Joint inversion of refraction and gravity data for the 3-D basement structure beneath Osaka Basin

Afnimar and Kazuki Koketsu,

Earthquake Research Institute, University of Tokyo, Yayoi 1-1-1, Bunkyo-ku, Tokyo 113-0032, Japan (e-mail: afnimar@eri.u-tokyo.ac.jp; koketsu@eri.u-tokyo.ac.jp).

Abstract

Accurate 3-D modeling of an underground structure is one the most important factor for precise simulation of seismic ground motion. Modeling of the basement structure using traveltime data only sometimes encounter the ray covarage problem. Certain parts of the model cannot be reached by rays. We develop 3-D joint inversion of refraction and gravity data to solve this problem. Beside that, we have improved finite difference calculation of seismic traveltimes.

The method is applied to the data obtained around Osaka Basin, Japan. The result agrees well with geological setting in this region. The hidden Koyo fault and the extension of Ashiya fault are recovered clearly. The velocity and density of the basement are 5.341 km/s and 2.384 g/cm^3, respectively, which represent the elastic characteristic of the weathered granitic rocks which include ryolite and metamorphic rocks in this area. The instability due to the lack of data beneath Osaka Basin is improved by introducing depth constraints.

3-D FD traveltime calculation

Vidale [1], [2] introduced FD approximation to the eikonal equation for calculating first-arrival times through 2-D and 3-D gridded velocity models. This algorithm is faster than tracing rays to a large number of receivers because the traveltimes for all the receivers are computed at the same time. Unfortunately, his method fails for sharp velocity contrasts. Hole & Zelt [3] overcame this problem by adding some operators and a reverse propagation scheme (Podvin & Lecomte [4]) into Vidale's original algorithm. However, even this method still requires further modification for irregular interfaces, because this kind of interface often cause multipathing of head waves [5]. We define new 3-D operators if the multipathing occurs. Our method successfully apply to the synclinal model in Fig. 1. The distortion of wavefronts due to multipathing problem (Fig. 2a) is overcome well by our method (Fig. 2b).

Joint inversion of refraction and gravity data

If no ray intersects some parts of the interface (Fig. 3), the interface cannot be recovered well by using refraction data only (Fig. 4a). These parts can be recovered by using gravity data (Fig. 4b), thought the basement slowness is determined in the inversion.

The proposed method is applied to the seismic refraction and free-air gravity anomaly data obtained around Osaka Basin (Fig. 5). To produce the more resonable result, we introduce two treatments into our inversion. First, the finer mesh of knot points is applied to the interesting area as shown in Fig. 5. The main mesh size is 1 km and the finer mesh size is 0.5 km. Secondly, the height of basement outcrop in Rokko Mountain and Awaji Island

and the depth interpretation of reflection seismic data from Yokokura et al. [6] are used as absolute constraints in areas where only few data are available. The results in Figs. 6 and 7 show steep slopes corresponding to known faults. The steep interface along the cross-section AA‘ (Fig. 8a) is recovered well. In particular, the valley part is recovered better than Inoue et al. [7]'s result because this part is mostly constrained by the depth interpretation of the seismic reflection data mentioned above. This result implies the extension of the Ashiya Fault (Fig. 7) to the west. The Koyo Fault zone is also recovered well with its extension toward the west. Along the cross-section BB‘ (Fig. 8b) our inversion cannot recover the steep interface in the Uemachi fault zone. This problem is due to the poor distribution of gravity stations in this zone. Fortunately, the depth of foot wall is recovered better than Inoue et al.'s result, thanks to Yamamoto et al.'s [8] depth profile from seismic reflection data.

References

[1] Vidale, J., 1988. *Finite-difference calculation of traveltimes*, Bull. Seism. Soc. Am., **78**, 2062-2076.

[2] Vidale, J., 1990. *Finite-difference calculation of traveltimes in three dimensions*, Geophysics, **55**, 521-526.

[3] Hole, J.A., and Zelt, B.C., 1995. *3-D finite-difference reflection traveltimes*, Geophys. J. Int., **121**, 427-434.

[4] Podvin, P. and Lecomte, I., 1991. *Finite-difference computation of traveltimes in very contrasted velocity models: a massively parallel approach and its associated tools*, Geophys. J. Int., **105**, 271-284.

[5] Afnimar, and Koketsu, K., 2000. *Finite-difference traveltime calculation for head waves traveling along an irregular interface*, Geophys. J. Int. (accepted).

