Appendix A: Computer Programs Written in MATLAB

A.1. Program grav_sphere.m

```
% vertical gravity attraction of a sphere
% 3 arrays
% G = universal gravity constant (synchronize unit of mgal) = 6.67 x 10^-11 kg^-1m^3s^-2
% rho = density contrast (g/cm^3)
% R = radius of sphere (m)
G=6.67e-3;
rho=1;
R=1;

% x,y =  coordinate Cartesian distance from the center (m)
% z = depth of sphere(m)
[x,y]=meshgrid(-2:0.2:2,-2:0.2:2);
r=(x.^2+y.^2).^0.5;
z=1;
z1=1.1;
z2=1.2;

% calculation vertical gravity effect for z = 1, 1.2, 1.3 m
g=((4*pi*G*rho*R^3)/3).*z./(r.^2+z.^2).^1.5;
g1=((4*pi*G*rho*R^3)/3).*z./((r.^2+z1.^2).^1.5;
g2=((4*pi*G*rho*R^3)/3).*z./((r.^2+z2.^2).^1.5;

% display
grid on;
subplot(3,1,1);
surf(x,y,g);
shading interp;
colormap(cool);
subplot(3,1,2);
surf(x,y,g1);
shading interp;
subplot(3,1,3);
surf(x,y,g2);
shading interp;
```

A.2. Program grav_thin_rod.m

```
% vertical gravity attraction  of a  thin rod dipping
% 2 arrays
% G = universal gravity constant (synchronize unit of mgal) = 6.67 x 10^-11 kg^-1m^3s^-2
% rho = density contrast (g/cm^3)
% A = cross-section (m^2)
% L = length of thin rod (m)
```

```
G=6.67e-3;
sigma=1;
A=1;
L=100;
% inclination
alfa=90;
alfa1=45;
alfa2=135;

% x is horizontal distance from O (m)
% z is depth of top thin rod (m)
x=-10:0.01:10;
z=1;

% calculation vertical gravity effect for alfa = 90°
g1=(G*rho*A)./(x*sin(alfa*pi/180));
g2=(x+z*cot(alfa*pi/180))./((z^2*(csc(alfa*pi/180))^2+2*z.*x*cot(alfa*pi/180)+
x.^2).^0.5);
g3=(x+z*cot(alfa*pi/180)+L*cos(alfa*pi/180))./(((L+z*csc(alfa*pi/180))^2+x.^2
+2.*x.*(L*cos(alfa*pi/180)+z*cot(alfa*pi/180))).^0.5);
g=g1.*(g2-g3);

% calculation vertical gravity effect for alfa = 45°
gg1=(G*rho*A)./(x*sin(alfa1*pi/180));
gg2=(x+z*cot(alfa1*pi/180))./((z^2*(csc(alfa1*pi/180))^2+2*z.*x*cot(alfa1*pi/
180)+x.^2).^0.5);
gg3=(x+z*cot(alfa1*pi/180)+L*cos(alfa1*pi/180))./(((L+z*csc(alfa1*pi/180))^2
+x.^2+2.*x.*(L*cos(alfa1*pi/180)+z*cot(alfa1*pi/180))).^0.5);
gg=gg1.*(gg2-gg3);

% calculation vertical gravity effect for alfa = 135°
ggg1=(G*rho*A)./(x*sin(alfa2*pi/180));
ggg2=(x+z*cot(alfa2*pi/180))./((z^2*(csc(alfa2*pi/180))^2+2*z.*x*cot(alfa2*pi
/180)+x.^2).^0.5);
ggg3=(x+z*cot(alfa2*pi/180)+L*cos(alfa2*pi/180))./(((L+z*csc(alfa2*pi/180))^
2+x.^2+2.*x.*(L*cos(alfa2*pi/180)+z*cot(alfa2*pi/180))).^0.5);
ggg=ggg1.*(ggg2-ggg3);

% display
plot(x,g,'k',x,gg,'r',x,ggg,'b');
```

A.3. Program grav_prism.m

```
% vertical gravity attraction of a vertical rectangular prism with cross section A
% 3 arrays
% G = universal gravity constant (synchronize unit of mgal) = 6.67 x 10-11 kg-
1m3s-2
% rho = density contrast (m)
% A = cross-section (m2)
% h1 = depth of top prism (m)
% h2 = depth of top prism (m)
```

```
G=6.67e-3;
rho=1;
A=1;
h1=1;
h2=100;
% koordinat x dan y (m)
[x,y]=meshgrid(-3:0.1:3, -3:0.1:3);

%calculation vertical gravity effect
g=G*rho*A.*((1./(x.^2+y.^2+h1^2).^0.5)-(1./(x.^2+y.^2+h2^2).^0.5));

% display
grid on;
surf(x,y,g);
shading interp;
colormap(hsv);
```

A.4. Program grav_rectangular.m

```
% vertical gravity attraction of a rectangular parallelepiped
% 3 arrays
% G =  universal gravity constant (synchronize unit of mgal) = 6.67 x 10-11 kg-1m3s-2
% rho = density contrast (g/cm3)
G=6.67e-3;
rho=1;

% looping horizontal distance
% x1,y1,z1 are coordinate Cartesian C from the origin (m)
% x2,y2,z2 are coordinate Cartesian K from the origin (m)
for k=1:10; x0(k)=k-1;
for l=1:10; y0(l)=l-1;
z1=1;

    % looping coordinate C, D, E, F
    for i=1:2;
    for j=1:2;
        x1=x0(k)+1.*i; y1=y0(l)+1.*j;
        r1=(x1.^2+y1.^2+z1.^2).^0.5;
        rx=(y1.^2+z1.^2).^0.5; ry=(x1.^2+z1.^2).^0.5; rz=(x1.^2+y1.^2).^0.5;
        cosl=x1./r1; cosm=y1./r1; cosn=z1./r1;
        cosalfa=z1./rx; cosbeta=z1./ry; coslamda=y1./rz; sinlamda=x1./rz;
        g(i,j)=G*rho*(z1.*(pi/2-asin(cosbeta.*coslamda)-
        asin(cosalfa.*sinlamda))+ ...
