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Overview of Nuclear SSCs Seismic Fragility Test 2 : Control Rod Insertion

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ABSTRACT

Now nuclear power is playing important role as precious carbon free energy source in worldwide and overview of seismic fragility evaluation for major SSCs of nuclear power plant, how done and acquired results, might be useful for young engineers and new commers. Overview of seismic verification tests to design level were already discussed by reference papers [1] and [2] at SMiRT25. The paper discusses seismic fragility capacity evaluation test acquired fragility data which is now contributing Seismic PRA in Japan, on Control Rod Insertion. Companion paper [3] “Overview of Nuclear SSCs Seismic Fragility test 1” covers Electrical Panel and Pump.

1. INTRODUCTION

Japan is located in one of the world’s highest seismicity areas and seismic safety of Nuclear Power Plants (NPPs) has been one of the key issues related to nuclear safety. Nuclear Power Engineering Corporation (NUPEC) and subsequently Japan Nuclear Energy Safety Organization (JNES), both established by Ministry of Economic Trade and Industry (METI), conducted seismic verification tests to Design Basis Ground Motion(DBGM),for major Structure, System and Components(SSCs) of 1100Mw class PWR and BWR plants during 1981~2002, using the then world’s largest shaking table located at Tadotsu in Shikoku, on test model of real or close to real scale. Ref. [4] and [5] report these tests for core internal of PWR and BWR respectively.

Now, Seismic PRA is important tool to evaluate seismic safety of NPPs quantitively in beyond DBGM region. Japanese guide for Seismic PRA is established as Ref. [6], in addition to the deterministic seismic safety evaluation guide Ref. [7] based on the previous capacity data shown in Ref. [8]. To contribute to development of seismic PRA in early stage, JNES conducted trial seismic PRA on four NPPs and screened out test specimens by evaluating Fusel-Vesely values as shown in Fig.1 and conducted fragility tests on screened out components in following steps.

Step 1 : Electrical panel and pump, enhancing vibration table ability up to 6 G* (2002~2004)
*G : Gravity acceleration, 9.8m / s^2

Step 2 : Control rod insertion system , using partial core model to acquire larger acceleration than verification test (2003-2005)

Step 3 : Overall evaluation to develop fragility data set of Step 1 and 2 (2004-2005)

Step 4 : Tank, valve, fan, etc (2005-2008)

The paper introduces outline of step 2 and 3*.

Ref. [9], a translation of summary report of Step 1,2 and 3, will support further understanding of readers.

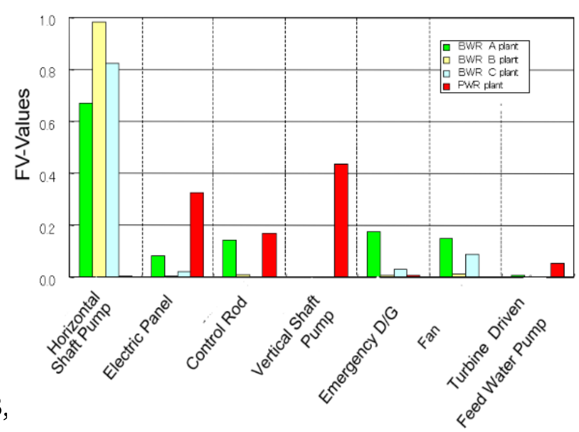

Fig.1 Screen out Test Specimens

* The views expressed in this paper are author’s view and do not represent positions or views of any other Organizations.

2.Seismic fragility capacity evaluation test of Control Rod Insertion

2.1 Outline

At the stage of seismic verification test of Core Internal , control rod insertion ability against DBGM S_2 *was confirmed up to $1.5S_2$ for PWR and $1.7S_2$ for BWR as shown in Ref. [4] and [5], using full scale core model containing up to 1 / 2 number of fuel assemblies .

