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Seismic proving tests for nuclear power plant no. 1

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ABSTRACT: For the construction of the public consensus, it has been planned that very important functions for the seismic reliability among the equipment of Japanese standardized 1100 MWe Nuclear Power Plant were selected and conducted the seismic proving tests. The test projects of first phase were selected to the four key components for PWR and BWR(total test objects are eight), respectively, which are Containment Vessel, Pressure Vessel, Primary Coolant Loop System and Reactor Core Internals. It was strongly recognized that the strength and functions of the key components were maintained with sufficient margin to the design earthquake motions, and the current design method used to secure the seismic safety give a conservative results through this projects.

1 INTRODUCTION

After the 1973 oil crisis, in which fossil fuels from the oil production countries were cut off, the Japanese Government aggressively promoted the construction of nuclear power plants (NPP) in order to secure a stable supply of electric energy in Japan. To set up nuclear power in Japan smoothly, it has been necessary to obtain nation wide consensus concerning the safety of NPP, based on a firm scientific understanding of earthquake engineering.

To achieve this public consensus equipment from the standard Japanese 1100 MWe NPP was selected and proving tests were carried out. It was required that the test equipment have a containment function of the first boundary during and after an earthquake, and that the size of the test equipment be the same or as near as possible to the actual equipment.

The four key components from PWR and BWR; containment vessel, pressure vessel, primary coolant loop system and reactor core internals (two each for a total of eight pieces of equipment in all), were selected as the equipment to be testes in the first phase.

In order to carry out these tests, a large-scale high-performance shaking table with a 1000 ton load capacity, was constructed at Tadotsu Engineering Laboratory (NUPEC) on Shikoku island in 1982. Seismic proving tests started in 1982 and finished at the end of March 1989. During the last three years the test results and evaluation of the seismic reliability of actual NPP was reviewed.

It was found that the strength and functions of the key components of NPP in Japan were maintained with a sufficient margin of safety when subjected to the design earthquake motion (S_1 and S_2), and the current design method gives conservative results throughout these test projects. It is expected that these results will be put to practical use in the development of advanced seismic technology, and the re-arrangement of the seismic design and analysis code and guidelines.

The second phase of the seismic proving tests is now under way. Scheduled to be tested are the emergency diesel generator system, computer system, reactor shutdown cooling system, the main steam and feedwater system and reinforced concrete pressure vessel.

2 DETAILS CIRCUMSTANCES ON THE SEISMIC PROVING TESTS FOR NPP

1) Ever since the 1973 oil shock, Japan, which is highly dependent on foreign energy resources, has strongly promoted the use of nuclear energy as part of a policy geared towards guaranteeing a stable supply of energy.

2) In 1973, three laws were enacted based on this experience, one relating to the use of land surrounding the facility, another relating to the electric development tax law and one relating to the Special Account for Power Resource Development.

3) Nevertheless, because atomic power generation is so technologically advanced and

its operating priciples so complicated, people are generally left with a persistent feeling of apprehension. This is especially true in an earthquake-prone country like Japan where an NPP's resistance to earthquakes is of central concern. Public apprehension has been that some anti-nuclear energy groups have even staged attacks on nuclear facilities.

4) In order to reduce public apprehension and promote the construction of NPP, it was considered prudent to conduct"seismic proving tests" on duplicates of a nuclear power plant's key components and equipments. Employing a large-scale, high-performance shaking table as an earthquake simulator the duplicates were subjected to vibrations in excess of those that occur during an actual earthquake. These experiments were designed with the conviction that actual test results would verify that NPP can withstand any earthquake which might occur in Japan.

5) In 1975, funding for the construction of the earthquake simulator and the duplicates was appropriated from the Special Account for Power Resource Development which is a special endowment for the development of electric power under the provisions of the three laws promoting the development of electric power resources.

6) Both the public and private sectors were involved in the construction, the government contributing half of the costs in the form of a grant and a group from the private sector consisting of electric power companies, heavy electric equipment makers and construction companies contributing the test. The specifications, construction schedule and other plans were the result of a study by academic, government and private enterprise.

