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EMPIRICAL ESTIMATE OF AVERAGE SHEAR-WAVE VELOCITY OF GROUND AT JMA STATIONS IN KANTO REGION, JAPAN

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ABSTRACT

We develop a method for estimating average shear-wave velocity in the upper 30 m (V_S30) at a strong-motion station by using recorded motions at a pair of stations located closely each other. Specifically, an estimate of V_S30 value at one of the stations, where the soil condition is unknown, is derived mainly from V_S30 at another station where the shear-wave velocity data is available and relative amplification factor between these stations. Application of this method to the ground motion recordings of the JMA, K-NET and KiK-net strong-motion networks provides the estimates of V_S30 at 49 recording sites in the JMA network in Kanto region, Japan. The V_S30 estimated from the recordings of station pair are compared to those inferred from boring log data obtained in the vicinity of the JMA station. The result indicates that the method proposed in this study can predict the V_S30 values at a strong-motion station with an accuracy of approximately +/- 50 m/s.

Keywords: average shear-wave velocity, amplification factor, strong-motion station pair, JMA

INTRODUCTION

Nationwide strong-motion seismograph networks, e.g., the K-NET and KiK-net of the National Research Institute for Earth Science and Disaster Prevention (NIED) and the 95-type seismometer network of the Japan Meteorological Agency (JMA) have been operated in Japan. Borehole shear-wave velocity logs are available at all of the K-NET and KiK-net stations, while the soil condition at the JMA station is not investigated. Therefore, it is difficult to analyze the strong-motion recordings obtained at the JMA station considering the local site condition.

To classify the local site condition, average shear-wave velocity to a certain depth of the ground has been widely used (Borcherdt, 1978). Especially, average shear-wave velocity in the upper 30 m (V_S30) is mostly in practical use in classification of surface geological unit, which is utilized in the National Seismic Hazard Mapping Project of Japan (Fujiwara et al., 2004) and in U.S. building codes (Borcherdt, 1994).

The V_S30 at a site can be computed from geotechnical data, such as velocity logging and boring log, or estimated from microtremor array observations (Konno and Kataoka, 2000). To obtain these data over a wide area, much time and labor are required because the data necessitate on-site drilling or measurement. The estimate of V_S30 is also obtained from surface geology in the nationwide geomorphologic database, the Digital National Land Information by using empirical equations (Fujimoto and Midorikawa, 2004; Matsuoka et al., 2006). Since the mesh size used in the database is 1km by 1km, the V_S30 estimated from such mapped geology may differ from actual V_S30 at a site.

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We develop a method for estimating V_S30 at a strong-motion station mainly from peak ground motions recorded at a pair of stations located closely each other. By applying the method to the recordings obtained at the K-NET, KiK-net and JMA networks in Kanto region, Japan, V_S30 at the JMA strong-motion station is estimated. The V_S30 estimated from the recordings of station pair are compared to those inferred from boring data obtained in the vicinity of the JMA station to examine the estimation accuracy of the V_S30.

METHODS AND DATASET

Methods

Figure 1 shows a schematic diagram of the method developed in this study. For a pair of strong-motion stations located closely each other, shear-wave velocity data is available at one of the stations. This station is called "known station", and average shear-wave velocity in the upper 30 m at the station is referred to as V_S30_k. For a certain earthquake, peak ground motion (i.e., *PGA* or *PGV*) recorded at the known station and hypocentral distance to the station are referred to as PGM_k and X_k, respectively. Similarly, ground motion parameter and hypocentral distance at another station, where the shear-wave velocity data is not obtained ("unknown station"), are referred to as PGM_u and X_u. Relative amplification factor (*AF*') between the known-unknown station pair is defined as a ratio of peak ground motions corrected by the reciprocal ratio of hypocentral distances as follows:

$$AF' = (PGM_u / PGM_k)(X_u / X_k) \quad (1)$$

Suppose that the *AF*' with respect to the known station increases (or decreases) monotonically with a decrease (or increase) in V_S30 at a rate of slope *b* (see Figure 1b), average shear-wave velocity at the unknown station (V_S30_u) can be expressed by Equation (2).

$$\log V_S 30_u = \log V_S 30_k + \log AF' / b \quad (2)$$

Mean of the slope *b* were obtained from the analysis for the ground motion records of nearby station pair composed of the K-NET and KiK-net stations (Fujimoto and Midorikawa, 2006). Therefore, the V_S30_u can be estimated by substituting average shear-wave velocity at known station (V_S30_k), relative amplification factor between known-unknown station pair (*AF*'), and mean slope *b* into Equation (2).

