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ORIGINAL PAPER

Japan's Nation-Wide Electronic Geotechnical Database Systems by Japanese Geotechnical Society

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Abstract On October 15, 2010, the Japanese Geotechnical Society (JGS) announced the public release of 'Nation-wide Electronic Geotechnical Database Systems,' which provides geotechnical information to the public on the internet. The information the system provides is a collection of ground models at 250 m by 250 m in plan built by using data from various geotechnical information databases. The paper first describes historical development of the geotechnical information databases in Japan, and introduces a 5-year project, 'Integrated Geophysical and Geological Information Database in Japan,' led by the National Research Institute for Earth Science and Disaster Prevention (NIED), and participated by the JGS. The paper then presents the JGS' 'Nation-wide Electronic Geotechnical Database Systems,' and describes why such system was proposed and built, followed by the presentation of the examples for possible application of the system.

Keywords Geotechnical database · Ground model · Database linkage · Information communication · Urban geo-informatics · Hazard map

The paper is substantial revision of the manuscript originally submitted to International Symposium on Advances in Ground Technology and Geo-Information (IS-AGTG) 1–2 Dec 2011, Singapore. The Nation-wide Electronic Geotechnical Database Systems is a part of the Integrated Geophysical and Geological Information Database Project headed by the National Research Institute for Earth Science and Disaster Prevention (NIED), and was financed by the Special Coordination Funds for Promoting Science and Technology under the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT) from 2006 to 2010.

For detailed reports (written in Japanese) of NEGDS, visit the following web site of the Japanese Geotechnical Society: http://www.jiban.or.jp/organi/bu/chousabu/jibandatabase.html.

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Abbreviations

AIST	The National Institute of Advanced Industrial Science and Technology
ATC10	The Asian Regional Technical Committee No. 10 for 'Urban Geo-Informatics'
IGGID	The Integrated Geophysical and Geological Information Database
JGS	The Japanese Geotechnical Society
MEXT	The Ministry of Education, Culture, Sports, Science and Technology, Japan
MLIT	The Ministry of Land, Infrastructure, Transport and Tourism, Japan
NEGDS	The Nation-wide Electronic Geotechnical Database Systems
NIED	The National Research Institute for Earth Science and Disaster Prevention
PL	Potential of liquefaction
PWRI	The Public Works Research Institute
SCFPST	The Special Coordination Funds for Promoting Science and Technology
SPT	The standard penetration test

1 Introduction

The construction of geotechnical information databases in Japan in organized effort started in the 1960s in large cities like Osaka, Tokyo, and Nagoya, which developed on coastal plains underlain by thick Holocene deposits where outcrops are hardly seen. The impetus for building the database was the desire to better understand the stratigraphy and distribution of the post-glacial deposits under rapidly developing metropolises. The first step of the database construction was to collect existing borehole logs and laboratory soil test results then available in print.

There are about 100 geotechnical information data books and databases built so far in Japan as shown in Fig. 1; most of them cover city-size areas while others cover large areas including several prefectures. Today there are seven regional geotechnical information databases covering such large areas. The databases are popular among geotechnical engineers, engineering geologists, and environmental geologists in Japan for preliminary design of foundations, city planning, infrastructure planning, and mitigation planning of natural disasters, among others.

The geotechnical information databases typically contain borehole logs, SPT N-values, water levels, borehole location data, and laboratory test data. Some prominent databases also include in situ test data, geophysical investigation data, and surface information such as geological maps. Government organizations normally supply the data sometime after the completion of projects for which geotechnical investigations were performed. A geotechnical investigation is rarely performed for the purpose of database construction in the engineering field.

The geotechnical information databases have rapidly evolved from the paper-based databases to digital databases with the development of the digital and storage technologies from the 1970s. The delivery of the data has changed from paper to floppy disks to CDs to the internet.

With the above background of the database development in Japan, the Asian Region of the International Society of Soil Mechanics and Geotechnical Engineering formed the Asian Regional Technical Committee No. 10 for 'Urban Geo-Informatics' (ATC10) in 2002 sponsored by JGS to promote cooperation and to exchange information on Urban Geotechnical Information Systems in Asia. ATC10 proposes the following new vision.

- Subsurface data accumulated are valuable public intellectual properties.
- We should hand over the data to the next generation.
- Various departments and organizations should share the information.
- The geotechnical data are 4-dimensional property, which vary with time.

While ATC10 was campaigning for the importance of and new vision about the geotechnical information databases, the National Research Institute for Earth Science and Disaster Prevention proposed a 5-year project, the Integrated Geophysical and Geological Information Database (IGGID), and JGS joined the project by setting up a new work team. The team's mission was to link the existing, independently operating geotechnical information databases to IGGID.

The team came up with the idea of building ground models across the country. Each model represents the ground of 250 m by 250 m in plan and to depths up to 100 m, generally 30–50 m from the ground surface depending on its location. They are built in consideration of types of soil materials and their properties such as strength, deformability, permeability, groundwater, and SPT N-values. The ground models are geometrically

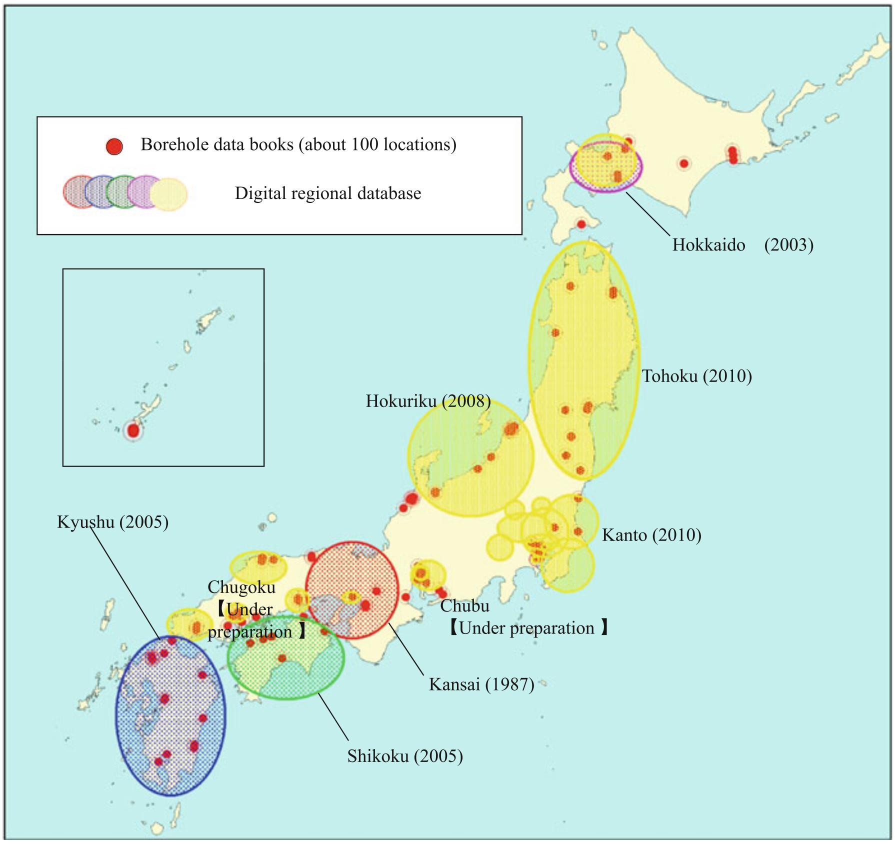


Fig. 1 Locations of typical geotechnical information databases in Japan (as of March 2012)

simpler and more geotechnical than geological models, which present succession of strata, geological ages, and their distributions. The team also developed the systems to build the models and to publish on the internet. After 5-year effort from 2006 to 2010, JGS published the ground models for 6 cities in Japan on October 15, 2010 on the internet. The ground models for additional 3 cities were published by July, 2012. By 2014 the ground models would cover 18 cities. The systems are useful in various aspects from construction planning to research as described later. The systems could also be the bases for geo-hazard analyses and hazard mapping.

2 Historical Development of Geotechnical Information Databases in Japan

Figure 2 illustrates the historical development of the geotechnical information databases in Japan. The subsequent descriptions follow the figure.

2.1 Jiban-zu (Borehole Data Book)

Early geotechnical databases in Japan started around 1960 covering coastal and urban areas in large metropolises like Tokyo, Osaka, and Nagoya. They are a sort of borehole data books, called Jiban-zu in Japanese, 'graphics of ground' literally in English, and are basically compilations of borehole data, soil cross sections, laboratory soil test results, in situ test results, geophysical exploration results, and description of local geology and topography.

"Borehole Data Book of Osaka Area (Kinki Chapter of Japanese Architectural Institute and Kansai Chapter of Japanese Geotechnical Society 1966)" is one of the earliest of this kind covering the megalopolis areas of Japan. More data books followed later to extend the coverage to provincial cities as well. To date the published borehole data books in Japan cover 34 out of 47 prefectures including Tokyo Metropolitan area. Their major editors often include (a) then

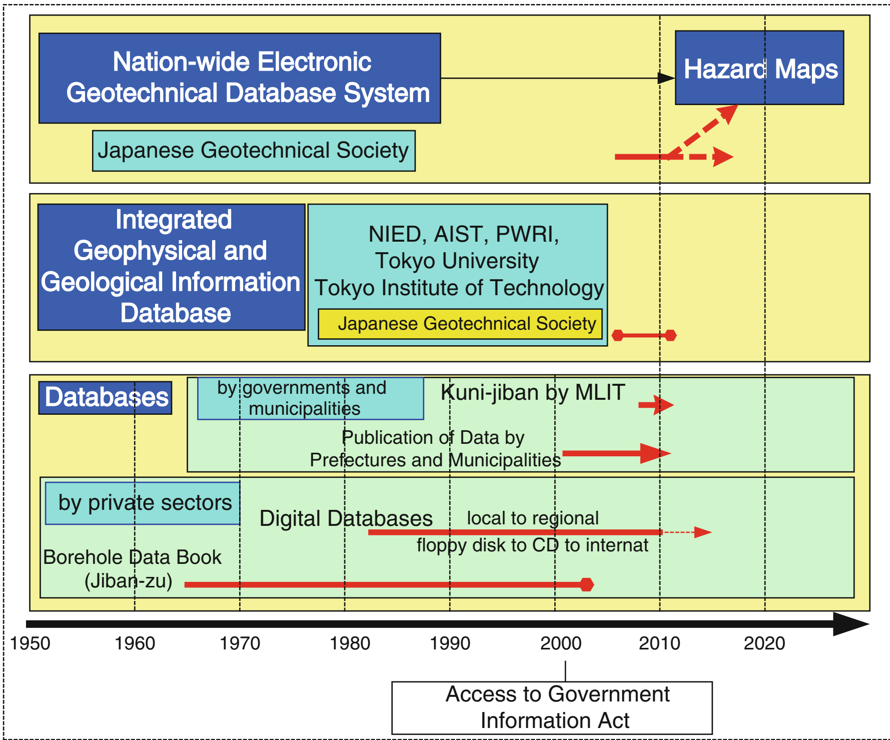


Fig. 2 Historical development of geotechnical information databases in Japan

Regional Bureaus of the Ministry of Construction, (b) prefecture and municipal governments, (c) JGS, (d) the Architectural Institute of Japan, (e) the Japan Institute of Architects, and (f) the Japan geotechnical consultant association. The latest editions of the borehole data books are "New Borehole Data Book of Tokyo Port (Bureau of Port and Harbor, Tokyo Metropolitan Government 2001)" compiling 5,800 borehole results and "Ground and Construction in Bay Area—Osaka Bay Area as an Example (Research Committee on Ground in Osaka Bay 2002)", which is the advanced edition of "New Borehole Data Book of Osaka Area (Kansai chapter of the Japanese Geotechnical Society 1993)."

