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TECHNICAL REPORT

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Construction of Web-GIS for integrating geophysical survey data with geotechnical information in the San'in region, southwest Japan

Isamu Nishimura, Tatsuya Noguchi* and Takao Kagawa

Abstract

Constructing geotechnical information database to collect information such as geophysical survey results and borehole data and then sharing it among researchers and engineers will be useful for developing research on the subsurface structure and the prevention of disasters such as earthquakes and landslides. The geotechnical information includes analysis results based on geophysical surveys, seismic observations, and borehole data. This database can be visually displayed on a map using a Geographic Information System (GIS). The existing analysis results can be checked consecutively. This will allow us to consider new observation plans and to improve the efficiency and accuracy of the subsurface structure model analysis. Therefore, in this study, a database of geotechnical information was developed for the San'in, Japan region. The San'in, Japan region is the western part of Honshu on the Sea of Japan side and includes Tottori and Shimane prefectures. The database of geotechnical information includes the results of microtremor and gravity survey, estimation of the subsurface structure based on seismic records, and borehole data in Tottori and Shimane prefectures. We gather high dense survey points from multiple references in the San'in region, Japan, such that the average space intervals of single station microtremor, microtremor array, gravity survey, and borehole were around 0.1–1, 1–5, 1, and 0.1–1 km, respectively. Furthermore, the corresponding sites of each survey type were conducted over 6000, over 280, over 7500, and over 3700, respectively. In addition, we developed a system to display the database on a map in a web browser (Web-GIS). GIS, Leaflet, a JavaScript library, were used to display the database of geotechnical information using the Geospatial Information Authority of Japan (GSI) tiled map as the base map. The developed database on the GIS system will be a useful tool that can be used by researchers, engineers, and other stakeholders in the future.

Keywords: Database of geotechnical information, Web-GIS, San'in region, Southwest Japan

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Graphical Abstract

Construction of Web-GIS for integrating geophysical survey data with geotechnical information in the San'in region, southwest Japan

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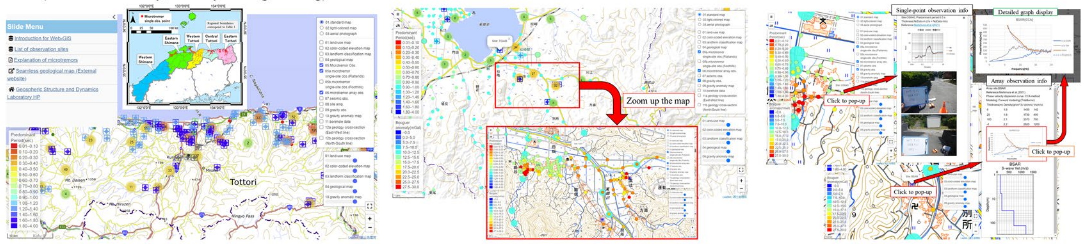
In this study, a database of geotechnical information was constructed for the San-in region. The database of geotechnical information includes the results of microtremor and gravity survey, analysis of ground structure by seismic observation, and borehole data in Tottori and Shimane prefectures. We then constructed a system (Web-GIS) to display the constructed database on a map in a web browser.



For the base system of the GIS, Leaflet, a Java Script library, was used to display the prepared database of geotechnical information using the GSI tiled map as the base map. The developed database and GIS system will be used to researchers and the public in the future.

Introduction

A geotechnical information database is imperative for estimating subsurface structures against hazards due to earthquakes and landslides. The database contains geotechnical information, including geophysical surveys, seismic record analysis results, and borehole data. The aggregation and sharing of these data among researchers and engineers will lead to the development of subsurface structure estimation research. To construct and visualize the databases, existing results and data can be shared using Geographic Information System (GIS). This process allows for the efficient assessment of additional observation plans. Also, it is possible to improve the accuracy of the estimation of the subsurface structure model by efficiently applying the existing results. The potential users of the database and GIS could be researchers and practitioners from research institutes and construction companies and general users from municipalities and educational institutions. Nowadays, parameters and the network environment of computers have improved. Many types of tilemaps such as topographic and geological maps are available digitally, so it would be useful to develop a display system using these maps.

