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DEVELOPMENT OF URGENT EARTHQUAKE DAMAGE ESTIMATION SYSTEM FOR ROAD FACILITIES

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SUMMARY

Earthquake damage of road facilities does not only reduce their functions but affects the socio-economic activities in and around the damaged area. Besides improving the seismic performance of road facilities, therefore, post-earthquake emergency activities to reduce the damage effects must be jointly promoted.

This paper presents an Urgent Earthquake Damage Estimation System for Road Facilities, which is developed at Public Works Research Institute, Ministry of Construction. By providing rough estimation on damage states and damage distributions in a short time, the system will support decision-makers to facilitate emergency actions immediately after earthquakes

INTRODUCTION

Emergency activities at sections that are in charge of road facilities can be classified into four stages□1□; i.e. assuming magnitude of the earthquake, grasping a damage outline in a whole affected area, conducting temporary repair works to secure transportation functions and conducting permanent restorations. To establish a scope of works for a series of emergency activities, it is quite important to conduct the second stage of grasping a damage outline as early as possible.

1995 Hyogo-ken Nanbu Earthquake was a first destructive earthquake attacked a highly integrated urban area in Japan 2. Based on that experience, following difficulties were pointed out for grasping a damage outline;

1) Much time was required for setting-up damage inspection teams,
2) Much time was required for investigations of widely spread severe damages, and
3) Adequate amount of damage information was not assembled at the headquarter due to disruptions/ congestion of telecommunication lines.

Table 1 Grasping Damage Outline at Headquarter

	Hyogo-ken Nanbu EQ (destructive)	Sanriku Haruka-oki EQ (moderate)
EQ Occurrence	05:46 1/ 17/ 1995	21:19 12/ 28 /1994
Damage Inspection	08:00 1/17 – 08:00 1/18	21:50 – 23:22 12/28
Required Time	Approx. 24 hours	Approx. 30 minutes

Table 1 shows the required time for grasping damage outline at the headquarter. The table also describes the time required in 1994 Sanriku Haruka-oki Earthquake, in which severe damage was not developed on road facilities. For promoting a series of emergency activities against a destructive event, quick decision-making is indispensable in spite of the difficulty of assembling damage information. Applications of information systems to support the decision-making of sectors are therefore considered to be essential.

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URGENT DAMAGE ESTIMATION SYSTEM (SATURN)

Based on the past disaster experiences, development of information systems to support emergency activities has been conducted in PWRI□3□□4□. The Urgent Damage Estimation System (SATURN: Seismic Assessment Tool for Urgent Response and Notification) is developed as an essential tool for grasping damage outline automatically immediately after an earthquake by providing rough estimations on damage states and damage distributions of road facilities.

Fundamental functions of SATURN are as follows;

1) The system estimates possibilities of ground liquefaction and highway bridge damage
2) Damage estimation is carried out using the pre-stored ground/ structural condition data and earthquake ground motion data monitored by the accelerographs network
3) Damage estimation is completed within 15 min., by that time emergency investigation team can be set-up
4) Estimated information is visually displayed on the CRT using digital map

Implementation of SATURN is considered to be effective in the following aspects;

1) Severely damaged area can be assumed in a short time. Damage inspections can be effectively engaged by a restricted amount of inspectors,
2) Damage outline can be understood smoothly based on damage inspections, and
3) Decision-making on the buck-up organization and stuffs/ devices management can be initiated from the early period of emergency responses.

