10

Trends of Disaster Simulation Technologies

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10.1 Introduction

In Japan, 50% of the population live within river flooding areas (floodplains), which accounts for 10% of the land area, and 75% of properties is concentrated within these areas. A great part of a floodplain consists of low-laying flatlands having new and unstable strata. Due to these geographical and geological conditions, occurrences of natural disasters result in fatalities.

To ensure the "security" of the citizens, countermeasures against disasters are vital issues. In the past, a main stream of disaster prevention was to provide countermeasures for checking the occurrences of disasters, which required enormous costs and long-term maintenance of the relevant facilities. Recently, the policy has been shifted to focus on "Damage Reduction," which emphasizes minimizing damages caused by disasters.

In order to materialize this "Damage Reduction," it is necessary to establish a disaster prevention plan supporting evacuation and rescue methods as well as providing the necessary facilities.

On this viewpoint, simulation technology for estimating damages and phenomena may be an effective method for providing fundamental information for such disaster prevention plan.

The development of simulation technology is largely supported by computer technology. Numerical analysis using a supercomputer capable of processing complicated phenomena in a short time exhibits strong abilities in the fields of earthquake analysis, weather forecasting, and so on.

On the other hand, according to the "public-opinion census on disaster prevention and information" conducted by the Prime Minister's Office, 52% of the citizens pointed out that they would like to gain knowledge and understanding of the inundation prediction map, the earthquake damage estimation map and the hazard map. To respond to these social needs, analysis results of the inundation prediction map and the earthquake damage estimation map were recently made public through the Internet. For earthquake damage estimation, in particular, relevant detailed data are published on the Internet to respond to the needs of the residents.

In this report, I will report on the current situation of disaster simulation technology, its recent trend from a viewpoint of the social background, and discuss about the effective methods for using this technology.

10.2 The current situation of technologies effectively using fundamental information

10.2.1 Digital national land information

Digital national land information has been provided by the Geographic Survey Institute, and various kinds of information including land shape, land use, etc., are classified in a mesh form and stored as digital data. This information will be updated every 5 years at the time of the national census, in principle. In the past, information of 100 m to 500 m meshes was used for analyses. For instance, a representative altitude was calculated by averaging several altitude data at different points. With this method, the accuracy of analyses was fairly coarse since detailed land shape could not be captured.

Then, the Geographic Survey Institute provided "Detailed Digital Information" for the Tokyo metropolitan area and the Chubu and Kinki regions, which consists of digital information of 10 m meshes on land use produced by deciphering aerial photographs. This information is based on the "Housing land use trend survey," which is conducted about every 5 years and whose data are sold publicly on CD-ROMs.

Recently, a new technology has been developed where laser beams are emitted from an aircraft to the ground, and then the time difference of the laser beams reflected from the ground are analyzed to measure land shape, positions and heights of natural features on the earth, while simultaneously acquiring images using a digital camera. This aircraft interlocks with GPS standard stations to calculate the 3-D coordinates of the laser measuring points and the digital image main points. Using this technology, digital information of 2 m meshes can be obtained, and the accuracy of analysis of flood simulations, etc., is expected to improve by leaps and bounds.

10.2.2 Current conditions of the technology of the Geographic Information System (GIS)

The technology of the Geographic Information System (hereinafter referred to as "GIS") was developed in the 1990s, and is now displaying its functions in various fields as increasing the social needs after that.

Promotion of the GIS is included in the IT basic strategy of the Japanese government's "e-Japan strategy," as one of the important issues.

For instance, the administrative organs of the Japanese government have already provided the GIS facilities for use with infrastructures including rivers and sewerages, etc., and the local autonomous bodies also promote the provision of the GIS for facilities under their management or classification of land use, etc.

In the GIS, data can be comprehensively managed together with maps and images, and overlapped with each other. As a result, the system contributes to effective management operations including management of use conditions of facilities and land, etc., by applying diversified processes.

