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DEVELOPMENT OF THE SEISMIC DISASTER INFORMATION SYSTEM FOR HIROSHIMA CITY

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SUMMARY

The Seismic Disaster Information System for Hiroshima City, which is capable to evaluate the disaster situation in real time manner, was developed as preparedness against future possible large earthquake. The System consists of three subsystems: Ground Monitoring Subsystem, Damage Estimate Subsystem, and Information Delivery Subsystem. In order to detect the ground motion, eight observation stations for acceleration monitoring were deployed. From the existing 6,500 boring log, a database for modeling the soil condition of the area was compiled. The System estimates the ground motion of the whole area at 1,735 calculating spots by response analysis using the supplemented bedrock motion from the observed acceleration by contour map drawing technique. And using the estimated ground motion and the estimated ground failure like liquefaction or landslide, damage to structure, fire occurrence, and casualties are estimated. Unexpectedly succeeded detection of actual accelerometer of small earthquake during the installation of monitoring system verified the effectiveness of the system.

INTRODUCTION

Since the Kobe Earthquake in 1995, many municipalities have considered that not only the structural strengthening but the preparedness against future big earthquake is inevitable to mitigate disaster. After the earthquake, Hiroshima City, populated by over 1.1 million residents, has established a Basic Plan for Disaster Reduction in 1997, following the recommendation of a committee chaired by Prof. K. Fujiwara.

The fundamental concept of this Basic Plan consists of three aids, which are the self-aid, the public-aid and the neighborhood-aid in an emergency where the aid-requiring spots are brought about at many places at once. In order to assist the self-aid by citizens and the neighborhood-aid among citizens, a special map (scale 1:15,000) has already delivered to each home in the city which indicates the possible hazard, evacuation places and routes, and offices of the public sectors including hospital.

For the rapid and effective public-aid by municipal organization, information about aid-requiring situation is essential. So it was recognized inevitable to develop a “real time disaster information system” to mitigate the possible enlargement of the disaster. Thus the Hiroshima City has decided to construct a Seismic Disaster Information System (SDI System), as one of the fundamental measures to make the city prepared against future earthquake. The System was basically intended to give an effective background for the strategic decision making in an emergency at the Fire Services Bureau of the city.

A technical committee has been established to study an effective structure of the System. The System is being developed along the results of this committee and began to be partly operated from the beginning of April 1999.

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During the development of the System, when the installation of the monitoring system was just completed an earthquake of JMA magnitude of 4.3 occurred nearby the area on February 7, 1999. This paper describes about the System and the measured ground motion of this earthquake.

OVERVIEW OF THE HIROSHIMA CITY AREA

General Aspect of the Area

The City of Hiroshima is located in the southwest of Honshu, Japan’s largest island, and is about 700 kilometers from Tokyo. It extends approximately 35 kilometers from east to west and from north to south and has now an area of 740.93 square kilometers.

Hiroshima had been developed as a seat of a feudal lord’s government since 1589 when Terumoto Mohri constructed the Hiroshima Castle. In Meiji era (1868-1912), it consolidated its position of the economic and political hub of the Chugoku Shikoku region. Regional branch offices of most organization such as government administration, finance and wholesale trade company are located in the Hiroshima City.

As illustrated in Fig. 2-1, Hiroshima City faces the Seto Inland Sea to the south, with the Chugoku Mountains behind. The mountain region, the peaks of which range from 600 to 1,000 meters above sea level, covers about two-thirds of the city area and surrounds the lowland region on the remaining sides.

The lowland region is centered on the delta formed at the mouth of the Ohta River and its tributary streams. When municipalized in 1889, the city area was no more than 27 square kilometers, however, the area had been extended to about 70 square kilometers by incorporation of seven towns and villages around the city by 1929. Thereafter, the lowland area was extended by land reclamation from sea for several times [Aboshi, 1991] as shown in Fig. 2-2, and the surrounding towns and villages have been incorporated. These have made the area to 740 square kilometers.

