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Integrated Disaster Simulator using WebGIS and its Application to Community Disaster Mitigation Activities

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ABSTRACT

This paper describes a newly developed information system dedicated to promoting the earthquake disaster mitigation practices of residents themselves. The system is based on a type of simulator that presents realistic personal disaster scenarios, related to actual seismic hazards, in order to help each resident gain awareness of his/her own hazard level, and to comprehend the need and methodology for making preparations. The simulator is built around a web-based online geographic information system known as WebGIS, and integrates a series of subsystems that provide a number of features including a high-resolution hazard map system capable of creating three-dimensional birds-eye overviews, a system for evaluating earthquake ground motion at a specific location, as well as a system for simulating earthquake effects and the possible collapse of a wooden house at a site (including the risks of falling indoor furniture). Furthermore, in order to provide comprehensive information on seismic hazards and disaster mitigation, various related programs that utilize online systems (including WebLog, Wiki and other interactive interfaces) have been incorporated. The applications of these systems to community disaster mitigation workshops in Nagoya City are described, together with the newly constructed web systems and education facilities of the Aichi Prefectural government.

Keyword: Hazard map, Wooden house, Geographic information system, E-learning, Workshops

1. INTRODUCTION

The Tokai area in Japan, which includes Nagoya city, has previously been the site of many disastrous earthquakes, and large earthquakes have been predicted for the Tokai, Tonankai and Nankai area along the southwest Pacific coast of Japan in the near-term future. If these earthquakes strike all three regions simultaneously, massive damage will occur and as many as 25,000 deaths could result. Additionally, the collapse of up to 900,000 houses is possible and economic losses of up to 81 trillion yen (spread over most of southwest Japan) could result (Cabinet Office, Government of Japan, 2003). To mitigate the extent of such a disastrous aftermath, the area’s civic population is being strongly encouraged to make their living and working environments as safe as possible, as soon as possible. The primary reason for the urgency is the fact that the greatest amount of damage resulting from earthquakes worldwide has historically been caused by collapsing buildings. While ideally, this is the responsibility of building engineers, since most buildings are private assets, the effectiveness of any building's countermeasures also depends on the level of awareness held by each resident, or in other words, the individual sense of reality they have regarding the potential earthquake damage risks they actually face.

Disaster mitigation activities have been investigated and implemented from various viewpoints (e.g. Matsuda and Okada, 2006, Show, 2009, Yamori, 2007). In the present paper, we consider the situations as follows to develop a series of systems and materials to encourage individual and local community activities.

The following four aspects are considered to be fundamental for disaster mitigation activities: people, knowledge, possessions, and money. For example, the promotion of seismic retrofitting requires the development of citizens' awareness of their own disaster risk caused by their personal living environment (people), the establishment of laws and systems that promote seismic retrofitting (knowledge and systems), the development of inexpensive and effective reinforcement methods (possessions and technology), and the creation of programs and economic incentives (money). The most important and difficult factor is the creation of awareness, especially in developed countries, because the problems related to the other three viewpoints, have for the most part, been overcome. To develop citizens' awareness, it is important to train the leaders tasked with the dissemination of information (people), develop effective methods for the dissemination of an effective disaster prevention education curriculum (knowledge), create educational materials for dissemination (possessions), and convince people that the process is affordable (money).

The following steps are considered to be vital for residents:

a) Understanding disasters
b) Convincing oneself of disaster risks and their causes
c) Honestly assessing individual risks based on situations
d) Deciding on countermeasures
e) Practicing individually

The first step a) requires data and materials such as hazard maps and various types of printed information on earthquakes and disasters. Step b) includes the contributions of experts and systems that can provide insightful and intelligent appraisals of disaster risks and their causes to each person. However, in Japan most people who consider themselves familiar with disaster mitigation topics remain locked in step a). This is because it is difficult to create an environment where people are willing to take steps b), c) and d) on their own, as well as one where people can become fully aware of the disaster risks they face and the actions they must take in response to them. Thus, it is very important to find ways to encourage people to proceed forward smoothly in actual practice from steps b) to d). Rowan (1994) introduced a general model for risk communication as CAUSE (Credibility, Awareness, Understanding, Solutions and Enactment). The steps from a) to d) in the present paper are more individual and may be more suitable for the situation especially in disaster active countries such as in Japan.

