AVERAGE SHEAR-WAVE VELOCITY MAPPING USING JAPAN ENGINEERING GEOMORPHOLOGIC CLASSIFICATION MAP

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A mapping of shear-wave velocity for all of Japan is performed using "Japan Engineering Geomorphologic Classification Map (JEGM)" which has been developed as a GIS-based ground condition map. At first, we calculate the average shear-wave velocity in the upper 30m (AVS30), which is a simple and useful predictor for estimating site amplification factors of peak ground velocity (PGV), for approximately 2,000 sites where shear-wave velocity has been measured in all over Japan. Geomorphologic units for all boreholes logging data are interpreted using land-classification maps that are the base paper maps for the JEGM. Next, we examine the correlation between not only geomorphologic units but also geographical information derived from the JEGM and the AVS30 values. The AVS30s show some dependency with elevations, slope angles, and distances from mountains or hills. In order to develop the estimating model of the AVS30, multivariate regression analysis is conducted using these geomorphologic indices. Then, we can achieve to create an AVS30 map with relatively high accuracy for all of Japan using the JEGM.

Key Words: average shear-wave velocity, geomorphologic classification, site amplification, Japan Engineering Geomorphologic Classification Map

1. INTRODUCTION

In preparation for massive earthquakes such as the Tokai, Tonankai and Nankai earthquakes that are expected to occur with high probability in near future, it is essential to compile shake-maps in advance assuming some scenarios of the magnitude and mechanism, etc. of such earthquakes in order to implement effective disaster mitigation measures. For the evaluations, it is necessary to obtain appropriate site characteristics of a wide area across administrative districts.

Accurate evaluation of ground amplification characteristics requires detailed soil profile information such as shear-wave velocity structures. It is pointed out, however, that approximate estimation of ground amplification is possible with the shear-wave velocity of the surface layer¹, and that the amplification of strong ground motion such as peak ground velocity is correlated with the average shear-wave velocity from the surface to a certain depth²³. In the U.S., average shear-wave velocity of ground in the upper 30m (AVS30) is used for soil classification for the seismic code⁴. There is also an attempt to estimate AVS30 at sites with unknown soil profile from microtremors⁵. For a wider area, amplification factor mappings can generally be estimated from surface geology and
Table 1 Criteria for estimating the average shear-wave velocity of ground\(^{19}\)

<table>
<thead>
<tr>
<th>Depth to the 1st layer (m)</th>
<th>-2.0</th>
<th>-5.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-wave velocity of the 1st layer (m/s)</td>
<td>-</td>
<td>&lt; 200</td>
</tr>
<tr>
<td>Depth of the known layer (m)</td>
<td>10.0 - 15.0 -</td>
<td>17.5 - 20.0 -</td>
</tr>
<tr>
<td>S-wave velocity of the deepest layer (m/s)</td>
<td>&gt; 1000</td>
<td>&gt; 500</td>
</tr>
</tbody>
</table>

geomorphologic condition\(^{16-18}\).

For example, Matsuoka and Midorikawa\(^{23}\) developed an empirical formula to estimate AVS30 based on shear-wave velocity data in Kanto district and the Digital National Land Information (DNLI)\(^{39}\). Kubo et al.\(^{10}\) digitized land classification map sets by prefectures\(^{11}\), and compiled a nationwide amplification map, applying the above empirical formula. It is pointed out, however, that the empirical formula based on the shear-wave velocity data and geomorphologic condition of the Kanto district is not directly applicable to other areas\(^{22}\).

Under these backgrounds, Fujimoto and Midorikawa\(^{33}\) recently reconstructed an empirical formula for nationwide ground amplification estimation from geomorphologic classification based on the nationwide shear-wave velocity data and the DNLI to evaluate the site characteristics of any given area in Japan more accurately. However, there is no guarantee that it accurately reflects the geomorphologic condition of the site because they referred to the land classification of the standard grid (approx. 1km square) that includes the site to decide the geomorphologic unit of the shear-wave velocity survey site.