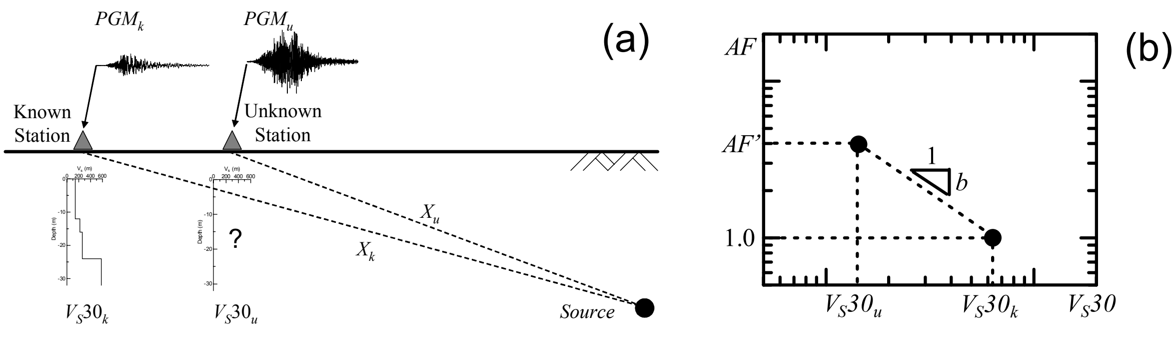

Figure 1. Schematic diagram of prediction method

Dataset

As for the JMA, K-NET and KiK-net strong-motion network, intervals of station spacing are several tens of kilometers. Combination of these strong-motion networks offers the opportunity to pair nearby strong-motion stations. The K-NET and KiK-net stations were chosen as the known station because borehole shear-wave velocity logs are available at all of these stations. Average shear-wave velocity in the upper 30 m at the K-NET and KiK-net stations was computed as V_S30_k. Among the nationwide

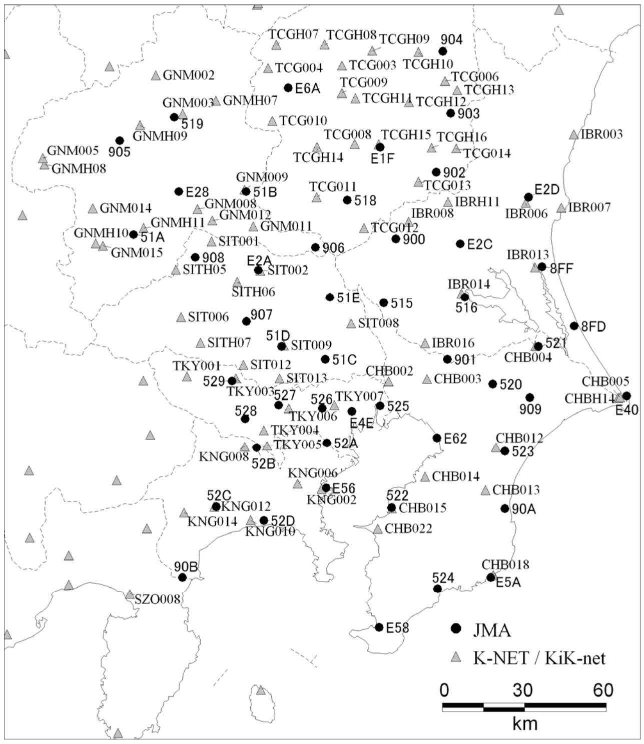

Figure 2. Strong-motion stations of JMA (closed circle) and K-NET/KiK-net (triangle)

