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The reevaluation of seismic safety of existing nuclear power plant

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ABSTRACT

We have carried out additional geological surveys in order to enrich our database on geological faults in the vicinity of Shimane Nuclear Power Plant (NPP). Prior to additional geological surveys, given the social importance of nuclear power plants, we hypothetically assumed that almost the whole length of an area covered by surveys would be an active fault that must be considered in seismic design, and tried to reevaluate the seismic safety of the NPP by applying an input earthquake ground motion larger than the level at the design stage. As a result, we have confirmed that seismic safety of the NPP can be maintained.

This paper describes the method that we employed to reevaluate the seismic safety of Shimane NPP.

KEY WORDS: reevaluation of seismic safety, seismic source fault, earthquake ground motion, wave superimposition method, amendment recipe, response spectra, time history response analysis, spectral-modal analysis, allowable limit, ultimate strength, design-basis evaluation, practical evaluation, stress evaluation, dynamic function evaluation, synthetic evaluation.

1. OUTLINE OF THE REEVALUATION OF SEISMIC SAFETY

In order to maintain the seismic safety of reactor facilities, an essential consideration is that facilities which are important in terms of safety have sufficient earthquake-resistance capability to prevent postulated seismic force from triggering a large nuclear accident. Viewed in this light, facilities which are important to nuclear safety have been reevaluated as described below.

Fig. 1 shows the flow to reevaluate seismic safety.

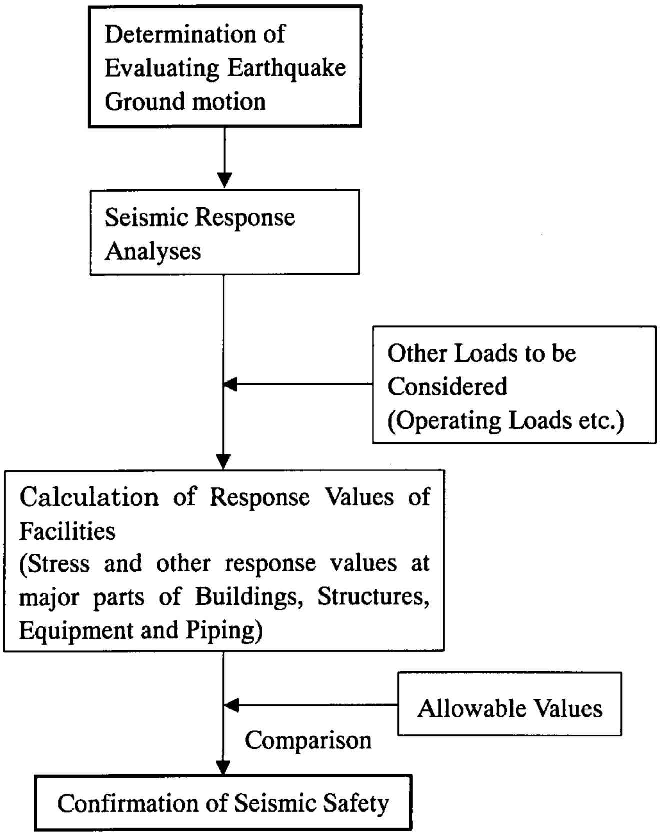


Fig.1 Seismic Reevaluation Flow

1.1 Earthquake Ground Motion for Reevaluation

The earthquake ground motion employed for the reevaluation of the NPP is generated under the presumed condition, that the seismic source fault is, as shown in Fig.2, located about 2km apart from the NPP and the fault length is 20km, by using the fault model with wave superimposition method proposed by Irikura [1].

The details of the model are determined based on the so-called “the amendment recipe” in ref. [2] also proposed by Irikura recently to have conservative input ground motion. The time histories obtained are shown in Fig. 3. Moreover, the response spectra of the time histories are shown in Fig.4, in comparison with that of basic design earthquake ground motion S_2. S_2 is the extreme ground motion for design that is determined on the basis of seismic geostructure, active faults, and a shallow-focus earthquake with a minimum Magnitude of 6.5.

The vertical ground motion was evaluated as a static seismic force.