In addition, Wakamatsu et al.\(^{14,15}\) pointed out with regard to the DNLI, on which the empirical formula of Fujimoto and Midorikawa\(^{33}\) is based, that the original maps used different geomorphologic classification systems and different unit names, depending on the prefectures\(^{11}\); thereby they prevent nationwide hazard evaluation related to ground conditions. Accordingly, some of the authors created the "Japan Engineering Geomorphologic Classification Map (JEGM)" based on a new engineering-based geomorphologic classification scheme. The JEGM consists of four attributes of data: geomorphologic classification, surface geology, slope angle, and relative relief. Using this map, the preliminary examination of amplification of strong ground motion was carried out\(^{10}\).

In this study, we compare the nationwide shear-wave velocity data and the geomorphologic units to perform more reliable amplification factor evaluation and to obtain its mapping using the JEGM. While performing such comparisons, we visually interpret the geomorphologic units of the shear-wave velocity data sites as accurately as possible from large-scale land-classification maps that are the base paper maps for the JEGM. We also propose an empirical formula for AVS30 estimation from geomorphologic information included in the JEGM, and develop a nationwide AVS30 distribution map.

2. CALCULATION OF AVERAGE SHEAR-WAVE VELOCITY OF GROUND (AVS30)

Nationwide shear-wave velocity data are currently available from K-NET (approx. 1000 sites) and KiK-net (approx. 500 sites) survey sites [K-data, H-data] of the National Research Institute for Earth Science and Disaster Prevention. We also used data from Yokohama City (150 sites) [Y-data], Kanto area (approx. 540 sites) [M-data], Hanshin area (approx. 70 sites) [F-Data], and major plains and their environs in Japan (650 sites) [T-data]. The total number of bore-hole logging sites is 2906\(^{13}\).

Firstly, average shear-wave velocity in the upper 30m (AVS30) weighted by travel time of shear-wave is calculated for all PS logging data. For this calculation, we apply the criteria of AVS30 calculation of Fujimoto and Midorikawa\(^{33}\). For sites with survey start depths greater than 0m and which satisfy the conditions stipulated in the upper row of Table 1, we assumed that the shear-wave velocity of the 1st layer continues to the surface. For data with depths less than 30m and that satisfy the condition stipulated in the lower row of Table 1, we calculate AVS30 assuming that the bottom layer of shear-wave velocity continues as deep as 30m. As for sites that are recorded with constant shear-wave velocity from surface to the engineering bedrock, such data is excluded because the velocity layer that should exist at the surface seems to be omitted.

These criteria reduce the number of sites that can be used for AVS30 calculation to 1811. For example, AVS30 cannot be calculated at approximately 70 percent of the sites of K-data. Most of these data have shear-wave velocity data for upper 10m; those surveyed as deep as 15m numbered 229, and those surveyed as deep as 20m numbered 201 sites. Accordingly, in order to use as much data as possible for our study, we investigated the validity of the assumptions of extending the bottom layer to 30m depth as to those sites which do not satisfy the conditions shown in the lower row of Table 1.

We extracted the sites which do not satisfy the
conditions of Table 1 for the layers in the upper 20m, and calculated AVS30 by simulation, assuming that the shear-wave velocity of 20m depth continues to 30m depth, and compared it with actual AVS30 in Fig. 1. The coefficient of correlation is as high as 0.97, and they correspond almost one to one, even in rather soft ground, so the above assumption proved to be basically acceptable. Figures 2 and 3 show the results of similar examinations for 15m and 10m layers, respectively. Both have slight dispersions, and the coefficient of correlation is low. Actual AVS30s tend to be slightly larger than simulated AVS30 values, and it is impossible to say that they correspond one to one. Based on these observations, we concluded that we could approximately calculate AVS30 of those sites which have survey depth of less than 30m and do not satisfy the conditions of Table 1, however, which have shear-wave velocity data in the upper 20m. Adoption of this criterion increased the data available for the study to 2028 sites.