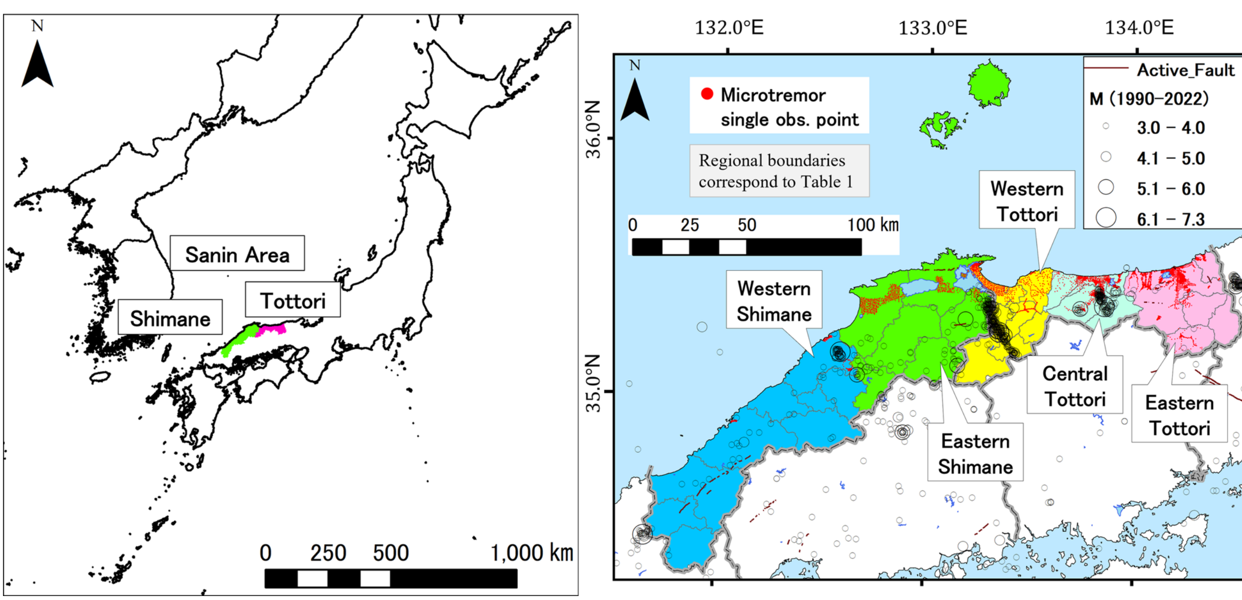


Fig. 1 Location of the San'in region (left map) and each region are shown in Table 1 (right map). The right map also shows the location of active faults, the distribution of epicenters of magnitude 3 or greater from January 1, 1990 to May 31, 2022 and the location of single-point observation sites for microtremors

Table 1 Contents of the geotechnical information database and number of observation points for each reference and observation methods

Area	Geotechnical information		References
	Microtremor		
	Single-obs	Array-obs	
Eastern Tottori	389	22	Noguchi and Nishida(2002)
	2744	123	Ishida et al.(2013)
Central Tottori	1536	93	Noguchi and Kagawa (2015), Nishimura et al.(2021)
Western Tottori	656	18	Yoshikawa et al.(2002)
Eastern Shimane	623	10	Adachi et al.(2006), Adachi et al.(2007), Adachi et al.(2009)
Western Shimane	283	18	Noguchi et al.(2009), Noguchi et al.(2020)
Total	6231	284	

Area	Seismic observation	References
Tottori, Shimane	10	Noguchi et al.(2016)

Area	Geotechnical information Gravity survey	References
Tottori	2417	Noguchi and Nishida(2002)
		Ishida et al.(2013)
		Noguchi and Kagawa(2015)
		Yoshikawa et al.(2002)
Shimane		Adachi et al.(2006), Adachi et al.(2007), Adachi et al.(2009)
Tottori, Shimane	3342	Komazawa(2013)
	1755	The Gravity Research Group in Southwest Japan(2001)
Total	7514	

Area	Borehole	References
Tottori, Shimane	3706	Chugoku Region Foundation Research Association(1995)

In this study, we focused on the San'in region, southwest Japan (Fig. 1). The San'in region, southwest Japan, is an active seismic area where relatively large-magnitude earthquakes such as the 1943 Tottori earthquake (Mj = 7.2), the 2000 Western Tottori prefecture earthquake (Mj = 7.3), the 2016 Central Tottori earthquake (Mj = 6.6), and the 2018 Western Shimane earthquake (Mj = 6.1) have occurred in the past. Figure 1 shows the location of active faults (Nakata and Imaizumi, 2002) and the distribution of epicenters of magnitude 3 or greater from January 1, 1990 to May 31, 2022 (The Japan Meteorological Agency 2022). These earthquakes have also caused damage in the region, making it a pilot region for promoting earthquake disaster prevention.

It is imperative to collect as much information as possible on the geotechnical structure to conduct seismic hazard assessments based on the earthquake damage surveys and geotechnical investigations. Therefore, it is important to consolidate geotechnical information efficiently and share it among researchers and engineers. An existing example of similar work is done by the Japan Seismic Hazard Information Station (J-SHIS) (The National Research Institute for Earth Science and Disaster Resilience 2005) for the results of seismic hazard assessment and the geotechnical information used in the assessment. Also, the work done by Kunijiban (The Ministry of Land, Infrastructure, Transport and Tourism 2008) and Geo-station (The National Research Institute for Earth Science and Disaster Resilience 2006) for borehole data. For the San'in region, there is a website where borehole data from Shimane prefecture can be viewed (Soil Research Center Shimane 2005). On these sites, we can only use the information managed by each institution, and we cannot add our information or change the operation specifications. It would be helpful for researchers and engineers if the results of the subsurface exploration by local research institutes could be immediately reflected in areas where the existing system's database is insufficient. Thus, we can

