SEDIMENTARY THICKNESS IN THE EASTERN KANTO BASIN ESTIMATED BY ALL-PASS RECEIVER FUNCTION USING DENSE EARTHQUAKE OBSERVATIONS

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ABSTRACT :

The sedimentary thickness varied to several thousand meters played an important role for the long-period ground motions, which were observed in the Kanto (Tokyo) basin recently. However, exploration of sedimentary thickness is costly. Utilizing dense seismographic stations of K-NET, KiK-net and Sk-net, we studied the thickness variation by the All-pass receiver function (APRF) method. At each station, the travel-time differences between converted PS and P waves, Tps-p, were calculated from recordings with condition of clear initial P waves in a range about 100 km distance. The conversion of the Tps-p to the sedimentary thickness is a complex question since both P and S waves velocities related, as well as thickness. The conversion question was figured out by regression functions for the thickness factor H to the wave's travel-time differences between S and P waves, Ts-Tp, from deep-well VSP data. By combination of hundreds of the Tps-p results and the regression functions, we estimated the thickness of sedimentary basin beneath each station and obtained the thickness contours in the eastern Kanto basin. The results at several dozen locations were well confirmed by deep-hotspring wells and fault investigations.

KEYWORDS: Sedimentary thickness, Receiver Function, VSP, Regression Function, Converted wave

1. INTRODUCTION

Strong ground motions with long periods have been observed in the Kanto area recently (Kohketsu & Kikuchi, 2000; Furumura & Hayakawa, 2007). The thickness of the Kanto (Tokyo) sedimentary basin, which varies irregularly to several thousand meters down to the pre-Neogene bedrock ($Vs \geq 2.5$km/s), should be crucial for these motions. The sedimentary thickness was investigated by deep-well drillings as early as 1950's for purpose of natural gas and hotspring in Kanto basin (Ishii, 1962; Suzuki, 1996; Suzuki, 2002). The Yumenoshima seismic refraction surveys from 1976 to 1988 made a great progression for underground structures (Shima et al., 1976; 1978; 1981; Seo & Kobayashi, 1980; Seo *at el.*, 1990), and therefore, resulted in the first two-layer sedimentary basin model (Kohketsu and Higashi 1992).

After the lessons learnt from the 1995 Kobe devastated earthquake, the Japanese Headquarters for earthquake research promotion (HERP) guided a series of earthquake disaster prevention strategies. Under these strategies, much more efforts were made for the investigation of Kanto basin structures from different ways, such as reflection surveys (e.g., Sato *et al*, 2005), deep drilling with VSP method (e.g., Yamamitsu, 2004), inversion methods using seismic waveforms (e.g., Hao *et al*, 1999), and microtremor surveys. Recently, a nationwide investigation of subsurface modeling and database was launched for evaluation of strong motions (Fujiwara *at el.*, 2006; 2008).

In the field of monitoring strong motions, NIED deployed 1000 sets of strong-motion seismographs in nationwide with an inter-distance of ~25 km, so-called K-NET (Kinoshita, 1998); furthermore, another 800 sets of pair seismographs at surface and borehole in nationwide, so-called KiK-net (Aoi *et al*., 2000). Municipals around Tokyo Metropolitan deployed over 900 sets of seismic intensity-meters, so-called SK-net with an inter-distance of ~2-10 km. Of them about 220 stations are located in the eastern Kanto basin as shown in Figure 1, averagely with an inter-distance of ~5-10 km. These advanced network-stations and huge accumulation of observations brought authors the opportunity to constrain the sedimentary thickness.

In this paper, we used the All-pass receiver function (APRF) to study the sedimentary thickness. The receiver function method was originally used for detecting the deep structure interfaces (e.g., Langston, 1979, Ammon, 1991, Soda *et al.*, 2001, Shiomi *et al.*, 2004). The upmost crust/sedimentary interface were targeted recently by using short period of waveforms for local events (e.g., Kobayashi *et al.*, 1998; Hao *et al.*, 2005, 2006, 2007). We have studied the thickness variation beneath the stations as shown in Figure 1, where the northern mountain area and southern upheaval of Boso peninsula are exclusion.

2. GEOLOGICAL SETTING AND DATA SET

Kanto sedimentary basin with about 100 km^2 is the largest basin, and also it is geologically and seismotectonically complex basin in the central of Japan. The Boso peninsula upheaval in southern Kanto was supposedly upheaved by the plate's subduction. The Western and northern Kanto areas are mountains areas.

