GPS Data Inversion to Estimate Elastic/Inelastic Strain Fields in the Earth's Crust: Basic Ideas and Mathematical Formulation

Akemi Noda[1]; Mitsuhiro Matsu'ura[1]

[1] Dept. of Earth & Planetary Science, Univ. of Tokyo

The nationwide GPS network (GEONET) operated by Geographical Survey Institute (GSI) provides direct information about the displacement rate fields in Japan. Sagiya et al. (2000) have estimated the continuous strain rate fields in Japan by analyzing the displacement rate data from GEONET with the standard inversion method proposed by Shen et al. (1996). Through this inversion analysis they revealed the existence of an inland deformation-concentrated zone (the Niigata-Kobe Tectonic Zone), which cannot be explained by elastic deformation due to plate-to-plate interaction. This suggests the long-term inelastic crustal deformation of Japanese islands. In order to understand the mechanism of the long-term inelastic deformation, we need to know the 3-D elastic/inelastic strain fields in the Earth's crust.

In general, the deformation of continuum is completely described by the nine independent elements of deformation gradient tensor. Since GPS measurements are restricted to the Earth's surface, unfortunately, three vertical gradients of the displacement vector are unobservable. Therefore, the estimable quantities are reduced to six. For this reason the strain analyses of GPS data have been treated as the two-dimensional problem estimating plane strain components. Furthermore, partitioning the observed crustal strain into elastic strain and inelastic strain, which is essential to understand the deformation mechanism, is left as an unsolved problem. Recently, we thought of an idea for the inversion method to estimate 3-D crustal strain fields from GPS data in the separate form of elastic and inelastic strain tensors. In this presentation we introduce the basic idea and mathematical formulation for the new method.

We can regard the Earth's crust as a linear isotropic elastic body including a number of preexisting cracks (weak interfaces). If tectonic stress is lower than a critical level, the preexisting cracks behave like the elastic body. However, if tectonic stress reaches the critical level, brittle fracture or plastic deformation occurs at the preexisting crack, and some amount of inelastic strain is generated. The generation of inelastic strain at the preexisting cracks or weak interfaces, which causes the surface displacements observed through GPS measurements, is represented by an equivalent moment tensor distribution (Backus & Mulcahy, 1976). Therefore, using theoretical expressions for displacements due to a moment tensor source (e.g., Yabuki & Matsu'ura, 1992; Hashima et al., 2008), we can compute the surface displacements caused by the generation of inelastic strain. Then, we can define the inverse problem of estimating the moment tensor distribution from observed GPS data. The strain fields computed from the inverted moment tensor distribution give the elastic strain tensor fields in the crust. On the other hand, since the moment tensor is defined as the product of the inelastic strain tensor and the elastic tensor of the surrounding medium, we can easily convert the inverted moment tensor distribution to the inelastic strain tensor distribution. Thus, we can estimate the 3-D crustal strain fields from GPS data in the separate form of elastic and inelastic strain tensors.

We can mathematically formulate the inverse problem mentioned above by extending the geodetic data inversion method based on the unified inversion formula (Matsu'ura et al., 2007) to the case in which the moment tensors are distributed not only on the plate interface but also in the 3-D space of the Earth's crust.