These steps also require the efforts of people who can motivate residents into obtaining a proper level of awareness, as well as the production of useful educational materials. However, because the number of disaster prevention experts is relatively small, it is difficult for them to reach each resident directly. This demonstrates that the development of each resident's awareness requires not only the cooperation and efforts of those various experts, but the participation of mediators that have the ability to contact local residents is also needed. (These include volunteers, community leaders, non-profit organizations, mass media, teachers, cooperatives, enterprise groups, and student circles.) To motivate such people to participate in disaster prevention activities, it is first necessary to cultivate awareness and create environments where such mediators can actively assist in the development of each resident. After they learn the causes of such risks, and find ways to avoid them, each organization or family can plan and implement countermeasures as part of step e).

In response to the need to promote civic-based disaster mitigation activities through these five steps, this paper describes a newly developed information system in the form of a series of simulators and database designed to promote such actions, and describes their application to disaster mitigation practices of community residents themselves.

Some related researches and developments have also been conducted concerning information systems for disaster reduction. An example of a web-based facility to compile knowledge on disasters is the Disaster Reduction Hyperbase (EDM-NIED, 2009). Various WebGIS and WebLog sites have been operated for providing disaster information and knowledge. E-learning sites concerning disaster and disaster reduction are also available on the Internet (e.g. Fire and Disaster Management Agency, 2004). For an example of a more integrated system that provides disaster scenarios such as those discussed in this paper, Meguro et al. (2009) show their scope on the universal earthquake disaster simulator including damage of buildings and social impacts. Katada and Kuwasawa (2006) developed a tsunami disaster simulator which is also available for disaster education and a workshop for inhabitants. Compared to these examples, the attempt presented in this paper integrates a series of simulators, personal database, e-learning and workshop-supporting interfaces, additional education materials and related community activities for each inhabitant to make his/her own house and living environments safer. The system is based on distinctive features of the local area, and is actually used as a powerful tool for groups of active disaster mitigation in Nagoya city and Aichi prefecture.

2. OUTLINE OF WEBGIS SIMULATOR AND ITS APPLICATIONS TO COMMUNITY ACTIVITIES

Figure 1 shows the various procedures for improving community disaster mitigation activities using the proposed disaster information and education system. The system is based around a simulator that provides realistic appraisals of hazardous conditions and is designed to help each resident improve his/her awareness of the hazards in his/her own environment. Each resident can thus learn both the necessity for, and the actual steps involved in preparing for those hazards.

While the system can also be used as a tool to assist facilitators in conducting disaster mitigation activities, its primary purpose is to encourage residents to conduct disaster prevention actions themselves by providing them with education materials that will help them regard earthquake dangers as familiar and solvable problems.

A series of subsystems have been integrated using WebGIS to provide the following tools:

a) High-resolution hazard map system capable of showing anticipated earthquake shaking intensity and potential levels of liquefaction based on the actual geological conditions of an individual site.

b) Three-dimensional birds-eye view system that shows the history of land use and development for specific areas.

c) Simulation system for earthquake ground motion that utilizes high-resolution surface soil models and specific earthquake source models.

d) System for simulating the possible collapse of a wooden house after considering the site's predicted earthquake ground motion.

e) Simulation system that shows the risks posed by falling furniture.

To provide additional information on seismic hazards and disaster mitigation, various other online e-learning tools (based on WebLog, Wiki and other interactive interfaces) have been adopted and introduced with practical contents.

Using these systems, residents can easily acquire knowledge on earthquake hazards, seismic risk evaluation methods as well as determine practical ways of retrofitting their houses and securing their furniture. Such web-based technologies make possible not only the integration of the subsystems, but also provide easy and interesting ways to utilize the system at any time.

The system is also designed to be available for user-groups that want to hold discussions and make preparations against disasters using the WebGIS map system. This system was designed to make it possible for users to create, maintain and use their own disaster response maps for disaster mitigation activities. Promoting such workshops is considered to be an effective way to support residents who wish to lead community disaster mitigation activities. This function is based on previous systems designed by us (Tobita and Fukuwa, 2004).

