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SYSTEM PARAMETER IDENTIFICATION FOR REACTOR BUILDING USING FORCED VIBRATION TEST AND EARTHQUAKE RECORDS

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ABSTRACT

To verify the seismic design procedure for BWR-type reactor buildings, a forced vibration test was performed after a plant was constructed. Furthermore, several earthquake records have been obtained from the installed earthquake observation network. This paper describes a newly developed system parameter identification method applied to both the vibration test results and the observed earthquake records. The soil-structure interaction effect and the rigidity and damping of the reactor building were successfully identified and the validity of the seismic design model and its evaluation method were confirmed.

1. INTRODUCTION

Forced vibration tests and earthquake observations after construction are very important in insuring the safety of nuclear power facilities. Furthermore, it will be necessary to verify the seismic design concept, the analytical model and the analytical method through the simulation analysis of the tests and observation results. This paper describes a newly developed system parameter identification applied to a BWR type reactor building, using both forced vibration test results and earthquake records. The identification method is able to optimize system parameters of mass, rigidity and damping of the assumed analytical model so as to minimize discrepancies between the observed data and the computation results.

2. REACTOR BUILDING

The Unit No.3 of the Hamaoka Nuclear Power Plant is a BWR-type building with 1100 MWe power generation capacity located in the Tokai coastal region of a high seismicity zone. The reactor building is made of reinforced concrete and has 4 floors above the ground and 2 floors under the ground. The total weight of the building is approximately 397,000 tons. Fig.1 shows a cross section of the reactor building. The main aseismic elements are composed of a shield wall (S/W), an inner box wall (I/W) and an outer box wall (O/W). The forced vibration test and earthquake observations are outlined as follows.

2.1 Forced Vibration Test

The forced vibration test was performed by applying a sinusoidal excitation force with 2 vibration generators on the operating floor. Displacement meters were used for measuring the vibration of the reactor building (ref.1). Fig.2 shows the resonance curves obtained on each floor of the I/W in the NS direction test. The fundamental frequency of all resonance curves was approximately 3.8 Hz. A damping factor of approximately 40 % was estimated from the resonance curves of the operating floor, by the Half Power Method.

2.2 Earthquake Observation

Earthquake observations have been continued in Hamaoka Unit No.3, using not only seismographs installed in the building and under the ground, but also earth pressure sensors under the ground. There is a total of 44 seismographs (58 components) in the reactor building. Several small or moderate earthquake records have been obtained since installation. Fig.3 shows acceleration time histories observed at I/W floors during the Izuoshima-Kinkai earthquake, which occurred on February 20, 1990.

3. IDENTIFICATION METHOD

A rough flow of the system identification method is shown in Fig.4. The method of identifying the system parameters is as follows.

1) The reactor building is replaced by a Sway-Rocking-type three-stick lumped-mass model. Each stick is composed of beam elements and lumped masses representing the S/W, I/W and O/W, and they are connected to each other by floor springs. Although the Lattice model was adopted as the seismic design model, to reduce the model size, the soil-structure interaction effect was taken into account by sway and rocking soil springs located at the bottom of the model and side soil springs at each floor level under the ground with linear viscous damping.

2) Parameters to be identified, denoted by x hereafter, are not modal parameters but physical parameters of the above analytical model, such as the rigidity and damping factor of the beam elements, floor springs and soil springs.

3) Evaluating function S(x) to be minimized is defined by the following function of the discrepancy between the observed response values E_{ij} and corresponding calculated values $Y_{ij}(x)$. Subscripts i and j denote the location in the building and the frequency, respectively.

$$S(x) = (1/2) \sum_i \sum_j W_j \| E_{ij} - Y_{ij}(x) \|^2$$

where W_j is the frequency weighting factor. In the concrete, E_{ij} denotes the complex displacement amplitude at the i-th measuring point under unit sinusoidal force with the j-th exciting frequency for identification using the forced vibration test results, and denotes the acceleration response spectra value for identification using earthquake records.

4) Two types of constraint condition can be considered. One is the grouping by which the parameters in a group are controlled to change by the same ratio. This is very useful for parameter groups having same characteristics from the technical viewpoint. The other is ranging by which the allowable range of individual parameters can be specified.

5) After this formulation of the problem, the evaluating function of S(x) is minimized by applying two common optimization methods. One is a combination of the Quasi-Newton Method and Line Search (QN method hereafter, ref.2). The other is the Random Search Method (ref.3). The QN method is very efficient when S(x) is smooth enough. However, the solution may not converge to the global minimum when S(x) has plural local minimums. On the other hand, the Random Search Method is of high performance for minimization problems containing local minimums. However, it is generally inferior to the QN method in terms of speed of convergence. Therefore, the following minimization procedure is adopted to make use of the advantage of the above two methods.