[6] Yokokura, T., Kano, N., Yamaguchi, K., Miyazaki, T., Ikawa, T., Ohta, Y., Kawanaka, T., and Abe, S., 1998. *Seismic profiling of deep geological structure in the Osaka Basin area*, Bull. Geol. Surv. Japan, **49**, 571-590, (in Japanese with English abstract).

[7] Inoue, N., Nakagawa, K., and Ryoki, K., 1998. *Gravity anomalies and basement structure in Osaka Plain*, Butsuri-Tansa, **51**, 1-16 (in Japanese with English abstract).

[8] Yamamoto, E., Nakagawa, K., Mitamura, M., Toda, S., Nishida, T., Terada, Y., Uda, H., and Yokota, H., 1992. *Seismic reflection method at the Central Osaka Plain-Yodo River (Juso∼Kunijima) line—*, Butsuri-tansa Gakkai Gakujutsu Kouen Ronbun Shuu, **86**, 235-240 (in Japanese).

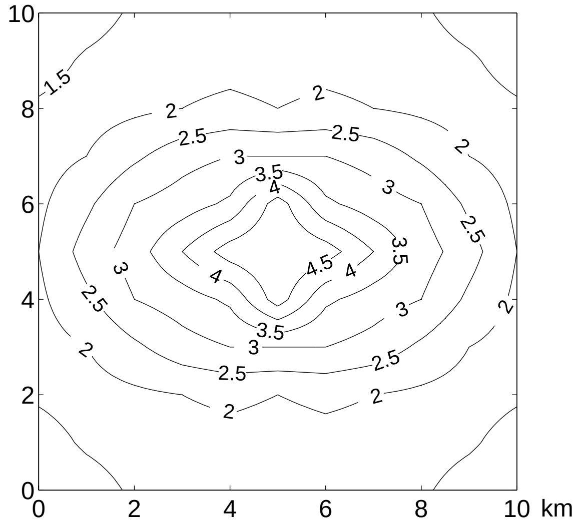

Figure 1: Topography of the synclinal interface in the two-layer model ($v_1 = 2.5$ km/s and $v_2 = 5.2$ km/s).

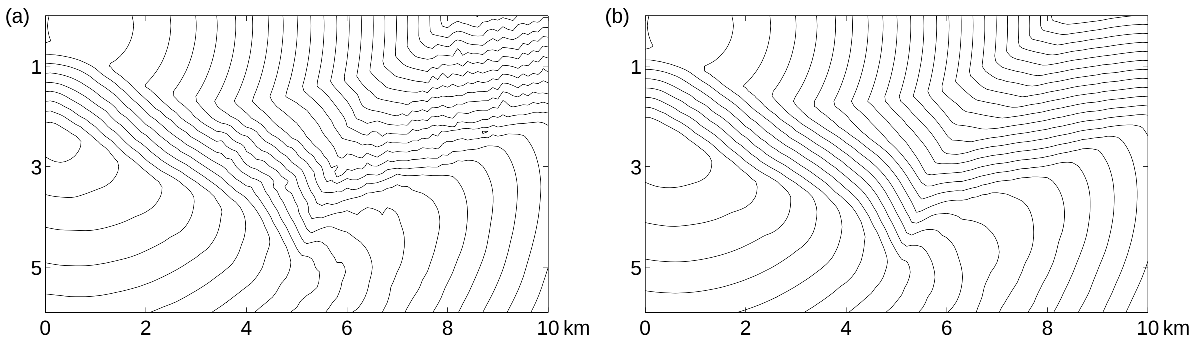

Figure 2: Vertical sections of traveltime contours at $y = 6$ km in the synclinal model with a point source at (1 km, 1 km, 0.5 km). The two diagrams show the results of (a) Hole & Zelt's 3-D algorithm and (b) our algorithm.