*S_2 : Ultimate DBGM for SSCs directly related to nuclear safety

Insertion ability parameter is deformation displacement of fuel by excitation. Based on data by extrapolating above test result by analysis, 36mm for PWR and 82 mm for BWR were used for seismic PRA in early stage. To acquire more precise fragility capacity of control rod insertion, real scale and minimum composition of fuel assemblies and control rod were excited up to 3.3 S_2 for PWR and $4.0S_2$ for BWR. At the test, no vital abnormality directly affect to control rod insertion function occurred but some deformation was observed on the surface of BWR control rod. Investigating the phenomena by control rod element test, a simulation analysis model was developed and well simulated behaviour of the system from DBGM region to high excitation region. Based on these, evaluation method for control insertion ability at large seismic motion was developed and fragility capacity larger than former value was obtained.

2.2 Test outline

2.2.1 Test model

Fig.2 shows outline of test model, 1/1 scale, composed of minimum set of fuel assemblies, a control rod, and a control rod insertion mechanism.

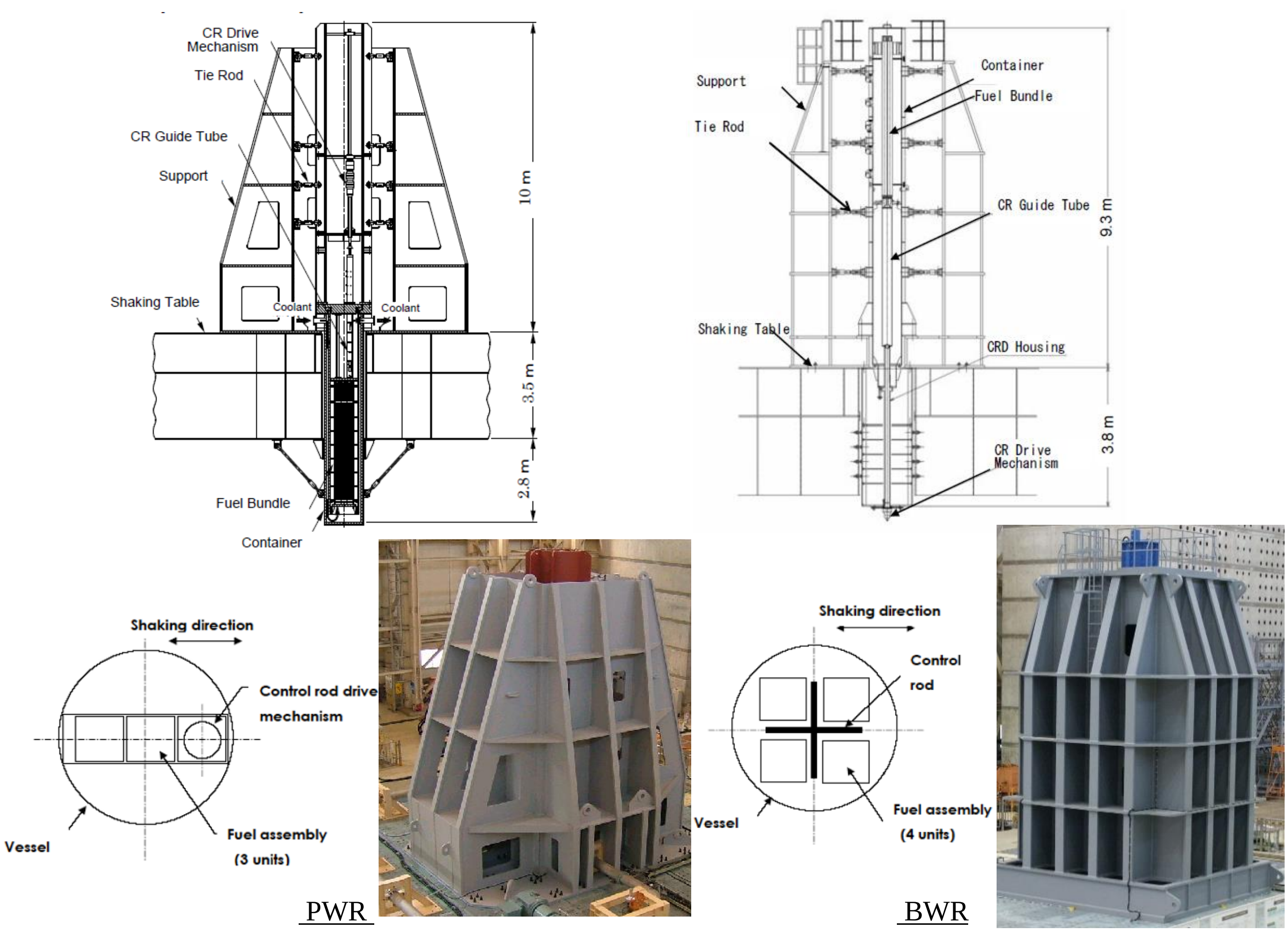

Fig.2 Outline of test model

2.2.2 Test Category

Fig.3 Shows the concept of test region, for design verification and fragility evaluation. Former test for design verification belongs Category Ⅰ and fragility capacity test belongs Category Ⅲ.

2.2.3 Test result

At maximum performance of vibration table in 3.3~4S_2, control rod insertion function of PWR and BWR were confirmed. However, as shown in Fig 4, BWR control rod surface deformation was observed. By element test to confirm the cause up to 5 S_2, control rod force-displacement characteristics was obtained as shown in Fig.5 and imcorporated into simulation analysis model of control rod insertion at large input. As shown in Fig.6, the simulation analysis well covered category Ⅰ to Ⅲ.

