B}$$

$$g_z = G\rho \left\{ (x-b) \log \left[\frac{(x-b)^2 + z^2}{(x-b)^2 + (z+2b)^2} \right] \right.$$

$$- (x+b) \log \left[\frac{(x+b)^2 + z^2}{(x+b)^2 + (z+2b)^2} \right]$$

$$+ 2(z+2b) \tan^{-1} \left[\frac{2(z+2b)b}{(z+2b)^2 + (x^2-b^2)} \right]$$

$$\left. - 2z \tan^{-1} \left[\frac{2zb}{z^2 + (x^2-b^2)} \right] \right\} \qquad \text{..........(A3.2)}$$

This equation was used in the program GRAVSIM.

APPENDIX 4

DERIVATION OF THE GRAVITY EFFECT OF A HORIZONTAL SEMI-INFINITE SLAB

The equation for a slab of thickness 2b extending to $(-\infty)$ in the x direction is obtained most readily from equation (A3.1) by letting $(x - b)$ tend to $(-\infty)$. This gives,

$$g_z = G\rho\left\{-(x+b)\log\left[\frac{(x+b)^2 + z^2}{(x+b)^2 + (z+2b)^2}\right] + 2b\pi\right.$$

$$+ 2(z+2b)\tan^{-1}\left[\frac{x+b}{z+2b}\right]$$

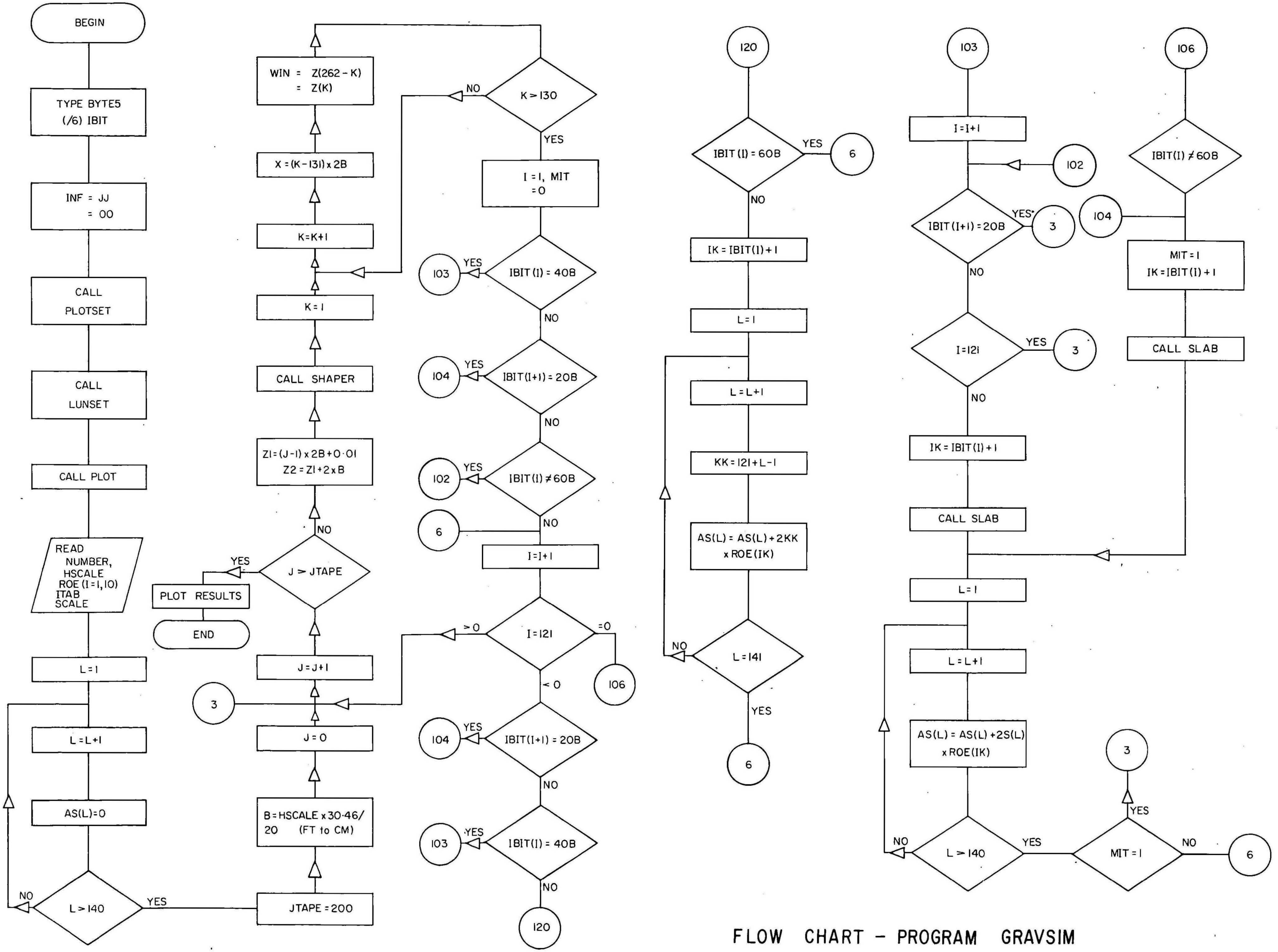
$$\left. - 2z\tan^{-1}\left[\frac{x+b}{z}\right]\right\} \qquad \text{...........(A4.1)}$$