- Step 1 : The Random Search Method is applied to re-determine the initial values of x.
- Step 2 : Using the initial condition improved in step 1, the QN method is applied.

Differential derivatives (sensitivity coefficients) of S(x) with respect to x which are necessary in the QN method, were calculated numerically in this study.

4. IDENTIFICATION USING FORCED VIBRATION TEST

Firstly, the identification method was applied to the forced vibration test results. The rigidity and damping of all the elements representing the building structure and soil springs are chosen as the parameters x to be identified. Referred resonance curves for calculating the evaluating function are those observed at each floor of S/W, I/W ,O/W and the center of the roof. The frequency range of the resonance curves is limited to 1.0 Hz to 10.0Hz, which includes the major predominant frequencies of the building. The initial values of x for starting the minimization are determined as follows.

1) Stiffness of the building : The same shear area and moment of inertia as the seismic design model are assumed for the beam elements, but a concrete Young's modulus of 420 ton/cm^2 is adopted, being the average value obtained from the testing of the concrete test pieces.
2) Damping of the building : 5 % to critical damping at the fundamental frequency.
3) Soil springs : Stiffness of the bottom soil springs are obtained from rough evaluation of the test results. The side springs are evaluated as Novak's springs. Damping of all of the soil springs are 30 % to the critical damping at the fundamental frequency.

Constraint conditions were introduced using both ranging and grouping. The damping and stiffness parameters for the beam elements of the building are put into two group : those above the operating floor (4F-RF) and those under it (B2F-4F). To minimize the evaluating function, the above two methods were applied in series, while the number of iterations in the Random Search Method was limited to 200.

The typical parameter values identified are listed in Table 1. Typical resonance curves obtained from the vibration tests, initial model and identified model, are compared in Fig. 6. Figs.7 and 8 show the variation in the damping factor of the bottom sway spring and the evaluating function value against number of the iterations. These results can be summarized as follows.

a) The identified curves show fairly good agreement with the test results both in peak height and in position. The final value of the evaluating function is about 1/15 of the initial value.
b) The identified distribution of building stiffness shows that the lower portion of the building surrounded by many auxiliary walls has higher rigidity than assumed in the seismic design.
c) The identified damping values for the sway and rocking bottom soil springs are very high : 54 % and 38 % of the critical damping value, respectively. The damping values of the higher portion of the building and the roof are relatively low : 1.7 % and 3.0 %. This is thought to be due to the structural simplicity and the presence of steel components such as the roof truss beam.

5. IDENTIFICATION USING EARTHQUAKE RECORDS

Next, identification was carried out using the earthquake records. In this identification , the initial values of the parameters x were given by the foregoing identification results. The response of the building was calculated by inputting the acceleration time history observed on the basemat (B2F) to the model in which the horizontal soil springs were eliminated.

The identified parameter values obtained from the identification are listed in Table 1. Typical resonance spectra with the damping ratio of 5 % are shown in Fig.9. Fig.10 shows the evaluating function. The evaluating function decreases to about 80 % of the initial value and there is little improvement in the agreement of response spectra. The change in the value of the parameters is not large basically. This might be due to the reason that the initial values were provided by the identification results using the vibration test. A considerable change in the

Table 1 Identified Stiffness and Damping Parameters

Used Data	Soil Springs (Bottom)		Building		
Location	Sway ($\times 10^5$t/cm)	Rocking ($\times 10^{12}$tcm/rad)	B2F-4F	4F-Roof	Roof (t/cm)
Vibration Test	2.82 (h=54.4%)	5.01 (h=38.0%)	729* (h=7.7%)	389* (h=1.7%)	9360 (h=3.0%)
Earthquake Records	-	4.42 (h=30.5%)	723* (h=5.6%)	368* (h=5.4%)	9280 (h=3.4%)

*given by equivalent concrete Young's modulus (t/cm^2)

parameters of the structural damping is thought to be due to the difference of the type of excitation, excited modes and vibration level between the forced vibration test and the earthquake response.

6. CONCLUSION

By applying the newly developed system parameter identification method to both the forced vibration test and the earthquake records of the reactor building, the rigidity and damping of the building structure and soil springs were successfully identified. The developed identification method is very practical for this kind of identification and the minimization method of successively applying the Random Search Method and the Quasi-Newton Method is better than applying only one of them, as can be seen from the comparison made in a preliminary identification shown in Fig. 11.