In the case of analyzing the extent of phenomena in the vertical direction, 3-D maps can provide very useful information. For instance, in previous inundation analysis, the speed and depth of running floodwater could be grasped, but the analysis would only indicate their influences on a two dimensional scale. By linking 3-D maps to the analysis, it is possible to grasp the distribution of the speed of running floodwater in its depth direction. With this technology, it is possible to individually estimate the influences of the impact of floodwater on different building structures such as wooden buildings and concrete buildings, etc., or influences on buildings by the way they are used. Through this, it becomes possible to analyze the influences of the respective buildings very accurately and thoroughly, such as damage estimation of underground facilities, influences on the people in hospitals and welfare facilities, etc., requiring support due to disasters.

10.3 Current situation and trends of various kinds of disaster simulation technologies

10.3.1 Outline of disaster simulation technology

Future development of various kinds of disaster simulation technologies are expected to make possible real-time prediction of natural phenomena and disasters by merging the developments of computer hardware and technologies for measurement and observation. It seems that the role of disaster simulation technology in disaster prevention and crisis management will become more and more important in the future. Subjects and contents of analyses of various kinds of disaster simulation are listed below in Table 1.

In the analyses, I set various calculation constants and coefficients in consideration of geographical and geological characteristics, and then verified the adequacy of these assumed values by applying them to phenomena that actually occurred in the past in order to ensure the accuracy of the analyses.

For the damage estimation, I made the necessary analyses as relating the results to the actual phenomena by using the digital national land information as mentioned in the section above.

Table 1: Outline of various disaster simulation analyses

Type of disaster	Phenomena	Major input data	Major output data
Flood	Flood effluences *1	Rainfall distribution in a basin, Topography of a basin, Topography data, Data of soil and vegetation	Fluxes at respective points on a river
	Outer drainage inundation*2	River courses flux, Shapes of broken banks, Topography data of an inundation area	Inundation flux, Depth of inundation, Inundation area, Speed of running water, Time to arrival
	Inner drainage inundation*3	Topography of a basin, Dimensions of draining facilities, River courses flux	Ditto
Landslide disasters	Avalanches of earth and rocks	Rainfall, Topography, Soil data, Vegetation, River courses flux, Speed of running water, Shear stress	Amount of escaped soil, Running speed and thickness of accumulation, Distance to arrival
	Landslips	Rainfall, Topography, Soil data, Vegetation, Pore water pressure	Slipping form, Amount of corrupted soil and distance to arrival
Volcanic eruptions	Steam of lava	Atmosphere data, Topography, Soil	Thickness of accumulation, Range of flow, Running speed
	Cinder and volcanic bombs	Mountain configuration	Distance to arrival, Speed, Impact
	Falling pyroclastic rocks	Mountain configuration, Atmosphere data	Distance to arrival, Thickness of accumulation
	Volcanic mud flow	Rainfall, Accumulated amount of volcanic ash, Topography	Range of flow, Thickness of accumulation, Running speed
	Pyroclastic flow	Mountain configuration, Atmosphere data, Topography	Range of arrival, Speed, Temperature, Thickness of accumulation
Earthquake	Strong ground motion	Seismic center, Intensity, Soil, Ground configuration	Acceleration distribution, Seismic intensity distribution, Liquefied soil distribution
Tsunami	Overtopping wave	Land topography, Height, Lasting time, Amount of overtopping wave	Depth of inundation, Distance to arrival, Hydrodynamics
Storm surge	Overtopping wave inundation	Topography of a basin, Flux in a river, Sea topography, Meteorological tide level data	Depth of inundation, Inundation flux, Time to arrival, Inundation range

*1 A phenomenon where rainfall flows from a basin to a river.
*2 A phenomenon where river water floods into a town due to the breakage of a bank.
*3 A phenomenon where rainfall floods into a town from sewerages in the case of a localized torrential downpour, etc.

Source: Author's own compilation

10.3. 2 Trends of disaster simulation technologies

In this section, I briefly explain about the current situation of various kinds of disaster simulation technologies and the technological development activities for solving the current issues. In Table 2, important issues on floods, landslide disasters, volcanic eruptions, earthquakes, tsunami and storm surge are summarized respectively.

