DEVELOPMENT OF AN INTEGRATED GEOPHYSICAL AND GEOLOGICAL INFORMATION DATABASE FOR STRONG-MOTION EVALUATION

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ABSTRACT :

We develop an integrated geophysical and geological information database of the whole of Japan for strong-motion evaluation. Once simulation of strong-motion concerned, we need a seismic velocity-structure with an attenuation model to evaluate strong-motions. In order to model velocity-structure for strong-motion evaluation, we have to consider a deep underground structure down to the earth crust, or to the plate boundary, up to a seismic bedrock, then to a structure of an engineering bedrock layer, and final to a structure of surface layers. In our study, we use various available data in all of Japan and build a database by integrating such information. Standardizing and integrating different kinds of data such as geological data and physical value data, we develop the dispersion-managed type network system to open each database distributed to each organization and utilize them each other. In order that many organizations can join the database, cutting the cost of installation, operation and maintenance fee of the system and securing mutual exploitation of data are desired. The management system on sharing databases is developed by the following concepts. i) Some open source software is adopted to cut the initial cost. ii) One organization runs a portal site, and others are responsible only for their own database. iii) Adopting the world standard, this system is more compatible with others or GIS software.

KEYWORDS: velocity-structure, integrated database, management on sharing, strong-motion

1. INTRODUCTION

Information on underground structure should be shared with the public. In particular, geophysical and geological information on ground structure from the surface layers to the deep layers utilized for evaluating strong seismic motion is essential for earthquake disaster prevention. Many organizations have conducted a number of surveys on underground structure for various purposes, but much of the data has ended up in dead storage or is scattered in different organizations. At present, we do not have a nationwide database on its underground structure in Japan. It is therefore an urgent task to collect the scattered data and develop a database available for nationwide use.

As underground structure information is usually obtained through surveys conducted for diverse purposes, the data is scattered among government agencies, municipalities, and institutions. Coordination between those involved is vital for integrating the data, which is one of our objectives. We wish to enhance the publication and utilization of underground structure information by developing an integrated database, offering the results of various kinds of surveys for widespread public utilization.

Japan is at a greater risk of being hit by a natural disaster including earthquake and has a greater need for data on underground structure. Despite this fact, data is organized and maintained only by related organizations, through their own efforts, and some of the scattered data is in danger of being lost. Therefore, it has become an urgent task to develop an integrated geophysical and geological information database that consolidates survey materials and data on geological and ground structure information.

With this background, the ‘Development of an Integrated Geophysical and Geological Information Database’ began in July 2007 as an important solution-type research project supported by the special coordination fund for science and technology promotion of Japan. In the following, we introduce this database.

2. CONCEPT OF THE INTEGRATED DATABASE

The project, which officially started in July 2006, was implemented by the National Research Institute for Earth Science and Disaster Prevention (NIED) with the participation of the National Institute of Advanced Industrial Science and Technology (AIST), Public Works Research Institute (PWRI), Tokyo University, Tokyo Institute of Technology, and the Japanese Geotechnical Society (JGS).

The research involves the systematic collection and management of geophysical and geological information on underground structure from the surface layers to the deep layers, with the main objective of preventing earthquake damage, and the development of an integrated geophysical and geological information database as a system for extensive utilization.

We will study and develop a method for wider data use by developing a database that allows for mutual utilization and publication of data through a network of each organization's databases.

The keyword of this research project is 'Integration'. The word implies several meanings, as demonstrated by the following six goals that we hope to achieve (Figure 1).

