A STUDY ON CLASSIFICATION OF LANDFORM BASED ON SRTM-3 FOR ESTIMATION OF SITE AMPLIFICATION FACTORS IN METRO MANILA, PHILIPPINES

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ABSTRACT :

Developing countries do not necessarily have to use detailed and precise method in estimating earthquake damage such as Japan. Considering cost and time, it can be more important to choose quick and accurate methods and determine where to input limited resources rather than to estimate detailed earthquake damage. From this point, we proposed landform classification based on Digital Elevation Model and examined validity of proposed method. However, since there was no data such as Digital Elevation Model based on the topography map produced by measurement, applicable regions were limited. Thus, we investigated applicability of SRTM-3 of NASA which covers most overpopulated areas of the earth for landform classification and site amplification factors in Metro Manila, Philippines. The results showed great possibility to be used in areas where earthquake damage estimation has been seldom executed.

KEYWORDS: Digital Elevation Model, SRTM-3, Landform Classification, Site Amplification Factors, Metro Manila

1. INTRODUCTION

For prevention and reduction of natural disaster damage, it is necessary to understand and evaluate the latent vulnerability of the region to disaster and reflect the result in the city planning and fire defense planning of the region and city. Furthermore, when disaster occurs, it is necessary to take countermeasures as quickly as possible using the limited resources to minimize the damage. For that purpose, assessment of the vulnerability to disaster in advance and right after disaster is important.

The method to evaluate seismic hazard using the nationwide Digital National Land Information has been proposed in Japan (Midorikawa and Matsuoka, 1995), and a real-time Earthquake Damage Estimation System has been developed to use the exiting data (for example, the database of census) to take measures before an earthquake occurs and carry out rational and quick emergency measures right after an earthquake (Zama and Hosokawa, 1996, Cabinet Office of Japan, 2001).

Meanwhile, in many developing countries including those in the Asian region, there are many areas where mesh data like the Digital National Land Information available in Japan has hardly been provided and evaluation of earthquake damage is completely impossible. Therefore, Jeong et al.(2003, 2004, 2005) has proposed a landform classification method that uses Digital Elevation Model (hereinafter referred to as DEM) and classified the landforms of Yokohama and Seoul in Korea, development an Earthquake Damage Estimation System of Seoul, Korea based on the result. However, the application of the DEM, which is the basis for landform classification made by digitizing a high-resolution topography map based on a survey, to developing countries will take time and cost, and it is desirable to use a global-scale DEM, if possible.

Jeong et al. (2006) classified the landform of Yokosuka City, using the NASA data (SRTM-3) and confirmed that the landform peculiar to Yokosuka, Japan can be represented. Since the topographic environment may differ according to the region, the applicability to the area in question must be examined before actually applying this

method.
In order to obtain the landform necessary for earthquake disaster evaluation in developing countries, the area around Manila, Philippines was selected in this study to classify the landform using SRTM-3. Furthermore, an attempt was made to estimate the site amplification factors for Peak Ground Velocity based on the result of classification and compare the result with the existing PS logging data in order to verify the effectiveness and possibility of landform classification using SRTM-3.

2. SRTM-3

For estimation of the site amplification, the elevation model of SRTM-3 (Shuttle Radar Topographic Mission) (hereinafter referred to as "SRTM-3") of NASA (National Aeronautics and Space Administration) was used in this study.
In the international project to gather topographic (elevation) data of Earth's surface using a space shuttle, SRTM-3 was obtained by synthetic aperture radar (SIRC/X-SAR) mounted on a space shuttle (Endeavor), covering 80% of all land (+/- 60 degrees latitude) except the two poles of the earth. The DEM was obtained by the interferometric SAR. Since the interferometric SAR can function irrespective of the existence of clouds, it is effective for humid climate zones where photographing with an optical sensor is difficult and areas for which no DEM has been provided. SRTM-1 (1 arc second; approx. 30 m; U.S. only) and SRTM-3 (3 arc second; approx. 90 m) have been release to public at present. However, because of the following features, attention is necessary when they are used for analysis.

(1) Data is missing in areas where the elevation model cannot be obtained because of interference processing.
(2) Fine irregularity has been produced because of the influence of water, and such phenomenon is outstanding especially in damp areas.
(3) Since tree crowns and buildings are included, the model is not a DEM but a DSM (Digital Surface Model).