These editions reflect updated information published on the geology and geotechnical engineering as much as possible. The application of the Jiban-zu in Japan increases, and will further increase, to the areas of the environmental impact assessment, such as the evaluation of soil and groundwater contamination. This is especially true after the approval of the Soil Contamination Countermeasures Act (53 of 2002) in May 2002 and its enforcement in February 2003.

The contents of the variety of the published borehole data books are often different from each other depending on their purposes. Also, some information presented in the borehole data books may vary with time. For example, the groundwater levels in urban areas had changed significantly after and where municipalities and prefectures officially banned groundwater pumping. In such a case, a borehole data book that shows the water levels before the ban may mislead the current ground conditions. The followings are general warning remarks on the application of the Jiban-zu:

- Contents of the borehole data books are not standardized and are often different from each other depending on the purposes of publication. Some data book places emphasis on geological conditions, some on the geotechnical characteristics of the ground and some on the data of earthquakes from a viewpoint of disaster mitigation.
- Although poor quality data are screened out to some extent in the process of editing, the quality of the data presented may not always be of high standard.

- The information presented in the data book might be out-dated. Users need to interpret the data with the latest knowledge.

2.2 Regional Digital Geotechnical Information Databases

The advance of the digital technology such as computer hardware, software, and large storage capacity stimulated the construction of the regional digital geotechnical databases as early as 1980s in the Kansai region, which is one of nine administrative regions consisting of several prefectures. A chamber was formed for the database development with cooperation of government organizations, local municipalities, universities, and geotechnical consultants. For example, the members of the chamber includes the Kansai chapter of JGS, the Kansai Regional Bureau of Ministry of Construction, the Third District Port Construction Bureau of Ministry of Transport, Osaka Prefecture, Kyoto Prefecture, Hyogo Prefecture, Osaka City, Kyoto City, Kobe City, Sakai City, Nishinomiya City, the Kansai Branch of Japan Highway Public Corporation, Hanshin Expressway Public Corporation, the Osaka Branch of Japan Railway Construction Public Corporation, the West Japan Branch of Japan Public Housing Corporation, Osaka Bay Regional Offshore Environmental Improvement Center, Kansai International Airport, Kansai Electric Power Company, Osaka Gas, West Japan Railway Company, NTT (Telecom), Geo-Research Institute, the Osaka Branch of General Contractor's Association, the Kinki Branch of Japan Civil Engineering Consultants Association, the Kansai Branch of Japan Geotechnical Consultants Association, and universities.

The construction of the regional geotechnical databases spread outside the Kansai region. Each local chapter of JGS took initiative to the development of the regional geotechnical databases, while they were built and published under the names of respective chambers. As of March 2012, seven regional databases are available out of nine administrative regions in Japan as shown in Fig. 1. Table 1 summarizes the regional geotechnical databases. Most of the data come with CDs or DVDs except Hokuriku and Tohoku regions, which distribute the data on the internet. Only the members who pay annual membership fee can purchase the data of Hokuriku, Kansai, and Shikoku regions, and receive the updated data when available, while anyone can buy the databases of Hokkaido, Kanto, and Kyushu regions, but there is no update until a new version is published.

2.3 Databases by Private Companies and Public Corporations

Private companies and public corporation such as electric power companies, gas utility companies, railway companies, highway companies, geotechnical consulting companies, and soil investigation companies, seem to have their own geotechnical databases for their internal use. However, those data are not disclosed to the public so far. This paper excludes discussion on these databases.

2.4 Municipalities' Databases

With the Act on Access to Information Held by Administrative Organs (Act No. 42 of 1999) enacted in 1999 and in force in 2001, the central government, prefectures and municipalities started publishing the data they had. However, such move is limited to those having certain amount of budget and personnel. Most of prefectures and municipalities cannot afford providing such services.

There are 1,886 municipalities in Japan including prefectures, cities, towns, and villages. They have two types of geotechnical data: one came from public works such as the construction of roads, sewers, and schools, financed by municipality; the other was the data submitted for building permit by applicants. With the Act on Access to Information Held by Administrative Organs in force in 2001, several prefecture governments and municipalities started releasing their data through the web sites. While the data obtained for the public works are published, the data submitted to the building permits are not disclosed because they are considered private data, not the data owned by the municipalities. Although the disclosure of the geotechnical data by the municipalities are welcome, uncoordinated and unsynchronized publication of the data by each administration with varying format, quality, and reliability are challenging for users, especially for non-professionals.

Among 1,886 municipalities, only 11 prefectures and 3 cities as shown in Fig. 3 have published the

Table 1 Regional geotechnical information databases in Japan (as of March 2012, see Fig. 1 for the locations)

Region	Current status
Hokkaido	Version 1996, CD, with fee,11,000 boreholes
	Version 2003, CD, with fee, with GIS, 13,000 boreholes
Tohoku	2010, distributed to members on the Internet, with fee, 13,400 boreholes
Hokuriku	2008, distributed to members on the Internet, with fee, 28,000 boreholes
Kanto	2010, published as a book including DVD, with fee, 40,000 boreholes
Chubu	Under preparation
Kansai	1987, CD to members only, with fee, updated yearly, 40,000 boreholes
Chugoku	Under preparation
Shikoku	2005, CD to members only, with fee, updated irregularly, 20,000 boreholes
Kyushu	2005, CD, with fee, 30,000 boreholes

geotechnical information as of March, 2012. They are: Tochigi Prefecture, Gunma Prefecture, Saitama Prefecture, Chiba Prefecture, Tokyo Metropolis, Kanagawa Prefecture, Yokohama City, Shizuoka Prefecture, Aichi Prefecture, Nagoya City, Gifu Prefecture, Mie Prefecture, Kobe City, and Shimane Prefecture. There are a few other prefectures and cities to follow. According to the survey conducted by the National Research Institute for Earth Science and Disaster Prevention (NIED) in 2007, about 1/4 of the 803 municipalities who returned the questionnaires have sections or departments that keep the data in order. Other municipalities do not systematically maintain the data, and most of them have no plan for systematic storage of the data, because of lack of budget and human resources.

2.5 Kuni-Jiban by Ministry of Land, Infrastructure, Transport and Tourism

The launch of the Kuni-Jiban (National Ground) in 2008 by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is an epoch making event in the world of the geotechnical information databases in Japan. The MLIT started releasing its own digital data collected for the purpose of national development on the internet (Kuni-jiban by the Ministry of Land, Infrastructure, Transport and Tourism). As of March 2011, the Kuni-Jiban has about 93,500 borehole data uploaded on the internet, out of about 140,000 boreholes the Ministry has. One significant character of the Kuni-Jiban is that the data concentrate along roads and rivers. As an example, Fig. 4 shows a computer screen displaying Kuni-Jiban's borehole locations around Tokyo. For the use of the Kuni-Jiban in urban areas, the geotechnical data from other geotechnical databases should be consulted with to supplement Kuni-Jiban.

3 Integrated Geophysical and Geological Information Database in Japan

In July 2006 a 5-year, nationwide, inter-agency project, the Integrated Geophysical and Geological Information Database (IGGID), started, led 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), the Public Works Research Institute (PWRI), Tokyo University, Tokyo Institute of Technology, and JGS. The project was financed by the Special Coordination Funds for Promoting Science and Technology (SCFPST) under the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT).

The project consists of three themes as shown in Fig. 5. Theme 1 is continuation and enhancement of the databases already built independently by NIED, AIST, and PWRI on their own initiatives. As NIED is a research institute to study earthquake disasters and mitigation, its database contents are rich in geological structures models related to earthquakes and wave propagation properties. A part of AIST was previously Geological Surevy Institute and its database consists of geological information such as geological maps, borehole logs, and drilling cores. PWRI supports public works and the data obtained for construction of dams, highways, river banks are stored as well as the seismic properties.

Theme 2 is the development of the systems to integrate and coordinate various databases through the internet. JGS took part in Theme 2 to develop the systems to link the existing geotechnical databases that JGS' local chapters participated in the construction and maintenance. In addition, Theme 2 is to invite prefectures and municipalities to join by

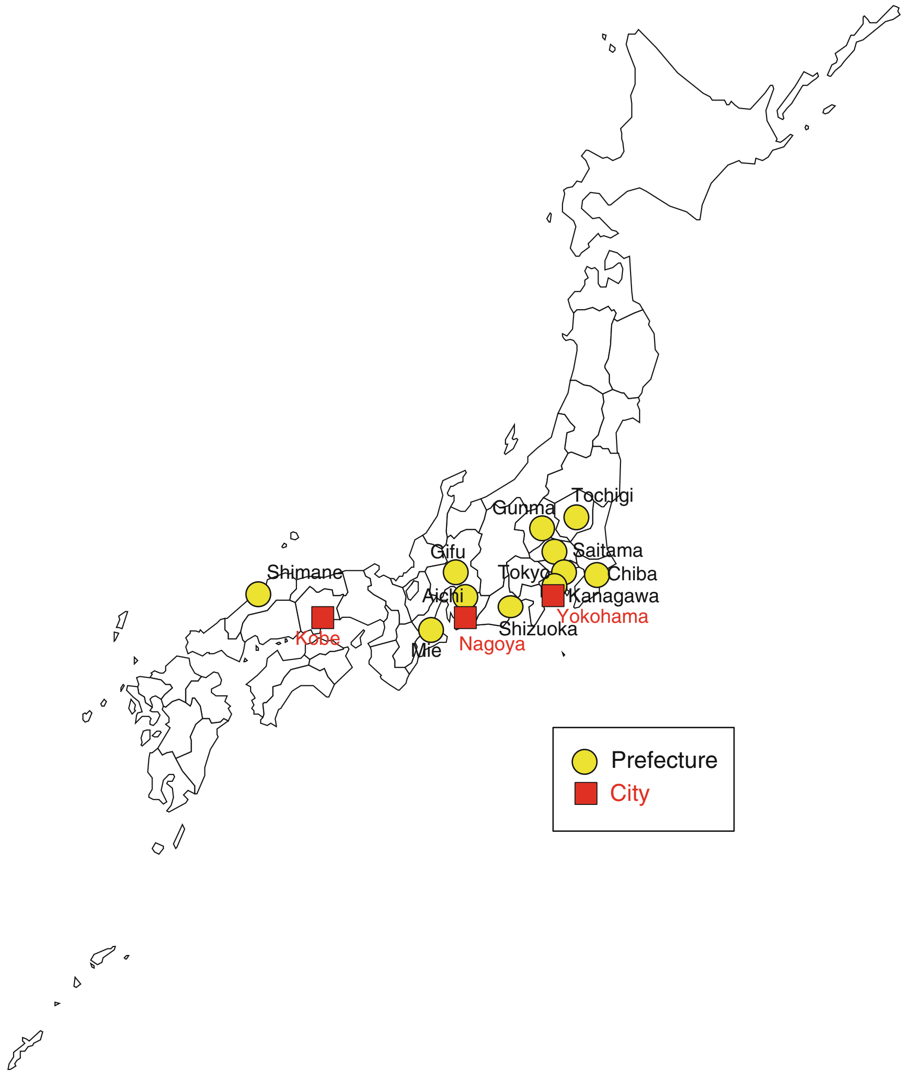


Fig. 3 Municipalities that published geotechnical information as of March 2012

connecting their databases to IGGID. The concept of the integration and management is called 'shared management system,' which is described below. Theme 3 is to study how to use the database for the earthquake prediction and publicizing potential disaster to local residents.