7) The crucial equipment incorporated in standard Japanese 1100 MWe PWR and BWR power plants were selected for testing. These were the reactor containment vessel, the primary coolant loop systems, the reactor core internals and the reactor pressure vessels.

8) After careful consideration of the dimensions and weight of the test objects, costs and the level of technology at the time, it was determined that the earthquake simulator be designed to handle a 1000 ton load and be capable of exerting an excitation force of 3000 tons.

9) The Nuclear Power Engineering Center (NUPEC) was established in 1976 and the seaside town of Tadotsu was chosen as the site for the earthquake simulator due to its convenient location. The construction of the large-scale high-performance shaking table was completed in July 1982.

10) The seismic proving test of NPPs were funded by Ministry of International Trade and Industry (MITI) beginning in 1980 and the planning, design and construction of the test specimens commenced in the same year. Tests commenced as soon as the facilities were completed and have continued up to the present.

3 EARTHQUAKE SIMULATOR

An outline of the shaking table facility at Tadostu is given below. (Please refer to the following Figs. 1 - 3 and Table 1)

Performance and specification

Table size	15m X 15m	
Max. lording capacity	1,000 t	
Excitation directions	Horizontal and Vertical axis (Simultaneously)	
Max. displacement	Horizontal	200mm
	Vertical	100mm
Max. acceleration	Horizontal	2.72G
	Vertical	1.36G
	(with 500 t load)	
Max. excitation	Horizontal	3,000 tf
	Vertical	3,300 tf

The table can create a artificial earthquake by oil pressure-driven horizontal and vertical exciters. The oil pressure, generated by the oil pumps, is channelled to the exciters at the time of testing after being accumulated in the accumulators.

The measurement and data processing system can measure a test model on the shaking table up to 300 points simultaneously with a computer by sampling them at a speed of up to 1 ms and can record the data up to 180 seconds.

4 BASIC POLICY ON SEISMIC PROVING TESTS (GENERAL)

4.1 The objective of the seismic proving tests

The objective of the proving tests is to obtain seismic response data on test models subjected to basic earthquake ground motions S_1 and S_2. The test models were designed and constructed based on the perspective that this criteria is a key component in the verification of seismic reliability. From this data, it was hoped that results would show conformance to the following three items: (1) Structural strength, (2) Functional maintenance and (3) Adequacy of the method used in analysing seismic design and response.

The results proved the safety and reliability of NPPs under the simulated earthquake criteria S_1 and S_2; that is: NPPs do not lose coolants during accidents, NPPs can be shut down and contained and NPP equipment functions effectively and prevents dispersal of radioactive materials even if a coolant loss should occur.

4.2 Selection of test model

In NPPs, in order to avoid radiation contamination of the surrounding environment caused by the damages to the plant equipment, seismic design is carried out according to the seismic classification (class As, A, B and C). A class As facility, the most important from the standpoint of safety against earthquakes, must satisfy the following requirements: operation without coolant loss during accidents, capability of the reactor to be shut down and stabilized, and regular maintenance of the reactor containment vessel. With consideration given to the tests described, the test equipment and the criteria for which the seismic test equipment was constructed, suitable components were selected to represent a standard 1100 MWe power plant. These components pertain to the reactor containment vessels, primary cooling systems, reactor core internals and reactor pressure vessels in both PWR and BWR systems. Fig. 4 shows a layout of this equipment in an NPP, and Table 2 lists the required functions of this equipment under earthquake conditions.

This equipment should be thought of as one dynamic system whose components dynamically interact with each other, and not as separate systems. This dynamic interaction of equipment can be analysed by using a complex model to clarify the process. Therefore, it is not difficult to carry out these tests using these test models independently and thereby prove the equipment's validity. Moreover, model of full scale or close to full scale were selected and manufactured by the same method and under the same quality control as those of actual plants in order to arrive at dependable estimations of actual nuclear reactor components.

4.3 Vibration test methods

To validate the structural strength of NPP equipment, maintenance of functions, and verification of the method used in design analysis, the following tests were conducted. Simulated earthquake waves were modified with respect to time and intensity so that the stress induced on the test model replicated the stress occurring on actual equipment.

1) Sinusoidal vibration test

The test models were excited with sinusoidal waves on the shaking table. The data proved that this dynamic analysis model of the equipment was appropriate.