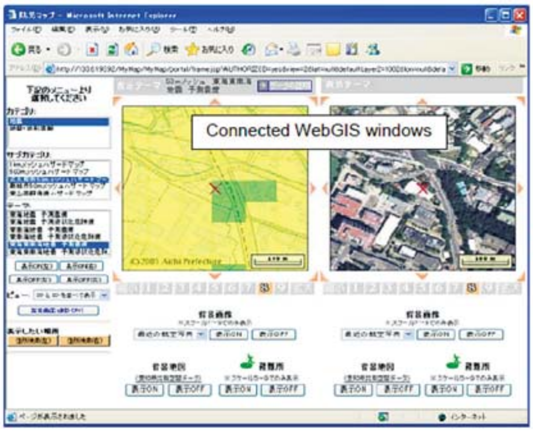
From another point of view, actual learning materials such as "the BURURU family" have also been incorporated and are used during the phase where individuals need to be convinced of the genuine personal risks of their situation (Fukuwa et al., 2008).

Figure1: Procedures for improving community disaster mitigation activities by using the proposed disaster information and education system.

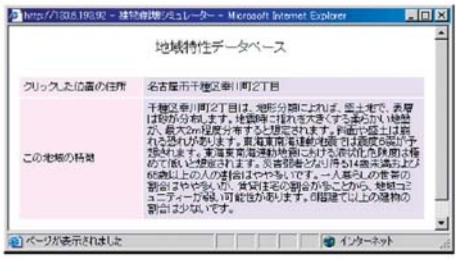
3. WEBGIS-BASED SIMULATOR FOR PROMOTION OF SEISMIC RETROFITTING

3.1. High-resolution hazard map on WebGIS with 3D birds-eye view

Figure 2 shows examples of the WebGIS view windows for high-resolution hazard maps. In this case, the words "high-resolution" refer to a 50-m grid in Nagoya city, which is considerably more detailed than the conventional wide-area hazard maps, which are normally prepared on 500-m or 1-km grids. The surface soil data was produced by compiling the results of soil bore surveys conducted at over 40,000 sites in Nagoya city and covering an area approximately 326 km^2 in size. Other information is also utilized when creating and presenting the data, such as microtremor and seismic recordings of the area. The high-resolution topographic features were obtained by analyzing aerial photos together with examinations of the ground surface sea level distribution. If the



(a) WebGIS window example

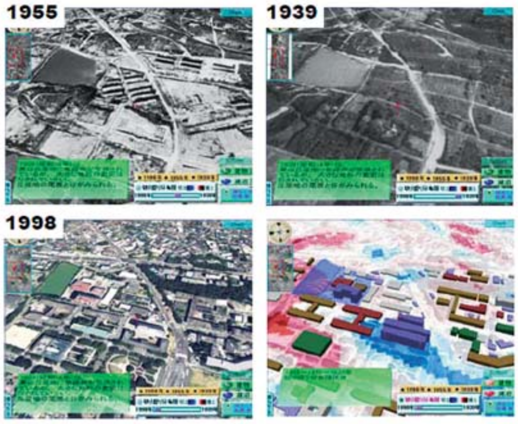


(b) Outline of selected area (in Japanese)

(c) Aerial photos (left:1963. right:1998)

(d) Potential liquefaction (left). topological classification (right)

(e) Three-dimensional birds-eye view of WebGIS



(f) Changes to topographic features over 40 years

Figure 2: High-resolution hazard map created via WebGIS and its effective application from a three-dimensional birds-eye view.

number of actual soil survey data samples is relatively small for a specific area, it is still possible to obtain high-resolution maps by using aerial photos together with soil boring data and microtremor observation results at those limited sites.

Figure 2(a) is a start window (which is preceded by some introduction and instruction pages) that allows the user to choose a specific site by using address lists, or simply clicking the map. The two maps show different (yet related) features for the same area and are connected in terms of movement and magnification/reduction. Using them, it is possible to analyze various disaster and damage prediction results by comparing the two map windows. With this system, residents can also readily understand the danger of earthquakes and their related damage predictions.

Community disaster prevention starts with learning about the community. Users can select the information they want to study from the menu on the left side of the window, while at the same time referring to the map. The map scale and display can be selected using the mouse. For example, if a resident clicks on the location where he/she lives, the window shown in **Figure 2(b)** displays the address and an information outline of the selected area along with a variety of details. Such details include the estimated seismic intensity, potential liquefaction risk, characteristics of the topography and the ground, industrial, commercial, and residential characteristics, building characteristics, and the age distribution of residents.