Figure 6 illustrates the concept of the integration. There are the following aspects of the integration;

- Integration of various data across the country
- Integration of various types of data from the original data (such as borehole logs) to various models (such as geological models and ground models)
- Integration of databases from multiple organizations
- Integration of data from shallow (less than 100 m) to deep (several kilometres) ground
- Integration of qualitative information (such as geological description) to quantitative information (such as property values)
- Integration of all the above data via the internet

The project aimed to integrate through the internet the databases that NIED, AIST, PWRI, and JGS were developing independently on their own initiatives. The concept of the integration is such that each organization is responsible for the management, development,

Fig. 4 Computer screen shot of borehole locations, Kunijiban

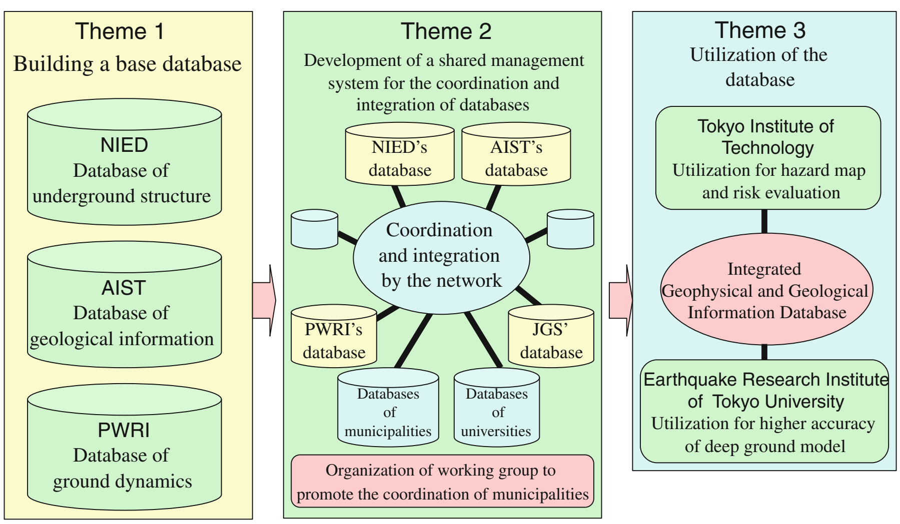


Fig. 5 Implementation concept of integrated geophysical and geological information database

and maintenance of their databases. In addition to NIED, AIST, PWRI, and JGS, anyone such as municiparities, prefectures, universities and others can join IGGID with the condition that they have to manage their databases by their own responsibility. The word, 'shared management' shown in the center of Fig. 6 is used to describe this arrangement. Figure 7 illustrates the concept of the shared management system where each organization manages their database that is connected to NIED's portal site while their database is open at their own web sites. The shared management means the management of the databases

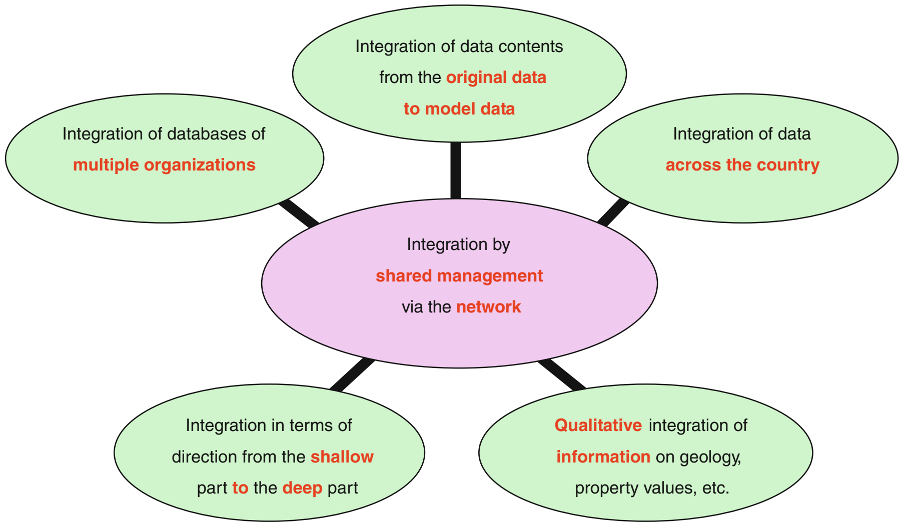


Fig. 6 Concept of integration

by each participating organization, not the management by a central organization.

While users can view the data of any organization at its web site, they can view the data from NIED's portal site, called Geo-Station, which shows all the data points (locations) on a computer screen from all participating organizations. The borehole points from NIED, AIST, and PWRI complement each other. For example, most of the data of NIED come from prefectures and municipalities, the data of AIST come from other prefectures and municipalities, and the data of PWRI (along roads and rivers as described in Sect. 2.5) originate from the MLIT. Those data are standardized so that the data from various organizations can be viewed, searched, and published in the net work systems. The concept of NIED's portal site is illustrated in Fig. 7 and more information can be found at the Geo-Station web site (Geo-Station by the National Research Institute for Earth Science and Disaster Prevention 2009).

4 Nation-Wide Electronic Geotechnical Database Systems

4.1 JGS' Mission in Integrated Geophysical and Geological Information Database

JGS' mission in the integrated geophysical and geological databases was to link the existing geotechnical databases that the Society's local chapters were involved for their construction, maintenance, and administration. For this purpose, JGS set up a work team for 'Shallow Ground Data Base Linkage.'

The paper applies the words 'link' or 'linkage' to express the Japanese word, 'renkei,' used in the scope of the work. The literal translation is 'join together' including the meaning of 'collaborations and cooperation.' The word 'renkei' emphasizes not only physical and electronic linkage of the databases, but also linkage among people who have developed and are maintaining the databases. As illustrated in Fig. 8, three levels of the linkage are defined: linkage within the respective regions of the Society's local chapters (there are 9 local chapters corresponding to administrative regions of Hokkaido, Tohoku, Hokuriku, Kanto, Chubu Kansai, Chugoku, Shikoku, and Kyushu Regions); linkage among regions; and linkage with the Integrated Geophysical and Geological Information Database (IGGID). The linkage within the region is collaborations and cooperation among databases operators as well as physical and electronic linkage of the databases within the region, which are the databases already built up, being built, and yet to be built. The linkage among regions is also collaborations and cooperation among the local panels set up to build and maintain the Nation-wide Electronic Geotechnical Database Systems (NEGDS), because there are profound differences in experience, knowledge, and know-how to develop and maintain databases among

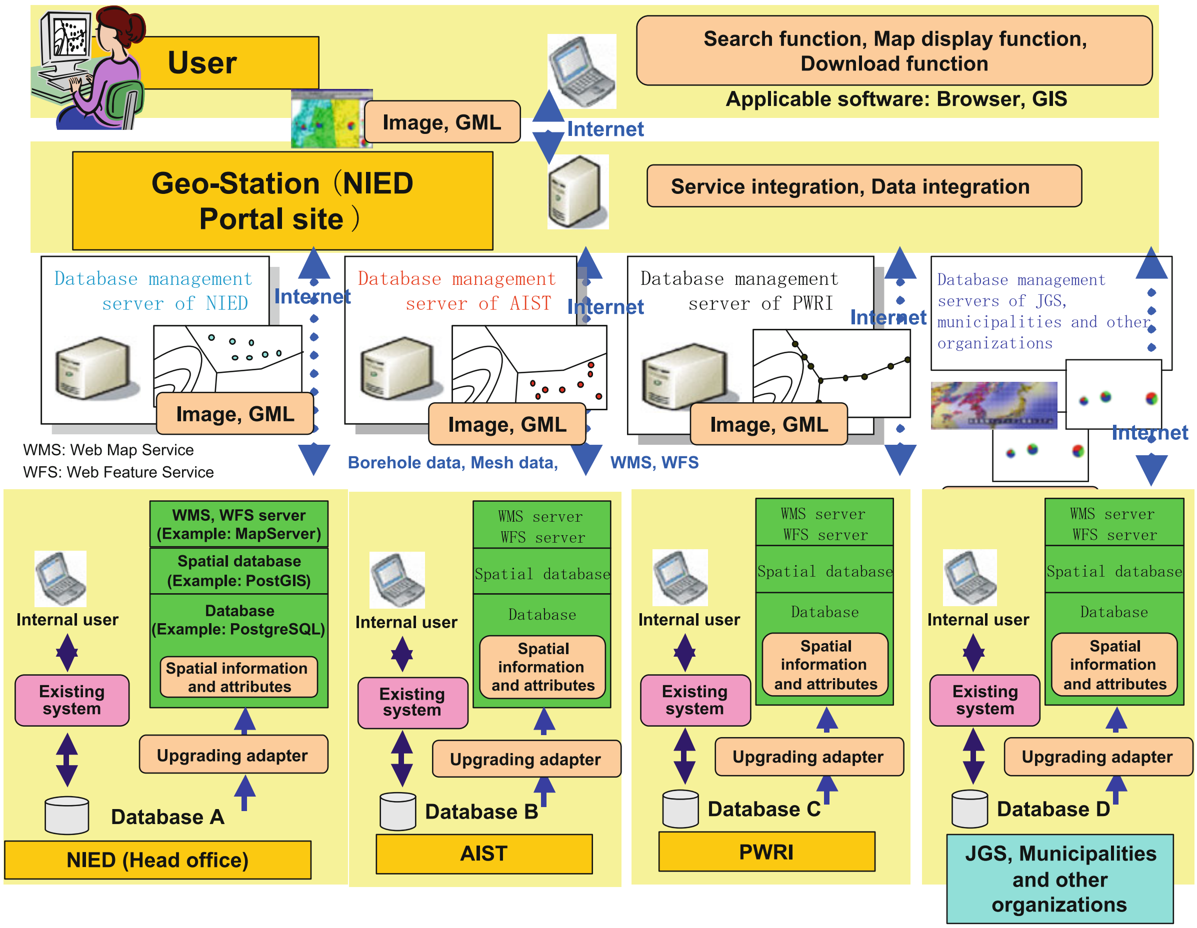


Fig. 7 Concept of shared management system and Geo-station of integrated geophysical and geological information database

them. The link to IGGID is physical and electronic linkage with the databases of NIED, AIST, and PWRI, municipalities, and others as shown in Fig. 8.

