EFFECTIVE APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM IN THE FIELD OF EARTHQUAKE ENGINEERING AND DISASTER PREVENTION

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SUMMARY

In order to accelerate the use of geographic information system (GIS) in the earthquake engineering research field, the effectiveness of GIS is demonstrated through originally developed systems and applications. The composite problem such as earthquake disaster prevention can be solved by accumulation and synthesis of knowledge and data under visualized interactive environment of GIS. First, the object-oriented analysis of earthquake engineering problem is conducted and the essential nature of problem is drawn using the object-oriented modeling technique. Based on this analysis, the conceptual design of total system was unified so that the common structure of method and data is embedded in each system. The developed systems are: (a) the facility management system of university campus: the system deals with both the environmental vibration problem and the earthquake disaster prevention problem. (b) The integrated and intellectual seismic ground motion evaluation system: first, the seismic source is modeled using various seismic information. Second, the seismic ground motion is evaluated both deterministically and statistically. (c) The dynamic soil modeling system: at arbitrary points in Nagoya area, the soil structure of velocity and density is modeled and the soil amplification is evaluated. (d) The earthquake damage estimation system: the damage of buildings in Nagoya area for arbitrary earthquake is interactively evaluated. (e) The quick earthquake damage estimation system: the seismic observation system is combined with the damage estimation system through university LAN. (f) The environment vibration alarm system: the seismic observation system is also used as daily vibration monitoring system. The vibration source is quickly detected and automatically informed to related companies through fax modem of EWS. (g) The disaster prevention information system working on the Internet: the above systems are extended to Web-GIS. All these systems cooperatively work to confirm the safety and the easiness of the residents in Nagoya area.

INTRODUCTION

In Japan, after Hyogo-ken Nanbu Earthquake, the large amount of seismic information began to be posted by various organizations to the public. The information, however, is not sufficiently utilized by general engineers. The translation of technical information is insufficient so that technical knowledge of researchers is difficult to be shared with the general engineers. This is caused by the shortage of interpretation of research to connect users with specialists. In order to cope with the disaster prevention problem, the construction of frameworks, which

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synthetically utilize knowledge and data, becomes important. It might be useful to shift from the conventional analytical research to the synthetical research. The mathematical planning approach may be useful with combining latest measurement, communication and computer technologies. Recently, the efficiency of the geographic information system (GIS) has been recognized as means for synthetic use of various knowledge and data. In this paper, the possibility of GIS in the earthquake-engineering field is demonstrated through the introduction of several systems developed by the authers.

REQUIRED PERFORMANCE TO GIS AND OBJECT-ORIENTED ANALYSIS OF PROBREM

Required performance to GIS

In the earthquake engineering, there are two kinds of research standpoints. One is a macroscopic research on the earthquake disaster prevention in the city scale. The other is a microscopic research on the seismic safety of individual building. In the former, a general grasp of the seismic damage in the whole city becomes a basis. Here, the followings are important aspects. These are (1) the database construction of enormous basic data, (2) the integration of knowledge in many fields, (3) the balance between accuracy and speed, (4) the evaluation of results from the social viewpoint, and (5) the visualized expression of comprehensible results for officers and citizens.

For disaster prevention officers, the system, which can deal with various demands in the process of pre-quake, in-quake and post-quake is required. We can add eye, nerve and brain to GIS by combining with the measurements, communication and computer technologies, such as seismic observation, portable telephone and mobile-computer, and the mathematical planning science, such as artificial intelligence and object-oriented approach. By this, it will be possible to develop the real-time seismic damage estimation system, the damage information collection system and the restoration and reconstruction support system. By the case, it will be also possible to utilize these systems as an environmental surveillance system for the daily use. In the meantime, for the citizen, the disclosure of accurate risk and safety information becomes important to improve their consciousness on the disaster prevention. Rapid popularization of Internet promotes the information disclosure of local government and fills the gap between usual and emergent state.

In order to make the system effective in the emergency, it is essential to conjugate for the daily use. It is effective to combine the disaster prevention with the facility management or the environment preservation. Frequent data update can be promoted by daily uses in addition to the emergent use. Still, the purpose of the earthquake disaster prevention ranges over diversity, and there are some limits of the data. Therefore precise and immediate corresponding is required for the purpose.

