A Study on Damping Characteristics of Equipments and Piping Systems for Nuclear Power Plant Facilities (Seismic Damping Ratio Evaluation Program)

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Summary:

Damping ratio is one of the most important parameters on seismic analysis of nuclear power plant facilities. As a current design criteria in Japan, the damping values derived from the early study of Dr. Housner are applied to piping system and equipment design. However, these values are sometimes considered too conservative compared to actual structural conditions. These damping values may be even lower than those specified by Regulatory Guide 1.61 as already described in SMiRT-5. A study group was constituted to conduct the study entitled Seismic Damping Ratio Evaluation Program to clarify damping characteristics and mechanism of piping systems in nuclear power plants, and to establish more rational design damping ratios. This program is divided into three phases.

Phase I was composed of a survey of damping values of literature and statistical analysis of damping data derived from pre-operating vibration tests of piping systems at the nuclear power plant sites in Japan. The summary of the results was reported in K 11/3 of SMiRT-5. In Phase II, systematic piping vibration tests were conducted to provide data for assesing damping characteristics of piping systems at high response amplitude of design earthquakes and to explore factors which may contribute to damping characteristics. In Phase III, a methodology was explored to analyze damping characteristics and to estimate damping ratios of piping systems with various support and boundary conditions.

At present, a reasonable approach for assessing more rational damping values was established. In near future, more rational damping ratios will be assessed for each category of piping systems as recommendation for licensing issues.

1. Introduction

Damping ratio is one of the most important parameters on seismic analysis of nuclear power plant facilities. As a current design criteria in Japan, the damping values derived from the early study of Dr. Housner are applied to piping system and equipment design. However, these values are sometimes considered to conservative compared to actual structural conditions. These damping values may be even lower than those specified by Regulatory Guide 1.61 as already described in SMiRT-5. A study group was constituted to conduct the study entitled Seismic Damping Ratio Evaluation Program to clarify damping characteristics and mechanism of piping systems in nuclear power plants, and to establish more rational design damping ratios. This program is divided into three phases as shown in Fig. 1.

Phase I was composed of a survey of damping values of literature and statistical analysis of damping data derived from pre-operating vibration tests of piping systems at the nuclear power plant site in Japan. The summary of the results was reported in K 11/3 of SMiRT-5. In Phase II, systematic piping vibration tests were conducted to provide data for assessing damping characteristics of piping systems at high response amplitude of design earthquake and to explore factors which may contribute to damping characteristics. In Phase III, a methodology was explored to analyze damping characteristics and to estimate damping ratios of piping systems with various support and boundary conditions.

In paragraph 2, interim results of Phase III Task are described. A brief description of scale model tests with pipe size 8B and 10B performed by Mitsubishi Takasago Institute is presented in paragraph 3 as an example of Phase II Task, and the results of the other piping vibration tests carried out by the other industries are presented in the related papers K6/4 and K6/5 of SMiRT-6.

2. Analysis and Evaluation of Rational Damping Ratio

2.1 Methodology of evaluation

In order to implement the final objective for assessing more rational design damping values, following procedures were applied.

(1) Examination of damping values by vibration tests of piping systems excited at high response level corresponding to the design earthquake.

(2) Development of damping evaluation program of actual piping systmes by the analyses of the test results of large piping systems and in conjunction with the results of damping characteristics tests of component systems.

(3) Numerical survey of damping values for piping systems with many types of support conditions by the above program, and evaluation to determine definite values for recommendation.

2.2 Damping Characteristics of Piping Systems at High Response Amplitude

Scale model tests of large piping systems at high response amplitude have been performed to clarify damping characteristics of actual piping systems. Through these examinations, it was confirmed that damping values are higher than those of current design practice at the response amplitude of design earthquake. For instance, as a results of 10B and 8B scale model tests in Fig. 5 conducted by Mitsubishi Takasago Institute, the detail is described in paragraph 3, damping ratios as a function of response amplitude are presented in Fig. 6 and Fig. 7. These properties are caused by energy dissipation mechanism with viscosity, friction and impact at supports.

