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Structural Safety Evaluation System Immediately after an Earthquake

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ABSTRACT When an earthquake occurs, the safety of the nuclear power station has to be quickly and precisely confirmed in order to keep a stable supply of electric power.

Above all, it is most important to carry out a visual inspection of the plant's buildings after an earthquake. But when an earthquake is of a considerably large level, an analytical investigation becomes most important in order to confirm the structural safety of the building. This is because, an analytical investigation can predict where the damage might occur.

Chubu Electric Power Co., Inc. (CEPCO) has improved the "Seismometry Synthesis System" into a more convenient one for quick evaluation via structural response using recorded data of the earthquake.

1. INTRODUCTION

1.1 PROFILE OF THE HAMAOKA NUCLEAR POWER STATION

CEPCO's Hamaoka Nuclear Power Station is located on the Pacific coast of Hamaoka-cho, Shizuoka prefecture, which is approximately in the center of Japan's mainland. This station supplies electric power to the highly populated Chukyo region, which includes the city of Nagoya, and a large industrial zone, including a world famous automobile company.

Nuclear plant unit 1 at the Hamaoka station started its commercial operations in March, 1976. Presently four units (units 1 to 4) are in service and generate an output of 3,617,000 kilowatts. Unit 5 is under construction now. Units 1 to 4 are boiling water reactors (BWR), and unit 5 is an advanced boiling water reactor (ABWR).

Figure 1 shows the location and the layout of the Hamaoka Nuclear Power Station, Table 1 shows each unit's data.

1.2 BACKGROUND OF THE SYSTEM'S IMPROVEMENT

When an earthquake occurs, the safety of a nuclear power station has to be quickly and precisely confirmed in order to keep a stable supply of electric power.

Above all, it is most important to check the structural safety carefully.

But when an earthquake is at a considerably large level, an analytical investigation becomes very significant in order to confirm the structural safety of the building, because visual inspection can not cover the entire building, and an analytical investigation can indicate where damage might occur.

At the Hamaoka station, the seismometers have been installed on several floors of the main buildings and also under the circumference grounds.

The seismometry data for each building was recorded on magnetic tapes using observational equipment. Because this is an old-fashioned system using magnetic tape, data cannot conveniently be utilized on a personal computer. It takes unwanted time and effort to convert the data from magnetic tape to floppy disk. So, considering the aforementioned, CEPCO has attempted to make a seismometry system which can more easily handle the data for an analysis.

2. OUTLINE OF THE SYSTEM

The soundness of the building when an earthquake is at a considerably large level can be confirmed from two view points: visual inspection and analytical investigation.

The analytical investigation is supported by two systems: the "Seismometry Synthesis System" and the "Quick Evaluation System" .

When an earthquake occurs, the "Seismometry Synthesis System" records the earthquake data on various floors and under the building's circumference grounds. Using the data measured on the base mat floor, the structural response can be analyzed by the "Quick Evaluation System".

Also, a visual inspection can be carried out according to the "Post-earthquake action manual".

Figure 2 shows the relevance of the two systems and the manual.

This paper describes the analytical investigation system and the action manual.

3. SEISMOMETRY SYNTHESIS SYSTEM

At the Hamaoka Nuclear Power Station, horizontal and vertical seismometers have been installed on several floors of the main buildings and their circumference grounds. Earthquake data is recorded by the observational equipment in each building.

Table 2 shows an abstract of the seismometry system of the Hamaoka Nuclear Power Station. Photographs 1, 2 and 3 show the observation rooms. These observational equipments store all records on magnetic tapes, and so; it takes unwanted time and effort to convert the data from magnetic tape to floppy disk for the "Quick Evaluation System".

Therefore, the system's improvement has been planned through the following two steps. Now STEP 1 has been installed.

CEPCO is studying to improve the system to STEP 2 in the future.