Figure 2(c) shows 40 years of change for an area using aerial photos, while **Figure 2(a)** shows a comparison of the predicted seismic intensity and an aerial photo. **Figure 2(d)** shows a comparison of the predicted liquefaction and a topographical classification map. The sample area is located on a hill where a valley exists from east to west. Examining these figures help residents comprehend the risk of seismic shaking and the potential of soil liquefaction (two items that are predicted from surface soil conditions and are strongly related to topographical features) as well as observe how things have changed in their area over the past decades.

Changes in the area's topographical features are also shown in **Figures 2(e)** and **2(f)** using a three-dimensional birds-eye view. The view is a composite of aerial photos that takes into consideration data on sea level states. Observing changes to the sea level over the previous 40 years, at each point, makes it possible to show the distribution, cutting and filling of the ground surface. (In the lower right of **Figure 2(f)**, the blue area shows cutting and the red area shows filling.) This view is created by real-time three-dimensional programming using Matrix Engine™, a program that is commonly used in the field of dynamic and interactive web content development. As shown in **Figure 2(f)**, it is possible to move the screen view by moving the mouse, and to make position changes (including moving, revolving, zooming in and out on the screen and changing the point of view) by dragging the mouse. It is also possible to review the previous history of land use and development for the area by dragging the time bar. Because residents can easily visualize the changes in topography and land use around their houses, they can more fully understand the relation between seismic activity, topography and local soil conditions.

3.2. Simulator of seismic ground motion at a specific site

Earthquake ground motion at each square of the grid is estimated by the statistical Green's function method at the engineering bedrock, while the surface soil response is calculated by using the evaluated soil layer structure of the site. A newly developed method by Takahashi et al. (2008) has also been tested for high-resolution ground motion prediction. This method utilizes an extended version of the empirical Green's function method and makes it possible to examine the realistic character of observed seismic records, together with shallow surface soil layers and deep subsurface composition down to several hundred meters or over one kilometer.

As shown in **Figure 3**, if a point on the GIS is clicked, the system provides the surface soil model estimates for that point. After the soil response is calculated, the system then displays an animation of simulated earthquake occurrence and the soil response for that site, as shown in the right side figure. This simulation enables residents to see the vibrations applied to their houses and comprehend the relationship between soil hardness and its response to those vibrations. **Figure 4** shows a specially developed shaking table facility that allows users to realistically experi-

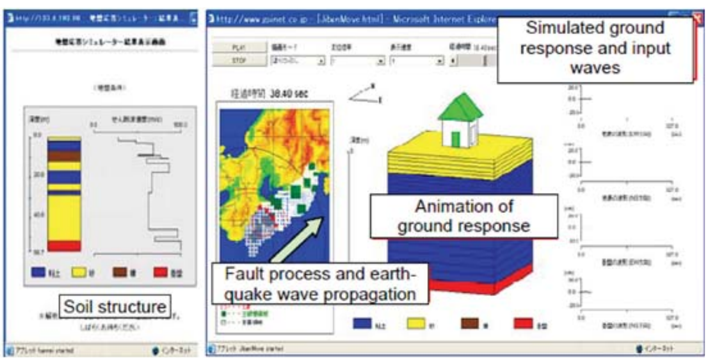


Figure 3: Earthquake response simulator at a specific site.

Figure 4: Realistic shaking experience. (Fukuwa and Tobita, 2008)

ence long-period, long-stroke and high intensity simulated ground motions and building responses (Fukuwa and Tobita, 2008). The realistic shaking experience, while considering personal conditions, is effective for stimulating awareness of seismic risk.