Similarly, for a slab extending to ∞ in the x direction,

$$g_z = G\rho\left\{(x+b)\log\left[\frac{(x-b)^2 + z^2}{(x-b)^2 + (z+2b)^2}\right] + 2b\pi\right.$$

$$+ 2z\tan^{-1}\left[\frac{x-b}{z}\right]$$

$$- 2(z+2b)\tan^{-1}\left[\frac{x-b}{z+2b}\right] \qquad \text{..........(A4.2)}$$



FLOW CHART - PROGRAM GRAVSIM

APPENDIX 6

```
      PROGRAM MAGSIM
      TYPE BYTE5(/6)IBIT
      EQUIVALENCE (A,IBIT)
      COMMON/FRED/SAHX(141),SAHZ(141),SBHX(141)
      COMMON /BILL/          IBIT(128),A(16)
      COMMON/SUE/AS(141)
      DIMENSION CHI(10),RM(10),PHI(10).THETA(10),XM(10).ZM(10),AHX(262),
     1AHZ(262),BHX(262),NUMBER(2),AX(141),AZ(141)
      INF=0                     $PI=3.1415926536
      CALL PLOTSET(2)
      CALL LUNSET(3)
      CALL PLOT (2..0.4,2)
      CALL PLOT (-14.0,+2.0,1)
      CALL PLOT(-14.0,0.0,3)
    7 READ 10,NUMBER,HSCALE,ALPHA,H,HINC,ITAB,SCALEX,SCALEXN,SCALEZ,SCAL
     1ET,IX,IXN,IZ,IT,(CHI(I),I=1,10),(RM(I),I=1,10),(PHI(I),I=1,10),
     2(THETA(I),I=1,10)
   10 FORMAT(2A8,2F4,F6,F4,I3,4F7,11X.4I1,2(/10F6),2(/10F5))
      IF(EOF,60)72,14
   14 PRINT 13
   13 FORMAT (1HZ)
      PRINT 15,NUMBER,HSCALE,H,HINC,(CHI(I),I=1,10),(RM(I),I=1,10),
     1(PHI(I),I=1,10),(THETA(I),I=1,10),ALPHA
   15 FORMAT(1H1,*CODE NUMBER=*,2A8,8X.*HOR. SCALE= *,F4,*METERS PER INC
     1H*/10X,*MAGNETIC INTENSITY OF EARTHS FIELD= *,F6,*GAMMAS*,10X.*INC
     2LINATION= *,F6.1,*DEGREES*/X,*MAG. SUS.*,6X.10(F6.4X),11HCOS*10**(
     36)/X,*REM. MAG.*,6X,10(F6.4X).*GAMMAS*/X,*AZIMUTH OF REM,*,10(F6.1
     4,4X),*DEGREES*/X,*INCLIN. OF REM.*,10(F6.1,4X),*DEGREES*/X,
     5*ANGLE BETWEEN TRAVERSE AND MAGNETIC NORTH = *,F6.1,* DEGREES*)
      JTAPE=200
      B=HSCALE/20.0*100.
C     THIS CONVERTS B FROM METRES TO CMS
      ALPHA=ALPHA*PI/180.
      H=H*0.00001
      HINC=HINC*PI/180.
      HX=H*COS(HINC)*COS(ALPHA)
      HY=-H*COS(HINC)*SIN(ALPHA)
      HZ=H*SIN(HINC)
      DO 8,I=1,10
      PHI(I)=PHI(I)*PI/180.
      THETA(I)=THETA(I)*PI/180.
      RM(I)=RM(I)*0.00001            $CHI(I)=CHI(I)*10.0**(-6)
      XM(I)=CHI(I)*HX+RM(I)*COS(THETA(I))*COS(PHI(I)-ALPHA)
    8 ZM(I)=CHI(I)*HZ+RM(I)*SIN(THETA(I))
      DO 51,L=1,141
      AX(L)=0                 $AZ(L)=0
   51 CONTINUE
      PRINT 16
   16 FORMAT(X,121(1H-))
      J=0
    3 J=J+1
      IF(J.GT.JTAPE)GO TO 82
      CALL SHAPER(J,JTAPE,INF,ITAB)
      IF(INF.EQ.1)GO TO 72
      Z1=(J-1)*2*B    +0.01
      Z2=Z1+2*B
      DO 41,K=1,262
      X=(131-K)*B*2.0
      AHX(K)=2*(ATAN2(Z1,(X+B))-ATAN2(Z2,(X+B))-ATAN2(Z1,(X-B))+ATAN2(Z2
     1,(X-B)))
      AHZ(K)=ALOG(((X+B)*(X+B)+Z1*Z1)*((X-B)*(X-B)+Z2*Z2)/(((X+B)*(X+B)
     1+Z2*Z2)*((X-B)*(X-B)+Z1*Z1)))
      BHX(K)=2*(ATAN2((X+B).Z1)-ATAN2((X-B),Z1)-ATAN2((X+B).Z2)+ATAN2((X
     1-B),Z2))
   41 CONTINUE
      I=1               $MIT=0
      IF(IBIT(I).EQ.40B)GO TO 103
      IF(IBIT(I).NE.60B)102,6
    6 I=I+1
      IF(I-121)105,106,3
  104 MIT=1 $ IK=IBIT(I)+1 $ GO TO 23
  105 IF(IBIT(I+1).EQ.20B)GO TO 104
      IF(IBIT(I).EQ.40B)GO TO 103
      IF(IBIT(I).EQ.60B)6,5
  202 CALL MAGSLAB(1,J,B,I,Z1,Z2)       $GO TO 500
   23 CALL MAGSLAB(-1,J,B,I,Z1,Z2)
  500 DO 501,L=1,141
      AX(L)=AX(L)+SAHX(L)*XM(IK)+SAHZ(L)*ZM(IK)
      AZ(L)=AZ(L)+SBHX(L)*ZM(IK)+SAHZ(L)*XM(IK)
  501 CONTINUE
      IF(MIT.EQ.1)3,6
  106 IF(IBIT(I).NE.60B) 104,6
  103 I=I+1
  102 IF(IBIT(I+1).EQ.20B)GO TO 3
      IF(I.EQ.121)GO TO 3
      IK=IBIT(I)+1                     $GO TO 202
    5 IK=IBIT(I)+1
      DO 50, L=1,141
      KK = 121 + L -1
      AX(L)=AX(L)+AHX(KK)*XM(IK)+AHZ(KK)*ZM(IK)
      AZ(L)=AZ(L)+BHX(KK)*ZM(IK)+AHZ(KK)*XM(IK)
   50 CONTINUE
      GO TO 6
   82 PRINT 18,JTAPE
   18 FORMAT (* JEND = *,I3)
      IF(IX.EQ.1)GO TO 17
      DO 1,I=1,141
    1 AS(I)=AX(I)*100000
```