3. RELATIONSHIP BETWEEN GEO-MORPHOLOGIC UNITS AND AVS30

(1) Geomorphologic interpretation at shear-wave velocity data sites


The shear-wave velocity data set is archived with the longitude and latitude information of the survey sites. Based on this information, we plotted the location of each shear-wave velocity data on land classification
maps on a scale of 1:50,000 that are the base paper maps for the JEGM and performed geomorphologic interpretation of the site. After geomorphologic judgment, we investigated the thickness of land fill at the sites with soil profile data. The sites with land fill thicker than 5m were excluded, because they hardly express the subsurface ground condition originated from their geomorphologic unit. Sites that cannot be represented by a single geomorphologic unit such as boundary areas of multiple geomorphologic units as well as water bodies were also excluded.

As a result, data that can be used for our study became 1937 sites: 509 K-data sites, 435 H-data sites, 87 Y-data sites, 425 M-data sites, 66 F-data sites, and 415 T-data sites. The map of site locations is shown in Fig. 4. The data number is slightly larger than those used by Fujimoto and Midorikawa. As observed in the previous chapter, this is because it contains a large number of data of rather soft ground areas where AVS30 values are approximately calculated.

Table 2 shows the correspondence of the geomorphologic units interpreted in our study to those extracted by rote from the standard grid cell of the JEGM. As to volcanic hills, terraces covered with volcanic ash soil, dunes, reclaimed lands, and filled lands, the geomorphologic units defined by visual interpretation coincided with more than 80%
of those in the standard grid cell of JEGM. However, seven types of geomorphologic units matched 60% or less. For example, according to data from the JEGM, most of mountain footslopes are misinterpreted as mountains, and as for valley bottom lowlands, about 30% are misinterpreted as mountains or hills, and 20% as terraces. As to natural levees, about 33% sites are misinterpreted as back marshes.

As for most of the geomorphologic unit attributes in the JEGM, the geomorphologic unit that occupies the largest area within a standard grid cell is registered as the representative geomorphologic unit of the grid cell\textsuperscript{14,15}. Table 2, however, suggests that attributes of the grid cell do not always represent the local site conditions when the shear-wave velocity data site is located in a geomorphologic unit of a narrow area. Therefore, the AVS30 and geomorphologic unit data set developed in this research by visual interpretations from a large-scale land classification map are considered to be more reliable than those extracted by rote from the standard grid cell.

(2) Characteristics of AVS30 by each geomorphologic unit

Figure 5 shows the results of investigation on the mean value and standard deviation of AVS30 by geomorphologic unit. As for mountains, we have divided them into Pre-Tertiary (1p) and Tertiary (1t) with reference to the geological map as the influence of its geology is expected. The horizontal axis corresponds to the above geomorphologic unit number, and numbers in a small font on the tops of error bars represent the counts of data. In general, the higher the elevation, the larger the AVS30 value becomes. Mountain footslopes are depositional landforms composed of material sourced from the mountains such as colluvium, talus, landslide, and debris flow deposits, and they are expected to have smaller AVS30 compared with that of mountains. Volcanic footslopes have smaller AVS30 than that of volcanoes. This is because they are topography composed of pyroclastic flow deposits such as ash, scoria, and pumice\textsuperscript{14,15}.

Both gravely terraces and alluvial fans consist of thick gravel layers. However, it is considered that the AVS30 of gravely terraces have become larger because the surface layer of the former consists of Pleistocene (diluvium), while the latter consists of Holocene (alluvium). As for lowland, the values of AVS30 are in the order of valley bottom lowland > alluvial fan > marine sand and gravel bars > natural levee > sand dune > abandoned river channels > delta and coastal lowland > back marsh. This almost corresponds to the grain size of deposits that form each geomorphologic unit (gravel > sand > clay). This trend is regarded as reasonable considering the environment of sedimentation of each geomorphologic unit\textsuperscript{17}.