STEP 1: Only the data necessary for analyses is down-loaded to floppy disk from the magnetic tape. The floppy disk is brought back from the equipment room in each building to the work office. In this case, it requires little modification of the system's end device, and the improvement can easily and quickly be carried out (Figure 3).

STEP 2: Action can be taken quickly and conveniently when the seismometry record is sent via telephone line to the office. But the present system, being an old type, cannot be connected to the telephone line system. So overall improvement of the system is required (Figure 4).

4. QUICK EVALUATION SYSTEM

The "Quick Evaluation System" is a personal computer system which can give spectrum analysis of an earthquake and response analysis of the buildings, using the earthquake data observed by the "Seismometry Synthesis System".

This system gives various analytical information as follows.

4.1 SPECTRUM ANALYSIS OF AN EARTHQUAKE

Using the observed record from the base mat floor, the acceleration response spectrum is calculated. Then it is possible to compare this spectrum with the design's spectrum. The degree of the earthquake input level is evaluated immediately.

Figure 5 shows the opening screen, and Figure 6 shows the first selection menu of the analysis: a spectrum analysis or a response analysis. This spectrum analysis can change the damping ratio (Figure 7).

Figure 8 shows an example of observed seismic waves.

Figures 9 and 10 show an example of the results of the spectrum analysis.

4.2 RESPONSE ANALYSIS OF THE BUILDINGS

The earthquake response is calculated instantly using the acceleration records for important buildings: the reactor buildings, turbine buildings, and auxiliary building. And the response analysis result and design earthquake load are compared.

This calculation is a frequency response analysis. The transfer function used in the calculation is that function which was estimated in the design phase.

Figure 11 shows a selection menu of a wave and a model.

Figures 12 and 13 show an example of the acceleration distribution and shear force distribution.

This system can investigate the effect of variable rigidity of the building. And the transfer function can be made, using each floor's observed record.

4.3 ESTIMATE OF CRACK OCCURRENCE

The system gives the cracking prediction. The cracking strength degree of the buildings are estimated, using the crack occurrence strength for shear force and bending moment. This strength is calculated using an empirical formula [1].

Figure 14 shows the cracking prediction.

5. POST-EARTHQUAKE ACTION MANUAL

The structural safety confirmation of the buildings needs a visual inspection. The "Post-Earthquake Measure Guide at the Hamaoka Station" prescribes a general action rule after an earthquake. It is requested to report the plant condition to the related posts immediately, within two hours on weekdays after an earthquake.

Visual inspection, therefore, should be carried out efficiently and speedily.

From this point of view, CEPCO has established the "Post-Earthquake Action Manual" pertaining to a detailed inspection of the building.

Figure 15 is an outline of the action to be followed for each earthquake level.

The guide is settled fundamentally in conformity to the "Technical Guidelines for Damage Grading and Seismic Rehabilitation of Damaged Buildings (in Japanese)"[2], and taking into account the site situation, the number of the buildings and the importance of the buildings.

The manual consists three kinds of investigations.

The "General Condition Investigation's" and the "Emergency Investigation's" observational checking sheets created by CEPCO consider urgent action. The "Detailed Investigation's" sheets prepared for CEPCO, provide the Guidelines [2] for statistical comparison of earthquake damage.

5.1 GENERAL CONDITION INVESTIGATION

The "General Condition Investigation" should be done during a limited time period. The investigation results, which show the general post-disaster state, are reported to related posts immediately.

5.2 EMERGENCY INVESTIGATION FOR TEMPORARY REPAIRS

The "Emergency Investigation for Temporary Repairs" is to check the interior of the buildings, after a considerably large earthquake. This investigation is done when the "General Condition Investigation" shows damage to the building or when structural damage of the building has been predicted. This prediction can utilize the "Estimate of Crack Occurrence" of the "Quick Evaluation System".

5.3 DETAILED INVESTIGATION FOR PERMANENT REPAIRS

The "Detailed Investigation for Permanent Repairs" is carried out to assess the necessary damage repairs of the building after an earthquake.

