Earthquake Information and Immediate Damage Estimation System

Takuya Kashiwazaki[2)], Tomoaki Ishida[1)], Tomiichi Uetake[1)], Hideo Tanaka[1)], Mitsugu Mashimo[2)] and Shuji Watanabe[2)]

1) Tokyo Electric Power Company, Japan
2) Tokyo Electric Power Services CO., LTD., Japan

ABSTRACT

When a large earthquake occurs near a nuclear power station, it is important to confirm safe conditions in a nuclear power station. It takes time and many hands to confirm the conditions for whole buildings in nuclear power plant after an earthquake. Otherwise, this proposed information prototype system estimates the facilities damage condition accurately and promptly by standardized evaluating scheme based on the database of the nuclear power station, for example characteristics of the dynamic response, soil strata and earthquake wave propagation. This system connects three power plant sites and the head office by the computer network and transmitted the information each other. The validity of the proposal damage estimating method, named DEAN-system, is shown by this experimental operation.

INTRODUCTION

The buildings in the nuclear power plants are designed by the seismic response analyses and are able to withstand large earthquakes. After a large earthquake, the safe conditions of the nuclear power station facilities have to be check quickly and carefully. In the viewpoint of structural damage of buildings, this proposed information system displays the overviews of the plant not only on site but also off site simultaneously. It is one of useful information to decide for resuming after a large earthquake.

After a large earthquake hits the nuclear power station, this proposed information system estimates the facilities damage condition accurately and promptly by standardized evaluating scheme based on the database of the nuclear power station, for example characteristics of dynamic response, soil strata and earthquake wave propagation. Furthermore, the information of the building condition is transmitted to on site and off site facilities immediately. If conventional information transmitting system is put into practice, long time and many hands are required to confirm the conditions for whole buildings in nuclear power plant after an earthquake, and it takes time to resume electric power operation. This system is in a developmental stage these days, three power plant sites, the head office and the laboratory center are connected each other by the computer network and transmitted the information. The validity of the proposal damage estimating method, that is named DEAN-system, is shown by this experimental operation.

OUTLINE OF EARTHQUAKE DAMAGE QUICK ESTIMATION SYSTEM

This prototype system is wired the headquarters in Tokyo, laboratory in Yokohama, three nuclear power stations of Tokyo Electric Power Company (TEPCO) and Tokyo Electric Power Services Co. (TEPSCO) by computer network as shown in Fig.1. The seismometers are set in place in three power stations to observe earthquake motion, which records come into use to accuse database in order to estimate structural damage of the facility buildings. This system provides the following functions.

1) This system make database of the earthquake information of the seismic intensity and the epicenter position announced from Japan Meteorological Agency (JMA), and observation records of the seismometer in three power stations are stored in database, too.

2) This system provides to estimate the structural damage of whole buildings in the power station by using the earthquake information database, the epicenter location announced from JMA and site observation records.

3) This system estimates the extent of damage in whole buildings after an earthquake and classified into none or negligible damage, moderate structural damage and heavy structural damage by displaying on CRT in green, yellow and red color, respectively.

After a large earthquake, the whole buildings of the plant have to be checked by the visual inspection, but it needs time and so many staff members. Inspectors are able to go around according to the procedure or the checkpoint, which is scheduled based on the extent of damage information displaying on CRT in green, yellow and red color, before the visual inspection under this proposed system. The quick and accurate visual inspection report can conduce to decide for resuming power plant after a large earthquake as soon as possible.

The Evaluation of Earthquake Input Motion to a Building

As shown in Fig.2 (a) and Eq. (1), the average maximum amplitudes ratio of acceleration C_{AMP} between two seismometers, which are set in place on the ground level and on the building base mat level, is determined.

$$C_{AMP} = B/A \tag{1}$$

In here, A and B are the amplitudes of seismic motion given by the past observation records at reference point and the representative building base mat, respectively.

The earthquake motion of base mat in the building can be calculated by C_{AMP} and the ground level seismometers record, which is taken into reference point in this system.

The Evaluation of Response Behavior in a Building

The earthquake response analysis is executed using the design earthquake motion, which is defined on the bedrock as shown in Fig.2 (b). The relationship between G_O and ${}_RC_O$ is shown as following equation.

$$G_O = {}_RC_O / C_{AMP} \tag{2}$$

In here, G_O and ${}_RC_O$ are the maximum amplitude of ground motion and base mat motion resulted by carrying out seismic response analysis, respectively.