1) Integration of databases of multiple organizations
2) Integration of data across the country
3) Integration of data contents from the original data to model data
4) Integration in terms of direction from the shallow part to the deep part
5) Qualitative integration of information on geology and property values
6) Integration by shared management via the network

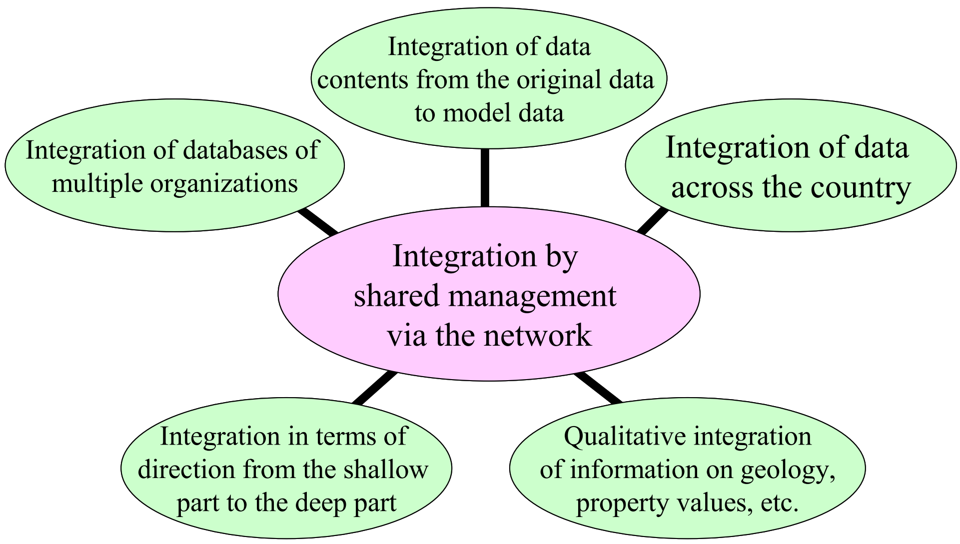

Figure 1 Image of integration.

3. MANAGEMENT SYSTEM ON SHARING

A database on underground structure that is integrated, coordinated, and shared is vital for research, analysis, and policy planning for earthquake disaster prevention. In addition, the promotion of further standardization, integration, and publication, and utilization of relevant data is an important issue that will greatly contribute to society.

Because there are many agencies and municipalities, both at home and abroad, that accumulate data on underground structure, forming a network through the participation of these agencies and integrating as many data sets as possible for mutual utilization will enhance the value of data owned by each agency. A reduction in the cost involved in the development and maintenance of the system, and achieving mutual data utilization and operation is necessary in order to have as many agencies as possible continue to play a role in the network. The management system on sharing should satisfy the three concepts of: (1) Using open-source software to reduce the initial cost of introducing the network, (2) Establishing a portal site in order to ask each agency to be responsible for managing its own data, and (3) Employing international standards to enhance integration with GIS software and other systems.

In developing the management system, we will base it on international standard specifications, published widely as open standards, so as to achieve mutual data utilization. Likewise, the software to be employed should be open-source software to facilitate utilization. We have chosen 'MapServer' as the WebGIS open-source software, and 'PostGIS/PostgreSQL' for spatial databases.

As Figure 2 shows, the management system is based on Web Map Service (WMS) and Web Feature Service (WFS), both of which are international standard specifications formulated by the Open Geospatial Consortium (OGC), and both of which convert data to images or data in an XML format. Users can access the service with via Web browsers such as Internet Explorer or GIS software such as WMS and WFS.

They also can conduct analysis using the data on hand with the aid of the service provided by WFS. We also are considering developing simplified GIS supporting open-source WMS/WFS to enable users to display underground structure data supplemented by map information using a simplified GIS.

The system configuration for the management system on sharing consists of the following three layers.

(1) First layer: Database management servers
Installed in each agency to distribute published data.

(2) Second layer: Portal site
Uses WMS/WFS to integrate and manage services of each agency to provide information on published data, and to enable users to utilize the flexible search function for published data and the map display function.

(3) Third layer: Client
Enables users to display and download published data using a Web browser such as Internet Explorer, and display and analyze published data using GIS software supporting WMS/WFS.