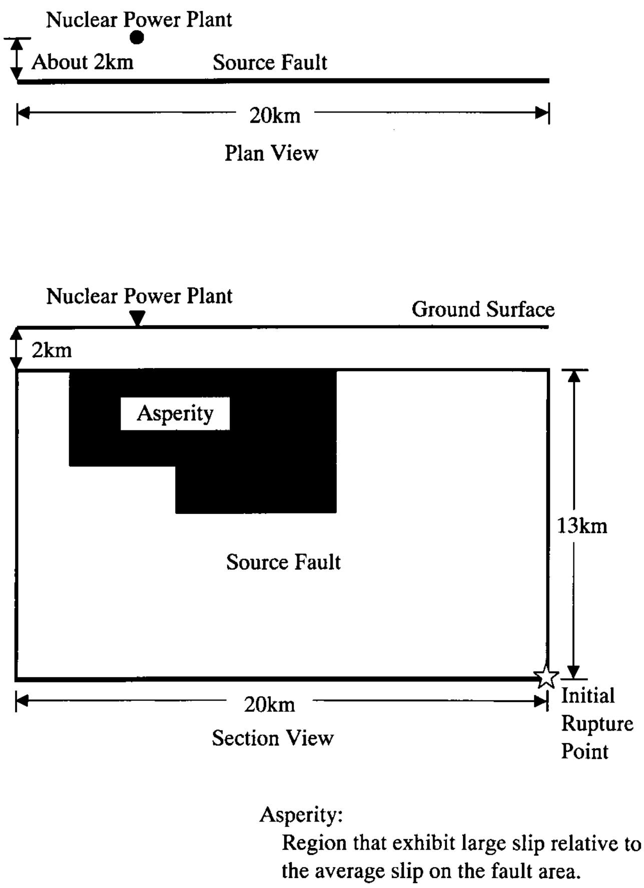


Fig.2 Presumed Fault and The NPP Site Location

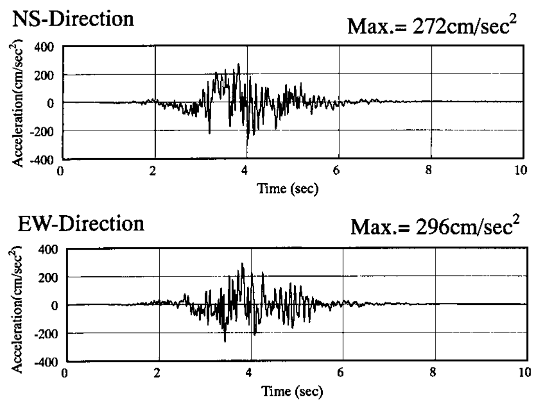


Fig.3 The Time History of Earthquake Ground Motions Used for The Seismic Reevaluation