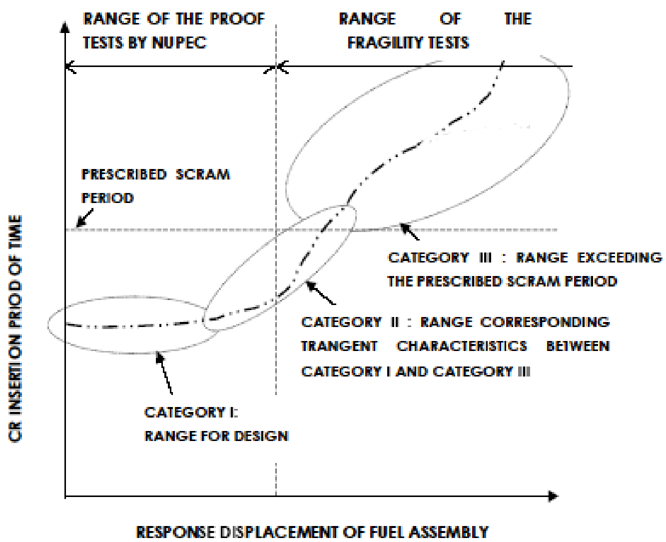

Fig.3 Concept of test region


Fig. 4 BWR Control Rod surface Deformation at 3 S_2

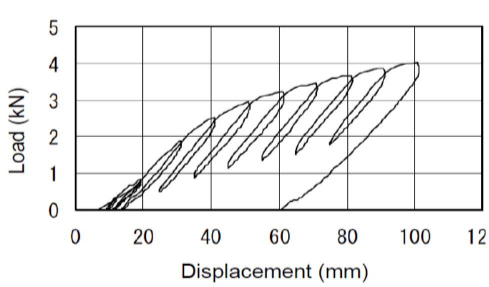

Fig. 5 BWR Control Rod Force-Displacement characteristics

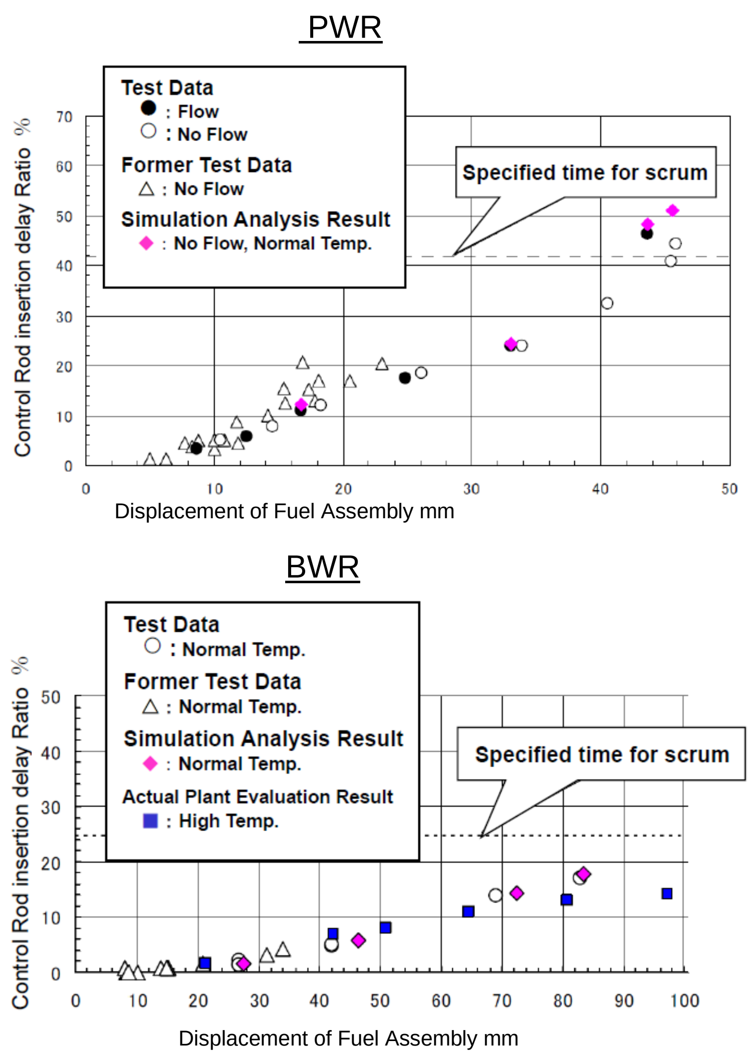

Fig.6 Control rod insertion time delay by excitation

2.3 New definition of fragility capacity for control rod insertion and evaluation result

Previously, critical situation for fragility evaluation was defined as that control rod insertion time over the specified scrum time. The value was evaluated by exploration of Category Ⅰ test conducted in ’80 era, as shown in Ref. [4] and [5]. However, now, insight of critical behaviour between control rod and fuel assembly is accumulated, including above element test for BWR control rod. Critical situation for control rod insertion was newly defined and fragility data for that are shown in Table 1 for PWR and Table 2 for BWR, respectively. These results were summarized in Ref. [9].

Table 1 New definition of fragility and evaluated data for PWR

	Fragility evaluation point	
	New	Previous
Critical situation	Control rod guide thimble damage by large displacement of fuel assembly	Large insertion time
Fragility capacity(Fuel assembly displacement) of 4 loop plant, Medium value	77mm*[1,2]	36mm
Logarithmic standard deviation	0.19	0.09

*[1] Control rod insertion time over the specified scrum time, but there still exists safety margin.

*[2] Close to upper limit of Control rod insertion analysis availability based on the region of data for non-linear behaviour of fuel assembly.