PROGRAM MAGSIM

SUBROUTINE MAGSLAB

To accompany Record No. 1972/49

```
      CALL PLOT(-14.0.0.0.1)
      CALL PLOT(-3.2.-0.6.3)
      CALL TEXT(NUMBER,16.4)
      CALL PLOT(-4.8.-1.2.3)
      CALL TEXT(24HHORIZ. FIELD ALONG TRAV.,24,4)
      CALL CURVER(SCALEX)
   17 IF(IXN.EQ.1)GO TO 11
      XY=H*COS(HINC)
      DO 9,I=1,141
    9 AS(I)=(SQRT((AX(I)+HX)**2+HY*HY)-XY)*100000
      CALL PLOT(-14.0.0.0.1)
      CALL PLOT(-3.2.-0.6.3)
      CALL TEXT(NUMBER,16.4)
      CALL PLOT(-6.4.-1.2.3)
      CALL TEXT(31H HORIZ. FIELD IN DIR. OF MAG. N,31,4)
      CALL CURVER(SCALEXN)
   11 IF(IZ.EQ.1)GO TO 12
      DO 4,I=1,141
    4 AS(I)=AZ(I)*100000
      CALL PLOT(-14.0.0.0.1)
      CALL PLOT(-3.2.-0.6.3)
      CALL TEXT(NUMBER,16.4)
      CALL PLOT(-2.8.-1.2.3)
      CALL TEXT(14HVERTICAL FIELD,14.4)
      CALL CURVER(SCALEZ)
   12 IF(IT.EQ.1)GO TO 7
      DO 2,I=1,141
      AX(I)=AX(I)+HX
      AZ(I)=AZ(I)+HZ
    2 AS(I)=(SQRT(AX(I)*AX(I)+AZ(I)*AZ(I)+HY*HY)-H)*100000
      CALL PLOT(-14.0.0.0.1)
      CALL PLOT(-3.2.-0.6.3)
      CALL TEXT(NUMBER,16.4)
      CALL PLOT(-2.4.-1.2.3)
      CALL TEXT(12HTOTAL  FIELD,12.4)
      CALL CURVER(SCALET)
      GO TO 7
   72 END
```

```
      SUBROUTINE MAGSLAB(N,J,B,I,Z1,Z2)
      COMMON/FRED/SAHX(141),SAHZ(141),SBHX(141)
      DO 10,L=1,141
      X=(I+10-L)*2*B+N*B
      SAHX(L)=N*2*(ATAN2(Z1,X)-ATAN2(Z2,X))
      SAHZ(L)=N*ALOG((X*X+Z1*Z1)/(X*X+Z2*Z2))
      SBHX(L)=N*2*(ATAN2(X,Z1)-ATAN2(X,Z2))
   10 CONTINUE
      RETURN
      END
```

