GPS Data Inversion to Estimate 3-D Elastic/Inelastic Strain Fields in Island-Arc Crust: The Niigata-Kobe Transformation Zone

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We can now directly observe the crustal deformation process of Japanese islands with GPS. However, since GPS measurements are restricted to the Earth's surface, we cannot obtain three vertical components of the gradient of displacement vectors. For this reason, in conventional geometric strain analysis, only three components of horizontal strain has been estimated. In addition, the partitioning of observed strain into elastic and inelastic parts, which is essential to understand the mechanism of crustal deformation, remains as an unsolved problem. In order to resolve these problems simultaneously, representing the source of crustal deformation by moment tensor, we have constructed a theory of physics-based strain analysis to estimate 3-D elastic/inelastic strain fields from GPS data (Japan Geoscience Union 2008 Meeting). The basic idea of the theory is as follows.

First, we regard the Earth's crust as a linear elastic body including a number of defects, and represent the brittle fracture and/or plastic deformation at the defects by moment density tensor distribution. Since we can compute the surface displacements caused by the moment density tensor distribution theoretically, we can define the inverse problem of estimating the moment density tensor distribution from observed surface displacement data. From the inverted moment density tensor distribution, performing conversion with the compliance tensor of the elastic body, we can directly obtain 3-D inelastic strain fields. On the other hand, using theoretical strain response functions to a unit moment tensor, we can compute the 3-D elastic strain fields due to the moment density tensor distribution. Directly observable strain is the sum of the elastic strain and the inelastic strain.

In the present study, on the theory of physics-based strain analysis, we mathematically formulated the inversion method to estimate 3-D elastic/inelastic strain fields from GPS data, and demonstrated its validity and availability through numerical examination with synthetic data and application to observed data. As a common model region in both analyses of synthetic and observed data, we took a region including the Niigata-Kobe transformation zone, in the northwestern part of Central Japan. Surface displacements are given at 60 GPS stations distributed in this region. The data used for inversion analysis are the changes in side-length of the optimum triangle meshes constructed form the GPS stations with the method of Delaunay triangulation. We used Lanczos' singular value decomposition method (Lanczos, 1961) to solve the inverse problem and Akaike's information criterion (Akaike, 1973) to select the optimum model.

First, we tested the validity of the inversion method through the analysis of synthetic data, and confirmed that the moment density tensor can be resolved into the isotropic part and the deviatoric part. Although the spatial resolution was not so good because of the sparse distribution of data points (20 km space on average), we could obtain the rough image of the given moment density tensor distribution. Next, we applied the inversion method to GPS horizontal velocity data (1996-2000), and succeeded in separately estimating 3-D elastic and inelastic strain rate fields in the Niigata-Kobe transformation zone. The results of inversion analysis show high elastic contraction rates near the surface and high inelastic shear deformation rates in the upper crust of the Niigata-Kobe transformation zone. The surface pattern of the inverted total strain field accords with the pattern of horizontal strain field estimated by Sagiya et al. (2000) from the same GPS data set with the inversion method by Shen et al. (1996).