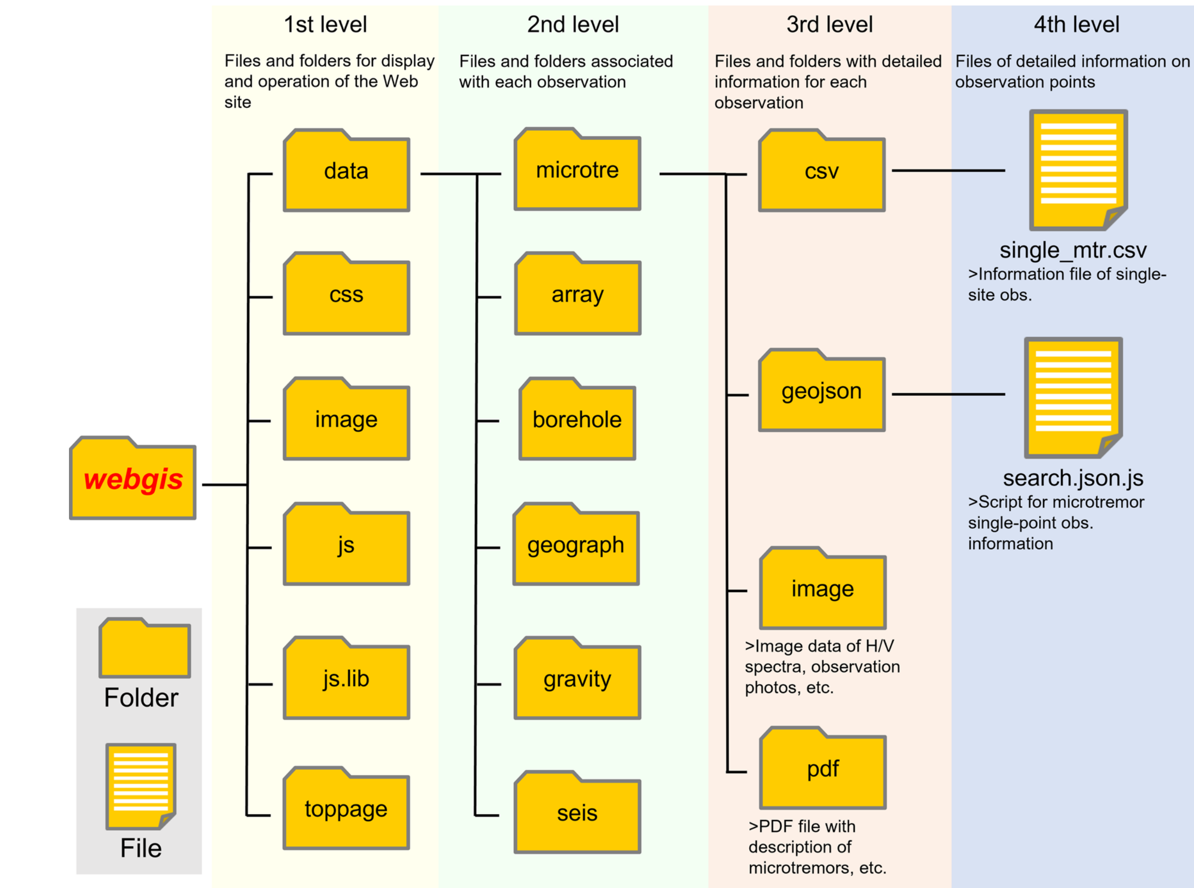


Fig. 2 This figure shows the directory structure of Web-GIS and the file structure related to the display of single-point observation points of microtremors

add more information and change the operating specifications needed to build our system.

In this study, the geotechnical information is based on geophysical surveys such as microtremors and gravity surveys, seismic observations and borehole data in Tottori and Shimane prefectures. We developed a system to display the information of the database on a map in a web browser.

Database of geotechnical information

The database of geotechnical information includes the results of microtremor and gravity survey (Noguchi and Nishida 2002; Ishida et al. 2013; Noguchi and Kagawa 2015; Nishimura et al., 2021; Yoshikawa et al. 2002; Adachi et al. 2006, 2007, 2009; Noguchi et al. 2009, 2020; Komazawa 2013; The Gravity Research Group in Southwest Japan 2001), analysis of ground structure based on seismic observation (Noguchi et al. 2016), and borehole data (Chugoku Region Foundation Research Association 1995) in Tottori and Shimane prefectures. As a data structure for use in the system, these data are used as point data. Attribute information related to the analysis results is added with the location information.

Table 1 shows the list of observation areas, corresponding research results, and data contents as of September 2021. The number of observation points for each reference and observation methods are also presented in Table 1. The areas shown in Table 1 correspond to those shown in Fig. 1 (map on the right). The regions of Tottori and Shimane Prefecture correspond to those shown in Table 1. Figure 1 also shows single-point observation sites for microtremors. The distribution of microtremor single stations is heterogeneous because the survey was conducted mainly in urban areas on the plains, since the objective was to obtain information related to earthquake disaster prevention. In other exploration and existing geotechnical information, there is a large amount of data in densely populated areas. The microtremor survey covers the plains of Tottori Prefecture (Tottori City, Kurayoshi City, Yonago City, Sakaiminato City) and Shimane Prefecture (Matsue City, Izumo City, Yasugi City, Ota City, Hamada City) and the densely populated mountain