Table 2 New definition of fragility and evaluated data for BWR

	Fragility evaluation point	
	New	Previous
Critical situation	Fuel assembly collision to shroud *[1]	Large insertion time
Fragility capacity(Fuel assembly displacement) of channel box 100mil type, Medium value	91mm	82mm
Logarithmic standard deviation	0.10	0.17

*[1] If a fuel assembly in outer region of core collides to shroud, then fuel assemblies should collide each other and over the availability of Control rod insertion analysis.

3. JNES and USNRC-BNL collaboration on Seismic fragility capacity test

JNES continued collaboration with USNRC on seismic fragility capacity test as same as on former seismic verification test. USNRC, collaborating with BNL, evaluated the result of fragility capacity test of JNES, comparing that of USA. Their insight was summarized in Ref. [10], including detail introduction of JNES test summery report Ref. [9]. Ref. [10] might be a good guide for new comer to know more detail in this field.

CONCLUSION

Outline of fragility capacity test for control rod insertion , essential for seismic PRA, is introduced. Capacity data acquired exceeded the value by previous test. These were quoted into Japanese seismic PRA guide Ref. [6] and are now contributing to get more precise Seismic PRA evaluation.

The author hopes this paper will be a guide for new comer and contribute to knowledge and experience transfer to next generation.

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