Title	Integrated Earthquake Simulator to Generate Advanced Earthquake Disaster Information
Author(s)	ICHIMURA, Tsuyoshi, SAMO, Takahiro, HORI, Muneo, ITAMI, Hirohito
Citation	Society for Social Management Systems Internet Journal
Date of issue	2014-12
URL	http://hdl.handle.net/10173/1211
Rights	
Text version	publisher

Integrated Earthquake Simulator to Generate Advanced Earthquake Disaster Information

Tsuyoshi ICHIMURA*, Takahiro SAMO**, Muneo HORI***, Hirohito ITAMI****
*Department of Civil Engineering, Tokyo Institute of Technology
**Department of Civil Engineering, Tohoku University
***Earthquake Research Institute, University of Tokyo
****Kajima Corporation

***ABSTRACT*:** Realistic simulation of possible earthquakes is crucial for producing a rational counter plan against earthquake disasters. This paper presents such a simulation method, the Integrated Earthquake Simulator (IES), which uses a computer-based high-resolution strong ground motion (SGM) simulator and a Virtual Reality (VR) city constructed from GIS/CAD data. The IES is an integrated computer system that is intended to simulate all phases of earthquakes numerically: earthquake hazards, earthquake disasters, and human and social actions against earthquake disasters. An efficient combination of GIS/CAD data and numerical simulation tools for each phenomenon on this computer system can achieve integrated earthquake simulation. This paper presents the methodology of reconstruction of a VR city and the IES prototype. An example of a VR city model is reconstructed and some earthquake disaster simulations are undertaken to examine the IES performance.

KEYWORDS: Integrated earthquake simulator, Numerical simulation, Virtual reality city

1. INTRODUCTION

Recent developments in strong ground motion (SGM) observation have revealed that SGM distribution is much more complicated than expected. It is strongly affected by the following complicated processes: fault mechanisms, wave propagation in the crust, and near-surface amplification. Large urban centers have become increasingly complicated with surprising speed. When SGMs with complicated distributions strike at these complicated urban areas, the resulting earthquake disaster is much more complicated than anticipated. With no reasonable model for an earthquake disaster, of course, it is impossible to plan countermeasures rationally. Reasonable earthquake disaster information based on common recognition among stakeholders can support construction of rational earthquake disaster countermeasures.

For producing such information, we have developed an Integrated Earthquake Simulator (IES)[1), 2), 3), 4)], which is an integrated computer system that is intended to numerically simulate all phases of earthquakes: earthquake hazards, earthquake disasters, and human and social action against earthquake disasters. An efficient combination of GIS/CAD data and numerical simulation tools for each phenomenon of this computer system can achieve integrated earthquake simulation. The IES provides well-visualized earthquake disaster information for stakeholders so that they can both recognize earthquake disasters and promote their common recognition.

This paper describes a primary study to construct such a system. A schematic view of the IES is depicted and a prototype of the IES is constructed as mentioned above. Some application examples are provided to illustrate this system's usefulness.

2. Schematic View of IES

The IES can serve to support construction of earthquake disaster countermeasures based on common recognition because it offers: 1) a virtual reality (VR) city that is reconstructed on a computer from measured digital data (GIS/CAD); 2) simulators for soil, steel, reinforced concrete structures, etc.; and 3) a strong ground motion (SGM) simulator with high resolution (Fig. 1 depicts the IES system). An SGM simulator shakes a VR city on the computer with a realistic setting. Consequently, we can realistically visualize and analyze an earthquake disaster. Estimation of an earthquake disaster in a whole city in such an integrated manner enables us to evaluate not only structural damage, but also the effects of network damage, and other damage.

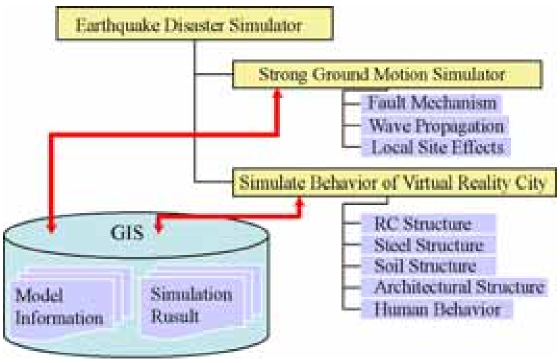

Figure 1: Schematic view of IES

3. Application Examples

This section describes two case studies as application examples and presents the usefulness of the IES approach using an IES prototype and VR city prototype.

