Transactions of the **14th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 14), Lyon, France, August 17-22, 1997

K20/7

Outline of recent proving tests on the seismic reliability of components for NPPs in NUPEC

Shibata H.[1], Terada K.[2], Sasaki Y.[2], Tanaka N.[2]
(1) Yokohama National University, Japan
(2) Nuclear Power Engineering Corporation, Japan

ABSTRACT

This paper will deal with the recent activities and the philosopy of testings in NUPEC in relation to the shaking table, Tadotsu Engineering Laboratory, TEL.

A series of seismic proving tests for equipment and systems which are critical for seismic safety of NPPs has been carried out by Nuclear Power Engineering Corporation, NUPEC, using the large-scale, shaking table at under sponsorship of the Ministry of International Trade and Industry, MITI. Since Tadotsu shaking table was completed in 1982, 12 proving tests have been conducted and 2 proving tests are scheduled now to obtain public acceptance and to verify the seismic releability of components of NPPs. as well as their seismic design method.

Since that eight large and heavy component models such as Reactor Containment Vessel, Reactor Core Internals of both PWR and BWR were tested and their seismic integrity was verified in the Phase I activity.

In the second phase, three functional components such as Emergency Diesel Generator System, Computer System were tested by using actual components mainly to verify system functional integrity during and after earthquakes.

Then, in the third phase proving tests to confirm seismic safety magins or to verify the functionality of new seismic technologies for advanced lightwater reactors are scheduled.

Following subjects will be presented at the 14th SMiRT conference, as individual subjects of current projects

· System function integrity verification - - - - - Reactor Shutdown Cooling System
· New seismic technology verification - - - - - Main Steam and Feedwater Piping Systems
· Seismic safety margin confirmation - - - - - Concrete Containment Vessels

1. Introduction

Since the beginning of the projects, the fundamental has been gradually changing. We have been calling all projects done by the Seismic Proving Test Executive Committee as "proving test". We can devide the items which were tested / is tested / will be tested into three phases as shown in Table 1. Starting from "proving test" to prove the design adequacy and the following fabrication by shaking its design basis earthquake. This project has been supported by the special fund for site establishment of nuclear power plants prepared by the MITI according to the National Policy. Also the purpose to explain the seismic safety for publics including the local governments in the site area is included.

All these characteristics and situations of the project has been kept without any change, their detailed intention has been changed gradually. In this paper, the authors try to explain how we organize the system of the research and reflect the result to future design procedure.

*Professor Heki Shibata
National Research Institute of Earth Science and Disaster Prevention
3-1 Tenno-dai, Tsukuba city, Ibaragi, JAPAN 305
Contact Address :
1-5-203 Sakurajosui 4, Setagaya, Tokyo, JAPAN 156
Tel. & Fax. : 81/3-3303-2591

2. Short History of NUPEC Tests

Since 1981, three phases of testings have been done at Tadotsu Engineering Laboratory (Tables 1 and 2). As the tests in the phase I, eight items were tested, and then three items have been tested as the phase II project. Now we started the phase III project. Those are listed in Table 1, even though deviding them as the phases is an informal way. First eight items were tested in the view point of their structural integrity, and we called "proving test". That is, the purpose of the test is to prove the design adequacy. As far as the core-internals, #3 and #4, of both BWR and PWR, functionality on control rod insertions during seismic motions was also tested, but these were exception. In the phase II, functional requirements were more emphasized in those tests. For the forth item of the phase II, the following two items, #12, simultaneously tested : a model of the main steam line of PWR, M-line, and a model of the feedwater line of BWR F-line, in relation to their boundaries and supporting devices. That is, functional characteristics of supporting boundaries and devices were more emphasized. Moreover, two types of them, those, which have been using in NPPs upto now, and newly proposed systems. The former ones are ordinary hydraulic snubbers, mechanical snubbers and hangers, and the later ones are new-type energy dispersion devices. This means that the change of the policy on their tests, because, at least, tests in the phase I were the test for proving the structural design adequacy of equipment and piping systems using for plants which were already completed or being constructed in principle, against the design basis earthquakes, S_1 and S_2. At the beginning, Phase I, the proving test was defined as follow : test to prove the design adequacy of a component as a specimen, which was designed according to the standard procedure currently done to meet the design basis earthquake. And also it had to be inspected based on the requirement after manufacturing. All procedures, including material checking, had to be done as a real one for a nuclear power plant. This philosophy has been continued upto now, and it makes the manufacturing cost of the specimen very expensive. Moreover, at first, there was some opinion that the test exceeding the design level hadn't to be done. But soon, additional margin tests became to be done.

