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**Division Ⅴ**

# Overview of Nuclear SSCs Seismic Verification Ⅰ-2 : Heavy Components

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## ABSTRACT

Now Nuclear Power is in second expansion stage worldwide and overview of major SSCs seismic verification by tests would be useful for young engineers and new commers. In particular, the paper focuses on heavy component tests listed in Table 1 : what was done; acquired results; comparisons with response of actual earthquakes; how the results relate to current issues; and use of these results from the future perspective.

Table 1 List of Heavy Component tests the paper covers

| | |
|---|---|
| a. PWR Reactor Containment Vessel | e. Prestressed Concrete Containment Vessel(PWR) |
| b. BWR Containment Vessel | f. Reinforced Concrete Containment Vessel(BWR) |
| c. PWR Reactor Vessel | g. Heavy component with energy absorbing support(PWR SG) |
| d. BWR Reactor Pressure Vessel | |

## INTRODUCTION

Japan is located in one of the world's highest seismicity areas and seismic safety of NPPs have been one of the keys related to nuclear safety. Nuclear Power Engineering Corporation (NUPEC) and then Japan Nuclear Energy Safety Organization (JNES), both established by Ministry of Economic Trade and Industry(METI), conducted seismic verification tests of major SSCs of 1100Mw class PWR and BWR during 1981~2004, using the then world's largest shaking table located at Tadotsu in Shikoku.
Results from these tests to the Design Basis Ground Motion (DBGM) $S_2$ and larger motions for margin evaluation have been reported in every pertinent SMiRT conferences and other international nuclear engineering conferences, and delivered worldwide through individual reports.
However, even in Japan, it seems that the young engineers may not be completely familiar with these previous tests. So, the authors intend to introduce overall outline and major result of these tests, attaching detail reference list for convenience. The paper uses data and figures in NUPEC Reports and SMiRT paper for PWR Reactor Containment Vessel.
And the following nomenclatures are used in the paper:

-Seismic class As / A : for SSCs directly relating to nuclear safety / relating to nuclear safety ;
-$S_1$ : DBGM for design in elastic region defined by Nuclear Safety Commission of Japan(NSCJ) at 1981 ;
-$S_2$ : Ultimate DBGM defined by NSCJ at 1981 ; -Ss : Enhanced ultimate DBGM by NSCJ at 2006 ;

## 1. Outline of Seismic verification tests by NUPEC and JNES

1) General Feature

Use of large-scale vibration table made possible to conduct the tests of large model close to actual scale, which resulted in more accurate tests and contributed to refine seismic analyses methods for design. The vibration table at Tadotsu was eventually closed in 2005 after completing tests of major SSCs of light water reactors. This legacy of major test results need to be shared with next generation worldwide.

2) Description of the test facility

Major performance of the Tadotsu shaking table was as following.
Please refer companion paper(Ref. 3 ) for detail performance, test objectives and schedule.

- Table Size:15 ×15m, -Loading capacity:1000ton, - Frequency range : 0~30Hz
- Maximum acc.: 500t load : 2.72G(Horizontal) , 1.36G(Vertical)
  1000t load : 1.84G(Horizontal) , 0.92G(Vertical)

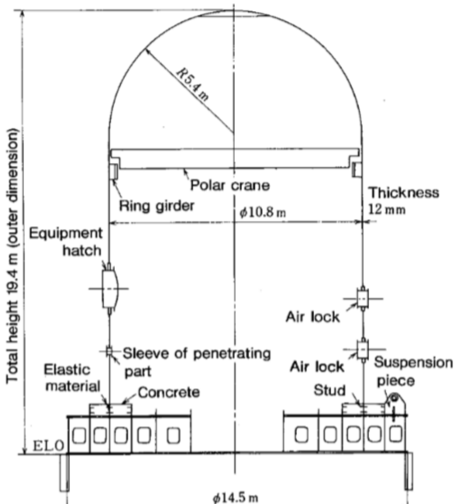
## 2. Outline and major result of component tests

This section describes the test models, excitation levels, and some major results of heavy component tests in Table 2. It is impossible to capture all of the major insights and all of the details of these results in this short paper. The References (Ref.2 for NUPEC Reports and Ref.4~10 for individual documents and papers) provide the details and they should be reviewed for further understanding**.**

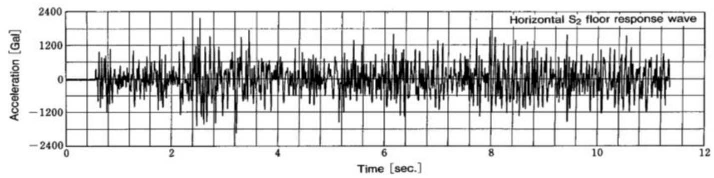
Table 2 Outline of heavy component tests

Containment Vessel : Using relatively close to actual size test model, structural integrity of shell and supplements (equipment hatch, support structure) and containment function were confirmed in the range of 1.4~1.5$S_2$ . In both PWR and BWR, oval or complicated vibration mode were observed. These were not well predicted and contributed to improve structural evaluation analysis for design.