Figure 6 shows the logarithmic standard deviation with symbol ‘■’ by geomorphologic unit. Dispersion differs depending on the geomorphologic unit: among geomorphologic units with high elevation, hill and volcano have slightly larger dispersion. One of the causes is that most of the earthquake observation stations for K-data and H-data on these geomorphologic units are located in marginal regions of geomorphologic units or boundary areas of valley bottom lowlands that are subject to weathering.
Among geomorphologic units of lowlands, dispersion of the AVS30 of valley bottom lowlands is especially large with its logarithmic standard deviation of about 0.22. Ground conditions of valley bottom lowland of rivers upstream and downstream are different. The former has a very narrow valley width between mountains or hills and has a bedrock that forms a mountain or hill at a shallow depth from the surface, while the latter has very wide valley width and has bedrock deep in the ground. Even in the same geomorphologic units, different depths to bedrocks are considered to be the factors of AVS30 dispersion.

Other geomorphologic units also have some factors for dispersion of AVS30s. For example, gravelly terraces are classified into three categories: so-called river terraces (along a river), coastal terraces, and uplifted alluvial fans. The difference in these formation processes seems to result in the differences in AVS30s. The areal extents of deltas and coastal lowlands range from wide areas formed behind estuaries of big rivers and large-scale sand bars and dunes to very small areas where mountain comes down very close to the coastline. The latter features shallower depth to the bedrock, and it is expected to have larger AVS30. As to back marshes, the thickness of the soft layer is expected to vary from area to area.

Figure 7 shows the comparison of estimated AVS30 (mean value by each geomorphologic unit) and actual AVS30 for the overall data. Estimation accuracy represented by logarithmic standard deviation is 0.150.

4. ESTIMATION OF AVS30 FROM GEOMORPHOLOGIC UNITS AND GEOGRAPHIC CHARACTERISTICS

(1) Geographic indices for AVS30 estimation

As described above, we confirmed that the geomorphologic unit and AVS30 are closely correlated. Within the same geomorphologic unit, there are dispersions of AVS30. Therefore, we take geographic conditions other than the geomorphologic unit into consideration. Precedent studies\(^7\,13\) used elevation and distance from a river as explanatory variables for AVS30 estimation. Since the sediments that form geomorphologic units change from coarse grain in the upstream to fine grains in the downstream\(^7\), they thought that the influence can be represented by elevation. As to the geomorphology formed by flooding, deposits near a river get thicker, and they get thinner as the distance from the river increases. They, therefore, tried to evaluate it in terms of the distance from the river.

In this study, in addition to these indices, the slope angle of the ground, the distance from a coastline, and even the distance from mountain or hill are added to the explanatory variables. The reason why we have included the slope angle is that sediments of alluvial fans, for example, change according to the slope angle of the alluvial fan, and it is known to have influence on liquefaction susceptibility\(^18\). As to valley bottom lowlands, when we focus on its sediments, valleys with steep slope angles formed by debris avalanche usually consist of, in general, boulders, while in valleys with a gentle slope angle, these consist of traction load such as sand and mud.

The sediment type may be estimated from topographic characteristics such as the valley slope angle. For typical lowlands in the Kanto area, there is a correlation between the ground slope and AVS30 values\(^9\). The distance from a coastline and that from a mountain or a hill are expected to be related to the thickness of a sedimentary layer in deltas and coastal lowlands, and to influence the AVS30s of valley bottom lowlands and gravelly terraces along rivers in mountainous regions.

(2) Extraction of geographic indices

Taking location data of shear-wave velocity data sites into consideration, we extracted elevation and slope angle from the JEGM. In the JEGM, the maximum, minimum, and average values, and median of the elevation and slope angle calculated with a 250m digital elevation model are given to each standard grid (approx. 1km square)\(^2\,15\). We employed the median of each value in this study. The unit of elevation is meter. Slope angles represent 1,000 times of tangent.