At the test of a containment vessel of PWR, input ground motions were those of natural earthquakes, like El Centro records, the Imperial earthquake-1941, Hachinohe record, Tokachioki earthquake-1968 and so on, because the current guideline(1), 1981 Version, hadn't be applied to plants. In 1981, the Project for the standardization and improvement of design the seismic of NPPs, both PWR and BWR had been completed based on the guideline. For the seismic design, two levels, four kinds of design basis earthquakes were settled. Based on their magnitude and epicenter distance, their horizontal ground motions were generated. Those have been employed for the standards ground motions both for the design and for the standard test upto now. The vertical ground motions hadn't been settled by the project abovemetioned. The vertical ground motions were generated only for this testing.

3. Role of Sub-committee for Evaluation on Testing Activity

Since 1981, the sub-committee to evaluate the testing activity on all themes has been operated. This committee is temporary called as "Sub-committee for Evaluation" in this article. The system of committees as shown in Fig.1. Testing of each items is designed and performed by each sub-committee in Category I. And also it plans and performs the evaluation of testing results and supplemental analysis to comple the report, and the sub-committee is reviewing them only in principle. In general, the sub-committee doesn't work for the improvement of design procedure. How to reflect the test result to the design procedure will be explained later.

This sub-committee to evaluating the testing activity is the second category one, and their function may extend to check almost all activities of individual sub-committees in Category I including the draft of their report. And, if necessary, the committee try to establish new key issues how to apply their results obtain from testing to future design improvements.

The members of this Sub-committee for Evaluation consist of specialists and experts, professors of university, researchers of national research laboratories, and experts of utilities. At first, there was discussion whether or not specialists in manufactures should be included to keep the independency from the process of the proving test. However, those also have been included as the members. The role of this committee is very significant to develop these projects. Also they discussed on basic philosophy and programs of tests including selection of input motions for testing.

The selection of input motions has been made for each items based on their individual requirements. For this purpose the working group named as "Working Group for Preparing of Input Motions". This job is difficult one far our imagine. They includes some seismologists and structural engineers also. The authors want to discuss this in next occasion.

The philosophy has been gradually changing as described in Chapter 4. However, the way of evaluation is still on a very primitive state. If one of the authors, Shibata, tries to remind how to operate the committee during he was the chairman, he can say that it was only primitive. They are just similar to committees like many advisory committees in the engineering fields.

Most members, consisting from experts, are expressing their opinion on a particular subject based on their opinion. Their points for checking the test result may be as follow :

1) Is it reasonably explained in general?

2) Is it correct according to a model in his mind?

3) Is there any possibility of occurence of unexpected phenomenon or event, if the test will be done by other parameters, conditions, or other approaches?

4) Is there still some doubts on the result according to his experience?

The discussion and examination have been continued on by comparing raw data, primary data, secondary data, result of simulation, and sometimes basic theory to each others. If necessary, some additional tests on the model are going to be proposed, or sometimes new tests on partial models to clarify particular feature for explaining the results of the main test on the shaking table.

Those activities of "Sub-committee for Evaluation" are very important to interpritate and to develop the test results to farther steps including the development of the design procedure.

After completing the project, at least three years, most of cases five years may be necessary from the beginning to the end as indicated in Table 2. Then according to the result, research activity on the more realistic design improvement, and sometimes additional tests has been done by utilities group under cooperations of fabricators, manufacturers, and constructors sometimes. Those results will be reexamined in Special Committee on Seismic Design Improvement, Japan Electric Association, JEA, by the instruction of the Ministry of International Trade and Industry, MITI. If they will conclude, it will be acceptable, then it will be an applicable procedure for the licensing to the aseismic design and construction of a nuclear power plant. Usually it takes approximately 10 years for this process. And the contents will be published as the series of "Technical Guidelines for Seismic Design of Nuclear Power Plants", JEAG 4601(2).