There are many buildings at the Hamaoka station, therefore many people must take part in the visual inspection of all buildings. Because the visual inspection records must be precise, using uniform criteria, recording sheets have been prepared for such a situation.

6. CONCLUSION

Since the improvement of the "Seismometry Synthesis System" by STEP 1, some minor earthquakes have been recorded. This data has been measured, and the "Quick Evaluation System" used to analyze the data and evaluate the building's response.

It is expected that the safety of the nuclear power station can be efficiently confirmed using the systems and the manual.

For the next step, Chubu Electric Power Co., Inc. (CEPCO) plans to improve the "Seismometry Synthesis System" which can observe the whole Hamaoka station.

Further, CEPCO is aiming to transmit the observed data to the head office by telephone line or satellite.

The present "Quick Evaluation System" uses design models for the analysis. In the future, CEPCO hopes to install a system which can use variable simulation models, at the Hamaoka office.

REFERENCES

[1] Japan Electricity Association, "Technical Guidelines for Aseismic Design of Nuclear Power Plants Supplement", JEAG4601-1991

[2] The Japan Building Disaster Prevention Association, "Technical Guidelines for Damage Grading and Seismic Rehabilitation of Damaged Buildings (in Japanese)", 1991

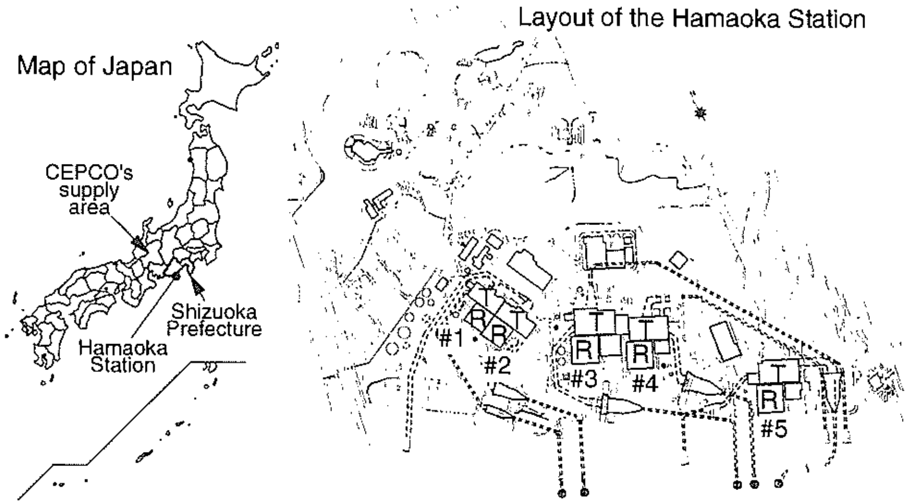


Figure 1 Location and Layout of the Hamaoka Nuclear Power Station

Table 1 Each Unit's Data

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5 (Planned)	Total Unit 1~4
Output	540,000kW	840,000kW	1,100,000kW	1,137,000kW	1380,000kW	3,617,000KW
When Constructed	Mar. 1. 1971	Mar. 5. 1974	Nov. 18. 1982	Feb. 22. 1989	1999	
Operation Started	Mar. 17. 1976	Nov. 29. 1978	Aug. 28. 1987	Sep. 3. 1993	2005	
Number of Fuel Assemblies	368	560	764	764	872	
Intake of Water	About 30 t/s	About 50 t/s	About 80 t/s	About 80 t/s	About 95 t/s	