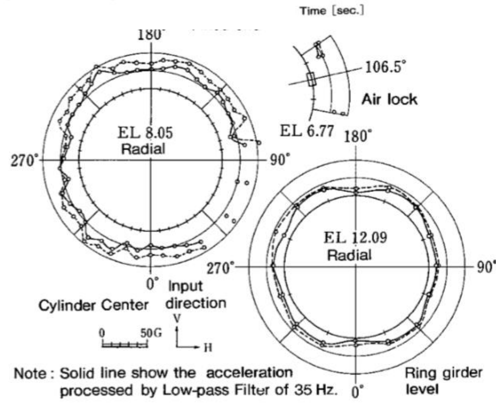
a. PWR Reactor Containment Vessel (See Ref.2-1 and Ref.4. Figures from Ref.4 in SMiRT 9 )




Scale: 1/3.7 METI improved 4 loop
Max.input:1.5 $S_2$



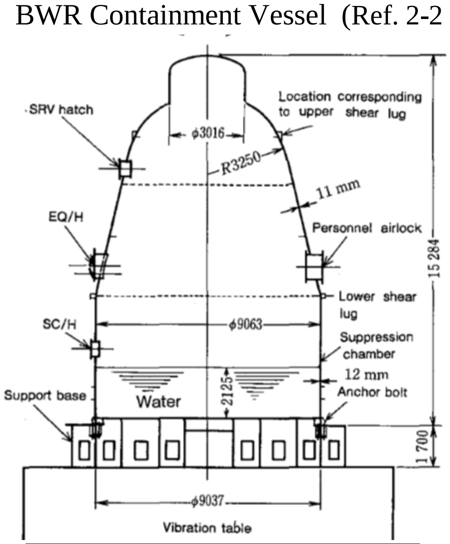

input $S_{2\,H}$



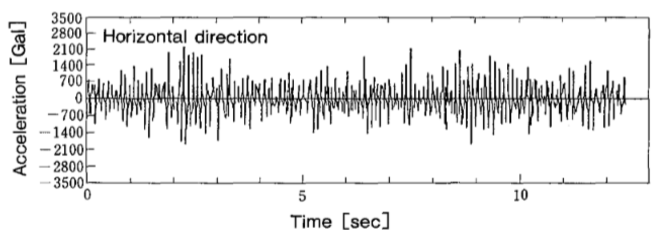

**Distribution of Max. Response Acceleration at the Marginal Vibration (1.5 $S_2$)**

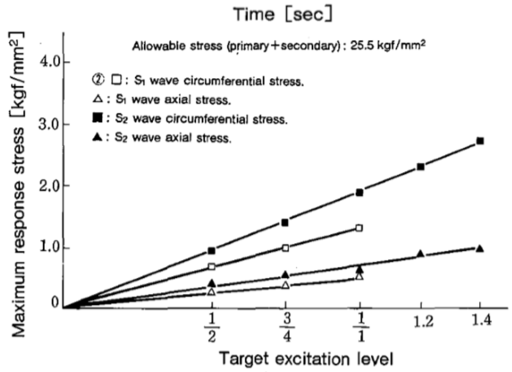
b. BWR Containment Vessel (Ref. 2-2 and Ref. 5)

input $S_{2\,H}$




Scale: 1/3.2 METI improved MK II
Max.input:1.4 $S_2$



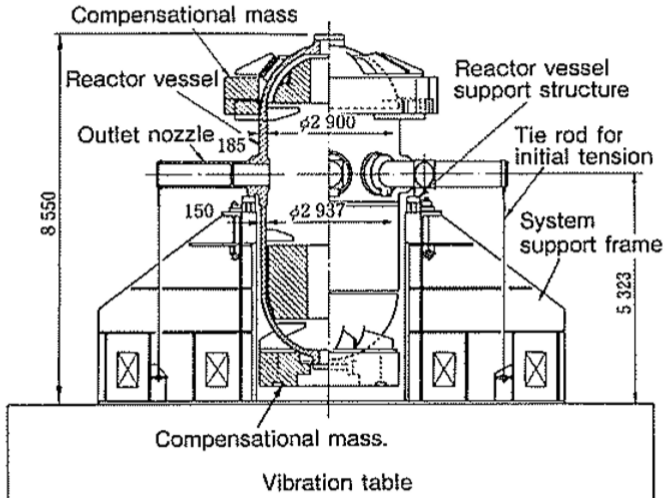



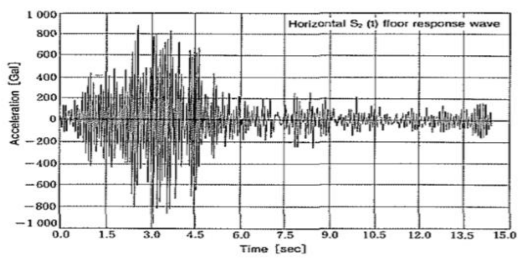

**Maximum Stress at Equipment Hatch Base (45° Direction) [$S_2$(H+V) wave excitation]**

Reactor Pressure Vessel: -Using close to actual size test model, integrity as primally pressure boundary and function of support equipment were confirmed in the range of 1.6~1.7$S_2$ .
-Actual plant margin evaluation was conducted.

c. PWR Reactor Vessel (Ref.2-3 and Ref.6)

Scale : 1/1.5 METI improved 4loop
Max. input :1.6* $S_2$
(*2.0 for nozzle integrity check)