4. Concept of Phase II and III Tests

For Phase II, the authors already described in Chapter 2, and a typical example is Emergency Diesel Generator #9. The concept gradually developed in to the phase III, currently the tests on a prestressed containment vessel for APWR, PCCV, #13A, and a reactor containment structure of ABWR, RCCV, #13B, have been planned, and the test on PCCV has been going on in April and May, 1997. These tests have been some differences from previous proving tests in the following two points. At first, APWR has never constructed yet, and only one ABWR plant was completed rather recently. Secondarily, their appearances as models are quite different from the original shapes (in Fig.2). The test on a heavy mechanical component #14 is more concentrated the effort to prove a non-linear model. The test will be done on a steam generator supported by energy dispersion devices, but the adequacy of numerical calculation of non-linear analysis is more emphasized rather than its original design. The interests for testings are concentrated to some theoretical subjects, and shapes of specimens have been modified from their original shapes (in Fig.2). In the future projects, these two points may be more emphasized.

5. Tests done in Recent Years

As already mentioned, the tendency of recent testing gradually developed into evaluating their margins. In the table (Table 3), the list of papers which will be presented in this SMiRT 14 related to the series of tests, which have been completed and currently going on by NUPEC.

Five papers out of eighteen papers from NUPEC are on the tests done by using the shaking table in Tadotsu Engineering Laboratory. And another paper related to shear wall test, whose purpose is a bench mark test for the project of OECD / NEA, is a summary of the test done by using the shaking table.

Five papers are on #11, #12, and #13A and 13B in Table 1. Test #14 is a new project on a subject for new energy dispersion device using for hung heavy component or inverse-pendulum type component. For a test, a model of a steam generator of APWR will be used. But the test will be focused on new energy dispersion, damping, device as mentioned. Therefore, these five papers are discussing on recent testing projects.

Test #11 was already completed in 1995 F.Y.. Test #12 was also completed at the end of March 1997. Test #13A and #13B are currently going on. Especially Test #13A, the test of PCCV for APWR has been run in April to June. And the final failure test is plan to be done on June 6. Those details are discussed in individual papers, but the authors will discuss on their specific features in the following chapters.

6. RHR Test, #11

RHR test, that is, the test on the residual heat removing system, or the reactor shutdown cooling system, was very unique. The test focused on safety related key components such as a pump, valves, sensors and so on. The system for data transmission system was one of them also.

Test-supporting systems, such as water tanks, other major pipings and additional valves to develop the scenario were designed far stronger compare to the specimens. The system was designed by combining two functional safety features of both recent typical PWR and BWR systems. By assuming the failure modes, mainly functional ones, the series of scenarios were examined. The surging type of hydraulic transmission lines from sensors to receiving devices was examined, and auxiliary tests were done on a smaller shaking table. After the one year discussion on possible functional failure and some structural failures, eight scenarios were selected. The ground motions for tests were selected to meet those scenarios. No significant ill-states had been observed. More details is discussed in the reference [3].

7. MS Test, #12

MS test stands for test on main steam lines. Even though, tests on the primary ping of PWR, and that of BWR were done in Phase I, this test was planned. In the case of PWR, also HLVT, a high level vibration test, was done by the cooperation of BNL in the view point of plasto-elastic behavior, including ratcheting, of a piping. In this test, two-types of pipings were selected, that is, a main steam line of PWR, M-line, and a feed water line of BWR, F-line. Both pipings have the penetration of its containment vessel. The main steam line of PWR is connected to the top of a steam generator, therefore, a moving head of the steam generator was modelized.

Those two pipings supported by original types of snubber, hungers and restraint rods at first. Then, newly designed energy-absorber types supports were restalled. During these period of testings, Hyogoken Nanbu earthquake-1995, so-called Kobe earthquake occured. So, the tests by using the ground motion recorded at the Kobe Ocean Meteorological observatory (KOB) were used for the demonstration. These two points were quite different from all previous testings.

Also three analytical approaches in comparison with test results as followings :

1) Simulation of responses of the behavior of pipings and supporting devices.
2) Simulation of non-linear behavior of new devices.
3) Energy flow in piping systems.

The first one is most significant in relation to the seismic design of a piping system. The second one is more theoretical, and some parts had been developed by Professor Igusa, Department of Civil Engineering of North Western University in the earlier stage of the development of new devices. The third one was done to make clear for energy flow in a piping system with multi-energy dispersion supports. This subject is significant for the study of the stability of the response of multi-nonlinear support system, including condition of chaos which provides more than three non-linear support, but the final conclusion hasn't been obtained.