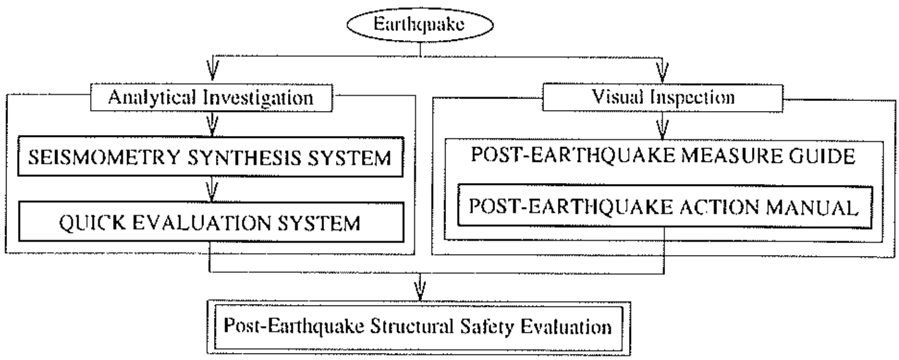
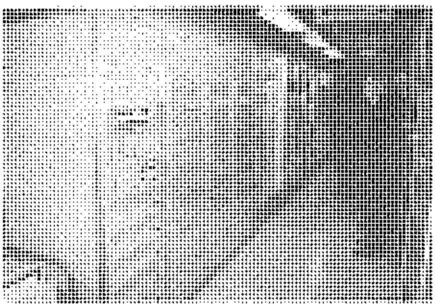


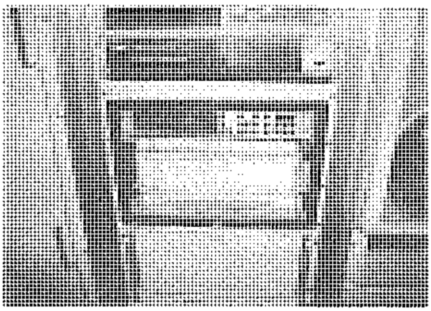
Figure 2 Relevance of the two systems and the manual

Table 2 Abstract of Sesmometry System of the Hamaoka Nuclear Power Station

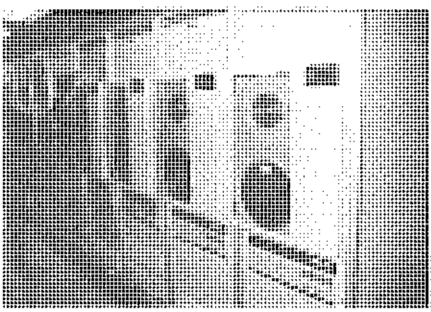
Unit	Classification	Model		Observation number	Monitor
		Sensor	Collecting		
1,2	Seismometer for feeble motion	Electromagnetic type (range±1G)	Digital Magnetic Tape	Building 40ch (R/B onry) Ground 37ch	Observation hut of the south of unit 1 reactor building
1,2	Seismometer for strong motion	SMAC-E mechanical type		Unit 1 3ch×3 Unit 2 3ch×3	Wave form printing with film
3	Seismometer for feeble motion	Servo type (range±2G)	Digital Magnetic Tape	Building R/B 58ch A/B 14ch T/B 13ch Ground 87ch	Observation room in unit 3 reactor building
3	Seismometer for strong motion	Servo type (range±2G)	Bubble Memory	R/B 3ch×3 T/B 3ch×1	
4	Seismometer for feeble motion	Servo type (range±2G)	Digital Magnetic Tape	Building 70ch (R/B only) Ground 33ch	Observation room in unit 4 reactor building
4	Seismometer for strong motion	Servo type (range±2G)	Bubble Memory	R/B 3ch×3	



