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SEISMIC ZONING FOR GROUND MOTION IN TOKYO BASED ON NATION-WIDE ELECTRIC GEOTECHNICAL DATABASE SYSTEM

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ABSTRACT

Representative soil profile models in Tokyo were estimated by Nation-wide Electronic Geotechnical Database System (NEGDS) based on a lot of existing boring data. The soil profile model was presented in the grids of 250 m by 250 m. Estimated area was 20 km by 12 km. Complex topographical boundaries between terraces and lowlands or valley plains are existed in this area. In the valley plains, damage to houses and buried pipes was severe during the 1923 Kanto earthquake. So, seismic response analyses were carried out to demonstrate the distribution of surface acceleration and velocity. The analyses showed large amplification occurs in the valley plains.

Keywords: Geotechnical database, Soil profile, Seismic zoning, Seismic response,

INTRODUCTION

Nation-wide Electronic Geotechnical Database System (NEGDS) has been studied in Japan from 2006 to develop representative soil profile models with a grid size of 250 m by 250 m within a depth of 100 m. The system can provide geotechnical information for engineers, researches and others. Moreover representative soil profile model (RSPM) is free from ownership of the data and copy rights. The NEGDS has been applied to Osaka, Fukuoka, Sapporo, Matsuyama and Niigata Cities to check usability and applicability of the software. In addition the authors applied the NEGDS to Tokyo. The area of 20 km by 12 km was selected to develop RSPM in the central Tokyo. Complex topographical boundaries between terraces and lowlands or valley plains are existed in this area. A lot of houses and water pipes were reported to have damage near the complex boundary or in the valley plains during the 1923 Kanto earthquake. Then the authors conducted seismic response analyses by using the RSPM and compared with the actual damage.

METHOD TO DEVELOP NATION-WIDE ELECTRIC GEOTECHNICAL DATABASE SYSTEM

In 2006, a 5-year, nation wide, inter-agency project called “Integrated Geophysical and Geological Information Database,” was started, led by National Research Institute for Earth Science and Disaster Prevention (NIED), with the participation of the National Institute of Advanced Industrial Science and

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Technology (AIST), the Public Works Research Institute (PWRI), University of Tokyo, Tokyo Institute of Technology, and the Japanese Geotechnical Society (JGS) (Fujiwara et al., 2009) in Japan. Recently, digital geotechnical databases with digital maps have been developed at various organizations in Japan as shown in Figure 1. The scheme undertaken by the JGS is to link the existing geotechnical databases. Then a technical committee called set up by the JGS in 2006 and proposed to build 'Nation-wide Electronic Geotechnical Database System (NEGDS)' as a tool to link the existing geotechnical databases

