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Equipment Fragility Evaluation by Vibration Test

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Japan Nuclear Energy Safety Organization (JNES)

Seismic Safety Division

Content

1. Background
2. History of vibration test
3. Fragility tests outline
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5. 2nd term: Over head Crane
6. Summary

1.Background of the tests

Revision of Seismic Design Guide

Old Seismic Guide:1987 Revised Seismic Guide:2006

Prevent to become inducible factors of big accidents against all earthquakes to be assumed

→

Cannot deny the possibility of occurrence of the earthquake which exceed assumed ones. "Residual risk" should be considered.

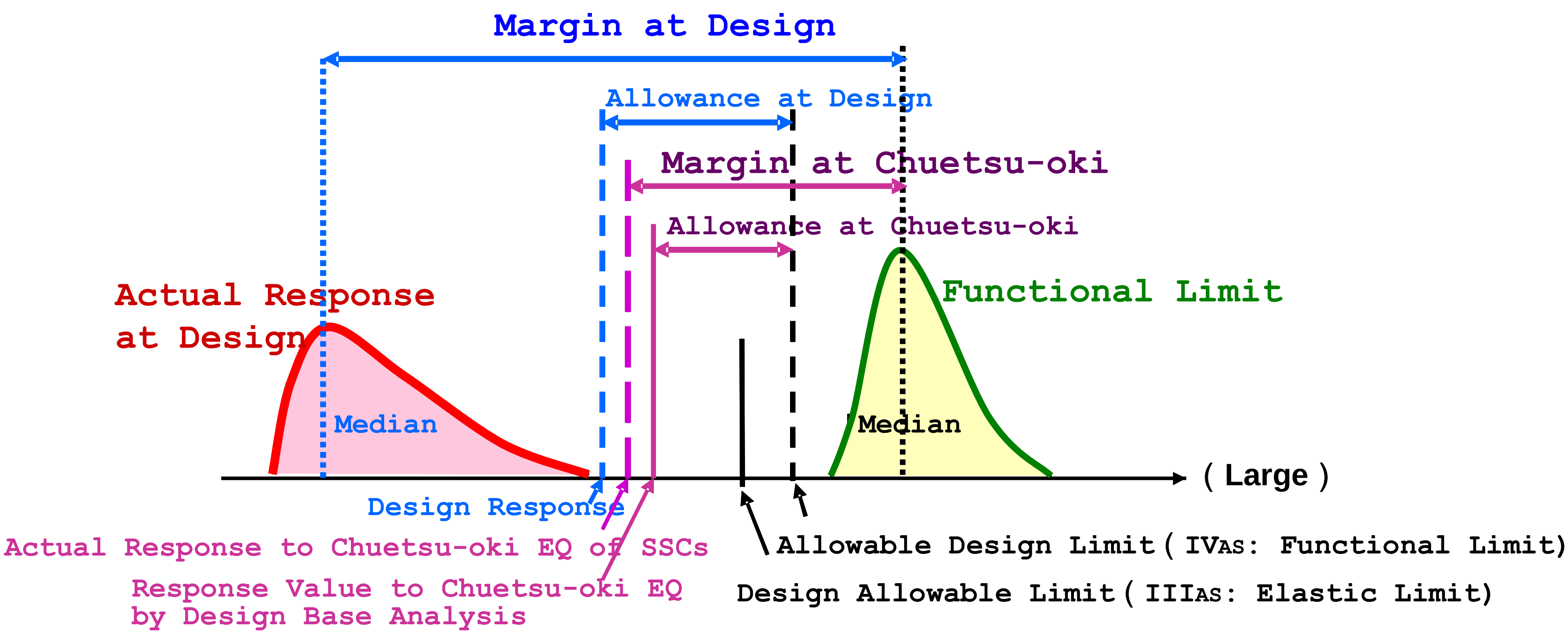
Test objective change

Design Proving → **Investigation of Fragility**

Background　: Margin

Seismic Safety is Secured by the Design which has Certain Margin

(Seismic Margin = Functional Limit / Actual Response)



Background：Necessity of Fragility Test

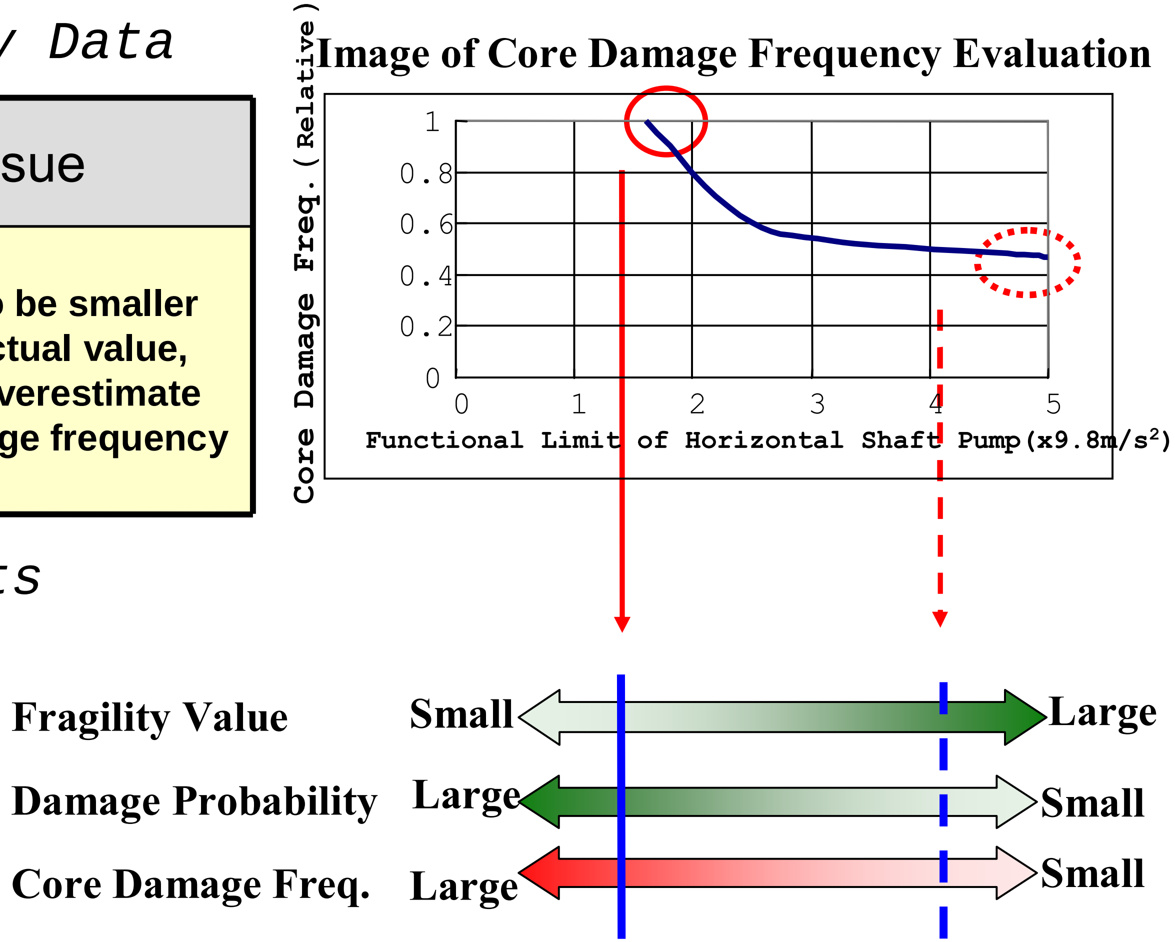
(1)Current Fragility Data

Currently Used	Issue
Estimation from Domestic Previous Research	Thought to be smaller than the actual value, and may overestimate core damage frequency
Partial Diversion of the U.S. Data	

(2)Objective of Tests

Grasp Realistic Fragility Data for Accurate Seismic Margin Evaluation and Seismic PSA

Image of Core Damage Frequency Evaluation



Current Fragility Values → Large Fragility Value=Small Core Damage Freq.

2． History of Vibration Tests on Large SCCs and Introduction of Fragility Tests

1980 1985 1990 1995 2000 2003 2009

Phase（Proving Tests of Large SCCs）

PCV(PWR,BWR), RPV(PWR,BWR),
Core Internals (PWR,BWR), PLR (BWR), Primary Loop (PWR)

Phase（Proving Tests of Compound System）

EDG System, Process Comp. System
RHR System

Phase（New Tech.SCCs and Structural Integrity）

Piping with Energy Absorbing Support ,RCCV、PCCV、
Steam Generator with Energy Absorbing Support,
Piping Ultimate Strength

Fragility Test Series（Phase）

(1) Horizontal Shaft Pump (RCWp)、Electric Panels
(2) Control Rod Insertion (BWR,PWR）
(3) Vertical Shaft Pump (RHRp)

NUPEC

JNES

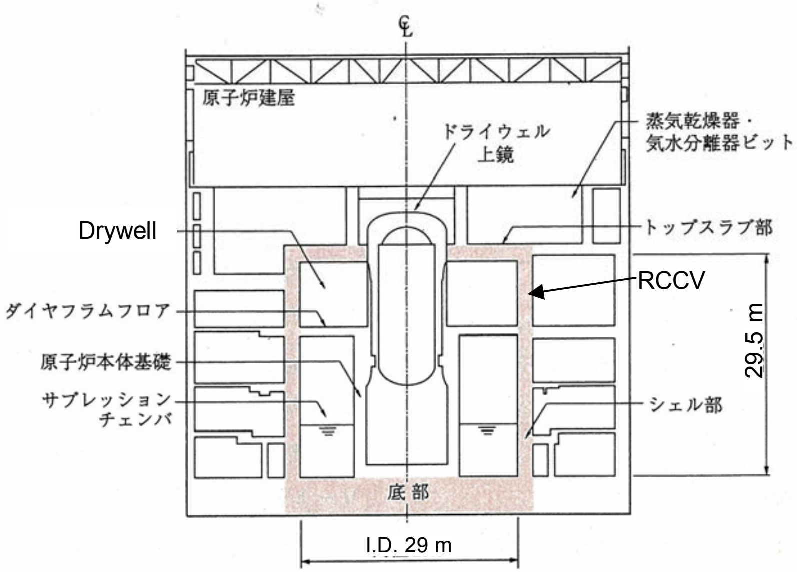
Fragility Test Series（Phase ）

(4) Tank
(5) Valve
(6) Overhead Crane
(7)Snubber,etc

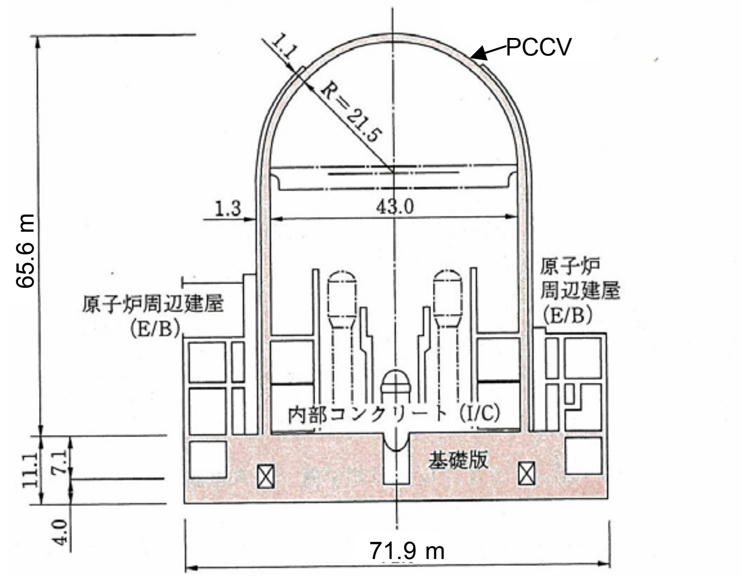
3. Fragility Tests outline

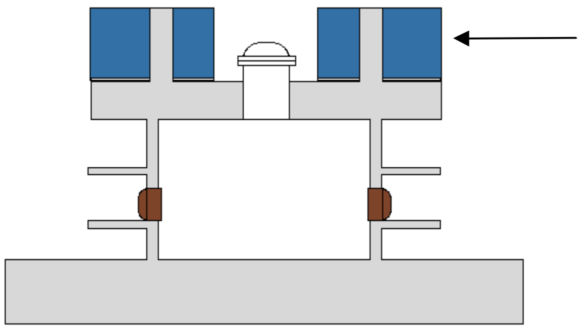
3.1 Concrete Primary Containment

Reinforced Concrete Containment for ABWR

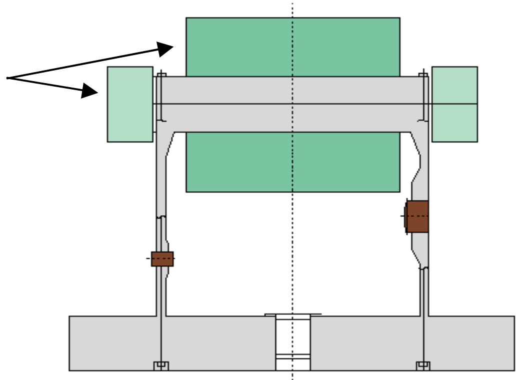


Pre-stressed Concrete Containment For PWR





Added Mass to Adjust Seismic Load at Lower Cylindrical Wall



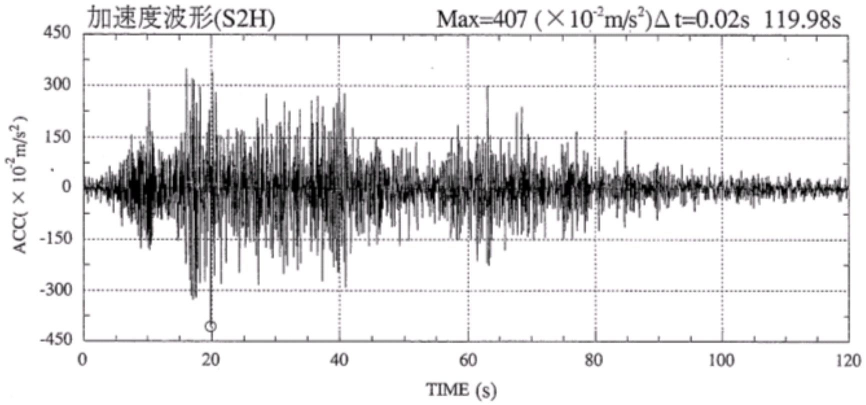
Specimen (1/8 Scale)