        (x1/2).*log(((r1-y1).*(rz+y1))./((r1+y1).*(rz-y1)))+ ...
        (y1/2).*log(((r1-x1).*(rz+x1))./((r1+x1).*(rz-x1))));
    end
    end
z1=2;

    % looping coordinate G, H, J, K
```

```
    for i=1:2;
    for j=1:2;
        x1=x0(k)+1.*i; y1=y0(l)+1.*j;
        r1=(x1.^2+y1.^2+z1.^2).^0.5;
        rx=(y1.^2+z1.^2).^0.5; ry=(x1.^2+z1.^2).^0.5; rz=(x1.^2+y1.^2).^0.5;
        cosl=x1./r1; cosm=y1./r1; cosn=z1./r1;
        cosalfa=z1./rx; cosbeta=z1./ry; coslamda=y1./rz; sinlamda=x1./rz;
        gg(i,j)=G*rho*(z1.*(pi/2-asin(cosbeta.*coslamda)-
        asin(cosalfa.*sinlamda))+ ...
        (x1/2).*log(((r1-y1).*(rz+y1))./((r1+y1).*(rz-y1)))+ ...
        (y1/2).*log(((r1-x1).*(rz+x1))./((r1+x1).*(rz-x1))));
    end
    end
dg(k,l)=gg(2,2)-gg(2,1)+gg(1,1)-gg(1,2)-g(2,2)+g(2,1)-g(1,1)+g(1,2);
end
end

% display
[x,y]=meshgrid(1:1:10,1:1:10);
grid on;
surf(x,y,dg);
shading interp;
colormap(hsv);
```

A.5. Program grav_cylinder_1.m

```
% vertical gravity attraction of a thick vertical cylinder (L >> z)
% 3 arrays
% G = universal gravity constant (synchronize unit of mgal) = 6.67 x 10-11 kg-1m3s-2
% rho = density contrast (g/cm3)
% R = radius of cylinder (m)
% z = the depth of the top cylinder (m)
G=6.67e-3;
rho=1;
R=5;
z=1;

% coordinate xx and yy (horizontal distance from O to P) (m)
[xx,yy]=meshgrid(-10:1:10,-10:1:10);
% calculation x and r
for i=1:21,
for j=1:21,
    x=(xx(i,j).^2+yy(i,j).^2).^0.5;
    r=(x.^2+z.^2).^0.5;
    % angle
    t=atan(x./z);
    ct=cos(t);

    % Polynomial Legendre
    p(1)=1;
```

```
    p(2)=ct;
    for n=2:2000,
           p(n+1)=(1/n).*((2*n-1).*ct.*p(n)-(n-1).*p(n-1));
    end

    % Coefficient  Series
    b(1)=0.5;
    for n=2:1000,
           b(n)=b(n-1).*((1.5-n)./n);
    end

    %  z << r << R
    if r<=R
       y(1)=1;
       y(2)=-(r./R).*p(2);
       for n=3:1000,
           y(n)=b(n-2).*((r./R).^(2*n-4)).*p(2*n-3);
       end
    % for r > R > z
    else
         for n=1:1000,
           y(n)=b(n).*((R./r).^(2*n-1)).*p(2*n-1);
         end
    end

    % summed y(n)
    s=0;
    for n=1:1000,
        ss=s+y(n);
        s=ss;
    end

    % calculation vertical gravity effect
    g(i,j)=2*pi*G*rho*R*s;
end
end
% display
grid on;
surf(xx,yy,g);
shading interp;
colormap(pink);
```

A.6. Program grav_cylinder_2.m

```
% vertical gravity attraction  of a vertical cylinder
% 2 arrays
% G = universal gravity constant (synchronize unit of mgal) = 6.67 x ^10-11 kg^-1m^3s^-2
% rho = density contrast (g/cm^3)
% R = radius of cylinder (m)
% z = vertical distance from center of cylinder to P (m)
```

```
% X = horizontal distance from O to P (m)
% l = half of cylinder height (m)
G=6.67e-3;
rho=1;
R=5;
z=5001;
for m=1:11,
  X=m-1;
  l=5000;
  % calculation (φ)n
  for n=1:100,
       x1(n)=(2*n-1.5);
       x2(n)=(n+1);
       y1(n,1)=1;
       y2(n,1)=1;
       y1(n,2)=x1(n);
       y2(n,2)=x2(n);
       for k=1:98,
            y1(n,k+2)=y1(n,k+1).*(x1(n)+k);
            y2(n,k+2)=y2(n,k+1).*(x2(n)+k);
       end
       for i=1:100,
          yy(n,i)= (y1(n,i)./y2(n,i)).*((R^2/((z-l)^2+X.^2+R^2)).^(i-1));
          yy1(n,i)= (y1(n,i)./y2(n,i)).*((R^2/((z+l)^2+X.^2+R^2)).^(i-1));
