Seismic proving test of BWR primary loop recirculation system

H.Sato
University of Tokyo, Japan
M.Shigeta
Mechanical Engineering Laboratory, Hitachi Ltd, Japan
Y.Karasawa
Nuclear Power Engineering Test Center, Japan

1. INTRODUCTION

The seismic proving test of BWR Primary Loop Recirculation system is the second test to use the large-scale, high-performance vibration table of Tadotsu Engineering Laboratory. The purpose of the test is prove the seismic reliability of the primary loop recirculation system (hereinafter abbreviated as PLR), one of the most important safety components in the BWR nuclear plants, and also to confirm the adequacy of seismic analysis method used in the current seismic design. To achieve the purpose, the test was conducted under conditions as near as possible to those for the actual systems using a test model of full scale with the structure as close as possible to that of the actual plants.

From August 1983 to June 1984, the strength proving test was carried out with the test model mounted on the vibration table in consideration of basic design earthquake ground motions and other conditions to confirm the soundness of structure and the strength against earthquakes.

Till March 1985 detailed analysis and analytic evaluation of the data obtained from the test was conducted to confirm the adequacy of the seismic analysis method and earthquake response analysis method used in the current seismic design. Then, on the basis of the results obtained, the seismic safety and reliability of BWR primary loop recirculation of the actual plants was fully evaluated.

This proving test was supported by the test executive committee and following members are the major contributors.

Shunsuke Otani	University of Tokyo, Japan
Kohei Suzuki	The University of Tokyo Metropolitan, Japan
Tetsuo Kubo	Nagoya Institute of Technology, Japan

2. TEST COMPONENTS AND CONDITIONS

2.1 Test Model

The test model is a full-scale mimic of one of the two PLR systems for the improved and standardized 1100 MWe BWR plant for high seismic zone. It consists of one test loop (including two partition valves, one recirculation pump, one motor and support) and its support structure (a mimic of the reactor pressure vessel and the gamma ray shield which supports the piping, pipe support frame).

The schematic illustration of the test model is shown in Figure 1.

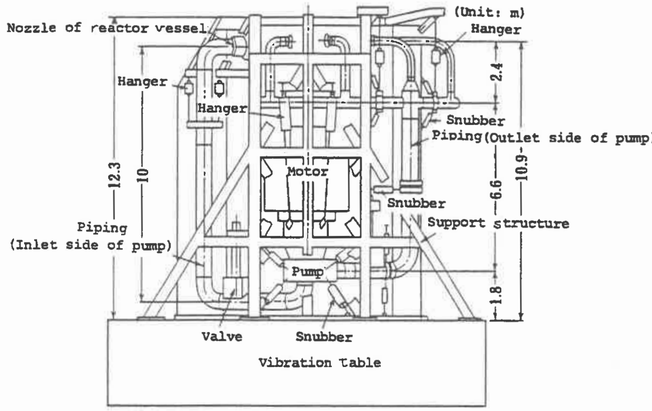

Figure 1 Schematic Illustration of Test Model

2.2 Test Conditions

2.2.1 Seismic Waves for Proving Test

The floor response waves at the pedestal top of the reactor pressure vessel were obtained using the analysis model for reactor building of standard BWR plant with applying S_1 and S_2 waves, which had been improved and standardized by MITI (Ministry of International Trade and Industry) for high seismic zones, and this was compared with the earthquake response wave used in the actual plant design. Then, the seismic waves were selected in such a way that the severest test results could be obtained.

The conditions for the seismic waves are shown in Table 1.

Table 1 Seismic Wave for Proving Test

Seismic wave	Duration Time [sec]	Excitation direction	Maximum Acceleration [Gal]
Floor response wave S_1	25	Horizontal and Vertical	Horizontal: 1097 Vertical : 197
Floor response wave S_2	20	Horizontal and Vertical	Horizontal: 2038 Vertical : 358

2.2.2 Excitation Direction

The test model was excited vertically and horizontally at the same time. The horizontal direction was determined to be rotated 45° from the actual system, in such a way that the severest seismic response could be yielded for the piping.

2.2.3 Conditions of Pressure and Temperature

The pipe was filled with water of room temperature and the excitation was conducted for the piping system under the pressurized condition of 70.7 kg/cm^2g, which was equivalent to the operational pressure of the actual plant.

3. TEST ITEMS

To achieve the test purpose, a variety of tests were conducted according to the predetermined procedures.