In the aseismic design of the individual building, structural engineers may use GIS to decide structural planning and to determine seismic load. By the case, it is expected that the application can be used make a consensus between designer and client on the building performance. Here, for arbitrary construction site, the site specific data acquisition and the seismic ground motion evaluation for structural design is expected. In the design of high-rise buildings or base-isolated buildings, the dynamic seismic load is individually evaluated at specific site so that the evaluation of seismic ground motion occupies the important position in the design process. In the performance-based design, even for usual buildings, it is expected that the designers determine the seismic load for each building according to the required performance and seismicity at the site. However, the general structural engineers have the impression that the evaluation of seismic ground motion is much difficult, since thinking quakes is distant from their daily work. Therefore, the shortening of distance should be one of the important viewpoints.

Object-oriented analysis of problem

The earthquake-engineering problem is analyzed using the object-orientated concept. The object-oriented concept expresses the problem using the objects. Object incorporates both data and behavior so that it is highly independent and matches the substances. In addition, the association, inheritance and aggregation relation between objects can be analyzed. Therefore, it is effective for analyzing complicated problem, such as the earthquake-engineering problem, which consists of various knowledge and data. Here, the authors try to clarify the common structure shared among systems constituting the earthquake-engineering problem. Generally the earthquake-engineering problem is composed of sub-problems such as source, path, soil, soil-structure interaction and structure. Then, each sub-problem is defined by the system-object, which involves method, data and knowledge. Since each sub-problem can be decomposed into more elemental sub-problems, we define the entire system as aggregation of sub-systems. Each sub-system is also decomposed into elemental sub-systems, which are finally expressed by the aggregation of elements. As a result, the system object is generalized by the hierarchical structure shown in fig. 1 where the notation follows Rambaugh(1991).

The process and data-flow, which the system object shares, is shown in fig. 2. The system object forms physical model from real data, which represents objective substances, based on knowledge on physical phenomenon and generates mathematical model based on knowledge of analysis method such as its applicability and efficiency. The mathematical model is solved using the numerical analysis algorithm, and the solution is evaluated based on the design criteria, and the final result is newly added to physical phenomenon knowledge base. The structure and process of system-object shown above expresses the acts that engineers do unconsciously in daily work. The earthquake-engineering problem has these difficult issues to solve in common. For the problem estimating the earthquake response of a structure, the data flow of total system is shown in fig. 3. The essences of figs. 1 and 2 are embedded in this figure. GIS shown in the next section has been constructed considering these common structures. So, the developed systems were excellent in the expansibility.