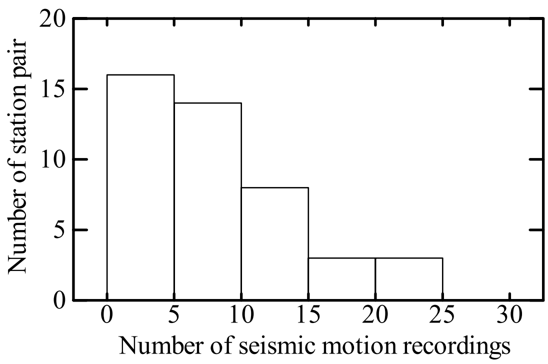

Figure 3. Histogram of number of recordings

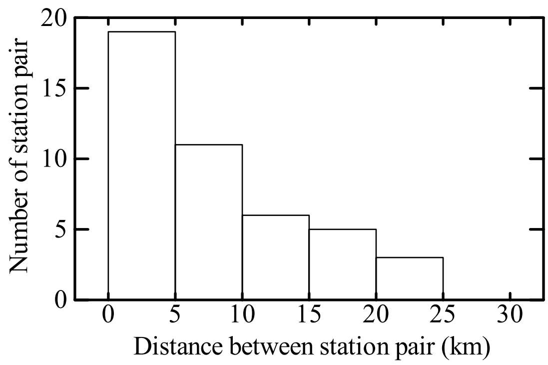

Figure 4. Histogram of station pair distance

JMA strong-motion network, 49 stations located in Kanto region were selected as the unknown station. Figure 2 shows the location of the JMA stations (closed circle), and the K-NET and KiK-net stations (triangle). In order to pair the JMA station (as unknown station) with the K-NET or KiK-net stations (as known stations), station-to-station distances from the JMA station to all of the K-NET/KiK-net stations were calculated, and then each JMA station was paired with the K-NET or KiK-net station with shortest distance. Since the propagation path effect is considered to be not negligible for the station pair with station distance greater than about 30 km (Borcherdt, 2002), the JMA Tateyama [E58] with the shortest station distance of 36 km was excluded.

For 48 known-unknown station pairs, ground motion recordings of the earthquakes occurred up until December, 2003 with peak ground accelerations less than 100 gal were collected. Common recordings obtained at both the known and unknown stations are necessary to compute the *AF*', however such recordings were not available at four station pairs: JMA Tomioka [51A], Maebashi [E28], Hatoyama [907] and Utsunomiya [E1F]. Therefore, the four pairs were not used in the subsequent analysis.

A histogram showing the number of common recordings obtained at a total of 44 known-unknown pairs is shown in Figure 3. Station pairs with common recordings from less than 10 earthquakes account for about 70% of the total pairs. Figure 4 shows the histogram of the distance between the known and unknown stations. Station pair distance ranges 300 m (JMA Kisarazu [522]-K-NET Kisarazu [CHB015] pair) to about 20 km (JMA Kamogawa [524]-K-NET Katsuura [CHB018] pair). Station pairs with station-to-station distance less than 5 km and 10 km make up about 40% and 70 % of all the pairs, respectively.

RESULTS

For 44 known-unknown station pairs, relative amplification factors (*AF*') are estimated by substituting peak ground velocities (*PGV*) and hypocentral distances into Equation (1). The *PGV* is adopted as the ground motion parameter (*PGM*) in Equation (1) because this parameter shows better correlation with V_S30 than does *PGA*. The *AF*' is defined as the largest value of the corresponding quantity computed from the two horizontal components obtained at each station pair.

Figure 5 shows the relation between *AF*' and magnitude (M) for station pair with common recordings from more than 10 earthquakes. Stable estimate of *AF*' are obtained at most of the station pairs, however a large variation in *AF*' is found at the station pair with the recordings from the earthquake of magnitudes 5.0 or less, e.g., the JMA Kuki [51E] and Mashiko [902]. The *PGV*, which is used to compute the *AF*' in Equation (1), correlates better with ground motion over a mid-period band (0.5-2.0 s) (Kobayashi and Nagahashi, 1978), however mid-period motions are less dominant in the recordings from the earthquakes with smaller magnitude than are short-period motion. Therefore, the variance of *AF*' may increase as magnitude of the earthquake becomes smaller.

