

Seismic Margin Assessment for Components Utilizing Full-Scale Test

**Nov. 25, 2010
at Niigata Institute of Technology**

**Toru Iijima, Masaki Nakagawa,
Akira Shibuya, Katsumi Ebisawa, Hiroyuki Kameda**

Japan Nuclear Energy Safety Organization (JNES)

CONTENTS

- Overview
- Evaluation Example
 - Electrical Cabinet
 - Cylindrical Tanks

OVERVIEW

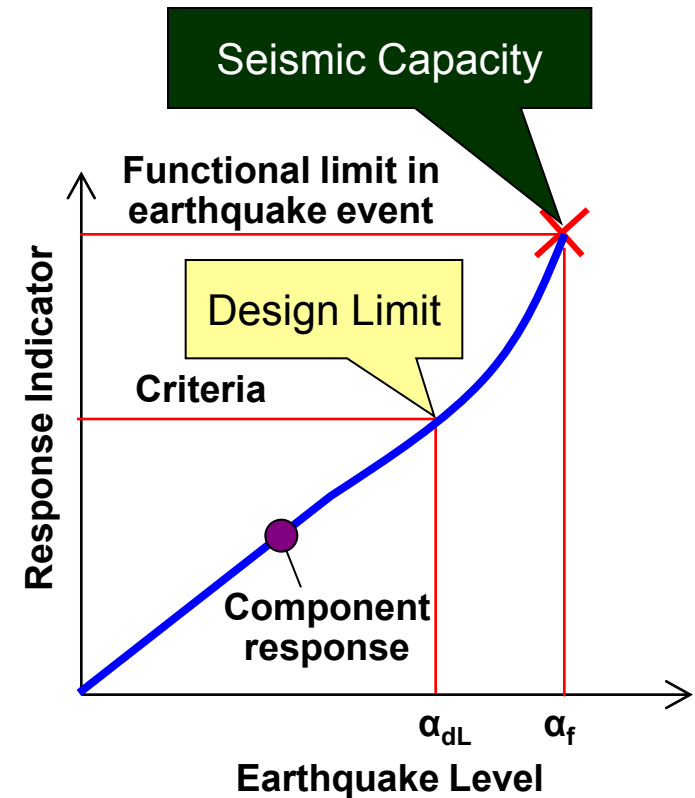
BACKGROUND

- Experiences at the Kashiwazaki-Kariwa (K-K) NPP (July 2007)
Although response acceleration of Niigataken Chuetsu-oki Earthquake exceeded the design basis earthquake motion, the functions of “**Shutdown**”, “**Cooling**”, and “**Containment**” were ensured and the safety was maintained.
- This incident aroused the interest in “**Seismic Margin**”.
- In addition, followings should be taken into account;
 - Function and dominant damage mode of component
 - Appropriate damage indicating parameter
 - Damage due to different seismic wave such as artificial wave with/without spectral envelope and fault-model based wave

OBJECTIVES OF THE STUDY

Even if response of component reaches design limit, it maintains intended function.

Seismic margin is roughly considered as separation between the response and the seismic capacity.



Objectives of our study are as follows;

- To clarify methodology of seismic margin assessment (SMA)
- To confirm availability of SMA by applying it to evaluation of components
- To propose practical use of SMA for seismic safety evaluation of NPP

FUNDAMENTAL CONCEPT OF SEISMIC MARGIN ASSESSMENT

SM	Evaluation Criteria
Seismic Margin Assessment at the Component Level	<div style="border: 2px solid black; border-radius: 15px; background-color: #fde9d9; padding: 10px;"> <p style="text-align: center;"> SMA of component integrity Evaluation by failure probability - Separation between Seismic Capacity and Realistic Response <i>Message to Engineers</i> </p> </div>
<div style="background-color: #004d00; color: white; padding: 5px; display: inline-block; font-weight: bold;">Fragility</div>	
Seismic Margin Assessment at the Plant Level	<div style="border: 2px solid black; border-radius: 15px; padding: 10px;"> <p style="text-align: center;"> Evaluation by seismic PSA - Separation from Performance Goal (Core Damage Frequency, etc.) <i>Message to the Society</i> </p> </div>

relationship

SEISMIC TESTS BY JNES

Purpose of the tests: To clarify seismic capacity of components important to safety
 To incorporate the seismic capacities into SPSA

year 2002 2005 2010

- Containment Vessel
- Primary Loop Recirculation System
- Reactor Core Internals
- Reactor Vessel
- Reactor Shutdown Cooling System
- Main Steam and Feedwater Piping
- Concrete Containment Vessel
- Ultimate Strength of Piping System (1980-2003)

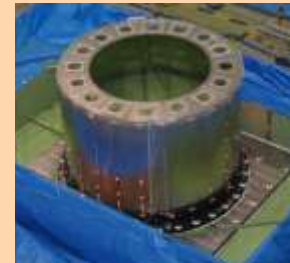


Horizontal Shaft Pump (2002-2004)



Control Rod (2003-2005)

TADOTSU Eng. Center Closed (2005)



**Cylindrical Tanks (2005-2007)
Valves (2005-2007)**

HVAC Fans Snubbers D/G



Electrical Components (2002-2005)



Vertical Shaft Pump (2003-2005)