The estimated amplitudes of acceleration ${}_RR_O$ on the building base mat and ${}_RR_I$ on each floor level are obtained from the following linear relationship between the ground motion G_O and the amplitude factor C_{AMP} as shown in Fig.2 (c).

$$\begin{aligned} {}_RR_O &= G_O \times C_{AMP} \\ {}_RR_I &= {}_RC_I \times {}_RR_O / {}_RC_O \end{aligned} \tag{3}$$

In here, ${}_RC_O$ and ${}_RC_I$ are the standardized maximum amplitudes of acceleration on the building base mat and on each floor level by seismic response analysis, respectively.

The Estimation of Structural Damage Level in a Building

The extent of the structural damage is estimated each floor as follows.

At first, a linear relationship between the response shearing strain γ_O and the response shearing force Q_O of each floor from the result of earthquake response analysis are determined by using the design earthquake motion as shown in Fig.3 (a).

Second, the equivalent ultimate strength Q_{EU} on the linear relationship point C in Fig.3 (b) can be substituted for the ultimate strength Q_U on the nonlinear relationship point D, which is derived from the structural design. A nonlinear relationship between the shearing strain and the shearing force are determined from the equivalent hysteresis absorbed energy theory as shown in Fig.3 (b), because the elastic energy in linear response can be equivalent with the hysteresis absorbed energy in the nonlinear response.

Third, the point B in this linear function, which corresponds to the elasticity limit design shearing force, is introduced in addition to the damage estimating function on each floor of the building as shown in Fig.3 (c). This function base on the relationship between the surface ground motion G_O at the reference point and the response shearing force Q_O in the building is linear, and can be enhanced Fig.3 (b) to Fig.3 (c).

Lastly, this linear relationship of the damage estimating system is taken advantage of the damage level classification after an earthquake as shown in Fig.3 (d).

Area-1 is none or negligible damage category. This indicates that a structure avoids being damage, because the response shearing force Q_R is smaller than the design shearing force Q_D.

Area-2 is moderate structural damage category. This indicates that a structure has some damage without heavy damage. This area is presumed that the response shearing force Q_R of a structure dose not exceed to the equivalent ultimate strength Q_{EU} though Q_R is greater than the design shearing force Q_D.

Area-3 is heavy structural damage category. This indicates that a structure has severe damage because the response shearing force Q_R exceeds the equivalent ultimate strength Q_{EU}.

INDEX OF EARTHQUAKE MOTION INTENSITY

The damage estimating method in the proposed system is based on the maximum acceleration of the building. Therefore, the damage degree on each floor of buildings can be estimated by using the above-mention linear relationship to the maximum acceleration at the reference point. But it is pointed out that the structural damage cannot be estimated accuracy using the maximum acceleration. In this proposed system, four indexes of the earthquake motion intensity are discussed, after the correlation between the ground response and the building response is researched on analyzing the observation records of the seismometers at the reference point and on the reactor building base mat. Four indexes, which are the maximum acceleration, the maximum velocity, the spectrum intensity (SI) [1], and the modified spectrum intensity (MSI) [2], are concluded as followings.

The Maximum Amplitude of Acceleration

The reference value of the maximum acceleration is introduced from the average maximum acceleration of two horizontal components, which are observed by time history.

The Maximum Amplitude of Velocity

The reference value of the maximum velocity is derived from the average maximum velocity of two horizontal components integrated observed acceleration time history.

The Spectrum Intensity (SI)

SI value is calculated as following Eq. (4). The spectrum of velocity Sv based on the observation records is integrated between 0.1 seconds and 2.5 seconds. Average SI values of spectrum intensity of two horizontal components are adopted in this system.

$$SI = \int_{0.1}^{2.5} S_V\,(h,T)\,dT \tag{4}$$

The Modified Spectrum Intensity (MSI)

MSI value is calculated as following Eq. (5). The spectrum of acceleration S_A based on the observation records are integrated between 0.1 seconds and 0.5 seconds. Average MSI values of modified spectrum intensity of two horizontal components are adopted here.

$$MSI = \int_{0.1}^{0.5} S_A\,(h,T)\,dT \tag{5}$$

The Comparison with the Four Indexes of Earthquake Motion Intensity

In the representative reactor building, the standard deviations σ shown by Eq. (6) in these four indexes can be calculated in order to compare with the observations and the estimations of the building base mat.