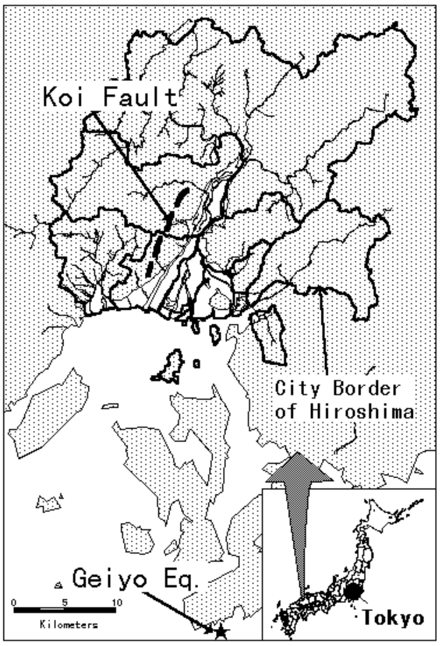

Fig.1:Hiroshima City (whiteportion is the lowland region)

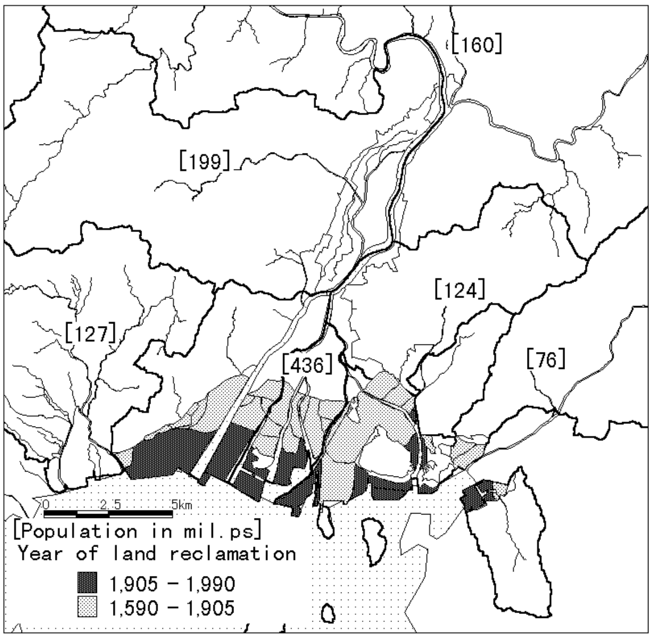

Fig.2: No. of habitants in the city and land reclamation history in Hirosihma Delta

The altitude of the reclaimed land from sea is lower than the high-tide sea level, and its subsoil condition is vulnerable to liquefaction during earthquake due to the loose sand layer underlain by silty layer. Six tributary streams of Ohta River separate the central downtown on the delta as shown in Fig. 2. This means that in one side the streams may work as the effective buffer to prevent the enlargement of fire, however in other side, they may cause the difficulties of evacuation. As the wooden house density is high along the coastal area of the delta, where no bridge connects east west direction traffic, careful preparedness is needed in this area.

Since 1965, land reclamation by cut and bank in the hilly area in outskirts of the city has been continued to provide the residential area due to the demand from the growth of population. The total area of these reclaimed hilly areas has reached 93.5 % of the total exclusive residential zone of 5,400 ha in the city.

2-2. Seismicity around the Area

There are several active faults, which might affect the area near the city. Hiroshima has been attacked repeatedly by magnitude-7 class earthquakes in the past. Once a strong earthquake attacks the area, therefore, severe liquefaction may take place on delta, which could easily cause the damage to lifeline systems, and land slide at places near the back hill

The possible earthquakes, which are anticipated to affect the city area, are summarized as Table 2-1.