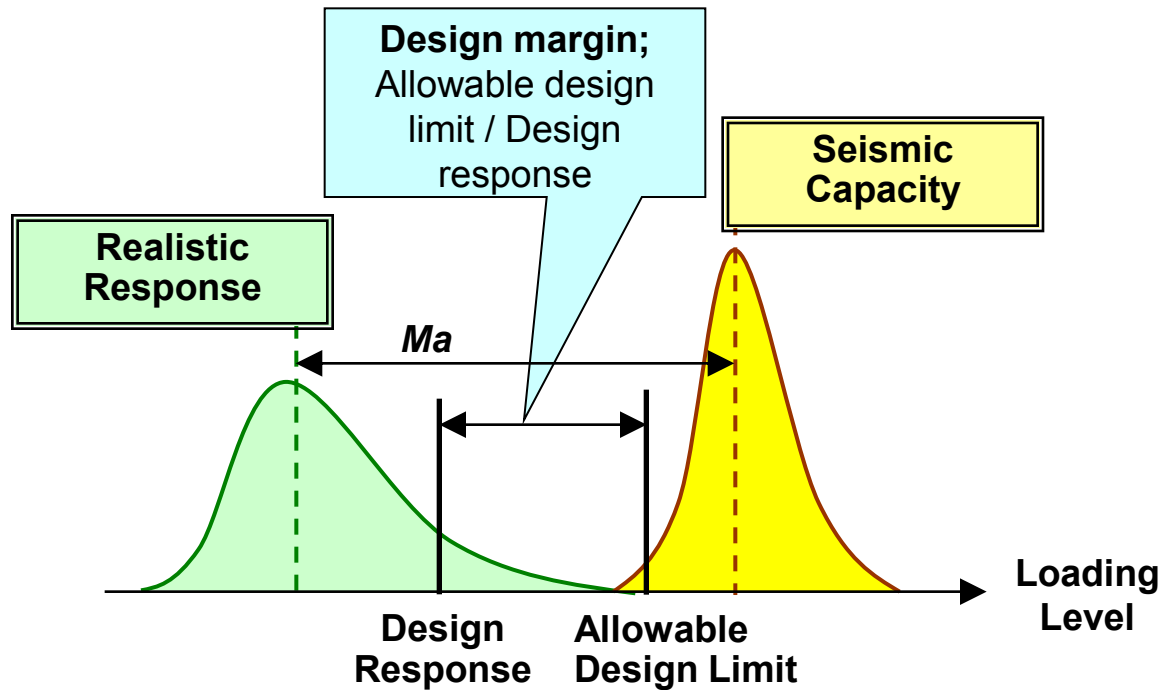
Crane (2006-2008)

SEISMIC PROOF TESTS

SEISMIC CAPACITY TESTS

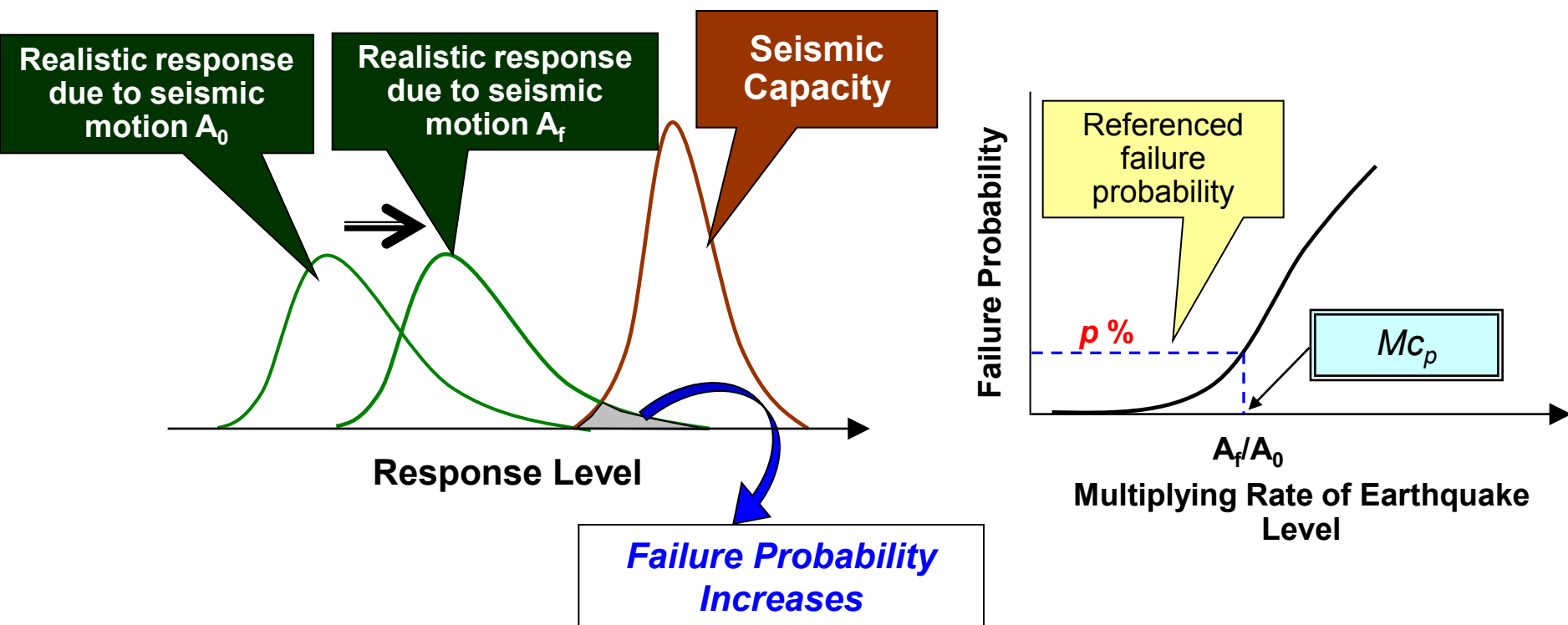
DESIGN MARGIN & SEISMIC MARGIN

Definition of Seismic Margin & Design Margin



No.	Seismic Margin	Definition	Feature
1	Median-based SM: Ma	Ratio of medians (Realistic response / Seismic capacity)	Averaged margin determined by the medians
2	Probability-based SM: Mc_p	Multiplying ratio of seismic motion level	Based on referenced failure probability

