Seismic Capacity Tests of NPP Components and Equipment

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at Niigata Institute of Technology

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1. History of Seismic Tests of NPP Structures, Systems and Components

1980 1990 2000 2003/10 2010

Phase I (Heavy components and equipment verification)

Primary containment vessel (PWR, BWR) ,Reactor (pressure) vessel (PWR, BWR)
Reactor core internals (PWR, BWR) Primary loop recirculation system piping (BWR)
Reactor cooling system piping (PWR)

Phase II (System verification)

Emergency diesel generator systems
Computer system
Reactor shutdown cooling system

Phase III (New technology and function verification)

(Seismic) Energy absorbing supports for main steam/main water feed system
Seismic energy absorbing supports for steam generator
RCCV , PCCV , Piping system

Nuclear Power Engineering Corporation (NUPEC)

Japan Nuclear Energy Safety Organization (JNES)

Component and equipment seismic capacity test series (Phase I)

(1) Electric panel, Horizontal shaft pump,
(2) Control rod insertion (BWR, PWR)
(3) Large vertical shaft pump

Component and equipment seismic capacity test series (Phase II)

(4) Motor operated valve
(5) Tank
(6) Overhead crane
(7) Ventilation Fan
(8) Emergency DG (Section model)

An overview of the test shown in red

2. Background and purpose of tests (Changes in test purpose)

Revised regulatory guidelines for reviewing seismic design

1978 – the old Regulatory Guidelines

- ◆ Maintain seismic integrity so sufficiently that no earthquake would induce significant accidents

2006 – the current Regulatory Guidelines

- ◆ Determine the basic earthquake ground motion Ss based on the fault model and response spectrum
- ◆ Consider Ss in the horizontal and vertical directions
- ◆ Adequately recognize the residual risk due to the earthquake ground motion exceeding Ss

Lessons learned from the beyond design base earthquake

2007 – the NCO Earthquake

- ◆ Need for seismic margin assessment of critical components and equipment for beyond design base earthquake conditions

Changes in test purpose

Seismic Verification Tests

- ◆ Verification of the reliability of seismic design

Seismic Capacity Tests

- ◆ Confirmation of functional and structural failure capacity applied for seismic margin and residual risk assessment

2. Background and purpose of tests （Challenges for enhancement）

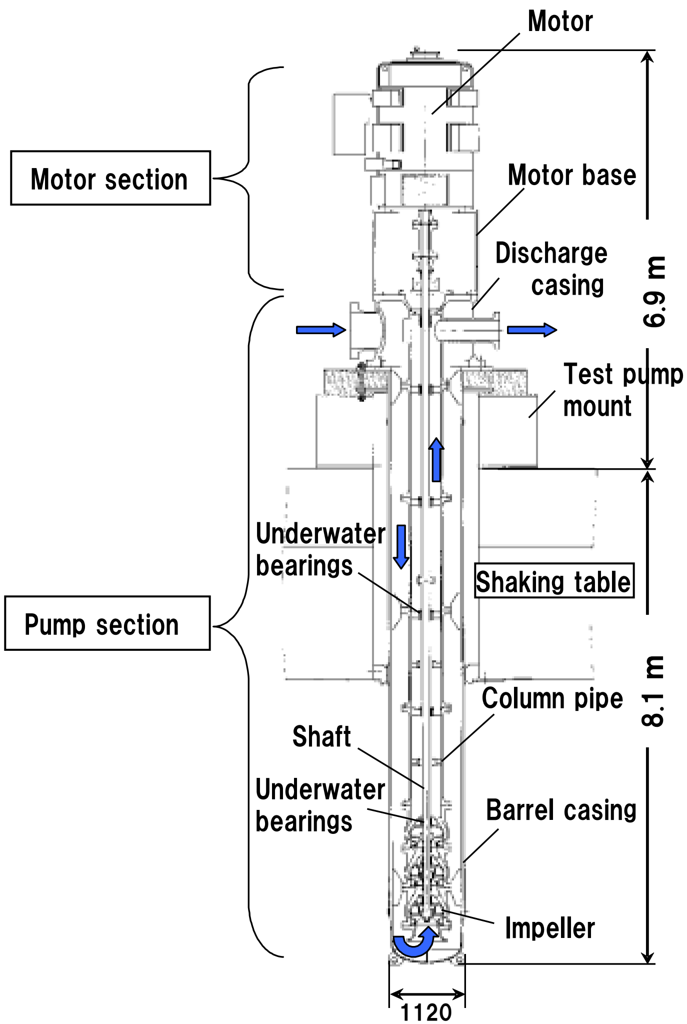
Challenges for enhancing the practical use of capacity test data

- Acquisition of capacity data under horizontal excitation up to 6G (10G or more for valves) and under vertical excitation over 1G.