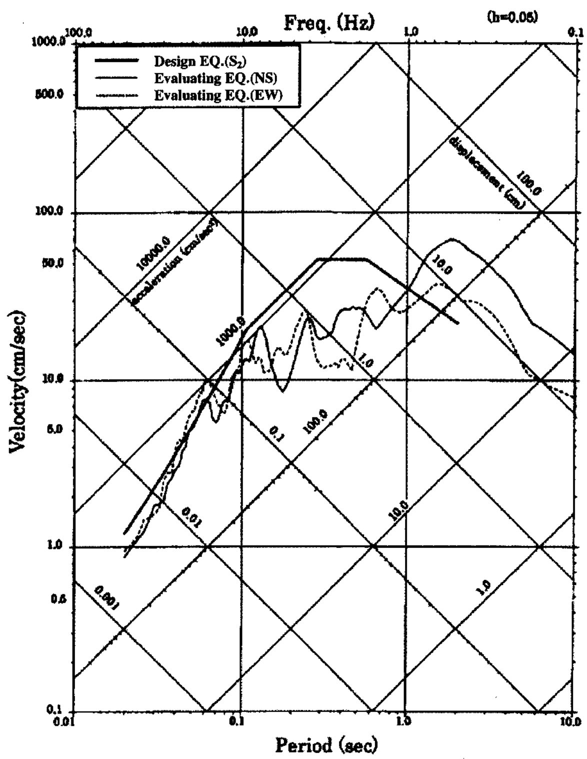


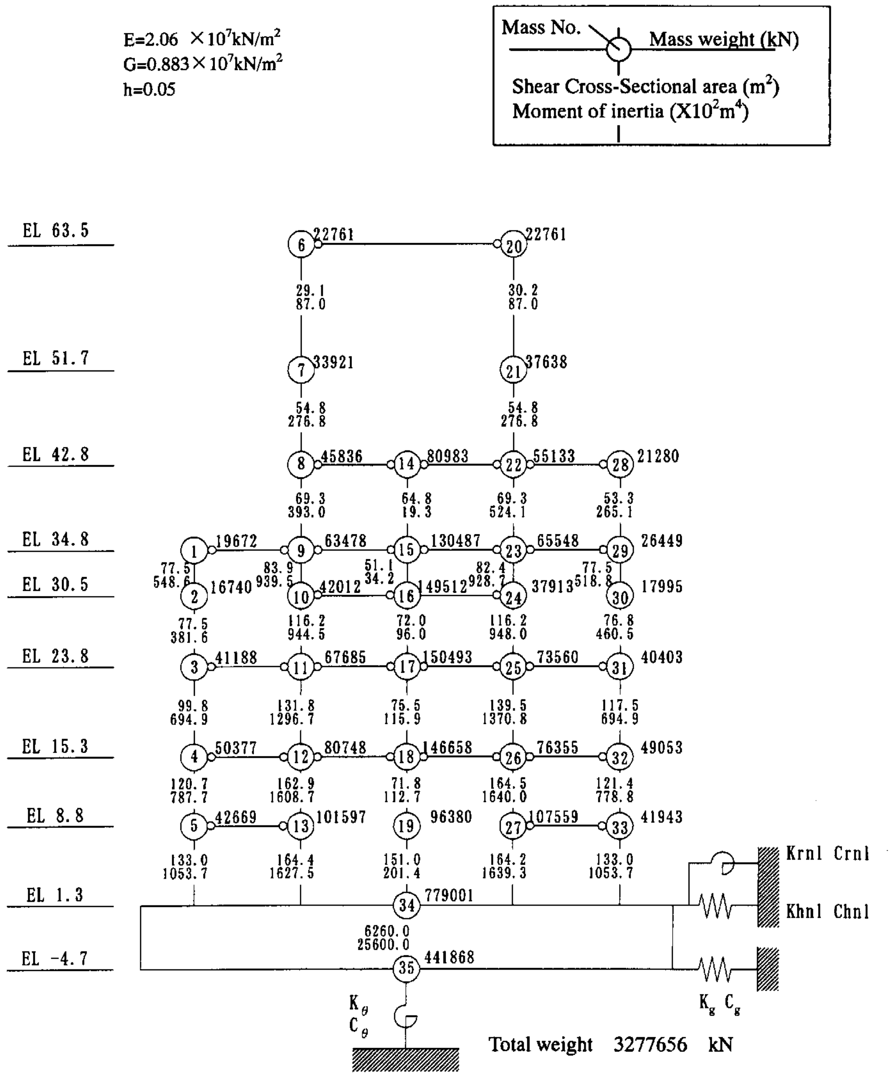
Fig.4 The Response Spectra of Earthquake Ground Motions Used for The Seismic Reevaluation

1.2 Structures and Components (SCs) for Reevaluation

From the viewpoint of the basic nuclear safety of NPPs, "Reactor Shutdown, Core Cooling and Radioactivity Enclosing", the SCs of the seismic importance category "As" are determined as defined in Japan Nuclear Safety Commission "Regulatory Guide for Aseismic Design of Nuclear Power Reactor Facilities, 1981"[3] and listed as evaluation items. SCs of the seismic importance category "As" are defined as the SCs that contain radioactivities or those closely related to the SCs containing radioactivities that might cause an accident of radioactivity release as a result of loss of the function, the SCs needed to prevent radioactivity release accidents, as well as the SCs needed to mitigate the effects of radioactivities at these accidents with particularly large effects and efficiencies.