Probability-based SM; Mc_p



Definition of probability-based SM; Mc_p

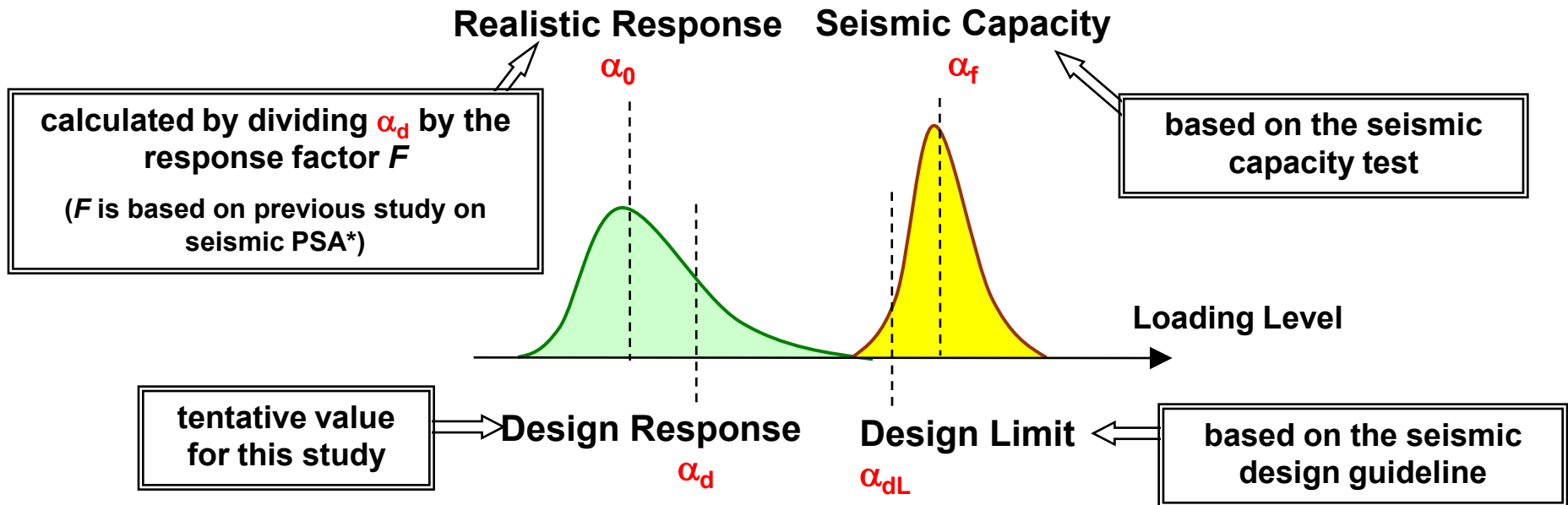
Multiplying rate of earthquake level at which the failure probability is equal to $p\%$.

In this study, referenced failure probability is tentatively set at 1% ($Mc_{1\%}$)

EVALUATION EXAMPLE

- Electrical Cabinet
- Cylindrical Tank

KEY FACTORS FOR SEISMIC MARGIN ASSESSMENT



α_f , α_{dL} , α_d and α_0 are defined as maximum response acceleration of representative part of component related to malfunction.

*Atomic Energy Society of Japan, "A Standard for Procedure of Seismic Probability Safety Assessment for Nuclear Power Plants: 2007", (in Japanese), 2007

Seismic Capacity Test

Purpose of the Test

Electrical components are vulnerable to earthquake event, and they are important in terms of SPSA.

The test was conducted to clarify the seismic capacities and to incorporate them into SPSA.

Tested Boards

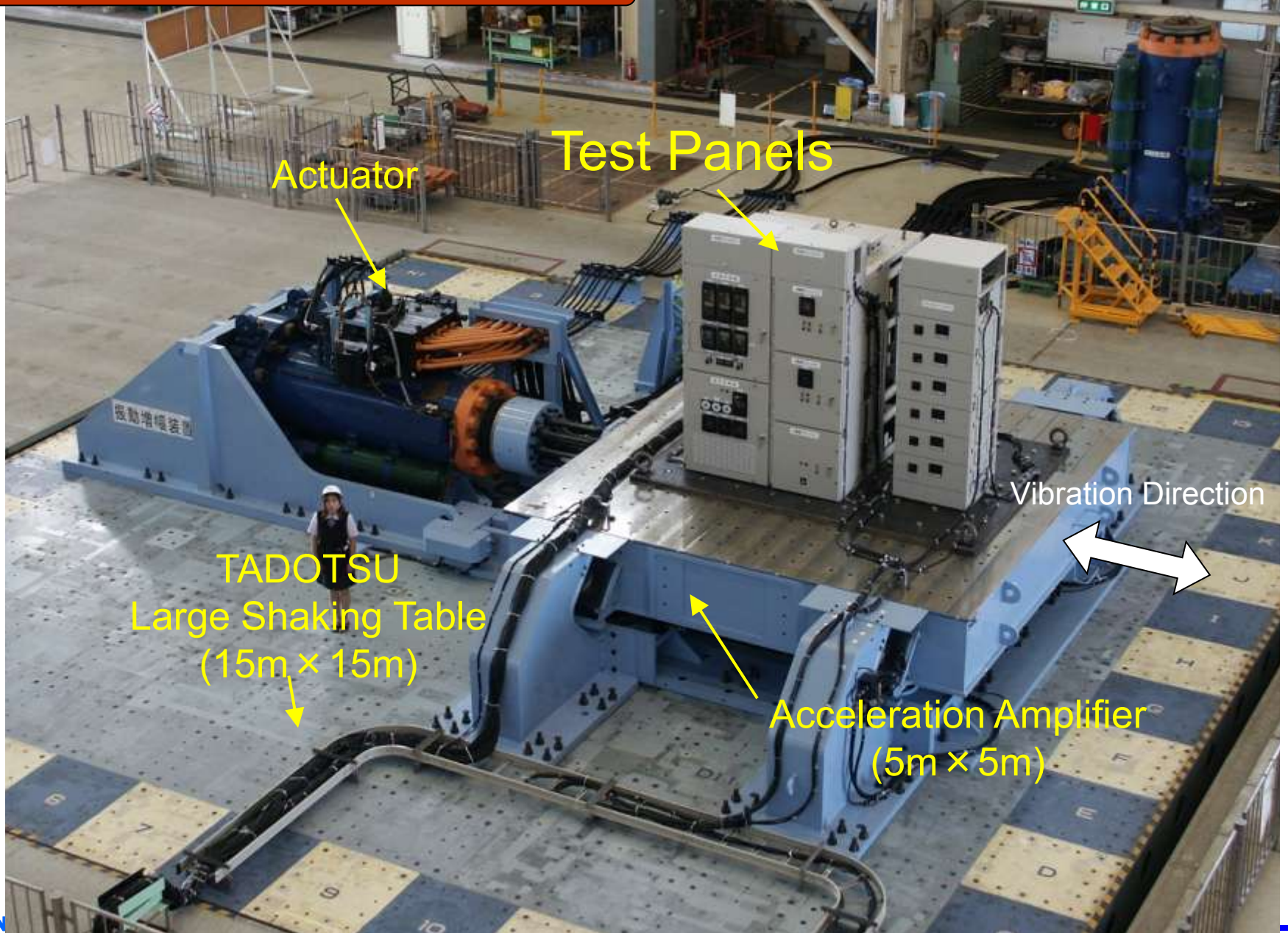
Eight kinds of typical electrical components were selected.