PROGRAM MAGSIM
SUBROUTINE MAGSLAB

APPENDIX 7

```
      PROGRAM GRAVSIM
      TYPE BYTES(76)IBIT
      EQUIVALENCE (A,IBIT)
      COMMON/FRED/ZS(141)
      COMMON /BILL/         IBIT(128),A(16)
      COMMON /SUE/AS(141)
      DIMENSION ROE(10),NUMBER(2),Z(262)
C     INPUT IS ROE = DENSITY CONTRAST. B= THE UNIT SQUARE. J IS THE
C              DEPTH CONTROL AND XX IS THE HORIZONTAL DISTANCE TO
C              THE CENTRE OF THE SQUARE.
      INF=0
      CALL PLOTSET(2)
      CALL LUNSET(3)
      CALL PLOT (2.,0,4,2)
      CALL PLOT (-14.0,+2.0,1)
      CALL PLOT(-14.0,0.0,3)
    7 READ 10,NUMBER,HSCALE,(ROE(I),I=1,10),ITAB,SCALE
   10 FORMAT(2A8,F4,10(F5.2),   I3,F7)
      IF(EOF,60)72,14
   14 DO 51,L=1,141
   51 AS(L)=0
      JTAPE=200
      PRINT 13
   13 FORMAT (1HZ)
      PRINT 15,NUMBER,HSCALE,(ROE(I),I=1,10)
   15 FORMAT(1H1,*CODE NUMBER=*,2A8,8X,*HOR. SCALE=*,F4 *METERS PER INCH
     1*,/X,*DENSITIES ARE*,10(F5.2 5X))
      B=HSCALE/20,0*100.
C     THIS CONVERTS B FROM METRES TO CMS
      PRINT 16
   16 FORMAT(X,121(1H-))
      J = 0
    3 J=J+1
      IF(J.GT.JTAPE)GO TO 82
      CALL SHAPER(J,JTAPE,INF,ITAB)
      IF(INF.EQ.1)GO TO 72
      Z1=(J-1)*2*B    +0.01
      Z2=Z1+2*B
      DO 41, K=1,131
      X=(K-131)*B*2.0
      WIN=2*Z1*ATAN2(2*Z1*B,Z1*Z1+(X*X-B*B))
      Z(K)=6.67*10.0**(-5,0)*((X-B)*ALOG(((X-B)*(X-B)+Z1*Z1)/((X-B)*(X-B
     1)+Z2*Z2))-(X+B)*ALOG(((X+B)*(X+B)+Z1*Z1)/((X+B)*(X+B)+Z2*Z2))+2*Z2
     2*ATAN2(2*Z2*B,Z2*Z2+(X*X-B*B))-WIN)
      Z(262-K)=Z(K)
   41 CONTINUE
      I=1
      MIT=0
      IF(IBIT(I).EQ.40B)GO TO 103
      IF(IBIT(I).NE.60B)102,6
    6 I=I+1
      IF(I-121)105,106,3
  104 MIT=1 $ IK=IBIT(I)+1 $ GO TO 23
  105 IF(IBIT(I+1).EQ.20B)GO TO 104
      IF(IBIT(I).EQ.40B)GO TO 103
      IF(IBIT(I).EQ.60B)6,5
  202 CALL GRAVSLAB(1,J,B,I,Z1,Z2)          $GO TO 500
   23 CALL GRAVSLAB(-1,J,B,I,Z1,Z2)
  500 DO 501,L=1,141
  501 AS(L)=AS(L)+ZS(L)*ROE(IK)
      IF(MIT.EQ.1)3,6
  106 IF(IBIT(I).NE.60B) 104,6
  103 I=I+1
  102 IF(IBIT(I+1).EQ.20B)GO TO 3
      IF(I.EQ.121)GO TO 3
      IK=IBIT(I)+1              $GO TO 202
    5 IK=IBIT(I)+1
      DO 50, L=1,141
      KK = 121 + L -I
   50 AS(L)=AS(L)+Z(KK)*ROE(IK)
      GO TO 6
   82 PRINT 18,JTAPE
   18 FORMAT (* JEND = *,I3)
      CALL PLOT(-14.0,0.0,1)
      CALL PLOT (-3.2,-1.2,3)
      CALL TEXT(NUMBER,16,4)
      CALL CURVER(SCALE)
      GOTO 7
   72 END
```

PROGRAM GRAVSIM

SUBROUTINE GRAVSLAB

```
      SUBROUTINE GRAVSLAB(N,J,B,I,Z1,Z2)
      COMMON/FRED/ZS(141)
      DO 10,L=1,141
      X=N*(L-10-I)*B*2.0-B
   12 WIN=2*Z1*ATAN2(X,Z1)
   10 ZS(L)=6.67*10.0**(-5,0)*(X*ALOG((X*X+Z1*Z1)/(X*X+Z2*Z2))+3.1415926
     1*(Z2-Z1)+WIN-2*Z2*ATAN2(X,Z2))
      RETURN
      END
```