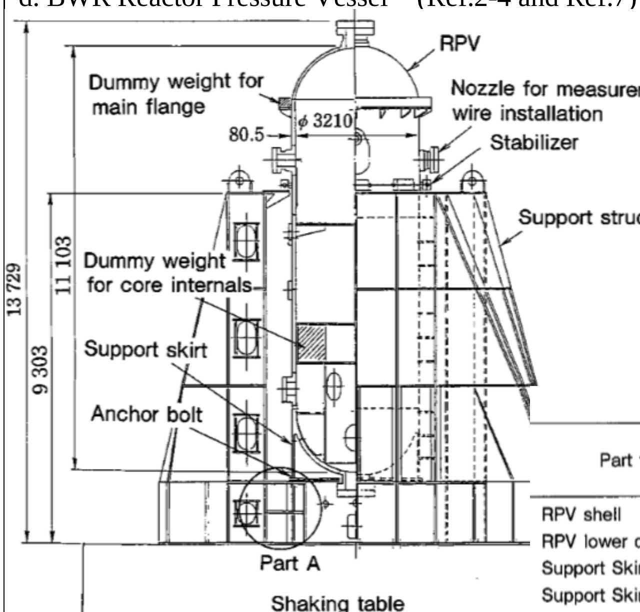

input $S_{2\,H}$

**Result of Stress Evaluation under Earthquake Condition for Support Structure of Actual Plant Reactor Vessel**

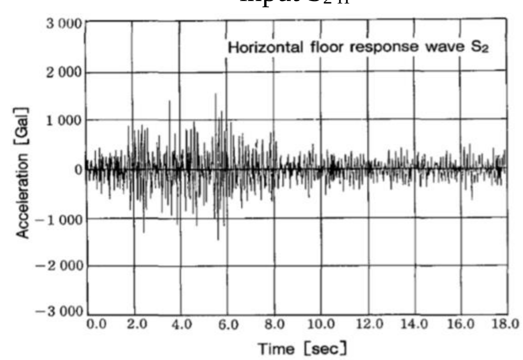
(Unit : [kgf/mm²])

| Earthquake condition | Analysis/evaluation point | | Stress: Design Analysis on Actual Plant | Stress: Simulation Analysis on Actual Plant | Allowable limit |
|---|---|---|---|---|---|
| $S_1$ | Support shoe | Bearing | 2.5 | 1.9 | 43.0 |
| | Support rib | Compression | 1.3 | 1.2 | 27.1 |
| | | Shear | 0.8 | 0.7 | 15.1 |
| | Anchor bolt | Tensile | 4.6 | 3.5 | 56.2 |
| $S_2$(2) | Support shoe | Bearing | 10.1 | 6.0 | 47.5 |
| | Support rib | Compression | 3.5 | 2.8 | 30.3 |
| | | Shear | 2.2 | 1.7 | 18.1 |
| | Anchor bolt | Tensile | 19.0 | 11.3 | 56.2 |

d. BWR Reactor Pressure Vessel (Ref.2-4 and Ref.7)




input $S_{2\,H}$




Scale: 1/2 METI improved MK II
Max.input:1.7 $S_2$

**Table 2・25 Seismic Margin of Actual RPV ***

| Part to be evaluated | Margin for allowable stress *1: $S_1$ | Margin for allowable stress *1: $S_2$ | Margin for earthquake *2: $S_1$ | Margin for earthquake *2: $S_2$ |
|---|---|---|---|---|
| RPV shell | 1.68 | 1.87 | 7.47 | 5.19 |
| RPV lower dished head | 3.25 | 3.58 | 68.3 | 47.8 |
| Support Skirt (on RPV side) | 6.68 | 5.55 | 6.44 | 5.18 |
| Support Skirt (on base side) | 6.79 | 5.45 | 5.28 | 5.94 |
| Stabilizer bracket | 4.39 | 2.76 | 4.39 | 2.76 |
| Anchor bolt | 6.20 | 3.63 | 6.20 | 3.63 |
| Stabilizer | 1.32 | 1.29 | 2.08 | 1.69 |
| Stabilizer bracket mounting base on cylindrical shell of RPV | 2.37 | 2.61 | 10.8 | 7.82 |

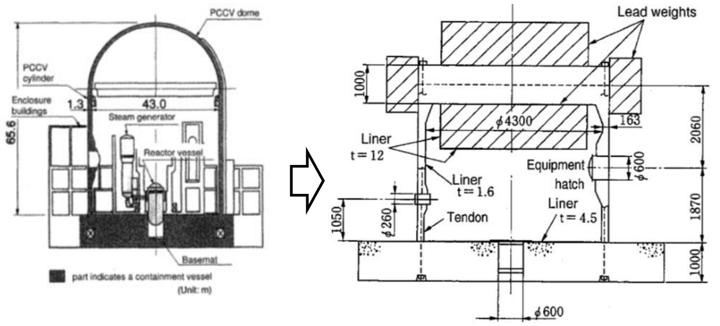
Concrete Containment Vessel

Using model with supplements such as equipment hatch, inside steel liner, and added mass on the top for adjusting stress of lower cylindrical wall, seismic performance limit were investigated by excitation up to $5S_2$ for PCCV and up to $9S_2$ for RCCV, where test models broke down.

-Small cracks were observed in cylinder wall of both model at $S_2$ level and grew and increased as excitation level went up. Integrity of steel liner inside was kept until concrete structure failure.