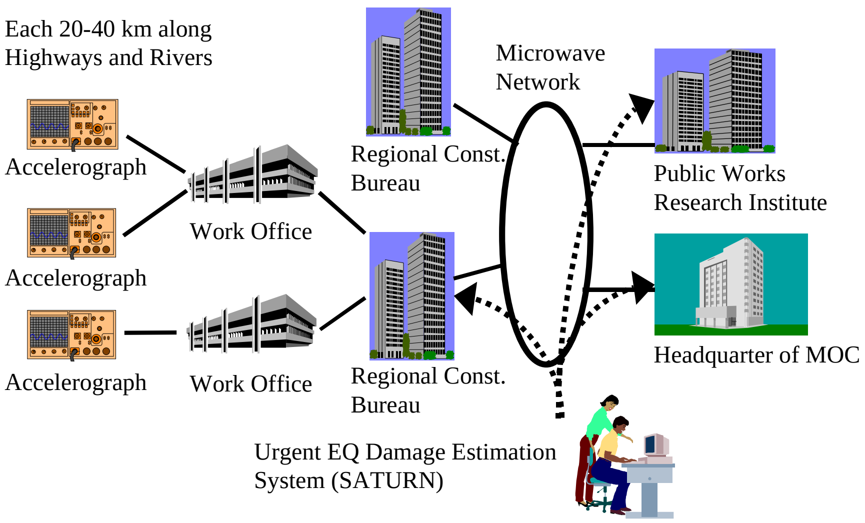
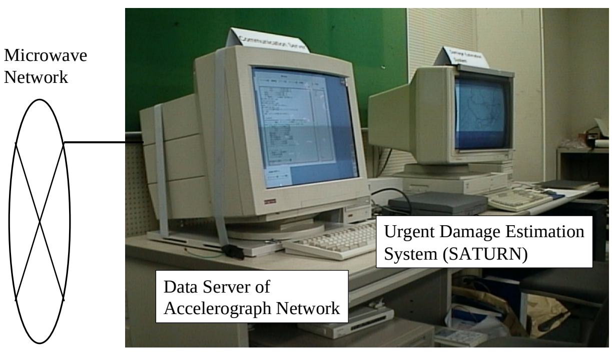


Fig.1 Accelerographs Network operated by MOC



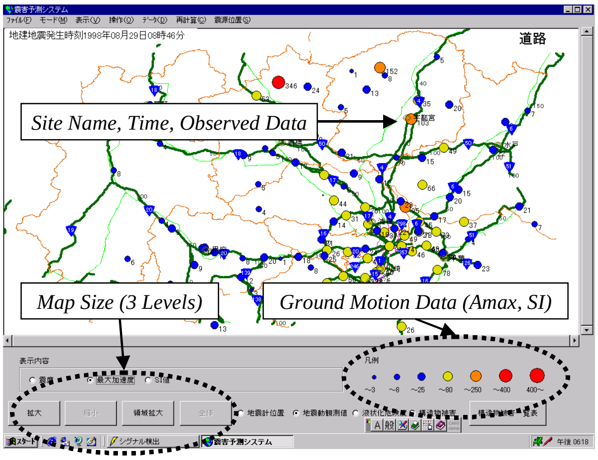
- Covers Tokyo Area (Tokyo and 8 Other Prefectures)
- Possibility of Ground Liquefaction (6,028 Highway Sites)
- Possibility of Highway Bridge Damage (368 Bridges)

Photo 1 Prototype System (under operation)

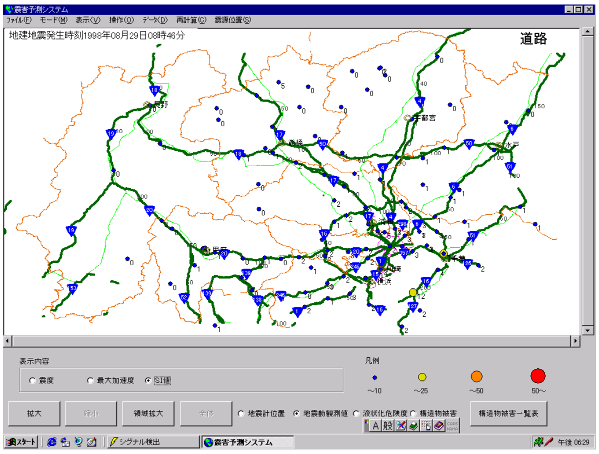
Fig.1 show a configuration of the accelerographs network operated by the Ministry of Construction. Approximately 700 strong motion accelerographs are installed along highways and rivers with an interval of 20-40 km. Ground motion data (maximum acceleration Amax and spectrum intensity SI) are transmitted real-timely to the headquarter and sectors in charge of emergency activities.