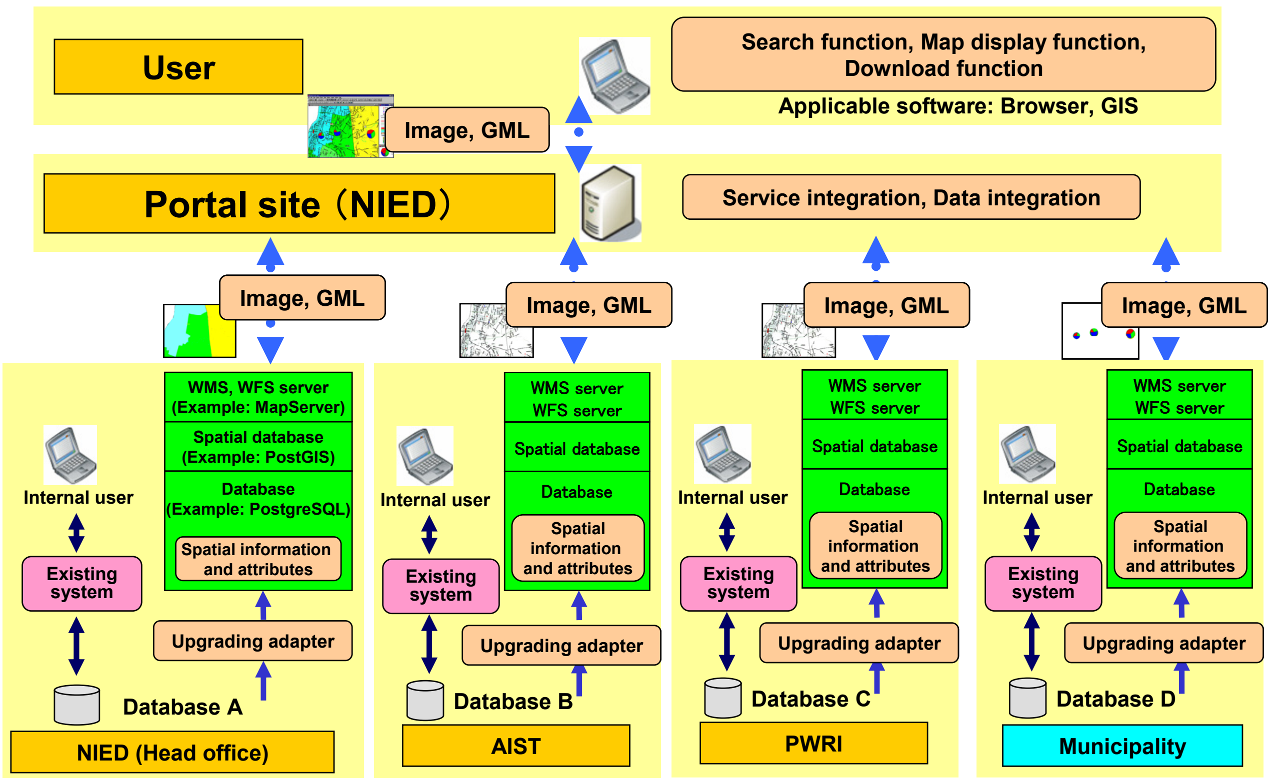

Figure 2. Diagram showing the concept of the management system on sharing.

4. INTEGRATED DATABASE FOR STRONG-MOTION EVALUATION

Information on underground structure is vital for quantitative evaluation for strong-motion using a physical model. Especially, the velocity structure is important for estimating strong-motion. From the viewpoint of evaluating strong-motion, the current practice is to set up a model for each of the three sections: structure of crust from the upper mantle to the seismic bedrock (Vs=3km/s), deep ground structure from the seismic bedrock to the engineering bedrock (Vs=400m/s～700m/s), and shallow ground structure from the engineering bedrock to the ground surface.