3.1 IES Prototype for Kobe City

The VR city prototype of the Kobe city area as it existed before the Great Hanshin Earthquake ((135°00'00"E, 34°36'00"N)) – (135°28'00"E 34°51'00"N)) was constructed using GIS/CAD data. Then, a prototype of IES was applied to simulate dynamic behavior of this VR city numerically to thereby demonstrate the IES approach.

3.1.1 Construction VR Kobe city

The VR Kobe city prototype, including the three-dimensional (3-D) soil structure, buildings and a bridge, is constructed using borehole data[5], surface elevation data (50 m grid)[6], two-dimensional (2-D) CAD data for buildings[7], classification data of buildings[7], a bridge blueprint, and other information. Figure 2 shows the target area, which contains 573,099 buildings.

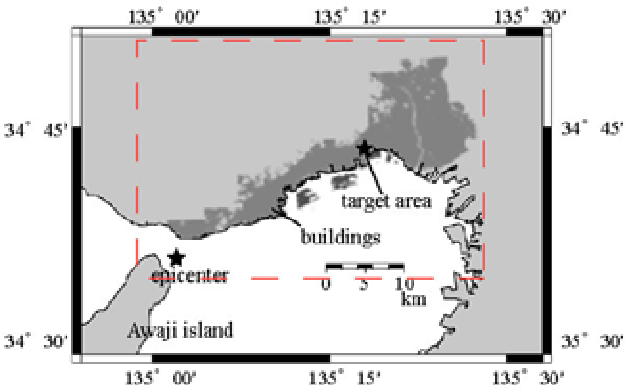

Figure 2: VR Kobe city

A small domain ((135°17'40"E, 34°42'58.5"N)) – (135°18'4.5"E, 34°43'19.5"N)) was selected as the target area for this application illustration, but an application example of the entire domain was also conducted. Figure 3 shows the VR city of the target domain including the 3-D soil structure, buildings, and bridges.

The 3-D soil structure was estimated using an approach similar to that of precedent studies [1), 8)] with borehole data[5] and surface elevation data (50 m grid)[6], as shown in Fig. 4. The surface topography is almost horizontal, but the interface between the soft layer and engineering basin is inclined in the east-west direction.

The VR city bridge is constructed using 3-D CAD data that were digitized from a blueprint of the actual bridge. This bridge has a data structure that