$$\sigma = \left[\frac{n\,\Sigma x^2 - (\Sigma x)^2}{n\,(n-1)} \right]^{1/2} \tag{6}$$

Where n is a number of observation records and x is the logarithmic ratio of each index between the observation records and the estimations of building base mat making use of the observation records on the reference point. The correlation between the observation records and the estimated values from the reference point records are shown in Fig.4. The standard deviation of the

MSI values is the smallest of all. The standard deviation of the SI values is smaller than that of maximum velocity. The response in the building takes an accurate estimation based on the MSI or SI. It is concluded that the SI value and the MSI value are available for the substitution of the maximum acceleration and the maximum velocity. In case of using the observation records at the reference point, this scheme is applied in order to estimate the responses of the buildings.

APPLICATION EXAMPLE OF DAMAGE ESTIMATION METHOD FOR POWER STATION BUILDINGS

The proposal damage estimating system named DEAN-system is in a developmental stage. This system is carried out on the experimental operation. Three power plant sites, the head office and the laboratory center are connected by the computer network and transmitted the earthquake information each other. In Fig.5, application examples of this damage estimating system using the MSI database as the prototype system are shown. Fig.5 (a) shows a simulation example result mapping in Fukushima-Daiichi, Fukushima-Daini, Kashiwazaki-Kariwa site for considerable Operation Basis Earthquakes. The estimated results in Area-I or Area-II are almost similar to these derived from the conventional prediction in according to the seismic priority classification of buildings. Fig.5 (b) shows detail of the estimation example results with each floor of buildings. Fig.5 (c) shows an example of displaying the distribution of seismic intensity and the epicenter location in the Eastern Honshu of Japan announced from JMA.

CONCLUSION

The simplified damage estimating method of the building based on the design data is proposed here. This damage estimating method is applied to the nuclear power station sites as a prototype system, which is named DEAN-system. This prototype system is now under experimental operation to verify system functions. The quick estimation is taken priority of the accurate estimation in this system. Therefore, in order to increase the reliability of estimated results, the following subjects are found in this system.

1) Earthquake observation will be carried in order to introduce the correlation between the input motion and building response.

2) The dynamic vibration characteristic of the buildings will be observed in order to estimate the extent of the damage accurately.

3) The dynamic nonlinear characteristic of the buildings will be researched in order to conduct the nonlinear response analysis.

REFERENCES

1. Housner, G. W., “Spectrum Intensities of Strong Motion Earthquakes”, Proc., 1952 Symposium on Earthquake and Blast Effects on Structures, Earthquake Engineering Research Institute, 1952.
2. Midorikawa, S and Kobayashi, H., “On Estimation of Strong Earthquake Motions with Regard to Fault Rupture”, Trans. of AIJ, 1979, No. 282, p.71-81.