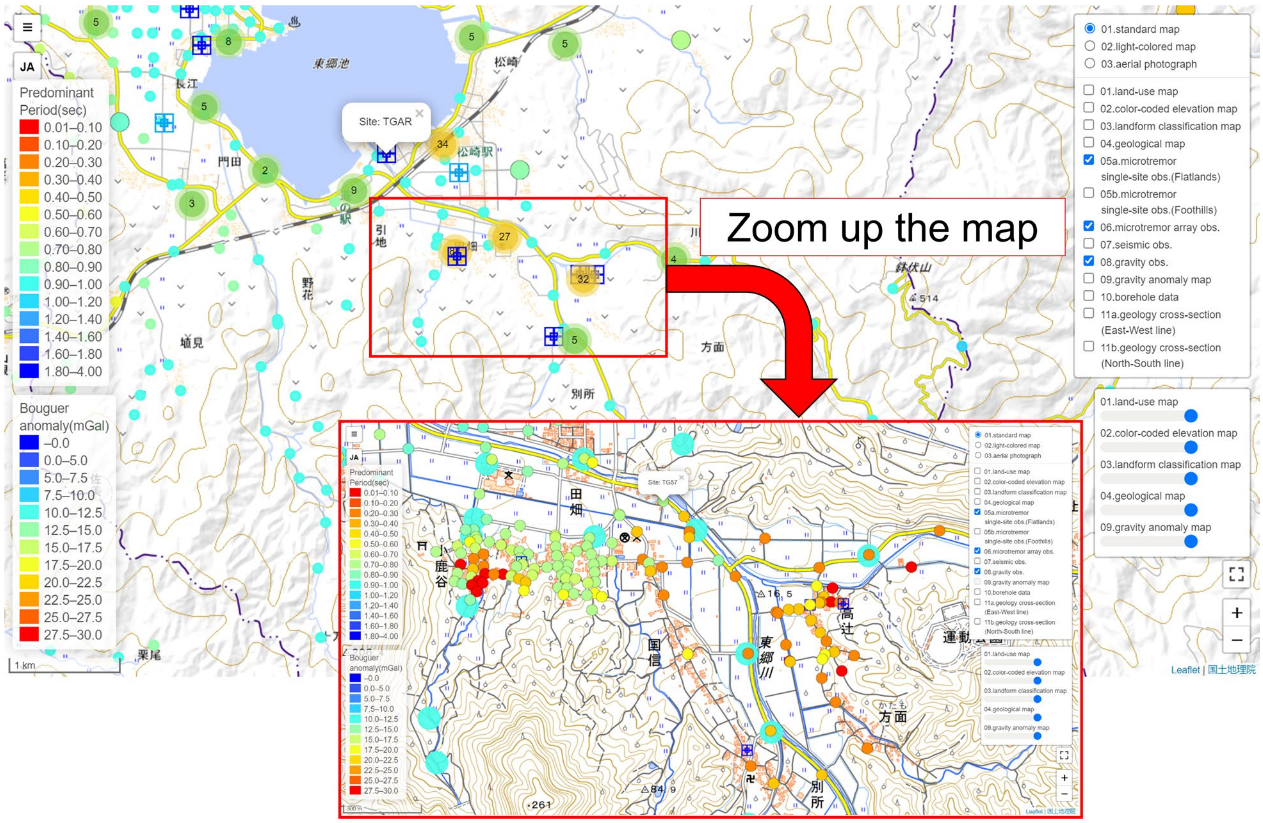


Fig. 3 Examples of a map with symbols of clusters, and a map with symbols of circle colors. The number of clustered points is displayed in the center of the symbol. Color symbols are displayed according to the colors in the legend on the left

areas of Tottori Prefecture (Chizu Town, Daisen Town) and their surrounding areas. The gravity survey data are available every 500 m in the plains and every 1 to 2 km in the mountains, covering almost the entire area of the target region except for a part of Shimane Prefecture. The average intervals for single station microtremor, microtremor arrays, gravity surveys, and boreholes were about 0.1–1 km, 1–5 km, 1 km, and 0.1–1 km, respectively. The sites corresponding to each survey type were conducted at more than 6000, 280, 7500, and 3700 sites, respectively. We plan to add microtremor and gravity survey sites in other densely populated areas in the future.

The results of the microtremor survey are the predominant period of the H/V spectral ratio and the layer thickness of the surface layer inferred from the single-point three-component observation, the phase velocity dispersion curve, the underground structure model from the observations. In some points, photographs taken during the observation are also included. The gravity survey results are the Bouguer anomaly at each station and the gridded data of the basement elevation obtained from the analysis. The results of the seismic observation are the H/V spectral ratio of the earthquake ground motion and the ground structure model. The borehole data include the soil conditions, layer thickness, and N-values at the study site. The cross-sectional geological map estimated from these data can also be displayed as images.