3. HEIGHT ERROR OF SRTM-3

The landform classification method is dependent on the elevation such as the slope and the difference in elevation from a river. Therefore, the accuracy will increase when the height error is smaller.
NASA reported that the absolute height error in SRTM-3 is approx. 16 m. However, the error differs slightly according to the continent, method of comparison, and the nature of data to be compared.
Therefore, we took a taxi to drive around Manila to record the elevation using the GPS and observed the condition of the area. Figure 1 shows the survey rout. The area is flat with little difference in elevation, and we compared the elevation of the area near the fault cliff (A-A' in Fig.1), which was known in advance during the previous examination, with that in SRTM-3 (Fig.2). The maximum difference in elevation is approx. 20 m, and we judged that SRTM-3 would permit sufficient landform classification. Since the elevation shown by the GPS is the elevation on a road, the maximum difference is approx. 12 m when the height of roads and bridges is taken into consideration.

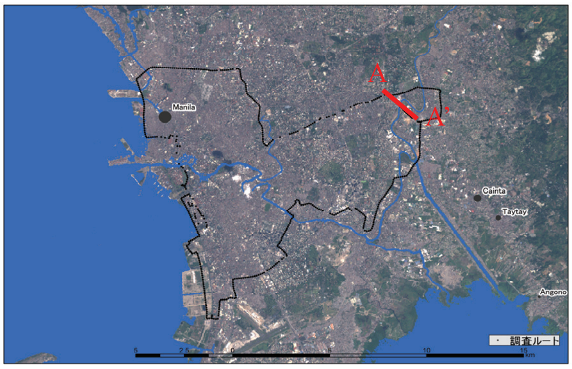

Fig.1 Analysis area of landform classification and route of field survey in Metro Manila, Philippines

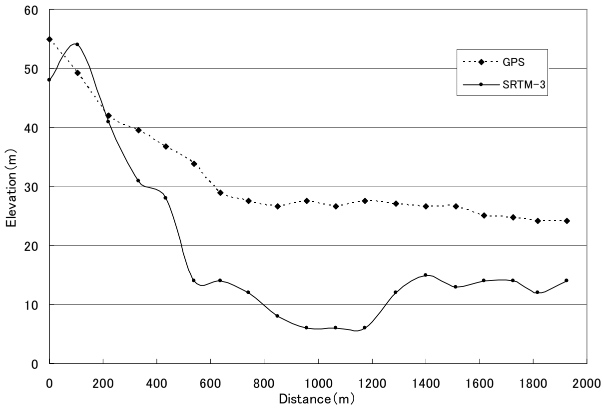

Fig.2 Comparison between GPS and SRTM-3(A-A')

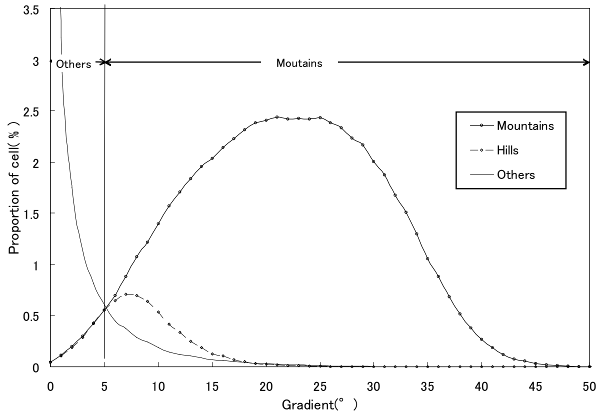

Fig. 3 Distribution of gradient of 7.5-Arc-Second Japan Engineering Geomorphologic Classification Map in Niigata

4. LANDFORM CLASSIFICATION USING SRTM-3

Based on the landform classification method using a DEM, which was proposed by jeong et al. (2003, 2004), the landform of Manila was classified with the help of SRTM-3. As compared with the classification in Yokohama City, for which the "50 m-mesh digital elevation model" of the Geographical Survey Institute and the DEM examined in Seoul City using a digital map, SRTM-3 has larger height errors. For example, classification of a delta that is a kind of geomorphology is difficult. Therefore, the number of categories of landforms has been reduced to six – Mountain, Plateau, Lowland (including a valley plain), Back marsh, Reclaimed land, and Natural levee.

A simple summary of the classification process is shown below.

(1) The elevation of the sea level was regarded as 0 m uniformly, and the elevation below 0 m in the area adjacent to the sea level and the onshore part of a damp area is regarded as 0.1 m uniformly. In order to remove the noise, a median filter with a 3 × 3 moving window was used. The median filter is usually used to eliminate the spike noise from an image, and it can round or fill isolated cells and holes that are called pits and peaks when applied to SRTM-3.