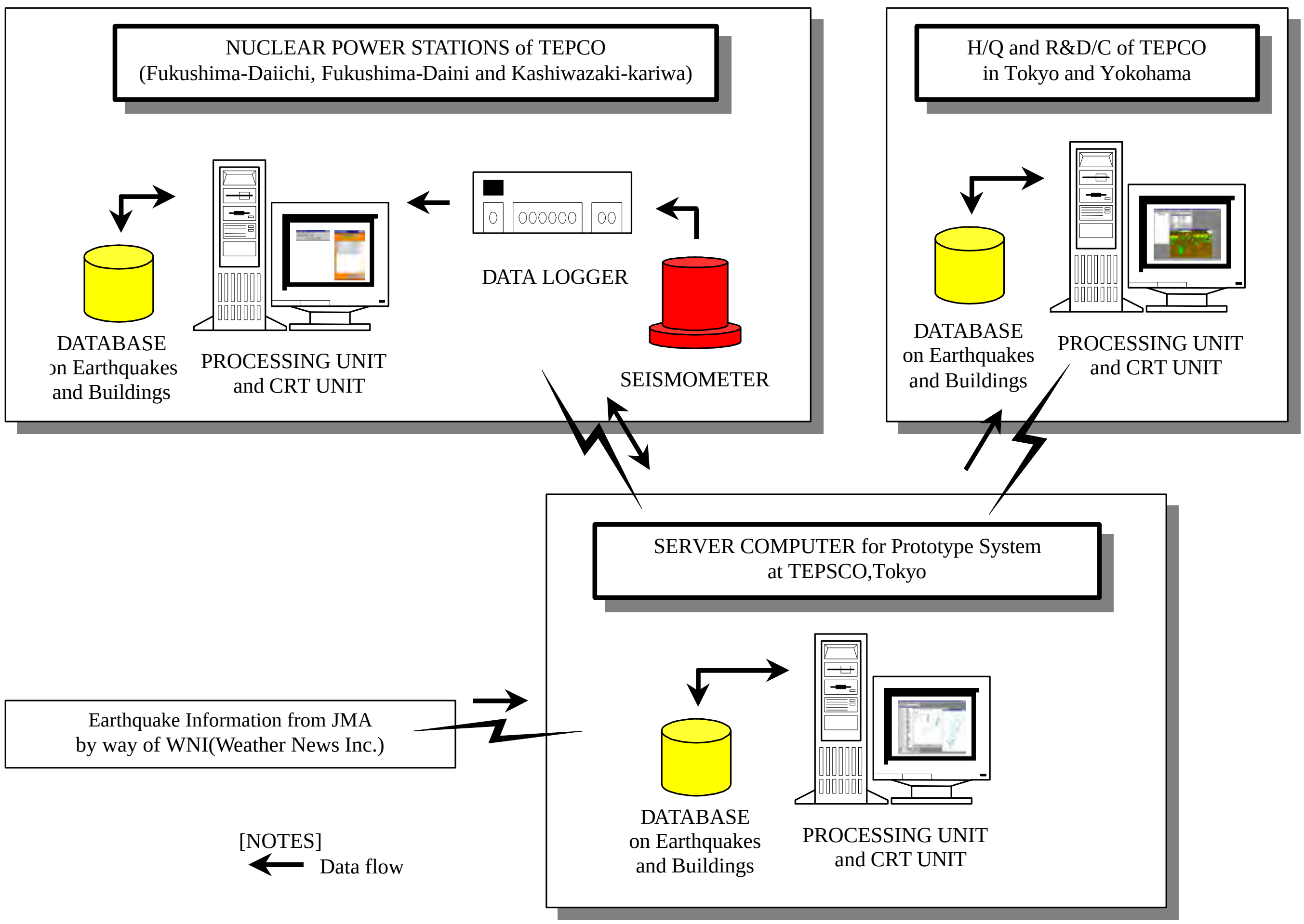

Fig.1 The Outline Composition of Prototype System

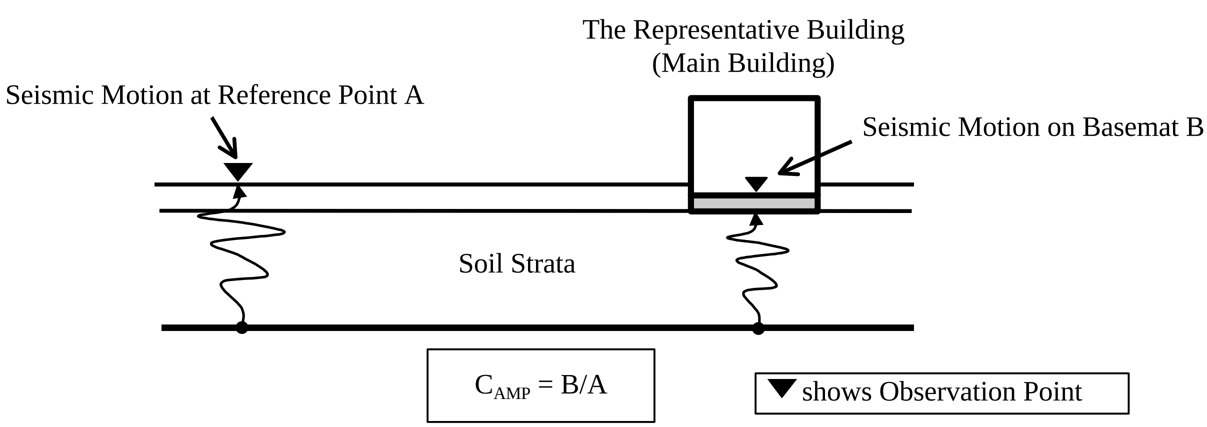

Fig.2 (a) The Building Amplification Coefficient C_{AMP} based on The Earthquake Observation Records