The identification results using the earthquake records were almost the same as those using the vibration test results. The validity of the seismic design model and its evaluation method are confirmed because the identified stiffness and damping in this study are basically coincident with that of the seismic design model as follows. The stiffness of the building corresponds to that of the seismic design model if the auxiliary walls and actual concrete rigidity are taken into account. The damping of the building under the operating floor is 5 % or more, while that of the other portion including the roof is relatively low. The identified soil springs have high damping characteristics, which coincide with the estimation by the wave propagation theory.

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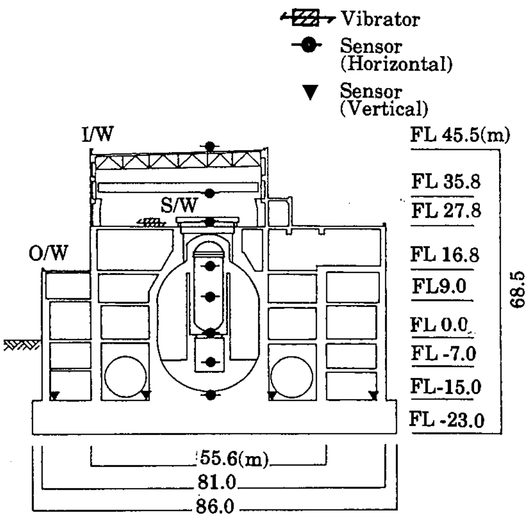
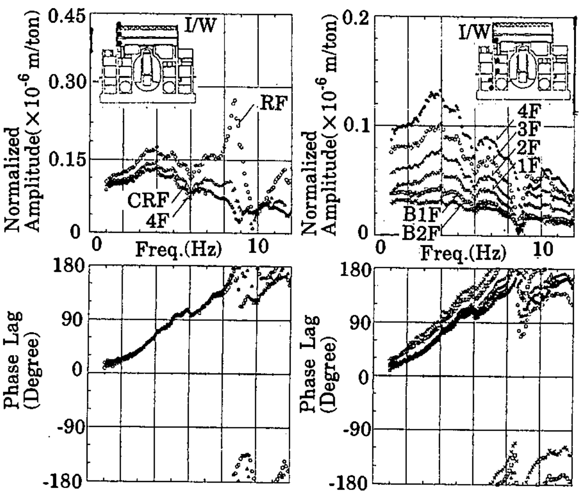


Fig.1 Cross Section of Reactor Building and Testing Arrangement for Vibration Test



(a) 4F-ROOF (b) B2F-4F

Fig.2 Resonance Curves obtained by Forced Vibration Test (NS direction)

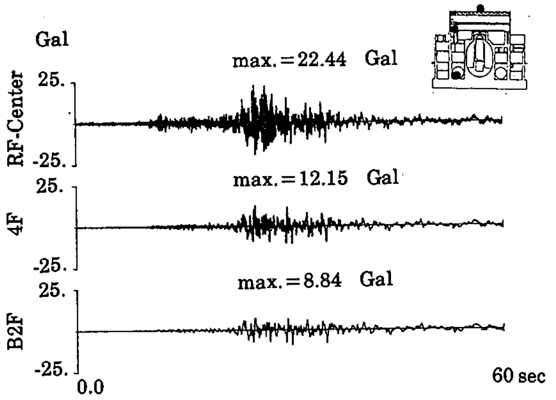
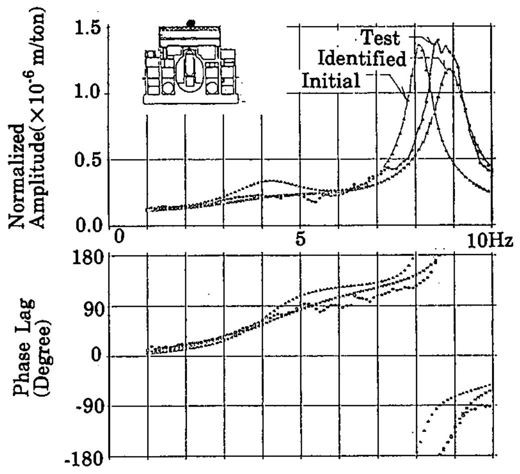
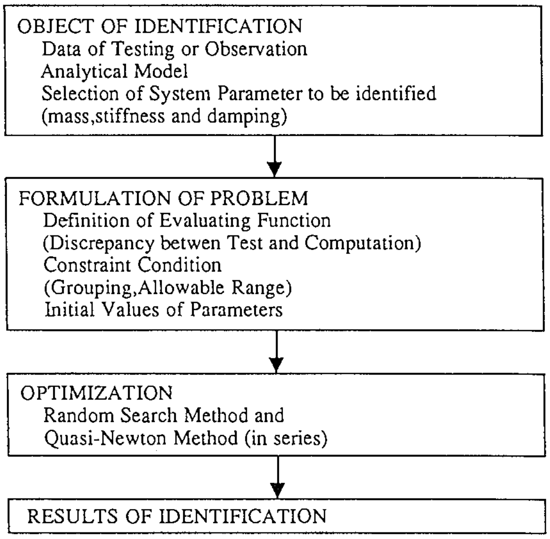