10.4 Examples of recent simulation technologies

10.4.1 The inner drainage inundation simulation of the Tsurumi River

In the past, it was difficult to analyze the amount of rainwater in drainage networks in the case of inner drainage inundation in a basin having sewerages, etc. In 2000, a high-accuracy version of software for inundation analysis in urban areas (MOUSE) was developed by the Danish Hydraulic Institute. As a result, it is currently possible to create an inner drainage inundation simulation using a solid analyzing method by entering the amount of the effluences of the “quasi linear effluences calculation model,”*1 an analysis of effluences in a basin of a river, into the software program as a boundary condition. This simulation has the following features.

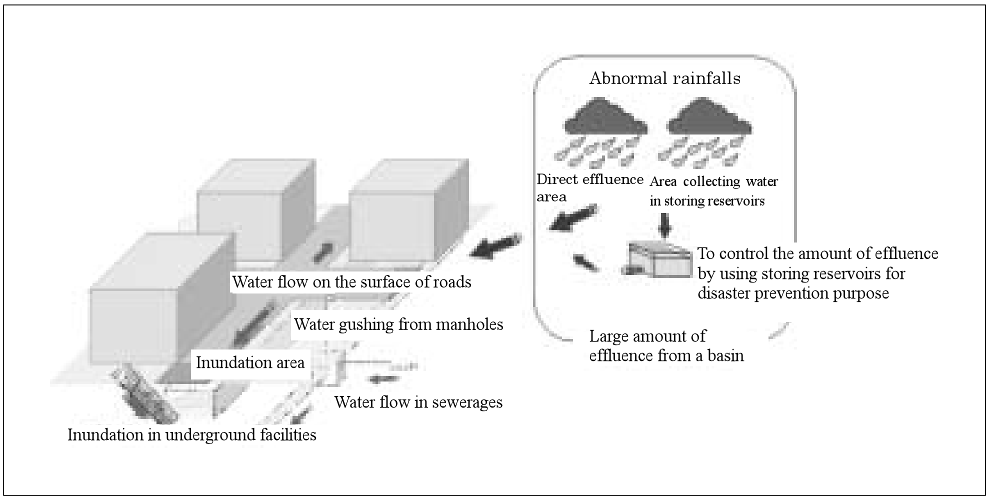
— You can grasp data on the amount of flowing water and water levels at an arbitrary point in a time series.
— You can incorporate information about drainage networks (including loop lines),

Table 2: Trends of various disaster simulation technologies

Type of disaster	Current technologies	Required development of technologies
Flood	— The effluence amount of inundation water, the running speed, the range of inundation, the depth of flood water and the inundation range can be displayed in a time series.	— To firmly materialize an inner drainage inundation simulation having effluence from sewerages, operating conditions of draining pumps and the effluence amount from a basin (Partially available).
Landslide disasters	— The shear stress of soil including large pebbles and scours on mountainsides can be estimated. — The Finite Element Method is used for landslips in the case of uneven ground conditions.	— There is an issue of accuracy in application of a coefficient of friction among soil particles in avalanche phenomena. — To develop a technology applying the Finite Element Method to corruption phenomena of rock beds, which are mainly cracks and dislocations.
Volcanic eruptions	— The respective phenomena associated with eruptions (Figure 1) can be analyzed numerically.	— To develop numerical analyzing methods for estimating transitions of eruptions and the relevant damages. — It is a significant issue to estimate the behavior of magma, which is a kind of multi-phase fluid.
Earthquake	— Strong ground motion simulation estimating shocks on the ground surface can be analyzed with fairly high accuracy. — Dynamic behaviors of buildings are practically analyzed with the Finite Element Method.	— To develop a numerical analyzing method for seismic wave motion propagation, accurately reflecting complex underground constructions. — To develop analyzing methods estimating the occurrence and size of liquefied soil. — To develop analyzing methods estimating the breaking processes of dislocations, and the forming processes of seismic dislocation on the ground surface that is caused by the dislocation.
Tsunami	— The final changing amount on the seabed can be calculated with a dislocation model assuming a rectangle slipping surface. — The tsunami propagation analysis can calculate the water level at every moment with the propagation equation.	— To develop a model of the energy loss relating to wave edge conditions for the retroaction analysis to the land and coarseness on the land. — To develop technologies for instantly making a numerical analysis with input of detailed data of topography of the seabed and observed values in the distant offing.
Storm surge	— As a result of the fact that accumulation of topography data on the seabed and tide levels observation data have expanded drastically, the wave calculation analysis is in practical use.	— To develop a numerical prediction method using a model solidly estimating tidal waves with the assumed size and course of a typhoon and inundation.