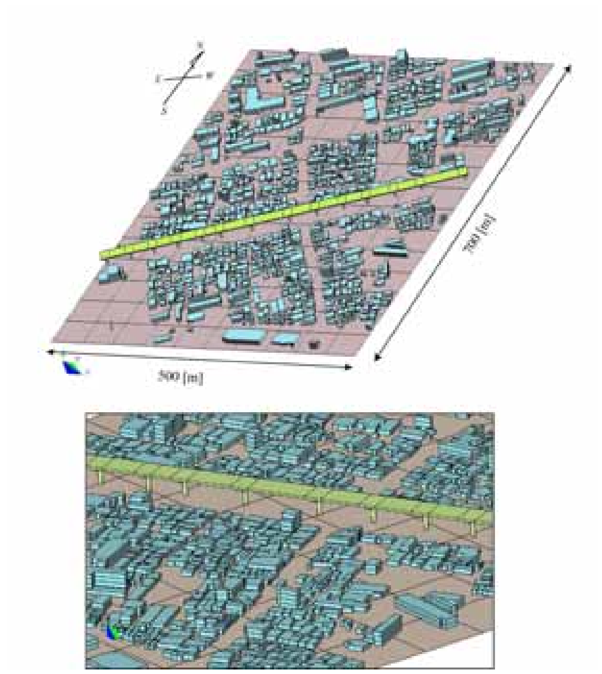

Figure 3: A Part of the VR City

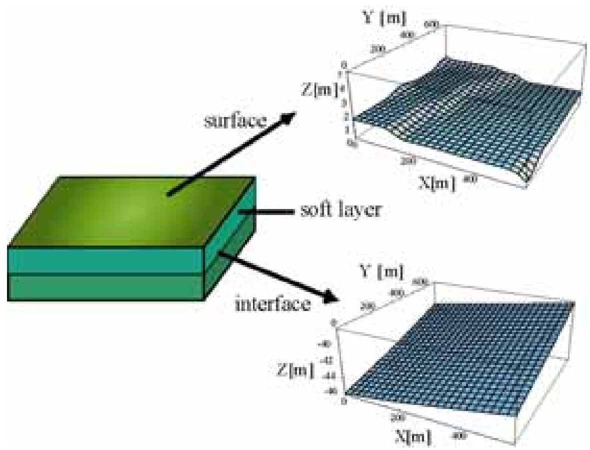

Figure 4: Estimated 3-D soil structure

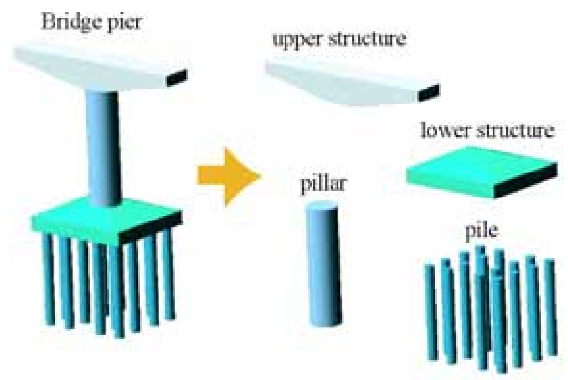

Figure 5: An example of bridge model in VR city

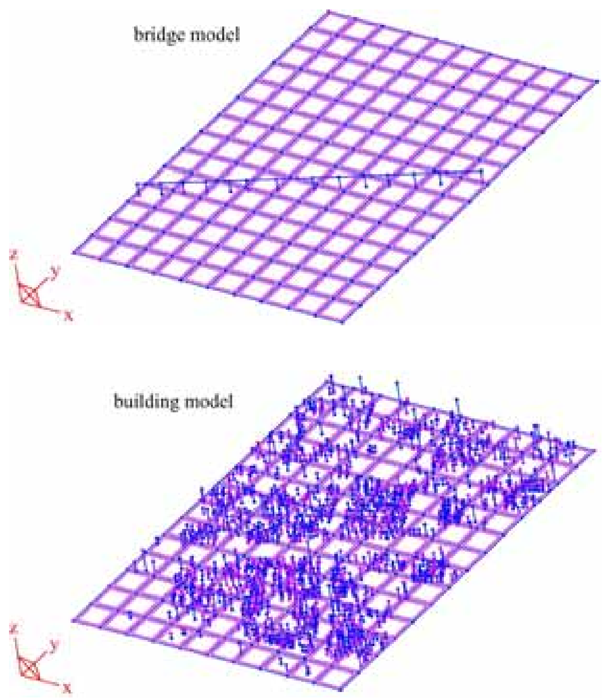

Figure 6: Example of transformation of model to a spring-mass model

readily allows us to model each bridge member using an ID and transform data resolution (see Fig. 5).

The 3-D building model is constructed using 2-D CAD data for buildings[7)] along with building classification data[7)]. The target domain includes 1261 buildings. Each building has an ID and an associated data file that includes data for location, 3-D geometry, classification, and other data.

Each structure in this VR city has a data structure and ID that make the voluminous data tractable. When we specify the ID, the structural data are extracted automatically. Furthermore, data transformation can be handled easily. For example, model transformation from the continuum model to the spring-mass model is depicted in Fig. 6.

3.1.2 Earthquake disaster in a VR Kobe city simulated by IES prototype

Earthquake disaster simulation is conducted using the VR Kobe city constructed in the above section and IES prototype. This IES prototype comprises an SGM simulator with high resolution (3-D dynamic FEM[9), 10)]), a bridge simulator (3-D dynamic FEM analysis tool for large-scale structure[11),12)]), and a building simulator (approximated modal analysis[13)]). These numerical simulation tools are selected to correspond to the data model quality because only limited data are available for construction of the VR city.