As to the distance from a river, we calculated the distance from a major river using river channel data.
from the DNLI. The distance from the coastline is also calculated using the coastline location data contained in the DNLI. The unit for these distances is the meter. As to the distance from a mountain or hill, we expect this characteristic to have a correlation with the depth to the bedrock under the sedimentary layer of the geomorphic unit formed during the Quaternary. Therefore, a mountain or hill formed during the older period (Pre-Tertiary or Tertiary) is the subject of our study. As the JEGM contains the surface geology data as described above\textsuperscript{15,15}, we used the distance to the grid cell that has the attribute of a mountain or hill of Pre-Tertiary or Tertiary. The unit is kilometer.

(3) AVS30 estimation by multiple linear regression analyses

We performed multiple linear regression analysis for each geomorphologic unit assuming average shear-wave velocity (AVS30) as a criterion variable, and the values sampled in the previous chapter, e.g. elevation (Ev), slope angle (Sp), distance from a river (Dr), distance from a coastline (Dc), and distance from a mountain or hill of Pre-Tertiary period or Tertiary (Dm) as explanatory variables. With reference to the preceding studies\textsuperscript{7,15}, we employed a linear regression model using a logarithm of each variable as the regression formula. When the value of the explanatory variable is less than 1, we fixed the value as 1.

Firstly, with multiple regression analysis, we confirmed whether there is multi-collinearity or not, and then, from among the variables, select one with a higher correlation. In estimation, we avoided using explanatory variables that have little contribution, and then examined regression equation by the variance analysis (the significance level is 1%). For example, in most of geomorphologic units, there was a high correlation between Ev and Dc. The contribution of Dr was smaller than that of other variables. As the result of analysis by each geomorphologic unit, the number of explanatory variables are reduced to three, Ev, Sp, and Dm, and the following the regression equation was obtained.

$$\log AVS30 = a + b \log Ev + c \log Sp + d \log Dm \pm \sigma$$

where, $a$, $b$, $c$, and $d$ represent regression coefficients, and $\sigma$ is a standard deviation. Table 3 shows the regression coefficients and standard deviation of each geomorphologic unit obtained by regression analysis.

What we can generalize from the regression coefficients is that the higher the elevation, the steeper the slope angle and the shorter the distance from the mountain or hill, AVS30 values become larger. In the mountainous upper reaches of a river (an area at a high elevation with a steep slope), the grain size of deposits is larger and the depth to bedrock is shallower; thus AVS30 becomes larger. The trend of the obtained regression coefficients is considered to be consistent with the sedimentary environment of the geomorphic units.

Table 3 also indicates the standard regression coefficients. According to the table, we can find that the
elevation has a large influence on $AVS30$ in general, and
that at gravelly terraces and valley bottom lowlands,
the distance from a mountain or hill makes rather large
contribution to $AVS30$ estimation.

In the deltas, coastal lowlands and back marshes,
the distance from a mountain or hill also influences the
$AVS30$ value. Conventionally, in these geomorpho-
logic units (especially in the area that includes Kanto
district), $AVS30$ was estimated with the distance from a
river\(^{14,13}\). However, as to the analysis based on the data
set in this research, the distance from the river scarcely
contributed, and instead, the distance from the mountain
or hill served as a characteristic that influences $AVS30$
values. The fact that we uniformly treat the data on a
nationwide basis may also contribute to this result.

Figure 6 shows the logarithmic standard deviation
of $AVS30$ estimated by the regression equation with
the symbol ‘○’. When compared with the results ob-
tained solely from the geomorphologic units (●), use
of a regression equation significantly improved $AVS30$
estimation accuracy for valley bottom lowlands, and
other geomorphologic units also showed smaller disper-
sion.

Figure 8 shows the comparison of estimated and
actual $AVS30$s for the whole data. Estimation by the
regression equation improved the estimation accuracy
by approx. 0.129 in logarithmic standard deviation,
which shows that $AVS30$ can be estimated more ac-
curately than by the existing empirical formula\(^{13}\).