1.3 Seismic Response Analysis

Buildings and structures (for example sea water intake pools) are modeled by multiple lumped mass system, and their seismic responses are computed using a time history response analysis method (See Fig.5). The seismic response analysis of equipment and piping is carried out by applying the time history analysis and the spectral-modal analysis that applies floor response spectra, using a single degree of freedom system model or multiple degree of freedom system model in accordance with its shape (See Fig.6).



Soil Springs		Soil Stiffness (kN/m,kN·m/rad)	Damping (kN·sec/m,kN·m·sec/rad)
Side horizontal Khn1,Chn1	EL1.3m	5.407E+07	2.309E+06
Side rotational Krn1,Crn1	EL1.3m	3.190E+10	1.049E+09
Bottom horizontal K_g,C_g	EL-4.7m	1.341E+09	2.070E+07
Bottom rotational K_θ,C_θ	EL-4.7m	1.894E+12	4.185E+09

Fig.5 Analytical Reactor Building Model (NS-direction) Used for The Seismic Reevaluation

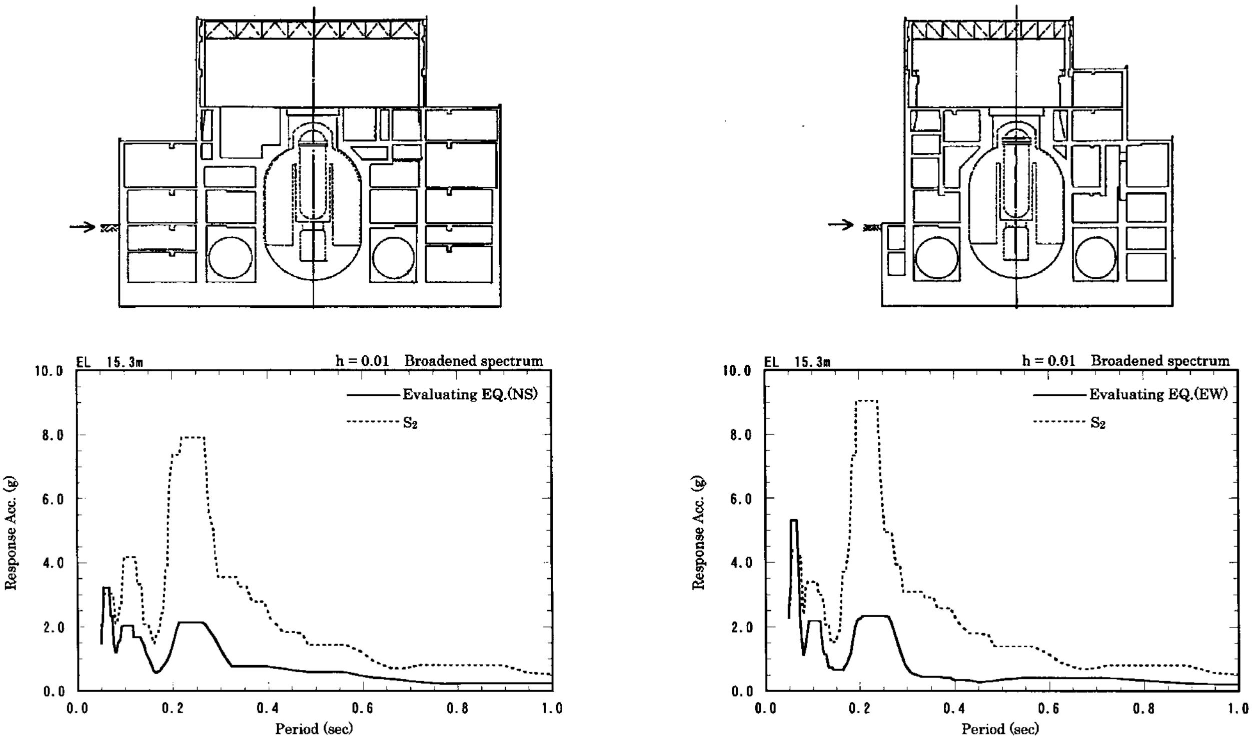


Fig.6 Examples of Response Spectrum Compared with That of Basic Design Earthquake Ground Motion S_2

1.4 Calculation of Response Values of SCs

The response values (the strain and stress in the member) of the buildings and structures are calculated by seismic response analyses. The response value (stress) at each part of equipment and piping is calculated by combining the load obtained by the seismic response analyses and other loads that should be considered in design.