       end

       b(n)=0;
       b1(n)=0;
       for j=1:100,
            c(n)=b(n)+yy(n,j);
            b(n)=c(n);
            c1(n)=b1(n)+yy1(n,j);
            b1(n)=c1(n);
       end
       phi(n)=((1/((z-l)^2+X.^2+R^2).^0.5).*((4*R^2*X.^2)/((z-l)^2+X.^2+
  R^2)^2).^(n-1)).*c(n);

       phi1(n)=((1/((z+l)^2+X.^2+R^2).^0.5).*((4*R^2*X.^2)/((z+l)^2+X.^2
  +R^2)^2).^(n-1)).*c1(n);
  end

  % calculation (x)n multiply by (φ)n
  x0=[0.25 0.75 1 2];
  for i=1:4,
       x(i,1)=1;
       x(i,2)=x0(i);
       for n=1:98,
            x(i,n+2)=x(i,n+1).*(x0(i)+n);
       end
  end
```

```
    for j=1:100,
            xx(j)=(((x(1,j)./x(3,j)).*(x(2,j))./x(4,j))).*(phi(j)-phi1(j));
    end

    % summed (xx)n  multiply by phi
    bb=0;
    for n=1:100,
            cc=bb+xx(n);
            bb=cc;
    end
    % calculation vertical gravity effect
    g(m)=G*rho*pi*R^2*cc;
end

% save vertical gravity effect in ascii data
save cyl_2.dat g -ascii;
for ii=1:11,
    x_axis(ii)=(ii-1);
end
plot(x_axis,g);
```

A.7. Program grav_sphere_rod.m

```
% vertical gravity attraction of a combination model of sphere and thin rod
% dipping
% function of pipe filled with magma at stations: JRA15, JRA13,  IPO0, JRA100;
% ; the top rod is at JRA13*
% 2 arrays
% G = universal gravity constant (synchronize unit of µgal) = 6.67 x 10-11
%  kg-1m3s-2
% rho_mag = density of magma (g/cm3)
% rho_sed = density of sedimen marine (g/cm3)
% rho_air = density of air (g/cm3)
% r_sphere = radius of sphere (m)
% r_rod = radius of thin rod(m)
G=6.67;
rho_mag=2.4;
rho_sed=2.1;
rho_air=0.001293;
r_sphere=137;
r_rod=20;
a_rod=pi*(r_rod)^2;
z0=8600;
x0=2000;
l_rod=(x0^2+z0^2)^0.5-r_sphere;
beta=(atan(x0/z0));

% density contrast
rho1=rho_mag-rho_sed;
rho2=rho_air-rho_sed;
```

```
% The distance (x,z) of observation JRA15, JRA13, IPO0, JRA100 to JRA13*
x=[-141.614 -20.000 92.796 151.321];
z=[43.244 10.000 46.747 68.544];

for j=1:4,
    z_s(j)=z0-z(j);
    x_s(j)=x(j)-x0;

    % calculation vertical gravity effect of sphere
    g_s(j)=((4*pi*G*rho1*r_sphere^3)/3).*z_s(j)./(x_s(j).^2+z_s(j).^2).^1.5;
    % length of pipe filled with magma (variable)
    for i=1:101,
     l_rm(i)=86.925*(i-1);

            % Vertical boundary pipe filled with magma (z_b)
            z_b(i)=(l_rod-l_rm(i))*cos(beta);

            if z_b(i) > z(j)

                    % calculation vertical gravity effect of rod filled with magma
                    z_rm(i,j)=(l_rod-l_rm(i))*cos(beta)-z(j);
                    x_rm(j)=x(j)-(z(j)*tan(beta));

                    g1(j)=(G*rho1*a_rod)./(x_rm(j).*sin(beta+pi/2));

                    g2(i,j)=(x_rm(j)+z_rm(i,j)*cot(beta+pi/2))./(z_rm(i,j).^2*(csc(beta+pi/2)).^2+2*z_rm(i,j).*x_rm(j)*cot(beta+pi/2)+x_rm(j).^2).^0.5;

                    g3(i,j)=(x_rm(j)+z_rm(i,j)*cot(beta+pi/2)+l_rm(i)*cos(beta+pi/2))./((l_rm(i)+z_rm(i,j)*csc(beta+pi/2)).^2+x_rm(j).^2+2.*x_rm(j).*(l_rm(i)*cos(beta+pi/2)+z_rm(i,j)*cot(beta+pi/2))).^0.5;

                    g_rm(i,j)=g1(j).*(g2(i,j)-g3(i,j));

                    % calculation vertical gravity effect of rod filled with air
                    z_ra=0;
                    l_ra(i,j)=l_rod-l_rm(i)-((z(j)*tan(beta)).^2+z(j).^2).^0.5;