APPENDIX 8

```
      SUBROUTINE SHAPER(J,JTAPE,INF,ITAB)
      COMMON /BILL/          IBIT(128).A(16)
      TYPE BYTES(/6)IBIT
      EQUIVALENCE (A.IBIT)
      DATA(MASK=40000000000000778)
   11 FORMAT (X,*NEWLINE MISSED AT I=*.I3,3X,*J=*.I3)
   12 FORMAT (X.16A8)
      MAT=NIT=0
      DO 901.K=122,128
  901 IBIT(K)=608
      I=1
    1 IBIT(I)=608
      N=(NEXTCHAR(N).AND.MASK)
   30 IF (N.EQ.-1) GO TO 210
      IF(N.EQ.028,AND,I.EQ.1)24,25
   24 N=(NEXTCHAR(N).AND.MASK)
      IF (N.EQ.078.OR.N.EQ. 778)GO TO 1
      J=J+1
      NIT=1    $  GO TO 2
   25 IF (N.EQ.078.OR.N.EQ. 778)GO TO 1
      IF (N.EQ.768) 21,22
   22 IF (N.EQ.028)GO TO 2
      IF(MAT.EQ.1,AND.N.EQ.00B)29.28
   29 IBIT(I)=IBIT(I-1) $ GO TO 503
   28 MAT=0
      IF(N.EQ.70B)26.27
   26 MAT=1 $ GO TO 29
   27 IF(N.EQ.32B)IBIT(I)=0
      IF(N.EQ.33B)IBIT(I)=209
      IF(N.EQ.359)IBIT(I)=408
      IF (N.EQ.01B) GO TO 500
      IF(N.GT.17B,AND.N.LT.32B)502,503
  502 IBIT(I)=N-20B
  503 I=I+1
      IF (I.GT.123) 4.1
    4 PRINT 11. I,J      $    STOP
  500 DO 501. I=1,ITAB
  501 IBIT(I)=608
      I=ITAB
      GO TO 1
  210 INF=1                     $RETURN
   21 JTAPE=J
    2 II=I+1
      DO 23. I=II,121
   23 IBIT(I)=60B
      PRINT 12.A
      IF (NIT.EQ.1)  31.32
   31 NIT=0                     $I=1
      GO TO 30
   32 RETURN
      END


      SUBROUTINE CURVER(SCALE)
      COMMON /SUE/AS(141)
      FMAX = FMIN = AS(1)
      DO 70. L=1,141
      IF (AS(L).GT.FMAX) FMAX=AS(L)
      IF (AS(L).LT.FMIN) FMIN=AS(L)
   70 CONTINUE
      AMP=FMAX-FMIN
      START=-FMIN
      IF(SCALE.GT.0.0001)GO TO 29
      CALL SCALEFIT(AMP.SCALE)
   29 PRINT 11.START.SCALE
   11 FORMAT(X,*BASELINE AT *.E9.2.* GAMMAS*.10X.*SCALE= *.E9.2.* GAMMAS
    1 PER INCH*)
      XX=-6.95
      YY=AS(1)+START
      CALL PLOT(1.0,SCALE.2)
      CALL PLOT (XX.YY,3)
      DO 71. L=2.141
      XX = XX+0.1
      YY=AS(L)+START
   71 CALL PLOT (XX,YY,4)
      CALL PLOT(2.0.0.4.2)
      CALL PLOT (14.0.0.0.3)
      CALL PLOT (0.0.0.0.4)
      CALL PLOT (0.0.0.1.4)
      CALL PLOT (0.0.0.0.4)
      CALL PLOT (-14.0.0.0.4)
      CALL PLOT ( 18.0.0.0.3)
      RETURN
      END


      SUBROUTINE SCALEFIT(AMP,SCALE)
      A=ALOG10(AMP)
      I=A$IF(A.LT.0)I=I-1
      POWER=10.0**I
      N=(AMP/POWER +0.5)
      IF(N/3 -1)1,2,3
    1 SCALE =0.5* POWER $ RETURN
    2 SCALE =1.0* POWER $ RETURN
    3 SCALE =2.0* POWER $ RETURN
      END
```