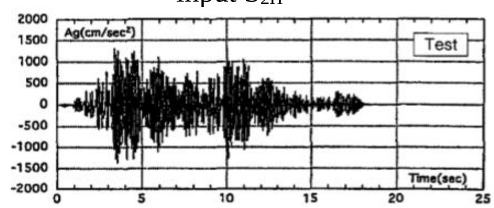
- Seismic margin investigation of cylindrical wall by cumulated energy velocity method was concluded.

e. Prestressed Concrete Containment Vessel (PWR) (Ref. 2-5, 8)

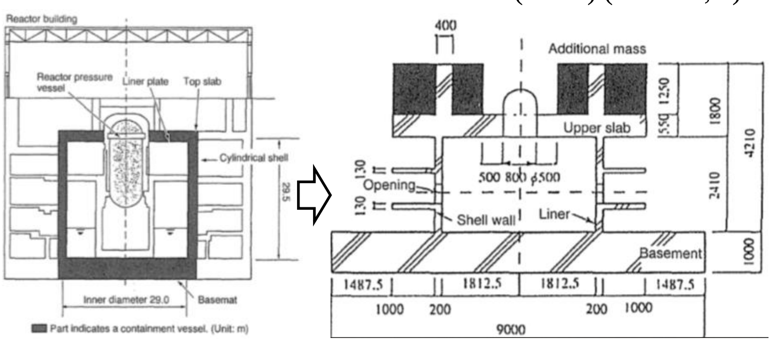



Scale: 1/10 METI improved 4loop
Max. input : $4.0S_2$ ($5.0S_2$ to brake)

input $S_{2H}$

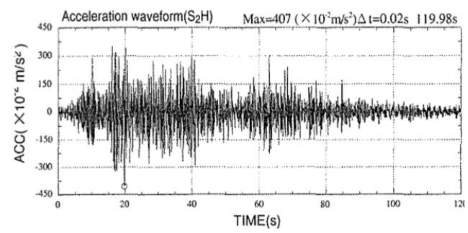



f. Reinforced Concrete Containment Vessel(BWR) (Ref. 2-6, 9)



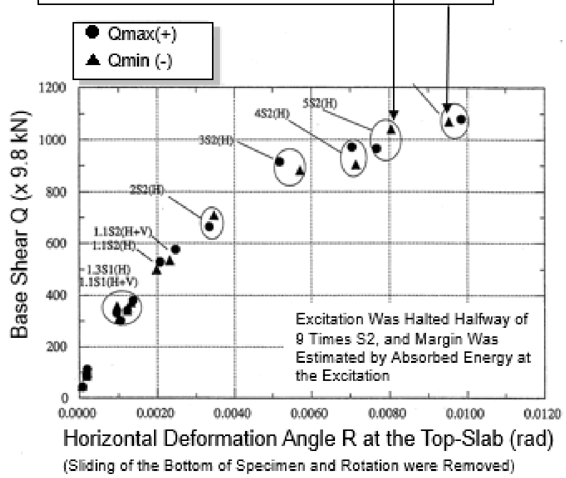

Scale: 1/8 ABWR
Max. input : $5.0S_2$ ($9.0S_2$ to brake)

input $S_{2H}$




Test result example : RCCV

- No leak up to 5 S2 Excitation
- Shear Failure during 9 S2 Excitation and Liner Failure



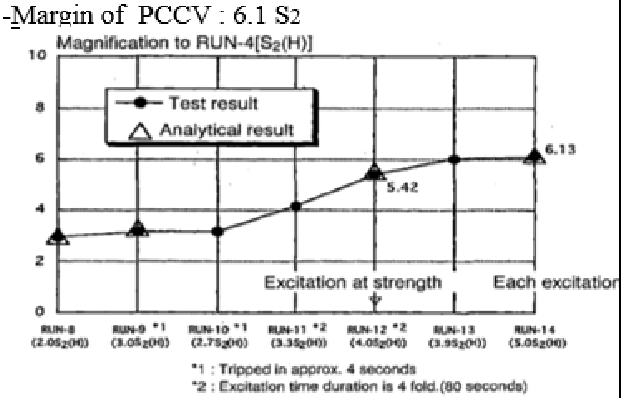

Load to deformation relation through excitation history

Margin Evaluation* by Energy Equivalent Velocity $V_E$

Accumulated Energy= m $V_E^2$

*Accumulated plastic-strain –energy method proposed by Prof. H . Akiyama

-Margin of PCCV : 6.1 S2

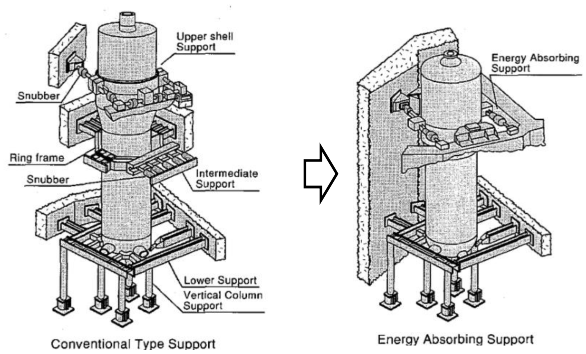


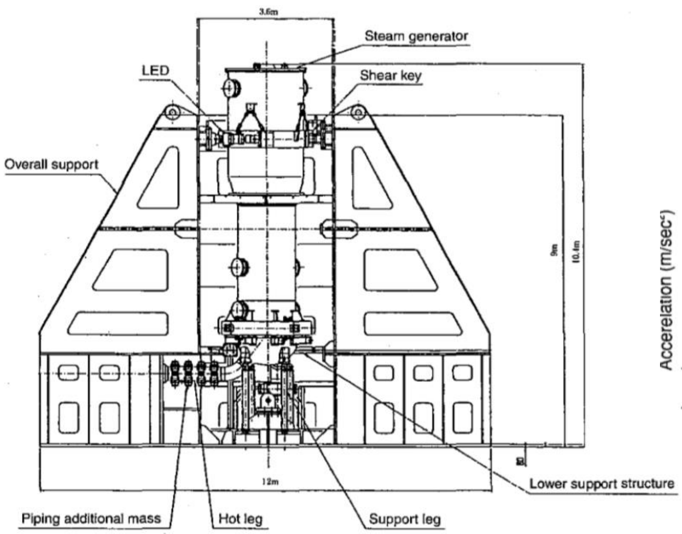

Ratio of Energy Equivalent Velocity (VE) to RUN-4[S2(H)]