As for structure of crust, a velocity structure model (e.g. Matsubara et al. 2008), is studied by using seismic observation network that is being built nationwide. It is necessary for strong-motion evaluation to construct a model down to the area including the Mohorovicic discontinuity in the depth direction for inland active faults, and a model that includes plate structure for subduction zone earthquakes.

The structure of deep sedimentary layers is what greatly affects relatively long-period ground motion, which is longer than 1sec, and is important for calculating ground motion within the frequency range where a deterministic approach such as simulation using the difference method and finite element method can be used. Data for velocity-structure modeling includes data from deep layer boring, reflection and refraction survey, microtremor survey, and gravity survey. In the modeling of underground structure for evaluating strong-motion, the velocity-structure is the most important parameter. Accordingly, as more data is gathered that allows these values to be obtained directly, the more accurate the model is. Ideally, if sufficient data is available, we can understand the velocity-structure at each point from multiple deep part boring data, and estimate a wide geometry from refraction data, and estimate the detailed structure such as the borders of mountain districts from reflection survey data. We can use microtremor array survey data, gravity survey data, and geological information to supplement the gap in order to make a three-dimensional model. However, there is usually not enough data to make a three-dimensional model. In such a case, gravity survey data and geological structure information is available as two-dimensional information, and it is necessary to estimate the velocity-structure indirectly. Therefore, an important issue is how to supplement the shortage of data in deep ground modeling.

The basic concept of modeling of surface soil structure is to make a ground structure using subsurface geological data and boring data. In evaluating a specific point, it is possible to conduct a survey proportionate to the prediction accuracy required at the point and conduct a detailed analysis including nonlinear analysis. However, much data must be collected in order to make a three-dimensional surface soil structure model that covers a wide area with high accuracy because surface soil structure has many local changes. It is important to develop a database for boring data.

We are collecting and organizing data on underground structure from the surface layer to deep parts, in collaboration with related agencies, to promote activities for disaster prevention by developing the basic database, and are modeling the underground structure to develop an underground structure database. Specifically, we are collecting and organizing various kinds of data including data obtained by boring. This data includes data used for improving the national seismic hazard maps for Japan (Fujiwara et al. 2006a) of the Earthquake Research Committee of the Earthquake Research Promotion Headquarters, data collected by agencies for earthquake research, data from related research projects, and data obtained from hazard evaluations conducted by the nation and municipalities.

As for deep sedimentary layers from the seismic bedrock to the engineering bedrock, we develop a model for whole of Japan and organize not only original data from various underground surveys, but also data showing the background of model development including intermediate data obtained while developing the model.

Regarding subsurface ground data, we aim to share the database owned by each municipality where possible in collaboration with municipalities in the Kanto region and surrounding areas. We are using this data to create a ground model in about 250-m mesh in the Kanto and surrounding areas for evaluating strong motion.

We are also compiling a nationwide version of the geomorphological classification database in 250-m mesh (Wakamatsu & Matsuoka 2006) to be used for evaluating strong-motion over a wide area. In developing the seismic hazard maps over a wide area, we have used geomorphological classification data of digital national land information in 1-km mesh as ground data for the area without boring data. However, these data are based on the surveys and editing by prefectures, and do not conform to a uniform national standard. We will therefore compile a nationwide version of the geomorphological classification database in 250-m mesh.

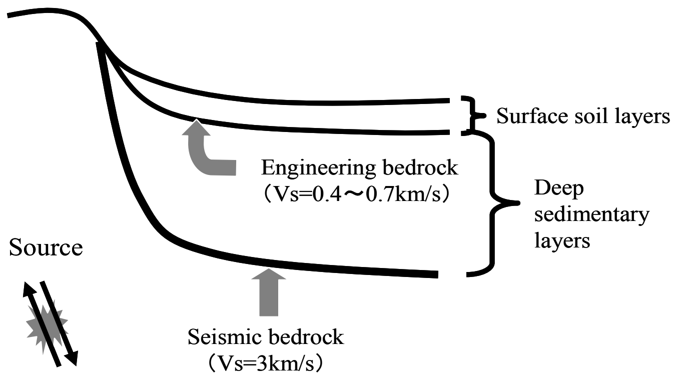

Figure 3. Schematic representation of underground structure.