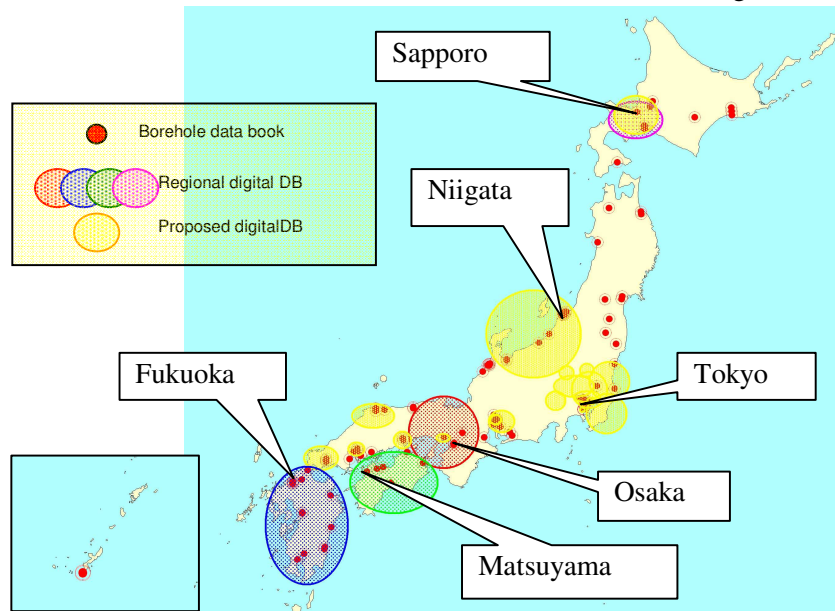


Figure 1. Areas where digital databases have been developed and NEGDS is applied

throughout Japan (Todo and Mimura, 2009, Mimura and Yamamoto, 2009, Yasuda et al. 2010). The system is essentially a collection of ground models with each size of 250 m by 250 m in plan and free from ownership of the data, copy rights, and disclosure of information on private properties. At least the following information have to be provided for each 250 m mesh; the location of the 250 m mesh (latitude and longitude), ground elevation, soil layers, SPT *N*-values, groundwater levels and the depth to bed rocks. Soil types used are, for the time being, the following 7 types: gravelly soil, sandy soil, clayey soil, organic soil, volcanic clay, peat, and artificial material.

Figure 2 shows a computer screen during the construction of a representative soil profile model (RSPM). Procedure to construct a RSPM is as follows:

- (1) A mesh to construct the model is selected. A standard 250 m mesh map published by the Geographic Survey Institute of Japan is used.
- (2) Place digital boring data in the mesh. If it is necessary, boring data in the neighbor meshes are placed also. However, inappropriate data are deleted by considering topography and geology. Then depth of the bedrock in engineering purpose is judged in each boring.
- (3) The RSPM by averaging soil type, SPT *N*-value and groundwater level is constructed automatically. The RSPM is constructed up to the depth of the bedrock.

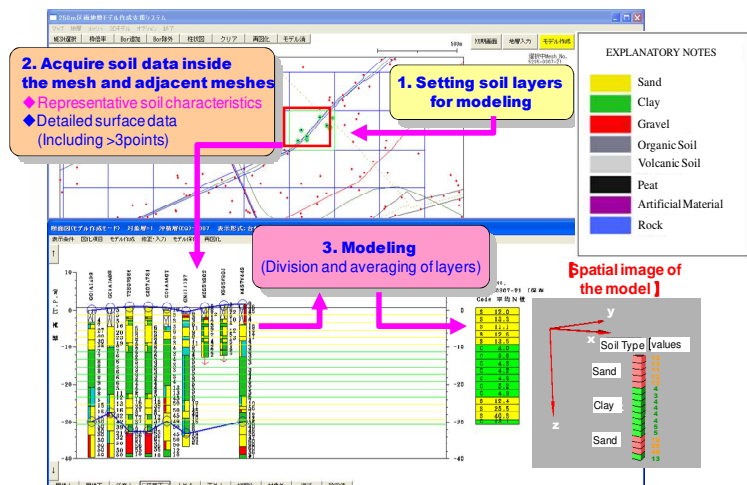


Figure 2. Operating window of the supporting system to develop representative

It is noted that the RSPM is not made by selecting one borehole inside the area. Rather, the RSPM is made in consideration of surrounding ground conditions. The RSPM thus represents average ground conditions in the area, not the ground condition at the center of the area. And, although a model may be constructed automatically, judgments based on the knowledge of local geology and soil conditions should be exercised.

In order to check usability and applicability of the software, a series of trials have been conducted at various ground conditions. This trial is necessary because the prototype software was developed for a typical ground of the Osaka Plain where a relatively large plain is developed with almost uniformly distributed thick Holocene deposits. The software has been modified and upgraded based on the trials. Selected areas for the trials are Osaka, Fukuoka, Sapporo, Matsuyama, Niigata and Tokyo as shown in Figure 1.