The work team does not have authority over other independent database operators and could not force them to link their databases to a new system the work team was going to develop. Under these circumstances, the work team invited representatives from the JGS' 9 local chapters to join in, because the local chapters are deeply involved in the administration of the regional geotechnical information databases as described earlier. The work team also had seats for the representatives from NIED, AIST, and PWRI.

The systems the work team was going to build should be such that the independently operated other databases would willingly join. After a year of discussion, the work team proposed to build NEGDS, which is essentially a collection of ground models with each size of 250 m by 250 m in plan to a maximum depth of 100 m. The systems can electronically construct, save, modify, and display the models. The information contained there can be viewed and downloaded from the internet.

The reasons why the work team proposed to build NEGDS rather than merely developing systems to link the existing databases and to siphon their data are as follows:

1. It is difficult to simply connect the existing borehole databases through the internet, because the existing databases are very much different in their construction, systems, data structures, data contents, and data quality. It is also very difficult to use such data coming from variety of databases with different contents and systems. It is important for a user that interpretation and quality of the

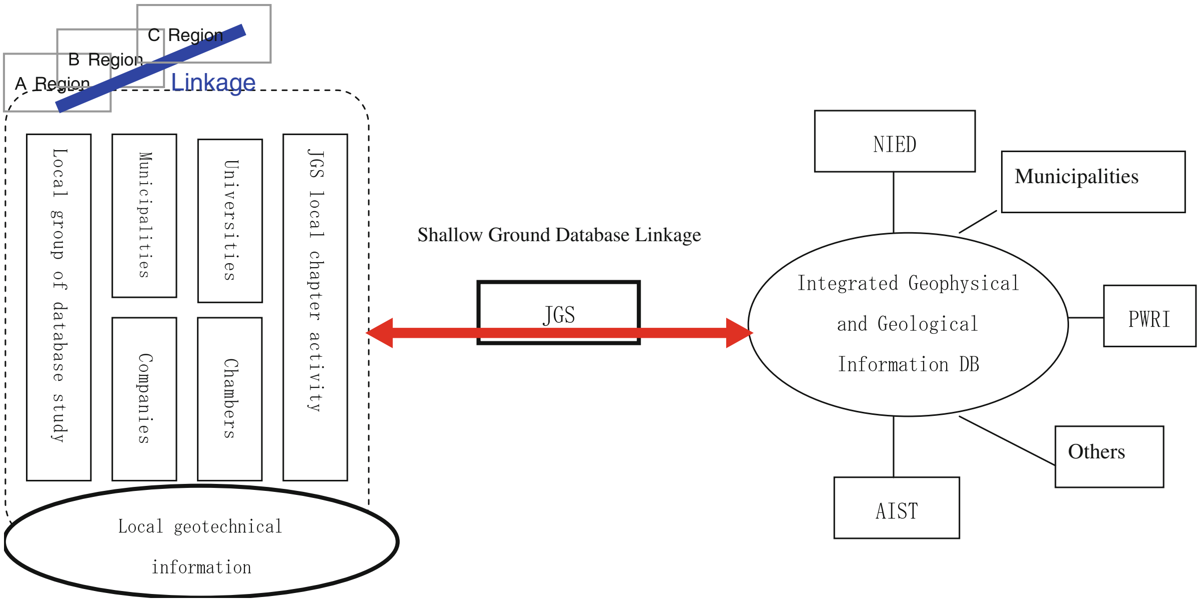


Fig. 8 Linkage, collaborations, and cooperation of shallow ground databases

data are unified at a certain standard, and the nation-wide database linkage should be user-friendly.

2. The research results funded by the Special Coordination Funds for Promoting Science and Technology (SCFPST) have to be open to the public. This condition makes many operators of the databases difficult to participate to the systems if the systems were to simply link the existing databases, because all the data linked to the systems have to be disclosed. Such disclosure is not acceptable for those who had supplied data with prior confidential agreement not to disclose the data due to ownership of the data, copy rights, and information on private properties. Some of the databases contained the data that were supplied with the conditions that data can be used for research only, and cannot be released to the public. These databases cannot join the systems that simply link various databases.

In order to overcome the above obstructions to use raw data such as individual borehole data, the work team decided to make ground models by interpreting all the available raw data. By making the ground models, the problems of the ownership and copy rights can be skipped. At the same time, the systems can provide quality information on the ground conditions by using only reliable data based on good knowledge of local geology. Such model will be much user-friendly to the public than just providing raw data from various existing databases.

4.2 Coverage of NEGDS in Japan

JGS published the databases on the internet on October 15, 2010 at the NEGDS web site (Nation-wide Electronic Geotechnical Database Systems 2010) for 6 cities in Japan. As of July 2012 the databases have expanded to 9 cities as shown in Fig. 9; they are, from north to south, Sapporo, Sendai, Niigata, Tokyo, Nagoya, Osaka, Hiroshima, Matsuyama, and Fukuoka. By the end of 2014, the database coverage is expected to expand to 18 areas as shown in the figure.

Since its publication, NEGDS has often been cited in mass media as a tool for the public to check the ground conditions under their own houses and to be aware of potential natural disasters related to the ground, especially after the Great East Japan Earthquake Disaster on March 11, 2011. However, the coverage areas are still few, and the data contents at present are limited to soil types and SPT N-values only. Interpretation of the data requires judgement by professionals, and the public is advised to consult with the professionals.

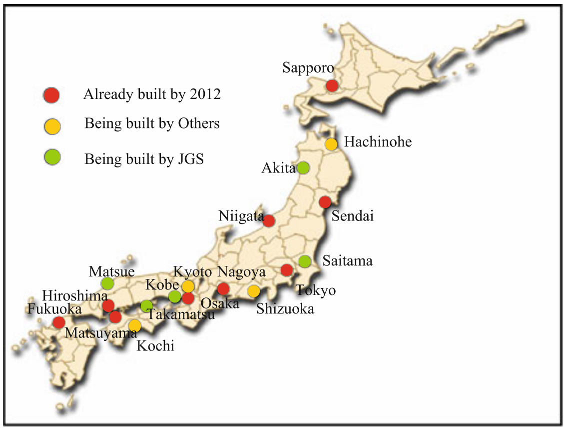


Fig. 9 NEGDS as of July 2012 and expected coverage in 2014

4.3 The Systems

4.3.1 Overview of the Systems

Figure 10 shows the systems configuration in relation to the databases outside the system. It consists of five sub-systems; (1) the software to aid construction of a single ground model based on the information from the databases that are outside the system (the databases of JGS' local chapter, universities, and municipalities, for example), (2) a viewer of a large collection of ground models, (3) a system for connecting to the internet, (4) another viewer for users through the internet, and (5) archiving function for PDF files of old borehole data books.

4.3.2 Information Contained in NEGDS

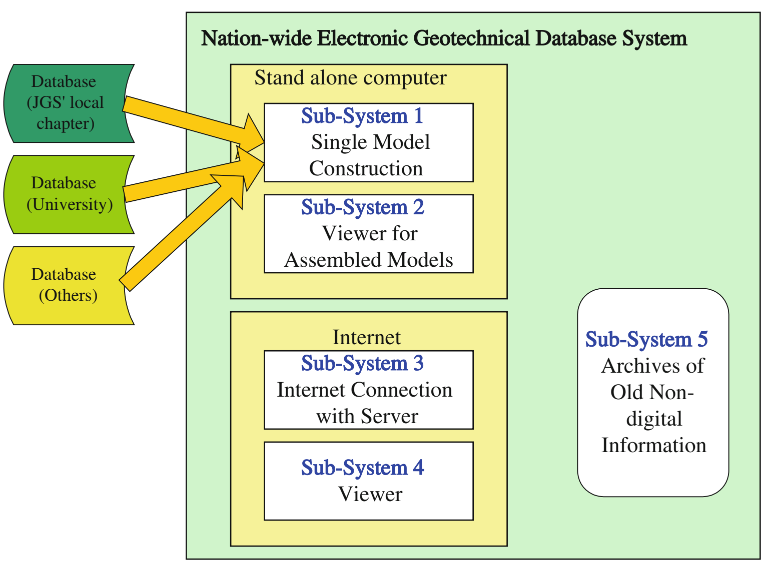
The system is intended to contain any type and any amount of data, such as borehole logs, laboratory test results, in situ test results, soil-cross sections, primary and secondary wave velocity logging (PS) data, geological description, changes in groundwater level with time, groundwater quality, ground settlement with time, and others. At present, the system contains borehole logs only.

4.3.3 Construction of NEGDS

Based on the existing digital geotechnical databases built at various locations in Japan, one can construct a ground model of a particular location of 250 m by 250 m area using the software (Sub-System 1 in Fig. 10) developed by JGS with reference to the borehole data in and around that area and with geological, topographical and engineering interpretation. It is noted that one should not simply make the model by selecting one borehole inside the area, but should build the model in consideration of surrounding ground conditions. The model thus represents average ground conditions in the area, not the ground condition at the center of the area. The model is constructed as follows:

1. A standard 250 m grid map published by Geographic Survey Institute of Japan is used.

Fig. 10 System configurations of NEGDS



2. The location for the model to be constructed is selected.
3. Ground model is constructed using borehole data available nearby in consideration of topography and geology. For making the ground model, the systems developed by the work team are used to assist construction of a ground model from the existing digital databases.

Figure 11 shows a computer screen shot during the construction of a model. A base map is seen with 250 m grid lines with the borehole locations plotted in red colour except the green coloured points located within the selected grid cell. The borehole logs in the grid cell are automatically displayed in a separate window with standard pattern diagrams and the SPT N-values. The one short borehole in the figure can be removed as they are not fit for further process. If any borehole is judged unreliable, it can also be removed. On the contrary, boreholes outside the selected grid cell may be added. Borehole elevations and water levels can be checked at this stage. Then soil types and SPT N-values are averaged at every 1 or 2 m intervals. An average model is shown on the right side. Although a model may be constructed almost automatically as described above, it is very important that judgements based on the knowledge of local geology and soil conditions should be exercised. Engineering judgement is always necessary to avoid misinterpretation of data.