Estimates of average shear-wave velocity at unknown station (V_S30_u) were computed by substituting average relative amplification factor (*AF*') from recordings with M > 5.0, average shear-wave velocity at known station (V_S30_k), and mean slope *b* specified as -0.852 (Fujimoto and Midorikawa, 2006) into Equation (2). To examine the estimation accuracy of V_S30_u, boring logs with SPT N-value located

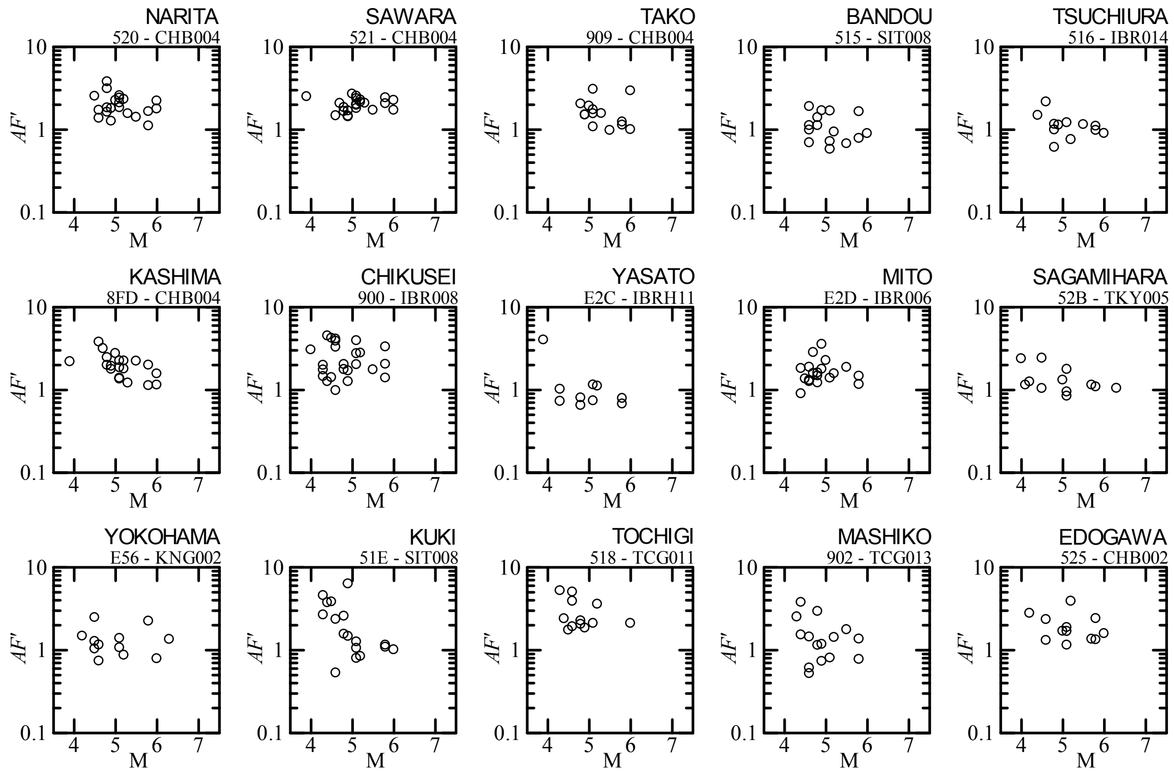

Figure 5. Magnitude (M) vs. relative amplification factor (*AF*')