CONSTRUCTION OF REPRESENTATIVE SOIL PROFILE MODELS IN TOKYO

Tokyo is divided into four areas in geomorphologic condition from west to east: mountain, hill, terrace and lowland areas. The lowland area is subdivided into four zones: a wide alluvial lowland formed by Sumida River, Ara River, Naka River and Edo River, a narrow lowland formed by Tama River, a beach along Tokyo Bay and artificially reclaimed lands constructed along Tokyo Bay. In the central Tokyo, the lowland, hill and reclaimed land are existed as shown in Figure 3. Tokyo Station is the boundary of the terrace and the large lowland area. In lowland area, an alluvial loose sand layer, Yu, is deposited from ground surface to the depth of about 10 m. An alluvial soft clay layer, Y1, is underlying with a thickness of about 20 to 40 m. Then Pleistocene loam and gravel layers are deposited. On the contrary, Pleistocene volcanic ash named Kanto Loam is deposited from the ground surface to the depth of about 10 to 30 m in terrace. Comparatively dense Pleistocene clay is underlying. Many narrow valley plains are formed in the terrace by eroding the Kanto Loam and the Pleistocene clay. Very soft clay including peat is deposited in the valley plains.

Topographical condition in the center of Tokyo is very complex as mentioned above. Then the authors dared to select the complex area to construct representative soil profile models. Digital boring data used was provided by Tokyo Metropolitan Government. Total number of boring data used was 34,127 in this area. Figure 4 shows the histogram of numbers of boring data in each mesh. The maximum number was 68 and predominant number was 1 to 7. In the construction of RSPM the following attentions were paid:

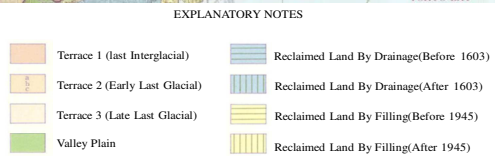
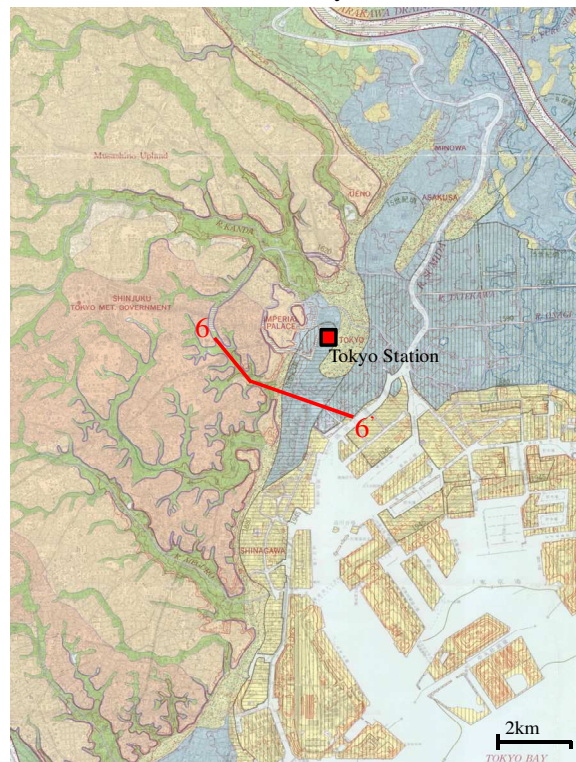


Figure 3. Geomorphological map in the central Tokyo (Kubo, 1993)