Photo 1 shows a prototype system installed at the regional construction bureau of MOC. The prototype system, which does not cover whole Japan but Kanto region (Tokyo and other 8 prefectures), has been under operation since 1997.4.

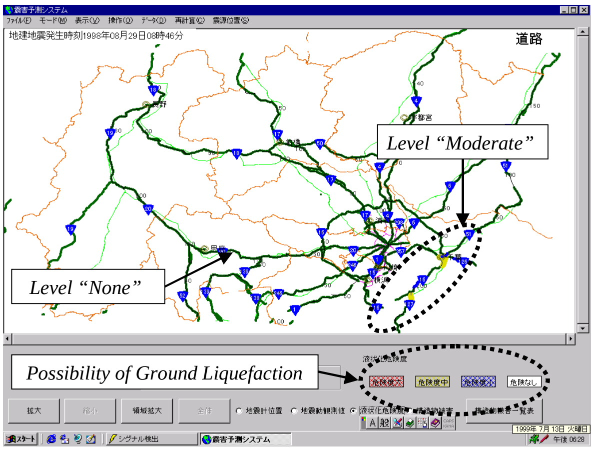
Fig.2 Shows the estimated information by the prototype system. Rough estimation of ground liquefaction states (at 6,028 highway sites) and bridge damage states (368 highway bridges) is available at this time. Maximum acceleration Amax and spectrum intensity SI (designated hereinafter as ground motion characteristic values) monitored by 100 seismographs installed at ground surface in Kanto region is adopted for the calculation.



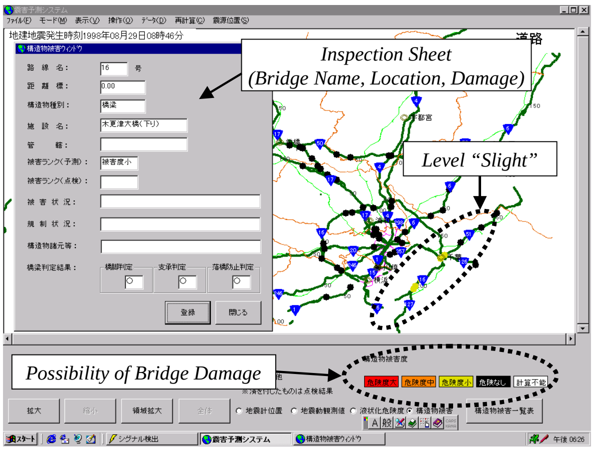
(a) Maximum Acceleration Amax



(b) Spectrum Intensity SI



(c) Possibility of Ground Liquefaction



(d) Possibility of Highway Bridge Damage

Fig.2 Estimated Damage by Prototype System (1998.8.29, M5.4)

DAMAGE ESTIMATION METHODOLOGY

3.1 Three Steps of Estimation

SATURN performs damage estimation by three steps as shown in **Fig.3**.
1) Estimation of Ground Motion Characteristic Values

For the judgement of ground liquefaction and bridge damage, ground motion characteristic values at the very site where the judgement is to be performed (designated hereinafter as a judgement site) are needed. Because the locations of observation sites are different from judgement sites, ground motion characteristic values have to be estimated analytically.