- Important to safety
- Belong to high aseismic importance

CONTROL / INSTRUMENT BOARD	POWER BOARD
Reactor Protection Rack	Metal-Clad Switchgear
Main Control Board	Power Center
Reactor Auxiliary Control Board	Reactor Control Center
Logic Circuit Control Panel	
Instrumentation Rack	

The tests were conducted (2002 – 2005) utilizing full scale models which were same with actual board.

Bird-eye View of the Testing Equipment

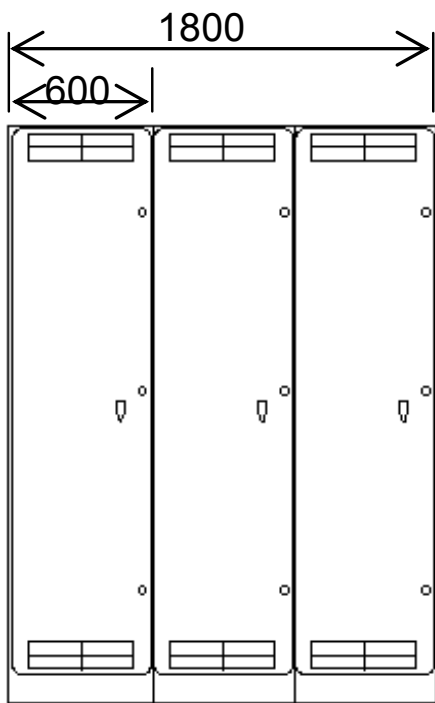




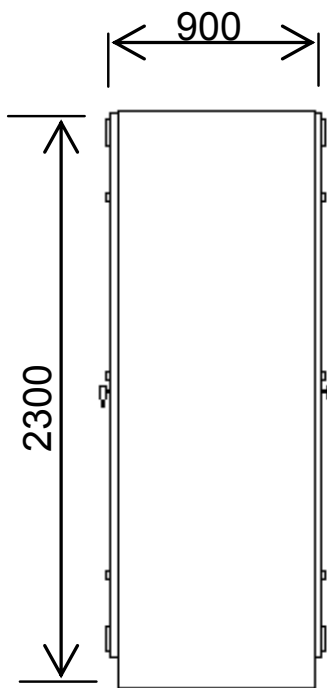
Power Center & Reactor Control Center (Maximum input acceleration = $6 \times 9.8 \text{m/s}^2$)

Test of Reactor Protection Rack

Configuration of Reactor Protection Rack

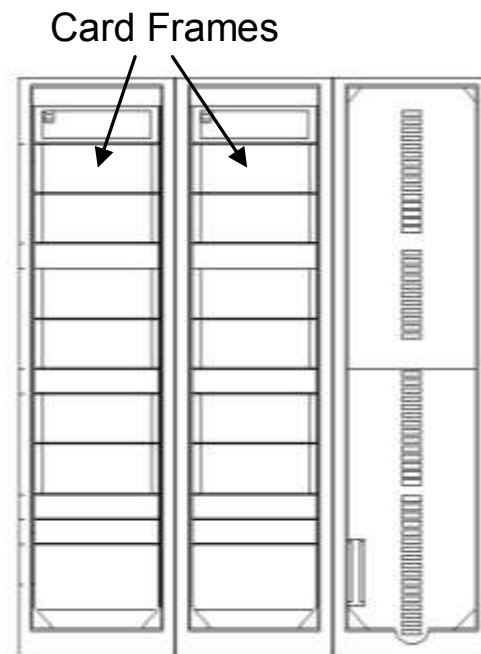


Front View



Side View

SIZE (m) W x H x D	1.8 x 2.3 x 0.9
WEIGHT (kg)	2160
FREQ. (Hz)	29.0 (side-to-side)