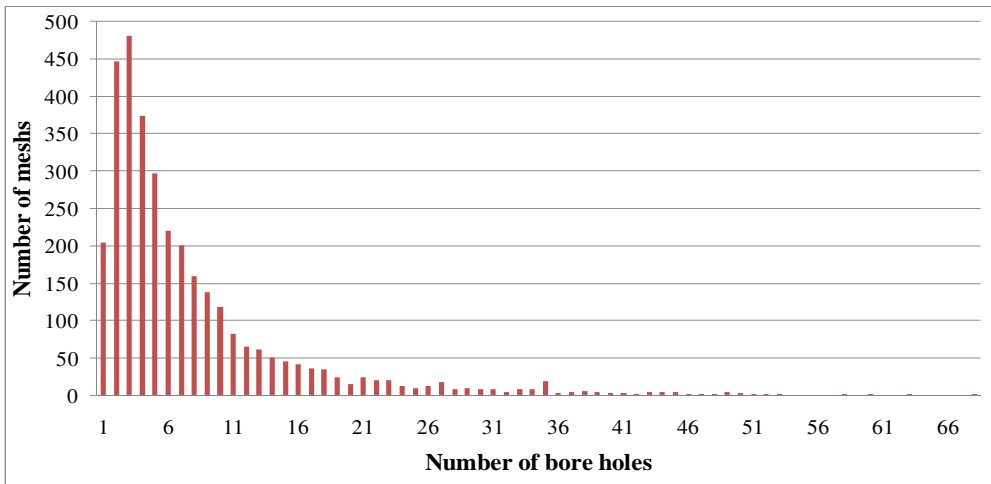


Figure 4. Histogram of numbers of bore holes data in each mesh

- (1) Depth of bedrock was judged from SPT *N*-value. If the SPT *N*-value of a layer is greater than 50, the layer was judged as the bedrock in engineering purpose.
- (2) If more than two geomorphologies are existed in a mesh, the boring data inside the predominant geomorphology only were selected to construct RSPM. Figure 5 shows an example at Moto-Azabu. Two topographies; terrace and valley plain, are existed in the mesh. RSPM “A” in the figure was constructed by averaging all data in the mesh. On the contrary, RSPM “B” and “C” were constructed by averaging the data in hill or valley plain, respectively. These models are quite different. As the area of terrace is wider than the area of valley plain in this mesh, RSPM “B” was selected.

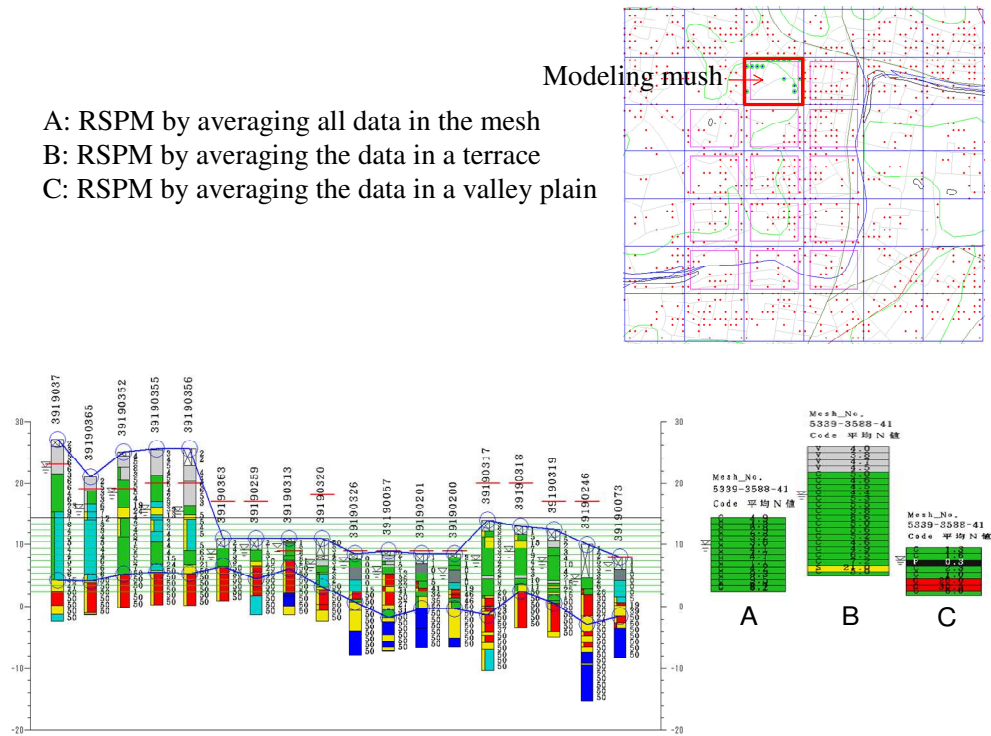


Figure 5. Three soil profile models at Moto-Azabu where a terrace and a valley plain are existed