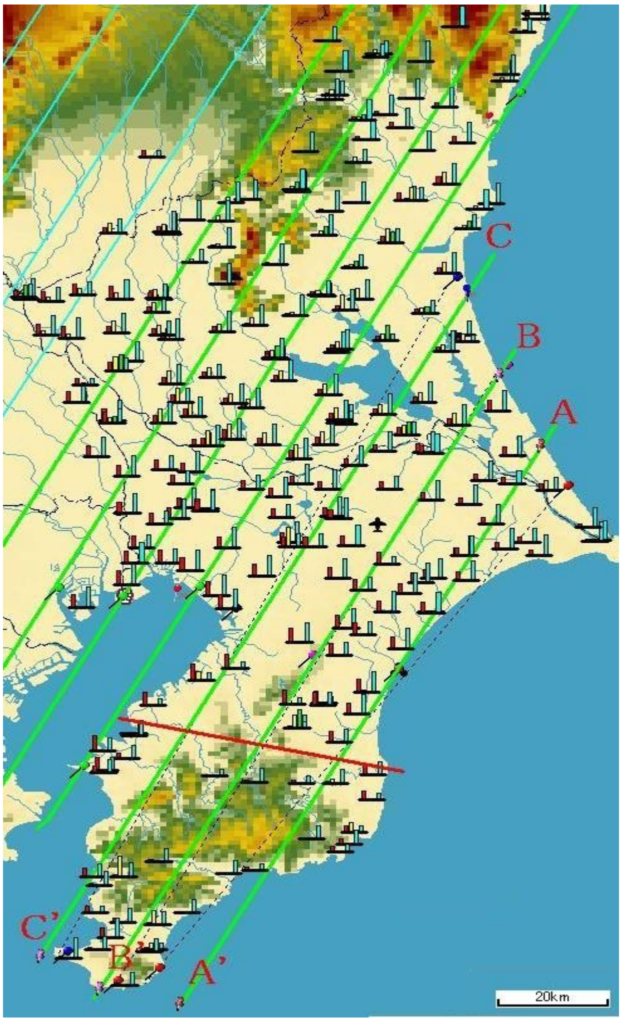

Figure 1 Locations of seismographs in the Eastern Kanto basin, Japan. Of bar graphs, red bars indicate travel-time difference Tps-p from 0 to 2.3 seconds; and shallow blue bars stand for data quality ranks from 1 to 3. Red line shows Kanto basin border with the upheaval of Boso-peninsula.

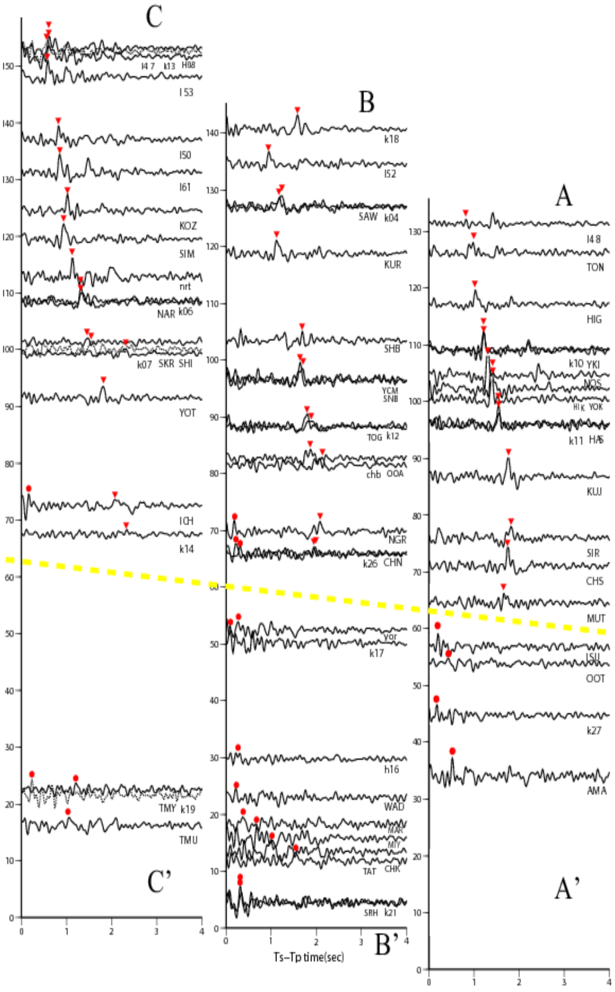

Figure 2 Examples of profiles constructed from AP receiver functions. Locations A-A', B-B', and C-C' are given at Figure 1. Triangle indicates time-lag of converted phase PS after excited on bedrock interface. Yellow line shows relative border between Kanto basin and the Boso upheaval. The details see text.