- Margin of RCCV : 7.4 S2

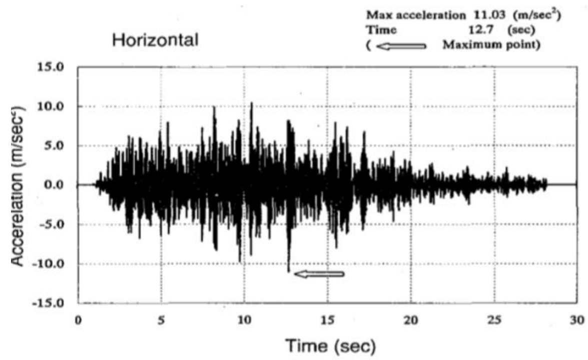
g. Heavy component with energy absorbing support (Ref. 2-7, Ref.10)

PWR SG is currently supported by many mechanical snubbers and if energy absorbing support like lead damper will be adopted, support structure should be simplified.
The test investigated reliability and margin of SG supporting system with lead damper to DBGM $S_2$ .




Scale: 1/2.5 METI improved 4loop
Max.input : $2.9S_2$



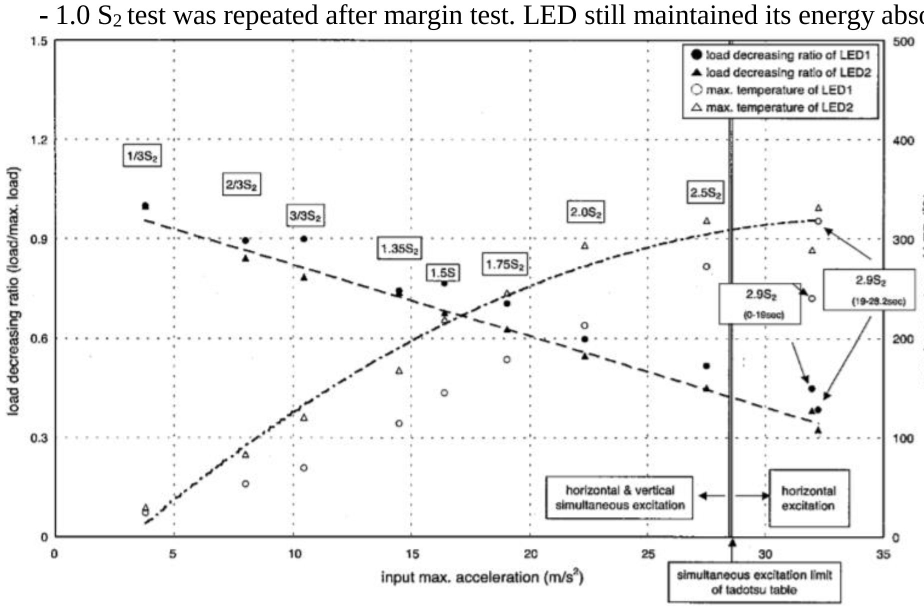

**i**nput $S_{2H}(3)$

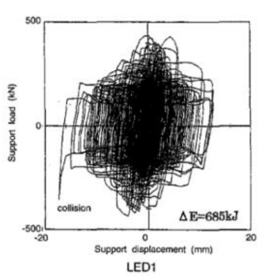
Test result

Watching temperature of lead in the damper, load decreasing ratio was investigated.

-At $2.9S_2$, LED collision to inside stopper occurred. LED damper worked up to its limit.

- 1.0 $S_2$ test was repeated after margin test. LED still maintained its energy absorbing function.




**Maximum Temperature and Load Decreasing Ratio of LED at Marginal Excitation Test**

LED Load-Displacement curve (Marginal excitation test, $2.9S_2$ wave(3) )

## 3. Comparison of test condition and actual seismic response of NPPs

1) Typical earthquake experience of NPP in Japan exceeding DBGM $S_2$

In Japan, BWRs had experienced large earthquakes.

Table 3 shows typical NPP experience of earthquake exceeding its $S_2$ at original design.

Table 3 Typical NPP seismic response in Japan exceeding DBGM

| Earthquake | NPP | Max. Response gal observed (design) at RB base/mat | | | | |
|---|---|---|---|---|---|---|
| | | Unit | Type | NS | EW | Vertical |
| 7.16, 2007 Niigata -ken Chuetsu Oki (NCO) earthquake (Mj:6.8 ) | Kashiwazaki Kariwa (KK) (to epicenter △16 km ) | 1 | BWR Mk II | 311(274) | **680**(273) | 408(235) |
| | | 2 | Mk II R | 304(167) | 606(167) | 282(235) |
| | | 3 | 〃 | 308(192) | 384(193) | 311(235) |
| | | 4 | 〃 | 310(193) | 492(194) | 337(235) |
| | | 5 | 〃 | 277(249) | 442(254) | 205(235) |
| | | 6 | ABWR | 271(263) | 322(263) | **488**(235) |
| | | 7 | 〃 | 267(263) | **356**(263) | 355(235) |
| | | ( ) Response by DBGM $S_2$<br>Average of observed / design ratio : NS 1.3 , EW 2.1 , Vertical 1.5 | | | | |
| 3.11, 2011 Tohoku earthquake (Mj: 9.0 ) | a. Onagawa (△130km) | 607(594 Back check Ss) gal NS at Unit 2<br>439(451 〃 〃 ) gal Vertical at Unit 1 | | | | |
| | b. Fukushima Daiichi (△ 180km) | 550(438 〃 ) gal EW at Unit 2<br>302(420 〃 ) gal Vertical at Unit 2 | | | | |

Up to now, largest seismic response at Reactor Building( RB) base/mat are;

-680 gal Horizontal(EW) at KK NPP Unit 1

-488 gal Vertical at KK NPP Unit 6

2) Comparison of test input vs actual earthquake response

Table 4 shows Max. test input and Kashiwazaki Kariwa NPP Max. response at object located level.