Web-GIS system

We developed a system to display various geotechnical information on a map using a web browser (from now on called Web-GIS). Leaflet, an open-source JavaScript library, displayed geotechnical information simply via a web browser. Figure 2 shows the directory structure of Web-GIS and the file structure related to the display of single-point observation points of microtremors. File structure and contents are shown in Additional files 1, 2, 3. The file structure to make this system work is as follows: (1) an Html file to display in a browser; (2) a pop-up display function for layer settings and attribute information; (3) a JavaScript file to load a tiled map, and (4) a CSS file to style the web page. The file information includes the observation method, data type, reference, observation point name, and location information. The tiled maps for the base map and the optional overlay are based on the mapping system provided by the Geospatial Information

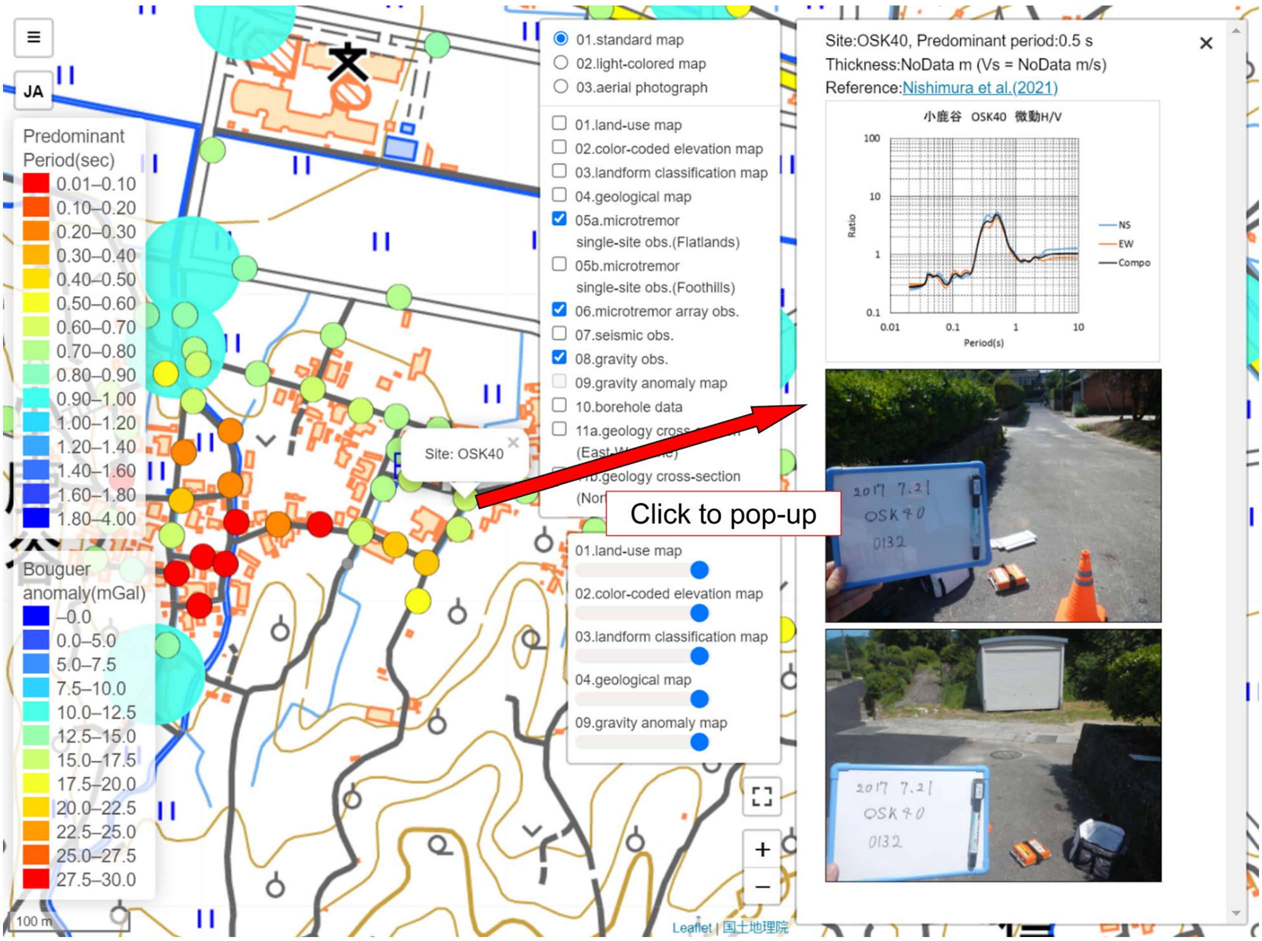


Fig. 4 This figure shows an example window of detailed information for a single-point. The right window of the single-point observation map shows basic information, H/V spectral ratio, and photos of the observation site

Authority of Japan. The base maps were standard, light-colored maps, and aerial photographs. Figure 3 shows an example of a map display in Web-GIS. The optional overlaid maps were land-use maps, color-coded elevation maps, landform classification maps, and geological maps (the right-side menu in Fig. 3).