Source: Author's own compilation

Figure 1: Analyzing concept



Source: Documents of the Ministry of Land, Infrastructure and Transport weirs and pumping facilities, etc.

— You can simultaneously analyze flows in drainages and inundation conditions of roads, etc., and, subsequently, you can grasp the conditions of water entering into underground facilities.

— You can provide various types of presentation using graphs and animation of the analysis results.

By using this simulation technology, Ministry of Land, Infrastructure and Transport conducted inner drainage inundation analysis of a lowland area of Tsurumi River (an area where forced draining with pumping facilities are required) in the case of a localized torrential downpour as follows.

Figure 2: Conditions in the basin and the subject rainfall

Area of the basin:	709 ha
Ratio of urban area:	About 99%
Underground mall:	1
Underground room:	18
Draining method:	By pumping facilities
Capacity of water storage for disaster prevention:	22,758 m^3
Subject rainfall	88 mm/hr

Source: Documents of the Ministry of Land, Infrastructure and Transport

The outlines of the analysis are as follows. They were able to make the following estimations, which were impossible in ordinary systems.

— As shown in Figure 3, the inundation will spread to almost all of the lowland areas, and the depth of inundation will be 2.0 m or more in some spots.

— As shown in Figure 4, the depth of inundation will reach 60 cm within about 40 minutes. Quick evacuation is required.

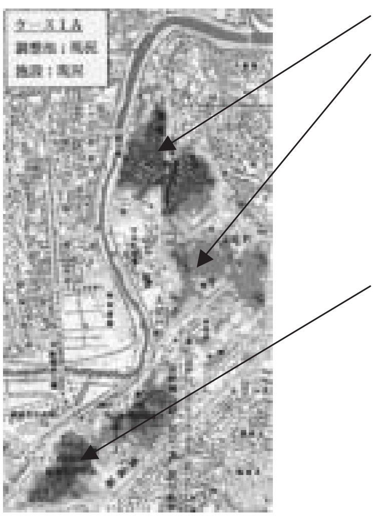
— In the area around Shin-Yokohama, all 18 underground facilities will be flooded.

Reference: Risks of underground rooms in the case of inundation

In the case of inner drainage inundation, underground facilities can be flooded within a short time. Some people were either killed or injured due to inundation in underground rooms in Fukuoka Prefecture, etc. From these facts, risks of underground facilities are pointed out.

They introduce an analysis based on a verification experiment about the risks of underground rooms in the case of inundation as follows.