4.1 Modeling deep sedimentary layers for the evaluation of strong motion

Velocity-structure of deep sedimentary layers from the seismic bedrock to the engineering bedrock greatly affects the characteristics of relatively long period strong-motion. As part of the activities of the Earthquake Research Committee of the Earthquake Research Promotion Headquarters of Japan to publish the national seismic hazard maps for Japan, we developed models of deep sedimentary layers for each area subject to evaluation of strong motion. Based on these models, we have been developing a deep sedimentary layer structure model that covers the whole of Japan (Fujiwara et al. 2006b).

The velocity-structure model for deep sedimentary layers developed for each area is the result of using the optimal approach within the modeling areas. However, simply putting these models together does not create a complete nationwide velocity structure model, because the development method for the models varies with area, the data used for model development varies with area, and the parameters vary with the model.

To develop a nationwide model, it is necessary to focus on common items in the approaches used for each area. From this viewpoint, we found that each area adopts the procedure of correlating property values, such as elastic wave velocity, to the geological division and estimating the velocity. An important parameter for determining elastic wave velocity structure in sedimentary basins is layer division according to geological age, rock type, and depth. Nationwide and homogeneous data on the basic geological distribution for Japanese islands is available. Therefore, we actively utilize this geological structure information to develop the nationwide model.

Geological age is basically set according to the evolution of creatures on the earth and is not directly related to the shape of layers formed in each geological age. Also, the boundaries of layer division by age do not necessarily correspond to the boundaries of property values for the layer. However, within a specific area (sedimentary basin), the layer division has a commonality of layer shape, and it is possible to correlate it to a certain geological age and possibly to elastic wave velocity division. In addition, by using the geological age division as the common parameter, it is possible to use the layer division to develop a model for a wide area because it can be used to determine the correlation of the layer to multiple areas and judge how it becomes continuous as the elastic wave velocity structure. The geological age divisions that we used for layer division of the nationwide velocity structure model are shown below. We regard plutonic rocks and regional metamorphic rocks formed before the Upper Cretaceous as earthquake bedrock.

We develop a nationwide layer structure model corresponding to this layer division, and develop a model that allows for allocation of property values, while ensuring that each layer reflects its regionality. At present, we do not have enough information to allocate one property value to one layer; consequently, we allocate appropriate property values to each area as needed; in other words, we use broader property values. Except for a very few areas, the model cannot be sufficiently verified through comparison between the calculation results of seismic motion using the property value model and the actual observation records for the areas in the deep ground model that this research is developing. Therefore, it is advisable to position the developing model as a draft version for a more sophisticated model in the future and as the ‘initial model’ for more refined analysis in the future.