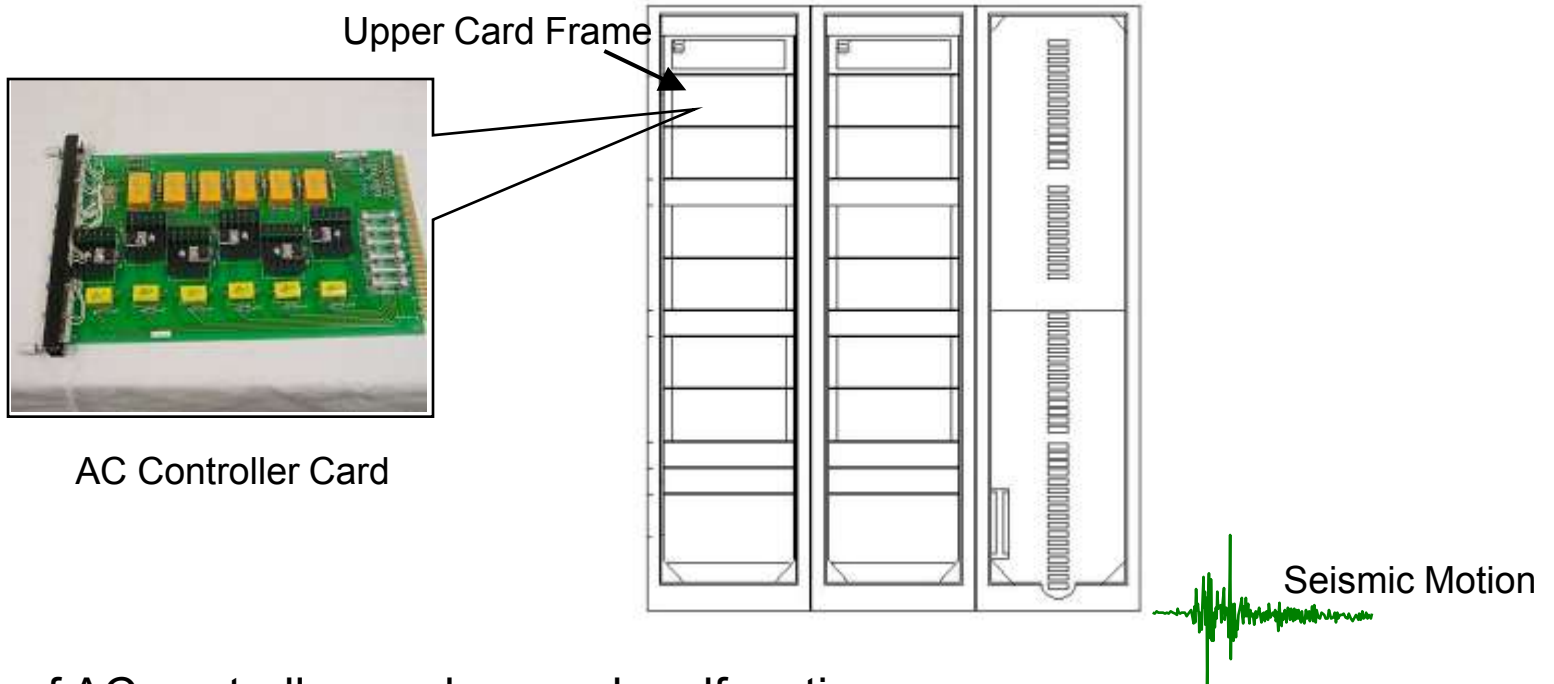
Inside of Cabinet

Reactor Protection Rack

Summary of Test Result

DIRECTION	MAXIMUM INPUT ACCERELATION (x 9.8m/s ²)	STATE
S-S	3.2	No Malfunction
	4.3	Error of AC controller card (relay chatter)
F-B	5.9	No Malfunction

S-S : side-to-side
F-B : front-to-back



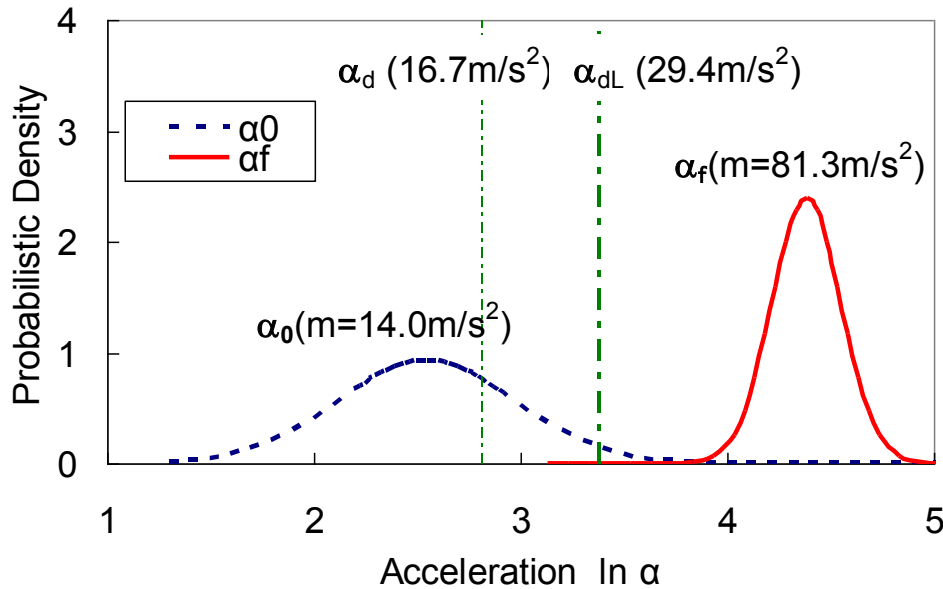
- Error of AC controller card caused malfunction

SMA of Reactor Protection Rack
Key Factors for Evaluation
Data of Reactor Protection Rack

ITEM	MEDIAN m (x 9.8m/s ²)	LOG-STANDARD DEVIATION β	EXPLANATION
α_f (Seismic capacity)	8.3	0.17	<ul style="list-style-type: none"> ➤ m; seismic capacity of AC controller card ➤ β; logarithmic standard deviation of AC controller card
α_d (design response)	1.7	-	<ul style="list-style-type: none"> ➤ Tentative design acceleration for evaluation
α_{dL} (design limit)	3.0	-	<ul style="list-style-type: none"> ➤ From verified acceleration described in seismic guideline
α_0 (realistic response)	1.4	0.43	<ul style="list-style-type: none"> ➤ m; Dividing α_d by response factor F ➤ $F=1.19$ (from previous study)