(Total Weight : 595ton、Height : 5.21m、Outer Dia. : 4.0m)

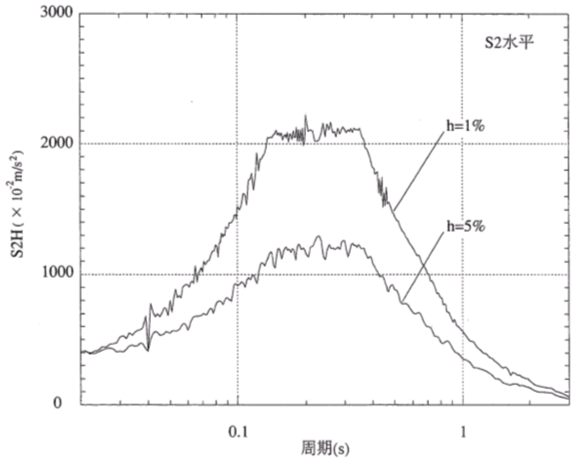
Specimen (1/10 Scale)

(Total Weight : 757ton、Height : 6.53m、Outer Dia. : 4.6m)

Test Condition



Acceleration Time History (S_2H)



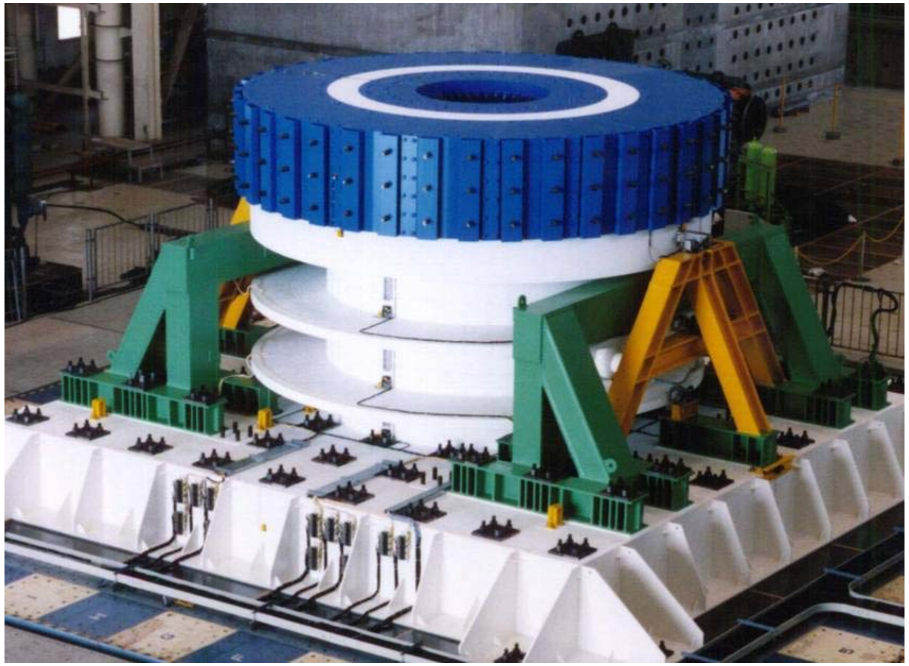
Response Spectrum (S_2H)

Input Motion for Reinforced Concrete Containment

- Severest Motion Selected from Design Motions of Real Plants
- Destructive Test beyond Design Condition

Test Item	Design Level Test		Margin Test
	S_1	S_2	
Structural Integrity	○	○	○
Functional Integrity	○	○	○

Specimens on the Table



Reinforced Concrete Containment

(Scale:1/8, Total Weight : 595ton

Height:5.21m, Outer Dia: 4.0m)

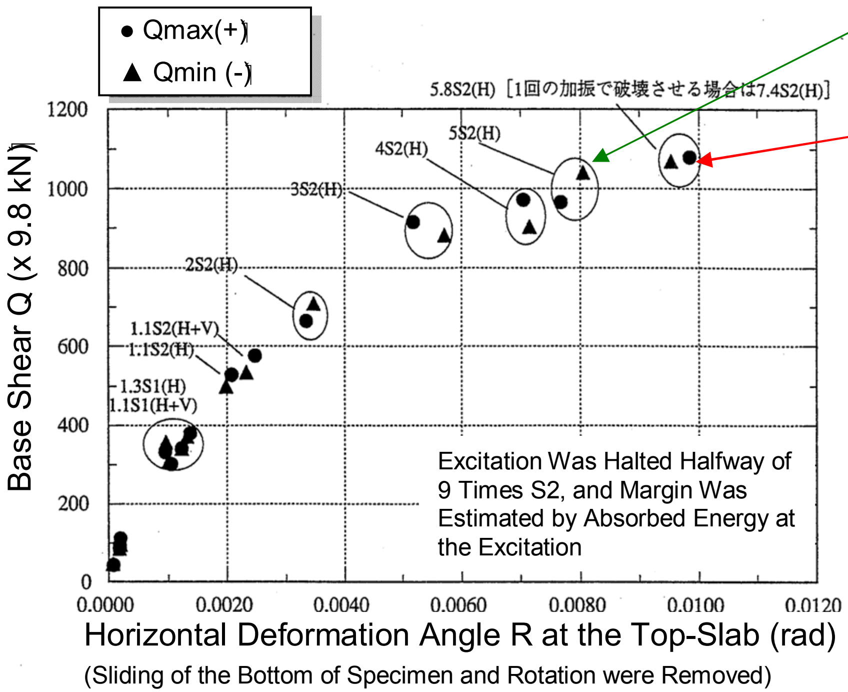
Pre-stressed Concrete Containment

(Scale :1/10, Total Weight: 757ton

Height: 6.53m,Outer Dia.: 4.6m)

Video of PCCV Destructive Test

Summary of CCV Test



Load to Deformation Relation
Through Excitation History
(RCCV)

- No leak up to 5 Times S2 Excitation

- Shear Failure during 9 Times S2 Excitation and Liner Failure
- Evaluation by the amount of energy absorbed only by 9 Times S2 Excitation :

  Failure at 5.8 Times S2

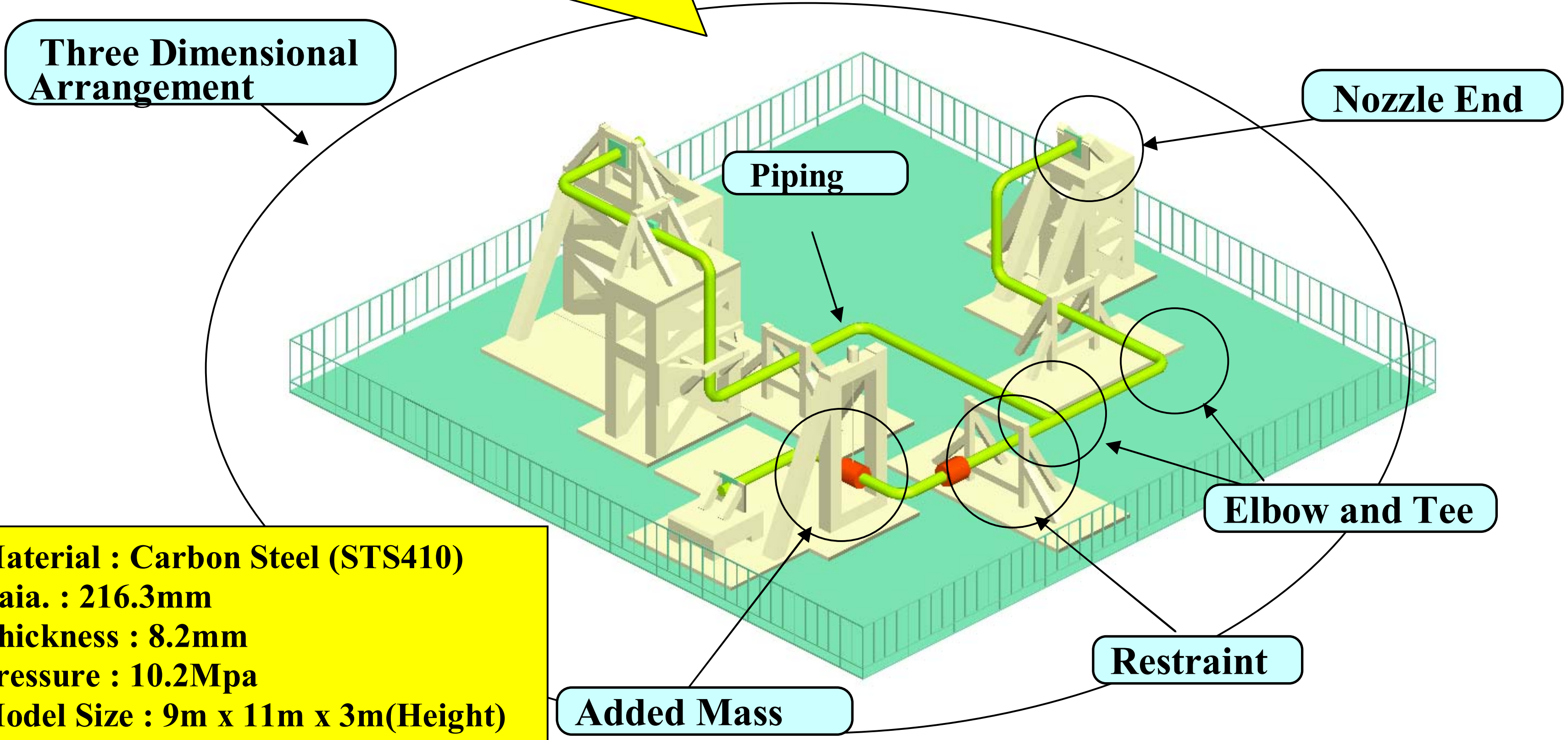
Margin Evaluation by the Tests

(Equivalent One Excitation Margin Evaluated by Energy Absorbed through Excitation History)