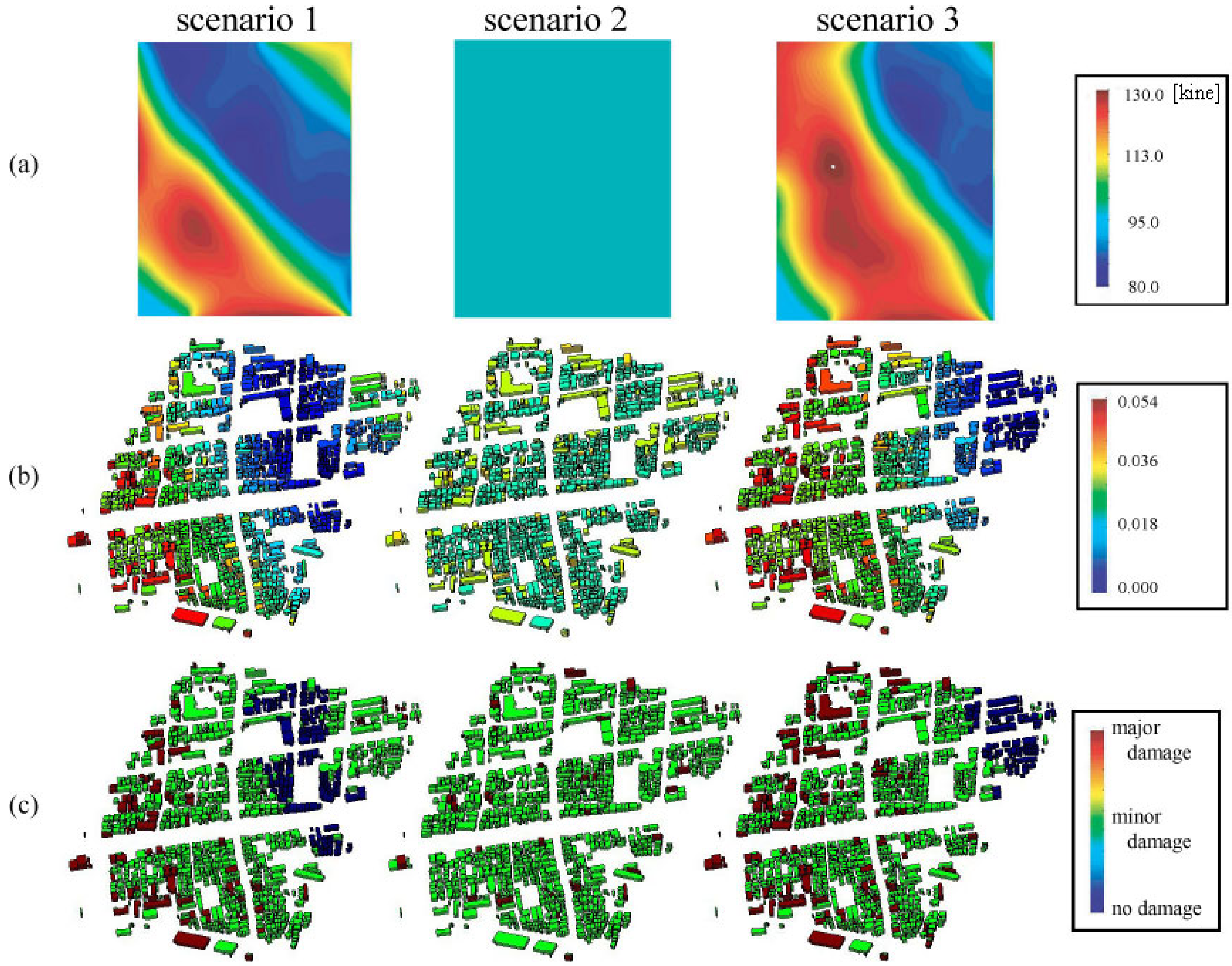

Figure 7: (a) maximum velocity distribution (kine), (b) maximum drift degree distribution and (c) damage distribution

The dynamic behavior of the VR Kobe city is estimated for three scenarios according to a primary study. RickerWavelet (center frequency 1 Hz, center time 1 s) is input from the bottom surface of the 3-D soil structure in the north-south and east-west directions. Maximum amplification is modified as fit to earthquake motion observed at Takatori Station during the Hanshin Great Earthquake. The following three scenarios are considered.

scenario 1: the wave input is from underneath and perpendicular.

scenario 2: the wave input is from underneath and perpendicular. The soil structure is approximated to horizontally layer media.

scenario 3: the wave input is inclined by 5°.