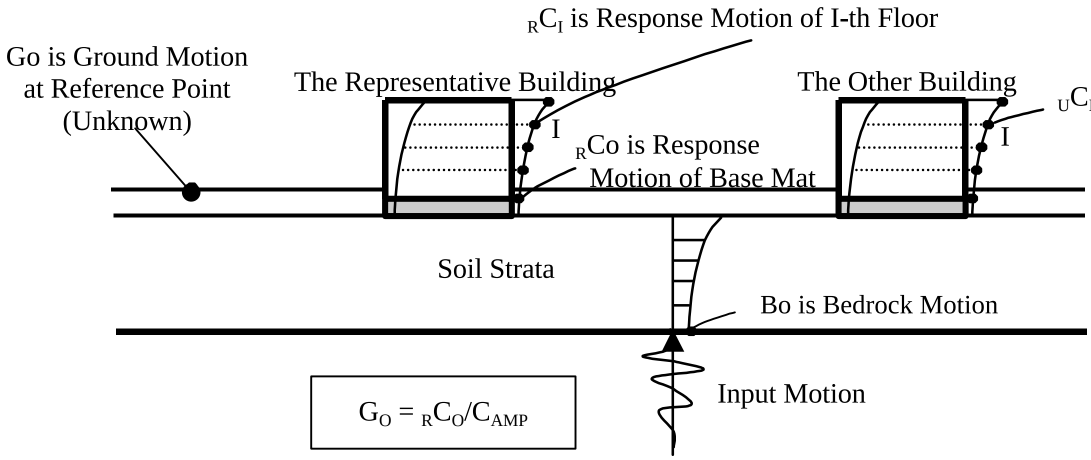

Fig.2 (b) Response Motions Calculated by Dynamical Response Analysis

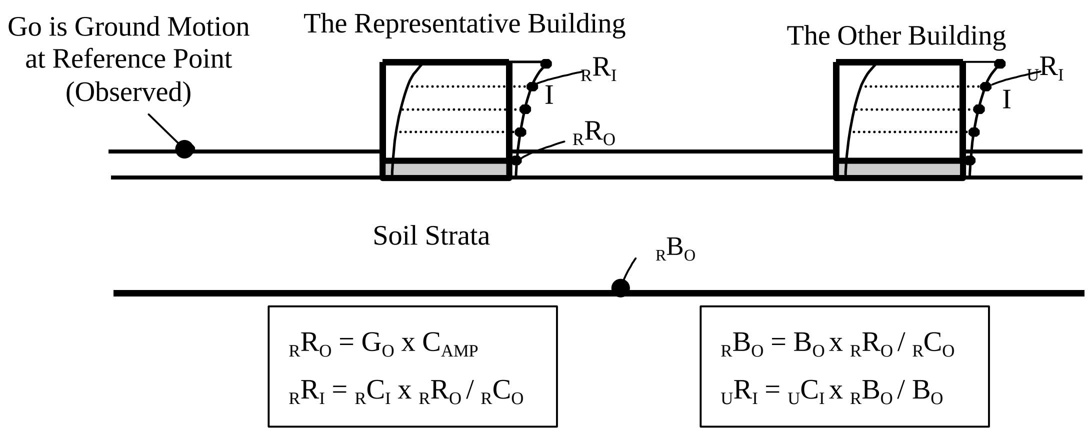

Fig.2 (c) Response Estimation based on the Observation Record of Reference Point

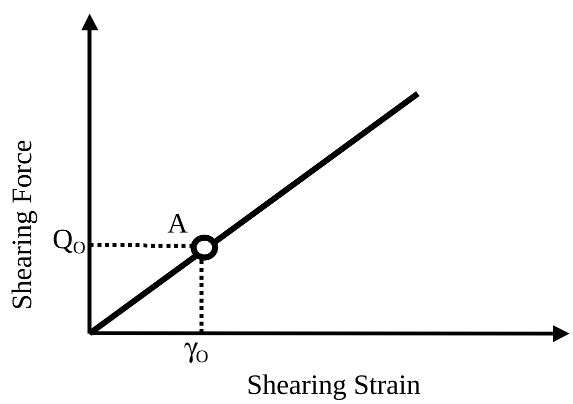

Fig.3 (a) The Standard Response Point based on the Design Earthquake Motion for the Estimation Function