- RCCV : 7.4 Times S_2
- PCCV : 6.1 Times S_2

3.2 Piping Ultimate Strength

Model Simulate Structural and Vibration Characteristics of Real Piping System

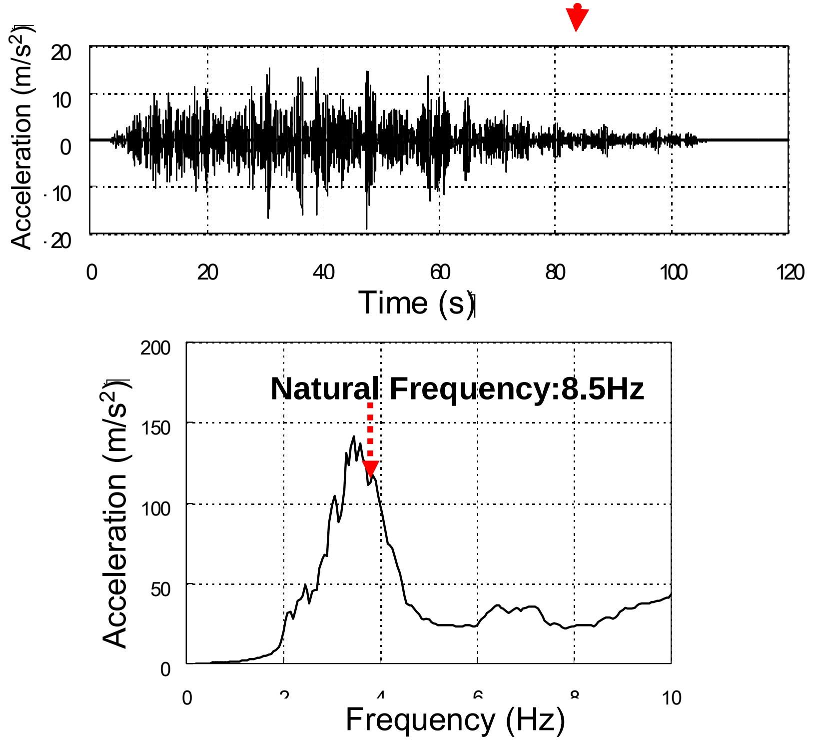


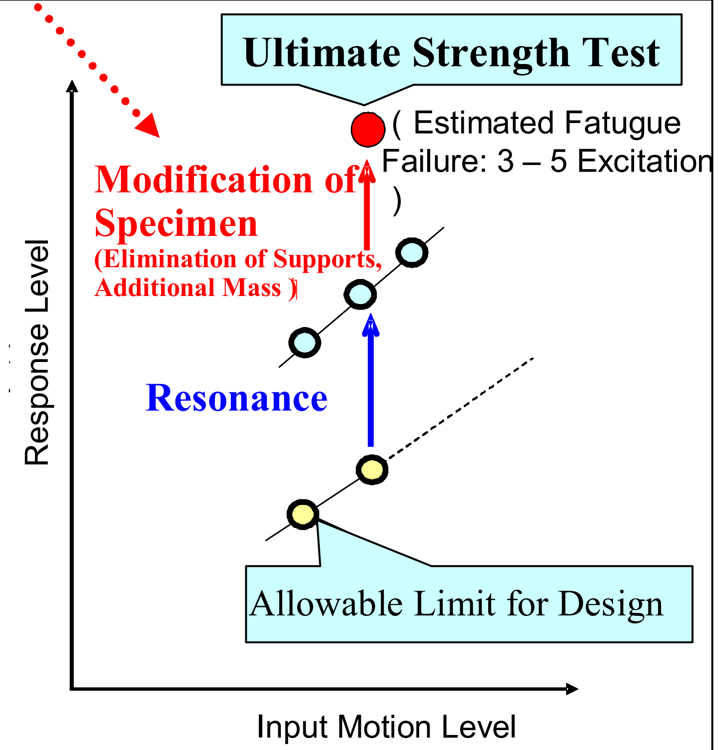
- **-Material : Carbon Steel (STS410)**
- **-Daia. : 216.3mm**
- **-Thickness : 8.2mm**
- **-Pressure : 10.2Mpa**
- **-Model Size : 9m x 11m x 3m(Height)**
- **-Total Weight : 63 ton**

Test Condition

Virtual Test Condition (Input Motion, Modification of Specimen) that Gives 8.5 Times Stress of Allowable Limit
- Modification of Input Motion (Acceleration, Time Scale (Resonance) and
- Modification of Specimen (Elimination of Support Points, Additional Mass)
- Stress of 8.5 Times Allowable Limit as the Result

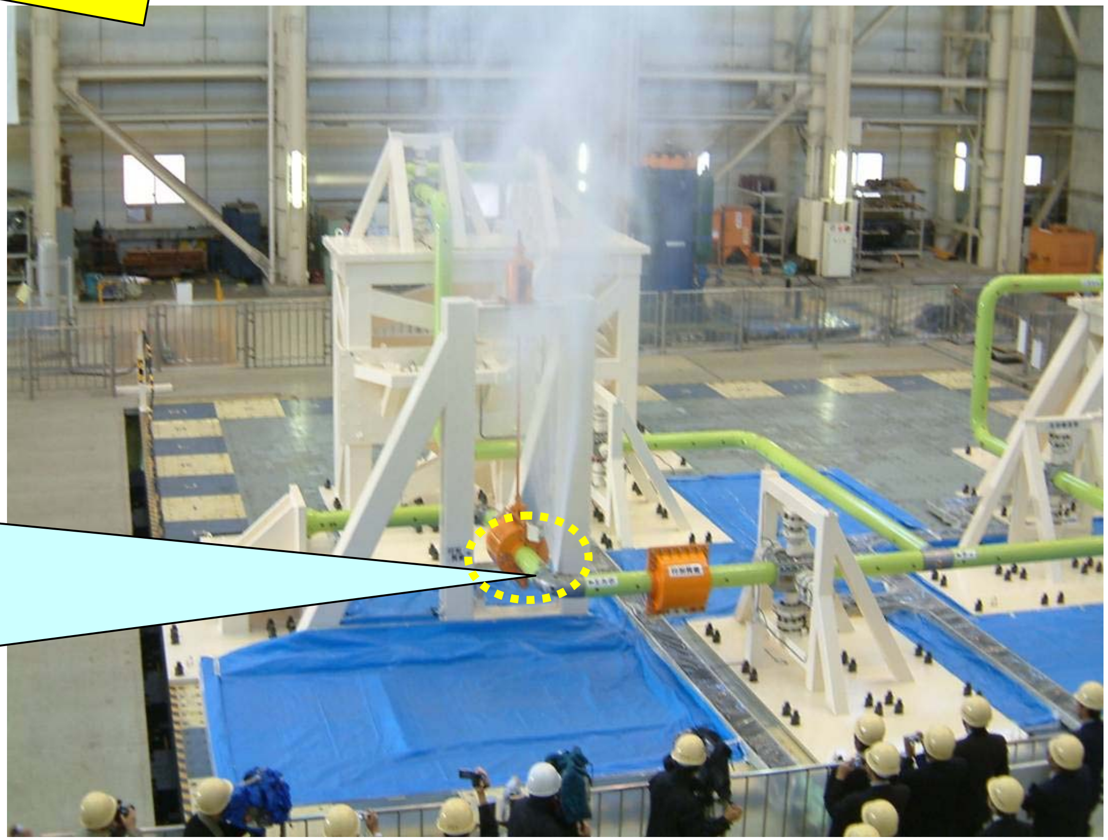
Limitation of Shaking Table Performance



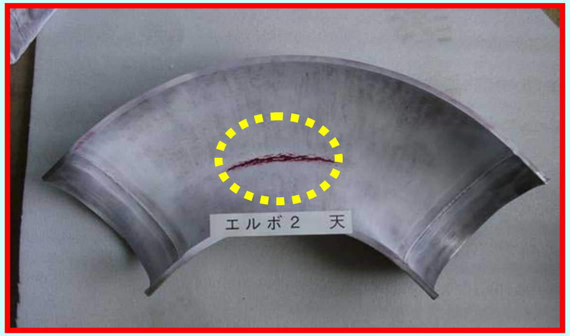


Excitation Test

Piping Ultimate Strength Test
(Excitation by 8.5 Times Allowable Level Input)



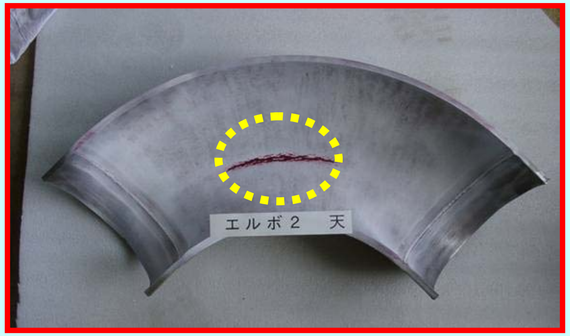
Fatigue Failure during Fifth Excitation

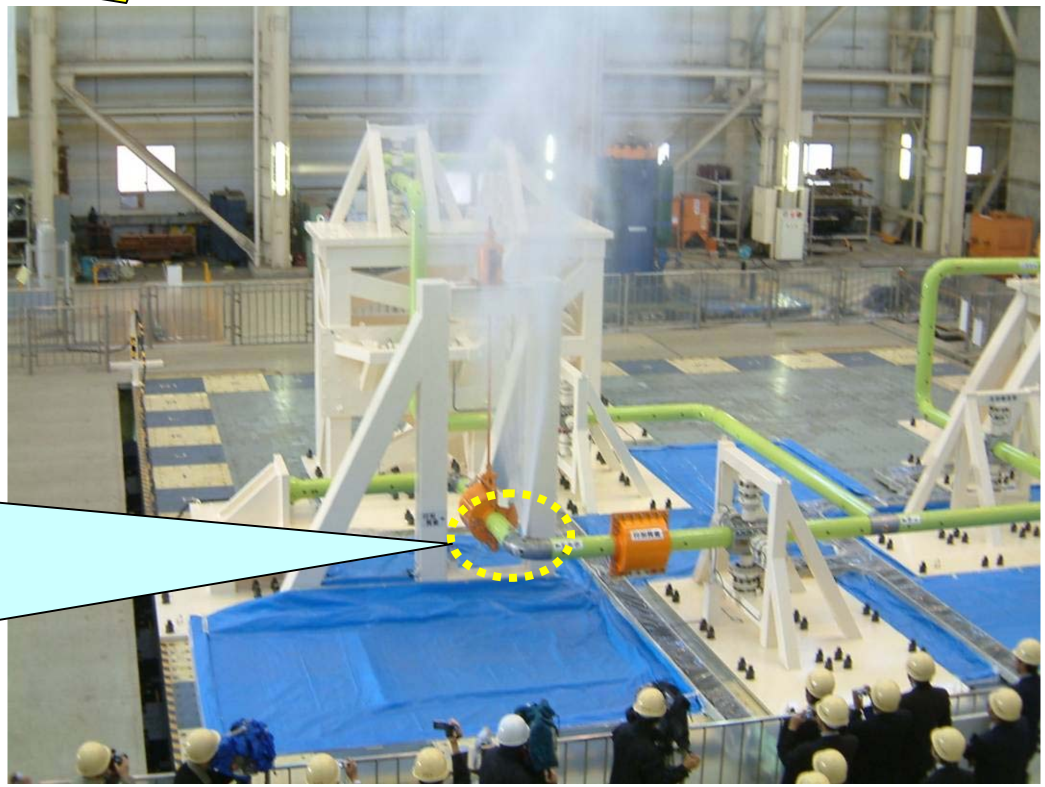


Excitation Test

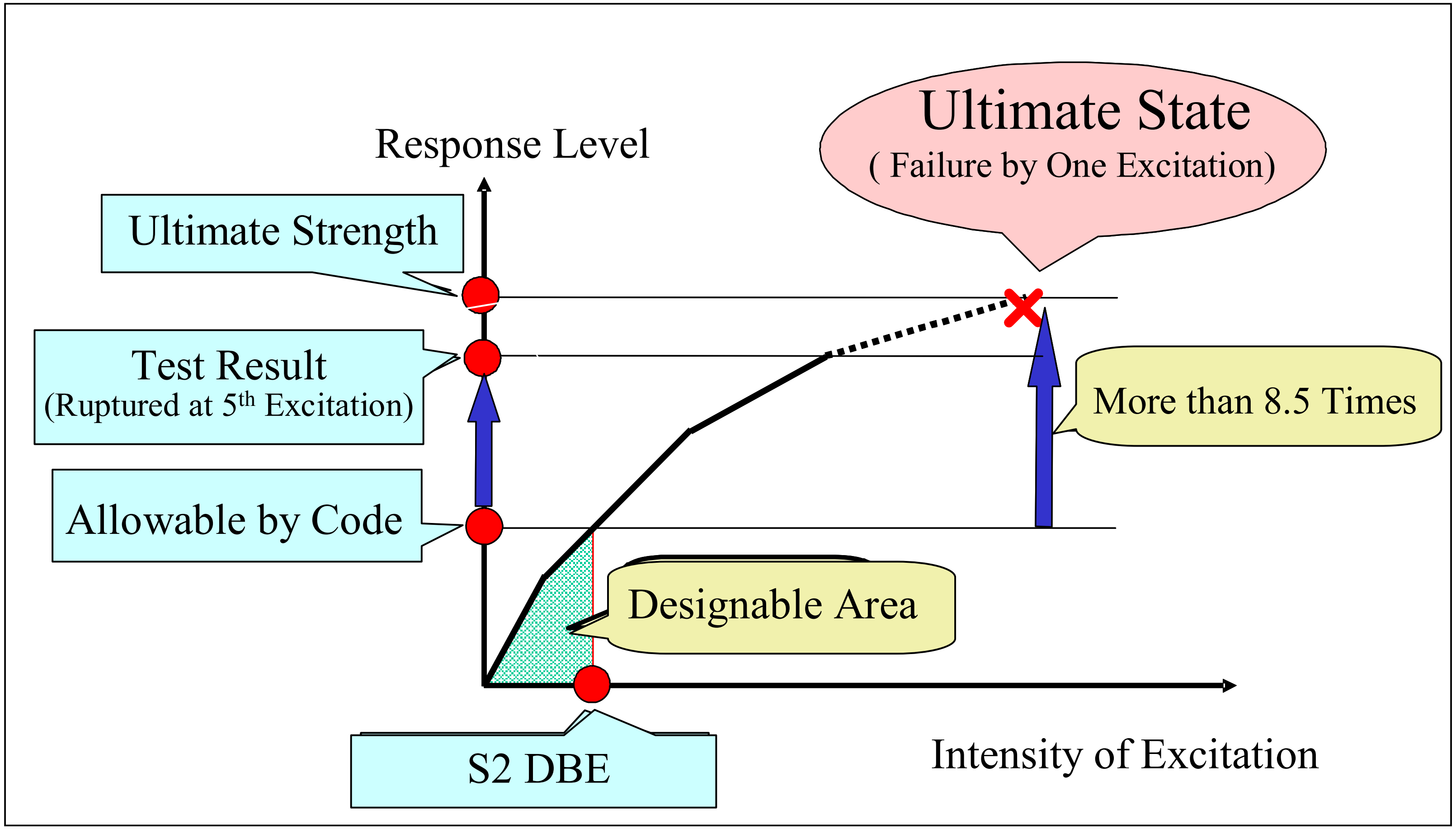
Piping Ultimate Strength Test
(Excitation of 8.5 times of the IV_{AS} Allowable Stress Level)