Table 1: Anticipated earthquakes near Hiroshima

Trough Type	Inter-plate Type --Nannkai Trough off the coast of Shikoku Plate-edge Type--Akinada-Iyonada
Active Fault	Koi Fault,Itsukaichi fault,Ogata-Oze Fault,Median Tectonic Line,Iwakuni fault,Kikukawa Fault,Yamazaki Fault,Others

Among them, the ones which may take place at the Nankai Trough are thought to have recurrence period of less than several hundreds years and their magnitude are order of M=8. However as the epicentral distance is large enough, it is considered that they will not cause severe damage in the Hiroshima area. Although the faults listed in Table 2-1 have the potential to cause severe damage to the city area, as the recurrence period of them are ranging from several thousands years to several tens of thousands years, no apparent evidence of historical earthquake is recorded.

On the contrary, the Plate-Edge Type earthquake which may take place in Akinada-Iyonada sea bottom is the one which is the most anticipated affecting the area. The magnitude of the ones that had occurred in this region in the past was the order of M=7, however, as the epicentral distance is short, comparatively large damage to the area may be induced if it occurs. Actual damage by this type of earthquake was recorded repeatedly in the past. Among them, by an earthquake in 1905, Geiyo earthquake, the JMA seismic intensity of V (five) was caused and four persons were killed and seventy persons were wounded. It was also reported that damage to structures associated with soil liquefaction was caused. The recurrence time of this type earthquake is thought 50-150 years. Considering the extension of the city area from 1905 as compared in Fig.2-2, an earthquake with the same order of the magnitude may cause severe damage to the area if no measure against the earthquake is prepared.

SEISMIC DISASTER INFORMATION SYSTEM

Overall Framework of the System

The SDI System is expected to give the rational base for the decision making at the Fire Services Bureau just after the occurrence of an earthquake. The decision includes whether or not to open the Disaster Headquarter, the mobilization scale, whether or not to require the external support from neighboring municipalities or the self defense force, and to prioritize areas to watch its damage. For this decision making it was desired to know the damaging potential in three minutes and to grasp the damage situation in twenty minutes after the shaking. In order to facilitate such a function, the System consists of three subsystems: the monitoring subsystem to detect the ground motion in the city area, the damage estimation subsystem based on the observed ground motion, and the information delivery subsystem to the decision maker.

The System is to distribute the observed ground motion to citizens through eight administrative wards or Internet system in an emergency, and is also expected to work as the drilling tools for the citizens in an ordinary occasion by utilizing its function as a simulator.

In Fig. 3, flow of information in this System is illustrated along with the activity of the Fire Services. The indices to express the ground motion, ground failure, and the damage are shown in Table 2. Those indices are to be illustrated on the GIS system in the information delivery subsystem.