Back to the first subject, the following discussion is very essential for the design practice, not only of piping systems, but also of all kind of flexible structures. Three data, test results, done by design analysis and results obtained by the simulation, should have the following relations to each others ; the simulated value should be equal to the test result as well as possible, and the values obtained by design analysis must have some margin against test results, that is, real responses (in Fig.3). Design analysis contains several points to induce marginal results. One of them, and which mostly affects to such discrepancies of test results, is the stress index designated by ASME-type Code. This coefficient is settled to cover some uncertainties in stress analysis of elbows, valves and so on. On the other hand, reaction forces of supporting devices are simpler than stress distribution, and directly related to the decision of their capacities. Distribution of acceleration is discussed very often, but it is not so significant to design values as above mentioned. For the comparison of those, acceleration and displacement are using in general, it is only for understanding the results, especially, through distribution of acceleration. The discussion above was done in Shibata's lecture at International Conf. on Mechanical Engineering, ASME, in the fall of 1996, and in the manuscript(4) which was sent to the journal.

8. Containment Vessel Tests, #13A and #13B

This project consists of two tests, that of a containment vessel for PWR #13A, and that of a containment part or a rector building of BWR, #13B. Both for proving tests of functional capacity of concrete structure with steel linear for the integrity as a container. Structural failure of concrete structure may loose the integrity of containment linear in the view point of radiation protection.

Models are very much simplified to emphasize the resistant capacity against shear force plus vertical force including static load as shown in Fig.2. Their walls provide steel liner, and its plasto-elastic deformation may cause leakage of contaminated gas in the case of the accident. The relation of its strain to amount of leakage is one of the measure of its function. But there are some difficulties in this testing. Causes of loosing air-tightness are the function of strain value of the liner. However, the details of penetrations, air locks and others are different both in this model and an actual structure. Moreover, the ratio of thickness of liners is not equal to the scale ratio for models and actual structures. The proving test on their functionality is one of the main subjects, but the key value hasn't be clarify yet, and in this test project, only the strain value is taken as its measure.

9. Remarks for Conclusion

This project will have been continued for next ten years, we expect. Now we completed the first plant of ABWR and plan to start the construction of APWR. We expect new subjects which we will meet during performing new projects in the near future. Also for new plants, we plan to introduce newly designed components to improve its seismic and non-seismic reliability, and to establish more reasonable design. Improving a control system, based on recent developments of a computer system, may develop a new philosophy of testing, which we made in previous tests on the computer and the residual heat removable system. We are not sure currently whether or not we will introduce the base isolation system for LWR, but if we introduce it, we need some tests to prove that the design procedure is adequate. The draft of the design guideline was completed, and the Special Committee on Seismic Design Improvement, JEA, already approved it.

In the winter of 1995, the Southern Hyogo-prefecture earthquake, so-called Kobe earthquake occured. This earthquake brought some new features, which we have been never experienced in the engineering view points in Japan. It is "long-period pulse-type ground motions", and it brought high velocity and large displacement to structures with it. We need more studied on such effects(4).

One of the feature subjects will be effects of rather long-period ground motions caused by a base isolation system. There is some difference from that observed is Kobe event, and also the peak values will be lower than those in Kobe, but we need to examine it carefully.

A new project to establish the new research center for the research on seismic disaster prevention including twin 1,000 ton shaking tables which can generate the Kobe-type ground motions. Shibata personally feel the necessity of the performance, which to generate Kobe-type ground motions, for the table in Tadotsu in the future.

The authors appreciate their supports and cooperations of the members of the Seismic Proving Test Executive Committee and the related subcommittees as well as MITI and Utilities, and also manufacturers of equipment and piping systems of NPPs, and related construction companies.

10. Reference

(1) Nuclear Safety Commission, Examination Guide for Seismic Design of Nuclear Power Reactor Facilities (1981)

(2) Park, Y.J. and HOFMAYER, C.H. *ed* Technical Guidelines for Aseismic Design of Nuclear Power Plants (Translation of JEAG 4601-1987), NUREG-CR-6241, BNL-NUREG-52422, (June, 1994) 922pp.

(3) See Table 3 Paper No. 3 by FUJITA, T. and others for SMiRT 14

(4) SHIBATA, H., Seismic Hazard and Damages—Avoiding Disaster through Simulation and Experience, *J. of Pressure Vessel of Pipings, ASME* (under reviewing)