- Confirmation of the effect on seismic response and damage due to different input waves such as artificial wave with/without spectral envelope, fault-model based wave, observed wave (NCO earthquake) and sine wave.

- Identification of failure mechanism and damage indicating parameters for ultimate capacity on functional failure and structural failure.

3.1 Large vertical shaft pump test

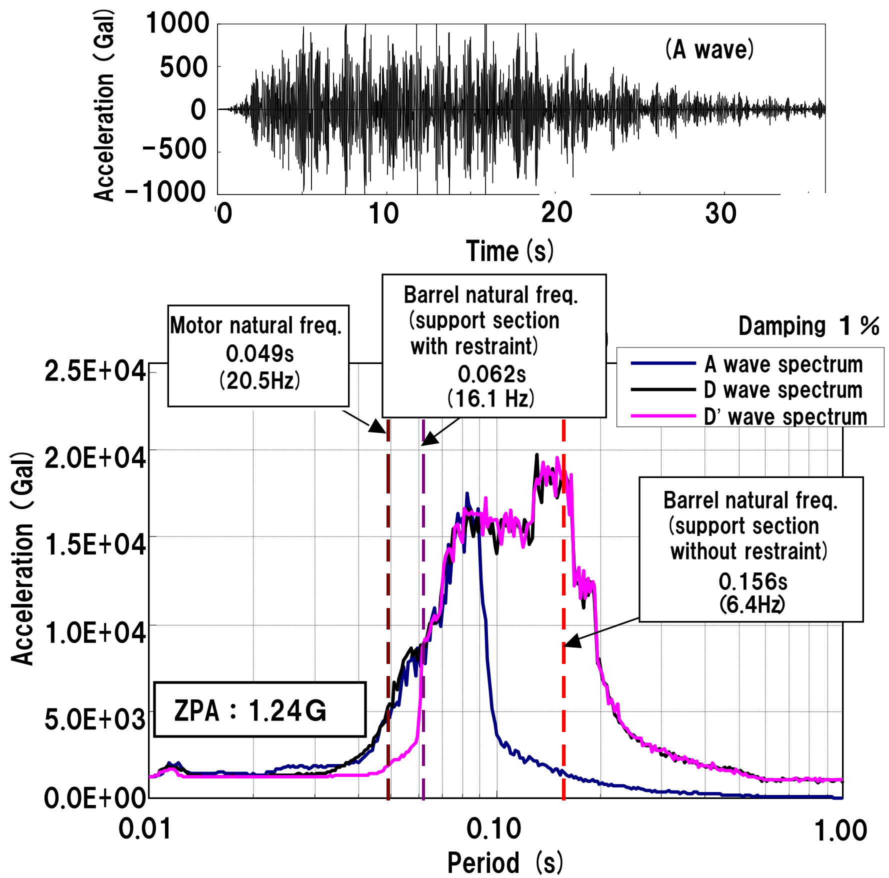


Reactor residual heat removal system（RHR）pump

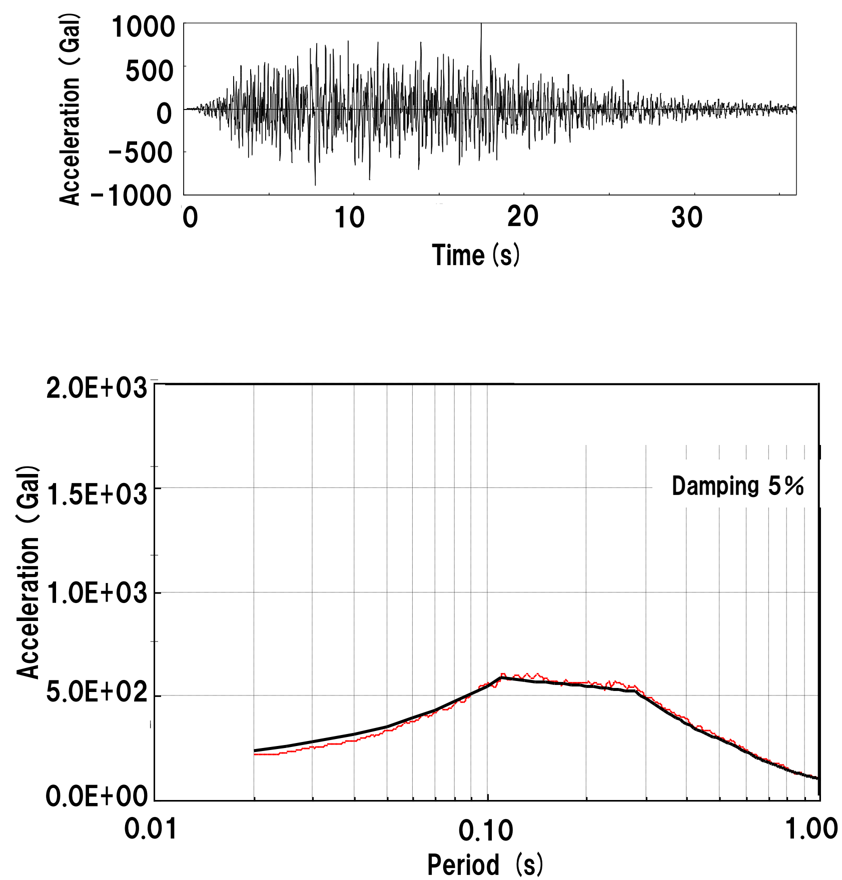
Actual test pump spec.（Scale: 1/1）	
Pump model	Pit barrel type
Total pump head（m）	92
Flow rate（m^3 /h）	1690
Rotation per minute (rpm)	1500
Mass（$x10^3$ kg）	42