SUBROUTINES

SHAPER

CURVER

SCALEFIT

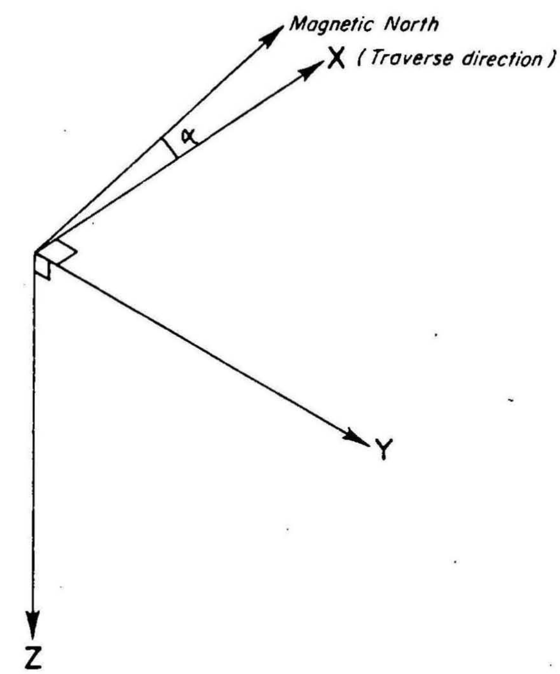


Fig. 1 Co-ordinate System

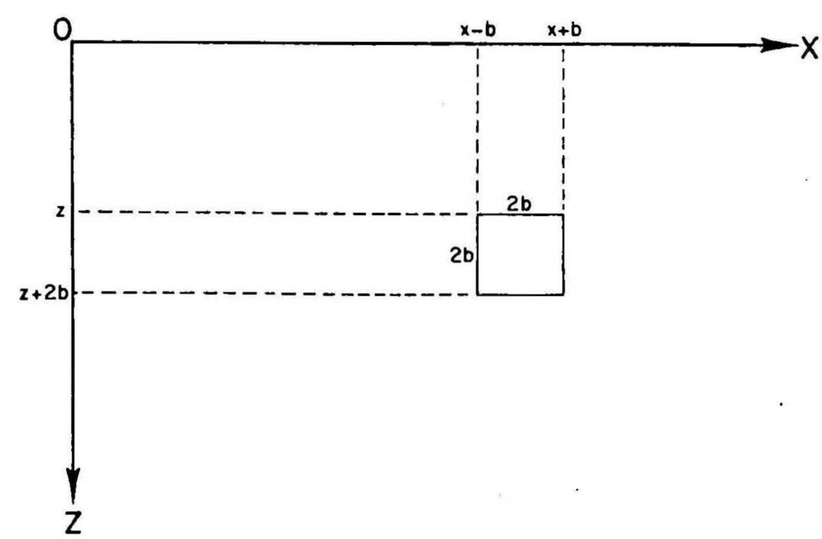
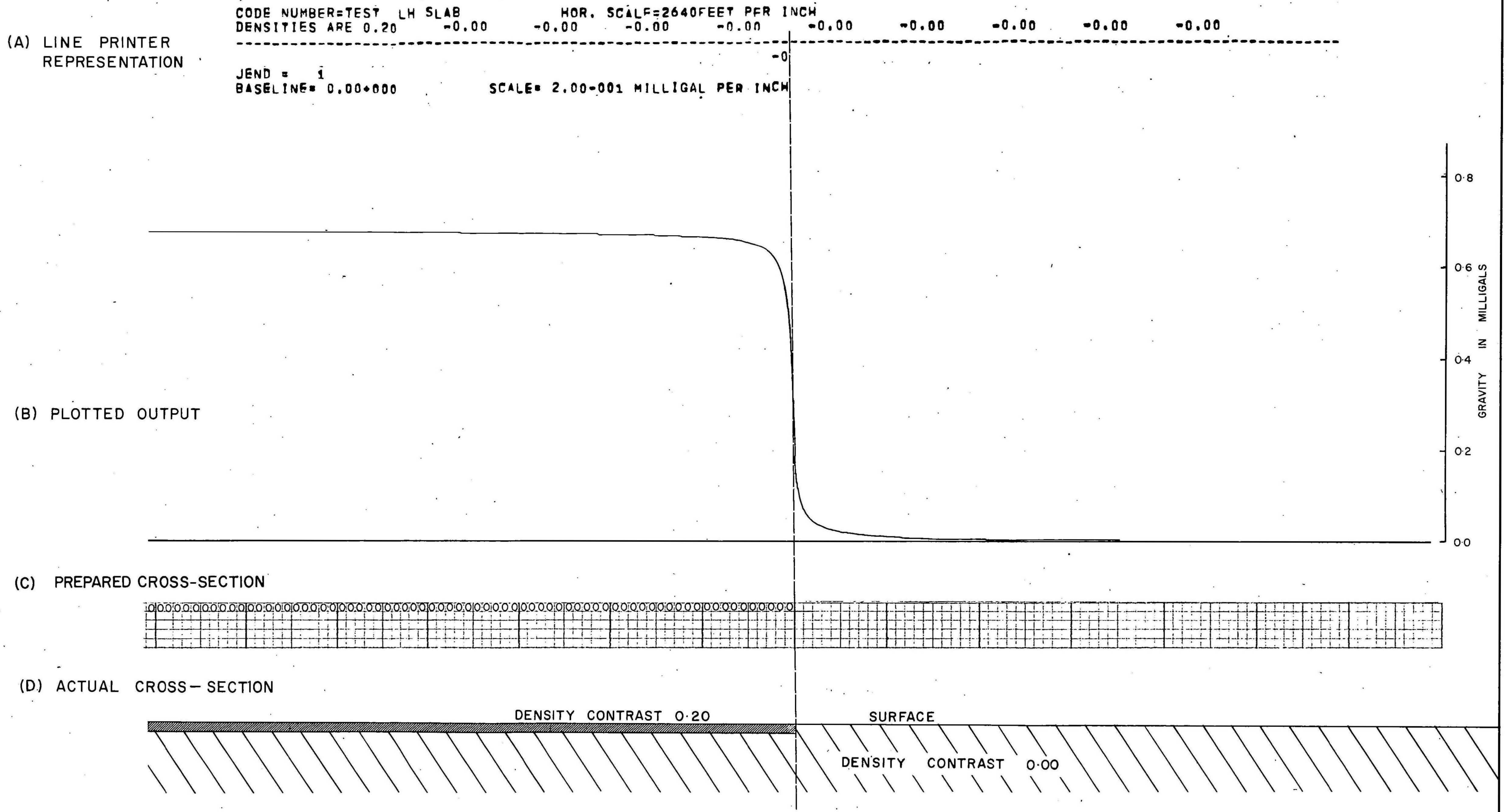