2) Earthquake vibration test

The test models were excited with simulated earthquake waves (S_1 and S_2) and the structural strength and maintenance of functions were proved. The data were compared with the analytical results obtained from the current seismic design analysis and the seismic design method was proved to be appropriate. The equipment of an actual NPP also proved reliable by the same design analysis, and its structural strength and maintenance of functions were evaluated.

3) Marginal vibration test

The test models were vibrated with an higher intensity of S_2 waves that exceeded the level of designed intensity for this equipment, showing that a safety margin exists.

4.4 Evaluations

1) Evaluation of seismic safety, reliability and maintenance of function

Based on the test data, the structural strength and maintenance of the test functions for the test models were proved.

2) Verification of design analysis method

Based on the test results obtained from the test data analysis, the following were carried out:

a) The test data was compared with the analytical results obtained from the current design analysis method, and it was clarified that the findings were statistically conservative. From these results, it was proved that the current design analysis is appropriate for seismic design of NPPs.

b) If there were any differences between the test results and analytical results, the reasons for variance were determined and the current design method was improved.

c) Based on this limited test data, the structural strength and maintenance of the functions were proved.

3) Evaluation of actual plant equipment

Based on the evaluations described above and considering other conditions not given in the proving tests or which could not be considered at the time of testing, the safety and reliability of an actual plant to seismic disturbances were evaluated.

4) Comprehensive assessment of the seismic reliability

After the tests were finished, the results of tests and related analysis for the eight key components were carefully reviewed and necessary additional investigation and analysis were carried out for the following items;

a) Reevaluation of design earthquake motion S_1 and S_2 based on the more appropriate techniques considering with the structure, foundation-soil interaction, and correlation study between this results and the earthquake motion for the tests.

b) Evaluation of safety margin of actual components in strength and in function during and after earthquake.

c) Evaluation of the applicability of the test results to actual plant components which were not directly tested.

d) Clarification of the necessity of future works.

5 RESULTS

The detailed test and evaluation results are described in the papers of No. 2 and No. 3 of this series. Here, the main results through this test projects are described as follows;

1) The structural strength of the containment vessel was proved to be safe under very severe input conditions.

2) As for the reactor core internals, the scramability function of the control rod was confirmed under the design earthquake input or more severe input conditions.

3) The structural strength of the primary coolant loop system was proved to be safe under severe input conditions.

4) The structural strength of the reactor pressure vessel was proved to be safe under severe input conditions.

6 CONCLUSIONS

Following conclusions were obtained from the reviews and reevaluations.

1) The seismic reliability of the every types of actual NPPs in Japan are proved through the tests and the evaluation works.

2) The design earthquake motions based on the more appropriate techniques are given safer responses than the motions for using tests which is based on the current design method.

3) The strength and function of the eight key components are clarified to maintain with sufficient margin during and after earthquake.

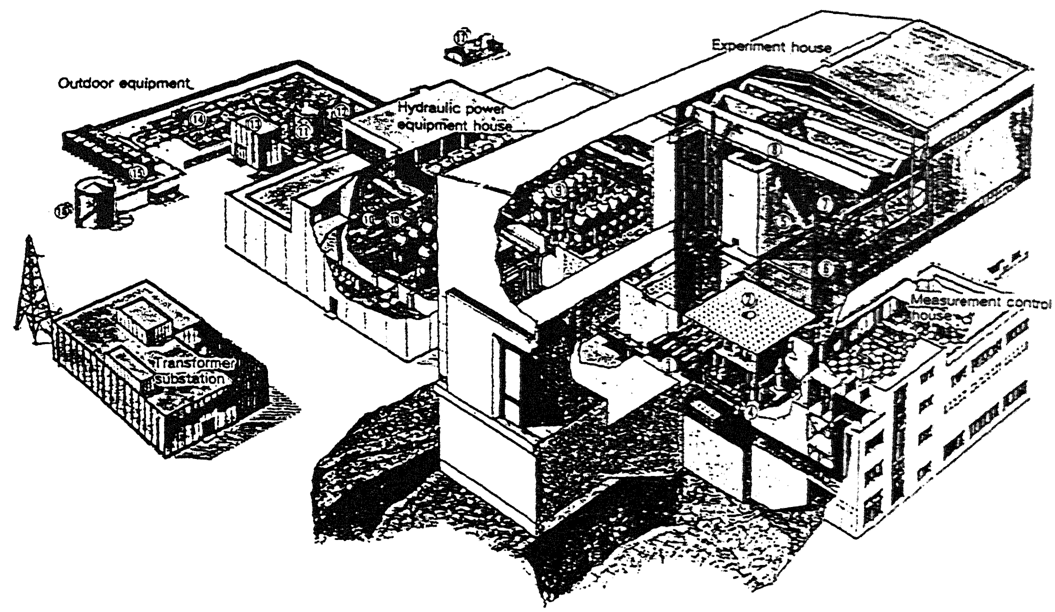
4) Current seismic design method used to secure the seismic safety verified to give a conservative result than the test results.