                    x_ra(j)=x(j)-(z(j)*tan(beta));

                    g11(j)=(G*rho2*a_rod)./(x_ra(j).*sin(beta+pi/2));

                    g22(j)=(x_ra(j)+z_ra*cot(beta+pi/2))./(z_ra.^2*(csc(beta+pi/2)).^2+2*z_ra.*x_ra(j)*cot(beta+pi/2)+x_ra(j).^2).^0.5;

                    g33(i,j)=(x_ra(j)+z_ra*cot(beta+pi/2)+l_ra(i,j)*cos(beta+pi/2))./((l_ra(i,j)+z_ra*csc(beta+pi/2)).^2+x_ra(j).^2+2.*x_ra(j).*(l_ra(i,j)*cos(beta+pi/2)+z_ra*cot(beta+pi/2))).^0.5;

                    g_ra(i,j)=g11(j).*(g22(j)-g33(i,j));
                    z_ra1=0;
                    l_ra1(j)=((z(j)*tan(beta)).^2+z(j).^2).^0.5;
```

```
        x_ra1(j)=-(x(j)-(z(j)*tan(beta)));
        g111(j)=(G*rho2*a_rod)./(x_ra1(j).*sin(beta+pi/2));

        g222(j)=(x_ra1(j)+z_ra1*cot(beta+pi/2))./(z_ra1.^2*(csc(beta+
        pi/2)).^2+2*z_ra1.*x_ra1(j)*cot(beta+pi/2)+x_ra1(j).^2).^0.5;

        g333(j)=(x_ra1(j)+z_ra1*cot(beta+pi/2)+l_ra1(j)*cos(beta+pi/2
        ))./((l_ra1(j)+z_ra1*csc(beta+pi/2)).^2+x_ra1(j).^2+2.*x_ra1(j)
        .*(l_ra1(j)*cos(beta+pi/2)+z_ra1*cot(beta+pi/2))).^0.5;

        g_ra1(j)=-(g111(j).*(g222(j)-g333(j)));
        g(i,j)=g_s(j)+g_rm(i,j)+g_ra(i,j)+g_ra1(j);
    else
        % calculation vertical gravity effect of rod filled with magma
        z_rm1=0;
        l_rm1(j)=l_rod-((z(j)*tan(beta)).^2+z(j).^2).^0.5;
        x_rm1(j)=x(j)-(z(j)*tan(beta));

        gg1(j)=(G*rho1*a_rod)./(x_rm1(j).*sin(beta+pi/2));

        gg2(j)=(x_rm1(j)+z_rm1*cot(beta+pi/2))./(z_rm1.^2*(csc(beta
        +pi/2)).^2+2*z_rm1.*x_rm1(j)*cot(beta+pi/2)+x_rm1(j).^2).^0
        .5;
        gg3(j)=(x_rm1(j)+z_rm1*cot(beta+pi/2)+l_rm1(j)*cos(beta+pi/
        2))./((l_rm1(j)+z_rm1*csc(beta+pi/2)).^2+x_rm1(j).^2+2.*x_r
        m1(j).*(l_rm1(j)*cos(beta+pi/2)+z_rm1*cot(beta+pi/2))).^0.5;
        gg_rm1(j)=gg1(j).*(gg2(j)-gg3(j));

        z_rm2=0;
        l_rm2(i,j)=((z(j)*tan(beta)).^2+z(j).^2).^0.5-(l_rod-l_rm(i));
        x_rm2(j)=-(x(j)-(z(j)*tan(beta)));

        ggg1(j)=(G*rho1*a_rod)./(x_rm2(j).*sin(beta+pi/2));

        ggg2(j)=(x_rm2(j)+z_rm2*cot(beta+pi/2))./(z_rm2.^2*(csc(bet
        a+pi/2)).^2+2*z_rm2.*x_rm2(j)*cot(beta+pi/2)+x_rm2(j).^2).^
        0.5;

        ggg3(i,j)=(x_rm2(j)+z_rm2*cot(beta+pi/2)+l_rm2(i,j)*cos(beta
        +pi/2))./((l_rm2(i,j)+z_rm2*csc(beta+pi/2)).^2+x_rm2(j).^2+2.
        *x_rm2(j).*(l_rm2(i,j)*cos(beta+pi/2)+z_rm2*cot(beta+pi/2))).
        ^0.5;
        gg_rm2(i,j)=-(ggg1(j).*(ggg2(j)-ggg3(i,j)));

        % calculation vertical gravity effect of rod filled with air
        z_ra2(i,j)=(((z(j)*tan(beta)).^2+z(j).^2).^0.5-(l_rod-
        l_rm(i)))*cos(beta);
        l_ra2(i)=l_rod-l_rm(i);
        x_ra2(j)=-(x(j)-(z(j)*tan(beta)));
```

```
          gggg1(j)=(G*rho2*a_rod)./(x_ra2(j).*sin(beta+pi/2));

          gggg2(i,j)=(x_ra2(j)+z_ra2(i,j)*cot(beta+pi/2))./(z_ra2(i,j).^2*(
          csc(beta+pi/2)).^2+2*z_ra2(i,j).*x_ra2(j)*cot(beta+pi/2)+x_ra2
          (j).^2).^0.5;

          gggg3(i,j)=(x_ra2(j)+z_ra2(i,j)*cot(beta+pi/2)+l_ra2(i)*cos(bet
          a+pi/2))./((l_ra2(i)+z_ra2(i,j)*csc(beta+pi/2)).^2+x_ra2(j).^2+2.
          *x_ra2(j).*(l_ra2(i)*cos(beta+pi/2)+z_ra2(i,j)*cot(beta+pi/2))).