Fig. 2 Cross-section of Infinite Prism

PLATE I

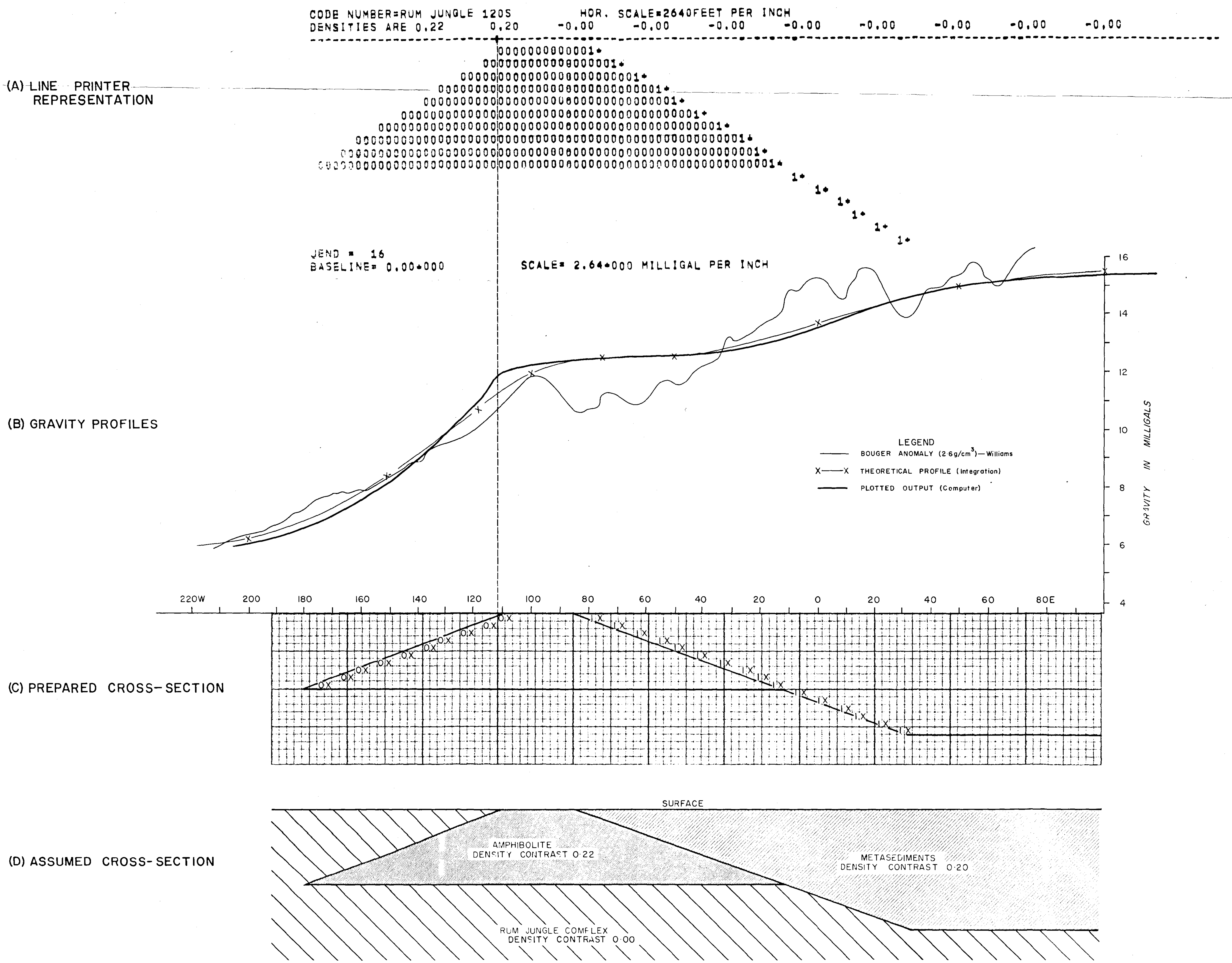


SIMULATION OF THE GRAVITY
ANOMALY OF A HORIZONTAL
SEMI-INFINITE SLAB

To accompany Record No. 1972/49

D52/B7-512

PLATE 2



TRAVERSE 120S, RUM JUNGLE EAST, NT

SIMULATION OF THE GRAVITY ANOMALY FOR A COMPLICATED

CROSS-SECTION

FEET
1000 0 2000 4000
300 0 1000
METRES

To accompany Record No. 1972/49

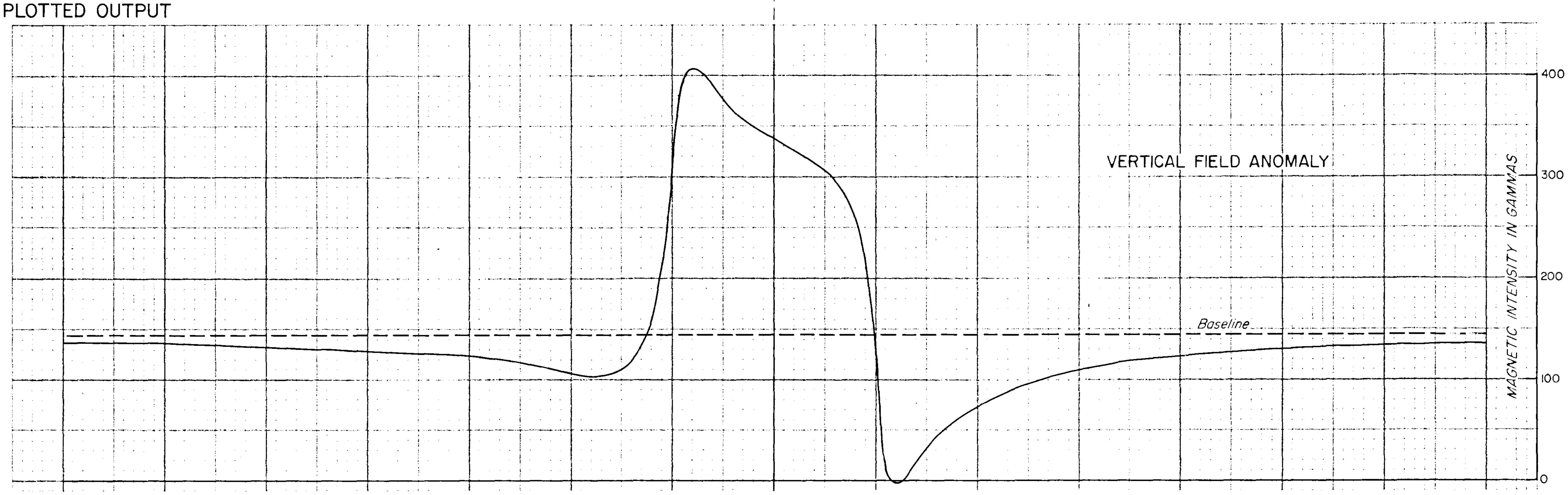
D52/B7-511

PLATE 3

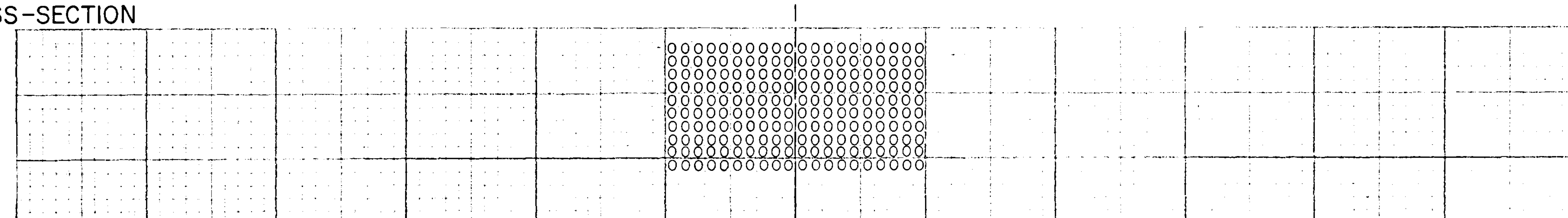
(A) LINE PRINTER REPRESENTATION

```
CODE NUMBER= GULATEE BLOCK          HOR. SCALE=  100METERS PER INCH
       MAGNETIC INTENSITY OF EARTHS FIELD=  50000GAMMAS              INCLINATION=   60.0DEGREES
MAG. SUS.           1500      -0      -0      -0      -0      -0      -0      -0      -0      -0    CGS*10**(6)
REM. MAG.             -0      -0      -0      -0      -0      -0      -0      -0      -0      -0    GAMMAS
AZIMUTH OF REM.  -0.0      -0.0    -0.0    -0.0    -0.0    -0.0    -0.0    -0.0    -0.0    -0.0    DEGREES