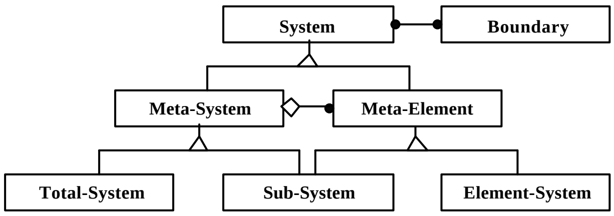


Fig. 1 Hierarchical structure of system object

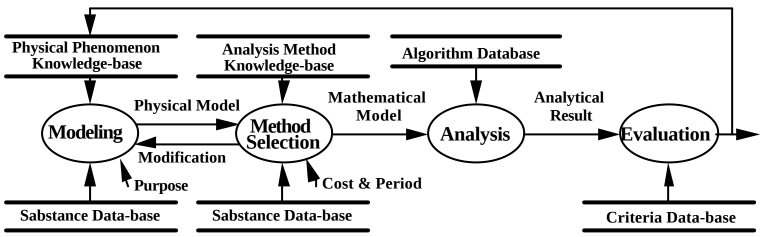


Fig. 2 Process and data flow of system object

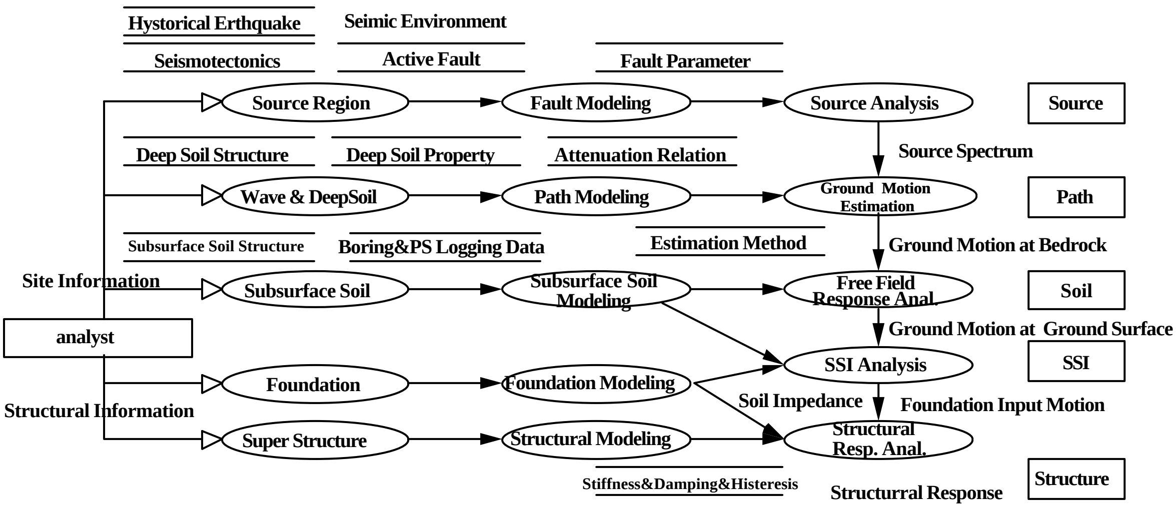
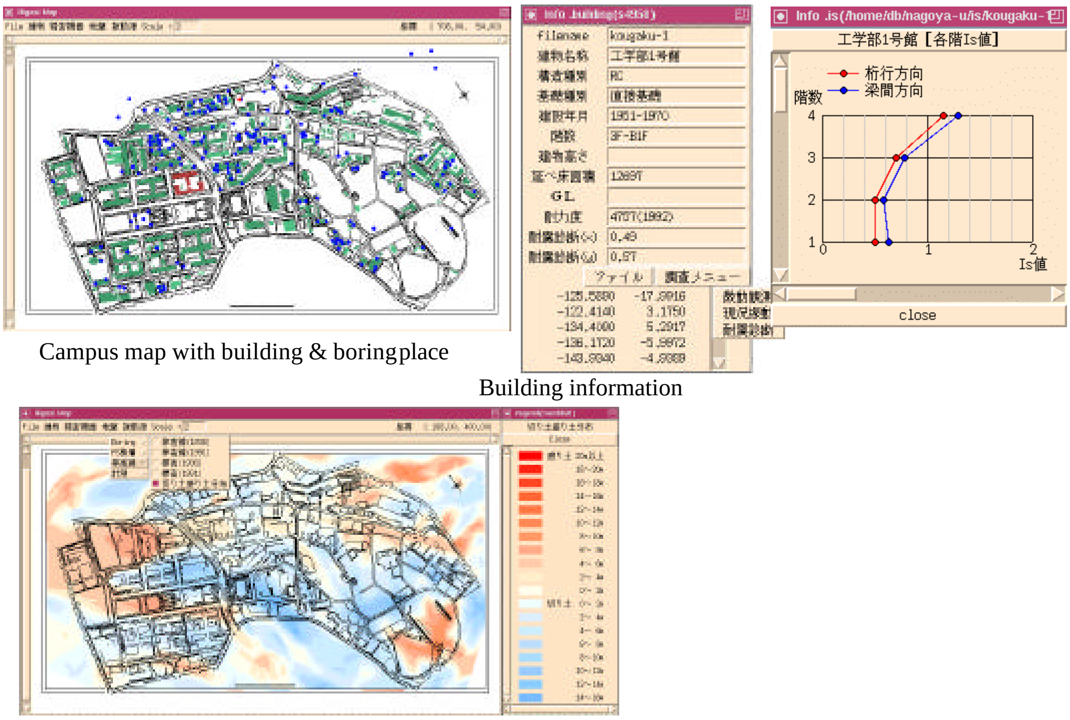


Fig. 3 Data flow in earthquake response analysis

APPLICATION CASE OF GIS

Application to facility management in Nagoya Univ.