Fatigue Failure during Fifth Excitation





Summary of the Test



Note) Design Allowable: Allowable Stress Condition VIAS (JEAG4601)

3.3 Electric Panel

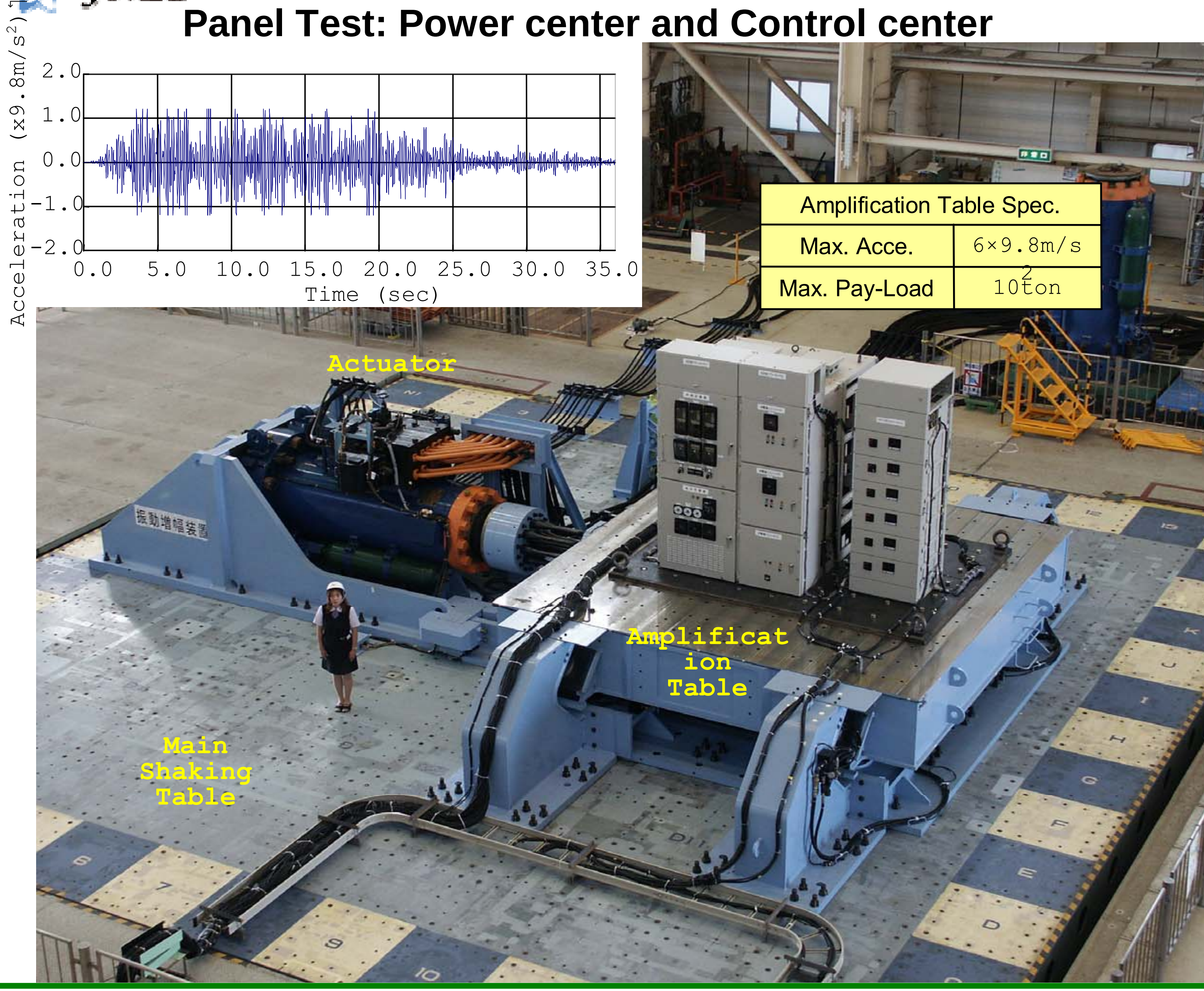
(1) Specimens

Panel	Mass (t)
Main Control Board	1.0
Reactor Auxiliary Board	2.5
Logic Circuit Panel	1.0
Reactor Protection Rack	2.2
Instrumentation Rack	0.7
Reactor Control Center	0.6
Power Center	4.0
6.9kV Metal-Clad Switch Gear	5.6

(2) Input Motion and Test Condition

Item	Condition
Basic Excitation Motion	Synthetic Motion Enveloped Actual Design Spectra (Max:1.2x9.8m/s^2)
Excitation Level	Basic to 6x9.8m/s^2
Electrical Condition	Active Simulating Real Operating Condition
Excitation Direction	Front to Back and Side to Side

Panel Test: Power center and Control center



Amplification Table Spec.	
Max. Acce.	6×9.8m/s^2
Max. Pay-Load	10ton

(3) Test Result

Main Control Board, Reactor Auxiliary Board, Logic Circuit Panel, Instrumentation Rack :

No Damage and No Malfunction up to 6×9.8m/s^2 (B-F, S-S)

Panel Name	Malfunction Mode	Input Level (x9.8m/s^2)
Reactor Control Center	Error of Magnetic Contactor Caused by Auxiliary Relay Chatter	6.1 (F-B)
Reactor Protection Rack	Error of AC Controller Card (Relay Error)	4.3 (S-S)
Power Center	Error of Breaker Closing	3.7 (F-B)
	Damage of Air Circuit Breaker	5.0 (F-B)
6.9kV Metal-Clad Switch Gear	Fall out of Fuses from GPT	2.5 (F-B)
	Damage of Vacuum Circuit Breaker	4.7 (S-S)

↓

Cause of Failure : Malfunction or Damage of Parts

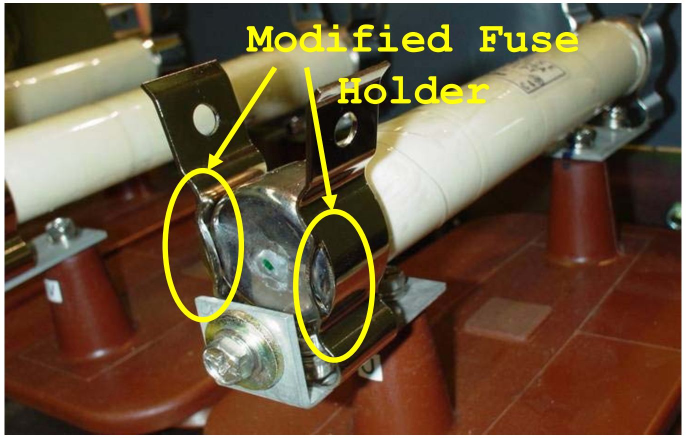
Element Test (Typical)

Test Condition

Item	Condition
Basic Input Motion	T.H. from Response Analysis of Panels
Input Level	Design Value to 10 x $9.8m/s^2$
Electrical Condition	Same as Operation Condition
Excitation Direction	Front to Bach and Side to Side

Element Test (Differential Relay)

Additional Element Test (Fuse of Metal-Clad Switch Gear)



Drop off of Fuse at $2.5x9.8m/s^2$ in Metal-Clad S.G. Test

After Modification of Fuse Holder : Function Maintained up to 6x9.8m/s2 (Element Test)

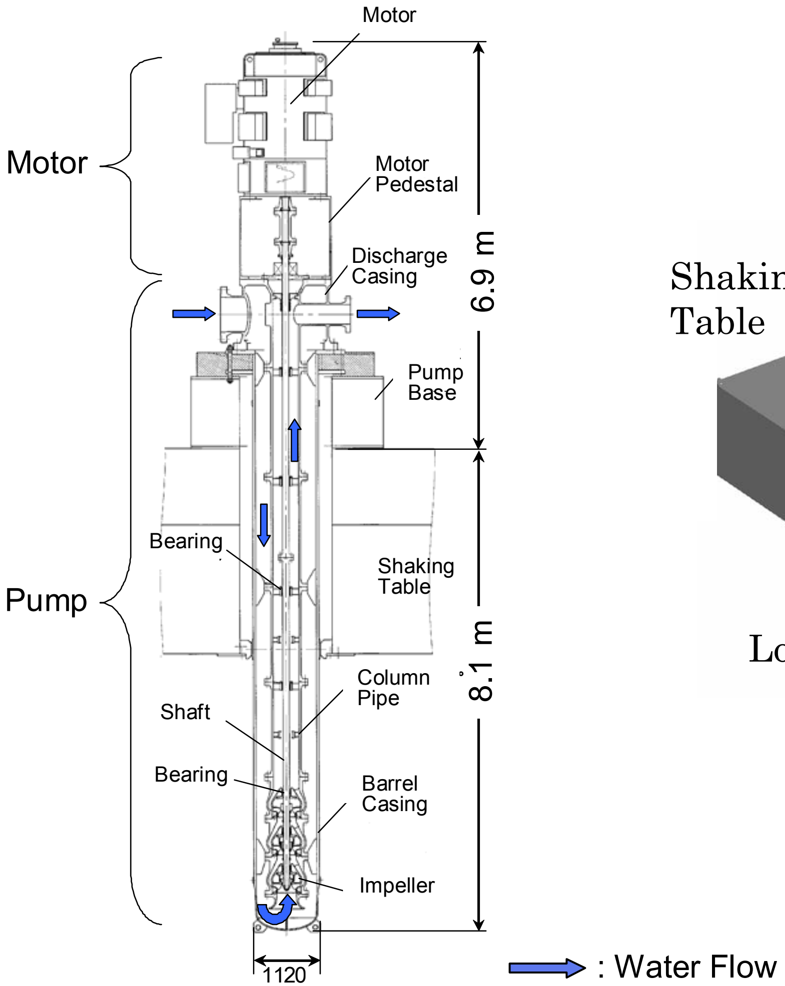
Final Evaluation of Panels

(Re-evaluation Result considering Element Tests and Modifications)