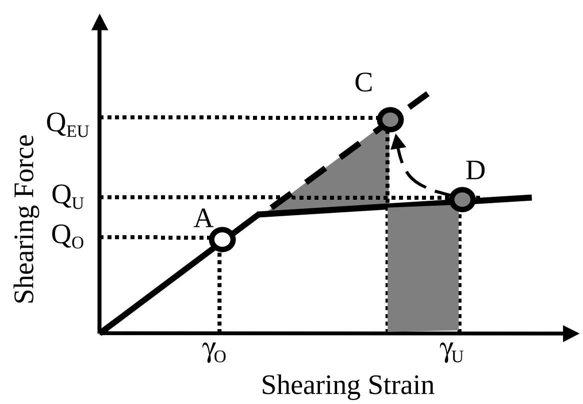

Fig.3 (b) The Equivalent Ultimate Strength Q_{EU} based on the Energy Equivalence Assumption

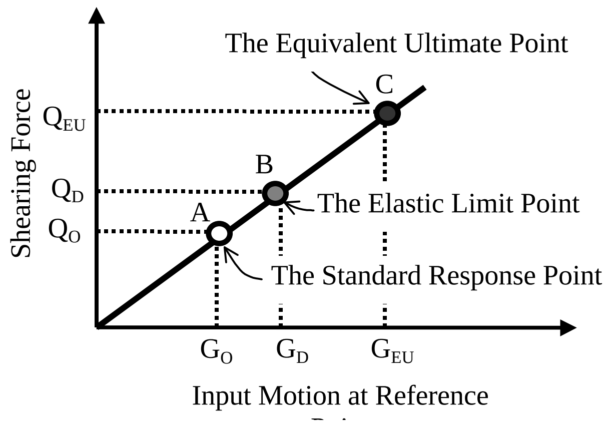

Fig.3 (c) The Enhanced Damage Estimating Function with Points B and C

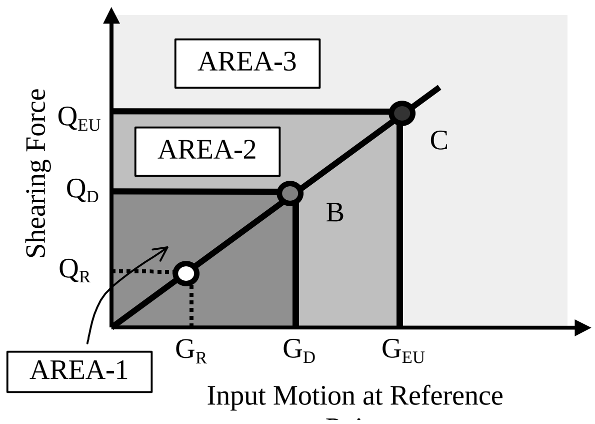

Fig.3 (d) The Three Rank Damage Area Classified According to the Damage Estimating Function