The ~3-4 km thick unconsolidated/consolidated sediments deposited on the pre-Neogene basements of unconformity interfaces in the Kanto basin. Miura group (Miocene to early Pliocene), Kazusa group (late Pliocene to early Pleistocene), Shimosa group (late Pleistocene) in turn deposited on the pre-Neogene basements; however, most of the groups interfaces are unconformity interfaces. The up-and-down pre-Neogene interface and other interfaces with very different thickness in-betweens consist of the Kanto sedimentary basin.
A total of 222 strong-motion stations, of which 153 stations from SK-net, 49 K-NET, and 23 KiK-net, were targeted to be explored for the underground structures down to the bedrock as shown in Figure 1. On average about 20 records were selected at each station, whose maximum amplitudes ranged up to ~558 cm/s/s. Over 5000x3 records were visually identified for clear initial P phases from events in a distance of 100 kilometers during 1999 to 2005 for SK-net, and 1996 to 2007 for K-NET and KiK-net.

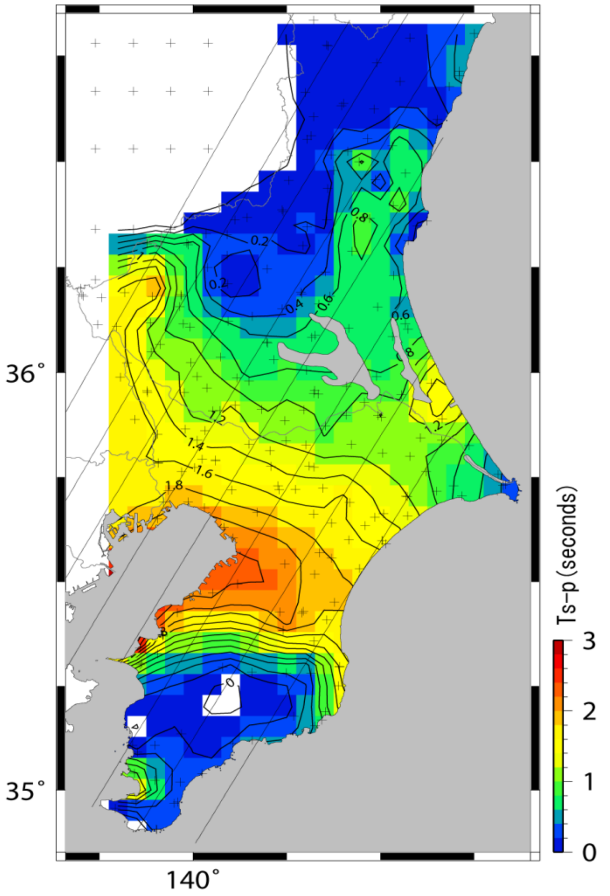

Figure 3 Travel time differences (Tps-p) in seconds between initial P- and converted PS-phases.

3. Ts-p by All-PASS RECEIVER FUNCTIONS (APRF)

The up-and-down interfaces may be detected by receiver function as long as there is a distinguished velocity contrasts between up layers and downside layers. The converted waves were induced by the interfaces and the travel time difference Tps-p between the direct P and the converted P-to-S waves can be calculated from the receiver function.
Receiver function was originally used for detecting deep interfaces in earth-internal, such as Moho. It was recently extended to detect sub-surface structure interfaces by using shorter period of waveforms for local events. However, for the shorter period of waveforms, the signals are easily disturbed by various factors, such as sub-reverberations of small size of structures. All-pass function (AP), which was deconvolved from minimum-phase-shift function (Papoulis 1979), can enhance the identify ability of signals (Izumi *et al.*, 1988a, 1988b, 1990). AP was applied to receiver function, so-called APRF (Satoh, 2005). Comparing the classic receiver function, APRF can improve the identification of P-to-S phase in the near-surface interfaces clearly, even for a higher frequency of 10Hz (Hao *et al.*, 2005, 2006, 2007).