This results made it possible to develop damping ratio evaluation program in conjunction with the test results of component damping characteristics.

2.3 Development of Damping Ratio Evaluation Program

2.3.1 Basic equations

According to the analyses of damping characteristics for experimental data derived from systematic vibration tests, a modal damping ratio of integrated piping systems will be estimated.

The modal damping ratio h_e^i is defind as a ratio between energy dissipation of component and **total strain** energy by eq. (1):

$$h_e^i = \frac{1}{4\pi} \cdot \frac{1}{E_i} \sum_j \Delta E_j^i \qquad (1)$$

where, h_e^i : modal damping ratio for mode i, E_i : **total strain** energy for mode i, ΔE_j^i : energy dissipation from support point j for mode i.

This procedure is presented schematically in Fig. 2.

2.3.2 Derivation of dissipation energy of components

Damping properties provided by hangers, oil snubbers, insulations and other components are divided into a few types of energy disipation mechanism. Energy dissipations produced by these components have been able to be evaluated.

For instance:

(a) Hanger

Damping provided by hanger or guide restraint reveals a typical coulomb damping characteristics. The dissipation energy ΔE is estimated in terms of friction force F.

(b) Rod Restraint and Oil Snubber

Damping provided by rod restraint or oil snubber is composed of viscosity, friction and impact. Equivalent damping coefficient C and stiffness K were derived from test results.

(c) Insulation of Calcium Silicate

This type of energy dissipation is caused mainly by impact damping in the boundary between insulation and piping. Damping effect is estimated as additional damping ratio to system damping ratio for each mode based on test results.

Moreover, damping effect of piping material is negligible and added damping does not exist for a piping by filling with internal fluid.

2.4 Evaluation of damping values for design

To demonstrate the damping effect contributed to a piping system by parameters of support conditions, and also to verify the prediction capability of eq. (1), numerical survey of an example of piping system models is performed. The model of 3B piping system and damping ratios as a function of response amplitude are presented in Fig. 3.

Two oil snubbers are installed to the piping system, and internal fluid and insulation are not considered. Generally good agreement is observed between the results of eq. (1) and measured values.

Subsequently numerical survey of damping values for piping system with variable conditions is proceeded. Last of all, more rational design criteria of damping ratios will be established for each category of piping systems.

Furthermore, it should be noted that extra margins of damping produced by following phenomena are implied in actual piping systems.

° Damping characteristics provided by material nonlinear behavior.

° Nonlinear damping effects caused by impact or banging in large gaps of supports.

° Energy dissipation by coupling effect between piping systems and large equipments.

And concerning current design of support components and boundary elements such as snubbers, hangers and insulations, intentional damping effects provided by damping promoting mechanisms are not considered. These component systems involving intentional energy absorption mechanism should be accepted for licensing issues in future.

3. Vibration test of scale piping models by Mitsubishi

On the vibration tests of phase II, MHI has been in charge of the investigation of damping effects due to seismic restraints, then the following tests were carried out.

i) Damping characteristics test of oil snubbers and rod restraints that are typical seismic restraints.

ii) Simplified piping model test, which supported by oil snubbers and rod restraints

iii) Scale model test of nuclear power piping systems

Items i) and ii) of these are the fundamental tests to support item iii). In this paragraph, the results of the scale model test of final step are shown.

3.1 Test models and test conditions

The test models are two ones shown in Figure 5, and are simulated of actual piping systems. The piping systems are so different in their constructed components due to design temperature condition and etc., that the tests combined following components were carried out.

° Seismic restrains ° Internal fluid ° Insulation

Where, the seismic restraints are of three types shown in Figure 5. Among them, the joints of the rod restraints and oil snubbers have gaps of approximately 1.0mm respectively. And, for the guide restriants restraining vertical movements, the piping weight is added, and from this also for the horizontal direction, the restriction forces due to friction are added.

The test conditions that combined the above mentioned components are summarized in Table I. Where, the supporting conditions of cases 1 and 2 simulate cold piping systems, and ones of cases 3 through 5 do hot piping systems.