Test conditions (Horizontal and vertical shaking)

Horizontal input wave

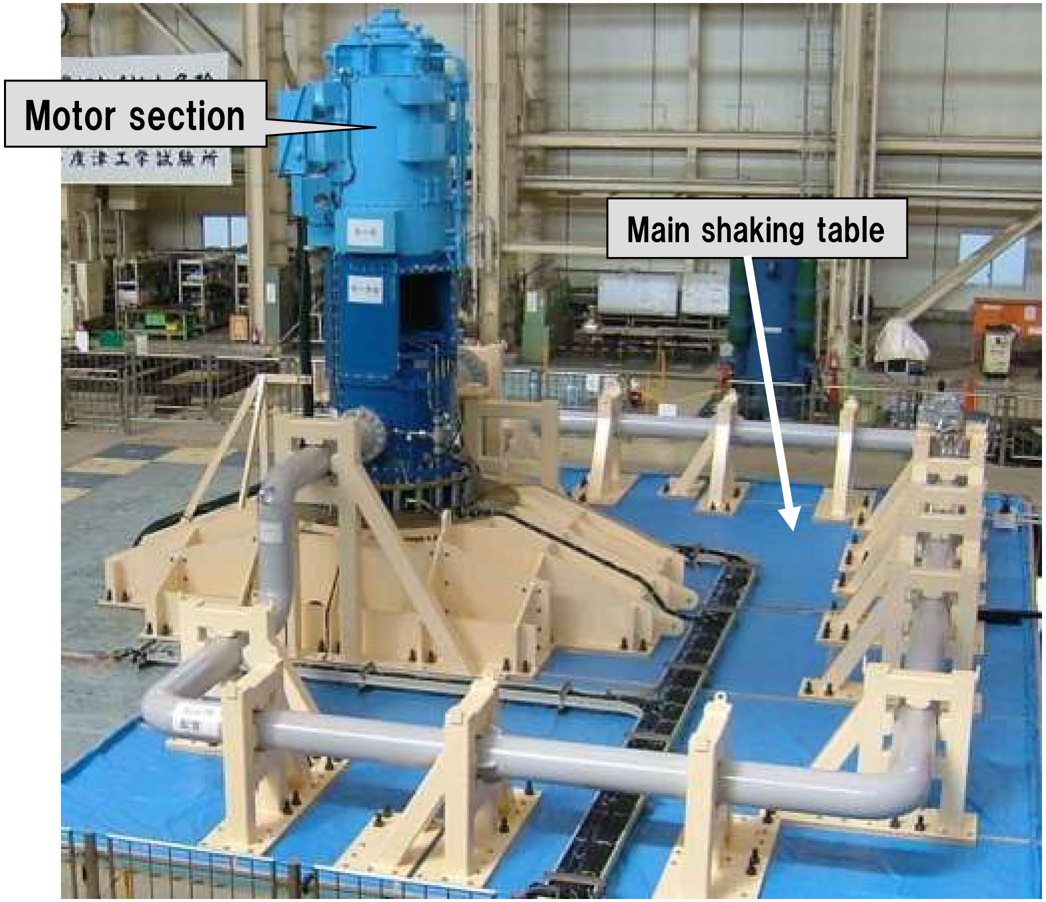


Vertical input wave



- Horizontal input acceleration was progressively increased up to 3G, while vertical excitation was up to 1.9G.
- Horizontal Input waves were simulated S2 waves (A, D, D') created from S2 wave envelope spectrum of Japan's BWR/PWR plants.
- Vertical input wave was simulated seismic wave created from improved standardization basic ground motion.