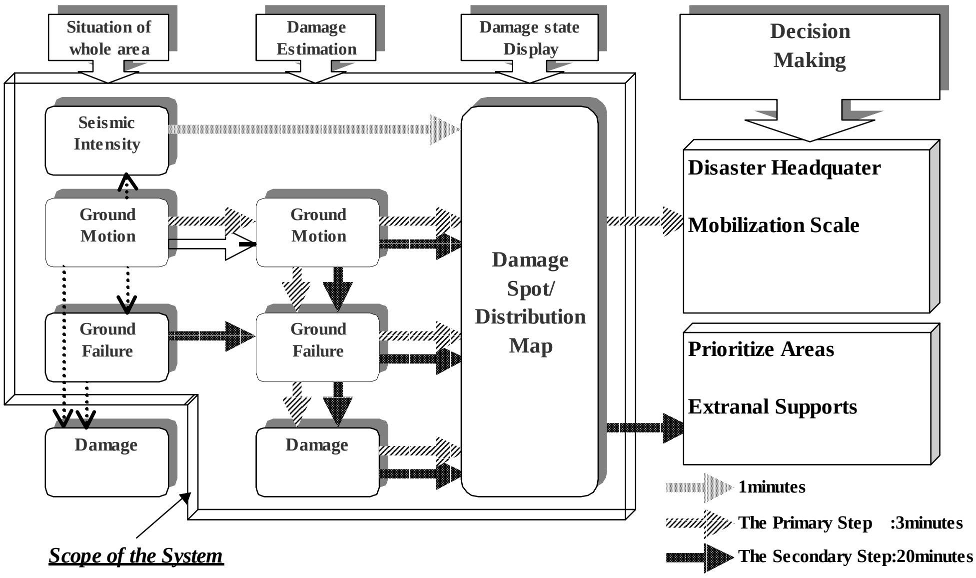

Fig. 4: Purpose and constitution of the System.

Table 2: Damage indices estimated from the observed ground motion

Ground Motion	Ground Failure	Probable damage
Seismic intensity	Liquefaction potential	
maximum acceleration	Land slide potential	
Spectral intensity		Lifeline System, Bridges
Response velocity spectrum		Buildings ,Fire,Casualties

Ground motion monitoring subsystem

In order to detect the ground motion during an earthquake, eight observation stations are deployed around the area. Two of them are set on the comparatively firm soil in hilly area and six of them are on soft soil inside the low land region. The locations of these observation stations are illustrated in Fig. 3-2, and the site conditions of them are summarized in Table 3-1. Among the eight stations, a vertical array is deployed at the Fire Service Air Base. The pore water pressure measurement is also provided at three sites.

Table 3: Site conditions at each station.

No.	Observation station	Accelero-meter	P.W.P	Bedrock depth m
[1]	Hirose-kita Park	GL 0		27
[2]	Ushita Water P.P.	GL 0		4
[3]	Garbage Station	GL 0		17
[4]	Fire Air Base	GL 0, -8,-21,36	GL-5.8	34
[5]	Sports Park	GL 0		2
[6]	T.C for F. W.	GL 0		5
[7]	Yano-S, P.	GL 0	GL-4.8	33
[8]	Minori Park	GL 0	GL-3.3	44

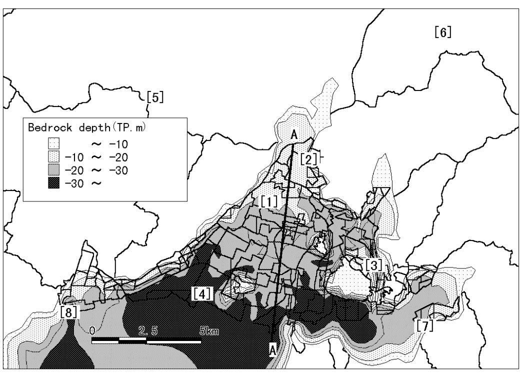

Figure 5: Bedrock depth and location of observation stations.

Three components servo type accelerometers that can detect 0-2000 gal acceleration by 10 ms intervals were installed at each station. Delay time for the pre-triggering event can be set more than 10 seconds. Triggering level is set to be 1.5 gal of composite acceleration of three directions. Crystal clock can automatically compensate the time by using the GPS signal. The detected acceleration at each site is to be transferred to the host computer at the Fire Services Bureau via telephone line or the wireless transmission route.

Damage estimation subsystem

Damage to structures are usually caused by either or both of the ground motion and the ground failure. Strong motion at ground surface during earthquakes is affected by the soil condition at sites and bedrock motion. So damage estimation in this subsystem is performed basically from the ground motion and its inducing ground failure. Ground failure includes soil liquefaction and slope failure.

However as actually the observing spots in the area are limited eight sites, ground response at spots in between these sites must be supplemented by calculation. For this purpose, observed ground motion at surface is converted to that at the base rock surface at eight sites, and the base rock motion at calculating spots are supplemented from these motions by using the contour line drawing method [Shiono, 1988] Then the ground motions at surface at calculating spots are obtained by the equivalent linear method, which can consider the frequency dependence of the reference strain [Sugito, 1994].