          ^0.5;
          gg_ra2(i,j)=-(gggg1(j).*(gggg2(i,j)-gggg3(i,j)));

          g(i,j)=g_s(j)+gg_rm1(j)+gg_rm2(i,j)+gg_ra2(i,j);
      end
  end
end

% display
plot(l_rm,g(:,1),'k-',l_rm,g(:,2),'b-',l_rm,g(:,3),'g-', l_rm,g(:,4),'r-');
save rod_sph.dat g -ascii;
```

A.8. Program isomap1.m and isomap2.m

Program isomap1.m

```
% contour map of gravity changes for each station point
% load rod_sph.dat (result of grav_sphere_rod.m)
load rod_sph.dat;
g=rod_sph(:,1);
for i=1:101,
  for j=1:101,
    d(i,j)=g(j)-g(i);
  end
end
[x,y]=meshgrid(0:86.925:8692.5,0:86.925:8692.5);
[c,h]=contourf(x,y,d,[-100 -75 -50 -25  0 25 50 75 100]);
colormap(autumn);
clabel(c,h,[-100 -75 -50 -25 0 25 50 100]);
hold on;
contour(x,y,d, [55.6 55.6],'b-');
```

Program isomap2.m

```
%  contour lines of gravity changes for each station point
load rod_sph1.dat; %load rod_sph1.dat
g1=rod_sph2(:,1);
g2=rod_sph2(:,2);
g4=rod_sph2(:,4);
for i=1:101,
  for j=1:101,
    d1(i,j)=g1(j)-g1(i);
```

```
    d2(i,j)=g2(j)-g2(i);
    d4(i,j)=g4(j)-g4(i);
  end
end
[x,y]=meshgrid(0:86.925:8692.5,0:86.925:8692.5);
hold on;
[c1,h1]=contour(x,y,d1, [944 1063 1182],'b');
clabel(c1,h1);
[c2,h2]=contour(x,y,d2, [1668 1787 1906],'r');
clabel(c2,h2);
[c3,h3]=contour(x,y,d3, [604 741 878],'g');
clabel(c3,h3);
```

A.9. Program grav_sphere_cyl.m

```
% vertical gravity attraction of a combination model of sphere and thick vertical
% cylinder as function of pipe filled with magma at stations:JRA13, JRA15,
JRA100, % JRA9, JRA6, JRA4, % JRA1
% ; the top rod in JRA13*
% 2 arrays
% the height position of magma is change
% G = universal gravity constant (synchronize unit of nm/s2) = 6.67 x 10^-11 kg-
% 2m3s-2)
% rho_mag = density of magma (g/cm3)
% rho_sed = density of sediment marine (g/cm3)
% rho_air = density of air (g/cm3)
% r_sphere = radius of sphere (m)
% r_rod = radius of thick cylinder (m)

G=66.7;
rho_mag=2.4;
rho_sed=2.1;
rho_air=0.001293;
r_sphere=137;
r_rod=20;
a_rod=pi*(r_rod)^2;
z0=8600;
l_rod=z0-r_sphere;


% density contrast
rho1=rho_mag-rho_sed;
rho2=rho_air-rho_sed;

% The distance (dx,dz) of observation JRA13, JRA15, JRA100, JRA9, JRA6,
JRA4,
% JRA1 to JRA13*
% dx=[20 141.643 151.339 666.276 1227.597 1661.975 2822.422];
% dz=[10 43.245 68.557 279.759 427.414 662.830 1168.504];

dx=[20 141.643 151.339];
```

```
dz=[10 43.245 68.557];

for jj=1:3,
    z_s(jj)=z0-dz(jj);
    x_s(jj)=dx(jj);

    % calculation vertical gravity effect of sphere
    g_s(jj)=((4*pi*G*rho1*r_sphere^3)/3).*z_s(jj)./(x_s(jj).^2+z_s(jj).^2).^1.5;

    % length of pipe filled with magma (variable)
    for ii=1:101,
              l_rm(ii)=84.63*(ii-1);

              % Vertical boundary pipe filled with magma (z_b)
              z_b(ii)=(l_rod-l_rm(ii));

              if z_b(ii) > dz(jj)

              % calculation vertical gravity effect of rod filled with magma
              X=dx(jj);
              lm=l_rm(ii)/2;
              zm=(z_b(ii)-dz(jj))+lm;

              % calculation vertical gravity effect of rod filled with air
              la=(z_b(ii)-dz(jj))/2;
              za=la;
              la1=dz(jj)/2;
              za1=la1;
%*************************************************************
              % calculation phi index n
              for n=1:100,
                        x1(n)=(2*n-1.5);
                        x2(n)=(n+1);
                        y1(n,1)=1;
                        y2(n,1)=1;
                        y1(n,2)=x1(n);
                        y2(n,2)=x2(n);
                        for k=1:98,
                                  y1(n,k+2)=y1(n,k+1).*(x1(n)+k);
                                  y2(n,k+2)=y2(n,k+1).*(x2(n)+k);
                        end
                        for i=1:100,
                                  yym(n,i)= (y1(n,i)./y2(n,i)).*((r_rod^2/((zm-lm)^2+