2) Estimation of Ground Liquefaction Possibility along Highways

Possibility of ground liquefaction is judged for each divided highway section. Division of highway sections is carried out so that the ground condition is assumed to be uniform in each section. Ground liquefaction states is judged based on a P_L value evaluated in each highway section. The P_L value is evaluated by eq.(1), where a liquefaction resistant ratio F_L(5) is evaluated by a ground condition and an estimated maximum acceleration in each highway section.

$$P_L = \int_0^{20} (1 - F_L)(10 - 0.5x)dx \cdots\cdots\cdots (1)$$

$$F_L = R / L$$

where,

- x : Depth from the surface (m)
- F_L : Liquefaction resistant ratio
- P_L : Potential of liquefaction
- R : Dynamic shear strength ratio
- L : Shear stress ratio during an earthquake

3) Estimation of Bridge Damage Possibility

Possibility of bridge damage is judged individually based on the structural database. As the structural database, bridge maintenance data accumulated at sectors are adopted in this estimation. Damage states of whole bridge is judged by comparing damage states of major bridge components. Damage states of major bridge components is judged by the SI value estimated at the judgement site. By using a SI value, it is possible to consider the cyclic effect of ground motion. The SI value is evaluated by eq.(2), where S_{vi} means the i (sec) component of velocity response spectrum.

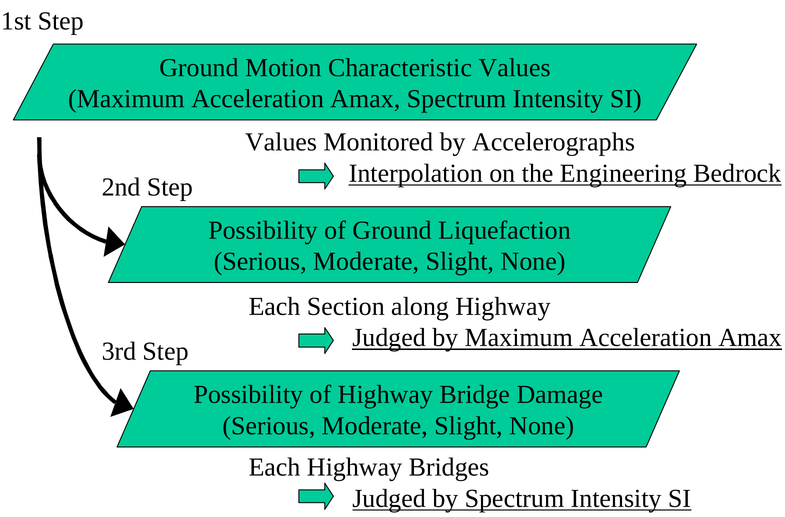


Fig.3 Flowchart of Damage Estimation

$$SI = \frac{1}{2.5} \sum_{i=0.1}^{2.5} S_{vi} \cdots\cdots\cdots (2)$$

3.2 Classification of Damage States

Estimated ground liquefaction states and bridge damage states are displayed in four categories, i.e. “Serious”, ”Moderate”, ”Slight” and ”None”. As shown in **Table 2**, categories were defined as a combination of an assumed loss of transportation functions and a necessity of emergency repair works.

3.3 Estimation of ground motion Characteristic Values

Fig.4 shows the estimation steps of ground motion characteristic values at judgement sites. Following procedure is adopted in this system for minimizing the estimation time with enough accuracy.

1) Evaluating ground motion characteristic values right under each observation site by assuming a ground response amplification ratio.
2) Evaluating a characteristic value right under a judgement site by an interpolation.
3) Evaluating a characteristic value at a judgement site by assuming a ground response amplification ratio.

Table 2 Categories of Damage States

Classification	Influence to Transportation	Required Works
"Serious"	Interruption for Weeks	Demolition/ Reconstruction
"Moderate"	Interruption/ Restriction for Days	Temporary Repair
"Slight"	Restriction for Hours	Temporary Repair
"None"	No Restriction	None