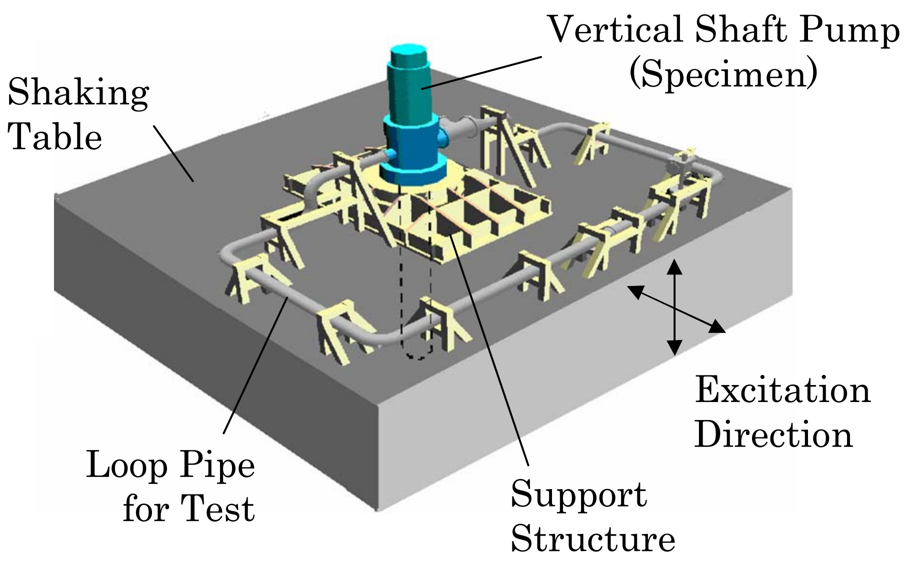
Panel Name	Critical Direction	Input Acceleration (Median)	Critical Component (Amplification Factor)
Main Control Board	S-S	5.6×9.8m/s^2	Flat Display(1.7)
Nuclear Auxiliary Board	F-B	9.8×9.8m/s^2	Module Switch(1.1)
Logic Circuit Control Panel	S-S	6.7×9.8m/s^2	Power Source (1.7)
Reactor Protection Rack	S-S	4.4×9.8m/s^2	AC Controller Card(1.9)
Instrumentation Rack	左右	4.2×9.8m/s^2	Differential Pressure Transmitter (2.5)
Reactor Control Center	前後	4.5×9.8m/s^2	Auxiliary Relay (1.3)
Power Center *	前後	4.4×9.8m/s^2	Air Circuit Breaker (1.0)
6.9kV Metal-Clad Switch Gear *	左右	4.2×9.8m/s^2	Vacuum Circuit Breaker (2.0)

Note :*After Modification of Elements

3.4 Vertical Shaft Pump



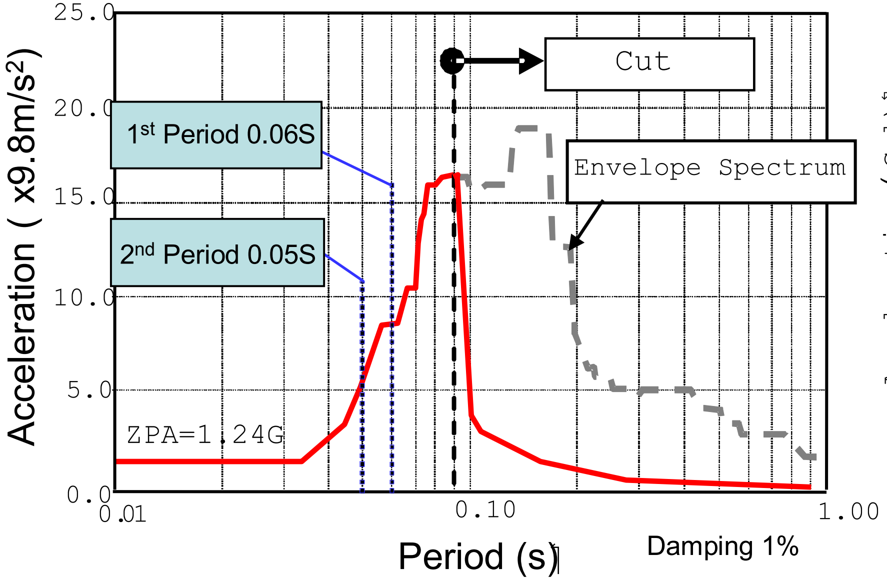
(Model :RHR Pump, Scale:1/1)

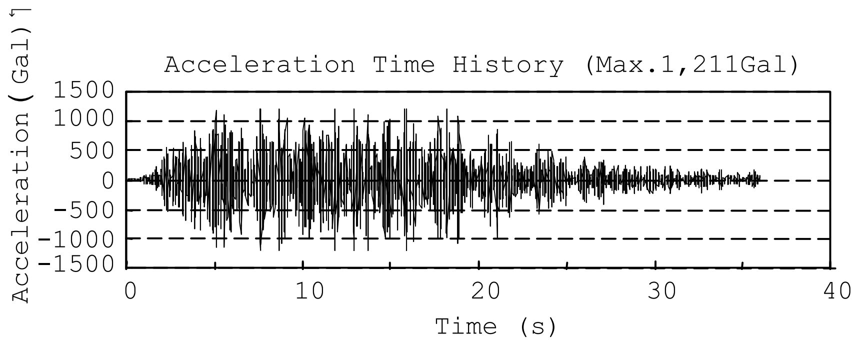


Test Condition

Input Motion : Synthetic Wave which Envelope Design Spectra of BWR and PWR in Japan and Filtered Long Period Ingredient more than 0.9 Second

Max. Acceleration : 3G

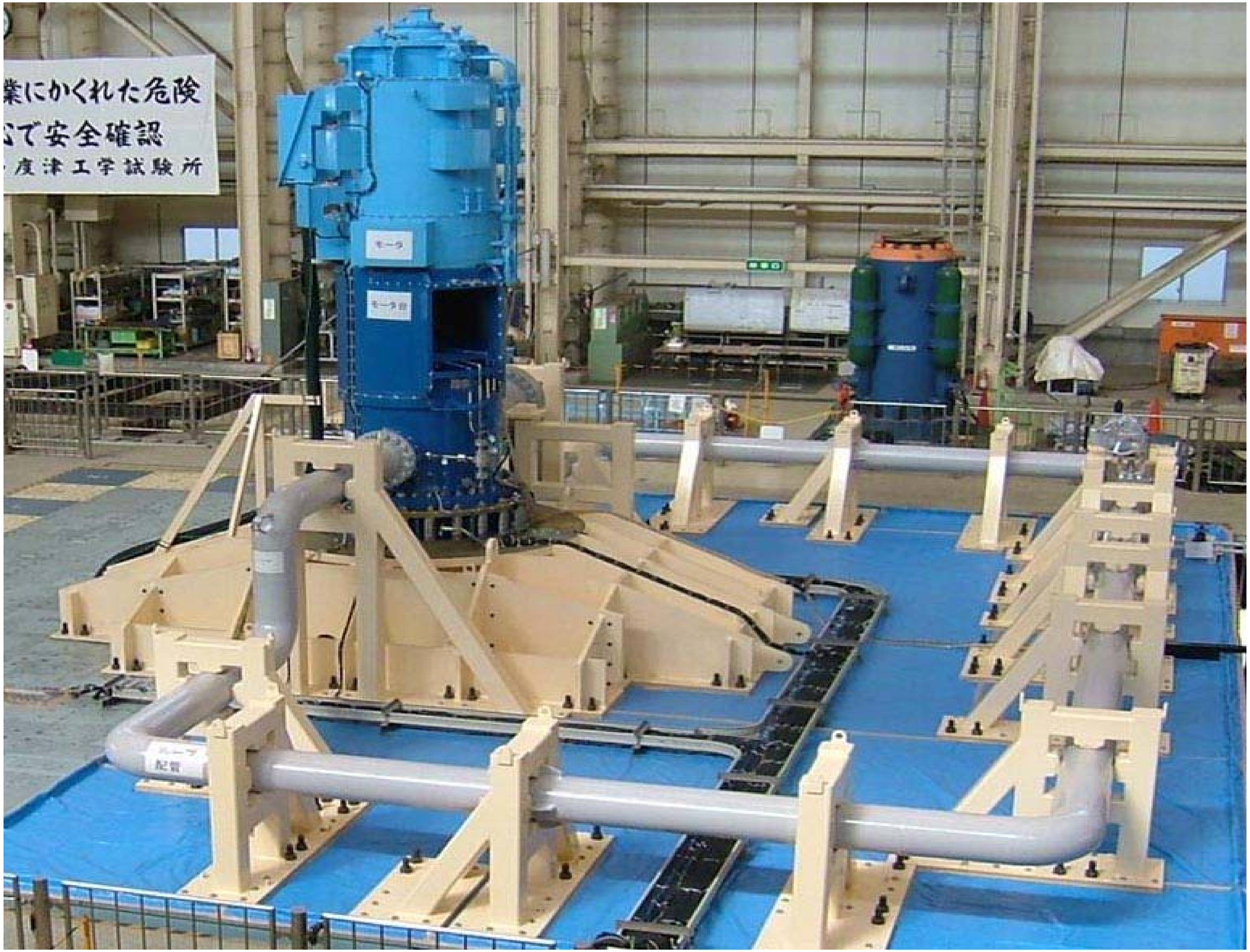




Basic Horizontal Input Motion

(Envelope of Design Spectra of BWR and PWR)

Test-scape



Summary of the Test

(1) Anomaly Observed in Test and Its Response Acceleration

→ **Structural Portions Only**

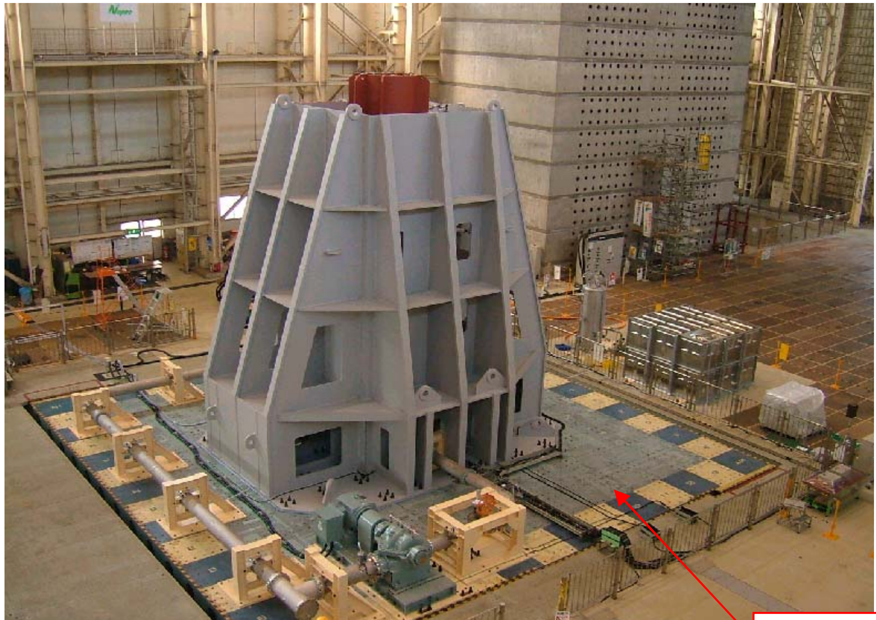
Portion	Abnormal Phenomena	Response Acceleration at Relevant Portion
Motor (Anchor Bolt)	Yield	$12\times9.8m/s^2$ (Motor Top)
Pump (Barrel Support)	Yield	$30\times9.8m/s^2$ (Barrel Tip)

(2) Max. Acceleration Where Functional Integrity was Confirmed after Anomalies were Fixed

Portion	Max. Acceleration	Max. Functional Integrity Confirmation Acceleration in Bygone Studies
Pump (Column Tip)	$35\times9.8m/s^2$	$10\times9.8m/s^2$
Motor (Top)	$14\times9.8m/s^2$	$2.5\times9.8m/s^2$

3.5 Control Rod Insertion Test of PWR and BWR

Scale : 1 / 1
Constitution of Specimens : Control Rod,
Fuel Bundle, Control Rod Drive Mechanism