In facility management and master planning of the university campus, it is necessary to synthetically manage facilities based on much information such as soil, building, facility and equipment. In the Nagoya Univ. Higashiyama campus, the construction works of buildings are widely conducted, and beneath the ground, the construction of subway and urban expressway is the progressing. Buildings in various ages exist on the campus, which has complicated ground condition by earth works such as cutting and filling. Therefore, the utilization of the existing buildings and boring data has the importance in the master planning stage. In addition, the ultra-precise equipments over 100 exist in the campus and are affected by small vibration. So, maintaining the research environment under the construction vibration and traffic vibration becomes also an important problem. In the meantime, Hyogo-ken Nanbu Earthquake raises the problem on the seismic safety, so that the seismic performance evaluation and retrofit are being carried out. Like this, the present condition of the university campus needs the appropriate countermeasure based on the many-sided analysis of various data. Fig. 4 shows GIS named 'Higashi' developed to solve these problems. In order to support the planing of the new building and the maintenance and management of the existing building, this system offers the various data obtained by the authors. These are soil data such as boring & landform data, building data such as seismic performance & dynamic characteristics of the existing building. This system can analyze the observation data such as the microtremor, strong-motion and environment vibration data obtained by vibration monitoring system described later. By combining above data with the analysis methods evaluating the dynamics of soil and structure, the system becomes integrated vibration analysis system.



Campus map with building & boringplace

Building information

Seismic performance

Earthworks of filling and excavating

Analysis tool of observed record

Fig. 4 GIS of university campus for facility management

Application to seismic ground motion evaluation

In the aseismic design and earthquake disaster prevention, the evaluation of the seismicity and the seismic ground motion is the most fundamental. In the evaluation of seismicity, the engineer should make the synthetic judgment based on the survey of various fault parameters of historical earthquake such as magnitude & hypocenter, and activity and histeresis of existing active fault. In the estimation of earthquake ground motion, the following items should be considered. These are (1) the specification of earthquake considered in aseismic design and damage estimation. (2) the level evaluation of the earthquake ground motion based on seismic risk analysis, (3) the prediction of ground motion at bedrock, (4) the grasp of soil amplification based on the earthquake response analysis of subsurface subsoil, and (5) the evaluation of surface ground motion. Since the existing knowledge and data on the ground motion evaluation are enormous, their appropriate synthesis contributes to accuracy improvement of estimated result. Here, GIS named QuSE' to evaluate earthquake ground motion is constructed, where the user can visually experience the fluctuation of the result due to the change of method and data. The user can select various parameters and evaluation techniques furnished in the system though the consultation of reference box, where the various information on seismic source data and knowledge on method applicability is provided. The system is composed of three subsystems as shown in fig. 5, which are (1) the listing and evaluation of the active faults and historical earthquake which affect the site, (2) the deterministic evaluation of ground motion for the inland active fault and inter-plate earthquake, and (3) the stochastic evaluation of the seismic risk. This system also promotes the education of the expertise related to the evaluation of seismic ground motion through the use of the system.