3.1 Preliminary Tests

3.1.1 Excitation of Support Structure

Prior to the demonstration test, the sinusoidal wave vibration test, the periodic random wave vibration test and the seismic response wave test were conducted for the support structure without pipe, pump and valves to confirm the basic characteristics of the vibration table and the vibration and response characteristics of the support structure.

3.1.2 Functional Test

After installation of the piping system, the installation conditions were checked and overpressure test (water pressure of 128 kg/cm^2g), the static force exerting test and vibration performance test (sinusoidal wave vibration, frequency random wave vibration) were carried out to confirm the performance of the test model including the instrumentation system.

3.1.3 Vibration Characteristics Test

The sinusoidal wave vibration test, the free vibration test and the frequency random vibration test were carried out to obtain the vibration characteristics of the test model.

3.2 Verification Test on Design Analysis Method

In order to obtain data required for verification of the adequacy of the design analysis method, the vibration test with the seismic waves for seismic proving test of a reduced acceleration level, and the vibration test with the seismic response waves of a well-known seismic wave (EL CENTRO) were conducted.

3.3 Strength Proving Test

In order to prove the seismic strength of the test model, vibration tests were conducted with the seismic wave of S_1 and S_2.

3.4 Marginal Vibration Test

In order to obtain data required for evaluation of the design strength margin of the test model, marginal excitation was conducted in view of the vibration table performance, using the seismic waves of S_2 for the strength proving test with increased acceleration level.

4. RESULTS OF SEISMIC PROVING TEST

4.1 Strength Proving Test

4.1.1 Accuracy of Seismic Waves

In the strength proving test with the seismic waves S_1 and S_2, the target waves to the test model (PLR piping system) were satisfactorily reproduced. As for pitching, sufficiently small valves (within 10%) were obtained in the range which the major frequency values of the test model vibration (0.07 to 0.3 second). The desired vibration was consequently achieved.

4.1.2 Response of Test Model

Distribution of the maximum response acceleration in the test model and time dependence of wave forms at the major points in the test model for S_2 wave are shown in Figure 2, Figure 3 and Figure 4 respectively. According to these test results, the response at the points around pump and motor was larger than expected, but resulted stress at each point remained sufficiently small (7.8 kg/mm^2 or less).

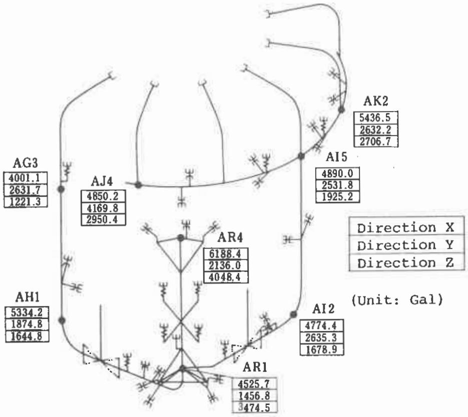

Figure 2 Distribution of Maximum Acceleration in S_2(H+V) Seismic Response Wave Vibration

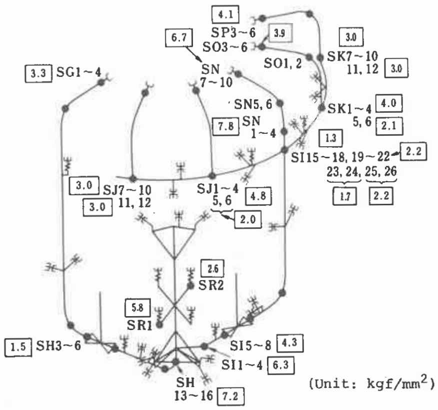

Figure 3 Distribution of Maximum Stress in S_2(H+V) Seismic Response Wave Vibration

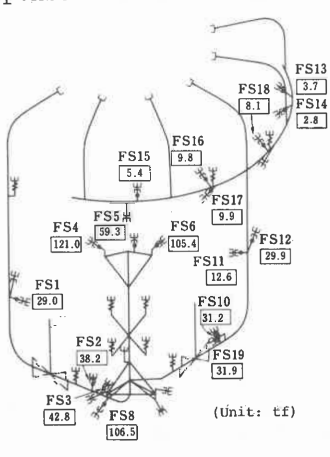

Figure 4 Distribution of Maximum Reaction Force in S_2(H+V) Seismic Response Wave Vibration

4.1.3 Inspection before and after Vibration Test

Before and after the test, measurement of residual stress and relative displacement in the static condition, visual check and measurement of clamping force of the bolts were performed to confirm structural integrity and leak tightness of inner fluid. As for the frequency characteristics, moreover, the sinusoidal wave sweep test was conducted before and after the strength proving test to confirm that the characteristic frequency and the response magnification had not been affected.