The construction of the ground models requires setting up local teams of specialists who have good knowledge of local ground conditions. The team

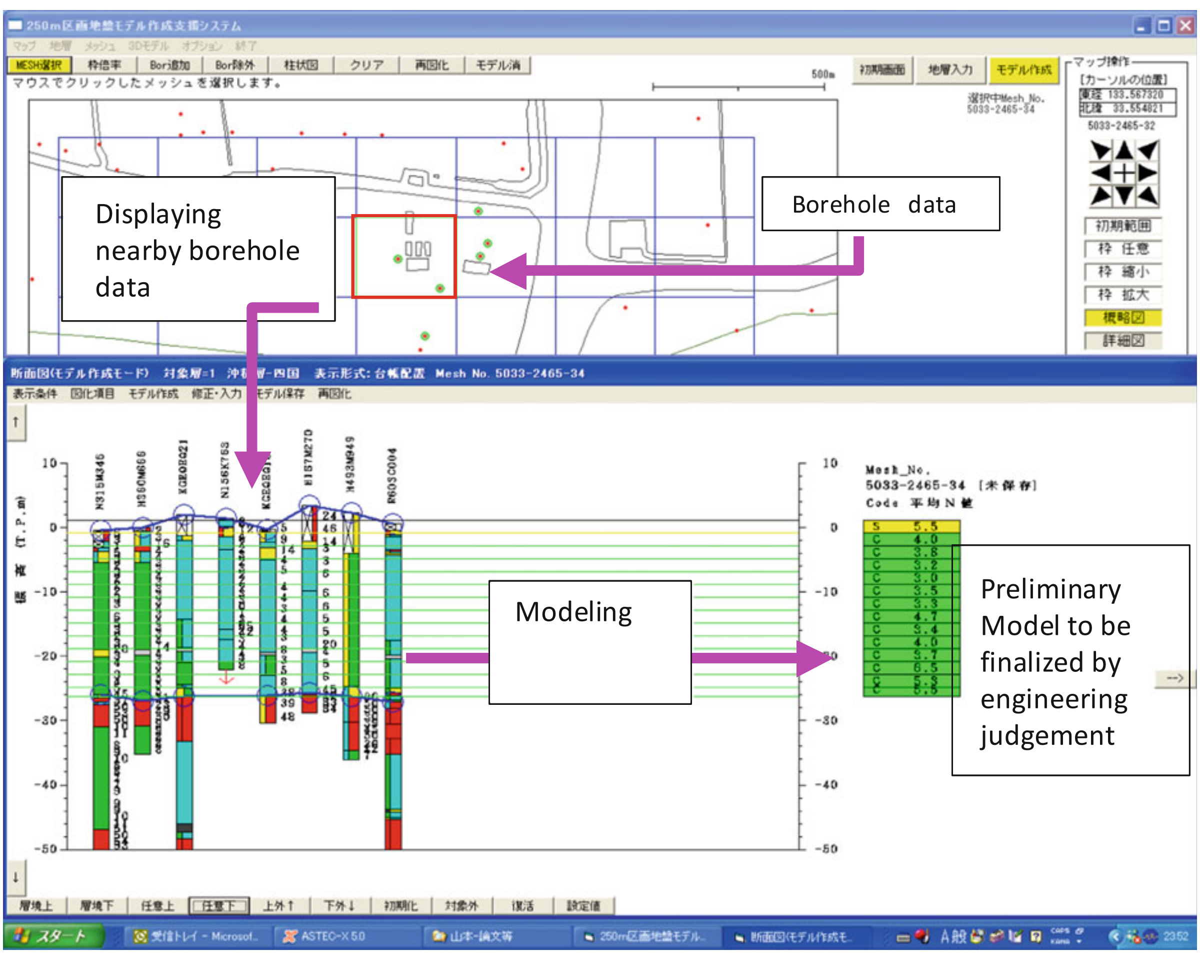


Fig. 11 Example of construction of ground model

Table 2 Ground conditions for trail construction of NEGDS

Area	Ground conditions
Osaka	Typical large alluvial plain
Fukuoka	Reclaimed ground, steeply sloped ground
Sapporo	Peat, volcanic ash
Matsuyama	Fan, sloped ground
Tokyo	Valley tributary etching terrace
Niigata	Natural and artificial sand ground

consists of geotechnical engineers, geologists, and specialists for topography and land formation from geotechnical consulting companies, universities, geotechnical investigation companies, for example. As of March 2012, there are 18 local specialist teams at 18 cities shown in Fig. 9.

The models can be modified anytime by the local teams if and when additional boreholes become available. The users can download the information contained in the model, but cannot modify the published models.

4.3.4 *Tests Against Various Ground Conditions and Improvements of Systems*

In order to check usability and applicability of the systems, the work team conducted a series of trials at various ground conditions. Table 2 lists the ground conditions selected for the trials. This trial was necessary because the prototype systems had been developed for a typical ground of the Osaka Plain where a relatively large plain is present with almost uniformly distributed thick Holocene deposits. The system was modified and upgraded based on the trials.

The number of the boreholes within a grid cell is not uniform. Some grid areas contain no borehole data, while other contains more than 20 boreholes. Figure 12 (Mimura and Yamamoto 2008) is an example from central parts of Osaka for uneven borehole density distribution. Also, the boreholes are not evenly spread within a grid area as shown in Fig. 13 (Mimura and Yamamoto 2008). Therefore, the model constructed by only the borehole data within a grid cell does not necessarily represent an average ground condition. The Nation-wide Electronic Geotechnical Database Systems (NEGDS) can overcome such uneven distribution of borehole data by taking the surrounding geology and ground conditions into consideration when constructing a model.

Discussions are in progress on how to model the ground where two or more different ground conditions exist within a grid cell. For example, in a central Tokyo area, complex tributary systems of valleys filled with alluvial deposits develop by etching

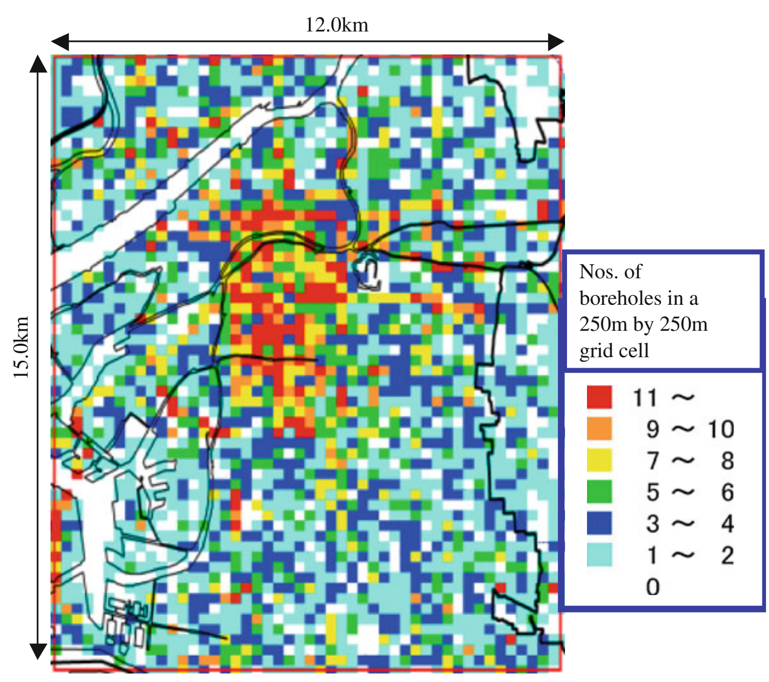


Fig. 12 Uneven borehole density distributions, Osaka as an example (Mimura and Yamamoto 2008)

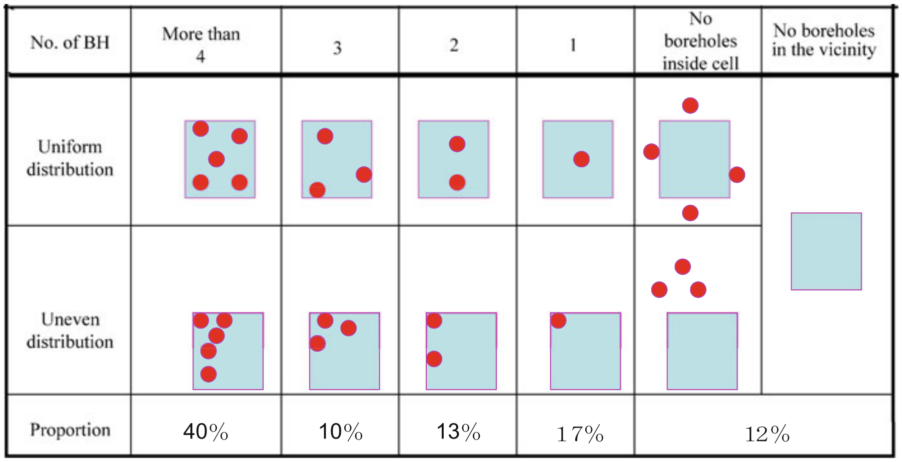


Fig. 13 Uneven distributions of boreholes in a mesh (Mimura and Yamamoto 2008)

terraces consisting of Pleistocene to Tertiary deposits as shown in Fig. 14, and both the alluvial and the terrace ground may be present within a single cell of 250 m by 250 m depending on the location. The methods to handle this situation being discussed are: (1) representing the entire area of the cell by the largest landform area in the cell, (2) overlaying the grid map by topographic maps and geological maps so that the viewers can understand different landforms being present within a grid cell, and (3) subdividing a 250 m by 250 m cell into smaller cells. The presently applied method is that the poorest ground conditions in terms of the geotechnical engineering represent the entire area of the grid cell concerned.

NEGDS has to include all types of soils distributed in Japan. During the trials, additional soil types were included in the systems. However, the present systems are incapable of representing all the soil types in Japan, for example, the volcanic ash. The pyroclastic flow deposits distributed near Sapporo, Hokkaido, and near Kagoshima, Kyushu, have a few distinct appearances such as original pyroclastic flow deposits, deposits of falling ash, and redeposition of those deposits after erosion, each having totally different geotechnical properties. The representation of these different types of materials needs to be developed in NEGDS.

The work team's initial intention to define the surface deposits by only geological history such as Holocene deposits did not work well, because foundation bearing layers that are often older than the Holocene are excluded. Also, there are places of thin Holocene deposits underlain by soft Pleistocene deposits or places of loose ground even in Pleistocene deposits. Instead of setting a uniform rule for a boundary, the work team decided to fix the target zone depending on local engineering practice such as foundation depth and bearing layers of piles. For example, SPT N-value of 30 within Holocene sand deposits is used to define the bottom boundary of the models in Niigata, while SPT N-value of 50 either in Holocene or Pleistocene deposits is used in Tokyo.

4.3.5 Viewer for Assembled Models

The work team developed viewers (Sub-systems 2 and 4 in Fig. 10) in order to view the ground conditions after a number of the ground models of 250 m by 250 in plan have been digitally accumulated. The viewer has the following functions:

Description of geological and topographical background The viewer has an explanatory section describing local geological conditions and sedimentation environment, especially Pleistocene to Holocene period together with micro-topographic conditions. It is important for the users to have knowledge of the local geology and topography before viewing the ground models.

Function to pinpoint a location on a map on computer screen The user can pinpoint the desired location. Then, an 'x' mark appears on the location as shown near a large letter 'A' in Fig. 15. The viewer displays a ground model at the location as shown on the left side of the figure. Yellow colour represents sandy soil and green colour clayey soil.