Figure 3: Inundation situation



Source: Documents of the Ministry of Land, Infrastructure and Transport

Figure 4: Changes of inundation conditions around Shin-Yokohama

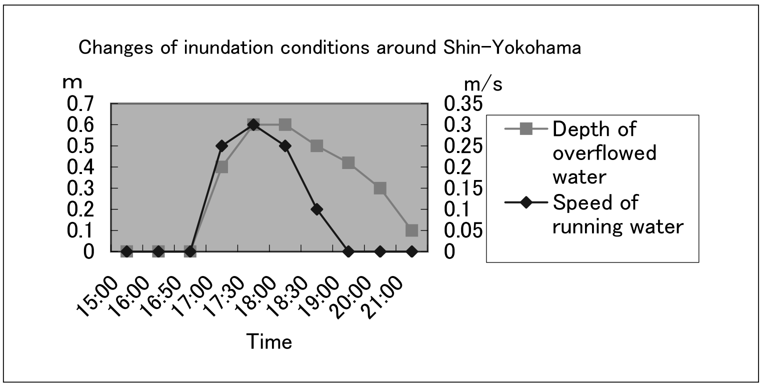
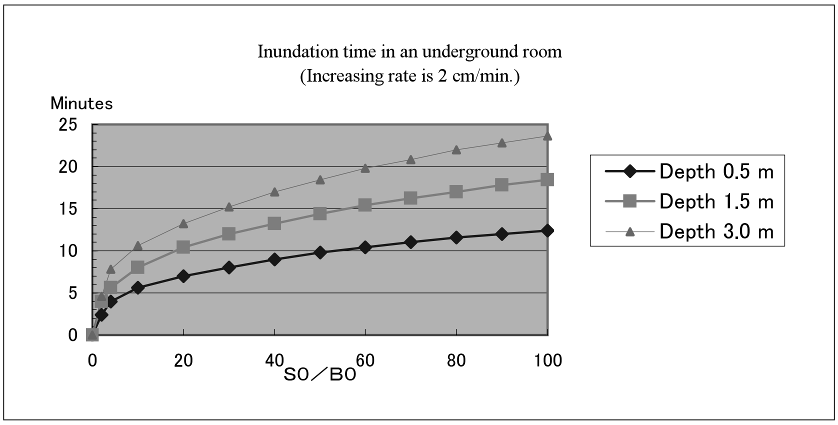


Figure 5: Relations of inundation in an underground room



Source: Documents produced by Nihon Kenchiku Bosai Kyokai

1) **Water will enter into a room very quickly**

If the flood increasing ratio at a town is 0.02 m/min. and there is no gap at the entrance, the relation between the depth of the flood in an underground room, and the ratio of the area of the room and the width of the entrance (S0/B0) will be as shown in Figure 5. For instance, if a room has an area of 10 m2 and its entrance width is 1 m, the water level height will reach 1.5 m within about 8 minutes.

2) **A door will not open immediately after flooding**

Many underground rooms have doors at their entrances. In the case of inundation, water first accumulates in the entrance room in front of the door. In this case, the door's operation will be as follows.

(1) In the case of a door that opens out

In the condition that water accumulates in an entrance room, you need to use force to push the door open. This required force is estimated to be 10 to 20 kgf for adults, and at least 4 to 6 kgf for aged people and children. If the necessary force is assumed to be 15 kgf, the corresponding water level will be around 26 cm. This means that the door of the above-mentioned underground room (1) will not open after only about 4 minutes from the start of flooding.

(2) In the case of a door that opens in

You need to use a large amount of force to turn the doorknob, due to the pressure of the water accumulating in the entrance room. This force is estimated to be 20 to 30 kgf-cm for women. Assuming that force of 50 kgf of water pressure is applied to the door, the corresponding water level will be 47 cm, i.e., you cannot open the door after around 5 minutes.

3) **Electric systems will fail due to the inundation, and all types of electric equipment will stop.**

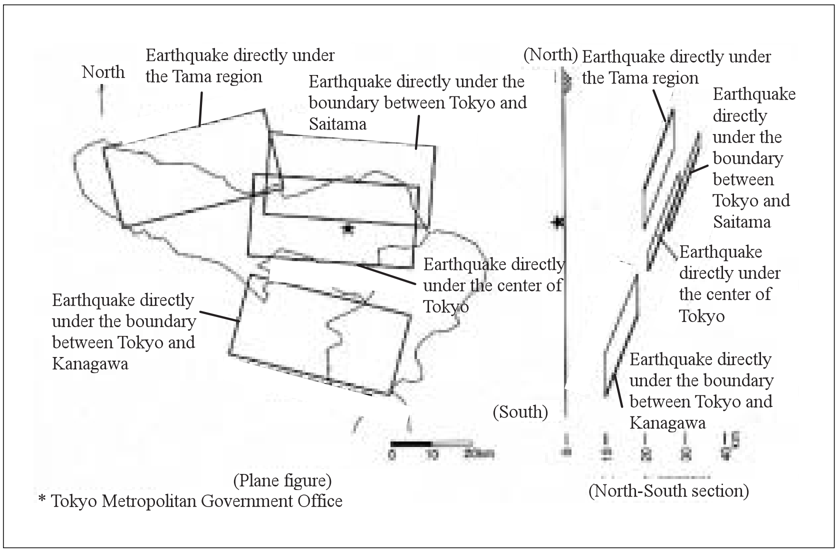
If an underground room is flooded, a series of power failure processes will take place, i.e., the deterioration of electric isolations — short circuits or leakage of electricity — cut of electric power by breakers — power failure, and all functions will be out of order. Even in the case of an emergency lighting facility, its functions may probably stop if the equipment and wiring are flooded.