(4) Regionality of AVS30 estimation

Fujimoto and Midorikawa\(^{13}\) point out that $AVS30$
has regionality, and when we divide Japan into three
regions: Northeast Japan, Central Japan, and Southwest
Japan, and apply the empirical formula of Midorikawa
and Matsuoka\(^{7}\), the estimation accuracy of $AVS30$s
for Northeast Japan and Southwest Japan decreases to
0.22 in logarithmic standard deviation. Accordingly,
we studied the applicability of the $AVS30$ estimation
formula obtained in our research for each region.
Classification of regions is the same as that of Fujimoto and
Midorikawa\(^{13}\).

Firstly, before applying the estimation formula, we
calculated $AVS30$ mean values by the geomorphologic
unit for each region. Those geomorphologic units with
higher elevation, such as mountains of Pre-Tertiary,
mountain footslopes, hills and volcanoes showed a
slight difference in $AVS30$ average values. As for
lowlands, $AVS30$ values in Central Japan are generally
smaller than those of other regions, and especially val-
ley bottom lowlands showed larger difference. Other
geomorphologic units showed no significant regionality
as far as the mean values are compared.

Secondly, we calculated the offset (mean value dif-
ference) and estimation accuracy (logarithmic standard
deviation) by each geomorphologic unit for $AVS30$
obtained by the estimation formula developed in the
previous section and actual $AVS30$, and compared them
in each of the three regions. Mean value difference
represents the difference of logarithmic mean of the
estimated value from that of the actual value. Exclud-
ing the geomorphologic units with less data, the value
of the hills in Northeast Japan showed approx. -0.12
(estimated values are smaller than actual values by
30 percent) difference in offsets. However, offsets in
almost all the other geomorphologic units are small,
and almost equal to zero when we see the region as a
whole.

As for the logarithmic standard deviation, hills in
Northeast Japan and Southwest Japan showed relatively
larger, more than 0.18. As Fig. 9 (a)–(c) show the cor-
respondence of estimation values with actual values
in the three regions, standard deviations in the region as a
whole are rather small: 0.136 in Northeast Japan, 0.124
in Central Japan, and 0.130 in Southwest Japan. As we
use the regression formula based on all data set, we can
not deny the fact that regions with larger number of data
have higher estimation accuracy. However, estimation
accuracy obtained by the empirical formula developed
for each region by Fujimoto and Midorikawa\(^{13}\) was
0.15, 0.14, and 0.15 for Northeast Japan, Central Japan,
and Southwest Japan, respectively. Accordingly, the
estimation formula proposed in this study has higher
accuracy.

Thus, we can estimate the features of nationwide
$AVS30$ with relatively high accuracy even with this
empirical formula developed without region classifi-
cation. The possible reasons for this are considered as
follows: 1) geomorphologic classification units follow
the classification criteria which are revised according to nationwide uniform standards, 2) geomorphologic unit interpretation at shear-wave velocity data sites is accurate, 3) explanatory variables such as slope angle and distance from a mountain or hill have been added.

Figure 10 shows, as an example, *AVS30* values of back marshes, deltas and coastal lowlands and their relationship with the distance from a mountain or hill, using different symbols for respective regions. According to this figure, most of the data for Northeast Japan have a smaller distance from a mountain or hill and large *AVS30*. These geomorphologic units for Central Japan, on the contrary, have larger distances and smaller *AVS30*. Data for Southwest Japan are almost in between those of the other two regions. When we see the data as a whole, *AVS30* values tend to decrease as the distance from a mountain or hill increases. Accordingly, by using explanatory variables such as distance from a mountain or hill, *AVS30* values can be generally expressed without regional classification. Similar trend was observed in gravelly terraces, valley bottom lowlands, reclaimed lands and filled lands.

