Tectonophysics 497 (2011) 15–22

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

The plate coupling in the Tokai District, the Central Japan, inferred from the different data using triangular dislocation elements

Tadafumi Ochi *, Teruyuki Kato

Earthquake Research Institute, the University of Tokyo, 1-1, Yayoi1, Bunkyo-ku, Tokyo, Japan, 113-0032

ARTICLE INFO

Article history:
Received 10 November 2009
Received in revised form 1 August 2010
Accepted 13 October 2010
Available online 20 October 2010

Keywords:
Estimation of plate coupling
Geodetic data inversion
Crustal deformation
Data type
Triangular dislocation element

ABSTRACT

We estimate interseismic coupling on the subducting plate interface in the Tokai area, central Japan, by inverting two geodetic data sets. The data record surface motion between March 1996 to May 2000; one represents vertical motion deduced from the leveling observations and the other is the horizontal velocity field deduced from GPS observations. In the inversion, we employed the analytical solutions of surface displacement due to a triangular dislocation element embedded in a homogeneous elastic half space in order to represent the curved plate interface. The vertical data show that the most strongly coupled portion of the subduction interface is concentrated beneath Omaezaki Cape, while the horizontal data show strongest coupling in the shallower region of the subducting plate interface. The estimated maximum value of coupling from the horizontal data is 40 mm/year, while that from vertical data is 25 mm/year.

1. Introduction

Recent studies show that the asperity where the two plates are strongly coupled together causes large slips at the time of earthquake so that the asperity is a key concept of earthquake prediction studies in Japan (e.g. Yamanaka and Kikuchi, 2004). In other words, estimation of plate coupling on the subducting plate interface is an important subject in the studies of earthquake generation along the subduction zones.

Southwest Japan is located in the region where the Philippine Sea Plate is subducting beneath the continental plate (Seno, 1977) and there have been many large historical events (Ando, 1975; Ishibashi, 1981). Ishibashi (1981) indicated that the eastern-most part of the region called the Tokai area has not ruptured for more than 150 years after the last event which is the 1854 Ansei Tokai earthquake, so that the area is said as a seismic gap.

As a part of earthquake prediction research, various types of observation have been carried out in the Tokai area. The Geographical Survey Institute (GSI) has performed frequent leveling observations, for example. There are a number of leveling routes in the Omaezaki area (see Fig. 1) and leveling surveys have been carried out for longer than a hundred years. In addition, a dense array of GPS stations was first constructed in as early as 1994, and was succeeded as a part of GPS Earth Observation Network (GEONET) over the Japanese Islands in 1996 (e.g. Hatanaka et al., 2003).

In order to estimate the coupling rate between the overlying continental plate and the subducting oceanic plate, the slip deficit (or back-slip) model proposed by Savage (1983) has been widely accepted. In this model, strain accumulation at subduction zone is represented by the superposition of steady state subduction and normal slip at an intermediate depth. We accepted this model and assumed that the crustal deformations on the Earth's free surface are caused by virtual normal slips on the buried fault at plate boundary.

In this way, Sagiya (1999) used GEONET GPS data from January 1997 to March 1999 and estimated plate coupling distribution that has a maximum 40 mm/year at the depth shallower than 20 km. El-Fiky and Kato (2000), on the other hand, studied the same region using leveling data from 1981 to 1995. They concluded the maximum coupling rate less than 30 mm/year and at the depth from 7 to 27 km.

In this paper, we separately analyzed the leveling data and the GPS data over the same period; March 1996 to May 2000. Since the operation of GEONET started in April 1996, we could not compare the data before March 1996. After June 2000, the crustal deformation in this area was much contaminated by the effect of the volcanic activities at and around Miyake Islands that had started in the end of June 2000 (Nishimura et al., 2001).

In order to approximate the curved plate boundary, we applied analytic solutions of the displacements on the Earth's free surface caused by a triangular dislocation element in a homogeneous elastic half space, which was first developed by Jeyakumaran et al. (1992).

In this article, we estimated the slip deficit distribution in the Tokai area using two different data; one by the vertical velocity inferred from the leveling observation and the horizontal velocity from the GPS observation. In inversion, we used the triangular dislocation elements to approximate the curved plate boundary. Then, we compared the two results of inversion.

* Corresponding author. Tel.: +81 3 5841 5781.
E-mail addresses: ochi@eri.u-tokyo.ac.jp (T. Ochi), teru@eri.u-tokyo.ac.jp (T. Kato).

0040-1951/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.tecto.2010.10.007

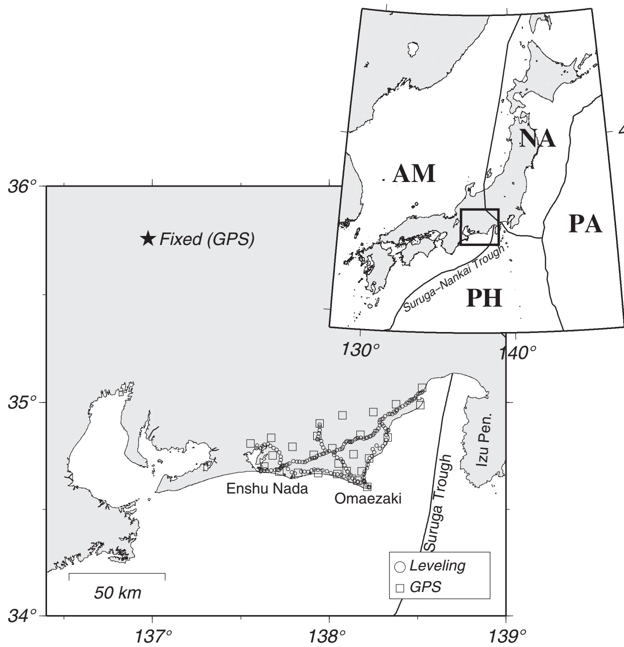

Fig. 1. Plate tectonic setting of the Japanese Islands (inset), where AM, NA, PA, and PH shows the Amurian, North American, Pacific, and Philippine Sea Plates, respectively (after Heki et al., 1999). Black star shows the reference point for the GPS analysis. Leveling benchmarks and GPS sites used in this study are also shown by open circles and open squares, respectively.