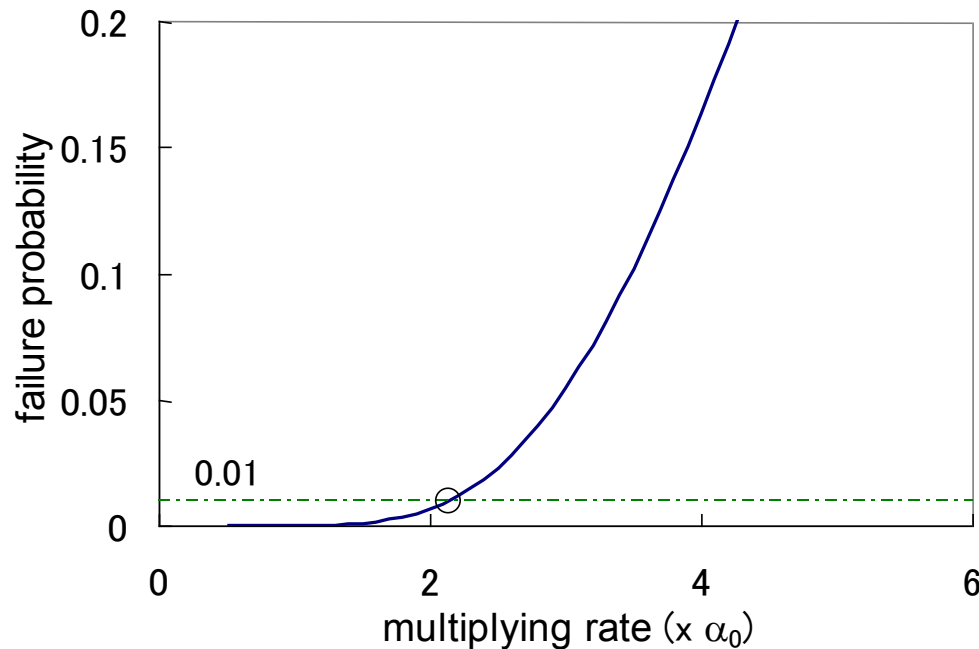
* Atomic Energy Society of Japan, “A Standard for Procedure of Seismic Probability Safety Assessment for Nuclear Power Plants: 2007”, (in Japanese), 2007

Evaluation Results of Reactor Protection Rack



$$Md(\text{design margin}) = \frac{\alpha_{dL}}{\alpha_d} = 1.8$$

$$Ma = \frac{\alpha_f}{\alpha_0} = 5.8$$



$$Mc_{1\%} = 2.1$$

CYLINDRICAL TANK

Seismic Capacity Test

Background

- In current Japanese design guideline for cylindrical tank, ***buckling*** is dominant criteria.
- Even if buckling occurs on cylindrical tank, the function of tank would not lose.
- Ultimate strength is higher than earthquake level which induces the buckling.

Purpose of the Test

The test was conducted to clarify the seismic capacities of the cylindrical tank and to incorporate them into SPSA.

CONFIGURATION	DOMINANT BUCKLING PATTERN	REPRESENTATIVE TANKS
High L/R Tanks <i>L: Cylinder height, R: Radius</i>	Elephant foot bulge (EFB)	<ul style="list-style-type: none"> •Refueling Water Storage Tank •Condensate Storage Tank •Light Oil Tank
Low L/R Tanks	Shear buckling	<ul style="list-style-type: none"> •Condensate Storage Tank

The ultimate strength tests were conducted (2005 – 2007) utilizing reduced size model.

Test Results (Condensate Storage Tank)

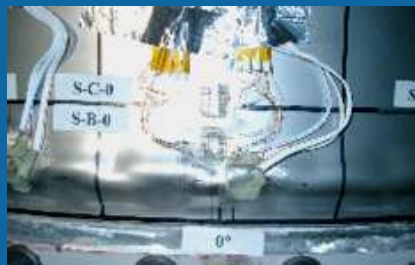
Exceed current design limit

Stainless Steel



EFB

Secondary Buckling



Secondary Buckling

Crack (water leakage)



Crack (water leakage)

Carbon Steel

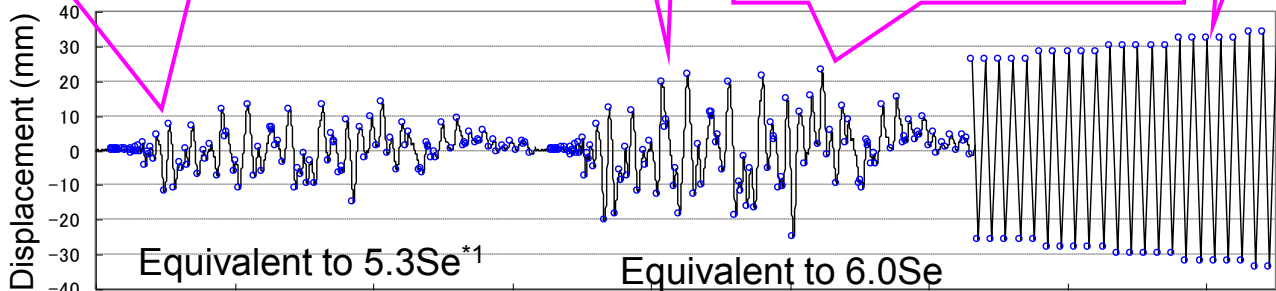


EFB

Crack (water leakage)



Crack (water leakage)