                                 X.^2+r_rod ^2)).^(i-1));
                                  ym1(n,i)=(y1(n,i)./y2(n,i)).*((r_rod^2/((zm+lm)^2+
                                 X.^2+r_rod ^2 )).^(i- 1));
                                  yya(n,i)= (y1(n,i)./y2(n,i)).*((r_rod^2/((za-la)^2+
                                 X.^2+r_rod ^2) ).^(i-1));
                                  yya1(n,i)= (y1(n,i)./y2(n,i)).*((r_rod^2/((za+la)^2+
                                 X.^2+r_rod ^2)).^(i-1));
```

```
         yyaa(n,i)= (y1(n,i)./y2(n,i)).*((r_rod^2/((za1-la1)^2+
        X.^2+r_rod ^2)) .^(i-1));
         yyaa1(n,i)=(y1(n,i)./y2(n,i)).*((r_rod^2/((za1+la1)^2+
        X.^2+ r_rod ^2)) .^(i-1));
    end

    bm(n)=0;
    bm1(n)=0;
    ba(n)=0;
    ba1(n)=0;
    baa(n)=0;
    baa1(n)=0;
    for j=1:100,
        cm(n)=bm(n)+yym(n,j);
        bm(n)=cm(n);
        cm1(n)=bm1(n)+yym1(n,j);
        bm1(n)=cm1(n);
        ca(n)=ba(n)+yya(n,j);
        ba(n)=ca(n);
        ca1(n)=ba1(n)+yya1(n,j);
        ba1(n)=ca1(n);
        caa(n)=baa(n)+yyaa(n,j);
        baa(n)=caa(n);
        caa1(n)=baa1(n)+yyaa1(n,j);
        baa1(n)=caa1(n);
    end
    phim(n)=((1/((zm-lm)^2+X.^2+r_rod^2).^0.5).*((4*r_rod^2
    *X.^2)/ ((zm-lm)^2+X.^2+r_rod^2)^2).^(n-1)).*cm(n);
    phim1(n)=((1/((zm+lm)^2+X.^2+r_rod^2).^0.5).*((4*r_rod^2
    *X.^2)/ ((zm+lm)^2+X.^2+r_rod^2)^2).^(n-1)).*cm1(n);
    phia(n)=((1/((za-la)^2+X.^2+r_rod^2).^0.5).*((4*r_rod^2
    *X.^2)/ ((za-la)^2+X.^2+r_rod^2)^2).^(n-1)).*ca(n);
    phia1(n)=((1/((za+la)^2+X.^2+r_rod^2).^0.5).*((4*r_rod^2
    *X.^2)/ ((za+ la)^2+X.^2+r_rod^2)^2).^(n-1)).*ca1(n);
    phiaa(n)=((1/((za1-la1)^2+X.^2+r_rod^2).^0.5).*((4*r_rod^2
    *X.^2)/ ((za1-la1)^2+X.^2+r_rod^2)^2).^(n-1)).*caa(n);
    phiaa1(n)=((1/((za1+la1)^2+X.^2+r_rod^2).^0.5).*((4*r_rod^2
    *X.^2)/((za1+ la1)^2+X.^2+r_rod^2)^2).^(n-1)).*caa1(n);
end

% calculation (x)index n multiply by phi
x0=[0.25 0.75 1 2];
for i=1:4,
    x(i,1)=1;
    x(i,2)=x0(i);
    for n=1:98,
        x(i,n+2)=x(i,n+1).*(x0(i)+n);
    end
end
for j=1:100,
```

```
        xxm(j)=(((x(1,j)./x(3,j)).*(x(2,j))./x(4,j))).*(phim(j)-phim1(j));
        xxa(j)=(((x(1,j)./x(3,j)).*(x(2,j))./x(4,j))).*(phia(j)-phia1(j));
        xxaa(j)=(((x(1,j)./x(3,j)).*(x(2,j))./x(4,j))).*(phiaa(j)-phiaa1(j));
        end

        % summed xx index multiply by phi
        bbm=0;
        bba=0;
        bbaa=0;
        for n=1:100,
                ccm=bbm+xxm(n);
                bbm=ccm;
                cca=bba+xxa(n);
                bba=cca;
                ccaa=bbaa+xxaa(n);
                bbaa=ccaa;
        end

        g_rm(ii,jj)=G*rho1*pi*r_rod^2*ccm;
        g_ra(ii,jj)=G*rho2*pi*r_rod^2*cca;
        g_ra1(jj)=-(G*rho2*pi*r_rod^2*ccaa);
        g(ii,jj)=g_s(jj)+g_rm(ii,jj)+g_ra(ii,jj)+g_ra1(jj);

%*************************************************************
        else
        % calculation vertical gravity effect of rod filled with magma
        X=dx(jj);
        lm1=(l_rod-dz(jj))/2;
        zm1=lm1;
        lm2=(dz(jj)-z_b(ii))/2;
        zm2=lm2;

        % calculation vertical gravity effect of rod filled with air
        la2=z_b(ii)/2;
        za2=dz(jj)-la2;

%*************************************************************
        % calculation phi index n
        for n=1:100,
                x1(n)=(2*n-1.5);
                x2(n)=(n+1);
                y1(n,1)=1;
                y2(n,1)=1;
                y1(n,2)=x1(n);
                y2(n,2)=x2(n);
                for k=1:98,
                        y1(n,k+2)=y1(n,k+1).*(x1(n)+k);

                        y2(n,k+2)=y2(n,k+1).*(x2(n)+k);
                end
```

```
for i=1:100,
        yym(n,i)= (y1(n,i)./y2(n,i)).*((r_rod^2/((zm1-lm1)^2
       +X.^2+ r_rod^2)).^ (i-1));