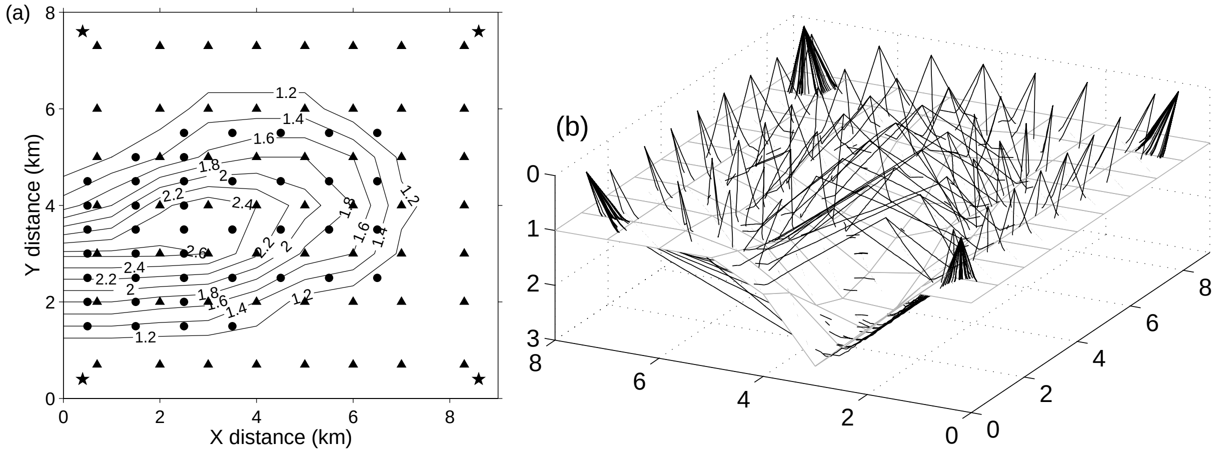

Figure 3: Contours of the interface of the two-layer simple basin model (a) with $v_s = 2.5$ km/s and $v_b = 5.2$ km/s. Distribution of gravity stations and recivers are denoted by black circle and black triangle symbols, respectively. The star symbols indicate the source position. (b) The rays (black lines) that cover the model.

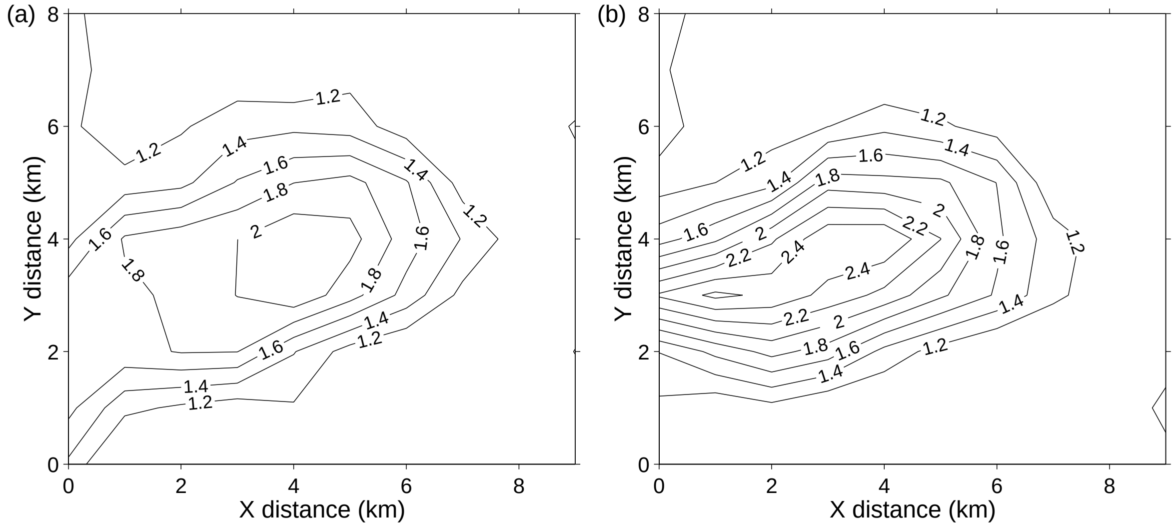

Figure 4: Contours of interface which are obtained by (a) traveltime only inversion and (b) joint inversion. In the joint inversion, the initial basement velocity is 4.5 km/sec and the final deviation of inversion result is only $5\,10^{-4}$ km/s

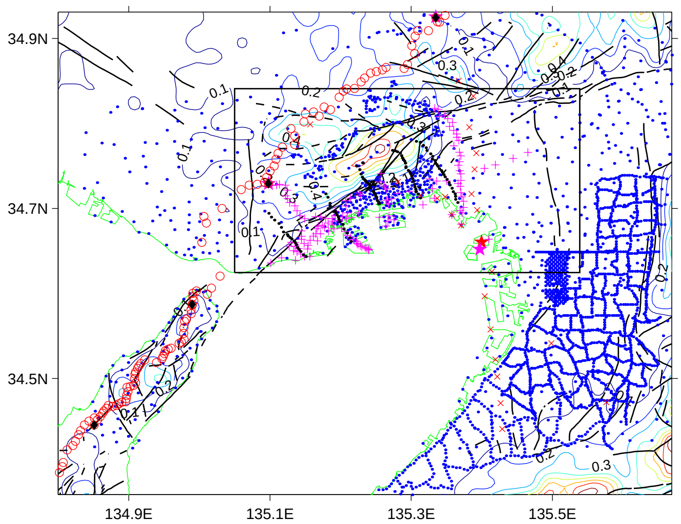

Figure 5: The distribution of seismic receivers for refraction experiments in the Hanshin and Osaka area. The star and diamond symbols denote shot points. The gravity stations are indicated by dots. The black rectangle is the interesting area with finer mesh.