FINDINGS

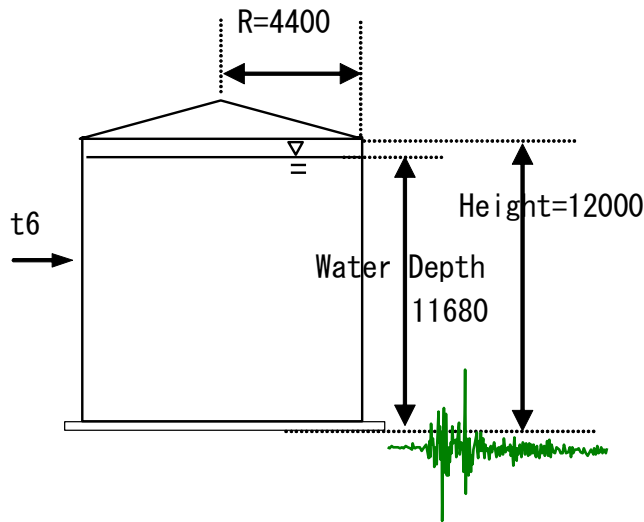
*1) Se covers design basis S2 earthquakes of PWR plants

➤ The secondary buckling is the main cause of water leakage.

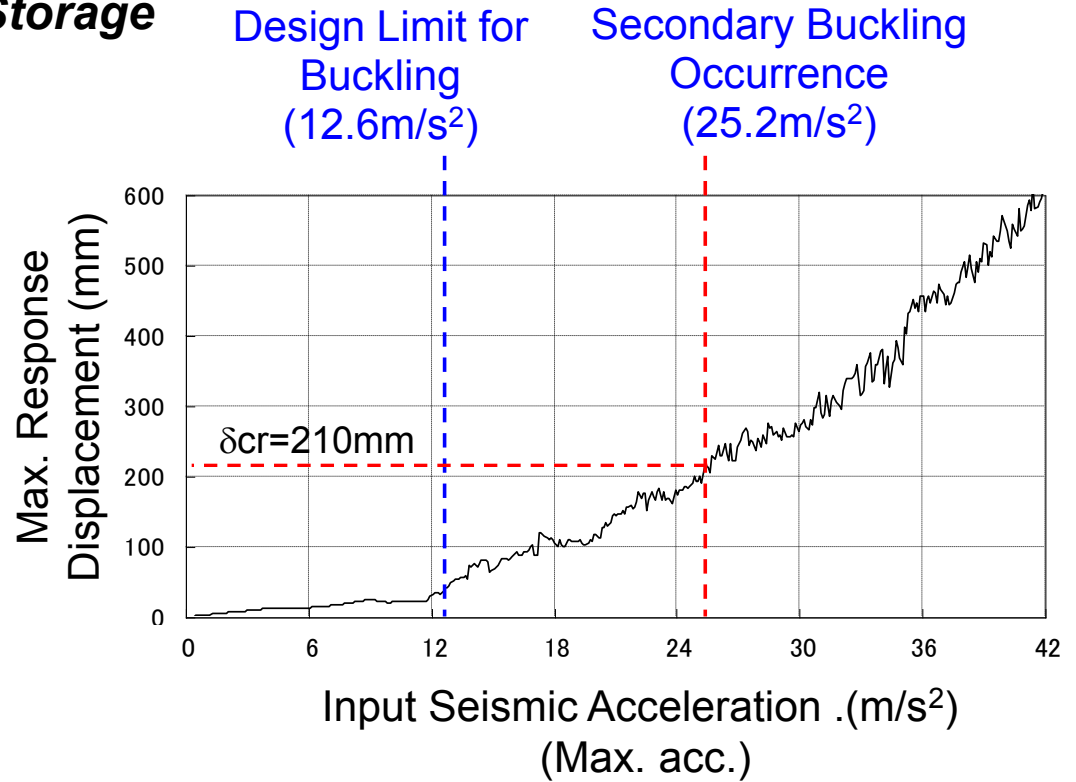
SMA of Condensate Storage Tank

Seismic Capacity of the Tank

Seismic capacity of **Condensate Storage Tank** was estimated.