5) Clarification of the necessity of future works are made through this works, and the recommendations to improve more seismic safety were proposed.

These results and conclusions are very effective to establish the public acceptance of the construction and operation of NPP in Japan.

Table 1 Main Performance of the Large-scale High-performance Shaking Table

Item		Performances	Remarks
(1) Maximum Loading Capacity		1 000 ton	
(2) Table	Size	15 m × 15 m	
	Weight	600 ton	Including movable parts of exciting mechanism
(3) Excitation Directions		X, Z Axis simultaneously	X: Horizontal Z: Vertical
(4) Maximum Stroke	Horizontal	±200 mm	
	Vertical	±100 mm	
(5) Maximum Velocity	Horizontal	75 cm/s	
	Vertical	37.5 cm/s	
(6) Maximum Acceleration	Horizontal	2 670 Gal 1 800 Gal	500t: (Inertia load) 1 000t: (Inertia load)
	Vertical	1 335 Gal 900 Gal	500t: (Inertia load) 1 000t: (Inertia load)
(7) Excitation	Horizontal	3 000 tonf	
	Vertical	3 300 tonf	
(8) Permissible Overturning Moment		6 500 tonf-m	To satisfy at the time of maximum vertical excitation
		12 000 tonf-m	No vertical excitation applied
(9) Permissible Yawing Moment		3 000 tonf-m	
(10) Duration of Excitation		20 sec.	Simultaneous two-axis excitation (at maximum speed sine-wave)
(11) Continuous Excitation		5 % of maximum speed	Simultaneous two-axis excitation
(12) Frequency Range		0~30 Hz	

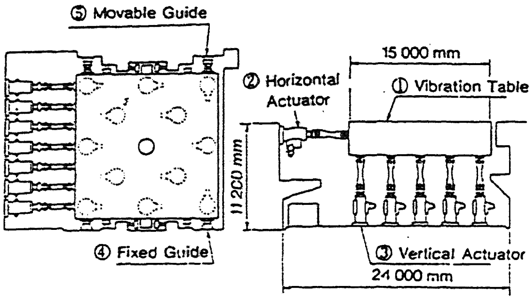


① Operating room
② Seismic vibation table
③ 7 Horizontal actuators
④ 12 Vertical actuators
⑤ Reaction wall
⑥ Test bed
⑦ Test pit
⑧ Cranes (250 ton × 2)
⑨ 36 Accumulator units
⑩ Oil hydraulic pumps
⑪ Main oil tank
⑫ Lubricating oil tank
⑬ Filter room
⑭ Oil coolers
⑮ Cooling towers
⑯ Water tank
⑰ Nitrogen gas storage