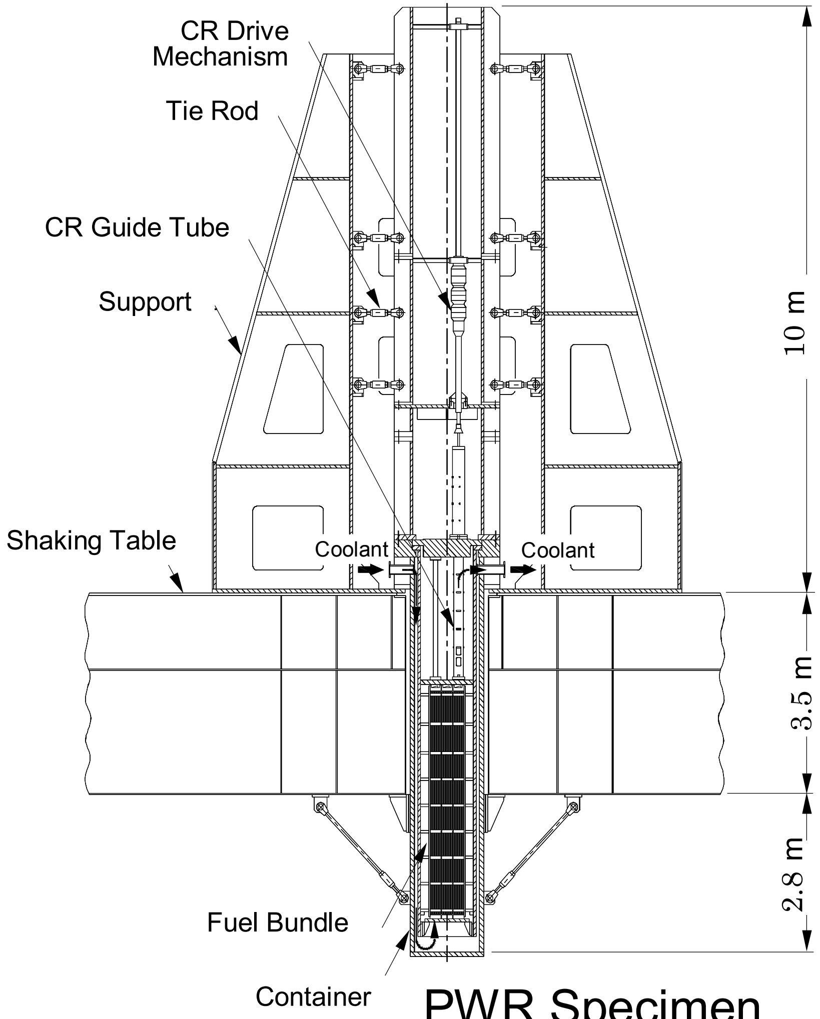
Shaking Table

PWR Specimen
(Height : Above Shaking Table : 10.2m , Under Shaking Table : 6.3m)

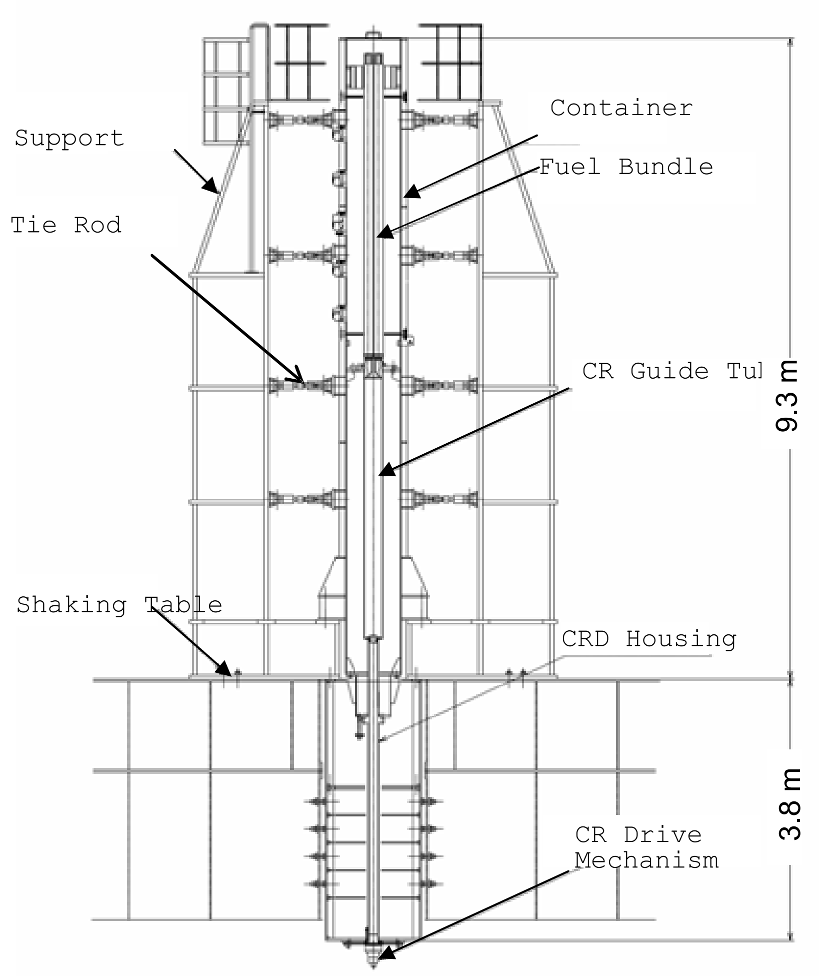
BWR Specimen
(Height : Above Shaking Table : 9.3m , Under Shaking Table : 4.2m)

Outline of the Specimen

Input Motion was Made to Give Fuel Bundles and Control Rod Drive Mechanism Equivalent Response as Real Plants

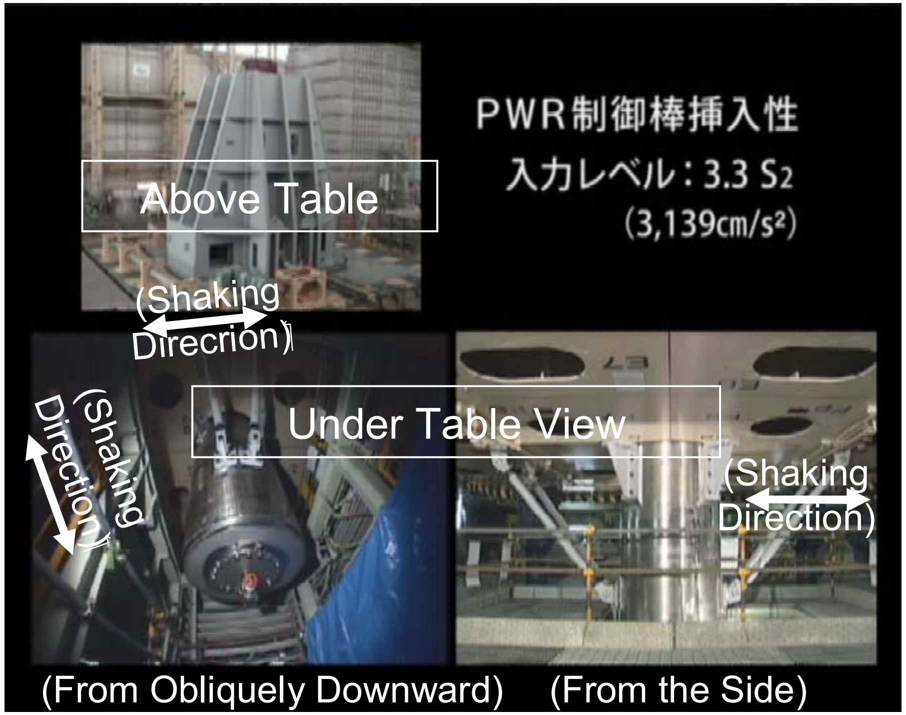


PWR Specimen

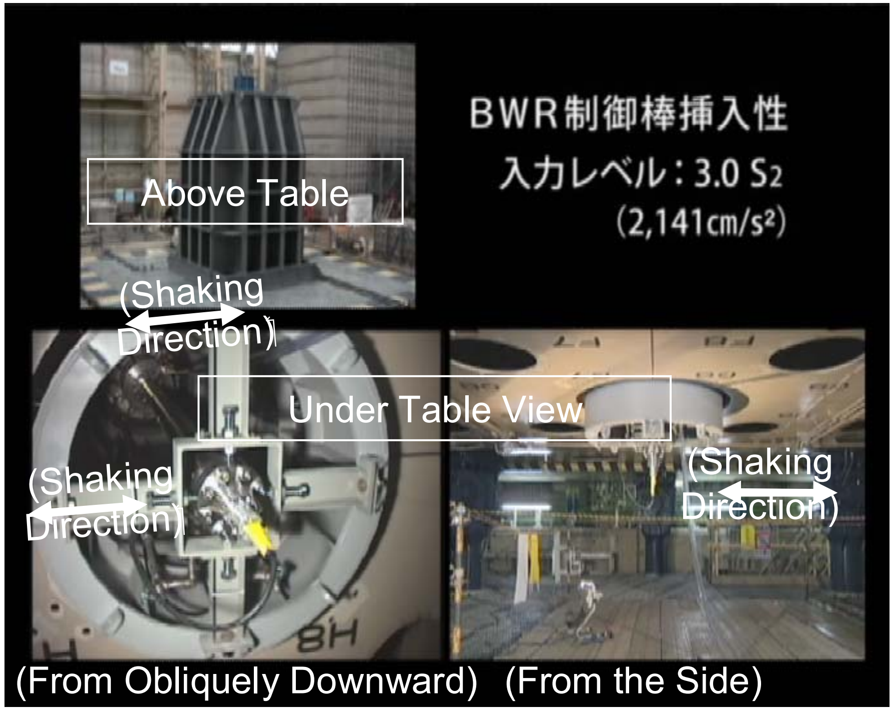


BWR Specimen

Test-Scape

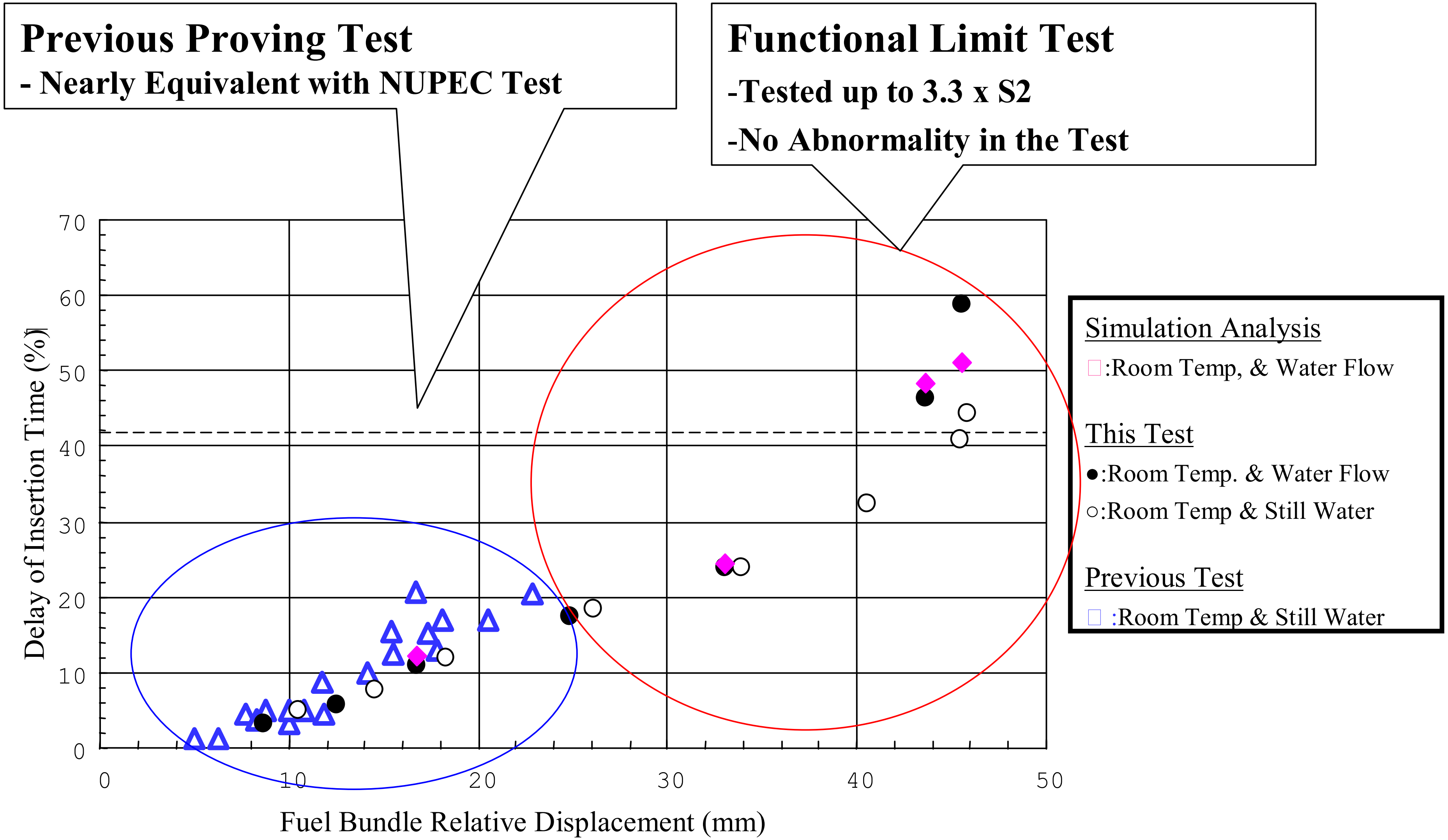


PWR CR Insertion Test
$3.3S_2$ Input Motion
($3{,}139cm/s^2$)