Photograph 1 Observation Room



Photograph 2 Data Logger



Photograph 3 Magnetic Tape Collecting Device

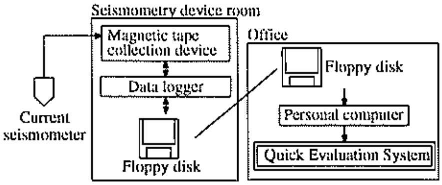


Figure 3 Outline of STEP 1

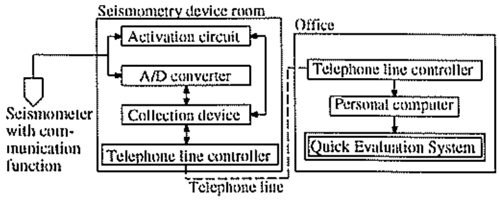


Figure 4 Outline of STEP 2

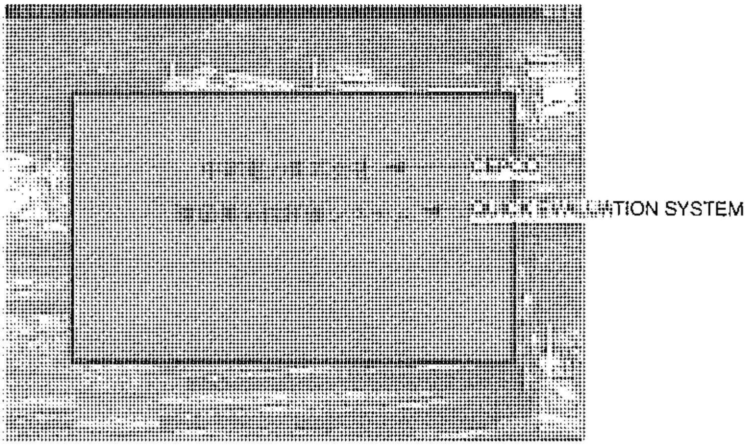


Figure 5 Opening of Quick Evaluation System

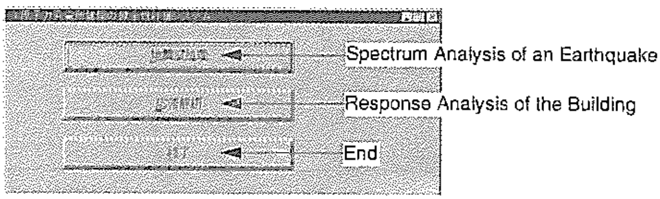


Figure 6 First Selection Menu

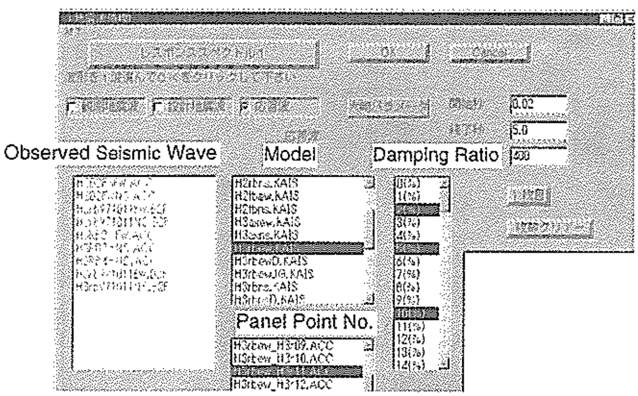


Figure 7 Selection Menu of Spectrum Analysis

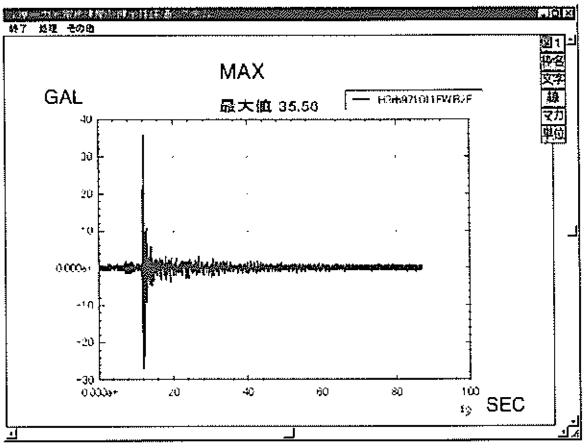


Figure 8 Observed Seismic Wave (Example)