Table 4 Max. test input to vibration table*1 and KK NPP Max. response at object located level(gal)

| Test object | Test input Max. *1 | Plant response Max.by NCO earthquake | | |
|---|---|---|---|---|
| | | Mk II R | ABWR | Location |
| CV ( Mk II R) | 1.4 $S_{2H,V}$ : H 1075<br>V 344 | H 606 EW at Unit 2<br>V 337 at Unit 4 | - | RB base/mat |
| RCCV(ABWR) | 5.0 $S_{2H}$ : H 2035<br>1.1 $S_{2V}$ : V 224 | - | H 356 at Unit 7<br>V 488 at Unit 6 | 〃 |
| RPV ( Mk II R) | 1.7 $S_{2\ H,V}$ : H 1360<br>V 435 | H 680 at Unit 1 $\times A_H$ *2<br>V 408 at Unit 1 $\times A_V$ *2 | - | top of pedestal |

*1 converted to actual plant acceleration by scaling law

*2 amplifying factor by pedestal

As shown in Table 4,

- CV : Test input covered the plant response in Horizontal and Vertical.
- RCCV : Dominant parameter of RCCV integrity is sheer strain and test input was enough covered the plant response in Horizontal.
- RPV : Pedestal amplifying factor A is necessary for precise comparison.

3) Evaluation of KK NPP SSCs integrity

After the earthquake, detail integrity inspection of KK Unit 1~7 on all seismic class As and A SSCs and major seismic class B and C SSCs were conducted. Even though the earthquake response exceeded DBGM $S_2$, no damage of seismic class As and A SSCs were found.

Especially, stress evaluation by design analysis were conducted on Unit 7 seismic class As and A SSCs . No SSCs indicated stress exceedance to allowable limit.
(NISA* final report dated 10.3, 2008 and NSCJ review statement dated 10.31,2008 ).
* Nuclear and Industrial Safety Agency in METI

Table 5 shows its typical result of heavy components.

Table 5 Example of KK Unit 7 component integrity evaluation after NCO earthquake

| Component | Evaluated part | a. Max. stress (MPa) | b.Allowable limit ( MPa, in ⅢAs) | a / b |
|---|---|---|---|---|
| RCCV | Cylindrical wall ( horizontal deformation angle ) | Radian $1.2\times10^{-3}$ | Radian $3.0\times10^{-3}$ | 40 % |
| | 〔Cylinder shell of equipment hatch, drywell top flange plate〕 * | | | |
| | Venting pipe(primary) | 56 | 127 | 44 % |
| RPV | Stabiliser rod (tension) | 227 | 513 | 44 % |
| | Stabilizer bracket ( membrane plus bending ) | 45 | 454 | 10 % |
| | 〔Shell, lower dished head, support skirt; Nozzles of MS,FW,RHR,HPCS, Instrumentation〕 * | | | |

* Stress evaluation same as at design was not conducted, in case a / b at design was below 20 %.

4) Rough comparison with test result

-RCCV : Test model kept its containing function up to maximum input larger than Unit 7 response by NCO earthquake. The result is coincident with RCCV response of Unit 7 in Table 5.

-RPV : The test pointed out that seismic margin of stabilizer is relatively low as shown Table 2.25 in page 3. RPV Stabilizer of KK Unit 7 indicated enough margin at NCO earthquake.

5) New DBGM Ss and seismic counter measures

Since the event, new DBGM Ss for re-evaluations were set larger*[1] than those recorded during NCO earthquake considering the causes*[2] of the large motions.

*[1] 1.2~1.4 times larger at RB base/mat

*[2] effect of 3D structure of underground soil and under estimate for some active faults, as the result.

All necessary seismic counter measures, such as enhancing seismic supports, were taken and subsequently, seismic integrity of all seismic class As and A SSCs of all units subjected to new DBGM Ss were confirmed by design analysis.

## 4. Current situation of NPP SSCs seismic verification

1) Robustness of seismic class As and A SSCs

Regarding seismic safety of NPPs, one of the most significant events worldwide is NCO earthquake and ground motion levels it imparted to Kashiwazaki Kariwa NPP, that were 1.3 ~ 2.1 times in average larger than ground motion for design at RB base/mat . This event did confirm robustness of seismic class As and A SSCs based on design method in use.

Main factors NSCJ pointed out for the robustness were (NSCJ statement 20 NSCJ 25, 10.31, 2008) ;
Efforts to keep margin in seismic design of SSCs as following ;

- Set DBGM $S_1$ for elastic design
- Set standard static seismic force 3 times larger than civil structure for As class structure
- Floor response spectrum peak broadening
- Verification and improvement of seismic design and evaluation method (Ref.1-1) by the tests conducted at Tadotsu laboratory.

These tests have been conducted under collaboration of Nupec-JNES-NRAJ and the US NRC, cooperating together in data analysis and simulation (Ref.8-1, 9-1, 10-1).
Shared experience and information ware summarized in NUREG/CR -7230
"Seismic Design Standards and Calculational Methods in the United States and Japan" (Ref 1-3).