4.2 Marginal Vibration Test

In order to confirm the seismic margin, the piping was excited under the pressurized condition with the marginal seismic wave of maximum acceleration of horizontal 2617 Gal and vertical 377 Gal almost to the vibration table performance limit, in which acceleration was made 10% larger than that of S_2 seismic wave for the seismic proving test. In this test, the response of the support structure showed good agreement with the target wave and the pitching was kept in a sufficient low level. However, the response data (acceleration stress and reaction force) of the PLR test model in excitation and the results of inspections before and after excitation did not show any abnormality in strength and in performance. Figure 5, Figure 6 and Figure 7 show dependence of the response acceleration, stress and reaction force at one of the major points of the test model on excitation level of S_2 seismic response wave. These showed overall approximate linearity of acceleration, stress and reaction force, respectively, and proved that the test model, as a whole, showed linear behavior even for such a high seismic level.

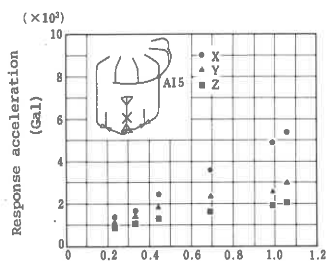

Figure 5 Response Acceleration/Response Spectrum Ratio for S_2 Wave

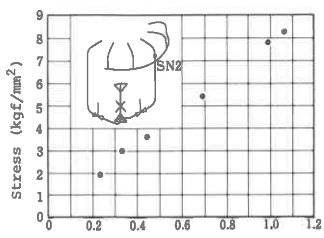

Figure 6 Response Stress/Response Spectrum Ratio for S_2 Wave

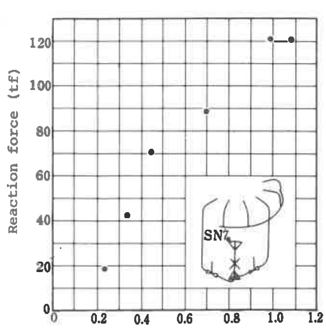

Figure 7 Support Response Reaction Force/Response Spectrum Ratio for S_2 Wave

5. EVALUATION OF DESIGN ANALYSIS METHOD

At each stage of the design analysis method verification test, the strength proving test, etc. in the present seismic proving test, various verification data was obtained to confirm adequacy of the seismic analysis method used in the actual design. Simulation analysis was conducted to clarify the difference between the values obtained in the test and the design values and an adequate numerical analysis model was formed to simulate nearly all the test results, except some special data, for the purpose of design analysis code verification.

6. SEISMIC ANALYSIS OF ACTUAL SYSTEM

Adequacy of the present design method and the analysis models was confirmed from the results of a variety of analysis and evaluation. On the basis of these results, the soundness of the actual PLR system was evaluated, by conducting S_1 and S_2 seismic response analysis for the actual system design model (separated piping model), in which conditions for simulation of the test model components such as supports were reflected and also by combining other loads which should be applied in design.

7. SUMMARY

The results of the seismic reliability proving test can be summarized as follows.

7.1 Evaluation of Test Results

The test model, which was manufactured according to the same seismic design analysis method as the actual system, showed sufficient margin in strength and the functional soundness was confirmed to be kept against the basic design earthquake ground motions (S_1 and S_2), which simulated the severest motion among the input conditions. Sufficient margins were also confirmed for severer earthquake than the designed earthquake motions.

7.2 Evaluation of Verification on Design Analysis Method

The designed values (acceleration, support reaction force, pipe stress) based on the present design analysis method were compared with the measured values. It was confirmed that the designed values lay on the safety side of the measured values. The designed conditions were well examined to prove adequacy of the present design analysis method. It was also confirmed that the vibration behavior of the test model could be reproduced with the numerical analysis model. Thus, adequacy of the present analysis code was evaluated and data could be obtained to be used for future improvement of seismic technology for PLR system, e.g. the method of pipe support arrangement.

7.3 Seismic Evaluation of Actual System

In accordance with the knowledge obtained from the test results, stress evaluation was made for the actual system, combining loads other than earthquake as well as seismic response analysis and seismic reliability of the actual primary loop recirculation system was confirmed.