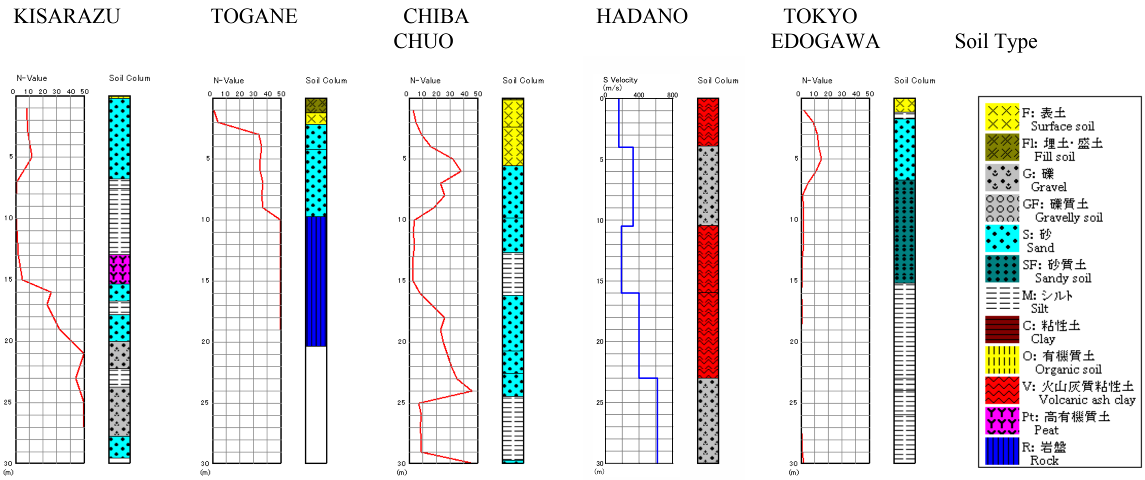

Figure 6. Boring logs near JMA stations

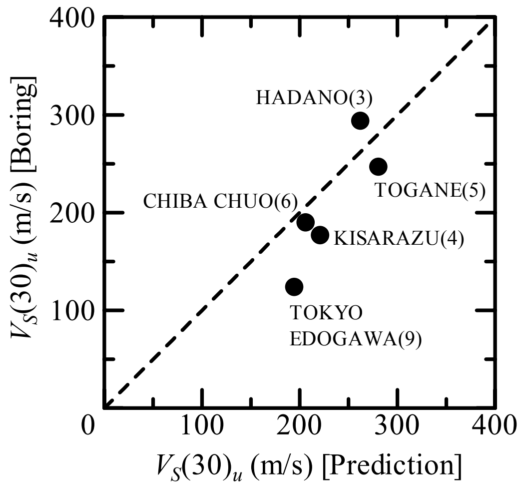

Figure 7. Comparison of average shear-wave velocity

within 200 m of the JMA station were collected. The boring logs with a drilling depth of 30 m or more were obtained at six sites near the JMA stations: Kisarazu [522], Togane [523], Tako [909], Chiba Chuo [E62], Hadano [52C], and Tokyo Edogawa [525]. Geologic conditions for the six JMA stations were compared with those for the corresponding adjacent boring sites by using geological map on a scale of 1:25,000. Except for the JMA Tako [909], the other JMA stations are located on same geological conditions for the adjacent boring sites. Figure 6 shows the boring logs near the JMA stations other than the JMA Tako.

Using the empirical equation (Ohta and Goto, 1978), average shear-wave velocities at the five boring sites near the JMA station (see Figure 6) were computed based on the shear velocity profile estimated from N-value and depth. Figure 7 shows a comparison of the V_S30 between the values predicted from recordings of known-unknown station pair and those estimated from adjacent boring log data. The agreement between the predicted and estimated V_S30 is excellent except for JMA Edogawa [525] which is located near a six-story building with one basement floor. As it is expected that the site amplification at the station is changed by the effects of soil-structure interaction and is different from that on the free field, inaccurate estimate of V_S30 may be obtained. Consequently, the result indicates that the empirical equation developed herein can predict the V_S30 at a strong-motion station with an accuracy of approximately +/- 50 m/s.

CONCLUDING REMARKS

Using the ground motion recordings obtained at a pair of nearby strong-motion stations, we developed an empirical equation for estimating average shear-wave velocity in the upper 30 m (V_S30) at one of the stations mainly from relative amplification factor between the station pair and average shear-wave velocity measured at the other station. From the recordings of strong-motion networks in Kanto region, relative amplification factors between the JMA station and the K-NET/KiK-net station are computed for 44 pairs. The amplification factors show a large scatter in some cases when using the recorded motions of magnitudes 5.0 or less. Substituting the relative amplification factor for the records of M > 5.0 and the V_S30 at the K-NET or KiK-net stations into the equation, the V_S30 at the JMA stations are estimated. The result indicates that the V_S30 values predicted from the equation developed herein show a good correlation with those estimated from boring log near the corresponding JMA station.

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