## 5. Issue and perspective of NPP SSCs seismic verification

Validity and robustness of Seismic design for NPP in Japan had been verified by KK NPP-NCO earthquake event. However, the event had pointed out importance of being concerned to low seismic class SSCs. IAEA is now preparing a project to collect and evaluate seismic experience including low seismic class SSCs.

## 6. Post-Fukushima

It is not the intent of this paper to discuss post-Fukushima seismic activities in terms of changing requirements and additional measures that are being undertaken. However, there are several new seismic requirements established by the new regulators NRAJ*, including enhancement of DBGM evaluation, requirement for a seismic PRA etc.

*Nuclear Regulatory Authority Japan

The readers are referred to references (Ref.1-2) for more information. What is important here is to indicate that results of tests described here are equally applicable as these activities are carried out. In particular, the functional demonstration of SSCs by tests provide insights on fragility and system modelling.

## 7. Summary

The event of NCO earthquake attack to Kashiwazaki Kariwa NPP confirmed the robustness of seismic design in use.

The Tadotsu tests have well contributed to verify and improve seismic design and evaluation methods.

The authors hope that the paper would be a guide for information of NPP heavy component seismic verification tests and will contribute to knowledge and experience transfer to next generation.

### Disclaimer

The views expressed in this paper are authors views and do not represent positions or views of any other organizations.

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### REFERENCES

**1. General**

-1 JEAG 4601(1987 )"Technical Guidelines for Aseismic Design of Nuclear Power Plants "
(NUREG/CR-6241, Translation by USNRC)

-2 NRAJ requirement

-1 Outline of New Regulatory Requirements For Light Water Nuclear Power Plants
(Earthquakes and Tsunamis) (Apr. 2013)

-2 Japan's nuclear regulation against natural hazards after the Fukushima Daiichi Accident
Presentation at IAEA technical meeting (Nov.2016)

-3 NUREG/CR -7230 "Seismic Design Standards and Calculational Methods
in the United States and Japan" Published May 2017

**2. NUPEC SEISMIC PROVING TEST REPORTs**

-1 PWR Reactor Containment Vessel (1985)

-2 BWR Reactor Containment Vessel (1989)

-3 PWR Reactor Vessel (1992)

-4 BWR Reactor Pressure Vessel (1992)

-5 Prestressed Concrete Containment Vessel (2001)

-6 Reinforced Concrete Containment Vessel (2001)
-7 Heavy component with Energy Absorbing Support(2004)

**3. Companion Paper**

Abe.H., Chokshi.N.,
"Over view of Nuclear SSCs Seismic Verification Ⅰ-1:Piping" SMiRT25 2019 ID907

**4. PWR Reactor Containment Vessel**

Akiyama H., T.Yoshikawa T., Tokumaru Y.,
" Seismic proving test of PWR reactor containment vessel" SMiRT 9 1987 K p523-528

**5. BWR Containment Vessel**

H. Sato, S.Otani, K. Suzuki, T. Kubo, O. Oyamada, M. Takayanagi, S.Kawakami, et al;
"Seismic proving test of BWR primary containment vessel" ASME PVP 1990 p. 215-222

**6. PWR Reactor Vessel**

H. Akiyama; H. Shibata; M. Kato; S. Kawakami; T. Ohno; K. Koyama
"Proving Test on the Seismic Reliability of the PWR Reactor Vessel" SMiRT 11 1991 K18

**7. BWR Reactor Pressure Vessel**

T. Taira; Y. Sasaki; H. Shibata; H. Sato; T. Kubo; S. Kawakami; T. Ohno; Y. Karasawa
"Large Scale Aseismic Proving Test of BMR Reactor Pressure Vessel by Tadotsu Table" SMiRT11 1991 K29

**8. Prestressed Concrete Containment Vessel(PWR)**

-1 NRC NUREG REPORT
N.C. Chokshi, NRC Project Manager
J.L. Cherry,Sandia National Laboratories R.J. James, L. Zhang, Y.R. Rashid,ANATECH Corporation
"Seismic Analysis of a Prestressed Concrete Containment Vessel Model" NUREG/CR-6639 SAN099-1464,1999

-2 SMiRT
Nakamura S., Sasaki Y., Kitani T., Hayashi K., Satoh K., Eto H., Nagahara K., Takiguchi K. and Akiyama H., "Seismic Proving Test of Concrete Containment Vessels-The Evaluation of the Test Results on Curved Shear Walls with Liner for the PCCV Test Model-," SMiRT 14, Vo1.11, K04/2, pp.91-98, Aug., 1997.

-3 The Third International Conference on Containment Design and Operation
Akiyama H., Terada K., Nakamura S.,Matsumoto T., Tabuchi M., Yamaura Y., Satoh K., Soejima M., Suzuki T., Eto T., Yamamoto M.,
"Plan for the Seismic Proving Test of Concrete Containment Vessels-JAPAN" 1999.

-4 WCEE
Nakamura S., Terada K., Suzuki T., Soejima M., Yamaura Y., Eto H., Tsuda K., Takiguchi K. and Akiyama H., "Seismic Proving Test of Concrete Containment Vessels PART 1
:Model Tests of a Curved Shear Wall for the PCCV" 11 th WCEE, No.1799, June, 1996..

-5 WRSM
Terada K., Sasaki Y. and Nakamura S.,
"Seismic Test of a Prestressed Concrete containment Vissel,Part1-Test Program-" 25th WRSM,1997.