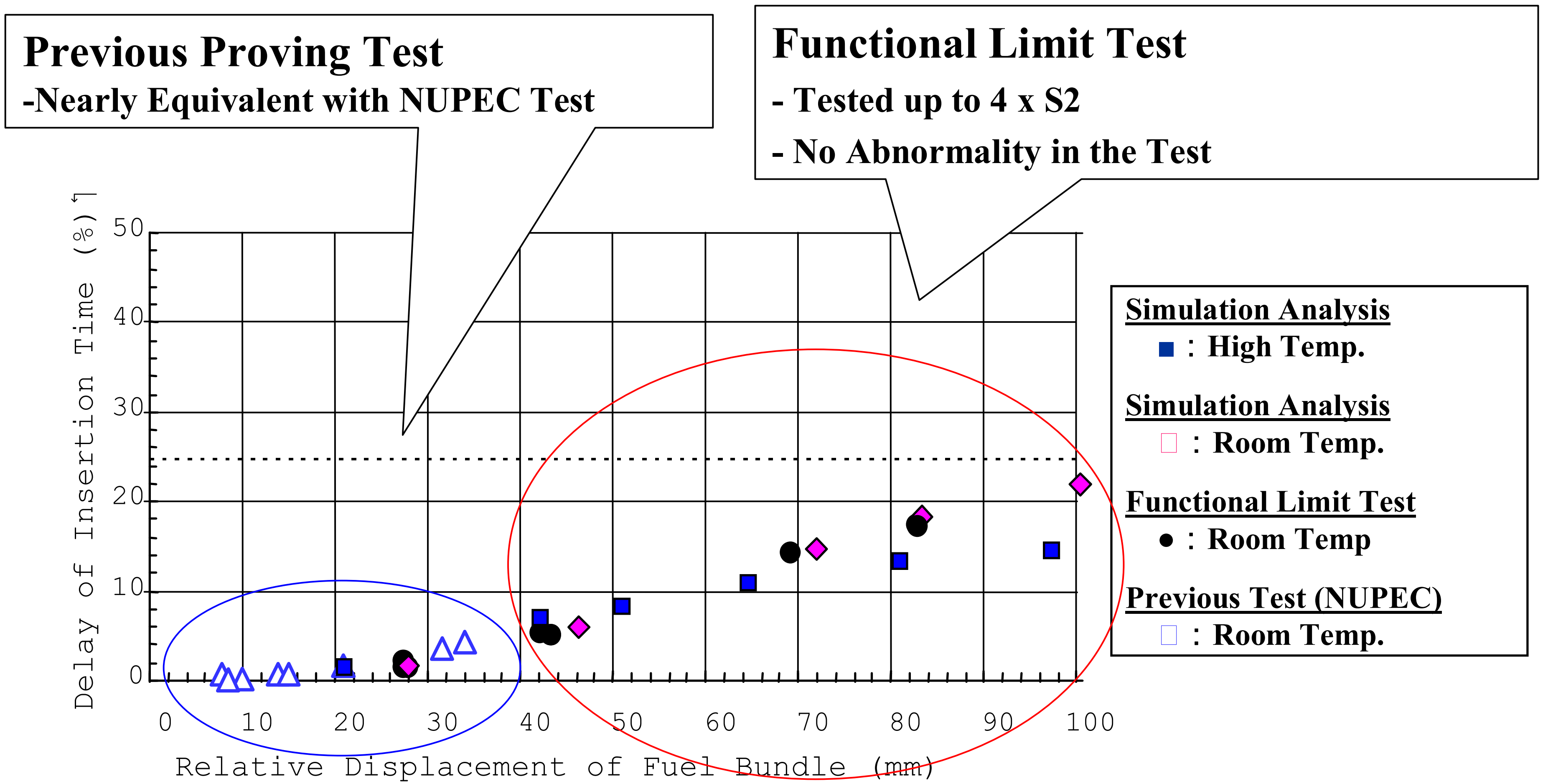
BWR CR Insertion Test
$3.0S_2$ Input Motion
($2{,}141cm/s^2$)

Summary of PWR CR Insertion Test



Delay Time of CR Insertion vs. Relative Displacement of Fuel Bundle（ＰＷＲ）

Summary of BWR CD Insertion Test



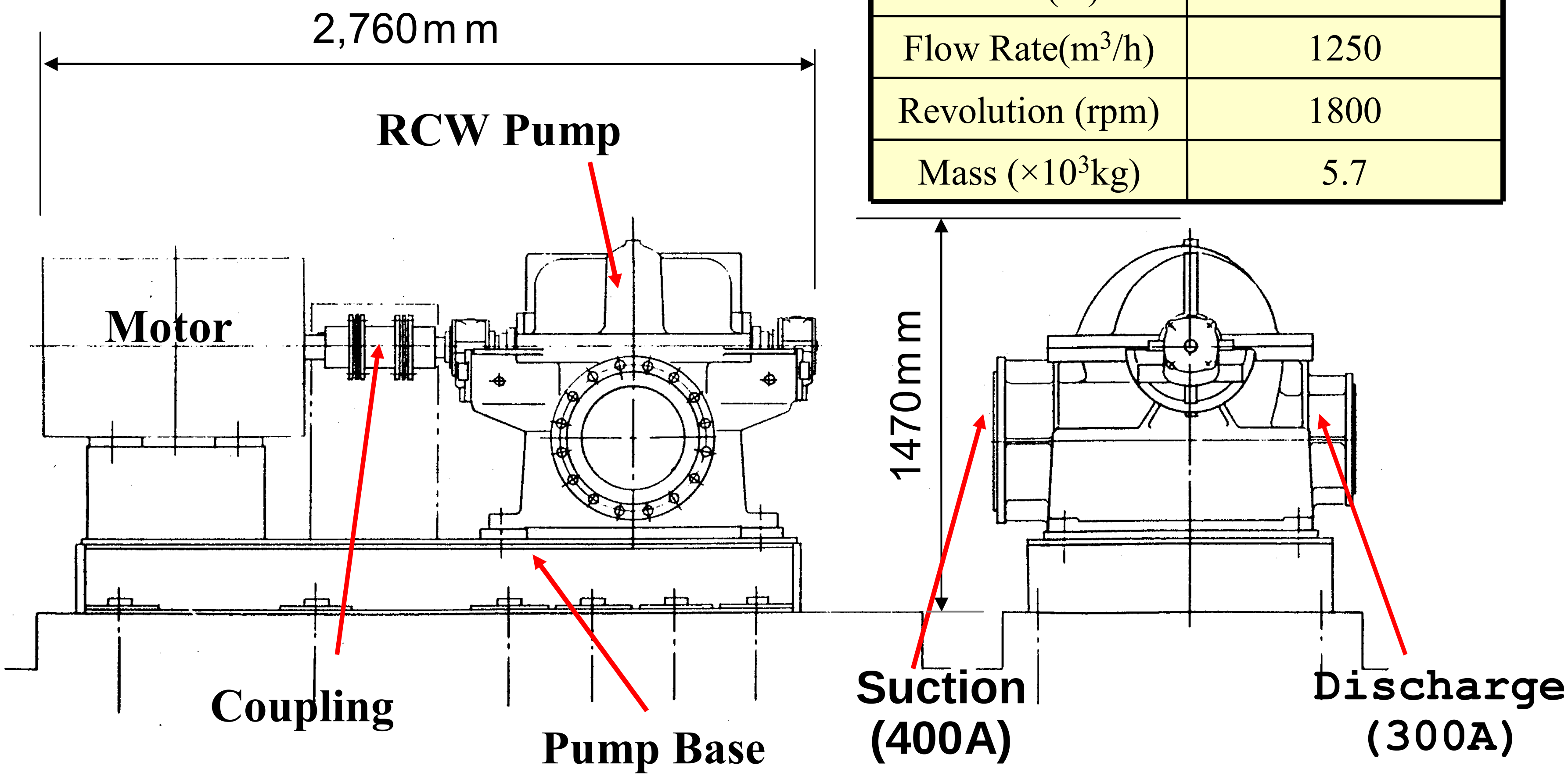
Delay Time of CR Insertion vs. Relative Displacement of Fuel Bundle （BWR）

3.6 Horizontal Shaft Pump

(1) Specimen

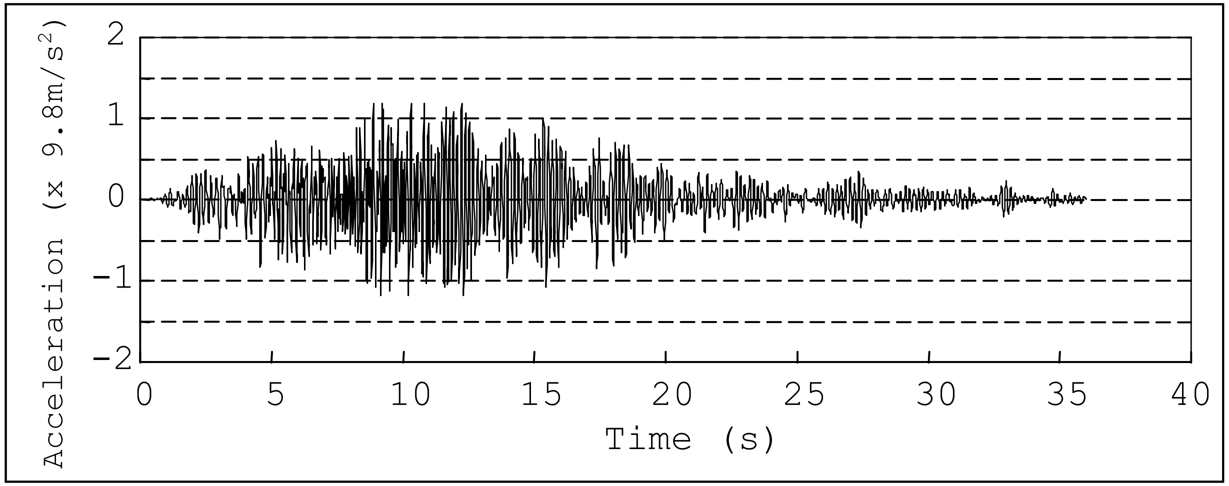
Reactor Auxiliary Cooling Water (RCW) Pump

Specification	
Type	Double Suction Single Stage Centrifugal
Head (m)	55
Flow Rate(m^3/h)	1250
Revolution (rpm)	1800
Mass ($\times 10^3$kg)	5.7