(2) The landform can be roughly divided into mountains and plains. The mountain includes mountains (including volcanoes) and hills, while plateaus and lowlands are included in plains (Suzuki, 1997). These are considered to be replaced by sloping lands (mountains) and flat lands (plains), and the angle of inclination of each cell with respect to the adjacent cell was calculated and the maximum value was used to judge whether the surface of the ground was flat or not. The surface of the ground can be classified into flat surfaces, gentle slopes, cliffs, and overhanging cliffs according to the angle of inclination. However, the boundary angles between these differ according to researchers and the field of study (Suzuki, 1997). The criterion for judging whether the area is flat or not is considered to be 5 degrees, and the sloping ground of 5 degrees or more is regarded as a mountain, while the area with the angle of inclination of less than 5 degrees is regarded as a flat land in this study, because the angle of inclination of an alluvial fan that is a micro highland on a lowland is 3 degrees or more, there are some studies that regards the standard for the difference between the gentle and steep slopes as 5 degrees, and the area can be classified into mountains and flat areas other than mountains using approx. 5 degrees as the standard as shown in Fig.3, which shows the ratio of the areas with the angle of inclination calculated on the basis of the 50 m elevation data to the mountains and flat areas other than mountains shown in the 7.5-Arc-Second Japan Engineering Geomorphologic Classification Map on the Niigata area prepared by Wakamatsu et al..

(3) The areas classified as flat surfaces other than mountains in (2) includes plateaus, natural levees, lowlands, and plains on the valley bottom plain. These areas are roughly divided into plateaus and lowlands including back marshes and natural levees, and the difference between plateaus and lowlands is the relative height with respect to the river. The lowland is almost flush with the river that flows over there (the difference in elevation is less than several meters), and the landform is created by the influence of the river. Plateaus are one step higher than the river flowing around them or the lowland, and they are not affected by the river although they have a gentle slope. In this study, areas where the slope is 2-5 degrees and the absolute difference in elevation with respect to a

river that is geometrically nearest is 4 m or more are classified as plateaus, while the others are classified as lowlands. The river mentioned here is not an actual river, but an imaginary river created by using STRM-3.
(4) Furthermore, the lowlands extracted in (3) include natural levees and reclaimed lands. Banks and back marshes that are the flooding sources, as well as lowlands on the valley bottom plain, are also included. Natural levees are micro highlands with a flat peak extending like a band on both sides or one side along the river, and the difference in elevation with respect to the ordinary water level is from more than ten meters to several tens of meters. Areas with the absolute difference in elevation of 2 m to 4 m with respect to the geometrically nearest river are classified as natural levees in this study, and the other landform units are classified as plains on the floor of a valley. Furthermore, areas with no absolute difference in elevation (1 m or less) with respect to the river are classified as back marshes.
(5) The back marshes extracted in (4) include reclaimed lands. Reclaimed lands cause a liquefaction phenomenon when an earthquake occurs, and they are classified as artificially created lands from a geomorphologcal point of view. Lowlands with the elevation of 3 m or less and the lowlands that are within 2 m from the sea geometrically are classified as reclaimed lands.

5. RESULT OF LANDFORM CLASSIFICATION

Figure 4 shows the result of landform classification of Metro Manila, Philippines based on the proposed method. The overall trends are similar to the existing landform classification map shown in Fig.5 (Matsuda et al., 2001). When examined individually, the valley bottom plains in the coastal lowland (section A in Fig.5) that is a flat land with almost no difference in elevation and the central plateau (section B in Fig.5) are not represented in the existing landform classification map, but fine results are represented in the landform classification using SRTM-3, showing the same result as the field survey. It has been understood that the boundary between a plateau and low land is similar to that shown in the existing landform classification map. However, there is still room for improvement, because the plateau in the upper right part of Fig.5 has been classified as lowland.