(3) Most recent earthquake which brought severe damage to Tokyo was the 1923 Kanto earthquake. According to literature survey, severe damage to houses and water pipes occurred in or boundary of valley plains as shown in Figure 6 (Yasuda et al, 1993). Several researches suggest very soft peat is deposited at the mouth of the valley plains. And the peat deposits locally. Actually, a detailed soil investigation conducted recently in a valley plain revealed remarkable soil characteristic of the peat (Yasuda et al, 2010). Water content, rate of organic, shear modulus in small strain were 300 to 500 %, 68.4 % and 2.0 to 2.4 MN/m², respectively. Therefore, in valley plain, boring data must be selected carefully not to neglect the peat in RSPM. Figure 7 shows an example in a valley plain at Moto-Azabu. RSPM “M₁” in the figure was constructed without pay attention to the peat. Though peat layers are deposited as shown in several soil profiles, the peat layer was not appeared in the simple RSPM. Then, the mesh was subdivided into four sub-meshes and constructed four sub-models “A” to “D”. A peat layer was appeared in “A” and “B”, however, thickness of the layer was only 1 m. Then, the boring data which have peat layers were selected and RSPM was constructed as shown “M₂”. Thickness of the peat layer became 2 m in this case. Then, “M₂” was selected as the RSPM in this mesh.

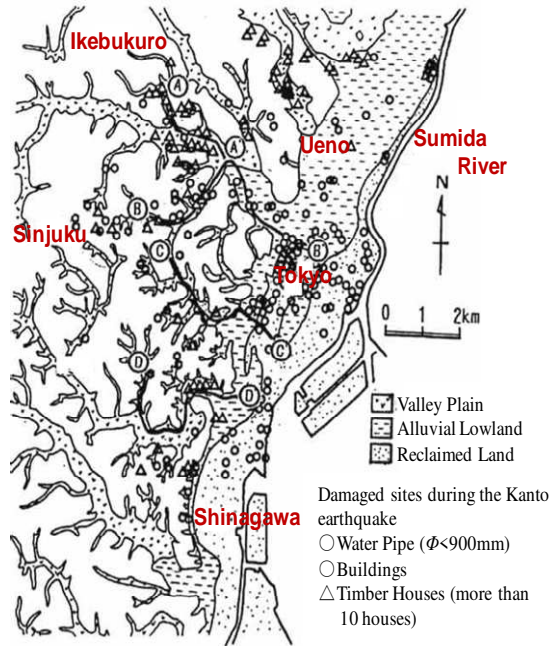


Figure 6. Geomorphological map and damaged sites of water pipes, buildings and houses during the 1923 Kanto earthquake

M₁: RSPM without pay attention to peat
 M₂: RSPM by selected boring data with peat
 A~D: RSPM of subdivided meshes