In order to save the calculation time for the primary step of the calculation in three minutes after shaking, bedrock motion is estimated by dividing Amax, SI and Sv at surface by the prepared amplification factors at eight sites. Instead, at the secondary estimation step in twenty minutes, the response calculation using time history of observed acceleration is conducted.

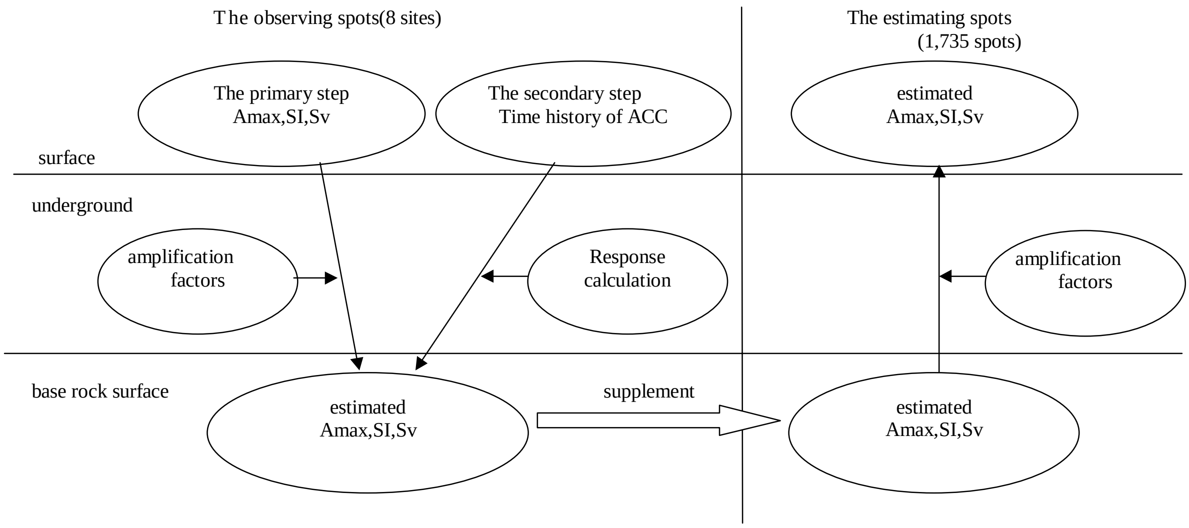

Fig. 6: Flow of ground motion calculation

In order to obtain a better estimation of the ground motion and the ground failure, the soil condition in the city must be well modeled. The city area was firstly divided into small sections by geomorphologic features. The lowland region was divided into 10 groups and the hilly or mountainous area was divided into four groups. The depth of the bedrock layer in lowland area was next examined from existing 6,500 boring log. By classifying the bedrock depth at each geomorphologic group by 5 m interval, then the total number of the categories in the lowland area became 42 and the total number of the categories in hilly area became 8.

The soil strata of each category and also the soil properties of each layer were finally examined by about 6,500 boring logs, then the soil condition of these 50 cases were found to be modeled into 126 types. An example of the soil condition model in database along the line A-A in Fig. 3-2 is shown in Fig. 3-3 together with soil profile.