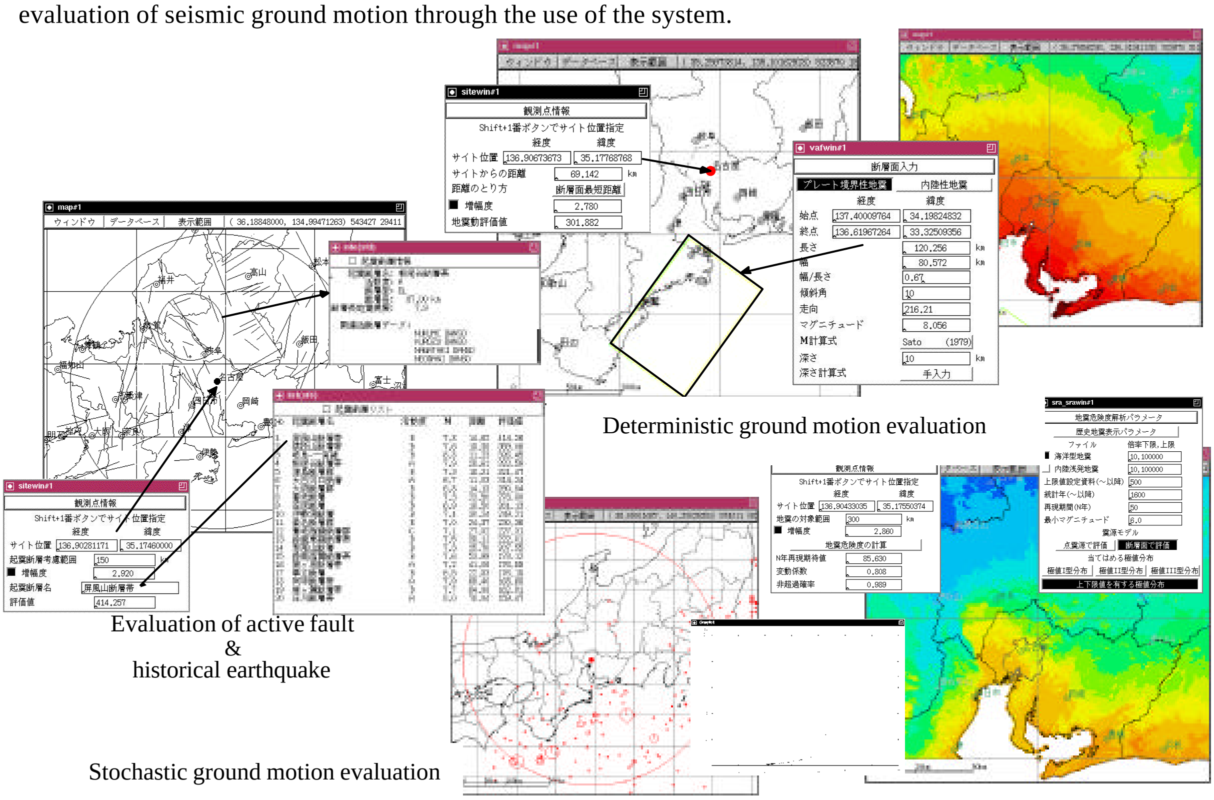


Fig. 5 GIS for evaluation of seismic ground motion

Application to soil modeling

GIS named 'SMACS' to estimate dynamic soil model in Nagoya urban area is constructed, which conjugates maximally all the existing limited subsurface exploration data. As shown in fig. 6, the system estimates the soil velocity & density layering structure at arbitrary site and evaluates the soil amplification. Basic policies to make the dynamic soil model are as follows. (1) PS logging data is prior utilized. There exists about hundred data with average depth of 57m and average bedrock shear wave velocity of 400m/s. (2) When the data of standard penetration test exists near the site, shear wave velocity and density are estimated using the regression formula, which derived by us using N value, depth, geological age and soil classification. In the city, there exists 4,200 data with average depth of 25m, which covers 20% of city area as 125m mesh data. (3) In the area lacking for sufficient boring data, the depth of each stratum at arbitrary point is estimated by interpolating depth contour line for each geological age. The shear wave velocity and density are estimated from the regression formula based on geological age and depth. (4) The deep soil structure is modeled by interpolating shear wave contour line of

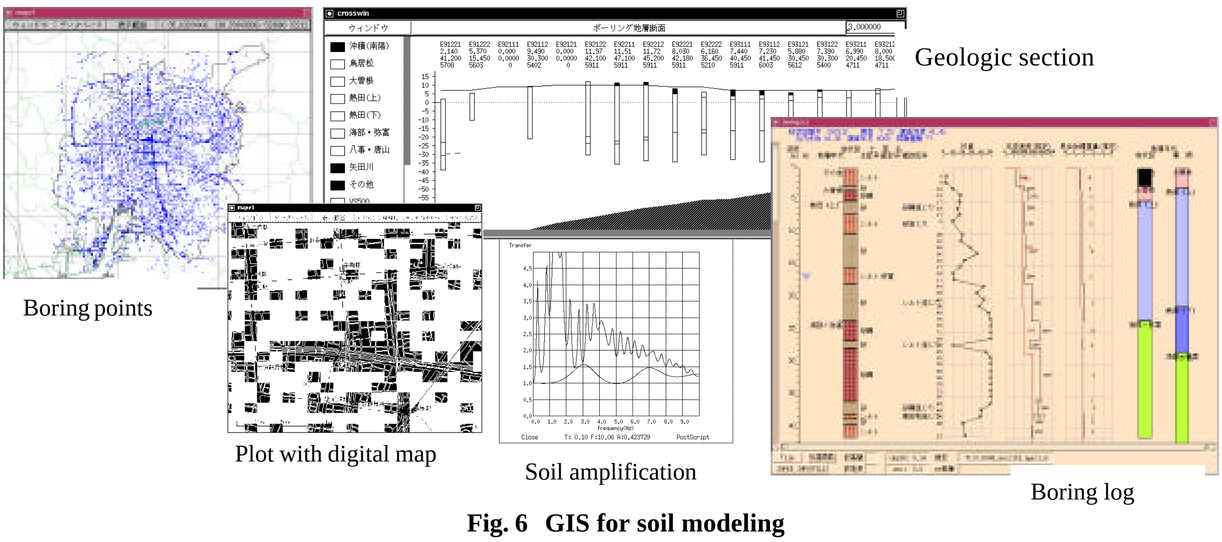
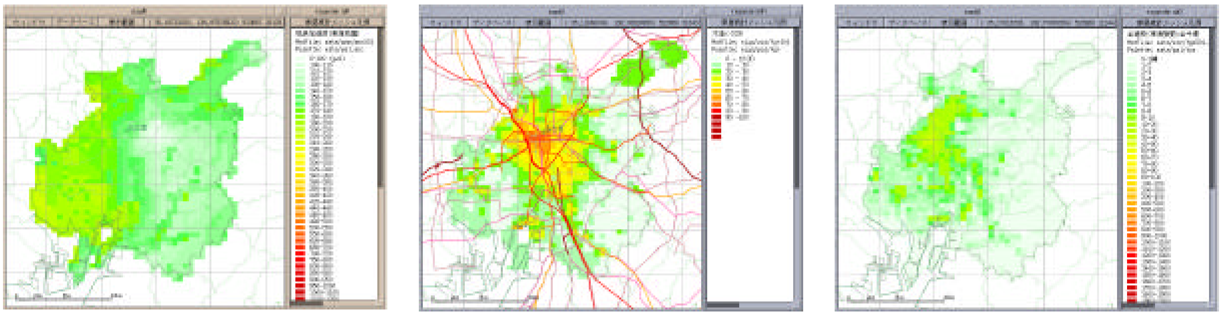