The calculation of the response value is carried out basically by applying the method which was taken at the design stage, specified in the Japan Electric Association's Technical Guidelines for Aseismic Design of Nuclear Power Plants (hereinafter referred to as the "Technical Guidelines")[4][5][6]. In some cases, calculation is carried out by employing some practical parameters based on the actual conditions or latest knowledge because this evaluation is performed for existing facilities.

In this reevaluation, the vertical seismic force is considered as the static force which is determined as half the value of the maximum acceleration amplitude of the horizontal earthquake ground motion. The force is combined with the dynamic horizontal seismic force with regard to their direction so that they work together in the unfavorable direction simultaneously.

1.5 Confirmation of Seismic Safety

The seismic safety is confirmed by checking that the response value of each facility to the earthquake ground motion for the reevaluation is lower than an allowable limit (allowable value). The allowable values used are described in the Ministry of Economy, Trade and Industry Notification No. 501, "Technical Standards on the Structure of Nuclear Power Facilities" (hereinafter referred to as the "Technical Standards")[7]. The values are determined with sufficient margins compared to the ultimate strength of materials.

2. METHODS TO VERIFY SEISMIC SAFETY OF BUILDINGS AND STRUCTURES

The seismic safety of buildings, as shown in Fig. 7, is evaluated by comparing shear strain caused by earthquake ground motion for evaluation on the reinforced concrete shear wall which is a main element of the building, with the standard value of the allowable limit under the Technical Guidelines (JEAG4601-1987)[5].

The seismic safety of structures, as shown in Fig. 8, is evaluated by comparing section force caused by earthquake ground motion for evaluation on the reinforced concrete members in structures, with the ultimate strength.

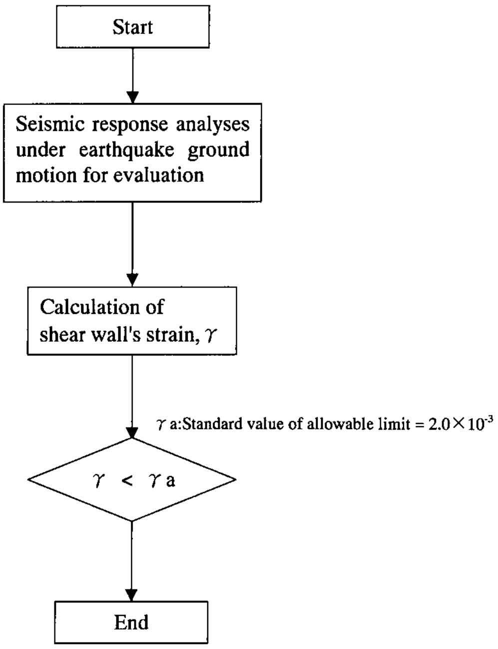


Fig.7 Evaluation Flow for Seismic Safety of Buildings

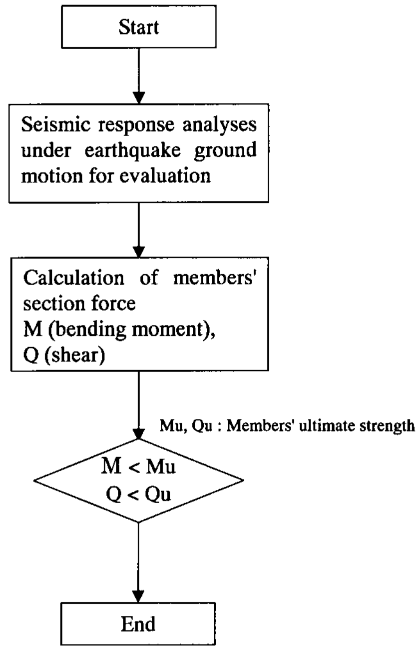


Fig.8 Evaluation Flow for Seismic Safety of Structures

3. METHODS TO VERIFY SEISMIC SAFETY OF EQUIPMENT AND PIPING

Evaluation of seismic safety is made basically by the methods specified in the Technical Guidelines [4][5][6]. However, because the evaluation is performed for the existing facilities, seismic safety is verified not only by the method used in the design stage but also by more practical conditions and methods (practical evaluation).