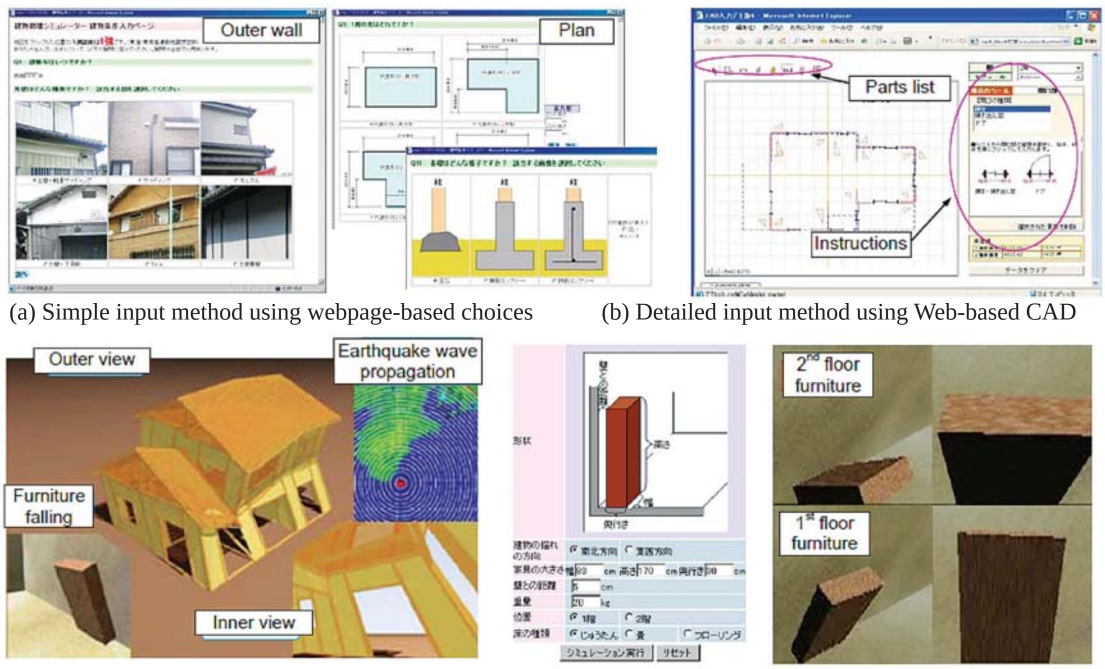
3.3. Simulator for earthquake damage to wooden houses and falling furniture

This system was developed as a way for residents to check the seismic capacity of their own houses. There are two input methods for two-story wooden houses. One (shown in **Figure 5(a)**) is a relatively simple method that allows residents to input basic details on their houses, such as the year of construction, using web-based choices. The other (shown in **Figure 5(b)**), is a more detailed input method and takes into consideration the actual plans of the house using an online Web-based CAD system. For both methods, as described in Section 3.2, earthquake response analysis will be performed on the generated model subjected to the simulated earthquake ground motion at the site. **Figure 5(c)** shows the animated result of response analysis. The simulation results that show house collapses will be referred to websites dedicated to seismic activity evaluation and retrofit, in order to encourage the user to begin countermeasures. If the house does not collapse, the falling furniture simulator begins. The user will then be asked to input the floor on which their furniture is placed as well as the size and weight of the furniture, the type of floor furnishings, etc. Once this is done, the furniture's response is analyzed based on the response waveform and displayed as an animation, as shown in **Figure 5(d)**. The user is then guided to websites promoting the safety of indoor environments.

4. LEARNING TOOLS WITH EFFECTIVE INTERFACES

4.1. Learning tools concerning vibration

The next step for residents who have become aware of their individual seismic risks and the importance of disaster mitigation action is education. To facilitate this, we have developed and tested various learning tools and materials related to ground vibration and building responses, seismic capacity and the effectiveness of retrofitting, as well as other important knowledge. These include a series of vibration experiment education materials collectively known as "BURURU" (**Figure 6**, Fukuwa et al. 2008), which demonstrate fundamental and important points related to vibration response and earthquake building damage



(a) Simple input method using webpage-based choices
(b) Detailed input method using Web-based CAD
(c) Animated response simulation results
(d) Input window and the results of the furniture falling simulator

Figure 5: Simulation of house damage and falling furniture based on a specific individual house.