Fig. 6 GIS for soil modeling

the same velocity, which is estimated based on the seismic refraction survey, gravity prospecting and deep well survey. (5) Using above estimated shear wave velocity and density, the soil amplification is calculated by one dimensional wave propagation analysis. (6) At the place where lacks for soil data, the soil amplification is estimated based on the regression formula using the digital national land information.

Application to seismic damage estimation

GIS named 'SDES' to estimate building damage for arbitrary earthquake can be constructed by combining the above GIS's 'SMACS' and 'QuSE' with the building information of urban area and the vulnerability function. Building number of each structural type and building age in each region is calculated on the basis of the taxation ledger. Then, the number of damaged building in each region is estimated using the vulnerability function for each structural type, building age and damage level which was derived from the analysis on damage and ground motion intensity in Kobe. Since the damage for arbitrary earthquake can be interactively grasped, it becomes possible to select the earthquake to be assumed, to specify the disaster weak region, and to investigate the cause of weakness. The system may offer effective information to make disaster prevention measure by adding human and social/economic point of view.



Surface Ground Motion | Distribution of old wooden building | Distribution of damaged building

Fig. 7 GIS for earthquake damage estimation

Application to early seismic damage estimation

By installing 16 seismometers in 3 campuses of Nagoya Univ. and by combining this seismic observation system with the above GIS, the early damage estimation system named 'EMA' can be constructed. The features of this system are in integrating seismic observation network system and damage estimation system 'SDES' by use of Internet and engineering workstation (EWS). The basic idea is to connect the seismometers via Internet with LAN interfaces, which are note type personal computers mounted to the hard disk of EWS. By this, it is possible to transmit the strong-motion records into EWS immediately, and to combine them with the various databases and damage estimation system 'SDES' constructed on EWS. In the system, just after the quake, first the hypocenter and magnitude is automatically determined, then the ground motion is estimated using attenuation