Fig. 9 shows the evaluation flow for seismic safety of equipment and piping. Stress evaluation is conducted on those parts that should be considered relevant for confirming the function of the facilities. Regarding facilities that have dynamic functions, evaluation is also carried out to verify whether they maintain dynamic functions.

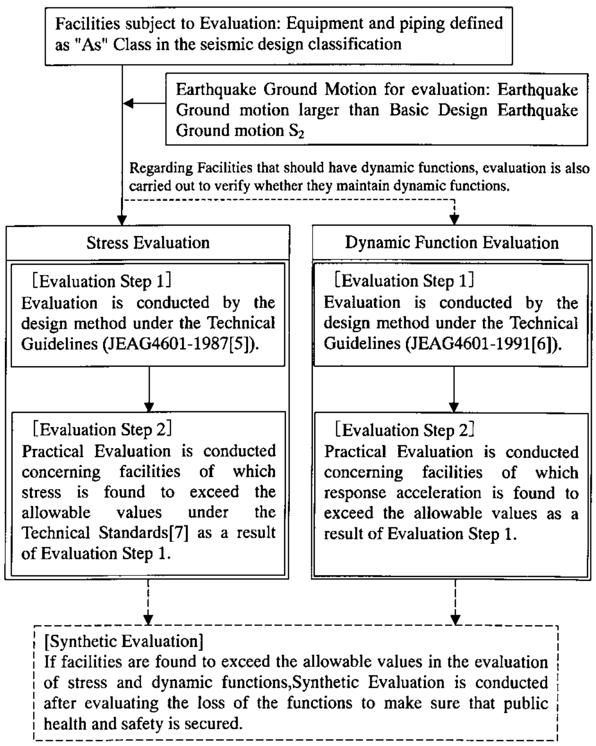


Fig.9 Evaluation Flow for Seismic Safety of Equipment and Piping

Equipment and piping are designed to have significant margin for the design allowable limit. Therefore, in order to reasonably conduct evaluation under the earthquake ground motion for evaluation, the design-basis evaluation method is applied for verification in the first stage (evaluation step 1) and, where necessary, practical evaluation (evaluation step 2) is conducted.

If equipment and piping are found to exceed the allowable conditions in the evaluation of stress and dynamic functions, synthetic evaluation is conducted after evaluating the loss of the functions, to make sure that public health and safety is secured under hypothetical earthquake ground motion.

3.1 Stress Evaluation

The stress evaluation flow is shown in Fig. 10.

(1) Evaluation Step 1

Evaluation in the first step is conducted through the design-basis evaluation method. In this evaluation, the stress value of allowable conditions is the allowable stress specified in the Technical Standards [7].

(a) Evaluation by the Response Ratio Method:
For evaluated facilities, stress is determined through multiplying the stress already acquired from basic design earthquake ground motion S_2 by the ratio (response ratio) of seismic intensity acquired from the earthquake ground motion for evaluation to that acquired from basic design earthquake ground motion S_2. And this stress value should be compared with the allowable value.

(b) Detailed Evaluation:
Based on the Technical Guidelines (JEAG4601-1987)[5], stress generated in the evaluated part is determined through spectral-modal analysis or time history analysis under the earthquake ground motion for evaluation as a condition and compared with the allowable value.