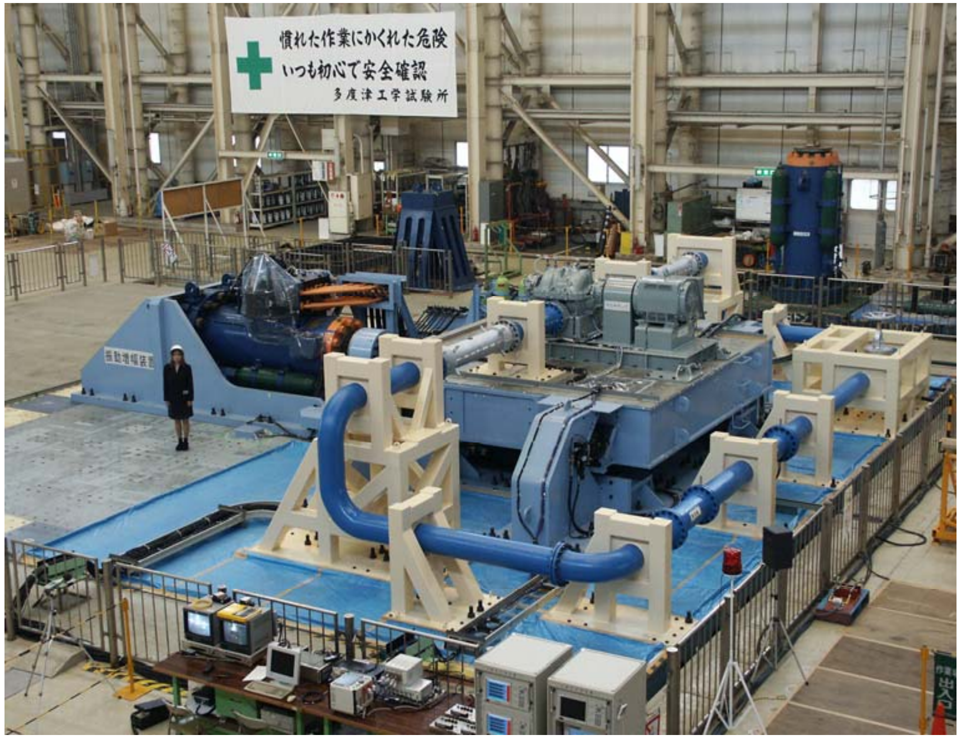


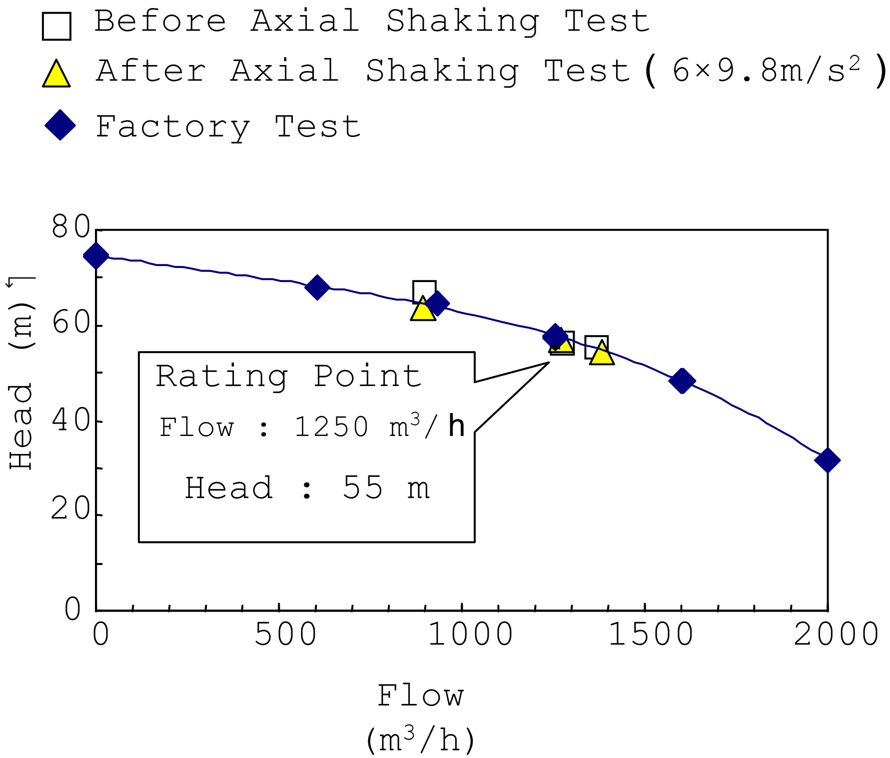
(2) Test Method

Item	内　容
Specimen	Reactor Auxiliary Cooling Water Pump
Basic Input Motion	Synthetic Motion which Envelope Design Spectra (1 x 9.8m/s^2)
Input Level	2 – 6 x9.8m/s^2
Pump Condition	Halt and Normal Operation Condition
Excitation Direction	Parallel and Perpendicular Direction to the Rotor Axis



(3) Test Result



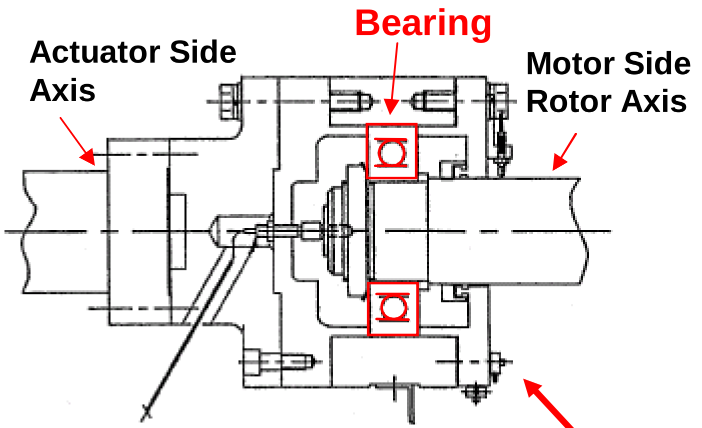


Input Acceleration :
Max. 6 x 9.8m/s^2

→ **No Abnomality**

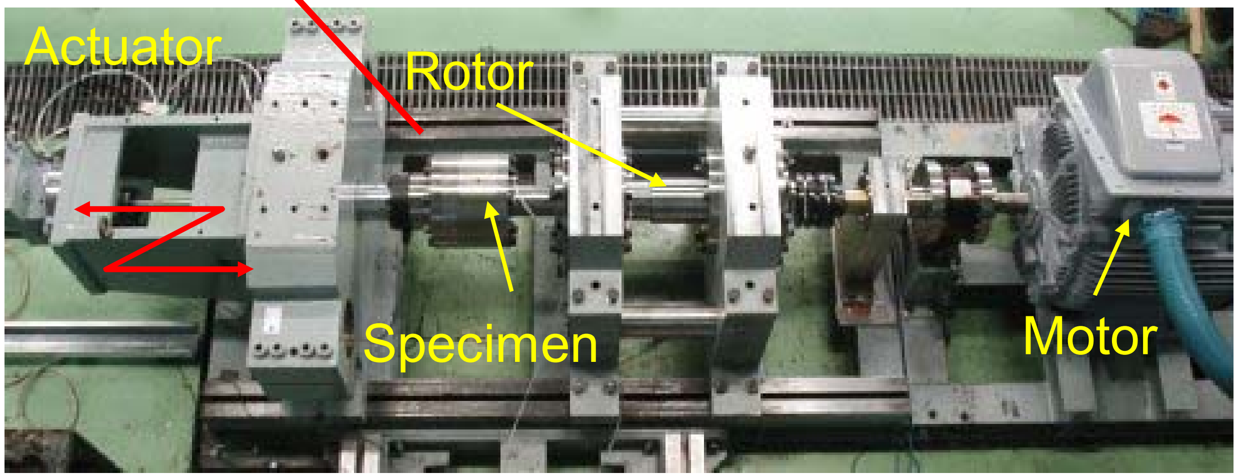
(4) Bearing Element Test

Dynamic Shaking Test of Bearings Used in Horizontal Shaft Pump



Element		Size (Type)	Quantity
Radial Bearin	Ball (Deep groove)	110mm O.D. (6310)	Three per One Element
		170mm O.D. (6316)	
	Slide (Sleeve)	60mm I.D.	
		80mm I.D.	
Thrust Bearin	Ball (Deep groove)	1100mm O.D. (6310)	
		170mm O.D. (6316)	
	Ball (Angular contact)	170mm O.D. (7316B)	
	slide (Kingsbury)	127mm I.D.	
Liner Ring	Flat	270mm, 267mm, 195mm, 175mm, 88mm (All in I.D.)	
	Groove	95.5mm I.D.	

Note: Ball bearing(6310) and 270mm liner ring are same type used in RCW pu

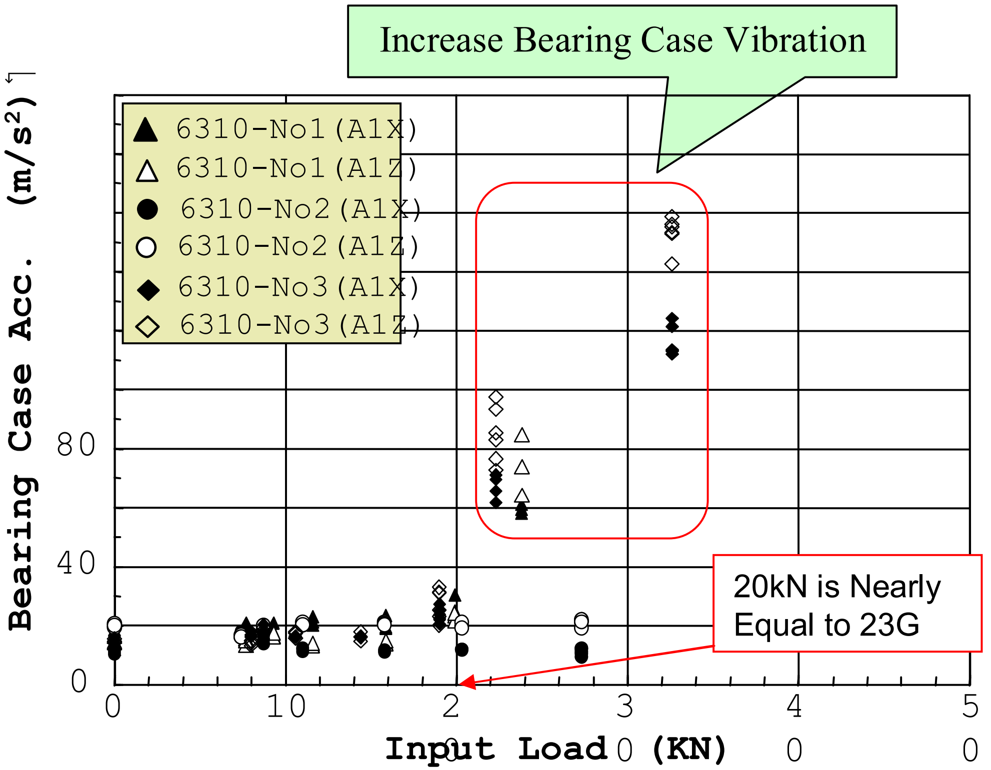


Test-Scape of Axial Direction

(4) Element Test Results

Bearing Case Vibration after Loading (Typical)

Specimen : 170mm O.D. Deep Groove Ball Bearing, Quantity 3
Loading : Dynamic Loading up to 10×9.8m/s², Axial
Result : Vibration Increase at Two Bearings out of Three Tested



(5) Summary of Horizontal Pump Test

Summary of Fragility Evaluation Considering Element Test

Horizontal Pump Type	Specification	Certified Acc.
Single-Stage (Test Specimen)	System：RCW Rated Flow：1250m^3/h Mass：5700kg Bearing：6316（Coupling Side） 6316（Opposite Side）	$8.4\times9.8m/s^2$
Multi-Stage (Analogous Equipment)	System：RCW Rated Flow：2050m^3/h Mass：8200kg Bearing：6318（Coupling Side） 7318B（Opposite Side）	$8.6\times9.8m/s^2$

4. Summary of 1st term

Specimen	Summary of Test
Concrete Containment	- Boundary Integrity is Secured until Destruction of Concrete - Margin against S_2 : 6 Times for PCCV, 7 Times for RCCV
Piping	8.5 Times of Design Allowable (Pipe Break Occurred at Fifth Excitation of 8.5 S2 Test)
Electric Panels	-No Abnormality in 6G Excitation for Main Control Board etc. -Malfunction Occurred in Some Panels around 2.5G Excitation, but Robustness can be Increased around 4G by Relatively Small Modification for Heavy Moving Parts or Fuse Holder
Vertical Shaft Pump	Functional Integrity was Confirmed up to 12G at the Top of Motor
Control Rod Insertion	PWR：Insertion Integrity was Confirmed up to 45mm Fuel Bundle Displacement BWR：Insertion Integrity was Confirmed up to 80mm Fuel Bundle Displacement
Horizontal Shaft Pump	Functional Integrity was Confirmed up to 8.4G Excitation

5. 2nd term: Overhead Crane

Revised Seismic Design Review Guide requires assessment of dynamic vertical response.

At the Chuetsu-oki Earthquake a overhead crane in the Kashiwazaki-Kariwa NPP was damaged.

■ Test Object

・Overhead crane with garters, a trolley, a hanging load, lugs, etc.

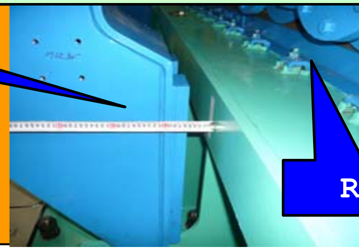
■ Contents of the Test

- Component Tests (in FY 2007)
  - (1) Factor analyses of the functional limit
  - (2) The mutual uplift and the collision assessment of garter/trolley/hanging load
  - (3) The assessment of the restitution coefficient of wheels
- Reduced Scale Model Test (in Oct. 2008)
  - (1) Additional investigation point from NCE
    Effect confirmation of the fall-prevention work (lug), etc.
  - (2) Analysis is ongoing.
    - ・Effectiveness of lugs was confirmed
    - ・The uplift behavior was understood.

Video of Whole View

Video of Wheel Part

Fall-prevention Work (Lug)



The nonlinear analysis of uplift mechanism for the vertical motions will be improved.
The results will be applied to the integrity criteria in the seismic re-evaluation.

6. Summary

Application of Fragility Test is;

Evaluation of Residual Risk*

* Risk due to beyond design earthquake

Where is Functional and Structural Limit?

How far can Design Endure?

Is Designed Function Maintained?

How SSCs Response to Earthquake?

After Niigataken Chuetsu-oki earthquake, JNES refined the road map of seismic safety research for;

1 . Earthquake ground motion evaluation
2. Residual risk assessment
3. Seismic margin assessment
4. After earthquake action

Today I present outline of fragility test for item 2 and3. If we have next opportunity, we hope to report the updated status of these researches.

We continue, through contribution for IAEA seismic safety program, to inform and to share our data and knowledge to worldwide nuclear community.

Thank you for your attention