3.2 Test procedure

The models were set up as shown in Figure 4, and were excited by the following two methods.

i) Sinusoidaly forced vibration

The models were excited by a hydraulic shaker, and the resonance curves and vibration modes were measured. And, after holding the models in a resonant condition, they were released to freely vibrate by stopping the shaker's operation. Then, the shaker was removed from the models as soon as its operation was stopped.

ii) Free vibration by wire cutting

The models were pulled by a wire. After the desired initial displacement was given, the models were released to freely vibrate by cutting the wire.

At the tests, the vibration characteristics of 1st-3rd modes under various loadings were measured, and the damping were obtained from the amplitude records of free vibration using the logarithmic decrement method.

3.3 Test results

As a part of the test results, the measured damping plotted versus response amplitudes are shown in Figures 6 and 7. At the low amplitude, the damping values are scattered and increased with the amplitude, and reach their peaks at the amplitude of nearly 1mm. Moreover, when the amplitude becomes larger, the damping values are stable and decreased with the amplitude.

This tendency is considered as follows:

Piping systems impact and slide at their supports, and energy dissipation in this manner is highest at the amplitude in the range of a gap at supports (0.8 - 1.0mm). However, at lower amplitude, impact and sliding behavior is so weak and unstable that the damping values are lower and scattered. And, at higher amplitude than the range of the gap, damping effects due to such behavior are gradually decreased with amplitude.

Comparing the damping values of the three cases, case 2 shows the largest values. This suggests that the energy dissipation in sliding would greatly contribute to the damping. Whiles, in cases 1, the piping is supported by rod restraints alone which give the low damping effect, and it shows the low values compares with cases 2 and 5.

4. Conclusion

This paper presents the status of Seismic Damping Ratio Evaluation Program.

The interim results of the program are summarized as follows:

(1) Vibration tests of large piping systems have been performed. Through these examinations, it was confirmed that damping values are higher than those of current design practice at the response amplitude of design earthquake. This property is considered to be caused by the energy dissipation mechanism with viscosity, friction and impact at supports.

(2) A methodology to evaluate damping values for actual piping systems was developed based on the test results of large piping systems or in conjunction with the results of damping properties of component systems.

(3) In near future, more rational damping ratios will be assessed for each category of piping systems as recommendation for licensing issues.

References

[1] Shibata, H, et al, "Investigation on the Design Damping Values for Seismic Analysis of Nuclear Power Plant Systems", Fifth International Conference on Structural Mechanics in Reactor Technology, Berlin, West Germany, August 13 - 17, 1979, Paper K 11/3.