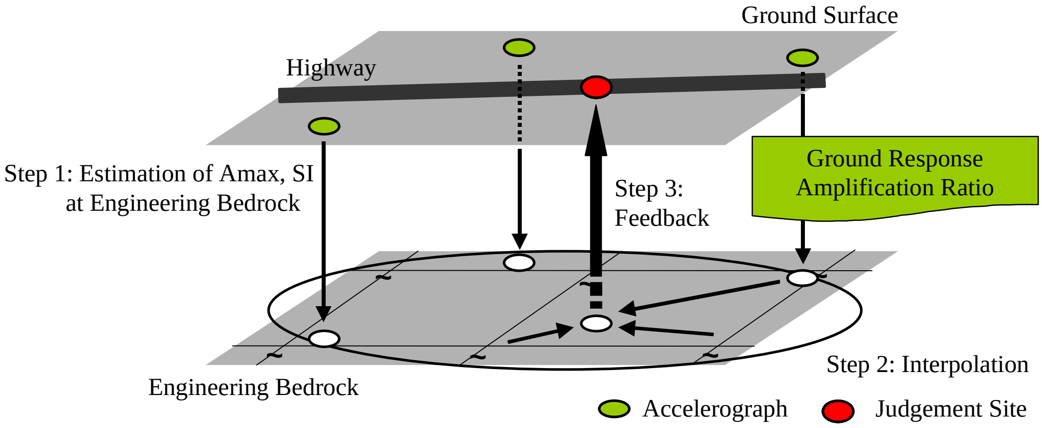


Fig.4 Estimation Steps of Ground Motion Characteristic Values

A ground response amplification ratio varies according to the cyclic characteristics of ground motions and non-linear property of ground soil deposit. For each observation/ judgement site, the amplification ratio α was calculated by "SHAKE" using a standard time history record. The Kaihoku Bridge record detected in 1978 Miyagiken-oki Earthquake was adopted as a standard time history because it provided the most average amplification ratio in trial calculations using five other typical records observed during past earthquakes. The non-linear property of ground can also be considered by eq.(3).

$$\alpha = a \times b^{-x} \cdots\cdots\cdots (3)$$

where, α :Ground response amplification ratio for each observation/ judgement site

x :Maximum acceleration (spectrum intensity) at engineering bedrock

a, b :Coefficients which represent the non-linear property of ground soil deposit

3.4 Estimation of Ground Liquefaction States along Highways

Table 3 shows a P_L□Ground Liquefaction States Matrix. Ground liquefaction states is judged with the Matrix by P_L value that is estimated for each highway sections. The Matrix was developed based on a series of experimental studies of past earthquake disasters at PWRI. By modifying the matrix in accordance with the future research development, accuracy of ground liquefaction states can be easily upgraded. Here, the P_L value for the damage state "Serious" was not defined in the matrix. This is because the ground liquefaction is hardly considered to induce serious damages to road facilities that would interrupt the transportation for a long time period.

Table 3 P_L Ground Liquefaction States Matrix

Classification of Ground Liquefaction State	Serious	Moderate	Slight	None
P_L value	----------	P_L > 15	15 † P_L„ 5	5† P_L

3.5 Estimation of Bridge Damage States

Table 4 shows the SI Value□Bridge Component Damage Matrix. Damage states of the major bridge components is judged with the matrix by the SI value that is estimated for each highway section including a bridge site. As for the damage states of major bridge components, following five failure mechanisms were considered due to their large effects on a whole bridge system, i.e. 1) bending failure of RC column, 2) shear failure of RC column, 3) buckling of ST column, 4) failure of bearing and 5) movement of foundation due to the liquefaction-induced ground flow.

Table 4 SI Value Bridge Component Damage States Matrix (Bending Failure of RC Column)

Design Code	Yield Seismic Coefficient	Damage State of Component			
		Ultimate	Before Ultimate	Yielding	Before Yielding
1979	-----------	SI„ 50	SI„ 30	SI„ 10	10† SI
1990	-----------	SI„ 50	SI„ 30	SI„ 10	10† SI
1995	0.6„ k_{hy}	SI„ 50	---------	----------	50† SI
	K_{hy}† 0.6	SI„ 100	SI„ 50	----------	50† SI

Table 5 Bridge Component Damage States Matrix～Bridge Damage States Matrix

Damage States of Bridge Component	Damage States of Bridge			
	Serious	Moderate	Slight	None
Bending Failure of RC Column	*Ultimate*	Before Ultimate	Yielding	Before Yielding
Shear Failure of RC Column	Failure	Before Failure	Shear Cracking	*Before Cracking*
Buckling of ST Column	Buckling	Before Buckling	Slight Deformation	Before Deformation
Failure of Bearing	Failure	Damage (tall bearing)	*Damage (short bearing)*	Slight Damage
Movement of Foundation	------------	Large Deformation	Small Deformation	*Slight Deformation*

œ Damage state of bridge is evaluated by comparing estimated component damage.
œ *Italic case*: Bridge damage is judged as “Serious”.