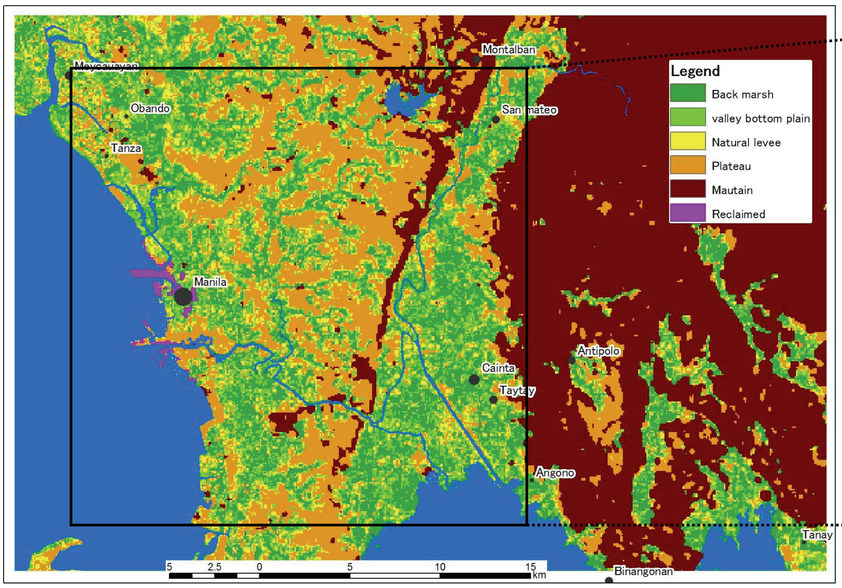

Fig.4 Result of landform classification based on SRTM-3

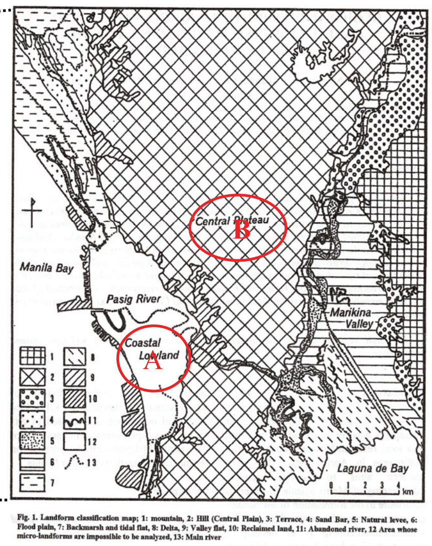

Fig.5 Existing landform classification map

6. ESTIMATION OF SITE AMPLIFICATION FACTORS OF PEAK GROUND VELOCITY BASED ON THE RESULT OF CLASSIFICATION

In order to verify that the result of landform classification by the proposed method is effective for estimation of the earthquake damage, we tried to apply to the estimation site amplification factors of PGV. According to Midorikawa and Matsuoka (1995), the site amplification factors of PGV (R) can be obtained from the equation below.

$$\log Vs = a + b\log h + c\log D \pm \sigma \quad (1)$$
$$\log R = 1.98 - 0.711\log Vs \quad (2)$$

"Vs" is the mean velocity of the S wave in the ground up to the depth of 30 m, "h" and "D" are the elevation and the distance (km) from the major river, respectively, and "a," "b," and "c" are the coefficients of landform. Since there are no coefficients of landform in Philippines, the coefficients by Midorikawa and Matsuoka (1995) were used first. "σ" is the standard deviation of each type of landform. Table 1 shows the coefficients of respective types of landform.

Table1 Coefficients in the regression equation (1)

Landform	a	b	c	σ
Mountain	2.64	0.00	0.00	0.17
Plateau	2.00	0.28	0.00	0.11
Valley plain	2.07	0.15	0.00	0.12
Back marsh	2.19	0.00	0.00	0.12
Natural levee	1.94	0.32	0.00	0.13
Reclaimed land	2.23	0.00	0.00	0.14