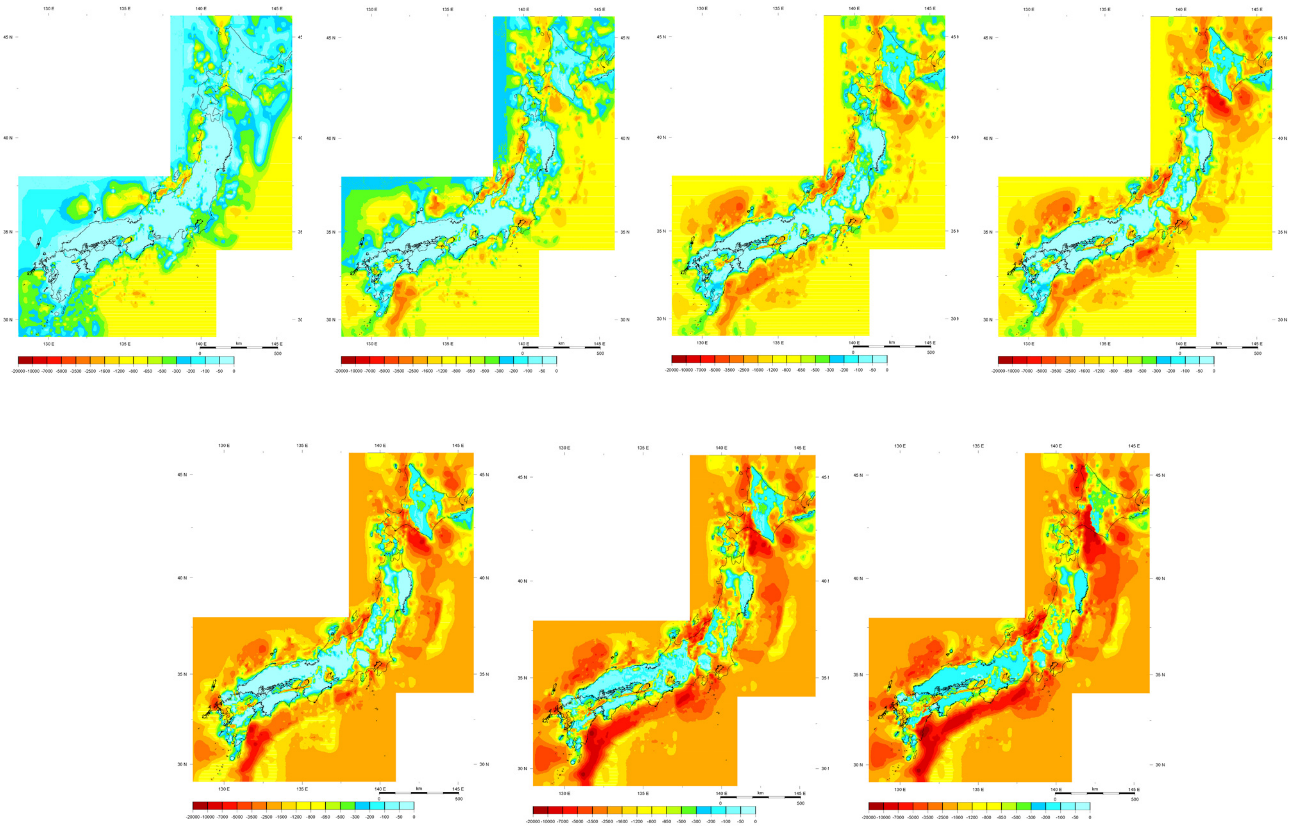

Figure 4. Subsurface structure model for deep sedimentary layers of the whole of Japan.

4.2 Modeling of surface soil layers

We have been collecting boring data and developing a surface soil structure model in collaboration with related agencies and municipalities in the Kanto district in order to be able to evaluate strong-motion in the Kanto Plain more accurately. After the Great Hanshin Earthquake Disaster, each municipality in the Kanto Plain reviewed a survey of estimated earthquake damage and published a report. However, over time the boring data collected and ground columnar model developed in the survey have become scattered. We are therefore improving the system to be able to use the boring data for making a ground model using GIS that matches the space database. We are also creating a database of data and information collected from each municipality in XML format to prevent data variability.

We have now collected data for about 140,000 borings in the Kanto area (Figure 5). This data includes: (1) A ground model in 50–500 m meshes developed for estimating the damage in the municipality, (2) Boring data owned by related agencies including municipalities, and (3) A ground model of the metropolitan area in 1-km mesh published by the Central Disaster Prevention Council.