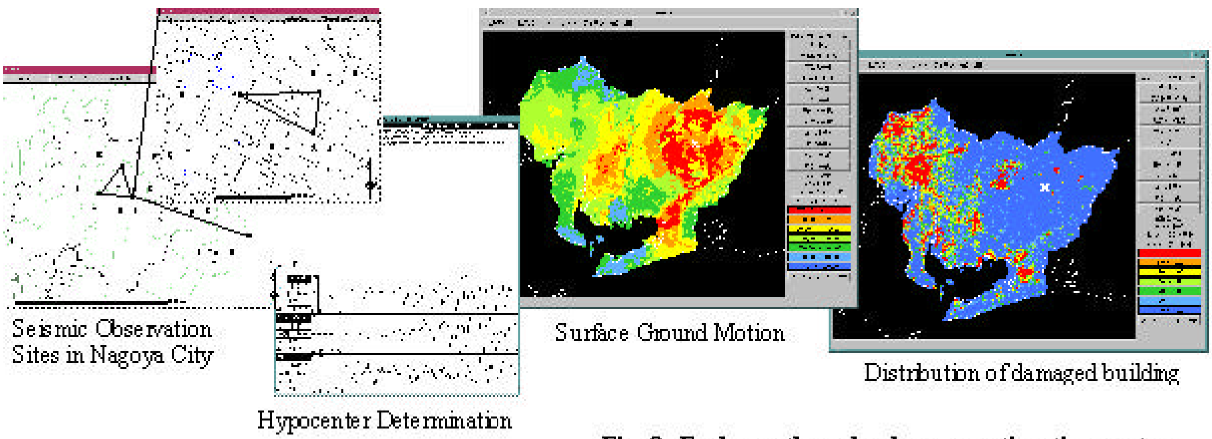
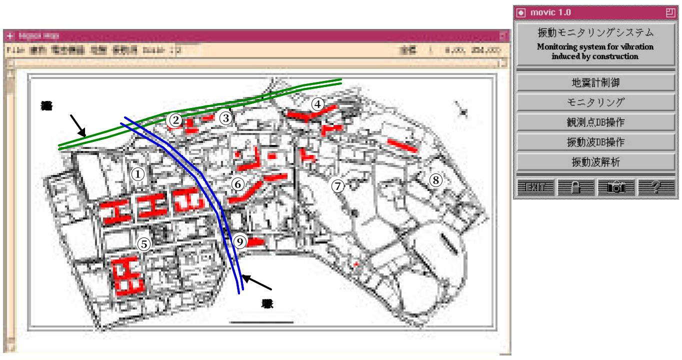


Fig. 8 Early earthquake damage estimation system

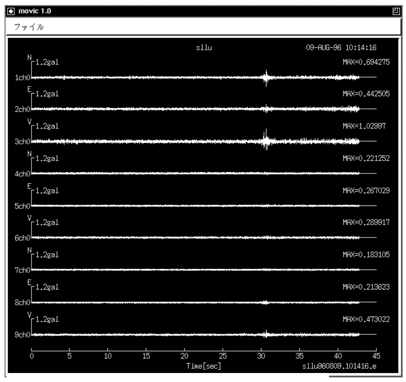
curves and pre-calculated soil amplification, and finally the building damage is predicted using building database and vulnerability curves. Since using the Internet and EWS, the data transfer is robust and high-speed. The extension of seismic network and the immediate offer of the strong-motion record and damage prediction result through the web are also technically easy to realize.

Application to environmental vibration alarm

In the urban area, since the environmental vibration such as traffic and construction induced vibration cannot be avoided, not only the discomfort on the human body but also the dysfunction to the precision instrument becomes an important problem. As above-mentioned, the subway and underground expressway is now under construction in Nagoya Univ. Therefore researchers using electron microscope or NMR are worrying about the construction vibration during following few years and the traffic vibration after the common use. And, the construction work with the reconstruction and the seismic retrofit of existing buildings are also schemed. On the other hand, the ultra-precise equipment for the advanced research is increasing. In order to solve this situation, the authors constructed the environmental vibration monitoring system named 'MoVIC'. This system always watches the vibration due to construction and traffic using 26 sensors placed in the campus connected to university LAN system. The basic idea of the system is same with the early seismic damage estimation system 'EMA' and is combined with the facility management system 'Higashi'. The system intends to cope with daily environmental vibration problem. This system displays automatically the waveform on EWS when detecting the vibration exceeding the allowable level of each instrument, while the same information is transmitted automatically to the construction work office through the FAX modem. The researcher who uses ultra-precise equipment is also being informed the environmental vibration situation through the web site. This system makes researchers feel easy for the vibration and forces the general contractor to change construction method to the less vibration method. As a result the various construction works make progress smoothly. The system also functions as a high-dense strong-motion network system, which has totally 40 sensors in the campus, combined with those in 'EMA' system.



Vibration monitoring points and buildings with ultra-precise equipment

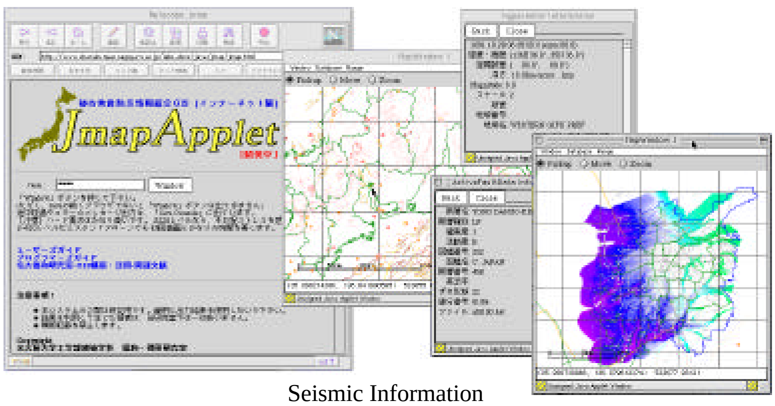


Monitoring windows

Fig. 9 Environment vibration alarm system

Application to information disclosure.