Test model \ Item	Full-scale Weight	Approx. Scale	Weight (incl. supporting structure)	Outline dwg.
1. PWR Reactor Containment Vessel	About 3,800 t	1/3.7	350 t	
2. BWR Primary Loop Recirculation System	About 800 t	1/1	685 t	
3. PWR Reactor Core Internals	About 500 t	1/1	555 t	
4. BWR Reactor Core Internals	About 500 t	1/1	750 t	
5. BWR Reactor Containment Vessel	About 3,500 t	1/3.2	350 t	
6. PWR Primary Coolant Loop System	About 1,000 t	1/2.5	525 t	
7. PWR Reactor Vessel	About 800 t	1/1.5	700 t	
8. BWR Reactor Pressure Vessel	About 600 t	1/2	600 t	
9. Emergency Diesel Generator System	About 600 t	1/1	450 t	
10. Computer System	About 300 t	1/1	81 t	
11. Reactor Shutdown Cooling System	About 300 t	1/1	294 t	
12. Main Steam and Feedwater Piping System	About 200 t	About 1/2.5	190 t	
13. Concrete Containment Vessels — PCCV	About 2,7000 t	About 1/10	About 810 t	
13. Concrete Containment Vessels — RCCV	About 19,000 t	About 1/8	About 560 t	
14. Heavy Component with Energy Absorbing supports	About 660 t	About 1/2.5	About 550 t	

Phase I : #1 ~ #8
Phase II : #9 ~ #12
Phase III : #13, #14

Table 1 List of Testings at Tadotsu Engineering Laboratory

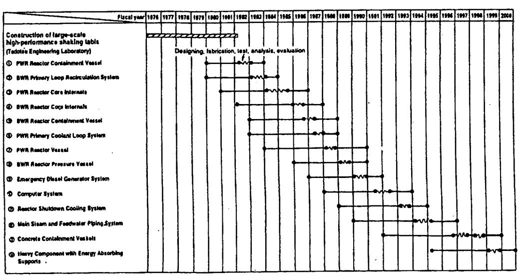

Table 2 Time-table of Testings

List of Papers for SMiRT 14

No.	Authors	Title	No. of Items (Table 1)
1	TAI, K. and others	Proving Test on the Seismic Reliability of the Main Steam Piping System (Part1:Simulation for PWR Main Steam Piping)	#11
2	SUZUKI, K. and others	Proving Test on the Seismic Reliability of the Main Steam Piping System (Part2:Simulation for VWR Feed Water Piping)	#12
3	FUJITA, T. and others	Seismic Proving Test on Reactor Shutdown Cooling Systems (Summary of Results)	#12
4	NAKAMURA, S. and others	Seismic Proving Test of Concrete Containment Vessels The Evaluation of the Test Results on a Curved Shear Wall for the PCCV Test Model	#13A
5	NAKAMURA, S. and others	Plan of the Seismic Proving Test for Reinforced Concrete Containment Vessel Part-1 Test Plan and Test Model Design	#13B

Table 3 List of Papers in Relation to NUPEC Project for SMiRT 14

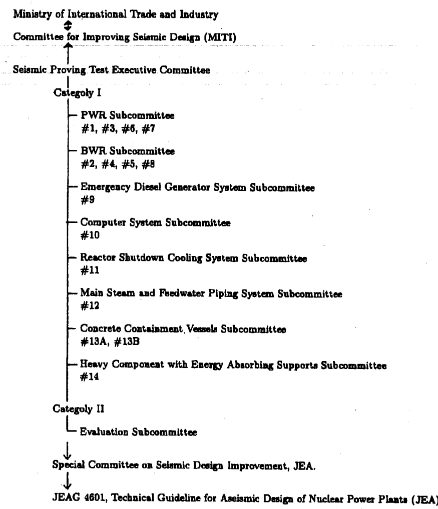

Fig.1 Organization of Committee Activities fo Proving Test in NUPEC

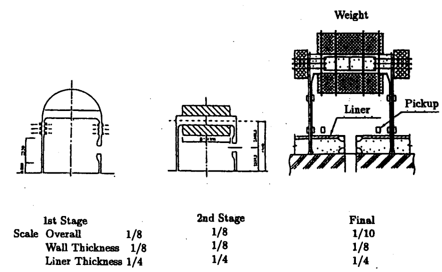

Fig.2 Development of Test Models for PCCV T

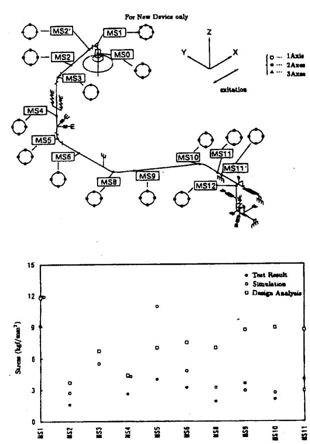

Fig.3 An Example of Stress Distribution of M-line at MS Test (#12)