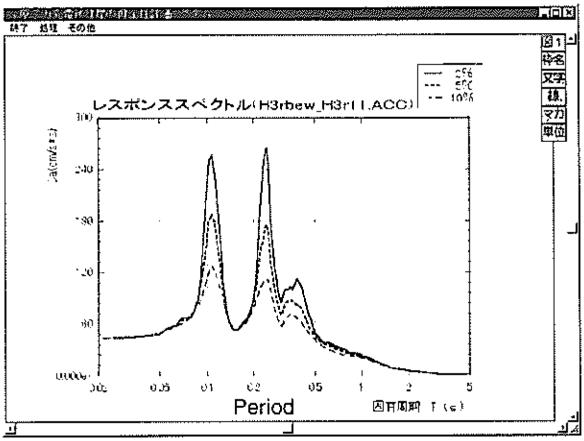


Figure 9 Result of the Spectrum Analysis : TYPE 1 (Example)

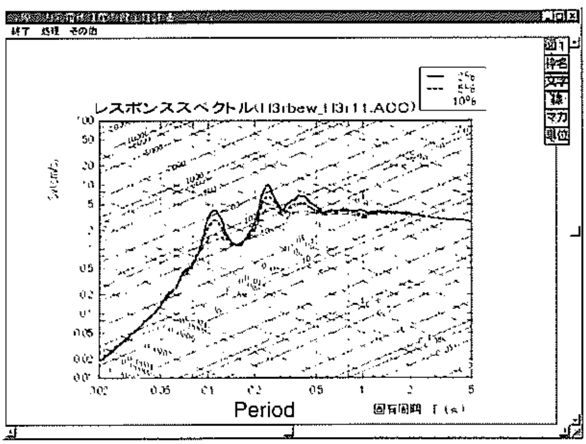


Figure 10 Result of the Spectrum Analysis : TYPE 2 (Example)

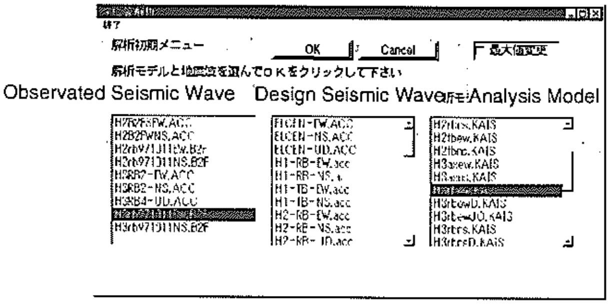


Figure 11 Selection Menu of Response Analysis

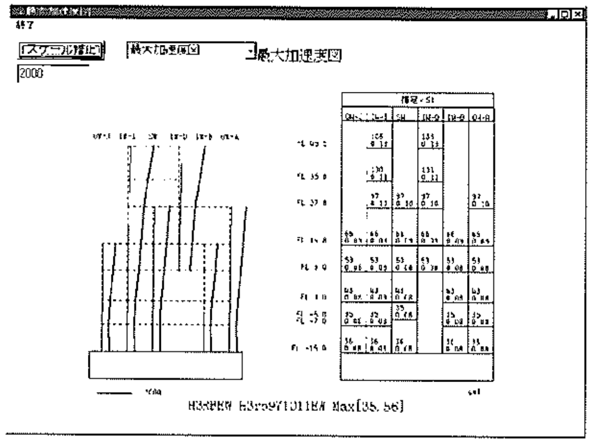


Figure 12 Acceleration Distribution (Comparison with design value) (Example)