        yym1(n,i)= (y1(n,i)./y2(n,i)).*((r_rod^2/((zm1+lm1)^2
       +X.^2+ r_rod^2)) .^(i-1));
        yymm(n,i)= (y1(n,i)./y2(n,i)).*((r_rod^2/((zm2-lm2)^2
       +X.^2+r_rod^2)) .^(i-1));
        yymm1(n,i)=(y1(n,i)./y2(n,i)).*((r_rod^2/((zm2+lm2)^2
       +X.^2+ r_rod ^2)).^(i-1));
        yya(n,i)= (y1(n,i)./y2(n,i)).*((r_rod^2/((za2-la2)^2
       +X.^2+r_rod^2)).^(i-1));
        yya1(n,i)= (y1(n,i)./y2(n,i)).*((r_rod^2/((za2+la2)^2
        +X.^2+r_rod^2)).^ (i-1));
end

bm(n)=0;
bm1(n)=0;
bmm(n)=0;
bmm1(n)=0;
ba(n)=0;
ba1(n)=0;
for j=1:100,
        cm(n)=bm(n)+yym(n,j);
        bm(n)=cm(n);
        cm1(n)=bm1(n)+yym1(n,j);
        bm1(n)=cm1(n);
        cmm(n)=bmm(n)+yymm(n,j);
        bmm(n)=cmm(n);
        cmm1(n)=bmm1(n)+yymm1(n,j);
        bmm1(n)=cmm1(n);
        ca(n)=ba(n)+yya(n,j);
        ba(n)=ca(n);
        ca1(n)=ba1(n)+yya1(n,j);
        ba1(n)=ca1(n);
end
phim(n)=((1/((zm1-lm1)^2+X.^2+r_rod^2).^0.5).*((4*r_rod^2
*X.^2)/((zm1-lm1)^2+X.^2+r_rod^2)^2).^(n-1)).*cm(n);
phim1(n)=((1/((zm1+lm1)^2+X.^2+r_rod^2).^0.5).
*((4*r_rod^2*X.^2) /((zm1 +lm1)^2+X.^2+r_rod^2)^2).^(n-
1)).*cm1(n);
phimm(n)=((1/((zm2-lm2)^2+X.^2+r_rod^2).^0.5).
*((4*r_rod^2*X.^2)/((zm2-lm2)^2+X.^2+r_rod^2)^2).^(n-
1)).*cmm(n);
phimm1(n)=((1/((zm2+lm2)^2+X.^2+r_rod^2).^0.5).
*((4*r_rod^2*X.^2)/(( zm2+lm2)^2+X.^2+r_rod^2)^2).^(n-
1)).*cmm1(n);
phia(n)=((1/((za2-la2)^2+X.^2+r_rod^2).^0.5).
*((4*r_rod^2*X.^2)/((za2-la2)^2+X.^2+r_rod^2)^2).^(n-

1)).*ca(n);
```

```
            phia1(n)=((1/((za2+la2)^2+X.^2+r_rod^2).^0.5).
            *((4*r_rod^2*X.^2)/((za2+ la2)^2+X.^2+r_rod^2)^2).^(n-
            1)).*ca1(n);
        end

        % calculation (x)index n multiply by phi
        x0=[0.25 0.75 1 2];
        for i=1:4,
            x(i,1)=1;
            x(i,2)=x0(i);
            for n=1:98,
                x(i,n+2)=x(i,n+1).*(x0(i)+n);
            end
        end
        for j=1:100,
            xxm(j)=(((x(1,j)./x(3,j)).*(x(2,j))./x(4,j))).*(phim(j)-phim1(j));
            xxmm(j)=(((x(1,j)./x(3,j)).*(x(2,j))./x(4,j))).*(phimm(j)-
            phimm1(j));
            xxa(j)=(((x(1,j)./x(3,j)).*(x(2,j))./x(4,j))).*(phia(j)-phia1(j));
        end

        % summed xx index multiply by phi
        bbm=0;
        bbmm=0;
        bba=0;
        for n=1:100,
            ccm=bbm+xxm(n);
            bbm=ccm;
            ccmm=bbmm+xxmm(n);
            bbmm=ccmm;
            cca=bba+xxa(n);
            bba=cca;
        end

        g_rm1(jj)=G*rho1*pi*r_rod^2*ccm;
        g_rm2(ii,jj)=-(G*rho1*pi*r_rod^2*ccmm);
        g_ra2(ii,jj)=-(G*rho2*pi*r_rod^2*cca);
        g(ii,jj)=g_s(jj)+g_rm1(jj)+g_rm2(ii,jj)+g_ra2(ii,jj);
%*********************************************************************
        end
    end
end

% display
%plot(l_rm,g(:,1),'k-',l_rm,g(:,2),'b-',l_rm,g(:,3),'g-',l_rm,g(:,4),'r-',l_rm,g(:,5),'c-
%',l_rm,g(:,6),'m-',l_rm,g(:,7),'y-');
%plot(l_rm,g(:,4),'r-',l_rm,g(:,5),'c-',l_rm,g(:,6),'m-',l_rm,g(:,7),'y-');
plot(l_rm,g(:,1),'k-',l_rm,g(:,2),'b-',l_rm,g(:,3),'g-');
save sph_cyl1.dat g -ascii;
```

A.10. Program concentric_cyl.m and optim_density.m

concentric_cyl.m

```
% vertical gravity attraction of  a thick vertical cylinder
% for modeling of water infiltration at stations: JRA9, JRA6, JRA4, JRA1,
% JRA0, BABA, MRIY, DELE, CEPO, KALI
% BUTU, MUNT, BOYO, KLAT, MVOY
% ; the top rod in JRA13*
% 2 arrays
% G = universal gravity constant (synchronize unit of nm/s2) =  6.67 x 10^-11
kg-
% 2m3s-2
% rho = density contrast (g/cm3)
% R = radius of cylinder (m)
% z = vertical distance from center of cylinder to P (m)
% X = horizontal distance from O to P (m)
G=66.7;
rho=1;
% The distance (dx,dz) of observation JRA9, JRA6, JRA4, JRA1,
% JRA0, BABA, MRIY, DELE, CEPO, KALI
% BUTU, MUNT, BOYO, KLAT, MVOY to JRA13*
dx=[666.276 1227.597 1661.975 2822.422 ...