4) **It is very dangerous to walk up a stairway against flowing water. The force of water coming from the upper stairs will become stronger and stronger.**

10.4.2 *Analysis simulation for Tokyo of an earthquake directly under the south Kanto region*

This analysis is based on the assumption of a plate-boundary type earthquake along the surface of the Philippine Sea plate, of which imminence has been pointed out in the Central Disaster Prevention Conference of the Cabinet Office and the largest amount of damage is expected from this disaster. In this analysis, they conducted seismic intensity analysis and liquefied soil distribution on the basis of the latest strong ground motion numerical analysis, and reflected

Figure 6: Estimations of seismic centers of an earthquake directly under the south Kanto region



Source: Documents provided by the Tokyo Metropolitan Government

detailed data on the actual damage in the 1995 Hyogoken-Nanbu (Kobe) Earthquake to this analysis. In estimating the damage, they analyzed the cause and effect relationships for the respective damaged items based on the damage data of the 1995 Hyogoken-Nanbu (Kobe) Earthquake and so on; provided a damage estimation formula; and then calculated the estimated amount of damages by applying the digital national land information to this formula. They produced and released this analysis in 2001, and used data of the digital national land information in 1998.

The assumptions of the earthquake and the damages are as follows.

The seismic center:
They estimated for 4 cases: directly under the center of Tokyo; directly under the Tama region; on the boundary between Tokyo and Kanagawa; and on the boundary between Tokyo and Saitama.
Intensity: Magnitude (M) 7.2
Depth of the seismic center:
20 to 30 km underground
Area of the seismic center(Area of the rock bed destroyed):
Length around 40 km x Width around 20 km
Time and weather conditions:
At 18:00 on on a weekday in winter, clear, wind velocity of 6 m/s

- The estimated items are as follows.

1) The shock of the earthquake, the liquefied soil, damages caused by tsunami and flood damages due to the earthquake
2) Damages to buildings, etc.
3) Fires
4) Damages to railways and roads, etc.
5) Damages to lifelines
6) Human casualties
7) Damages to social life (food, medical services, etc.)

— In calculating the estimated damage, they used the maximum acceleration for the ground surface for buildings, the ground surface velocity for lifelines, and the seismic intensity for railways/roads as the respective indexes.

Outline of the results of the damage estimation analysis

— Since the seismic center dislocation of the assumed earthquake was set to a deep point of 20 to 30 km underground, the maximum seismic intensities of the 4 cases are all around the 6th plus degree.

— Since the sinking angle of the Philippine Sea plate directly under Tokyo is nearly flat, the dislocation motion of the assumed earthquake also takes place in nearly a flat position. Consequently, the shock of the earthquake will spread horizontally, and, as a

Table 3: Results of damage estimation

Ward	Presumed population during the evening time	Area Km^2	Ration of seismic intensity relative to area (%)			Ratio of possibility of liquefied soil relative to area (%)		
			5th Plus	6th minus	6th Plus	A	B	Non
Chiyoda	837,243	11.64	34.1	65.9	0.0	27.3	20.5	43.2
Koto	476,981	39.2	0.0	37.5	62.5	65.1	33.9	0.0
Ota	706,786	59.46	0.0	70.0	30.0	78.6	0.0	21.4
Suginami	413,387	34.02	59.9	40.1	0.0	0.0	0.0	100
Entire center of Tokyo	11,222,592	616.35	26.6	59.1	14.3	46.4	6.6	45.7
Entire Tokyo Metropolitan	14,404,325	1,776.25	30.0	31.1	5.1	16.8	2.4	80.4

* In the case of Rank A of liquefied soil area, 18% of the mesh area will be liquefied, while Rank B means that 5% of the same will be liquefied