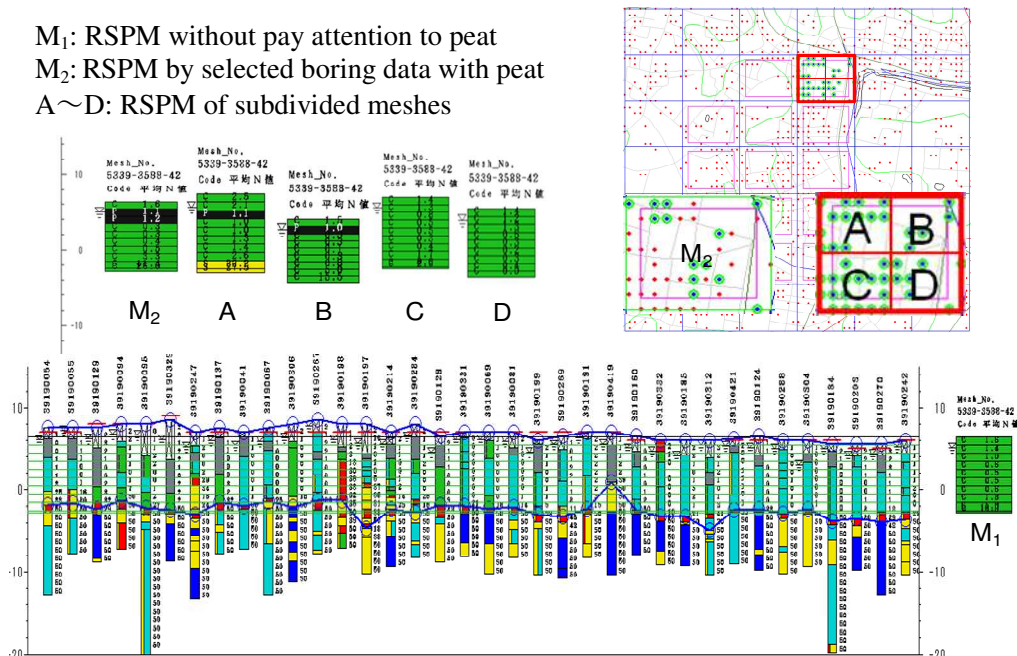


Figure 7. Several methods to construct a representative soil profile models in a valley plain at Moto-Azabu

Figure 8 shows a series of RSPM along 6-6' line. The soil profile at the most west side, No.1 in the figure shows a RSPM at in terrace where Pleistocene clay is deposited from ground surface to GL-6 m. Next seven profiles, No.2 to No.8 show RSPM in a valley plain, named Akasaka and Tameike where many offices and shops are existed. A very soft and thick clay layer is deposited from ground surface to about GL-15 m to GL-20 m. A peat layer with 3 m thick is sand witched in the clay layer. Many subways and lifelines have been constructed in the soft clay. At Toranomom (No.9 to No.10), which are the mouth of the valley plain, medium dense sand layers are deposited. However, a very soft and thick clay layer is deposited again at Hibiya (No.11). Then, loose to medium dense sand is deposited at Ginza (No.12 to No.15) which is near Tokyo Station and the most famous shopping area in Japan. East end of this line is Tsukiji (No.16) which faces to Tokyo Bay. An alluvial loose sand layer is deposited from ground surface to GL-6 m. Very soft clay layer is underling.