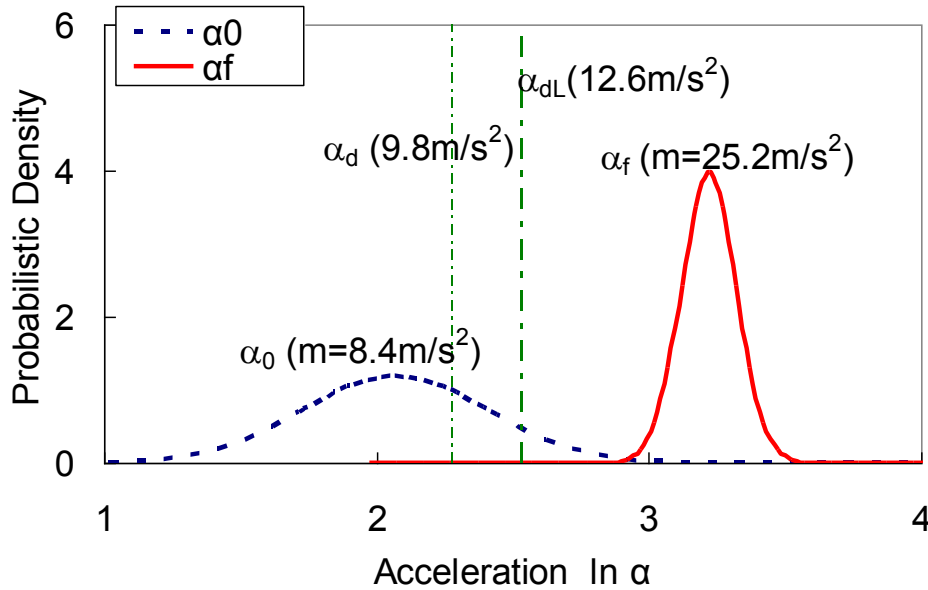


Main Dimensions of the Tank



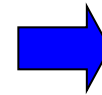
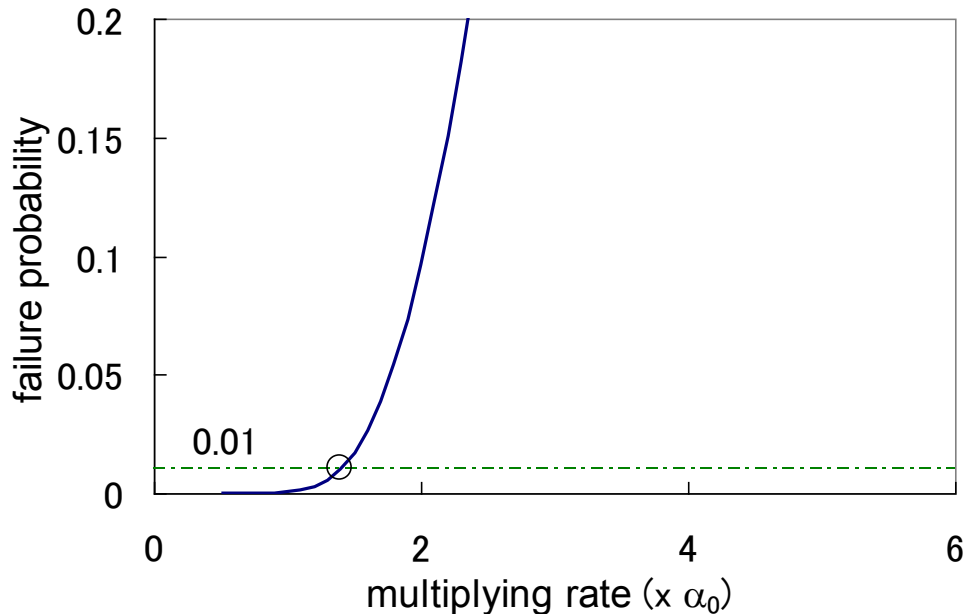
Condensate Storage Tank	
Seismic Capacity	25.2m/s ²

Evaluation Results of Condensate Storage Tank



$$Md(\text{design margin}) = \frac{\alpha_{dL}}{\alpha_d} = 1.3$$

$$Ma = \frac{\alpha_f}{\alpha_0} = 3.0$$

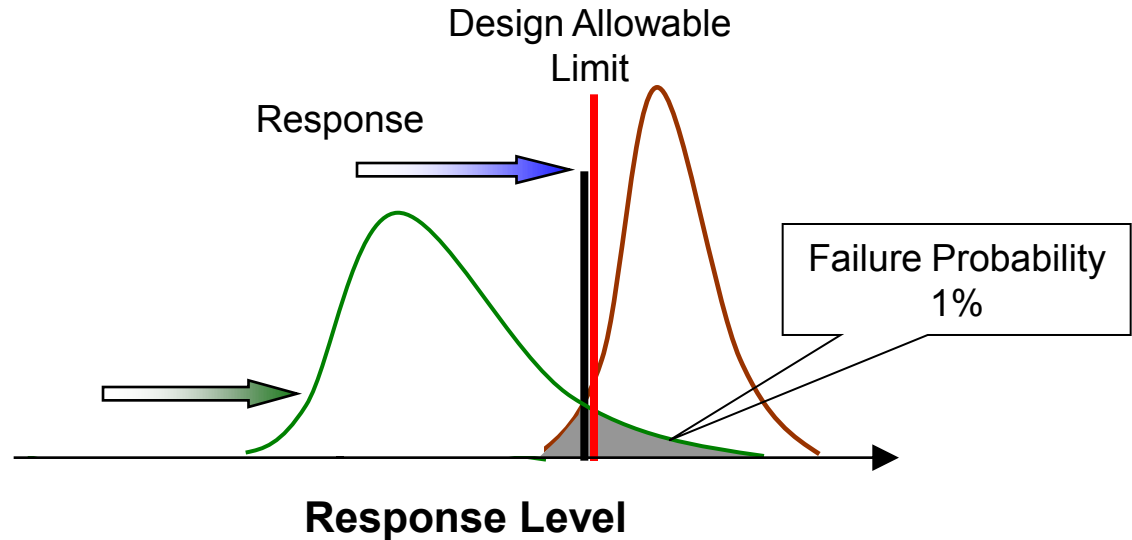


$$Mc_{1\%} = 1.4$$

AVAILABILITY OF SEISMIC MARGIN ASSESSMENT

SMA for Components

Components	Ma	$Mc_{1\%}$	Md
Reactor Protection Rack	5.8	2.1	1.8
Condensate Storage Tank	3.0	1.4	1.3



Results of Seismic Margin Assessment

- In this evaluation example, probability-based margin $Mc_{1\%}$ s are a little higher than Md . Even if the response increases to the design limit, failure probability of those components would be less than 1%.
- Seismic integrity can be explained with failure probability enhanced by seismic capacity test results.

Applicability to Seismic Safety Evaluation of NPP

- Seismic margin evaluation of components for pre-earthquake stage
- Acquisition of status of safety-important components for post-earthquake activity

SUMMARY

JNES launched a study on seismic margin assessment (SMA). The SMA is based on the seismic capacities of components.

- **JNES has the seismic capacity data of safety-important components obtained from tests.**
- **The seismic capacity is estimated considering appropriate damage indicating parameter.**
 - **For example; dominant indicating parameter of cylindrical tank is response displacement.**
- **JNES is going to enhance the seismic capacity data with vibration tests.**

The advantages of the SMA are as follows;

- **The SMA is effective to understand the quantitative margin related to the functional anomaly of component.**
- **Following applications of the SMA to seismic safety evaluation of NPP are expected;**
 - Seismic margin evaluation of components for pre-earthquake event**
 - Acquisition of status of safety-important components for post-earthquake activity**