As discussed above, the *AVS30* estimation formula developed in this study does not depend on regional classification, so it does not create problems in its practical application as the *AVS30* values for the same geomorphology do not become discontinuous at regional borders. Therefore, the estimation formula presented in this study is more explicit and rational than existing formulas. Furthermore, by using the JEGM which classifies nationwide ground conditions based on nationally standardized classification criteria, more uniform and homogeneous ground amplification characteristics evaluation becomes possible as compared with existing methods that employ the DNLI [7,8,13].

5. AVS30 MAPPING BASED ON “JAPAN ENGINEERING GEOMORPHOLOGIC CLASSIFICATION MAP”

With the JEGM and the estimation formula developed in the previous chapter, it is possible to create a nationwide *AVS30* map. Elevation (Ev) and slope angle (Sp) are included in the JEGM, and distribution of distances from a mountain or hill of Pre-Tertiary and Tertiary (Dm) can also be calculated from the JEGM. Figure 11 shows the *AVS30* map obtained by using these indices and the regression formula (1), and the coefficients in Table 3. *AVS30* values in major plains are small, while geomorphologic units with higher elevation have larger *AVS30* values. Figure 12 shows the distribution of the ratios of *AVS30* values estimated by this study to those obtained by Fujimoto and Midori-kawa [13].
Fig. 11 Average shear-wave velocity distribution estimated by using the JEGM

Fig. 12 Distribution of average shear-wave velocity ratios
According to the figure, in the most of major plains, the AVS30 obtained by the two results are almost the same. In other plains and circumjacent terraces, AVS30 values estimated in this study are smaller than those of Fujimoto and Midorikawa\textsuperscript{13}, though only locally. In the mountain range, however, AVS30 of this study is slightly larger. Fujimoto and Midorikawa\textsuperscript{13} classified mountains into two categories: 1) the Paleogene and older and 2) the Neogene according to the age of their formation; AVS30 of the former is 550 m/s and that of the latter is 460 m/s. In our research, however, we classified mountains into Pre-Tertiary and Tertiary, and AVS30 of the former is 775 m/s, and that of the latter is 640 m/s.

AVS30 of Pre-Tertiary mountains almost corresponds to the result obtained from the shear-wave velocity data in the U.S.\textsuperscript{20}. This suggests that geomorphologic unit interpretation performed in this study is more accurate. As for mountains and hills, however, most shear-wave velocity survey sites are in locations subject to weathering. In addition, artificial transforming to the topography of hills in metropolitan areas for housing land development has a considerable influence on AVS30. Accordingly, more detailed analysis is required in future.

The ground average shear-wave velocity mapping obtained in this study is based on the standard grid cell of approx. 1km square, and we are now developing more detailed map with 250m grid cells. With the map, we perform geomorphologic unit interpretation and registration for each 250m grid cell, thereby further improving spatial resolution. By employing the empirical formula obtained in this research to this map, it is possible to develop more detailed average shear-wave velocity mapping and amplification distribution estimation.

6. CONCLUSIONS

In this study, we intended to estimate average shear-wave velocity in upper 30m (AVS30) that is closely related to site amplification using "Japan Engineering Geomorphologic Classification Map (JEGM)" that was developed according to engineering-based geomorphologic classification criteria. AVS30s using the nationwide shear-wave velocity survey data were calculated and the relationship between AVS30s and geomorphologic units at survey sites was clarified. At the same time, we made it clear that approximate AVS30 can also be obtained for those sites of which survey depth of shear-wave velocity is less than 30m, by extending the depth range of the shear-wave velocity layer at 20m to 30m.

We also performed accurate geomorphologic interpretation of the survey sites based on the paper maps for the JEGM. As a consequence, a significant difference in AVS30s by the geomorphologic unit was confirmed. Next, multiple linear regression analyses using geographic characteristics, such as elevation, slope angle, distance from a mountain or hill, as explanatory variables were carried out to estimate AVS30. Finally, we demonstrated that nationwide AVS30 mapping by using the JEGM.

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REFERENCES

8) Yamazaki, F., Wakamatsu, K., Onishi, J. and Shabestari, K.T.: Relationship between geomorphological land classification and


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