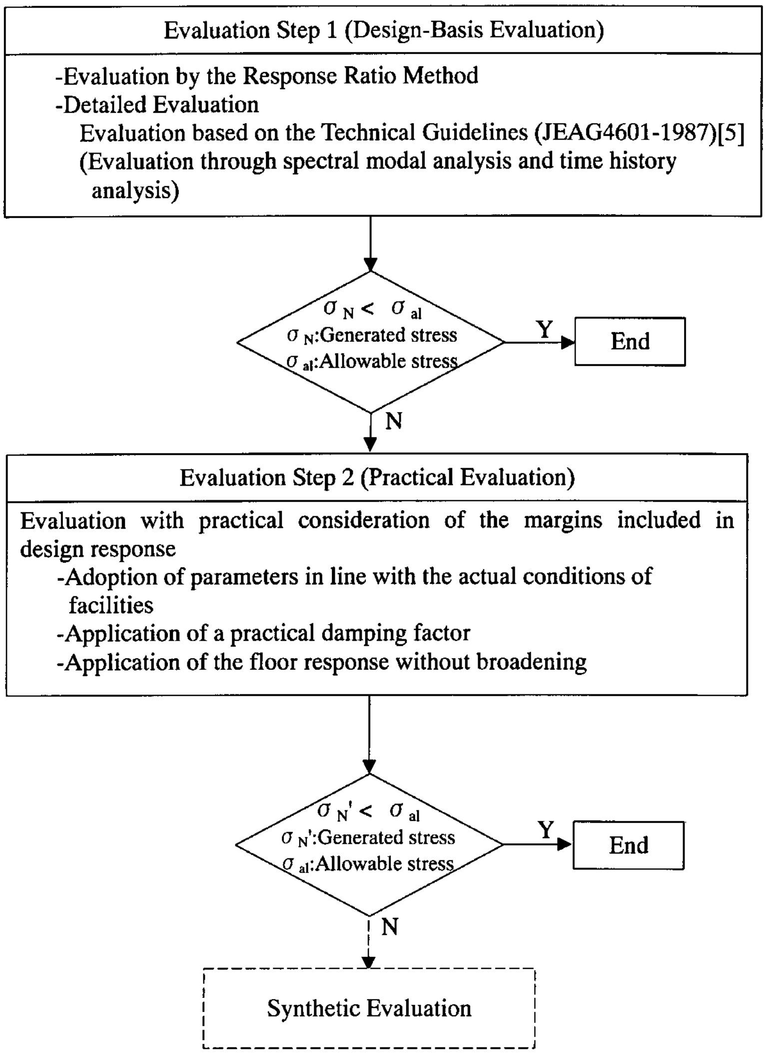


Fig.10 Stress Evaluation Flow

(2) Evaluation Step 2

Stress is determined through practical evaluation concerning those facilities which exceed the allowable value in the results of Evaluation Step 1. The matters that should be considered in practical evaluation include:

(a) Adoption of parameters in line with the actual conditions of facilities;
(b) Application of a practical damping factor (adoption of data gained in tests); and
(c) Application of the floor response spectrum without broadening.

With (a), (b) and (c) above given as input conditions, evaluation is conducted by the same method as used in detailed evaluation in Step 1. In this evaluation, the stress value of allowable conditions is the allowable stress specified in the Technical Guidelines (JEAG4601 1984)[4].

3.2 Dynamic Function Evaluation

The dynamic function evaluation flow is shown in Fig. 11.

(1) Evaluation Step 1

In order to check whether active equipment such as pumps and valves are able to maintain their functions in an earthquake, evaluation is conducted by comparing the function-approved acceleration under the Technical Guidelines (JEAG4601-1991)[6] as the allowable condition with the response acceleration generated by the earthquake ground motion for evaluation.

Likewise, the insertability of control rods is evaluated by comparing the maximum relative displacement of fuel assemblies caused by the earthquake ground motion for evaluation with the function-approved value under the Technical Guidelines.

(2) Evaluation Step 2

Response acceleration is determined through practical evaluation concerning those facilities which exceed the allowable value in the results of Evaluation Step 1. The matters that should be considered in practical evaluation include:

(a) Adoption of parameters in line with the actual conditions of facilities;
(b) Application of a practical damping factor (adoption of data gained in tests); and
(c) Application of the floor response spectrum without broadening.

With (a), (b) and (c) above given as input conditions, evaluation is conducted by the same method as used in Evaluation Step 1.