   5532.019 4273.533 5241.000 5357.318 7529.312 7085.331 ...
   28306.154 16698.093 18162.648 24226.510 29256.534];
dz=[279.759 427.414 662.830 1168.504 ...
   1660.910 1674.821 1770.153 1887.583 1945.279 2100.327 ...
   2330.151 2550.004 2588.362 2788.888 2839.600];

% Radius variation of cylinder (outer radius)
%RR=[750 1250 2000 4000 6000 7500 9000 10000 9000 30000];

% Radius variation of cylinder (inner radius)
RR=[20 750 1250 2000 4000 6000 7500 9000 750 9000];

% Length variation of cylinder
ll=[2750 1250 1250 1250 1250 1000 700 1200 1500 1000];

% Top cylinder from MSL
zzz=[750 750 750 750 750 500 200 200 -500 -1000];

% Depth variation of top cylinder to JRA13* (2977.762 m)
zz=2977.762-zzz;
for jj=1:15,
  X=dx(jj);
    for ii=1:10,
        l=ll(ii)/2;
              z=(zz(ii)-dz(jj))+l;
        R=RR(ii);

%**********************************************************
% calculation phi index n
```

```
for n=1:100,
    x1(n)=(2*n-1.5);
    x2(n)=(n+1);
   y1(n,1)=1;
    y2(n,1)=1;
    y1(n,2)=x1(n);
    y2(n,2)=x2(n);
     for k=1:98,
     y1(n,k+2)=y1(n,k+1).*(x1(n)+k);
     y2(n,k+2)=y2(n,k+1).*(x2(n)+k);
     end
     for i=1:100,
     yy(n,i)= (y1(n,i)./y2(n,i)).*((R^2/((z-l)^2+X.^2+R^2)).^(i-
     1));
     yy1(n,i)= (y1(n,i)./y2(n,i)).*((R^2/((z+l)^2+X.^2+R^2)).^(i-
     1));
    end

    b(n)=0;
    b1(n)=0;
       for j=1:100,
          c(n)=b(n)+yy(n,j);
          b(n)=c(n);
          c1(n)=b1(n)+yy1(n,j);
          b1(n)=c1(n);
      end
   phi(n)=((1/((z-l)^2+X.^2+R^2).^0.5).*((4*R^2*X.^2)/((z-l)^2+
   X.^2+R^2)^2).^(n-1)).*c(n);
   phi1(n)=((1/((z+l)^2+X.^2+R^2).^0.5).*((4*R^2*X.^2)/((z+l)^2+
   X.^2+R^2)^2).^(n-1)).*c1(n);
end

% calculation (x)index n multiply by phi
x0=[0.25 0.75 1 2];
for i=1:4,
   x(i,1)=1;
   x(i,2)=x0(i);
   for n=1:98,
      x(i,n+2)=x(i,n+1).*(x0(i)+n);
   end
end
for j=1:100,
    xx(j)=(((x(1,j)./x(3,j)).*(x(2,j))./x(4,j))).*(phi(j)-phi1(j));
end

% summed xx index multiply by phi
bb=0;
for n=1:100,
```

```
                cc=bb+xx(n);
                bb=cc;

         end

         g(jj,ii)=G*rho*pi*R^2*cc;

%**********************************************************
   end
end
%(outer radius)
%save cyl_out.dat g -ascii;

%(inner radius)
save cyl_in.dat g -ascii;
```

optim_density.m

```
load cyl_out.dat;
load cyl_in.dat;
gcyl=cyl_out-cyl_in;

% Gravity changes Merapi II-I (Feb. 1998 - Aug. 1997), 15 stations
%gobs=[-402;-640;-36;-295;-399;-203;-325;-367;136;-73;42;-199;-331;-7;0];

% Gravity changes Merapi III-I (Aug. 1998 - Aug. 1997), 15 stations
%gobs=[403;565;937;224;-16;136;560;122;394;330;434;-19;-111;-6;0];

% Gravity changes Merapi IV-I (Aug. 1999 - Aug. 1997), 15 stations
%gobs=[224;139;615;457;76;77;191;316;326;71;-35;-227;-2;61;0];

% Gravity changes Merapi V-I (Aug. 2000 - Aug. 1997), 15 stations
gobs=[709;769;1418;525;98;91;112;46;85;195;-446;-377;-332;-236;0];

options=optimset('PrecondBandWidth',inf);
%lb=-0.05*ones(10,1);
%ub=0*ones(10,1);
lb=[0;0;0;0;0;0;0;0;0;-0.05];
ub=[0.05;0.05;0.05;0.05;0.05;0.05;0.05;0.05;0.05;0];
[x,resnorm,residual,exitflag,output,lambda]=lsqlin(gcyl,gobs,[],[],[],[],lb,ub,[],o
ptions);

%display
x
exitflag
output
gpre=gcyl*x
v=gobs-gpre
```