In this paper, we first calculated APRFs using the all of available records and stacked APRFs as one representative APRF at each station. On average, the process emphasized the PS signal and eliminated the influences from incidence angles. The same way was carried out over all of stations. Then, we constructed APRF multi-profiles to find the possible converted phases PS changing as triangles shown in Figure 2. The time-lag of the travel time differences Tps-p gradually increases from north to south, but it was disconnected at approximately time-lag range of 2.1-2.3 second's where the area of the upheaval of Boso-peninsula is. We also can identify peaks with shorter time-lag as red dots shown in Figure 2. Most of them are supposed related the 2nd and/or 3rd shallower subsurface interfaces in the upheaval area of Boso-peninsula.

To summarize all of Tps-p results, we plotted Tps-p contour in seconds as shown in Figure 3. Ichihara (red color) in Chiba prefecture is the deepest area in eastern Kanto basin since the longer time-lag of the Tps-p, the deeper of the basin is. From Ichihara, the Kanto basin towards the south was bordered on the upheaval of Boso-peninsula; and became gradually shallower northwards, until the northern mountain area.

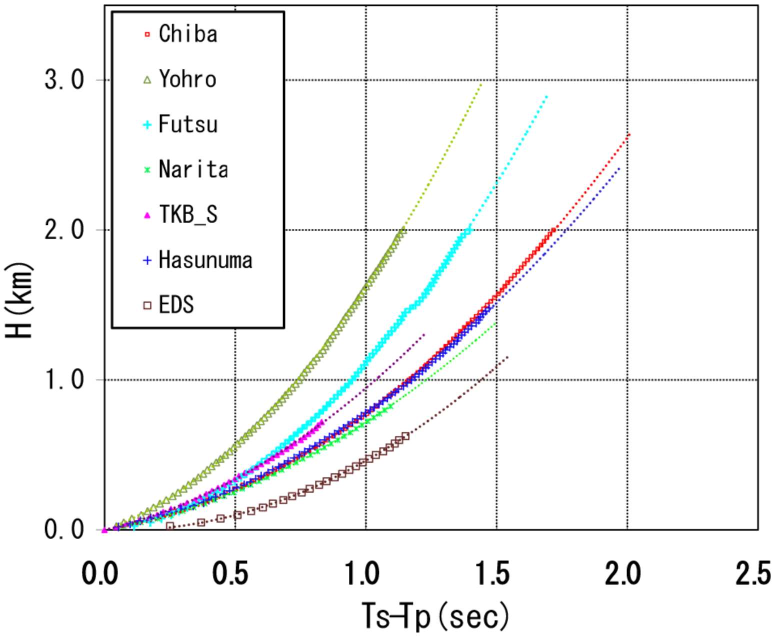

Figure 4 Regression functions for sedimentary thickness H(km) versus the travel time differences Ts-Tp of direct P and S waves in the east Kanto basin. Thin lines show the extrapolations by the regression functions

4. REGRESSION FUNCTIONS FROM VSP

Converting of the travel time difference Tps-p to thickness is another key question since Tps-p is related to velocities Vp, Vs, and sedimentary thickness. Among the conventional geophysical prospecting methods, the vertical seismic profile (VSP) method may give a high-resolution seismic image at a borehole in both of the P and S wave information. However, VSP is only limited to a few areas since it is too costly to be widely distributed. A dozen of deep-wells extending 2000 meters below ground with VSP in the Kanto area have been drilled over the past 15 years by NIED (Yamamizu, 2004). In order to extend the high-quality VSP results effectively, utilizing these VSP data we derived a set of regression functions for sedimentary thickness H(km) versus the travel time difference Ts-Tp of direct P and direct S waves at Narita(green), Chiba(red) and three other locations in the Chiba area (Hao and Fujiwara, 2007). The equalization of travel time difference between Tps-p and Ts-Tp was verified at Narita. We have recently obtained two more results from Hasunuma(blue) and TKB_S(pink) as shown in Figure 4. Two higher curves, the cases Yohro and Futsu, which are located on the upheaval of Boso-peninsula, were not considered. One lower curve EDS is also an exception. The rest of the four functions are close each other. We chose the case of Chiba (red) Eqn. (4.1) as the representative regression function since it was in-between of the average and having the thickest sedimentary of 2000 meters.

$$H(km)=0.562(Ts\text{-}Tp)^2+0.2564(Ts\text{-}Tp) \qquad (4.1)$$

Where H(km) means sedimentary thickness in kilometer; Ts-Tp indicates the travel time difference of direct P and direct S waves based on VSP data.