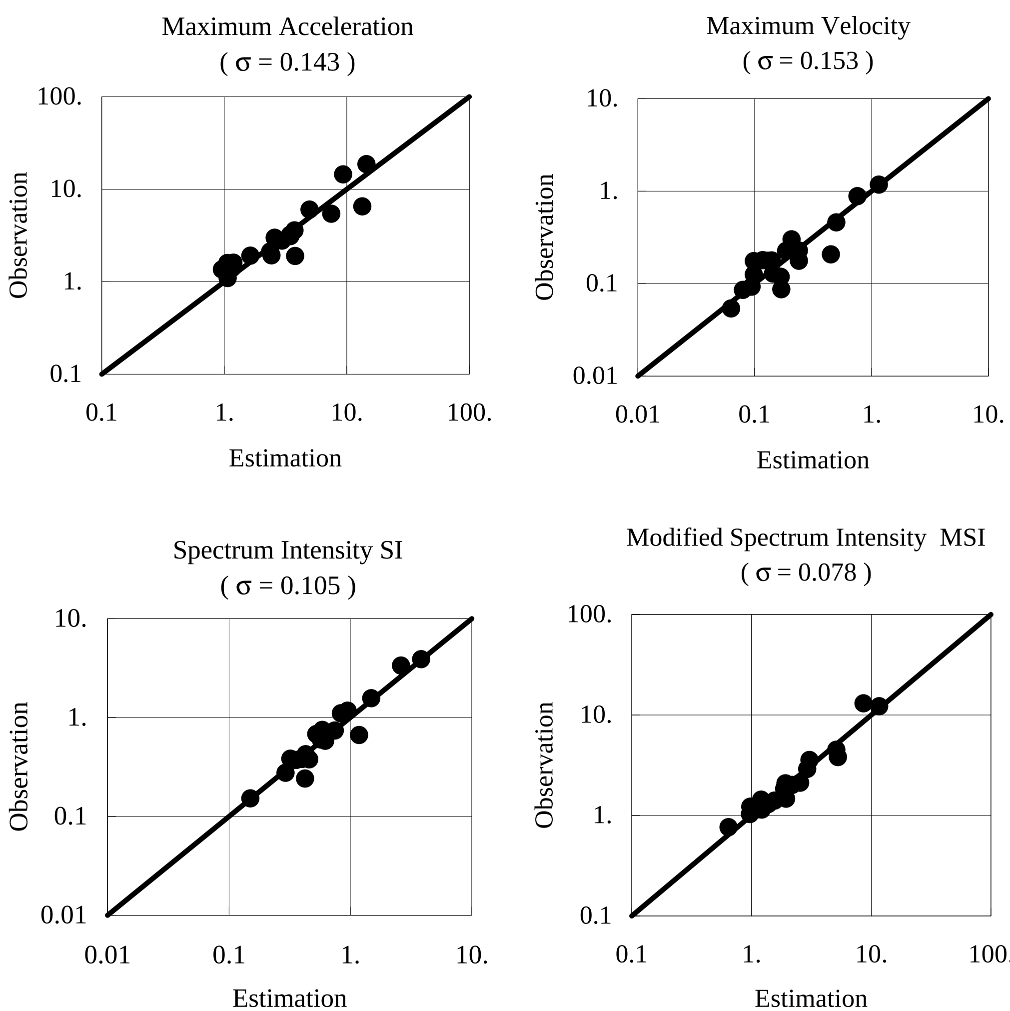

Fig.4 The Comparison Between Observation and Estimation in Indexes of Earthquake Motion Intensity

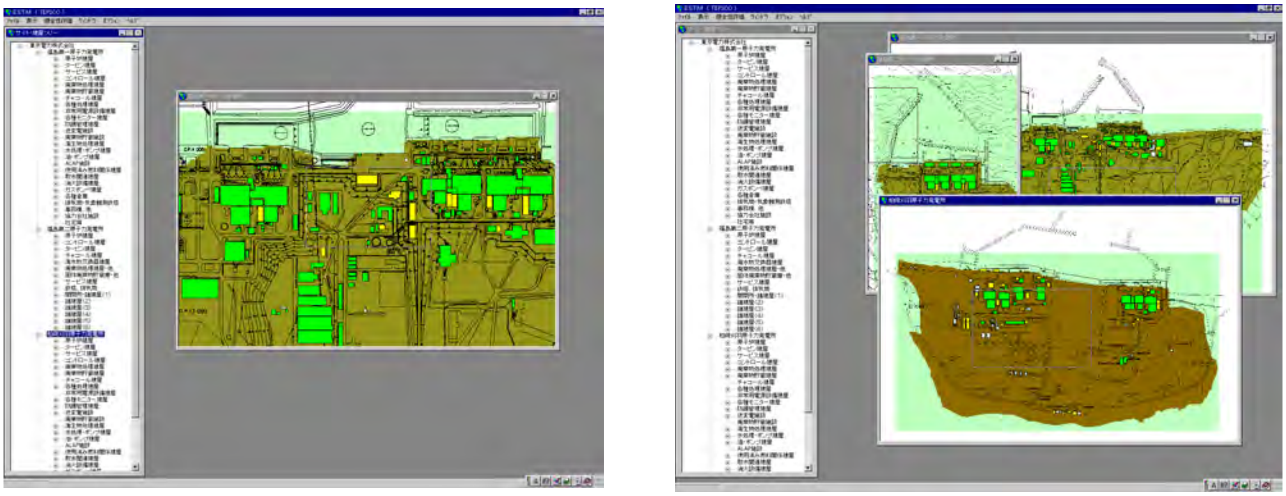

Fig.5 (a) The Simulated Damage Results Mapping of Buildings in Fukushima-Daiichi, Fukushima-Daini, Kashiwazaki-Kariwa Sites on Considerable Operation Basis Earthquakes