Fig.3 Observed Acceleration Time Histories (NS direction)



a) RF - Center



OBJECT OF IDENTIFICATION
Data of Testing or Observation
Analytical Model
Selection of System Parameter to be identified
(mass,stiffness and damping)

FORMULATION OF PROBLEM
Definition of Evaluating Function
(Discrepancy betwen Test and Computation)
Constraint Condition
(Grouping,Allowable Range)
Initial Values of Parameters

OPTIMIZATION
Random Search Method and
Quasi-Newton Method (in series)

RESULTS OF IDENTIFICATION

Fig.4 Flow of System Parameter Identification

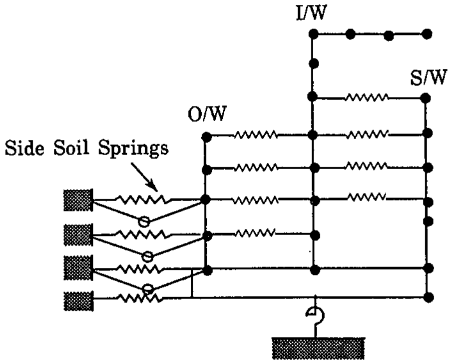
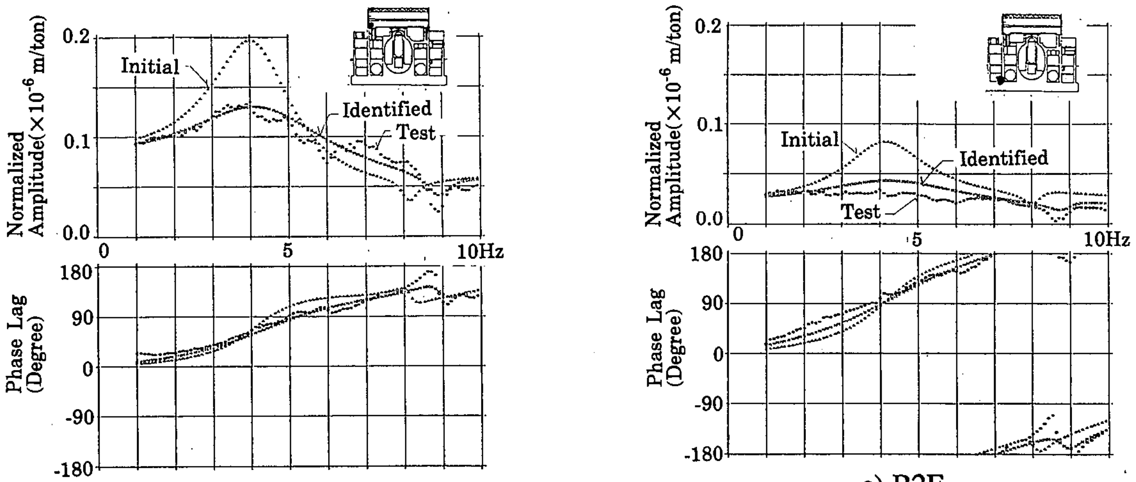


Fig.5 Rocking-Sway Model



b) I/W - 4F

c) B2F

Fig.6 Comparison of Resonance Curves

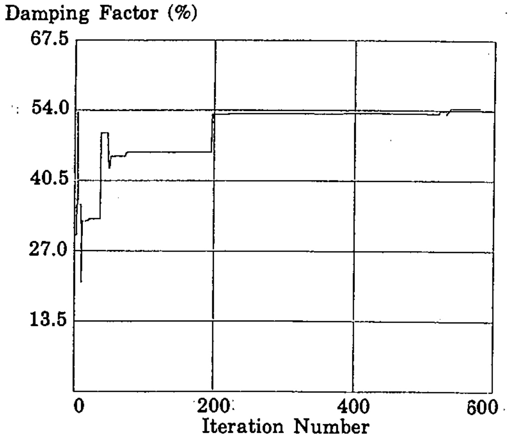


Fig.7 Variation of Damping Factor of Sway Spring (Vibration Test)