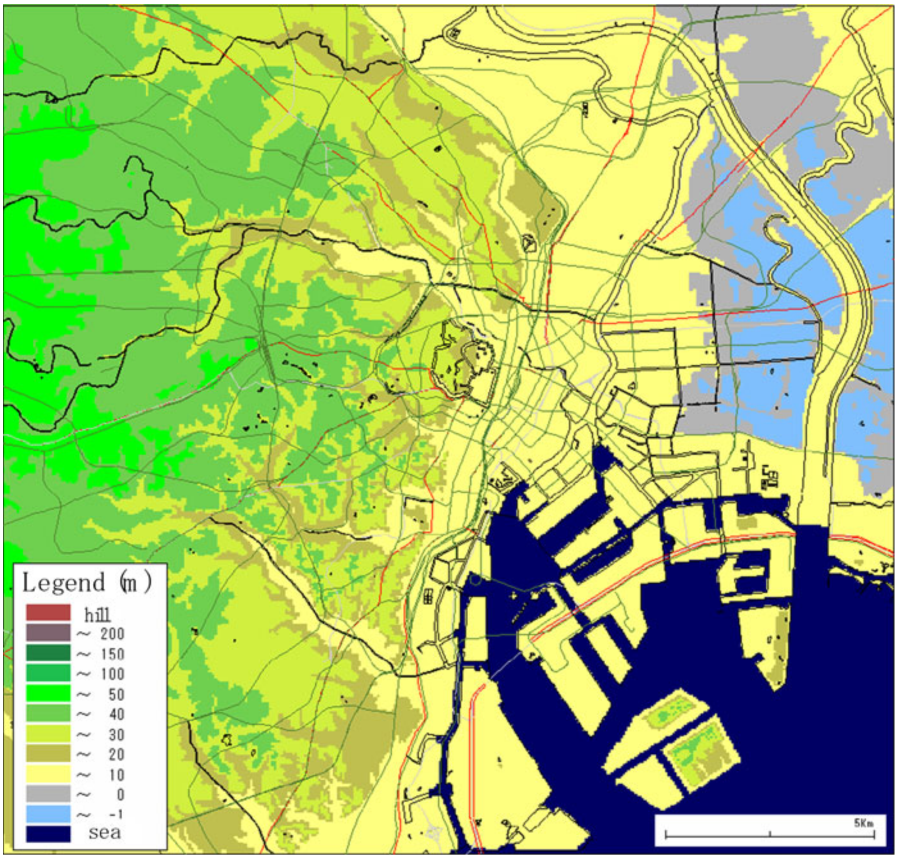


Fig. 14 Tributary of valleys in Tokyo central area

Function to draw a soil cross section Where the user wants to view a soil cross section, the user can draw a line on a map displayed on a computer screen (shown as line A-B in Fig. 15), and a separate window appears with a soil cross section along the line as shown in Fig. 15.

Function to display depths to foundation bearing layers Figure 16 is an example from Tokyo, showing different depths to the foundation-bearing layer in different colours. Foundation engineers commonly assume a foundation-bearing layer for heavy structures in Tokyo area to be the soil layers having thick zones of SPT N-values greater than 50. Similarly viewed by the systems are the thickness of the Holocene deposits, depths to SPT N-value of 50, depths to SPT N-value of 30, and others.

Function to show soil types at different depths Figure 17 shows a plan view of soil types at depth of 10 m at Tokyo, indicating each soil type in different colour; clayey soil in green, sandy soil in orange, and gravel soil in red. Difference in tone of the colour signifies different ranges of SPT N-values. The system has another plan view function to show SPT N-value numerically at each grid cell at a specified depth instead of a range of SPT N-value as shown in Fig. 17.

4.3.6 Internet Connection

Once connected to JGS' server through the internet, a user is guided to select a city and can look at the figures like those presented above by manoeuvring buttons on the screen. The web site is accessible from all countries, but only displayed in Japanese for the time being. There is a message box for users to submit comments to the work team, who is currently operating NEGDS. This is Subsystem 3 in Fig. 10.

4.3.7 Archiving Non-digital Data

There are a lot of old geotechnical databases in Japan published as borehole data books containing borehole

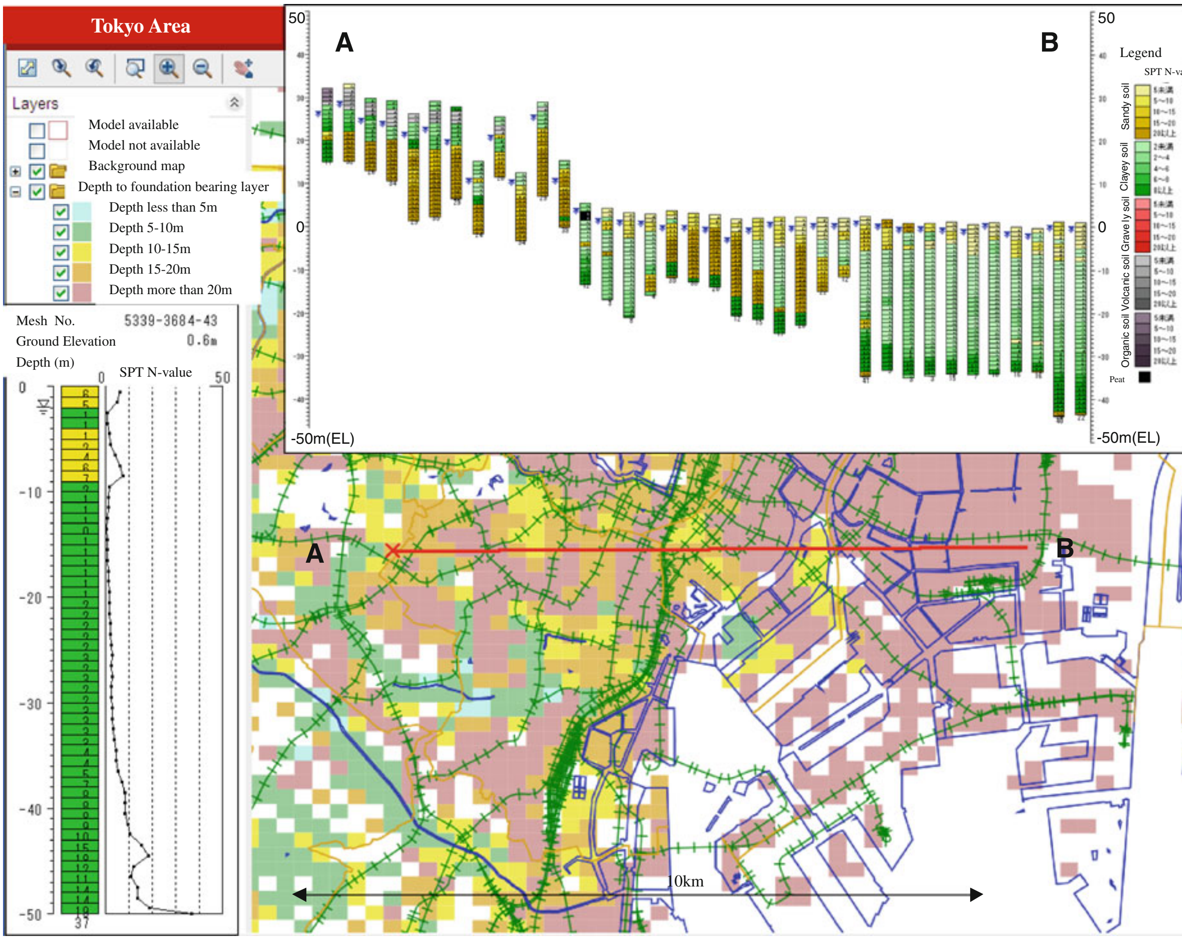


Fig. 15 Soil models cross section, central Tokyo

logs, soil cross sections, laboratory data, in situ test data, and other geophysical investigation data as described in Sect. 2.1. With passing time after their publication, they were forgotten, lost, abandoned, or buried under piled documents. Before they are completely gone, the work team attempted to archive those data. The intention of providing the archiving function in NEGDS is to collect and save those old, non-digital data, which are difficult to digitise and incorporate into NEGDS at present. If they are collected and archived, these data could one day in future be incorporated into NEGDS. Subsystem 5 in Fig. 10 represents this function.

The final form of the archives is collection of PDF files produced by scanning old borehole data books, and other information on the ground conditions such as geotechnical literature and construction records. As the first step, the work team conducted the survey for the old borehole data books with the following information: title, ownership/publisher, area coverage, number of boreholes, and permission for archiving. The survey data will be, as the next step, published on the internet.

5 Merits and Application of NEGDS

There are merits and possible application of NEGDS in the geotechnical engineering as follows.

Merits for researchers on geotechnical properties of soils The systems can provide geotechnical information on urban areas, which is important subject for the researchers of geotechnical engineering. A new research area on soil properties may grow because the systems, covering the entire Japan, make it possible to

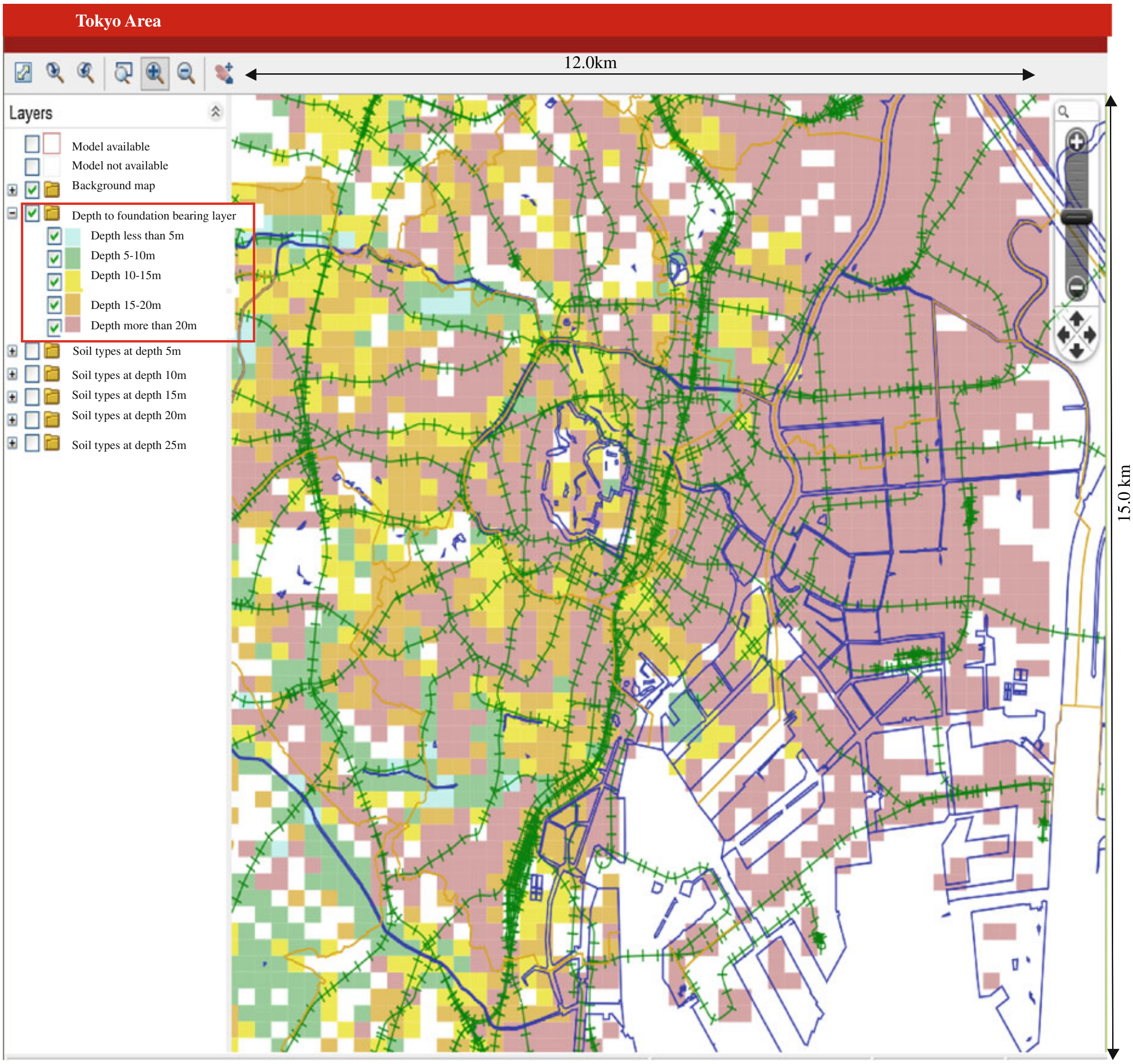


Fig. 16 Depths to foundation bearing layer, central Tokyo

compare properties of similar soil types with similar depositional environment, the same depositional age, but in different localities. Conventionally, most of researches on soil properties have concentrated on soils in particular areas familiar to them. It is expected that such comparative studies of soil properties provide more in-depth understanding of properties of local soil deposits.