Therefore, Eqn. (4.1) was used for the conversion of thickness in the Kanto basin.

5. RESULTS AND CONCLUSION

With the regression function Eqn. (4.1), about 200 of Tps-p were converted to sedimentary thickness down to bedrock in the eastern Kanto basin as Figure 5 shown. The white areas indicate the zero thickness and/or absent data in mountains areas of Boso peninsula upheaval and of northern Kanto areas.
The thickest sediment is around 3km thickness in the Ichihara (red color) in Chiba prefecture. From the Ichihara, the thickness changed to thin and/or zero rapidly towards southern as bordering on the upheaval of Boso-peninsula; and became gradually thin northwards until the northern mountain area. The general basin depth pattern by APRF is similar with the upper boundaries of the pre-Neogene by Suzuki (2002). But depths are different in some areas in detail. One possible reason is that our results are emphasis on velocity contrast interfaces instead of geological stratigraphic interfaces.

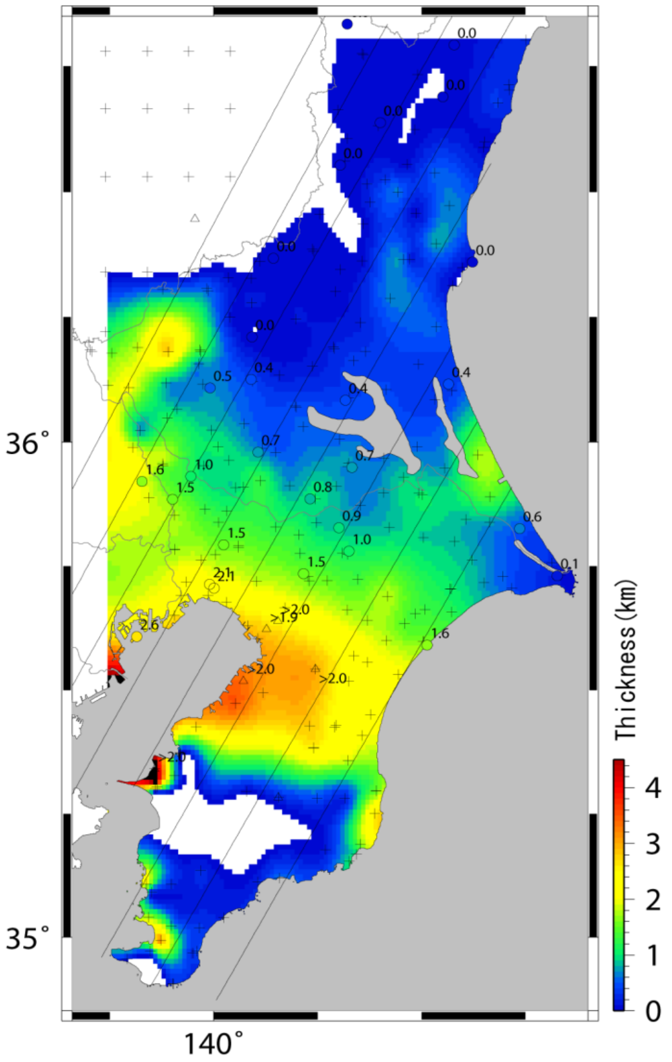

Figure 5 Sedimentary thickness converted from Tps-p using VSP's regression function. Warm colors indicate thicker sediments, while cool colors indicate thin sediments. The result was examined by deep-well's information: filled cycles with color scale and digital indicate the depth on bedrock penetrated; triangles with digital mean bottom depth but bedrock untouched.

For the examination of sedimentary thickness, a dozen of deep-well's information was added on Figure 5. Good agreements were confirmed between calculated thickness and well information (filled cycle) with the same color scale. Until now, no wells were penetrated to bedrock in the southern part below 35.6°N, but the Tps-p can provide information of bedrock until the border of the of Boso upheaval, around 35.4°N.

The APRF profile on the line B-B' is comparable with reflection survey on shallower parts by Sato *et al.* (2005). We conclude that APRF can be a useful method to explore the sedimentary thickness as example reported in this paper. With a combination of reflection surveys, further results can be expected in future study. With more and more seismic observation stations in Kanto basin, the precision of the results can be also increased.

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