Estimation of dip angles of faults near the surface in Toyama by eigenvalues and eigenvectors of the gravity gradient tensor

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The Toyama prefecture, central Japan, hosts several active faults, including the Kurehayama fault, the Isurugi fault, the Takasyouzu fault, and the Kurobishiyama fault. Many researchers have studied these faults, with investigations having been performed into their morphological, geological, and geophysical characteristics.
Numerical simulations of intense ground motion caused by fault activity play an important role in planning how damages can be mitigated in the event of an earthquake. In such simulations, the length, width, and dip angle of a fault are important parameters. Fault dip angles would usually be estimated by geophysical techniques, such as seismic and gravity exploration. Seismic needs large expense. Although gravity exploration does not need so large expense, this exploration needs seismic exploration data because the gravity is a function of density and structure (distance) and the gravity exploration can’t determine unique solutions from gravity anomaly data only.
A new method for estimating the dip angle of a fault using eigenvalues and eigenvectors of the gravity gradient tensor has recently been developed by Beiki and Peterson (2010: Geophysics), Beiki (2013: Geophysics), and Kusumoto (2015: Butsuri-tansa). This method relies upon the maximum eigenvector of this tensor being parallel to the orientation of the causative body, from which the dip angle of a fault or structural boundary can be estimated without supplemental geophysical and geological data.
A gravity gradient tensor can be obtained via gravity gradiometry, which measures the gradient of a gravity field in multiple directions. Three gravitation components (g_x, g_y, and g_z) form around a causative body, with the combined set of x-, y-, and z- derivatives of each forming the gravity gradient tensor. This tensor is known to be symmetric, with its diagonal components summing to zero in order to satisfy Laplace’s equation. Thus, the gravity gradient tensor consists of five independent components, which can be obtained for any subsurface structure using gravity gradiometry at a single observation point. By contrast, a conventional gravity survey can only identify one out of three gravitational components, which must then be used to estimate the nature of any subsurface structures. A gravity gradiometry can thus obtain five-times as much information as a gravity survey can.
Since no gravity gradient surveys have yet been undertaken in Toyama, we derived gravity gradient tensors by calculations based on the study of Mickus and Hinojosa (2001: Jour. Appl. Geophys.). The method described therein estimates a gravity gradient tensor as follows: (1) a Fourier transformation is made of a gravity anomaly, (2) an estimation of gravitational potential is made by integration of the gravity anomaly in the Fourier domain, (3) calculation of gravity gradient components is achieved by calculating second-order derivatives of the potential in each direction, and (4) the acquisition of all components of the tensor in the spatial domain is performed by applying Fourier inverse transformation.
We applied this technique to the Kurehayama fault, Isurugi fault, Takasyozu fault, and Kurobishiyama fault, and estimated that they have dip angles in the range of 45-60°. Our results are consistent with dip angles obtained by surface geomorphological and geological surveys.