- 6 International Symposium on Current Issues Related to Nuclear Power Plant Structures, Equipment and Piping
Sasaki Y., Tsurumaki S., Hattori H., Akiyama H., Takiguchi K., Satoh K., Eto H., Goto M. et al
"Seismic Proving Test of Concrete Containment Vessels"
7th ISCOSAR Equipment and Piping, No. IV-1, Dec., 1998.

-7 ASME PVP
-1 Sasaki Y., Tsurumaki S., Akiyama H., Satoh K., Fuyama H. and Eto H.,
"Seismic Proving Test of a Prestressed Concrete Containment Vessel,"
ASME PVP-VoI.364,pp.227-236, Aug., 1998.
-2 Sasaki Y., Tsurumaki S., Satoh K., Eto H. and Akiyama H.,
"Seismic Proving Test of a Prestressed Concrete Containment Vessel(PCCV)-Analytical Evaluation-"
ASME PVP-VoI.387, pp.241-248, Aug., 1999.

-8 ICONE
Sasaki Y., Tsurumaki S., Satoh K., Fuyama H., Kitani T., Eto H., Tsuda K., Takiguchi K. and Akiyama H., "Seismic Proving Test of a Prestressed Concrete Containment Vessel-Shaking Test and Analytical Results-" ICONE-7, E2-1, No.7405, pp.31, April, 1999.

**9. Reinforced Concrete Containment Vessel(BWR)**

- 1. NRC NUREG REPORT
A. J. Murphy, NRC Project Manager J. L. Cherry/Sandia National Laboratories R. J. James, L. Zhang, Y. R. Rashid/ANATECH Corporation
"Seismic Analysis of a Reinforced ConcreteContainment Vessel Model" NUREG/CR-6707 SAND2001/0022P

-2. SMiRT
-1 SMiRT 14 1997
Nakamura S., Sasaki Y., Horibe K., Nakajima M.,Hoshino K., Takahashi T., Hasegawa T., Kei T., Mieda T., Takiguchi K. and Akiyama H.,
"Plan of the Seismic Proving Test for Reinforced Concrete Containment Vessel-Test Plan and Test Model Design-," SMiRT 14, Vol.11, K04/1, pp.83-90
-2 SMiRT 15 1999 "Seismic Proving Test of a Reinforced Concrete Containment Vessel(RCCV)
-1 Hattori K., Tateno S., Shiba K., Kei T. and Akiyama H.,
Part 2 "-Results of Shaking Table Tests-," SMiRT 15, Vo1.8, K08/1, pp.313-320
-2 Sasaki Y., Tsurumaki S., Tateno S., Kobayashi T. and Nakajima M.,
Part-3"SimulationAnalysis of Shaking Table Tests-" SMiRT 15, Vo1.8, K08/2, pp.321-328
-3 SMiRT 16, Aug., 2001
-1 Sasaki Y., Hattori K., Goto M., Hasegawa T.,Shiba K., Hirama T. and Tanaka R.,
Part-4 "Results of Shaking Table Tests up to Ultimate Strength,"
-2 Sasaki Y., Hattori K., Nakajima M, Kobayashi T.and Suzuki A .,
Part-5 "Simulation Analysis of the Safety Margin Test"

-3 NED
-1 Hirama.T.,Takiguchi.K.,Akiyama.H.,et al;
" Seismic Proof test of a RCCV Part 1 : Test model and pressure test" NED 235(2005) 1335-1348
-2 Hirama.T., Goto. M.,Takiguchi.K.,Akiyama.H.,et al;
" Seismic Proof test of a RCCV Part 2 : Results of shaking table tests" NED 235(2005) 1349-1371

-4 ASME PVP
-1 Hattori, K., Tateno S., Katayama H., Naito Y. and Akiyama H.,
"Seismic Proving Test of a Reinforced ConcreteContainment Vessel(RCCV)-PART1. Outline of the Test, Result from Small Acceleration Excitations and Analysis Method for Observed Data-," ASMEPVP-VoI.387, pp.269-276,Aug., 1999.
-2 Sasaki Y., Tsurumaki S., Hirama T., Yamanaka H.and Akiyama H.,
"Seismic Proving Test of a Reinforced Concrete Containment Vessel(RCCV)-PART2. Test Results and Simulation Analyses-," ASME PVP-VoI.387, pp.277-284, Aug., 1999.

-5 WRSM
Tsurumaki S., Sasaki Y., Akiyama H. and Goto M.,
"Outline of a RCCV Seismic Proving Test Results" 27th WRSM, Session4, Oct., 1999.

**10. Heavy component with energy absorbing support(PWR SG)**

-1 BNL Report
"BNL Review of the NUPEC Program on Energy Absorbing Supports for Heavy Components" BNL Technical Report W-6081-1203, December 2003

-2 SMiRT
Iwatsubo,T., et aI.,
"Seismic Proving Test of Heavy Component with Energy Absorbing Supports-Status of Seismic Proving Test Results-" Proc. of 16th SMiRT VoI.K2.

-3 ASME PVP
-1 Iwatsubo,T., et aI.,
"Seismic Proving Test of Heavy Component with Energy Absorbing Support-Project Plan and Preliminary Test Results -" ASME PVP 2000,VoI.402-2,pp219-224.
-2 Iwatsubo,T., et aI.,
"Seismic Proving Test of Heavy Component with Energy Absorbing Support-Proving Test Results-", ASME PVP 2002, VoI.445-1,pp107-111.

-4 ICONE
Abe,H., et aI., 1999,
"NUPEC Project; Seismic Proving Test of Heavy Component with Energy Absorbing Support", 7th Intenational Conference on Nuclear Engineering, ICON-7406