Merits for practicing geotechnical engineers Using the systems, practicing geotechnical engineers in Japan can understand potential problems and risks for proposed structures anywhere when they plan geotechnical investigations, because the system can provide the ground conditions at any part of in Japan. They can also obtain literatures or case records of similar problematic ground conditions in other areas.

Merits for the public Based on the soil information obtained from the systems, the public can easily get advices on potential troubles related to the ground from professionals when they plan to buy land or houses. Liquefaction, ground subsidence, and slope movements are examples for the potential troubles. The NEGDS model information may have certain influence to the public. Misinterpretation of the

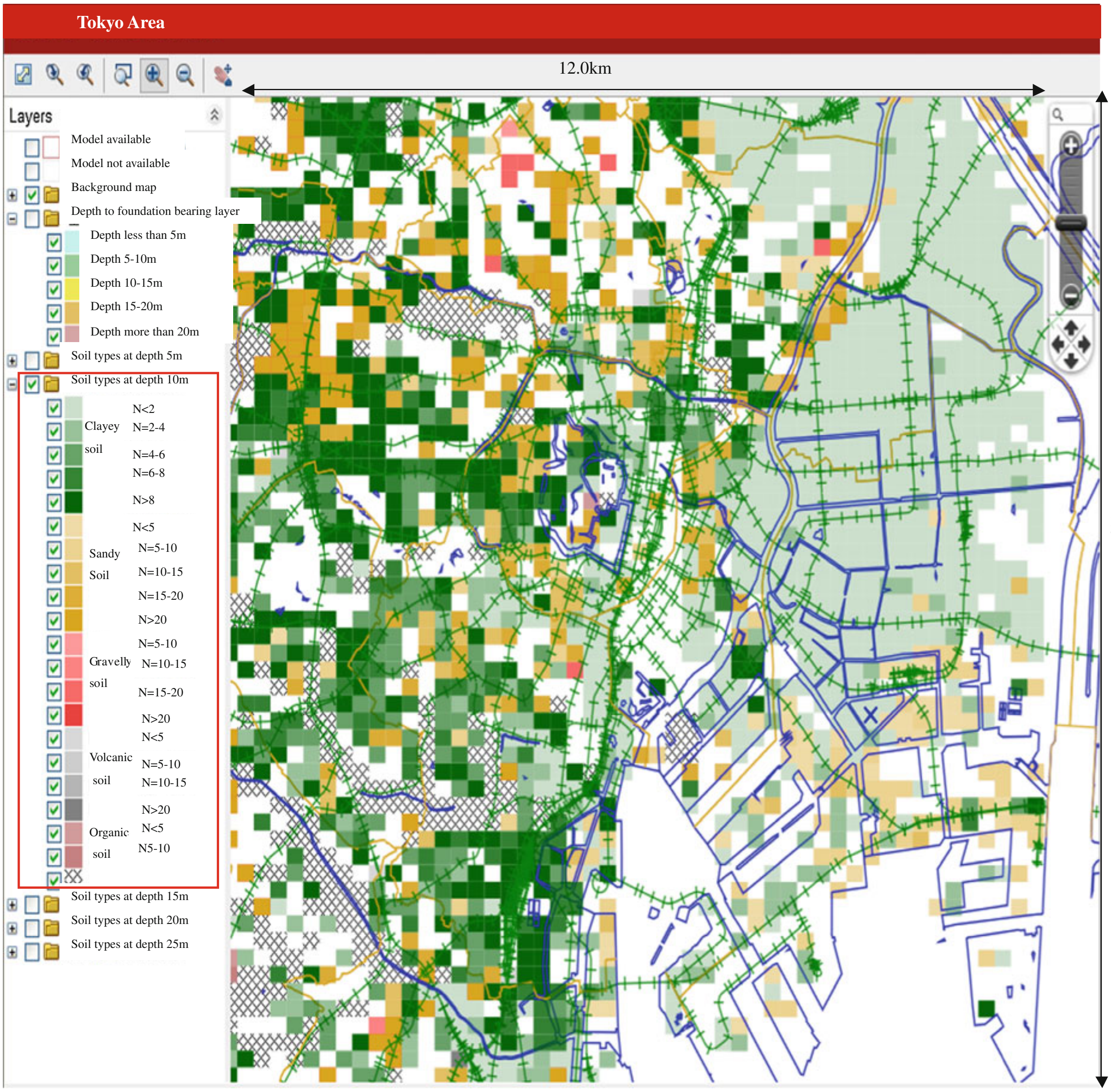


Fig. 17 Soil types and SPT N-values at depth of 10 m, central Tokyo

models may lead to improper perspective on the ground conditions and false awareness of potential geotechnical problems and geo-hazards.

It is advisable for the public to consult with the professionals for interpretation of the models, because judgement for potential troubles needs a little technical knowledge and geotechnical practice. When a 250 m grid cell is selected on the map shown on a computer screen, a ground model comes out in a separate window with soil types (sand or clay) and SPT N-values at every 1 or 2 m depth to the bottom of the model, as shown in Fig. 15. With such information, geotechnical professionals are able to tell potentials for liquefaction, ground subsidence, and other geo-hazards that the public is normally concerned with. Since more information is attached to the model, such as ground water levels and various test results, the professionals can analyze potential problems in detail if judged necessary.

It is emphasized that the model represents average ground conditions of a 250 m by 250 m area, not the ground conditions at a pin point location, where the ground conditions may differ significantly from the average ground conditions. In that context, the ground models NEGDS provides are preliminary information on the ground conditions. The models are not suitable for actual foundation designs, and building authorities do not grant building permits without geotechnical investigation results obtained at pin-point locations.

Quality evaluation of data contained in geotechnical information databases The trial application during the development of NEGDS as described in Sect. 4.3.4 immediately made it evident that a lot of faulty data was contained in many existing databases, which are seemingly subjected to rigorous screening procedures and supposedly very reliable databases. For example, ground elevations are missing, groundwater levels are absent, and soil types of reclaimed ground are unavailable. Furthermore, a single borehole was doubly registered at different locations and at different elevations. About 1 % of total 30,000 registered boreholes in Kyushu Geotechnical Information Database were found to be not reliable. As one of the advantage of NEGDS, questionable data are excluded as much as possible during modelling procedure by the local specialist teams as described in Sect. 4.3.3 because each borehole data is checked by comparing with the surrounding ground conditions and nearby borehole data, while only an individual borehole data is checked in case of a usual borehole database without reference to surrounding data. Thus NEGDS provides ground models with reliable data only.

Application to Liquefaction Hazard Maps The work team plans to develop and install add-on functions to NEGDS, one of which is simple software to calculate liquefaction potential. With a series of calculation to be performed by the work team (not by the users), NEGDS is able to show potential liquefaction in a grid cell area during earthquake. This information is useful when someone considers buying a house or a piece of land in earthquake prone countries like Japan. After the Great East Japan Earthquake Disaster, the ground conditions are one of the concerns for the public when buying a house, because liquefaction occurred in a very large scale at many places causing damage to many houses. Figure 18 is an example of liquefaction hazard maps assuming the present ground water levels in Osaka (Kasugai et al. 2009). The figure presents liquefaction potential by non-dimensional value of PL (potential of liquefaction), which are differentiated by different colour; high PL values in red and low values in green.

Application to Seismic Hazard Map NEGDS has a potential capability for estimating the distribution of the surface peak particle velocity, the maximum acceleration, and the maximum displacement during an earthquake. This application is still at the beginning stage of research and development. Figure 19 is an example of the peak particle velocity distribution in Tokyo (Yasuda and Watanabe 2010) obtained by trial calculations for demonstrating potential use of NEGDS for the seismic hazard map. In the calculation of this example, a seismic wave of a certain period was applied at the bottom of each model, causing the wave to travel one dimensionally and reciprocally between the top and the bottom of the model. The calculation requires various assumptions to be made, such as wave propagation velocity in the model ground, modulus of different soil materials, damping factors, and the epicentre and magnitude of the earthquake, all of which need tremendous efforts for researchers to establish.

Figure 19 shows that surface particle velocities are low in the eastern part of Tokyo, which corresponds to low-lying area as shown in topographic features in Fig. 14. The places where the peak particle velocities are high in Fig. 19 correspond to the edge of the terrace ground seen in Fig. 14 where mouths of valleys are present with soft organic deposits.

How to present to the public the prediction of the velocity, acceleration, and displacement during earthquakes is another issue. Publication of such prediction should not confuse the public and should not send wrong messages. Such publication should be combined with public awareness programme for potential seismic risk, and social education for correct knowledge of shaking prediction and preparedness for possible seismic disaster.