INCLIN. OF REM.  -0.0      -0.0    -0.0    -0.0    -0.0    -0.0    -0.0    -0.0    -0.0    -0.0    DEGREES
ANGLE BETWEEN TRAVERSE AND MAGNETIC NORTH =   45.0 DEGREES
------------------------------------------------------------------------------------------------------

                                    00000000000000000000
                                    00000000000000000000
                                    00000000000000000000
                                    00000000000000000000
                                    00000000000000000000
                                    00000000000000000000
                                    00000000000000000000
                                    00000000000000000000
                                    00000000000000000000
                                    00000000000000000000

JEND =  11
BASELINE AT  1.45+002 GAMMAS              SCALE=  1.00+002 GAMMAS PER INCH
```

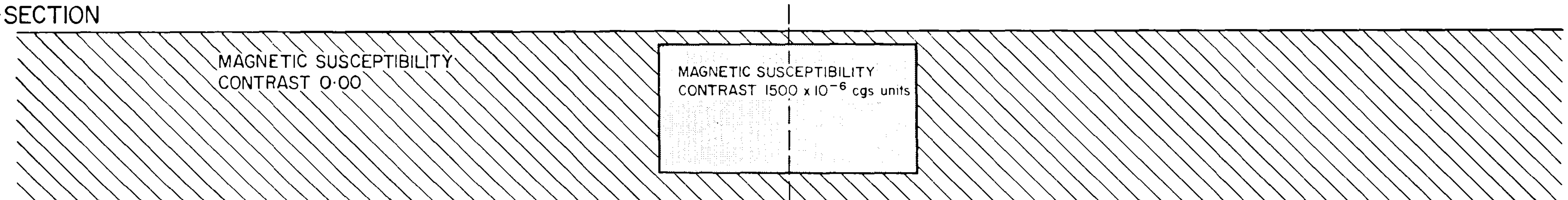
(B) PLOTTED OUTPUT



(C) PREPARED CROSS-SECTION



(D) ACTUAL CROSS-SECTION



SIMULATION OF THE VERTICAL MAGNETIC ANOMALY FOR AN INFINITE RECTANGULAR PRISM