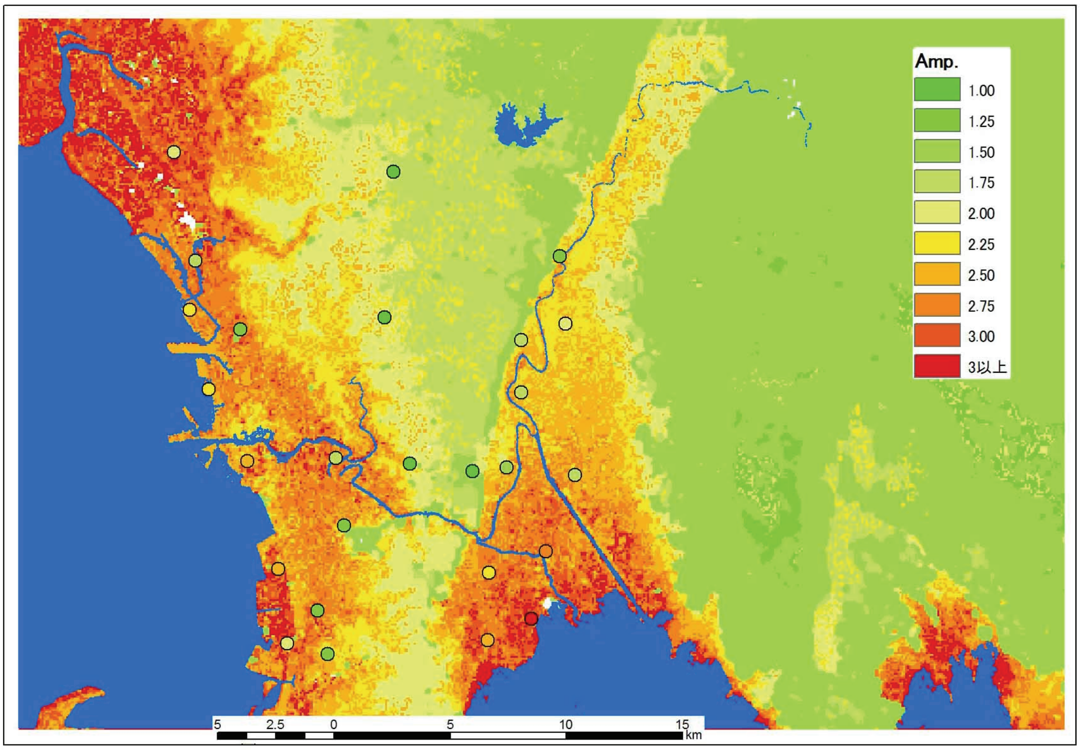

Fig.6 Distribution of site amplification factors and PS logging data

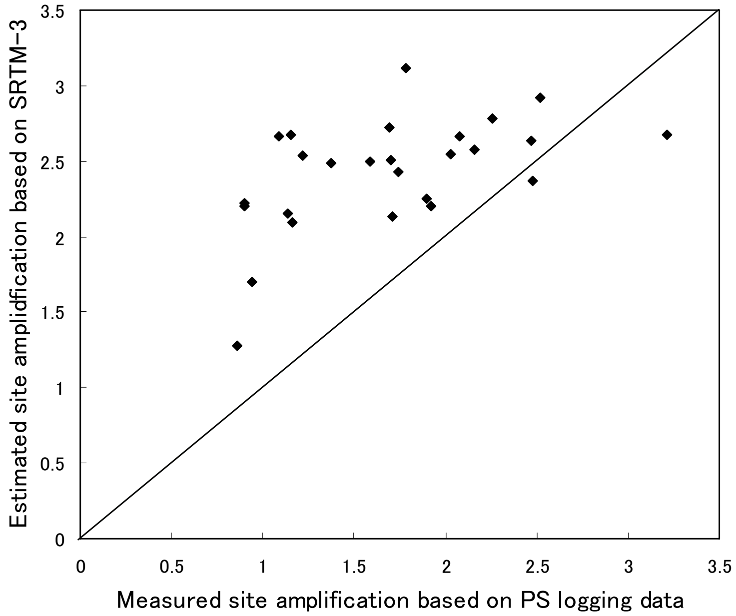

Fig.7 Comparison between measured and estimated site amplification factor

Figure 6 shows the estimated site amplification factors of PGV, which is a tentative solution.
For comparison with the result of actual ground survey, the PS logging data prepared by JICA were collected. PS logging was conducted at 31 points in Metro Manila, including five points that have not been covered by the current study. Using these data, the measured site amplification factors of PGV by the ground up to the depth of 30 m was assessed by equation (2).
Figure 7 compares estimated site amplification factors with measured site amplification factors obtained by the ground survey. The estimated site amplification factors in this study are greater as a whole, because the empirical equation and coefficients used in Japan were used and the basement rock in and around Manila are shallow. The resent study points out that the difference is double in different areas although the landform is identical. Therefore, the coefficients of empirical equation must be selected carefully for each landform unit.
Based on the above, SRTM-3 and the method proposed by the authors are considered to provide fundamental data for regional planning also in the developing countries in Asia and other regions of the world, where preparation of fundamental data has been delayed and earthquake damage has hardly been estimated.

7. CONCLUSIONS

When the way that earthquake damage estimation should be in developing countries is to be examined, high-resolution detailed earthquake damage estimation adopted in Japan may not be necessary is a sense. In consideration of the cost, it is necessary to take damage estimation measures with certain accuracy at an early stage and select appropriate areas where the limited resources should be input selectively.
From such a point of view, this study shows that the application of the SRTM-3 that covers almost all areas on the earth and the landform classification method based on DEM, which has been proposed by the authors, will permit estimation of spatially detailed site amplification factors.
We will verify the accuracy of the obtained site amplification factors and confirm the usefulness of the method proposed in this study through case studies in more countries and regions, because the landform environment differs from region to region.

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