Application to Regional Geotechnical Study Since the NEDGS provides basis for 3 dimensional grid model of the ground, geotechnical studies for broad areas such as earthquake response of the ground, ground settlements, and groundwater flow in prefecture sizes may advance using, for example, finite element analyses. Of course three dimensional finite element analyses for the ground under vast extent of land consisting of various topographic features, various

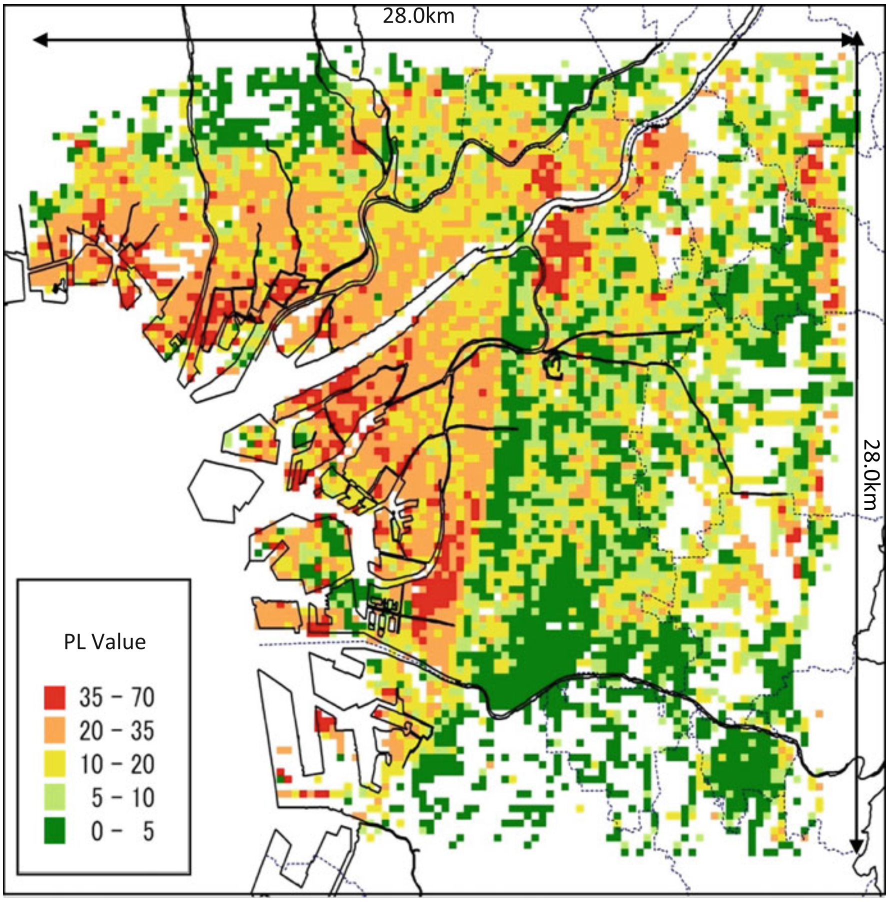


Fig. 18 Liquefaction potential map, Osaka (Kasugai et al. 2009)

PL = 0.0	No or little potential of liquefaction
0.0 < PL≦5.0	Low potential of liquefaction
5.0 < PL≦15.0	Liquefaction possible
15.0 < PL	High potential of liquefaction

geological formations, and various soil and rock materials requires tremendous volume of reasonably accurate data, as well as high-specification computers.

6 Challenges for Further Development

There are challenges for the further development of NEGDS in addition to the problems described earlier.

Funding problems for sustainable development of NEGDS Even after the NEGDS project supported by national fund completed in 2010, JGS continues expanding the coverage areas and maintaining the systems until March 2014 without outside financial support. The current work is supported by volunteers of JGS members from various parts of Japan. Permanent arrangement for the financing is challenging for continuing further expansion of the coverage areas and the on-line delivery of the data.

Organization for further development of NEGDS In order to continue building the database systems beyond the 5-year funding period, the work team proposed to set up a study organization to continuously build and maintain NEGDS. The study organization will consist of nine regional panels at each regional chapter of JGS and the central panel at the head-quarter of JGS.

The regional panels (1) back up development of local geotechnical databases within their region, (2) study local soil conditions and geology with the

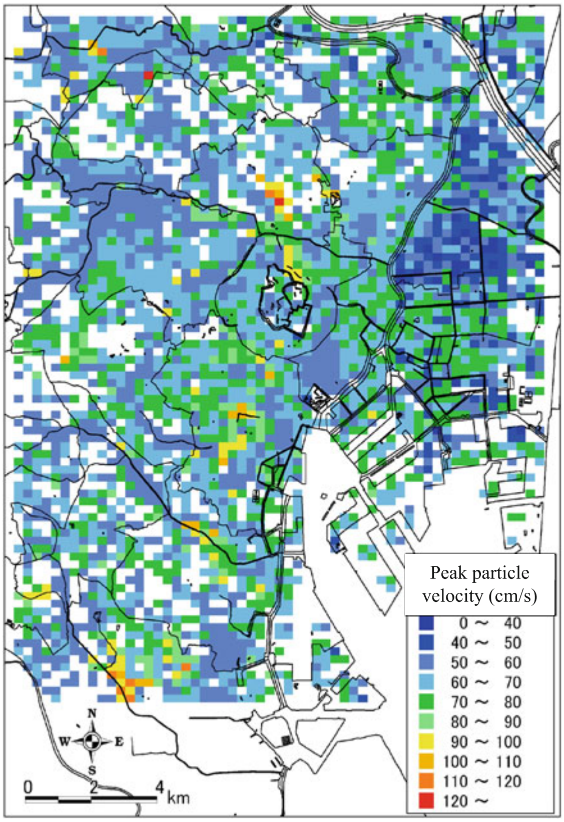


Fig. 19 Example of calculated surface peak particle velocity, Tokyo (Yasuda and Watanabe 2010)

assistance of geotechnical databases, (3) research how to use the databases, and (4) build and maintain the local portion of NEGDS.

The central panel (1) backs up the regional panels in the development of local geotechnical databases, (2) coordinates cooperation among the regional panels, (3) backs up the study of the local soil conditions and geology with the assistance of geotechnical databases, (4) assembles NEGDS based on the those each regional panel has constructed, and (5) coordinates linkage of NEGDS to the Integrated Geophysical and Geological Information Database (IGGID).

The regional panels that have been already active for a long time for development, maintenance, and administration of the regional geotechnical information databases and NEGDS are expected to back up and support other regional panels that started activity lately by providing the following knowledge and experience. The expected back up and supports are as follows:

- Data contents that the geotechnical information database should have
- Funding method
- Quality evaluation of the data
- Function the database should provide
- Application of the databases
- Issues related to digital networking of the databases
- Issues related to ownership, copy rights, and use right of the data
- Privately obtained data submitted to the authorities as a part of building permit
- Means to collect private companies' data as described in Sect. 2.3
- Maintenance and administration of the databases
- Responsibility of each party involved in various aspects of the databases

Problems related to modelling There are numerous problems related to the modelling, some of which are presented as follows.

- Discontinuous planes such as faults, line structures like river dykes, and localized landforms and ground need better way of expressions.
- The presently published models, which are the results of the trial development, are limited to central parts of 9 cities as shown in Fig. 9 and contains soil types and SPT N-values only, although the models are designed to contain as many and as much information as possible, as described in Sect. 4.3.2. As the coordinated construction of the models all over Japan has just started, the public can expect much more development of the quality and quantity of the models.
- User education is necessary for correct interpretation of the models as more various types of geotechnical data are to be contained.

Continuous improvement of ground models and the systems The systems allow modifying the ground models from time to time when new borehole data are available. A permanent organization such as the local panels as discussed above is required to continuously modify the ground models. The updating of the models is necessary when the topographic conditions have changed, like reclamation, filling, and excavation. The change of the groundwater levels should also be incorporated into the models.

7 Conclusions

The paper introduces Japan's NEGDS, which JGS built aiming at linkage, collaboration, and corporation of various databases in Japan. The systems, although still rudimentary in data contents, were published on the internet on October 15, 2010 and have received attention of mass media as a tool for the public to check the ground conditions.

NEGDS can electronically construct, save, modify, and display the ground model of 250 m by 250 m in plan. The information is available to the public through the internet. The presently published models are limited to central parts of 9 cities and contain very limited source of information such as soil types and SPT N-values.

The systems provide opportunities for researchers to compare properties of similar soil types with similar depositional environment, the same depositional age, but in different localities in Japan. Such comparative studies of soil properties provide more in-depth understanding of properties of local soil deposits.

Practicing geotechnical engineers in Japan can understand potential problems and risks for proposed structures anywhere and they can incorporate such knowledge when they plan geotechnical investigations. As the systems provide geotechnical information in general, detailed geotechnical investigations are necessary at pin-point locations when designing foundations, excavations, slopes, and retaining walls. The ground models NEGDS provides are preliminary information on the ground conditions and are not suitable for actual foundation designs.

The NEGDS provides information, albeit in general, for preliminary judgement of potential geohazard such as liquefaction, earthquake shaking, ground subsidence, and slope movements.

The public can easily get advices on potential troubles related to the ground from professionals when they plan to buy land or houses. The public is advised to consult with the professionals for interpretation of the models. User education is necessary for correct interpretation of the data, as NEGDS become more popular in the public.

Potential application of NEGDS includes liquefaction hazard maps, seismic shaking hazard maps, estimates of ground subsidence in broad area, and groundwater flow maps. Advance of these application requires extensive research on model parameters.

Stable funding method is being sought in order to expand coverage areas of NEGDS, to improve data contents in each model, updating the existing models, and to research various applications.

For the continuous development of NEGDS as well as local geotechnical databases, an organization consisting of the central panel and nine regional panels was proposed to set up. NEGDS models need to be improved and refined to more accurately represent the ground conditions. Data contents have to be improved.

Acknowledgments The authors are grateful to Geo-Research Institute, who developed the computer software of the systems under the supervision of JGS' work team, 'Shallow Ground Data Base Linkage.'

References

Act on Access to Information Held by Administrative Organs (Act No. 42 of 1999), English translation available at http://eiyaku.hounavi.jp/eigo/h11a04201.php

Bureau of Port and Harbor, Tokyo Metropolitan Government (2001) New borehole data book of Tokyo Port, 2001 (written in Japanese)

Geo-Station by the National Research Institute for Earth Science and Disaster Prevention (2009) available at http://www.geo-stn.bosai.go.jp/jps/index.html (English pages are available)

Kansai chapter of the Japanese Geotechnical Society (1993) New borehole data book of Osaka Area. Korona-Sha, 1993 (written in Japanese)

Kasugai M, Oshima A, Hamada T, Yamamoto K (2009) Liquefaction potential in alluvial sand layers in Osaka Area and effects of countermeasures by lowering groundwater levels. Symposium on groundwater and geo-environment 2009 (written in Japanese)

Kinki Chapter of Japanese Architectural Institute and Kansai Chapter of Japanese Geotechnical Society (1966) Borehole data book of Osaka Area. Korona-sha, 1966 (written in Japanese)

Kuni-jiban by the Ministry of Land, Infrastructure, Transport and Tourism (2008) available at http://www.kunijiban.pwri.go.jp (written in Japanese)

Mimura M, Yamamoto K (2008) Development of representative soil profile model based on geoinformatic database. International symposium and exhibition on geoinformation 2008, Kuala Lumpur, Malaysia

Nation-wide Electronic Geotechnical Database Systems (2010) web site at http://www.denshi-jiban.jp (written in Japanese)

Research Committee on Ground in Osaka Bay (2002) Ground and construction of Bay Area—Osaka Bay area as an example. Association of Research on Geotechnical Information in Osaka Bay, 2002 (written in Japanese)

Soil Contamination Countermeasures Act (Act No. 53 of 2002), English translation available at http://eiyaku.hounavi.jp/eigo/h14a05301.php

Yasuda S, Watanabe H (2010) A study on vibration of ground at Central Tokyo during earthquakes using the nation-wide electronic geotechnical database systems. In: Proceedings of 13th Japan earthquake engineering symposium (written in Japanese)