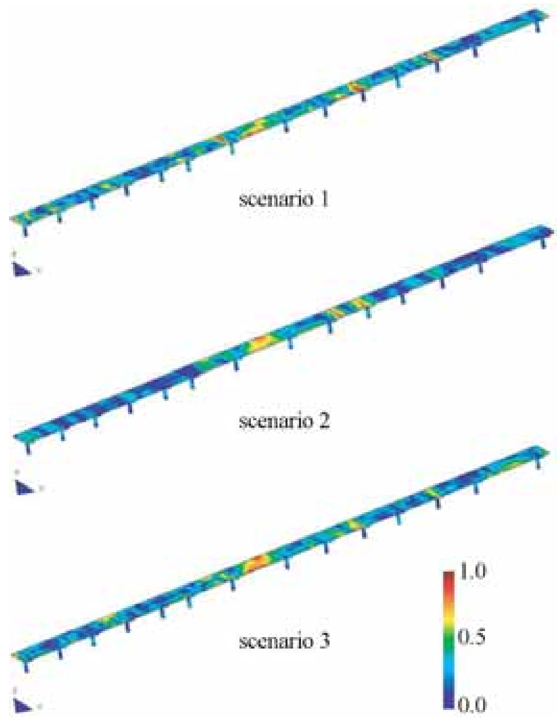

Figure 8: von Mises stress distribution

Estimation of dynamic behavior of the VR Kobe city is summarized briefly (for detailed discussion, see [4]). Figures 7(a) and 7(b) show maximum velocity distributions on the surface and the maximum drift angle (DA) of each building. The SGM distribution is uniform and DAs of similar buildings are the same in scenario 2 because the soil structure is approximated to horizontally layered media. On the other hand, the SGM and DA distributions are not uniform and localized in scenarios 1 and 3. Figure 7(c) shows estimations of building damage; they were conducted based on the maximum DA and criteria for each building type[14),15),16),17)]. The damage distribution indicates that building damage is affected strongly by local effects of SGM and the buildings' characteristics. Evaluation of the buildings' damage in the target area is summarized in Table 1 based on the damage distribution. For simplicity, minor damage and major damage respectively give 0.5 and 1.0 costs. We can then readily evaluate such damage because all results are stored in the IES computer system as digital data. Dynamic behavior of the bridge is estimated using SGM data and 3-D dynamic FEM[11), 12)]. Figure 8 shows the maximum von Mises stress distribution normalized by the maximum value. Distributions differ mutually because the input wave for the bridge is remarkably different among scenarios. These estimations and discussions reveal that different scenarios engender remarkable differences of resulting earthquake disasters in complicated cities.

3.2 IES Prototype with Network Analysis for Miyagi

The VR city prototype of a part of the Miyagi area is constructed using GIS/CAD data; then the IES prototype with network analysis is applied to numerically simulate that area's dynamic behavior and network damage of this VR city in a simulated Miyagi-oki earthquake.

Table 1: Damage amount

	wood	steel	RC	steel/RC
scenario 1	545.0	62.0	28.0	654.0
scenario 2	525.0	17.5	13.0	565.0
scenario 3	500.0	105.5	19.5	644.0