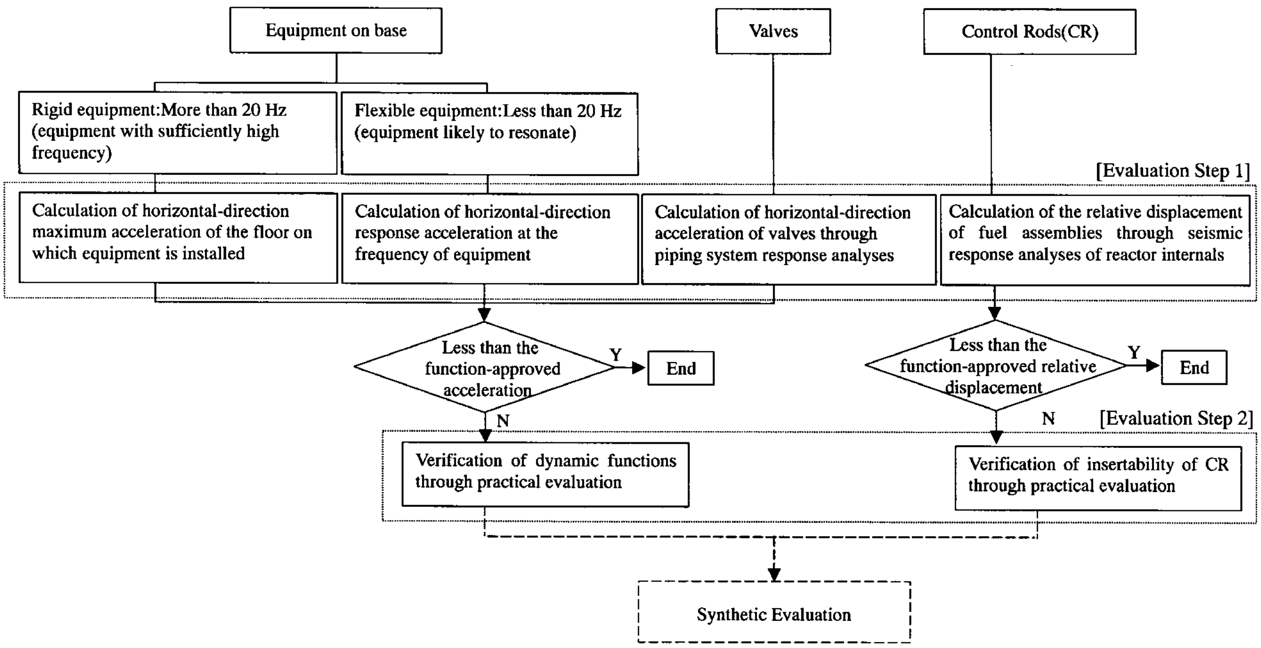


Fig.11 Dynamic Function Evaluation Flow

3.3 Synthetic Evaluation

If facilities are found to exceed the allowable value in the results of Evaluation Step 2 for the evaluation of stress and dynamic functions, the loss of the functions are evaluated. Evaluation should be conducted comprehensively to verify whether alternative systems are available and examine allowable values. Seismic safety under the earthquake ground motion for evaluation is verified to make sure that public health and safety can be secured.

4. RESULTS OF REEVALUATION OF SEISMIC SAFETY

Because the earthquake ground motion used for evaluation partially exceeds basic design earthquake ground motion S_2 as shown in Fig. 4, the seismic safety of equipment and piping, which fall under As Class in the seismic design classification, and buildings and structures for supporting these equipment and piping were reevaluated.

As a result, it has been confirmed that buildings and structures have a sufficient margin for the allowable limits of shear strain and strength, and are capable of maintaining their functions, and that equipment and piping are not subject to excessive deformation, cracking or damage, and do not affect the safety functions of the facility.

In the evaluation of equipment and piping, their seismic safety has been verified in Evaluation Steps 1 and 2, synthetic evaluation has not been conducted. In Evaluation Step 2, parameters to meet the actual conditions of facilities have been adopted and practical damping factor has been applied.

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