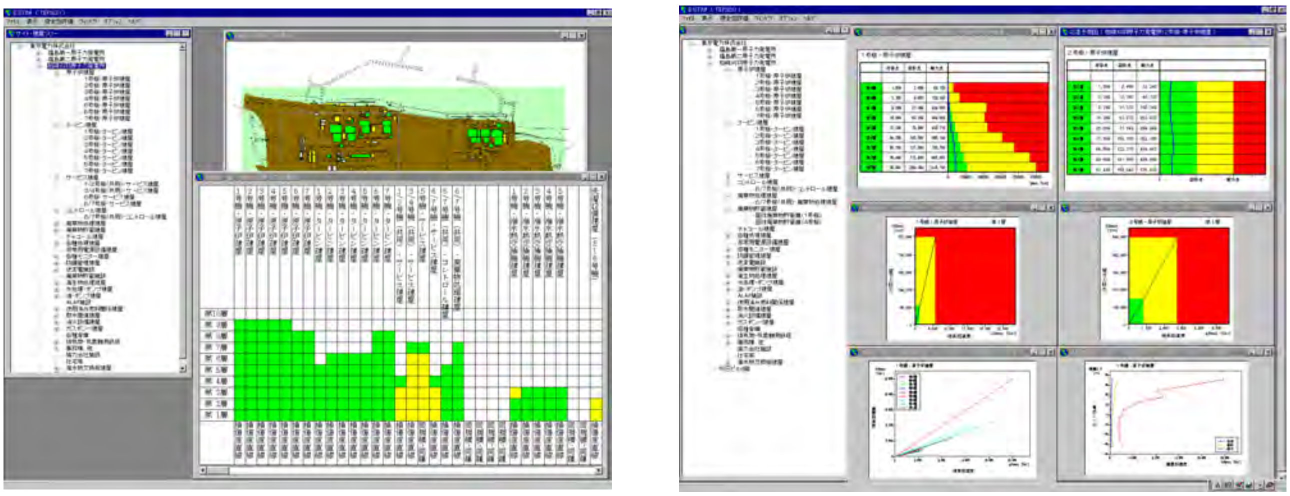

Fig.5 (b) Details of Estimated Damage Results and Estimating Functions with Each Floor of the Buildings

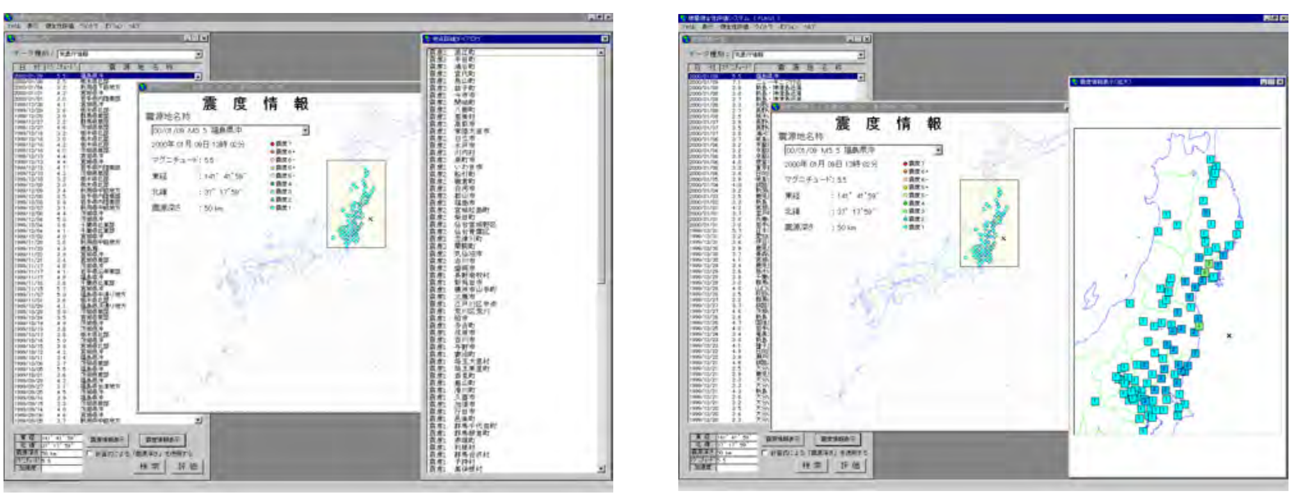

Fig.5 (c) A Displaying Sample of the Earthquake Information Announced from JMA
(The Distribution of Seismic Intensity and the Epicenter location in the Eastern Honshu of Japan)