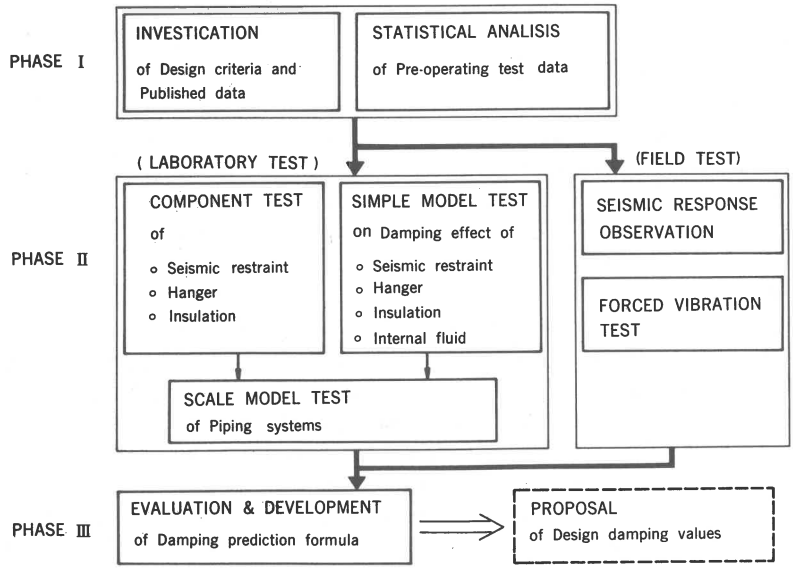

Fig.1 Study Program on Damping of Piping Systems

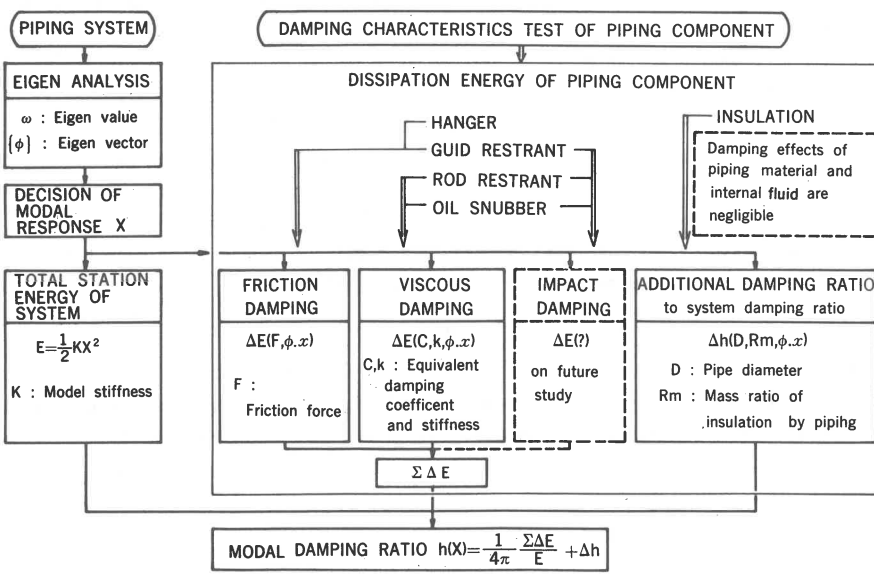

Fig.2 Schematic diagram for the evaluation of system damping

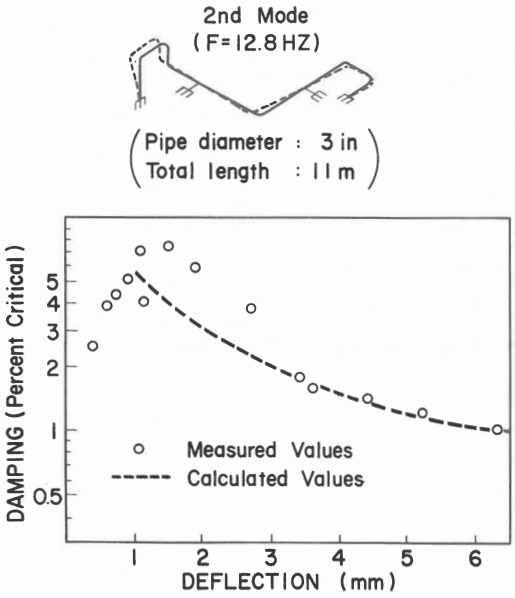

Fig.3 Damping of Simple Piping Model Supported by Oil Snubbers

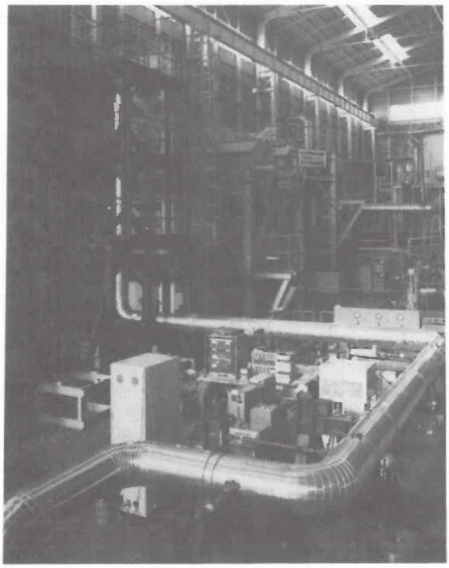

Fig.4 Set-uped A MODEL

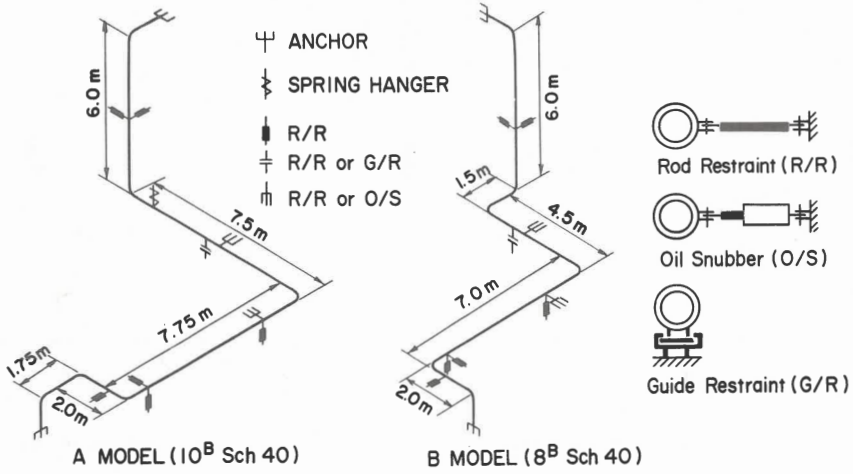

Fig.5 Outline of Scale Piping Models

Table 1 Test Condition of Scale Piping Models