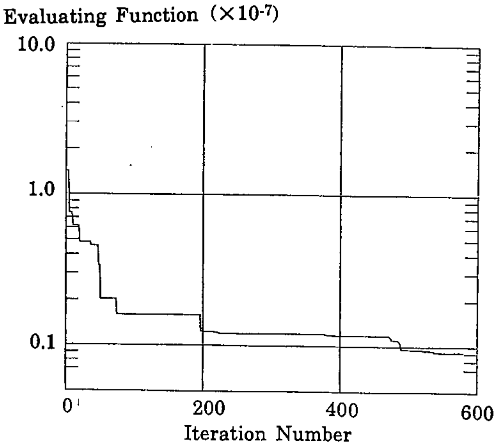
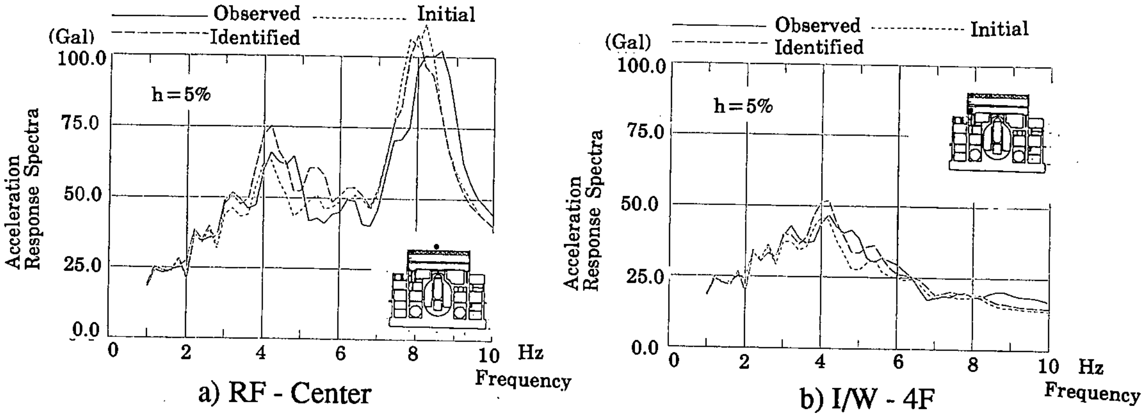


Fig.8 Decrease of Evaluating Function (Vibration Test)



a) RF - Center

b) I/W - 4F

Fig.9 Comparison of Response Spectra

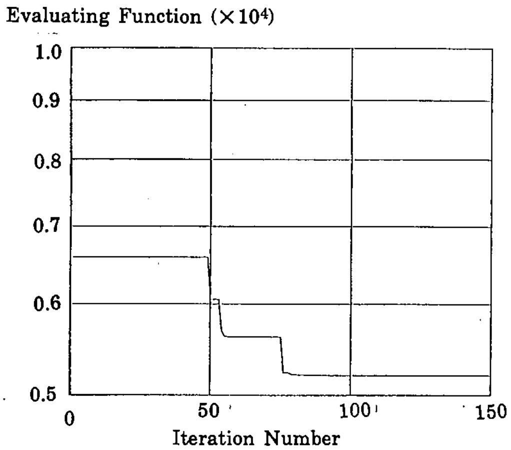


Fig.10 Decrease of Evaluating Function (Earthquake Observation)

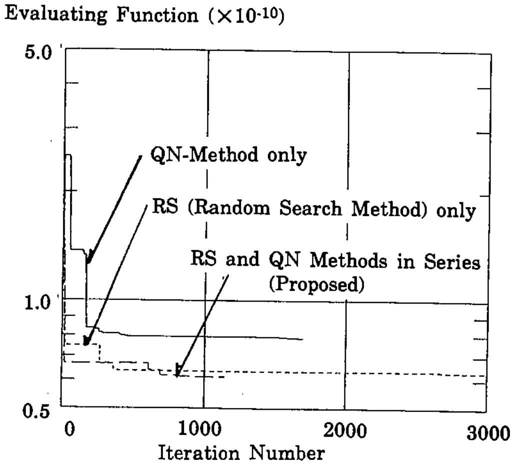


Fig.11 Comparison of Optimization Methods