The display functions and operations of Web-GIS are explained below (Fig. 3, Fig. 4, and Fig. 5), where results from microtremor surveys are displayed as an example. Figure 3 shows an example of displaying information from a single-point observation of a microtremor. On the map of the microtremor observation, the location of the three-component microtremor observation point and the predominant period of the H/V spectral ratio at that point are shown as color-coded circle symbols. The location of the array observation point is shown as a square symbol. The cluster display function is used according to the scale of the map because of the large number of points within a small region. An example of the automatic cluster display is shown in two red rectangles in Fig. 3. It is not easy to check individual survey points. At the same time, several tens of sites are located in the left one that a reasonable number of points in the cluster is displayed in the center of the symbol. The range of clustering is switched in several stages depending on the map scale. When the map is zoomed in further, a circle symbol in a different color is displayed for each point. The color coding is a gradation of colors from red to blue in 0.1-s increments up to 4.0 s. Figure 3 (lower map) shows an example of a map with symbols of circle colors. The predominant period at the foot of the mountains is shorter than that at the plains, and the band of variation is narrower. To highlight these changes, a distribution map with colors changing in increments of 0.05 s up to 0.7 s can be selected as the “05b.microtremor single-site obs. (Foothills)” function from the right-hand side menu in Fig. 3. When the user clicks on the circle symbol, another window appears on the right side of the screen, showing the name of the

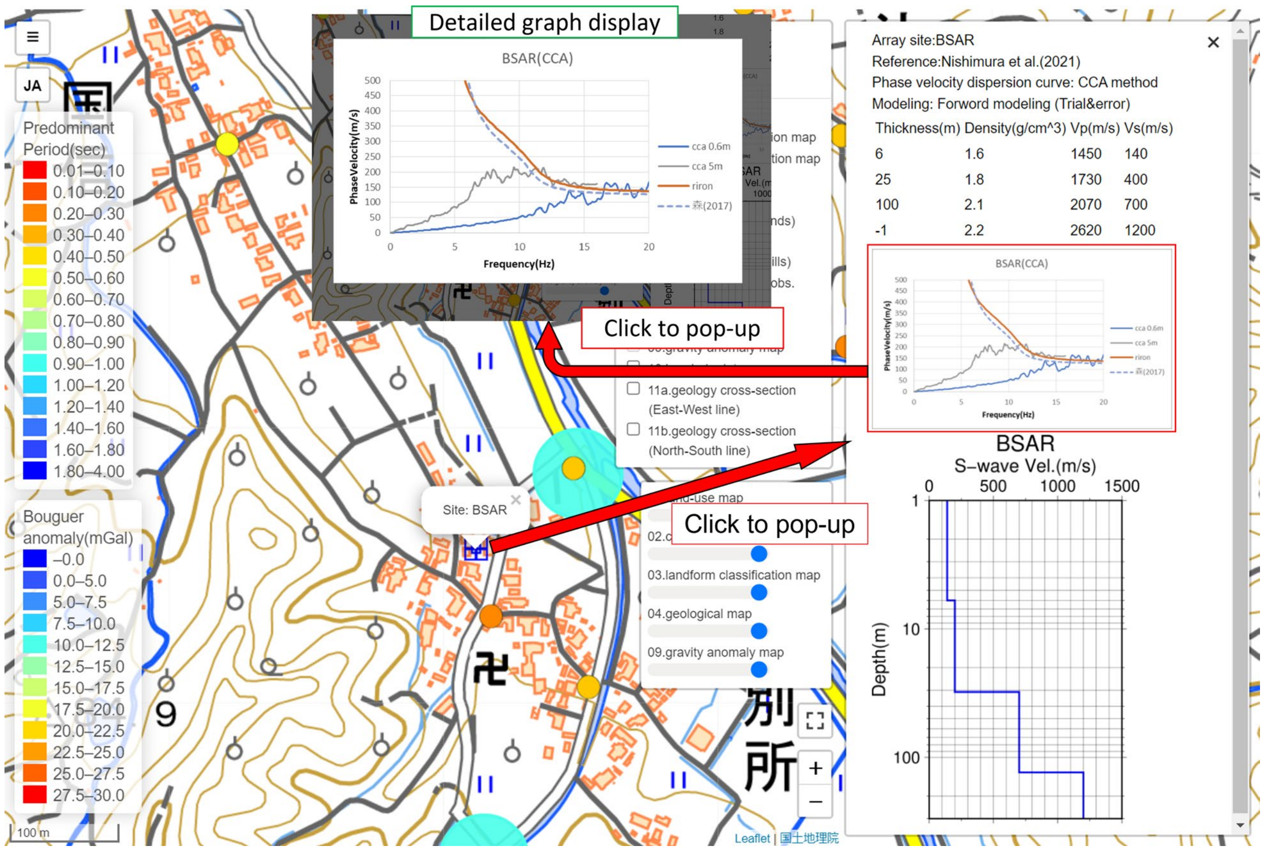


Fig. 5 This figure shows an example window of detailed information for array observations. The right window of the array observation map shows the subsurface model, the phase velocity dispersion curve, and a graph of the S-wave velocity model

observation point, the value of the predominant period, a link to the reference paper, a graph of the H/V spectral ratio, and a photo of the scene at the time of the observation if available (Fig. 4). In the future, we plan to display average S-wave velocity of the top 30 m of surface strata from microtremor H/V and ground structure model, and the layer thickness of the sedimentary layer at the location (currently set as No Data). By clicking on the square symbol of the microtremor array observation point, the name of the observation point, ground structure model, phase velocity dispersion curve, and estimated S-wave velocity structure models are displayed with the source of the results on the right side (Fig. 5). By clicking on the right-hand side figure (lower-right graph in Fig. 5), the detailed graph of the dispersion curve could be checked (center of the figure). Examples of gravity anomaly map, and seismic stations information are shown in Fig. 6 (Noguchi and Kagawa 2015), and Fig. 7, respectively.