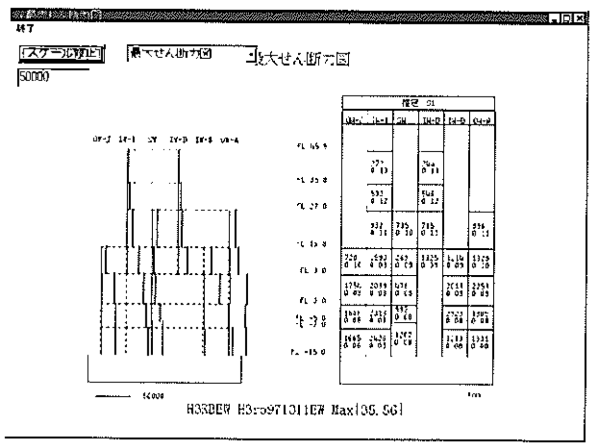


Figure 13 Shear Force Distribution (Comparison with design value) (Example)

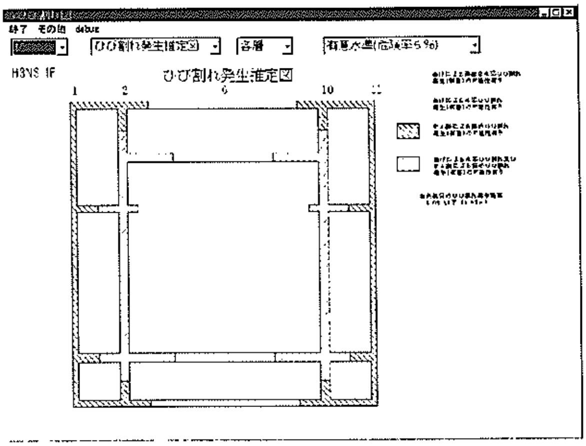


Figure 14 Cracking Prediction (Example)

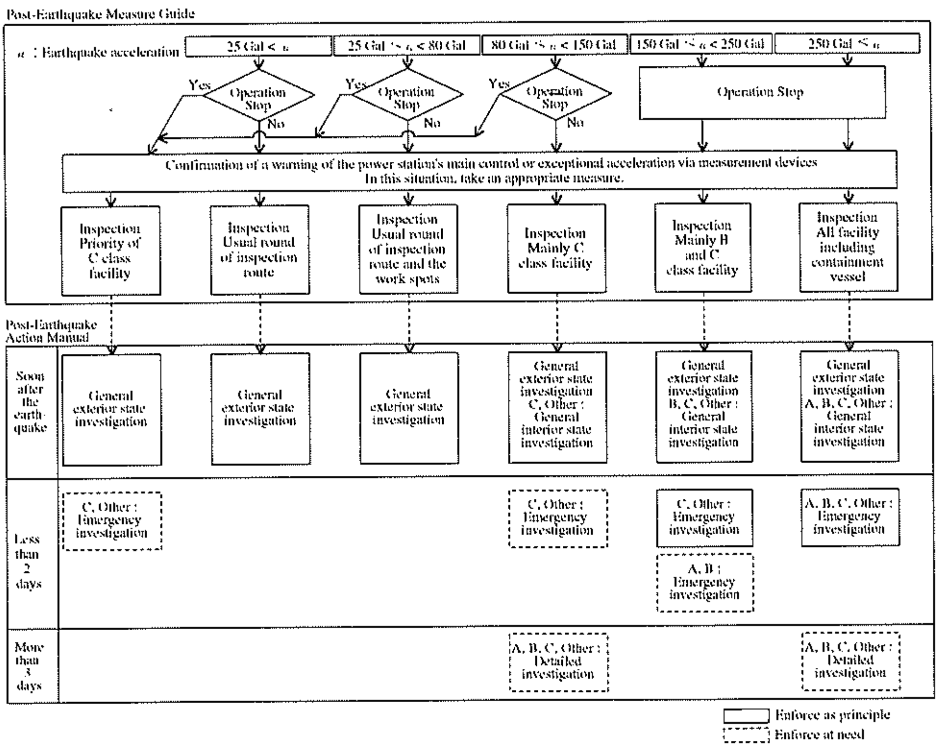


Figure 15 Outline of the Action for Each Earthquake Level