TEST No.	SUPPORT CONDITION (R/R)	(G/R)	(O/S)	INTERNAL FLUID	INSULATION	1st FREQUENCY** A MODEL	B MODEL
CASE 1	9	—	—	—	—	14.9 HZ	14.9 HZ
CASE 2	8	1	—	—	—	14.9	14.9
CASE 3	7	—	2	—	—	14.9	14.9
CASE 4	7	—	2	Included	—	11.2	11.3
CASE 5	7	—	2	Included	Attached	10.3	10.1

* R/R : Rod restraint
G/R : Guide restraint
O/S : Oil snubber

** Calculated frequency of 1st mode

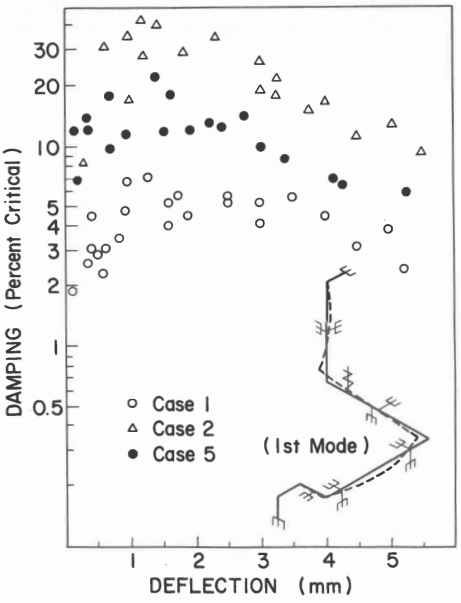

Fig.6 Modal Damping Versus Amplitude of A MODEL

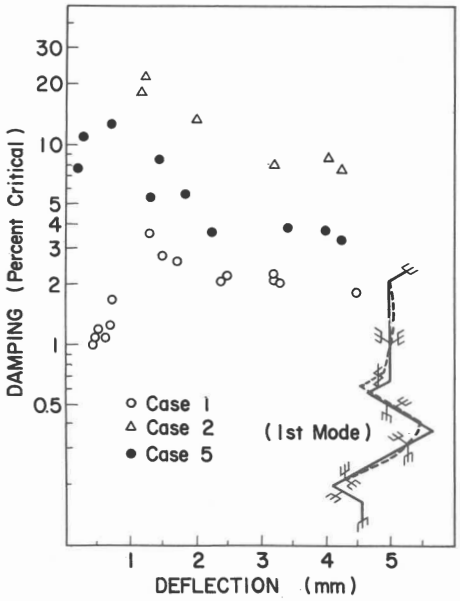

Fig.7 Modal Damping Versus Amplitude of B MODEL