Geofísica Internacional (2015) 54-1: 49-65

Original paper

Estimation of multiple density-depth parameters from gravity inversion: Application to detached hanging wall systems of strike limited listric fault morphologies

V. Chakravarthi* and M. Pramod Kumar

Received: September 30, 2013; accepted: May 20, 2014 published on line: December 12, 2014

Resumen

Se desarrolló un algoritmo de inversión para estimar simultáneamente la geometría de plano de falla y los parámetros que pertenecen a cualquiera de las densidades o profundidades de múltiples formaciones geológicas, con el sistema de colgado en la pared, en un plano de fractura limitada de las anomalías de gravedad observadas. Se describen planos de falla de las estructuras mediante funciones polinómicas de grado arbitrario pero específico. La aplicabilidad del algoritmo se demostró tanto en las anomalías artificiales y reales de la gravedad de campo. En el ejemplo de síntesis se añadió ruido pseudoaleatorio a las anomalías de gravedad de la estructura antes de la inversión. En la inversión de anomalías de gravedad, producidos por una estructura sintética, se encontró que los parámetros estimados más o menos imitan los parámetros obtenidos, incluso en presencia de ruido aleatorio. Las densidades y profundidades estimadas de las formaciones de inversión independiente de anomalías de gravedad del mundo real desde el margen de la subcuenca Chintalpudi en la India se correlacionan bien con la información disponible de la perforación.

Palabras clave: morfología de fallas lístricas, falla finita, variaciones arbitrarias de densidad-densidad, anomalía de gravedad, inversión.

Abstract

An inversion algorithm is developed to simultaneously estimate the fault plane geometry and the parameters pertaining to either densities or depths of multiple geologic formations within the hanging wall system of a strike-limited listric fault from the observed gravity anomalies. Fault planes of the structures are described by polynomial functions of arbitrary but specific degree. The applicability of the algorithm is demonstrated on both synthetic and real field gravity anomalies. In the synthetic example, pseudorandom noise is added to the gravity anomalies of the structure prior to inversion. From the inversion of gravity anomalies produced by a synthetic structure it was found that the estimated parameters more or less mimic the true parameters even in the presence of random noise. The estimated densities and depths of the formations from independent inversion of real-world gravity anomalies from the margin of the Chintalpudi sub-basin in India correlate well with the available drilling information.

Key words: listric fault morphology, finite strike, arbitrary density-density variations, gravity anomaly, inversion.

V. Chakravarthi*
M. Pramod Kumar
Centre for Earth & Space Sciences
University of Hyderabad
Gachibowli, Hyderabad – 500 046 (A.P.)
India
*Corresponding author: vcvarthi@rediffmail.com

Introduction

Listric faults are curved normal faults in which the fault surface is concave upwards because the main detachment fracture follows a curved path rather than a planar path. Because of the non-planar nature of listric fault planes it is often difficult to estimate the amount of extension from surface geological observations of dip and throw of the faults (Mckenzie, 1978). On the other hand, the displaced rock masses on either side of such fault planes can create lateral contrasts in subsurface densities and accordingly generate detectable step-like gravity anomalies across the fault planes. These anomalies can be appropriately analyzed to quantify the fault morphology.

Although fault morphologies more often than not possess non-planar fault planes (Brady *et al.* 2000; Goussav *et al.* 2006; McKenzie and Jackson 2012), many existing algorithms assume planar surfaces for the fault planes to analyze the gravity anomalies. For example, Thanassoulas *et al.* (1987) developed a method and a computer program in Basic, Murthy and Krishnamacharyulu (1990) devised an algorithm and a relevant code in Fortran to estimate the parameters of fault structures from the observed gravity anomalies. Abdelrahman *et al.* (1989) proposed a method to determine the dip angle of a fault plane from the maximum positive and negative amplitudes of gravity anomalies, where the relative movement between two semi-infinite horizontal slabs was confined to a planar surface. Rao *et al.* (2003) used generalized inversion and single value decomposition techniques to analyze the gravity anomalies of fault structures. Abdelrahman *et al.* (2003) presented two approaches to determine the depth and amplitude coefficient, related to the density contrast and the thickness of a buried faulted slab using numerical horizontal derivative anomalies obtained from 2D gravity data. On the other hand, Stavrev and Reid (2010) used the concept of extended Euler homogeneity of potential fields to analyze the gravity anomalies of a thick faulted slab. Recently, Essa (2013) developed an algorithm that make use of numerical first horizontal derivatives computed from the observed gravity anomaly to estimate the depth and the dip angle of a buried fault structure, whereas Toushmalani (2013) proposed a technique using particle swarm optimization to interpret the anomalies.

The above 2D strategies find limited application when analyzing the gravity anomalies of listric fault morphologies because i) the fault planes associated with these structures are often non-planar in nature, and ii) the density of the sedimentary load within the hanging wall is rarely uniform (Maxant 1980; Moral *et al.* 2000; Rybakov *et al.* 2000; Nagihara and Hall, 2001; Adriasyah and McMechan, 2002; Gómez-Ortiz 2005). Realizing the fact that the density of sedimentary rocks varies with depth, Rao (1985) used a quadratic density function, Sundararajan and Brahmam (1998) adopted a linear density function, and Chakravarthi and Sundararajan (2004) used a parabolic density function to analyze the gravity anomalies of fault structures, again treating the fault structures as 2D with fault planes as planar surfaces.

Martín-Atienza and García-Abdeslem (1999) developed a technique using a quadratic density function to compute the gravity anomalies of geologic sources bounded either laterally or vertically by continuous functions. Though this method can be used to simulate the geometries of listric fault sources to compute gravity anomalies, it is efficient only for 2D sources. Based on the fact that the fault structures on the continental regions often possess finite strike lengths (Peirce and Lipkov 1988), Chakravarthi (2011) developed an automatic inversion to interpret the gravity anomalies of 2.5D strike listric fault sources, where the fault planes are described by polynomial functions of arbitrary degree and the variation of density within the hanging wall by a parabolic density function. This technique is effective when the density contrast of sedimentary load within the hanging wall decreases monotonically with depth. On the other hand, Chakravarthi (2010) devised a strategy with a relevant code in Fortran to compute the gravity anomalies of strike limited listric fault morphologies, where the hanging wall was assumed to consist in several geologic formations of differing densities and thicknesses. To realize forward modeling, this method requires the coefficients of the polynomial (used to describe the fault plane geometry) and the parameters pertaining to both thickness and densities of formations within the hanging wall as part of input, which in reality are not known a priori. Therefore, a need exists to develop an appropriate algorithm to estimate these parameters from the observed gravity anomalies (inverse process).

In the present paper, we develop a gravity inversion technique using ridge regression to estimate the parameters of a listric fault structure from the observed gravity anomalies, where the structure is assumed as a 2.5D source with the detached hanging wall consists in several geologic formations; each one