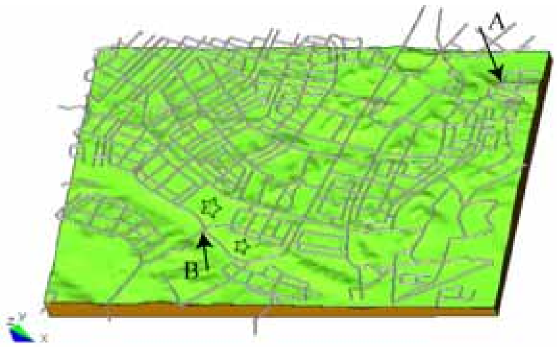

Figure 9: VR city in a part of Miyagi

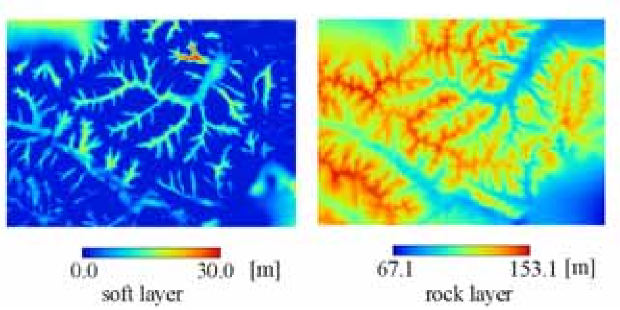

Figure 10: Soil structure in a part of Miyagi

3.2.1 Construction of a VR City with a Network in Miyagi

The 2500 [m] × 2000 [m] domain in the Miyagi area is selected as the target area. Figure 9 shows the VR city, including its 3-D soil structure and road network. It is constructed as a 3-D soil structure using CAD data and a digital map[18)]. The soil structure consists of a soft layer and a rock layer. The soil structure is complicated, as shown in Fig. 10, which shows the respective layers' thickness, but the domain shown there is not large. The road network has 575 nodes and 807 links with associated sub links.

3.2.2 Earthquake disaster simulated by IES with network analysis

Network damage simulation in the assumed Miyagi-oki[19)] earthquake is conducted using the VR

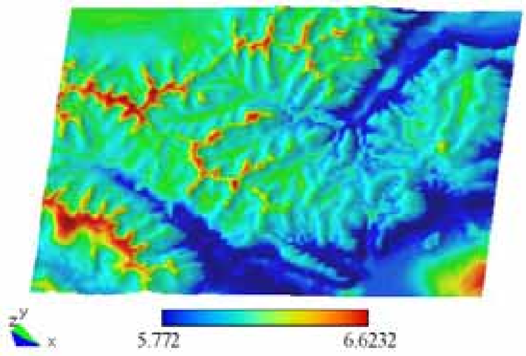

Figure 11: Distribution of seismic intensity

Figure 12: Use frequency of each link

city constructed in the above section and the IES prototype with network analysis. The SGM simulator (statistical Green's function approach[19), 20), 21)] and one-dimensional wave theory for near-surface wave amplification [22)]), a road-damage simulator based on [23), 24), 25)], and a network analysis simulator (Dijkstra method) are implemented in this prototype IES. These numerical simulation tools are also selected to correspond to data model quality because available data for construction of the VR city are limited.

The accessibility of point B from point A shown in Fig. 9 is estimated using the IES described above. The star shown in Fig. 9 indicates a shelter. Considering the uncertain soil structure, Monte Carlo simulation is conducted with 1000 cases. Figure 11 indicates an example of the seismic intensity factor distribution. Although the target domain is not large, the resultant SGM distribution is complicated; it is also strongly affected by the 3-D soil structure. Figure 12 shows the use frequency of each link. Concentration of the use frequency to some links indicates that these links are important in this network. The 137 cases show the impossibility of access to point B from A in this simulation, meaning that some people cannot reach shelter. As shown in that figure, the IES prototype with network analysis reveals the ranked importance of links and weak points of networks.

4. Concluding Remarks

This paper described the construction of an IES prototype. Some application examples were presented to illustrate the need for integrated simulation and integrated estimation on earthquake disasters, and the utility of the IES.

In the near future, more simulators for various structures will be incorporated into the IES. A data transfer protocol to provide links among various simulators will be examined. Sensitivity analyses against data will be made from the viewpoint of required data for reasonable earthquake disaster simulation. Following the explorations mentioned above, earthquake disaster simulation in a more realistic setting will be attempted using the IES.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge members of the Integrated Earthquake Simulator Committee of JSCE for helpful discussion and Professor Y. Fujino at the University of Tokyo for bridge blueprint data.

REFERENCES

1) F. Yang, T. Ichimura and M. Hori: Earthquake Simulation in Virtual Metropolis Using Strong Motion Simulator and Geographic Information System, *Journal of Applied Mechanics* JSCE, Vol.5, pp. 527–534, 2002.