Use of databases and Web-GIS

The database and Web-GIS are now being used at Tottori University. Web-GIS has an intuitive and easy-to-understand screen structure that can be accessed from a browser without complex procedures and does not require difficult setup and operation. In addition, we established an interaction responding system for users to feedback or self-operated the overlay comparison system with existing information that allows users to update the data immediately after analysis and check the results on the map. This makes it possible to compare the preliminary analysis results with the previous analysis results on the map and perform the analysis efficiently. It is also expected to improve the estimation accuracy of the subsurface structure model. If new geotechnical information is added in the future, the database will be updated consecutively. Information on subsurface structure and ground amplification estimated from microtremor and gravity survey results will be added. We also plan to add data not only from the San-in region, but also from Japan and overseas.

We are considering a simple file structure where data updates can be performed in line with other research institutes in the future. The research institute to which the author belongs will improve the display system, and

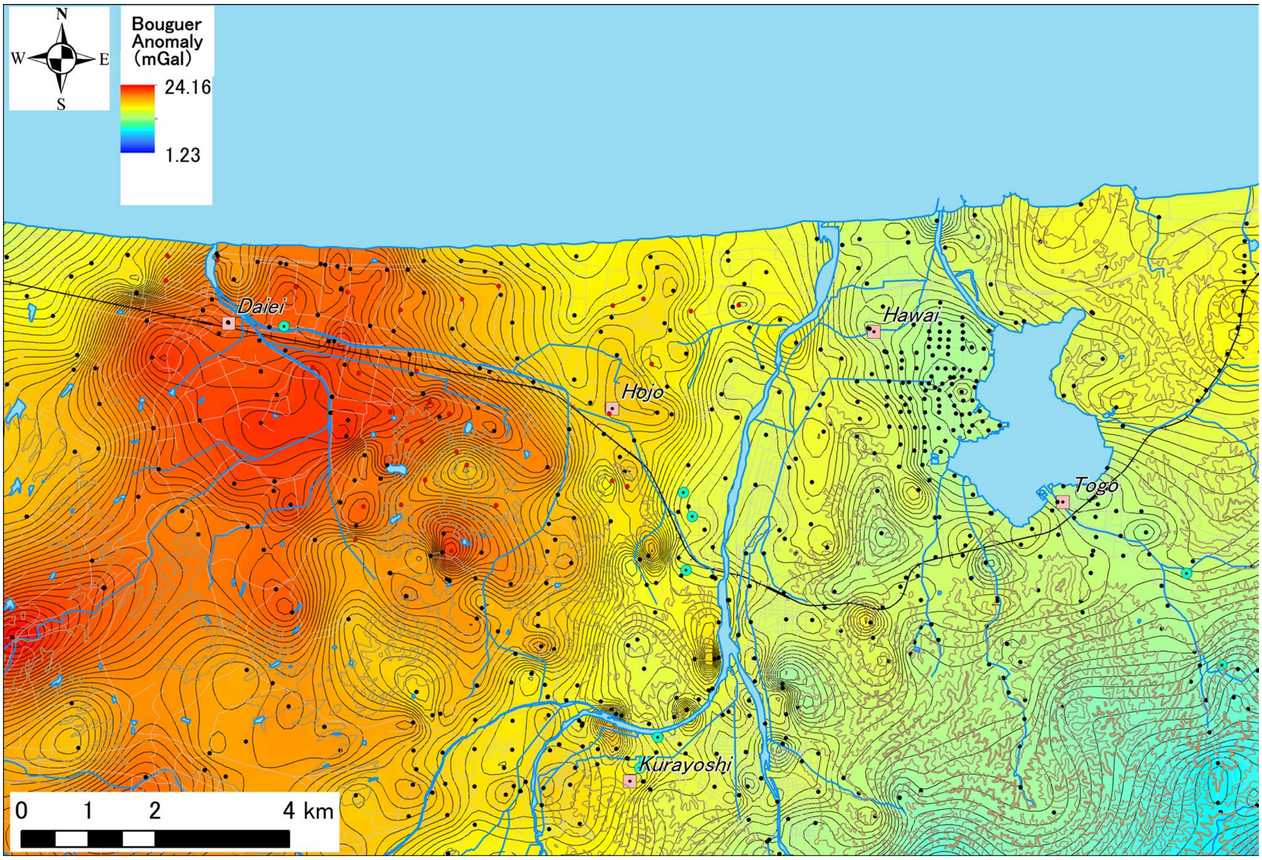


Fig. 6 This figure shows example windows of detailed information for the Bouguer anomaly map

each user, including researchers at the same institute, will add data. To add data, simply create a text (CSV format) file containing the location information (latitude and longitude) of the target site and geotechnical information (e.g., microtremor predominant period, gravity anomaly) obtained from various observations, and upload the file.