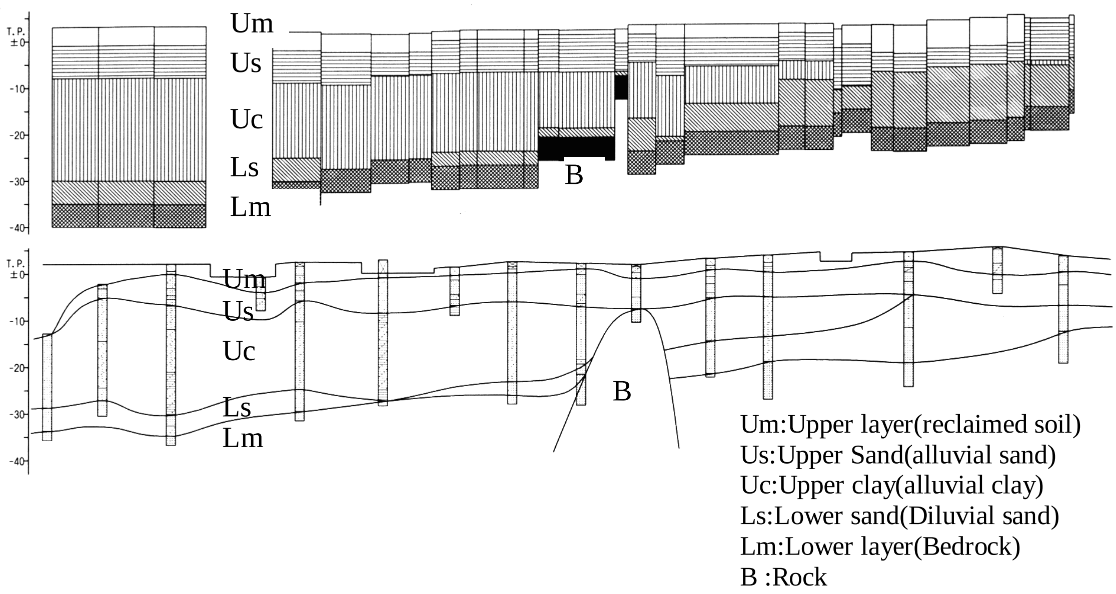

Fig.7: Soil condition modeling

Ground response is to be analyzed at proper intervals of distance considering the attenuation characteristics of the bedrock motion with distance. For this purpose of selecting the calculating spots, administrative zoning in lowland area and the mesh (500m by 500m) zoning for hilly area were used adding to above-mentioned 126 subdivision. The number of thus subdivided sections where the response analysis is to be conducted is 1,735 for whole city area including 588 sections in lowland area as illustrated in Fig. 8 and 9.

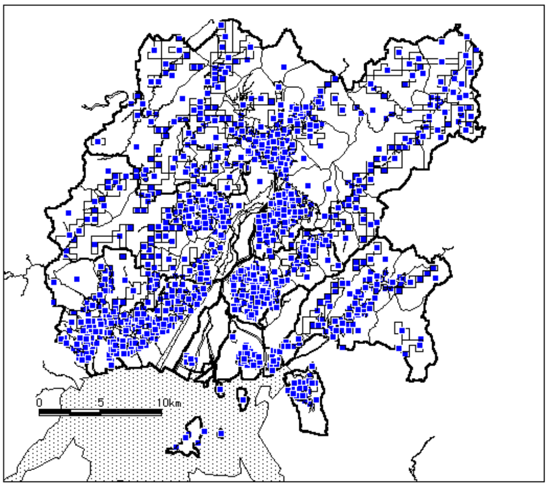

Fig.8: Calculating spots excluding lowland region (1,151 Spots)

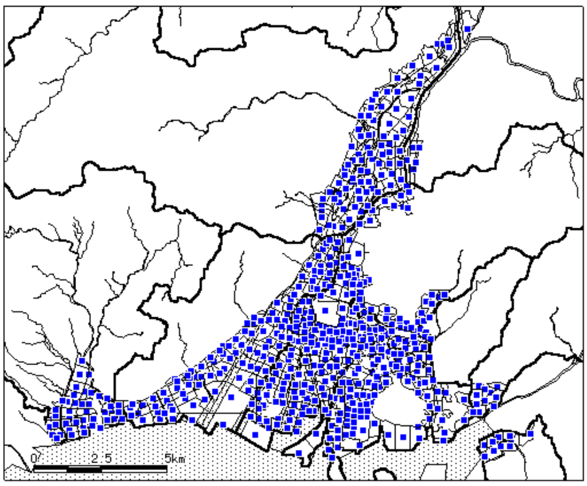

Fig.9: Calculating s pots in lowland region (588 spots)

Liquefaction potential at lowland area is calculated using the estimated maximum ground acceleration at surface and the soil condition compiled in the soil condition database at 588 spots by using the similar manner that is used in highway bridge code (Japan Highway Association). Only difference is the reduction factors to calculate the dynamic shear stress ratio at depth. The reduction factors should be different by earthquakes and by soil conditions, so they are evaluated for each site against the several levels of acceleration during an assumed earthquake of Akinada.