2) T. Ichimura and M. Hori: Development of Prototype of Integrated Earthquake Disaster Simulator using Digital City and Strong Ground Motion Simulator with High-resolution, *13th*

World Conference on Earthquake Engineering, No. 1418, 2004.

3) T. Ichimura, M. Hori, K. Terada, and T. Yamakawa: On Integrated Earthquake Simulator Prototype: Combination of Numerical simulation and Geographical Information System, *J. Struct. Mech. Earthquake Eng. JSCE*, (in press).

4) T. Ichimura, H. Itami, T. Samo, M. Hori, and N. Yamaguchi: Construction of Digital City Kobe & A Basic Discussion on Application of IES approach to Earthquake Disaster Simulation, *Journal of Structural Engineering*, JSCE, Vol.51A, pp. 513–520, 2005.

5) Construction Engineering Research Institute Foundation: Hanshin-Awaji (Kobe) Earthquake and the ground in Kobe: Construction of "Kobe Jibankun" and analysis of the ground and damage, 1998.

6) Geographical Survey Institute: numeric topography data (50 m mesh) JAPAN-III, Japan Map Center, 2001.

7) Building Research Institute: A Survey report for Building Damage due to the 1995 Hyougo-ken–Nanbu Earthquake, 1996.

8) K. Shiono, K. Wadatsumi and S. Masumoto: Numerical Determination of the Optimal Bedding Plane, *Geoinformatics*, Vol. 12, pp. 299–328, 1987.

9) T. Ichimura and M. Hori, Macro-Micro Analysis Method for Wave Propagation in Stochastic Media, *Earthquake Engineering & Structural Dynamics*, (in press).

10) T. Ichimura and M. Hori, Strong Ground Motion Prediction using Macro-Micro Analysis Method, *Earthquake Engineering & Structural Dynamics*, (in press).

11) T. Yamada, T. Ichimura, N. Ohbo, T. Samo, K. Ikeda, and M. Hori: Seismic Response of Underground Complicated Structure by 3D FEM Analysis, *Journal of Applied Mechanics* JSCE, Vol. 7, pp. 909–916, 2004.

12) T. Yamada, T. Ichimura, N. Ohbo, T. Samo, K. Ikeda, and M. Hori: Seismic Response Behavior of Ramp Structure in the Tunnel and its Countermeasure, *Journal of Structural Engineering*, *JSCE*, Vol. 51A, pp. 561–568, 2005.

13) Y. Osawa, T. Minami, and Y. Matsushima: *Dynamic Analysis for Structures* Vol. 38, Shokokusha, 1999.

14) Architectural standard method enforcement order, 1995.

15) Housing Bureau of the Ministry of Land, Infrastructure and Transport: Calculation example by Limit power calculation method and the explanation, 2001.

16) Y. Hayashi: Development of earthquake damage simulator for adaptive management at community level, 2002.

17) H. Kawase: Earthquake Damage Prediction for Buildings and the Future Direction for Damage Reduction, *Journal of Geography*, 110(6) pp. 885–889, 2001.

18) Geographical Survey Institute: Digital map data 25000 (spatial data infrastructure).

19) The Headquarters for Earthquake Research Promotion, Earthquake Research Committee: Report on strong ground motion prediction for next Miyagi-oki earthquake, 2003.

20) D.M. Boore: Stochastic simulation of high-frequency ground motions based on seismological models of the radiated spectra, *Bull. Seism. Soc. Am.*, 73, 1865–1894, 1983.

21) K. Dan, T. Sato: Strong-Motion Prediction by Semi-Empirical Method based on Variable-Slip Rupture Model of Earthquake Fault, *J. Struct. Constr. Eng., AIJ*, No. 509, 49–60, 1998.

22) I.M. Idriss and J.I. Sun: User's Manual for SHAKE91, Center for Geotechnical Modeling, Department of Civil Engineering, University of California, Davis, 1992.

23) The Cabinet Office: Central Disaster Prevention

Council, *Related material of Special Investigation Committee such as the Southeast seas and Southern sea earthquakes (16th)*, 2003.
24) Japan Road Association: Specifications for Highway bridge V: Seismic Design, 2002.
25) Miyagi Prefecture Government: The third report of earthquake damage estimation, 2004.