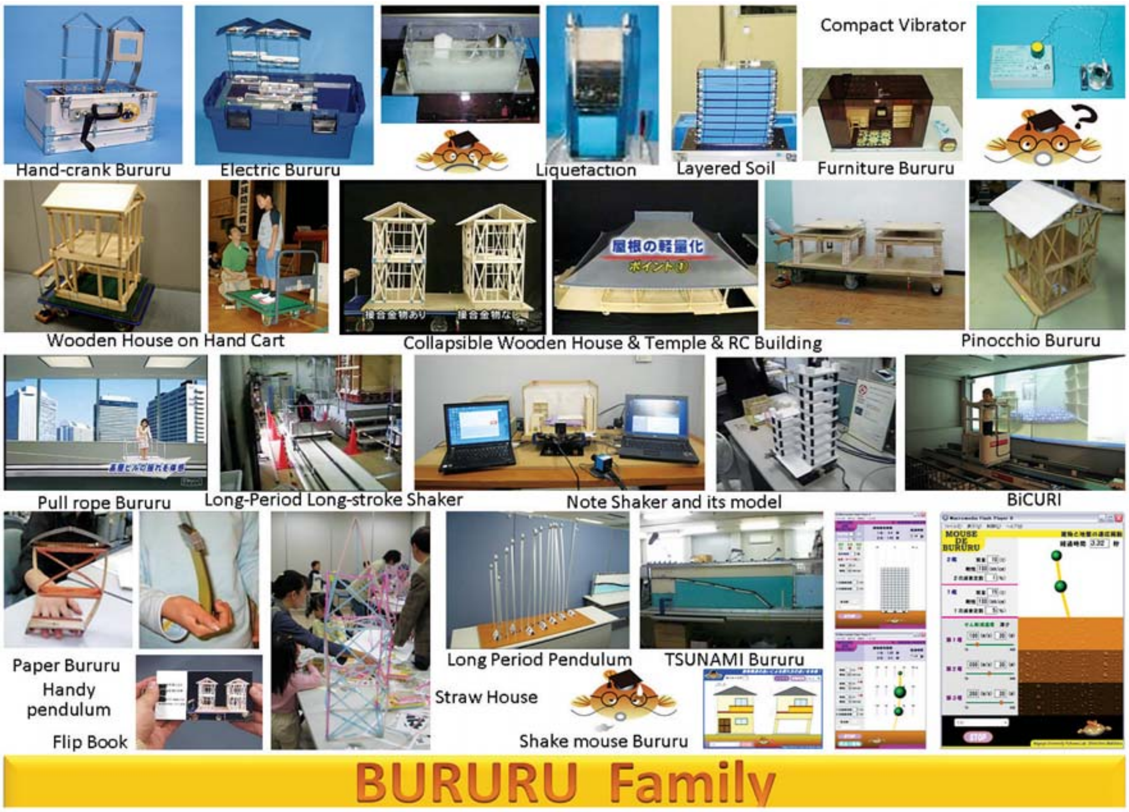


Figure 6: The "BURURU" family, which consists of a series of educational devices that demonstrate earthquake-related vibrations and other phenomena in ways that assist disaster mitigation training activities.

and ground actions by using simple physical tools and online simulation software.

One of the most popular examples of the BURURU series is a paper model kit for a two-story house and an accompanying user manual that can easily be downloaded and printed. The paper model can be used to explain the importance of roof weight as well as the effects of cross bracing and wall balance. Such hands-on educational materials are effective for supplementing the virtual information systems described in this paper.

4.2. E-learning systems using popular Web-based interfaces

Other types of e-learning assets concerning disasters and disaster mitigation have also been prepared. For example, in order to show the effectiveness of furniture falling countermeasures, videos showing comparative experiments on shaking tables (by using various prevention methods) can be viewed on the Internet. These tools make it easy to confirm the effects of countermeasures aimed at preventing falling furniture.

To assist in the development of such e-learning materials, we have utilized new technologies that make it easy to create and navigate between numerous online resources. One such is an application of the "Wiki" system, which we have adopted as the foundation of a disaster mitigation knowledge database. **Figure 7** shows an example of some of the interacting pages. The Wiki system is widely used on the Internet and has proved to be an effective method of building databases because it operates by soliciting the collaboration and contributions of multiple users.

Another example is an interactive conversation interface designed to provide easy access to the web-based e-learning system. When a user verbally asks the system for answers to even vague questions, an appropriate reply will be generated using familiar web-address navigation tools (**Figure 8**).

