Estimation of Depth and Shape Factor of Buried Structure From Residual Gravity Anomaly Data

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Abstract: This paper presents an effective method for shape and depth determination of a buried structure from residual gravity anomalies along profile. The method utilizes the anomaly values of the origin and characteristic points of the profile to construct a relationship between the shape factor and depth of the causative source. For fixed points, the depth is determined for each shape factor. The computed depths are then plotted against the shape factor representing a continuous monotonically increasing curve. The solution for the shape and depth of the buried structure is then read at the common intersection point of the depth curves. This method is applied to synthetic data with and without random errors. Finally, the validity of the method is tested on a field example from the IRAN.

Key words: Polygon and horizontal cylinder, Depth and shape factor estimation, Parametric curves.

INTRODUCTION

Interpretation of gravity data aims essentially to estimate location and depth of the causative source. This interpretation is non-unique because different subsurface bodies may yield the same gravity field at the surface. However, a unique solution may be obtained by incorporating certain a priori information about the geometry of the causative source (Roy et al., 2000). Several methods have been presented to interpret the residual gravity anomalies. These methods include Fourier transformation (Sharma and Geldart, 1968), Euler deconvolution (Thompson, 1982; Reid, 1990), Mellin transforms (Mohan et al., 1986), least-squares minimization approaches (Gupta, 1983), neural network (Elawadi et al., 2001). In these methods, the source geometry is assumed and therefore, the accuracy of the results depends upon how closely the assumed model approximates the real structure. Recently, some approaches have been developed to estimate the nature (shape) of the source bodies from gravity anomaly data. Examples of these approaches are Walsh transform technique (Shaw and Agarwal, 1990), analytic signal (Nandi et al., 1997), and least squares minimization (Abdelrahman et al., 2001). In this paper, we present a method to provide information about the nature of the source from residual gravity data. The method is tested using synthetic examples created for polygon, horizontal cylinder models at different depths. In addition, practical utility of the method is demonstrated using field example for a salt dome in Iran.

The Method:

The general gravity anomaly produced by a polygon, and a horizontal cylinder is given in Abdelrahman (2001) as

\[ g(x_i, z, q) = A \frac{Z^m}{(x_i^2 + Z^2)^q} \]  

where \( Z \) is the depth, \( q \) is the shape factor, \( x_i \) is the position coordinate, \( \sigma \) is the density contrast, \( G \) is the universal gravitational constant, \( A \) is amplitude coefficient, and \( R \) is the radius. At the origin \( (x_i=0) \), eq. (1) gives the following relationship:

\[ g(0) = \frac{A}{Z^{2q-m}} \]  

Using eq. (1), we obtain the following normalized equation at \( x_i = \pm N \) (\( N = 1, 2, 3, \ldots \)):

\[ \frac{g(N)}{g(0)} = \left( \frac{Z^2}{N^2 + Z^2} \right)^q \]  

Let \( T = g(N)/g(0) \), then from eq. (3) we get
\[ Z = N \sqrt[1/q]{\frac{T}{1 - T^{1/q}}} \] (4)

Equation (4) is then solved by simple calculation to determine the shape (shape factor) and the depth of the buried structure. In details, the method uses the gravity anomaly values of the origin point and characteristic points of the profile to set a relationship between the shape factor and depth of the buried structure. For several fixed points, the corresponding depth is determined for each shape factor. The obtained depths are then plotted against the shape factor generating a continuous monotonically increasing curve. The estimated solution of the shape and depth of the buried structure is then read at the common intersection point (or narrow zone) of the depth curves. The estimated parameters are then needed to be interpreted and assessed with the known geology of the area under study and other available geophysical results.

**Synthetic Examples:**

We have computed two different residual gravity anomalies due to a horizontal cylinder, and a polygon. Equation (4) has been applied to the residual anomaly profiles, yielding depth solutions for all possible \( q \) for \( N = 1, 2, 3, 4, \) km. The computed depths are plotted against the shape factor leading to continuous depth curves for the different \( N \) values, and the results are summarized in Fig. 2. Figure 2 shows that the depth curves intersect at the correct locations of each of the two structures. In all cases, the solutions for shape factor and depth are in excellent agreement with the true parameters given in Fig. 1.

**Fig. 1:** Residual gravity anomalies of a polygon and a horizontal cylinder.
Fig. 2: The depth versus shape factor for N = 1, 2, 3, and 4 km as obtained from the gravity anomalies using the present method. The estimated depth and shape factor are shown.

In order to examine the effect of noise on the suggested method, 5% random errors were added to each gravity anomaly to produce noisy data (Fig. 3). In all cases, the solutions for shape and depth are in a good agreement with the parameters given in Fig. 1. This demonstrates that our method could produce reliable results even when the gravity data are contaminated with noise.

Fig. 3: The depth versus shape factor for N = 1, 2, 3, and 4 km as obtained from the gravity anomalies after adding 5% random errors to data using the present method. The estimated depth and shape factor are shown.
**Field Example:**

A residual gravity profile of the Ajichai salt dome, was digitized at an interval of 2m (Fig. 4). Equation (4) was used to determine the depth and shape factor using all possible cases of N values (N = 1, 3, 5 and 7 m). The results are plotted in Fig. 5.

![Figure 4: Residual gravity profile over Ajichai salt dome; Abscissa: latitude, ordinate: mGal.](image)

![Figure 5: The depth versus shape factor for N = 1, 3, 5, and 4 km as obtained from the gravity anomalies using the present method. The estimated depth and shape factor are shown.](image)

**Conclusion:**

A effective method to simultaneously determine the shape and depth of a buried structure from the residual gravity anomalies has been introduced. The technique utilizes the gravity anomaly values along profile to construct a relationship between the shape factor and depth of the causative source. The depth of the buried structure is determined for each shape factor using a number of fixed points along the profile. The determined depths are then plotted against the shape factor generating a continuous monotonically increasing curve. The solution for the shape and depth of the buried structure is then read at the common intersection point (or narrow region) of the depth curves. The method has been applied to synthetic data with and without random errors and produced good results.

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