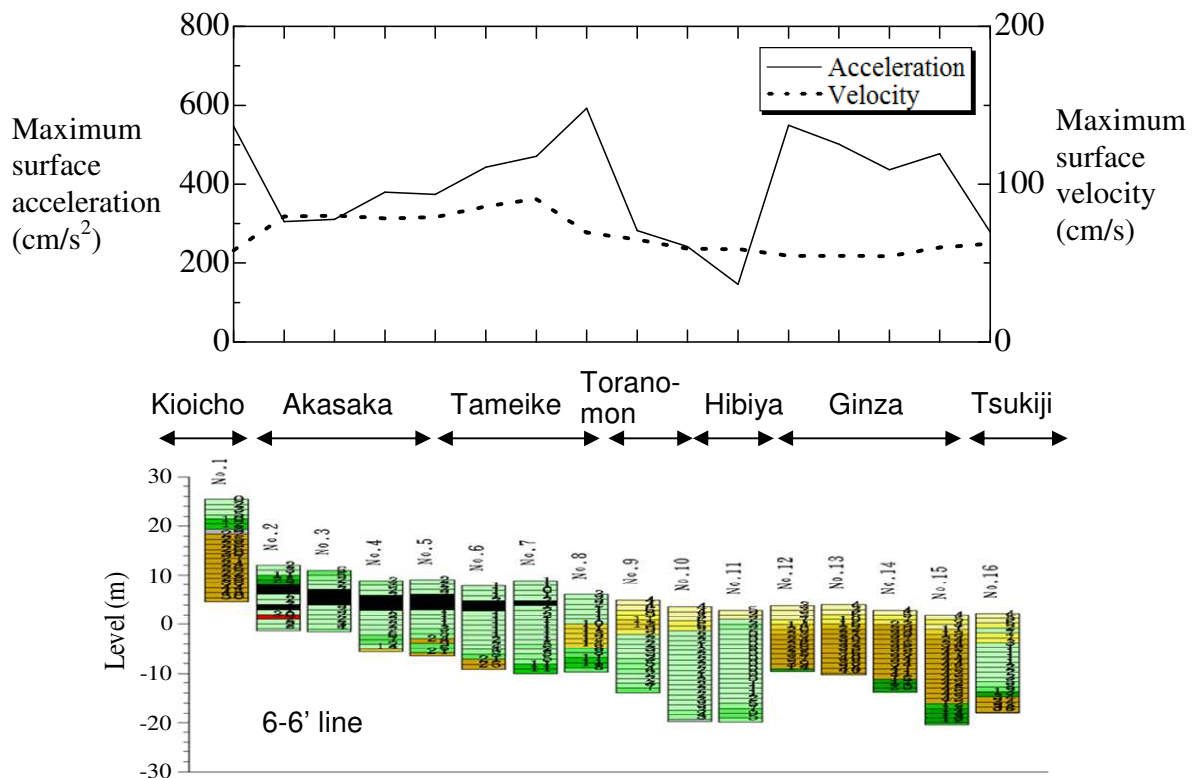


Figure 8. Representative soil profile models along 6-6' line

SEISMIC RESPONSE ANALYSES BY USING THE RSPM IN TOKYO

One dimensional seismic response analysis by the computer program “SHAKE” was carried out to demonstrate the usefulness of the RSPM. Seismic wave “Rinkai92” which was proposed by The Japan Building Disaster Prevention Association (1992) was selected for the analysis. Input soil data for the analysis are shown in Table 1. The shear modulus in small strain, G_0 , and the $G/G_0 - \gamma$ and the $h - \gamma$ relationships for peat and soft clay in valley plains were derived from cyclic torsional tests for the undisturbed sample taken at a valley plain in Tokyo (Yasuda et al, 2010). The G_0 for the peat was very small as 2.2 MN/m^2 . In other soils, shear wave velocity, V_s was estimated from SPT N -values by the relationship introduced in the Specification of Highway Bridge in Japan (Japan Road Association, 1996). The $G/G_0 - \gamma$ and the $h - \gamma$ relationships for other soils were estimated based on mean diameter, D_{50} and effective overburden pressure by the relationship proposed by Yasuda and Yamaguchi (1985). The G_0 of bedrock was decided as 350 m/s .

Table 1 Input soil data for the analysis

	Lowland		Hill or Terrace		Valley plain	
	γ_t (kN/m ³)	D_{50} (mm)	γ_t (kN/m ³)	D_{50} (mm)	γ_t (kN/m ³)	D_{50} (mm)
Gravelly soil	0.35	0.35	20	0.3	20	0.3
Sandy soil	0.15	0.15	19	0.2	18	0.15
Clayey soil	0.02	0.02	15	0.04	14.1	-
Organic soil	0.02	0.02	12.3	0.02	12.3	-
Volcanic soil	0.04	0.04	14	0.04	14	0.04
Peat	0.02	0.02	12.3	0.02	12.3	-
Artificial soil	0.15	0.15	18	0.15	18	0.15

Figure 9 and 10 show the distributions of the analyzed maximum surface acceleration, A_{\max} and maximum surface velocity, V_{\max} in the studied area, respectively. The A_{\max} varied from 200 cm/s^2 to 900 cm/s^2 . And the V_{\max} varied from 40 cm/s to 110 cm/s . By comparing with the geomorphology shown in Figure 3, the following relationships can be found:

- (1) In alluvial lowland, both A_{\max} and V_{\max} are small.
- (2) In terrace, both A_{\max} and V_{\max} are small.
- (3) Both A_{\max} and V_{\max} are large in valley plain.

The distributions of A_{\max} and V_{\max} along the 6-6' line are shown on the upper diagram in Figure 8. The A_{\max} at Tameike and Ginza are the largest and the A_{\max} at Hibiya is the smallest. The V_{\max} at Tameike is the largest also. However, the V_{\max} at Ginza is the smallest. As both A_{\max} and V_{\max} are large at Tameike where is a valley plain, it must be necessary to concern the damage to many structures during future earthquakes.