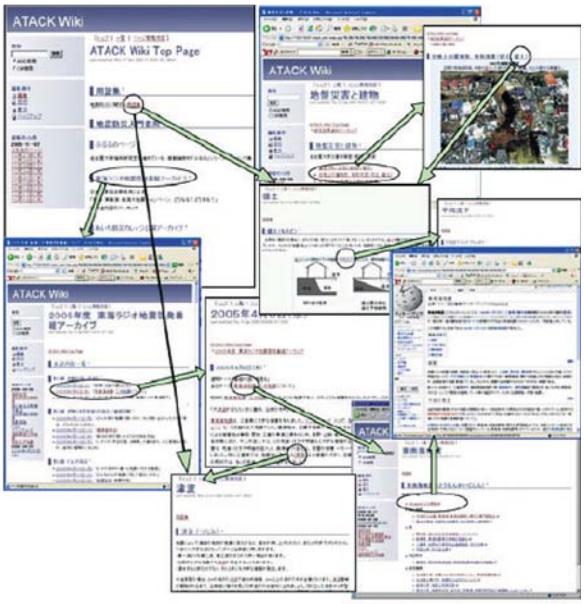


Figure 7: An example of Wiki-based pages used for the disaster mitigation knowledge base.

Figure 8: The interactive BURURU conversation interface.

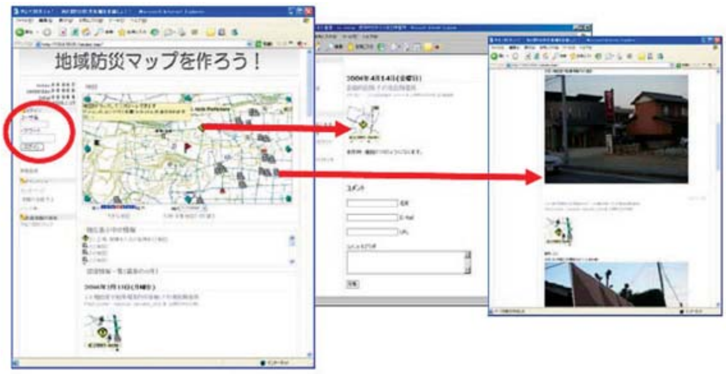


Figure 9: An example of the community disaster mitigation map system utilizing WebGIS with WebLog interface.

Figure 10: A community disaster mitigation workshop using newly developed system.

5. APPLICATIONS FOR COMMUNITY DISASTER MITIGATION ACTIVITIES

5.1. Support system for community disaster mitigation workshop

The systems developed thus far have already been tested during actual community disaster mitigation activities. One of the most popular uses of the system is the creation of hazard maps by residents that are based on their own knowledge and other information related to their neighborhood. **Figure 9** shows an example of an online community hazard map created by the proposed system in conjunction with a newly developed input interface based on “WebLog.” WebLog is a popular interface for making web-based diaries known as “blogs”, and is capable of providing an effective foundation for the ongoing activity needed to make and use such maps. In other words, the interface adds the time history of the activity to the location based GIS.

Figure 10 shows active discussions during a workshop of community members who are using the developed system. If facilitators or leaders are available to guide the group discussions, it is not necessary for each participant to use the computer system individually. This point is especially important for users who are not familiar with computers and other newer information devices. In such a way the system will be a powerful tool for community leaders who are eager about disaster reduction activities. Furthermore, it is observed in every workshop that the participants who are interested in using the system will be potential leaders for community activities.

5.2. Community disaster mitigation festival

An additional application of the presented systems and activities that have been held extensively is the community festival for disaster mitigation activities, an example of which is shown in **Figure 11**. The events include various trial booths of the system for beginners, demonstrations of realistic shaking via the large shaking table, town watching tours searching for dangerous objects and sites for disaster, an active consultation desk for answering questions related to the seismic retrofitting of houses and buildings, and a disaster mitigation discussion corner. Using the developed simulator and other materials in the event, it is important that the majority of the participants are interested in and aware of their own disaster risk.

This type of event is also considered to be especially enjoyable and effective for family participants working to study and remember the important points of community disaster mitigation. Thus, related recreational activities are included such as competitions where children learn how to make rigid and beautiful structures using straws and clips, a short comic play based on disaster mitigation as well as sport competitions using rescue facilities and fire fighting tools.

The festivals have already been held three times in 2007 and 2008 at three wards in Nagoya city, which were planned and managed by volunteer groups and inhabitants, joined by local governments, companies and university researchers. Such events will lead to the creation of an effective basis for collaborative disaster mitigation activities in the local region. The next events are scheduled in 2009 at two cities in Aichi prefecture.

5.3. Application of practical disaster mitigation systems to local government institutions

In April 2008, a practical version of this system was activated on the Internet website of Japan's Aichi Prefectural government (Aichi Prefectural government, 2008). Since that time the number of access requests has steadily increased and strong positive evaluations have been reported. However, it was expected that some problems would be experienced, and thus detailed improvements related to the user interface and security have been continuously implemented in response to users' comments.