The urban disaster prevention is the problem of which the information disclosure to citizen is highly expected. Recently, the system working on Internet becomes easy to construct by the popularization of JAVA and CGI. The web GIS 'Jmap-applet', which offers seismic and soil information, is constructed as shown in fig. 10. This system is constructed by translating the above-mentioned systems 'QuSE' and 'SMACS' into



Seismic Information

Alluvium soil deposit

Fig. 10 Web GIS on seismic and soil information

JAVA. The system was easily expanded to web-GIS because original systems were self-developed software designed by object oriented concept.

Fig.11 shows an example of web pages informing strong-motion records and microtremor records collected by authors. In earthquake disaster prevention and aseismic design, it will be important to widely inform the basic data through the web to public.

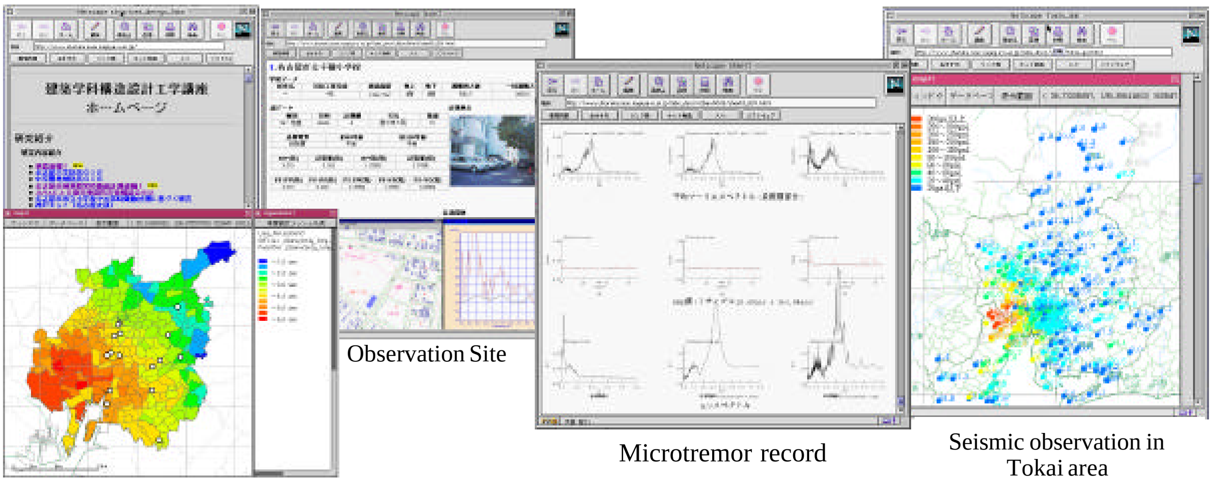


Fig. 11 Disclosure of microtremor and seismic observation data through World Wide Web

CONCLUDING REMARKS

In this paper, the earthquake-engineering problem was analyzed using object-oriented analysis technique from the two points of view which are macroscopic one of earthquake disaster prevention and microscopic one of aseismic design of building, and the usefulness of GIS was shown through the introduction of application cases developed by ourselves. GIS has rich presentation and integration ability so that it is suitable for local government staffs to grasp the situation in a moment, for citizen to understand visually their risk, for engineers to master the analysis method and grasp the sensitivity of the result. We, however, should recognize that GIS itself is a convenient tool and the real performance of the system depends on the basic data and analysis methods. Since the limit of the system will come soon when biased only for the effective utilization of existing data, the steady acquisition and maintenance of basic data becomes most important. Sophisticated judgments are necessary in the selection of the analysis method adopted in the system. In order not to fall into the black-box system, it is important that the reliability of the system is guaranteed by showing the limit of application and analysis sensitivity to users through the use of system. We want to call this kind of system ‘gray-box system’. It is important to realize that the progress of information and software engineering and the combination of sensors, communication equipment and mobile computers are expected in the future.

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