Using these data, we are making a shallow ground model in 250m mesh which can be used to evaluate seismic hazard in the South Kanto area as shown in Figure 6 (Ooi et al. 2006). In the model, the ground structure is modeled based on boring data as well as the ground model developed in the survey of estimated earthquake damage conducted by each municipality. We use the boring data if PS well logging exists in the mesh, and use the formula relating the N value from boring data with Vs if no PS well logging exists in the mesh. If no boring data are available, we allocate a ground model by referring to the geomorphological classification database. The lowest layer of the shallow ground model is equivalent to an S wave velocity of 700 m/s for the sake of consistency with the deep ground model developed by the Central Disaster Prevention Council and the Earthquake Research Committee of Earthquake Research Promotion Headquarters.

In developing shallow ground, it is important to evaluate the depth and shape of the engineering bedrock, the structure and spread of sedimentary layers above the engineering bedrock, and the spread of combinations of sedimentary layers. It is also necessary to closely examine the distribution of property values, each factor, and regionality when bringing geological factors that affect them into the model.

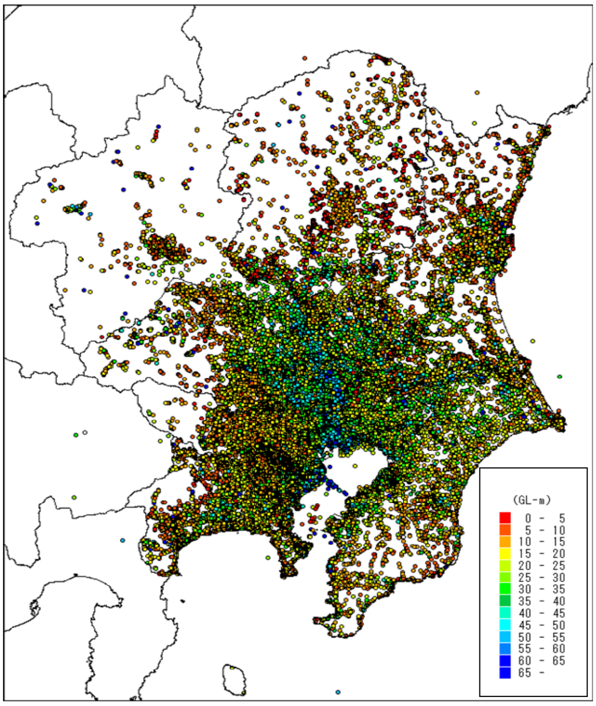

Figure 5. Distribution of boring data in the Kanto area.

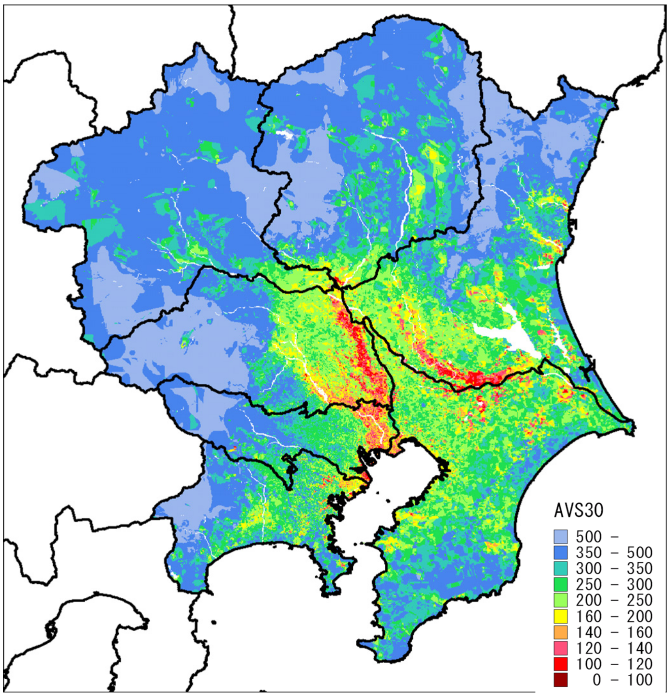

Figure 6. Distribution of AVS30 based on the 250-m mesh model that we are currently developing.