Furthermore, a separate institution has also been opened in a Shinshiro city in Aichi prefecture to provide information on disasters and disaster mitigation activities (Shinshiro city, 2008). That institution utilizes the proposed system along with various other kinds of realistic educational materials (**Figure 12**). This facility was conceived as a permanent version of the above-mentioned community festival where citizens can enjoy and study disaster mitigation activities, and includes a number of features especially designed for school children.

Figure 11: Various scenes of the "Bousai Festa" community festival for disaster mitigation activities.

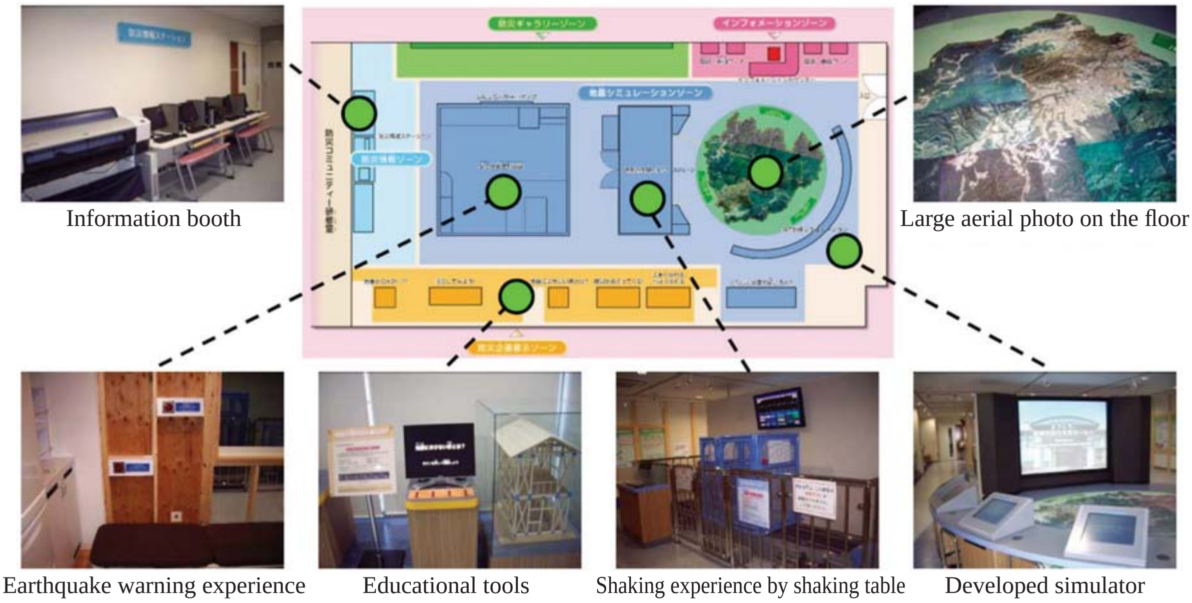


Figure 12: Newly built institution for studying and experiencing disaster mitigation activities.

Such implementation on the web and in the actual institution by local governments will lead to the obtainment of citizens' credibility on contents and indicated countermeasures.

6. CONCLUSION

In this paper, we discussed the development of a disaster information system built around a simulator that provides realistic seismic hazard scenarios in order to help each resident become aware of his/her own hazard level and to learn the need for (and methods related to) home seismic retrofitting. It has clearly been shown that the WebGIS-based systems are capable of providing a hazard map database in an easy-to-understand interface. Furthermore, it can be easily seen that the simulator is effective in helping individuals evaluate their own environments as they pertain to ground shaking, earthquake response, possible house collapse and indoor safety. The system has also proved to be an effective part of community disaster mitigation activities.

Application of the system to various communities is ongoing, and new developments are expected for the future. Project related activities for developing and utilizing such systems have resulted in the spread of community disaster mitigation activities throughout Aichi Prefecture and the surrounding region. The combination of these various project activities has come to be known as "the Nagoya-originated model" and has been highly appraised in Japan and other countries. The developing group is resolute in its determination to maintain and encourage disaster mitigation activities into the far future and thus ensure the best possible preparations have been taken should a large earthquake occur.

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