The quality of the data is checked by the authors' institute, which manages and operates this system, at the time the data are added. The quality of the data is checked at the time the data are added by the research institutes to which the authors belong that manage and operate this system. The current system uses research data and publicly available information, and the details of the data are compiled in research papers and reports. In this way, we believe that the quality of the data can be maintained, since it can be conditioned to have been used or discussed in some way in the research. In the future, this policy will be the basis for any other researcher or engineer who provides us with the data.

The system and database are uploaded to a web server and are ready for public access at any time. We plan to make it widely available as part of our contribution to the community in the future. First, it is expected to be used by research institutes, local governments, and construction companies that need geotechnical information in the San'in region. In the past, Tottori Prefecture installed a system to receive information on seismic activity in real-time from the Disaster Prevention Research Institute of Kyoto University, tried to use it as disaster prevention information, and studied the development of a GIS database of information on subsurface structures and earthquakes (Noguchi et al. 2004). The current technology development is more advanced than in the past, making it easier for ordinary users to install and use this research system.

In the future, users will be able to discuss with the distributors to revise the necessary information and distribution methods after using the system. For example, for use in earthquake disaster prevention, the results of ground amplification obtained from geotechnical information and the distribution of maximum seismic intensity based on the prediction of strong ground motions should be added. The data should be made available on tablet terminals. In addition, we plan to expand the use of the information and a database of geotechnical information that would be useful for schools and the public.

Code:TogoOffice, Name: togo
Operator: TottoriPref
Number of EQ: 13
Source: 2020_nishimura
Reference: 2021_nishimura

Subsurface structure model based on seismic observations

Thickness (m)	Density (g/cm^3)	Vp (m/s)	Vs (m/s)	Attenuation factor: h
14.6	1.63	1111.4	115.5	0.075
9	1.87	1335.5	483.2	0.019
66.4	1.99	1686.4	779.6	0.011
142.1	2.05	3762.4	948.8	0.006
369.3	2.38	4588.3	2164.9	0.004
∞	2.56	5500	3000	0.003

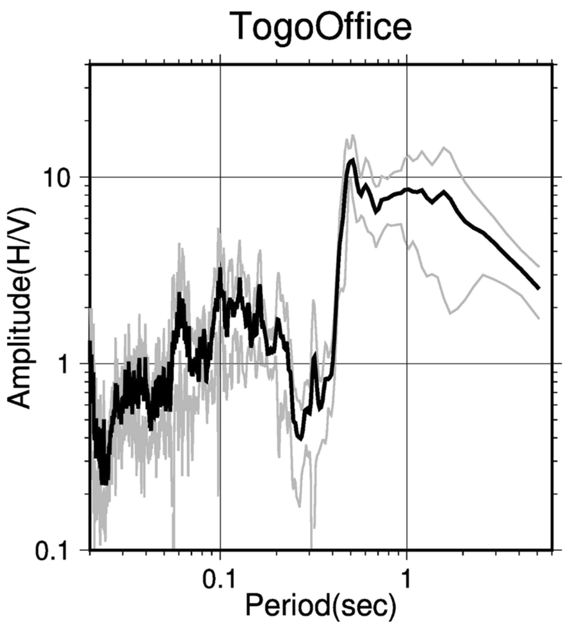


Fig. 7 This figure shows example windows of detailed information for seismic observations (observation point information, estimated subsurface structure, and H/V spectral diagram of earthquake ground motion)

The system can be used for disaster education as part of classes using computers and tablet terminals in schools. For the general public, the system can be used in disaster prevention caravans and events to help users understand the ground conditions in their area. If the information to be displayed is increased or the target users are expanded, operations within the page may become more complicated. Therefore, it is necessary to devise operational measures such as separating pages for professional use (e.g., researchers and engineers) and for disaster education (e.g., school education and general disaster education), and allowing users to switch content menus.

Summary

In this study, we developed a geotechnical information database that would be useful for future strong motion prediction in the San'in region, Japan, and a GIS system with a web browser interface for practical use. The database and GIS system is expected to increase the efficiency and accuracy of geotechnical investigation planning and analysis by promoting their use and dissemination to researchers and engineers. For example, the system can be used to efficiently investigate new geotechnical structures by allowing prior investigation of existing geotechnical information, and to improve estimation accuracy by easily comparing the results of previous investigations with the analysis of survey data.

Abbreviation

H/V: Horizontal components over Vertical component.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40623-022-01707-1.

Additional file 1: **Table S1**. The directory structure for Web-GIS main page and operation screens.

Additional file 2: **Table S2**. The directory structure for each observation point information and analysis results displayed in Web-GIS.

Additional file 3: Table S3. This Table shows the items of the data file (single_mtr.csv) regarding the information on single-point observations of microtremors in detail.

Acknowledgements

The Web-GIS developed in this study uses map data from the Geospatial Information Authority of Japan (GSI) and Leaflet as a JavaScript open-source library to manipulate the map data. The authors appreciate Mr. Kenryo Nishida who constructed a prototype of the Web-GIS.

Author contributions

IN, TN constructed the geotechnical database and IN, TK developed the Web-GIS. After discussion among authors, IN drafted the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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