4.3 Integrated database of NIED

We are collecting and organizing data on underground structure from the surface layer to deep parts, in collaboration with related agencies, to assist disaster prevention by developing the basic database described in sub theme 1, and are modeling the underground structure to develop an underground structure database.

Specifically, we are collecting and organizing various kinds of data including data obtained by boring and the reflection method from research to date. This data includes data used for improving the seismic estimate map of the Earthquake Research Committee of the Earthquake Research Promotion Headquarters, data collected by agencies for earthquake research, data from related research projects, and data obtained from hazard evaluations conducted by the nation and municipalities.

Regarding subsurface ground data, we aim to share the database owned by each municipality where possible in collaboration with municipalities in the Kanto region and surrounding areas. We are using this data to create a ground model in about 250 m mesh in the Kanto and surrounding areas for evaluating strong motion.

As for deep ground from the seismic bedrock to the engineering bedrock, we will develop a model for the whole of Japan and organize not only materials and original data from various underground surveys, but also data showing the background of model development including intermediate data obtained while developing the model. In addition, for areas where there are well-organized data and accurate models, we are trying to develop an integrated model of the subsurface ground model and deep underground structure model. Table1 shows data on underground structure we have collected.

Table 1. Contents of Integrated database of NIED.

Data	Total quantity
Borehole data	371,345 boreholes
Data of reflection survey	339 Lines
Data of refraction survey	44 lines
Data of microtremor survey	293 points
Data of gravity survey	13 areas
Three-dimensional velocity-structure model	31 models
Materials including reports	336 materials

5. SUMMARY AND OUTLOOK

In the development of an Integrated Geophysical and Geological Information Database, we will combine data collected and organized in each project into one database and provide users with a seamless data service through the network in collaboration with related agencies affiliated with several government agencies.

Distribution of data of underground structure is important for using the underground structure database in practice. In principle, we will publish the results of our modeling using boring data collected by us. However, because original data such as boring data are mostly borrowed under a contract between NIED and the data provider that limits data utilization, they will naturally be used only for NIED's internal purposes. In the future, we need financial, institutional, and personnel support for database developers and approaches that consider legislative preparations in light of various rights , such as ownership right, property right, and personal information protection law, associated with the acquisition, storage, obligation to disclose, and utilization of underground structure data, in order to enable the data to be widely used.

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REFERENCES

Fujiwara, H., Kawai, S., Aoi, S., Morikawa, N., Senna, S., Kobayashi, K., Ishii, T., Okumura, T. and Hayakawa, Y. (2006a). National seismic hazard maps of Japan, *Bull. Earthq. Res. Inst. Univ. Tokyo* **81**, 221-232.

Fujiwara, H., Kawai, S., Aoi, S., Senna, S., Ooi, M., Matsuyama, H., Iwamoto, K., Suzuki, H. and Hayakawa, Y. (2006b). A subsurface structure modeling of whole of Japan for strong-motion evaluation, *Proceedings of the 12th Japan earthquake engineering symposium*, (in Japanese), 1466-1469.

Matsubara, M., Obara, K. and Kasahara, K. (2008). Three-dimensional P- and S-wave velocity structures beneath the Japan Islands obtained by high-density seismic stations by seismic tomography, *Tectonophysics* **454**, 86-103.

Ooi, M. Fujiwara, H. and Toyama, N. (2006). A surface soil structure modeling in south Kanto region for strong-motion evaluation, *Proceedings of the 12th Japan earthquake engineering symposium*, (in Japanese) 318-321.

Wakamatsu, K. and Matsuoka, M. (2006). Development of the 7.5-arc-second engineering geomorphologic classification database and its application to seismic microzoning, *Bull. Earthq. Res. Inst. Univ. Tokyo* **81**, 317-324.