Slope failure potential is to be estimated from the slope angle, maximum acceleration and acceleration dependent fragility curves which are assigned to slope angle [Nakamura, 1997]. There are 1,545 steep slope spots in the hilly area. These steep slope spots are designated by law as dangerous slope against heavy rain or earthquake, identified from the slope steep-ness (more than 30 degree), height (more than 5 meter) and the number of residential houses inhabited at the toe (more than five).

Failure of structures is estimated from the response velocity spectrum, and ground failure. The occurrence of fire is estimated from probability of the wooden house failure and the wooden house density of a zone, and casualties is estimated from wooden house failure probability and fire probability.

Information delivery subsystem

Delivered information must be easy to understand. The seismic intensities in each administrative wards are displayed at once when the monitoring accelerometer is triggered, and the calculated maximum acceleration distribution is displayed by the monitor at the decision maker's office as rapid as possible, in three minutes at latest. Estimated damage state expressed by probable occurrence zones of liquefaction, slope failure, houses and buildings failure, failure of lifeline facilities including bridges, and probable causalities in twenty minutes. Figures 10 and 11 show examples of the display.

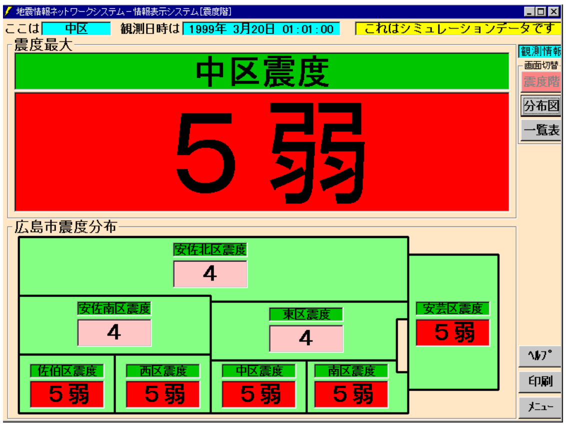

Fig.10: Seismic intensity display

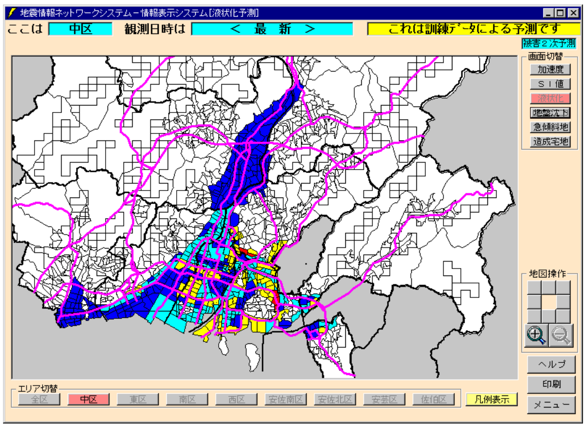

Fig.11: Liquefaction potential distribution

OBSERVED GROUND MOTION BY AN EARTHQUAKE ON FEBRUARY 7, 1999

During the development of the SDI System, when the installation of the monitoring system was just completed an earthquake of JMA magnitude 4.3 occurred nearby the area in Yamaguchi prefecture where is apart by about 30 km from the City. The event, although it was not so big earthquake, was successfully recorded by the monitoring subsystem [Kano et. al., 1999]. Figure 12 shows the recorded acceleration at the ground surface of the Fire Services Air Base station as an example of record during this event.