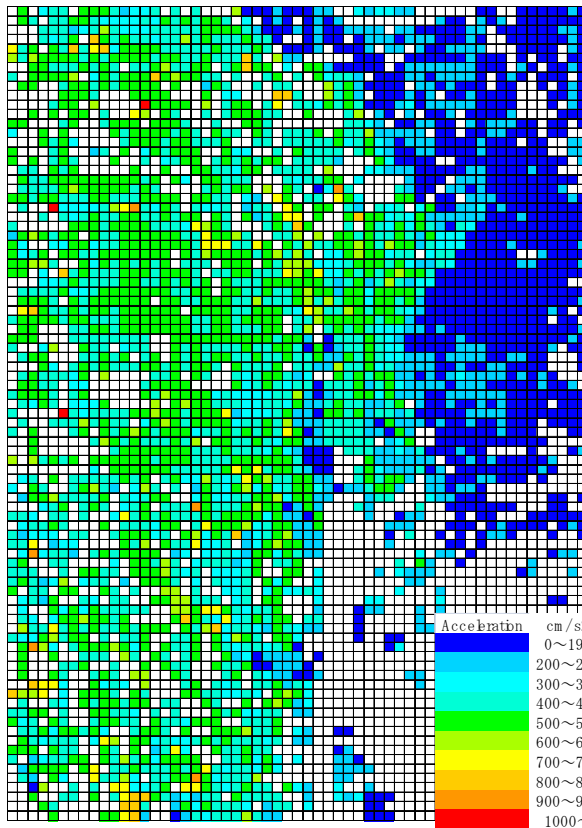


Figure 9. The distributions of the analyzed maximum surface acceleration

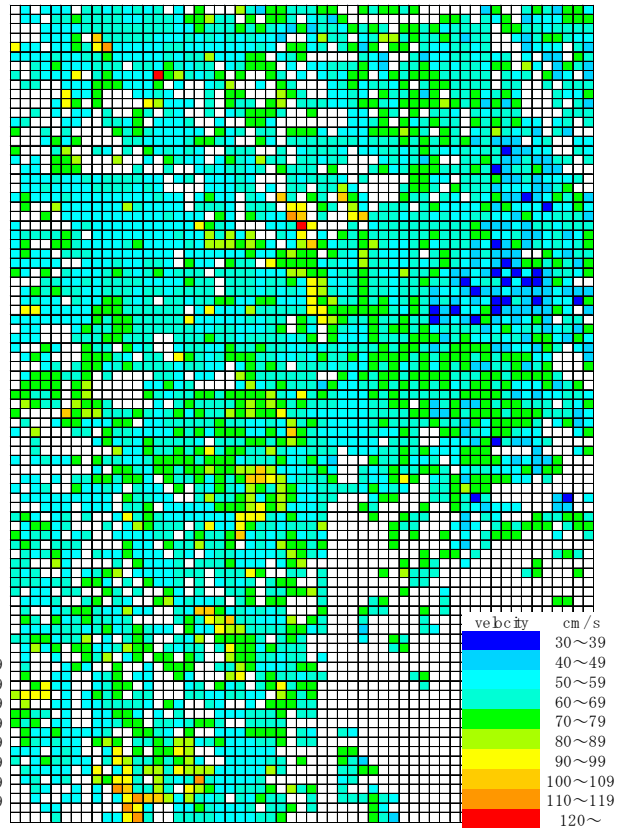


Figure 10. The distributions of the analyzed maximum surface velocity

CONCLUSIONS

The study on the Nation-wide Electronic Geotechnical Database System (NEGDS) in Japan is introduced at first. The study started in 2006 and application of the system to several cities has been conducted to check usability and applicability of the software. Application to Tokyo has just finished and introduced in this paper. According to the representative soil profile models, complex soil conditions in Tokyo can be presented. Seismic response analyses were conducted based on the RSPM. Amplification at various sites could be analyzed. And it was found that both A_{\max} and V_{\max} are large in valley plain.

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