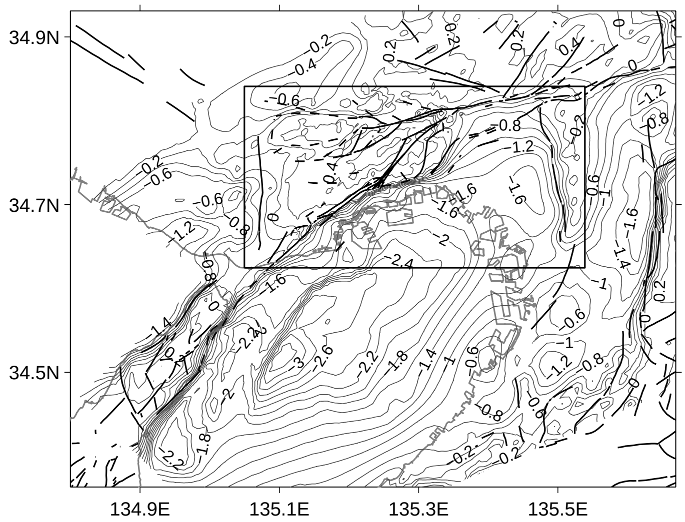

Figure 6: Contours of the sediment/basement interface from the result of the joint inversion with intervals of 0.2 km. The solid and dashed thick lines denote clear and possible fault traces.

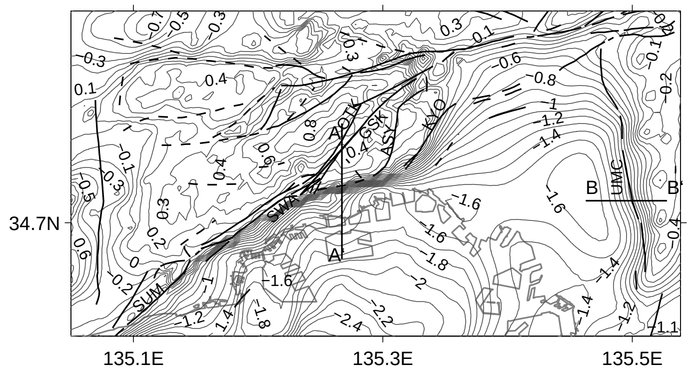

Figure 7: Close-up of the interface contours in the black rectangle in Fig. 6 with intervals of 0.1 km. The names of faults are abbreviated as follows. ASY, Ashiya Fault; GSK, Gosukebashi Fault; KYO, Koyo Fault; OTK, Ootsuki Fault; SUM, Suma Fault; SWA, Suwayama Fault; UMC, Uemachi Fault.

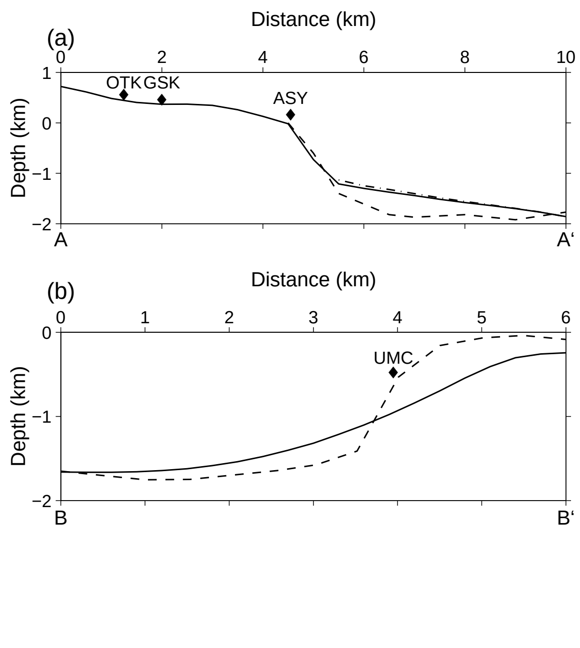

Figure 8: Cross sections (solid lines) of the interface along AA' (a) and BB' (b) in Fig. 7. The dashed and dash-dotted lines denote the cross section from Inoue et al's results [7] and from the depth interpretation of seismic reflection data by Yokokura et al [6], respectively.