Figure 1 Large-Scale High-Performance Shaking Table Facility

Table 2 Type and Scale of Test Model and Function of Actual Component

Type / Item / Test Model	PWR Plant Weight [tons]	PWR Approx. Scale	PWR Weight [tons]	PWR Height [meters]	BWR Plant Weight [tons]	BWR Approx. Scale	BWR Weight [tons]	BWR Height [meters]	Items required at the time of earthquake
Reactor Containment Vessel	3 800	1/3.7	340	19m	3 500	1/3.2	350	16m	The functions are maintained even when additional load due to the loss of coolant accident is added to vessel against the basic design earthquake ground motion (S_1). The functions are maintained even against the basic design earthquake ground motion (S_2).
Primary Coolant Loop (PWR) Primary Loop Recirculation System (BWR)	1 000	1/2.5	550	11m	800	1/1	665	13m	The structure should be such that it is strong enough against the basic design earthquake ground motions (S_1,S_2) and that an earthquake does not cause a loss of coolant accident.
Reactor Pressure Vessel	800	1/1.5	700	9m	800	1/2	290	14m	The structure should be such that it is strong enough against the basic design earthquake ground motions (S_1,S_2) and that an earthquake does not cause a loss of the coolant accident.
Reactor Core Internals	500	1/1	555	17m	500	1/1	750	12m	It should be strong enough against the basic design earthquake ground motion (S_1). The control rod should be inserted without any difficulty and it should be possible to shutdown the operation of the reactor when the basic design earthquake ground motion (S_2) is presented.



No.	Equipment	Number	Major Specifications
1	Vibration Table	1	15 m × 15 m × 3.5 m(H) Weight 420 ton
2	Horizontal Actuators	7	Exciting Force 450 ton f Stroke ± 200 mm
3	Vertical Actuators	12	Exciting Force 300 ton f Stroke ± 100 mm Built-in Balance Cylinder
4	Fixed Guide	4	Compression Force 360 ton f
5	Movable Guide	4	Compression Force 360 ton f Stroke 100 mm

Figure 2 Table Pit Layout

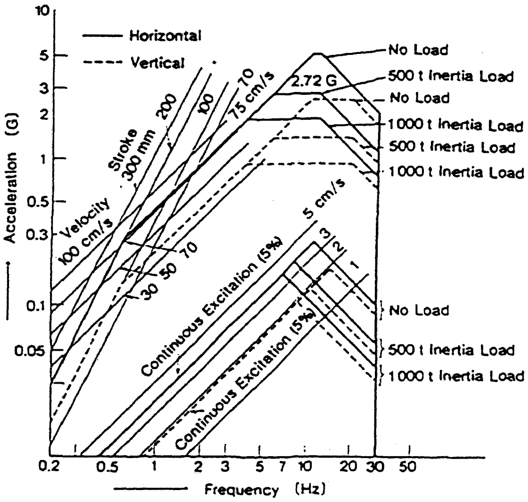


Figure 3 Limit Performances (Simultaneous Horizontal- Vertical Excitation)

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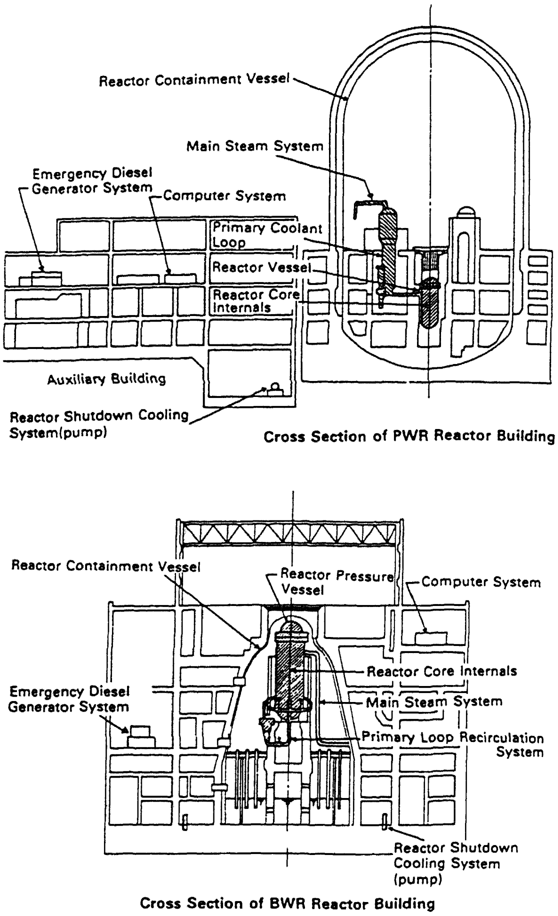

Figure 4 Layout of Key Nuclear Component in Reactor Building