Ward	Ratio of buildings completely destroyed (%)	Ratio of failed lifelines (%)				Lost area Km^2	No. of fatalities	No. of persons seriously and slightly injured	No. people who cannot return home
		Water supply and sewerage	Gas supply	Electricity	Telephone				
Chiyoda	3.3	33	66	16	4	0.00	114	8,868	603,930
Koto	4.4	62	100	15	33	2.63	227	9,689	71,265
Ota	3.1	46	82	27	59	10.76	1,104	11,822	118,967
Suginami	0.8	11	0	29	53	8.69	478	4,962	53,331
Entire center of Tokyo	2.2	31	32	20	30	74.85	6,717	136,825	3,348,023
Entire Tokyo Metropolitan	1.6	27	25	17	27	95.75	7,159	158,032	3,714,134

Source: Author's compilation on the basis of documents of the Tokyo Metropolitan Government

result, the estimated area of damage will spread widely in the Tokyo region, even though it takes place directly under Tokyo.

— It is estimated that there will be numerous damaged buildings, and damages caused by fires will be extensive in areas where many wooden houses are densely built up such as areas along Loop-7 or the Chuo Line of JR, etc.

Table 3 shows estimated damages in some typical wards in Tokyo, in the case of an earthquake directly under the center of Tokyo.

10.5 Conclusion

In this report, I outlined the current situation and the trends of disaster simulation technologies, as well as the trends of fundamental information supporting the analysis technologies. The following is a summary of the items that must be promoted in the future.

1) Construction of a real-time disaster prevention information providing system, etc.

— In terms of crisis management, it is important to construct a system providing short-time rainfall prediction and detailed digital national land information as well as real-time disaster prevention information obtained using the GIS technology.

— In is necessary to promote the elucidation of the mechanisms of earthquakes / dislocations, and establish simulation technologies reproducing and predicting such phenomena.

2) Efforts to be made by local autonomies standing at the forefront

— As a result of the revision of the Flood Prevention Act, the flood inundation prediction map of rivers under the control of the government and prefectures must be provided and released publicly as a matter of duty. And the coverage of the designated rivers requiring inundation prediction has been expanded to rivers under the control of prefectures. In the future, it will be necessary to provide flood inundation prediction maps and short-time prediction announcements including rainfall prediction for more than 20,000 rivers under the control of prefectures.

— Disasters will have a terrible long-term influence on the economic activities and civil life in urban areas together with the human casualties and damages to buildings. Other than reproduced simulations of natural disasters, development of evacuation, rescue and relief simulations at the time of disasters should be promoted as well.

— Based on disaster simulations, slightly less than 20% of the hazard maps for flood, slightly less than 30% of the same for landslide disasters, and slightly less than 50% of the same for volcanic eruptions are currently provided and publicly available. It is necessary to promote the provision and announcement of further information.

— In providing simulation analyses and hazard maps, it is necessary to have some expert support from people of leaning and experiences, and budgets from the government as well.

3) Expansion of applications

— There is currently no noticeable policy to use disaster prevention simulation other than uses for the hazard map and disaster prevention plans. In the future, simulation must be used effectively in various fields. For instance, risks estimated in the simulation must be actively made public, information based on disaster simulations must be added to "Important items to be explained" stipulated in the Housing Trading Act at the time of purchasing houses, as a matter of duty, and the results of inundation simulations must be reflected in the building standards of underground room constructions.

— The national topographic maps at a scale of 1/25000 are currently used in the fundamental maps for inundation prediction, etc., and inundation prediction map data are displayed in a mesh form of around only 500 m. In the future, the inundation map or the liquefied soil distribution map must be displayed on large-scale information maps such as the residence area map, etc., after utilizing as much as possible the detailed digital national land information and the GIS technology.

Reference

[1] Computational Engineering and Science Vol. 6, No. 3 2001
The Japan Society for Computational Engineering and Science

Glossary

*1 Quasi linear effluences calculation model
This is a model that can estimate the respective changes caused by use of land in a basin, including storage and permeation of rainfall, in addition to the ordinary effluence model simulating effluence conditions of rainfall from a basin to a river.

(Original Japanese version: published in April 2002)