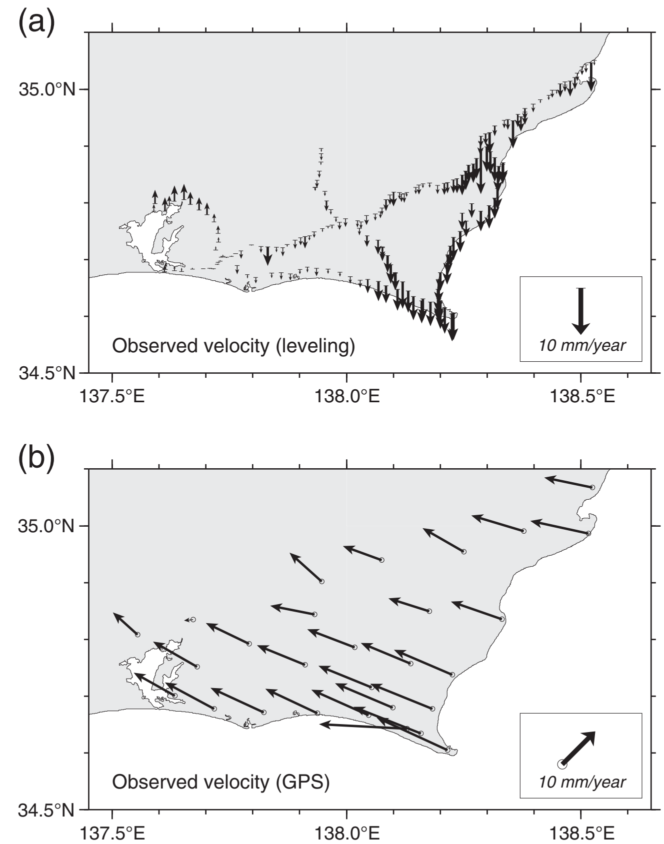

Fig. 3. Crustal deformation data used in the inversion: (a) vertical data obtained by the leveling observations using the adjustment analysis and (b) horizontal data by the GPS observations.

2. Data

We used the leveling and the GPS data for the period from March 1996 to May 2000.

2.1. Leveling data

Leveling data employed here are from the first- and the second-order leveling measurements carried out by GSI. The leveling benchmarks used in this analysis are shown in Fig. 2. The heights of benchmarks along the route from Omaezaki to Mori via Kakegawa have been measured four times a year and others are less than or equal to once a year. The details of the leveling analysis are explained in the next section. Estimated vertical velocities are shown in Fig. 3(a).

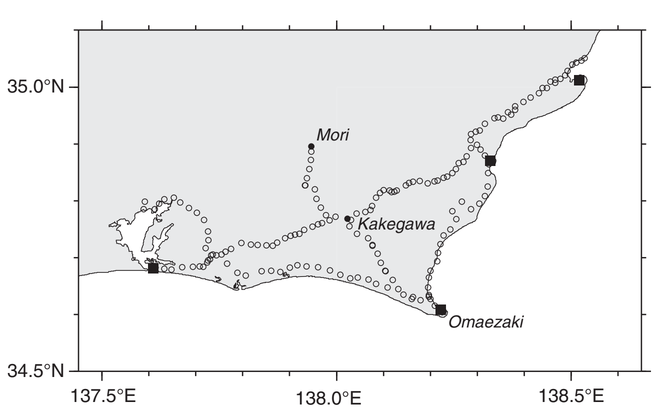

Fig. 2. The benchmarks of the leveling observations used in this study. Open circles show the benchmarks and solid squares show the tidal stations.

2.2. GPS data

In order to compare the result of vertical and horizontal data, we chose the 28 GEONET stations so that the distribution resembles to the leveling benchmark distribution. The original data were the daily coordinates of F2 solutions analyzed by GSI (Geodetic Observation Center, 2004). Following Sagiya et al. (2000), we estimated site velocities by fitting the following equation to the daily time series data of the i-th component of the n-th station:

$$x_n^i(t) = a_n^i + b_n^i t + c_n^i \sin(2\pi t) + d_n^i \cos(2\pi t),$$

where the first two terms of the equation correspond to the linear trend and the last two terms are the annual variation. We applied this model to all three components separately and estimated all by least squares method. Then, the estimated velocities were transformed to the relative velocity to the station 950283 (Hachiman). Estimated horizontal velocities are shown in Fig. 3(b).

3. Analysis of leveling data

In order to investigate the vertical crustal movement, we applied the velocity model for the benchmarks proposed by Fujii (1991). In this model, the height of the j-th benchmark at time t, $h^j(t)$, is described as follows:

$$h^j(t) = h_0^j + \Delta^j + v^j(t - t_0), \tag{1}$$

where t_0 is the reference time, h_0^j is an approximate height of j-th benchmark at time t_0, Δ^j is the correction to h_0^j, and v^j is the rate of the vertical movement linear with time, respectively.