The matrix was defined based on both a series of experimental studies and dynamic response analyses at PWRI. Basic concepts for the judgement of damage states are as follows;

1) Bending failure of RC column: Relationships between SI values and damage states were studied for several column types. Relationships were determined by the dynamic response analyses on approximately 400 columns. Column types were classified by structural specifications such as section size and weight. Damage states for each column type were classified by the SI value.

2) Shear failure of RC column: By a combination of h/D value and design year, a possibility of shear failure to be developed prior to the bending failure is estimated. h/D value is a ratio of a column height against a section size. Damage states were classified by the SI value based on a series of experimental studies of past earthquake disasters.

3) Buckling of ST column: A possibility of buckling is estimated by design year. Damage states were classified experimentally by the SI value.

4) Failure of bearing: A possibility of failure was classified experimentally by the SI value. Because a failure of bearing induces a gap of road surface, the damage states are to be judged by the bearing height.

Movement of foundation due to lateral ground spread: Verifying the distance between foundation sites and water lines, a possibility of the liquefaction-induced ground flow is estimated. Damage states were classified by a combination of a distance and a ground liquefaction state.

Table 5 shows a Bridge Component Damage States～Bridge Damage States Matrix. The damage state of a whole bridge system is judged by comparing the damage states of major bridge components, i.e. the maximum damage state among those of major bridge components represents the damage state of a whole bridge system.

CONCLUSIONS

1. The Urgent Earthquake Damage Estimation System for Road Facilities (SATURN) was introduced. By providing rough estimation on the damage states and damage distributions of road facilities immediately after an earthquake, the system will support decision-makers to facilitate emergency works, i.e. damage inspections with restricted amount of inspectors, management of buck-up organization, and management of construction stuffs/ machinery.
2. SATURN estimates possibilities of ground liquefaction and highway bridge damage within 15 minutes. Damage estimation is carried out using pre-stored ground/ structural condition data and earthquake ground motion data monitored by the accelerographs network. Evaluation of damage states is made by the maximum acceleration Amax and spectrum intensity SI as judgement indexes.
3. Prototype system that covers Tokyo area is under operation at the regional construction bureau of MOC. For activating this system to the disaster prevention practice, further research will be required on the following subjects;
    1) Verification of damage estimation methodologies with use of the prototype system.
    2) Developments of damage estimation methodologies on the other road facilities, such as the slope failure, embankment sinking and damage of underground lifelines.
    3) Clarifying the seismic information system architecture including SATURN and other advanced information technologies, such as the wide area monitoring technology, data collecting technology, data analyzing technology using GIS, and decision-making support tools.

REFFERENCES

1. Public Works Research Institute (1986), “Manual for Repair Methods of Civil Engineering Structures Damaged by Earthquakes”, Technical Note of PWRI, Vol. 45

2. Public Works Research Institute (1996), “Report on the Disaster caused by the 1995 Hyogo-ken Nanbu Earthquake”, Report of PWRI (Japanese), Vol. 196

3. H. Sugita, S. Odagiri and M. Kaneko (1997), “Development of Real-time Seismic Information System for MOC”, 29^{th} UJNR Joint Panel on Wind and Seismic Effects

4. H. Sugita and T. Nozaki, “Seismic Information System for Civil Infrastructures”, 30^{th} UJNR Joint Panel on Wind and Seismic Effects

Japan Road Association (1996), “Design Specification of Highway Bridges; Part V Seismic Design”