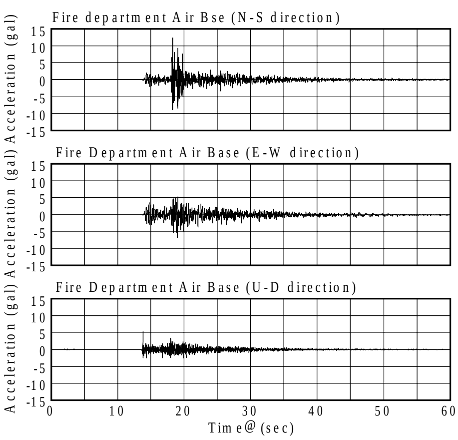

Fig. 12 Recorded acceleration

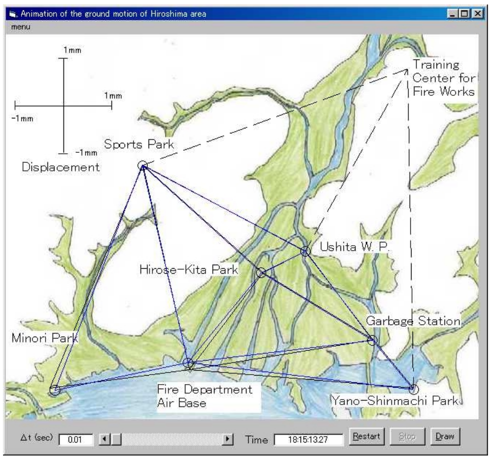

Fig. 13 Displacement distribution

The calm state during first 13-14 seconds in Fig. 12 shows that the delayed recording system worked normally. Fig. 13 shows an image of animation, which illustrates the distribution of displacements at each station when the maximum displacement was observed at the Minori park station. By dynamically displaying the whole displacements at every station simultaneously, the ground motion is shown like animation.

The maximum acceleration (Amax), maximum velocity (Vmax), maximum displacement (Dmax) and duration of shaking (Td) at each station are shown in Table 4-1. Velocities and displacements were calculated from recorded accelerations and the duration was calculated as the time while the acceleration amplitude exceeds 1-gal. According to Table 4, Amax, Vmax, Dmax and Td were almost proportional to the depth of bedrock and they were comparatively larger inside the delta than those outside the delta, while they were in inverse proportional to the distance from the epicenter. It is thought that the easily amplified region in Hiroshima City area will be identified by accumulating the data like the record shown above.

Table. 4: Amax, Vmax, Dmax and Td at each point

	Bedrock depth(m)	Amax cm^2/sec	Vmax cm/sec	Dmax mm	Td sec
Hirose-kita Park	27	12.0	0.38	0.19	19.7
Ushita Water Plant	4	7.0	0.16	0.08	15.07
Garbage Station	17	7.6	0.17	0.06	16.18
Fire Department Air Base	34	12.5	0.26	0.15	16.31
Sports Park	2	6.9	0.14	0.05	15.17
T.C for fire Works	5	-	-	-	-
Yano-Shinmachi Park	33	5.0	0.14	0.08	14.72
Minori Park	44	27.7	0.59	0.37	20.65

CONCLUSION

An actual case of the Seismic Disaster Information System as a measure against earthquake in Hiroshima is introduced, focusing on the modeling of the geotechnical condition of the area into a soil condition model which is incorporated into the damage estimation subsystem. And the ground monitoring result, which was luckily obtained during the course of developing on February 7, 1999, was also introduced.

Although the earthquake was small, it gave a precious occasion to the System to verify to work normally. It was also clarified that the ground response was influenced by the depth of soil layer above the bedrock and the distance from the epicenter. Furthermore animation what represents dynamically the recorded ground motion simultaneously is effective to understand the ground response during earthquakes.

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