Test scene



Large vertical shaft pump test video

Evaluation of test results (Horizontal shaking)

■ **Structural failure found during test** ⇒ **Yielding of component material**

Location	Abnormality event	Response acceleration when abnormality occurred (Location)	Input acceleration (Shaking waves)
Motor (retaining bolts)	Yield	$12 \times 9.8 m/s^2$ (Motor crown)	$1.5 \times 9.8 m/s^2$ (D wave)
Pump (barrel casing)	Yield	$31 \times 9.8 m/s^2$ (Barrel bottom) ＊1,2	$2.8 \times 9.8 m/s^2$ (D' wave)

■ **Function maintaining acceleration verified after reinforcement of section where material yielding occurred**

Location	Maximum response acceleration	Previous research data on verified function maintaining acceleration
Motor (Crown)	$14 \times 9.8 m/s^2$	$2.5 \times 9.8 m/s^2$
Pump (Column head)	$35 \times 9.8 m/s^2$ ＊1	$10 \times 9.8 m/s^2$

＊1: The value include a high frequency ingredient caused by the collision between the barrel and its support.
＊2: The value of considerable barrel support section yielding becomes about $13 \times 9.8 m/s^2$ when excluding a high frequency ingredient caused by the support collision.

Evaluation of test results (Vertical shaking)

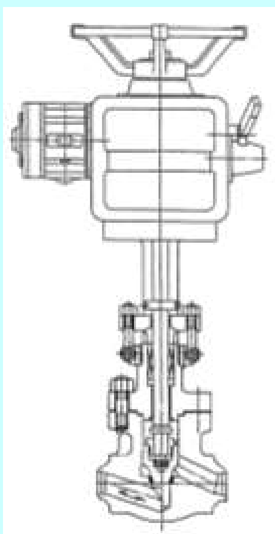
■ Function maintaining acceleration

Location	Maximum response acceleration	Previous research data on verified function maintaining acceleration
Motor (Crown)	$2.3\times9.8m/s^2$ *3	$1.0\times9.8m/s^2$
Pump (Column head)	$1.6\times9.8m/s^2$ *3	$1.0\times9.8m/s^2$

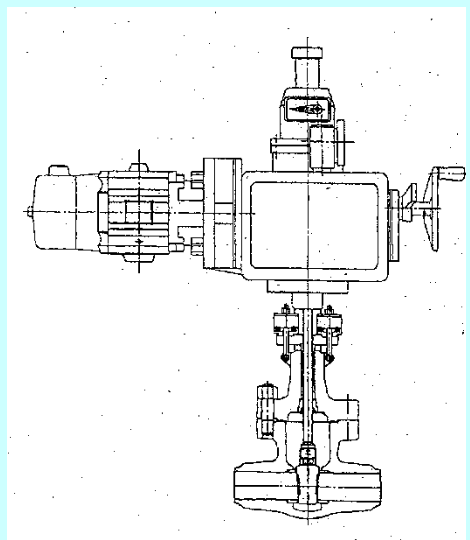
*3: Input acceleration: $1.9\times9.8m/s^2$

3.2 Motor operated valve test

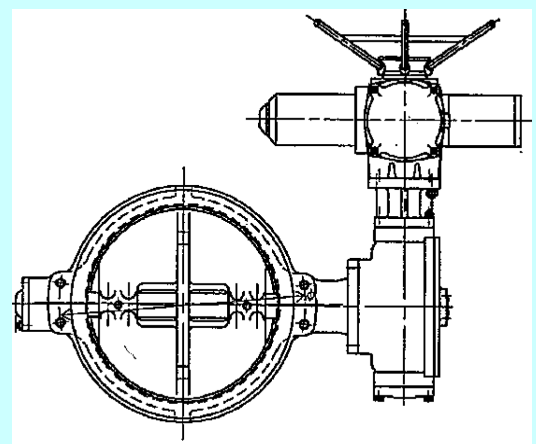
Gauge	Valve type	Required safety functions	
2-inch	Motor operated globe valves	β	α: Required to be operable during earthquakes (Example: BWR main steam system isolation valve) β: Required to be operable after earthquakes (Example: PWR containment vessel spray system stop valve)
3-inch	Motor operated gate valves	α	
16-inch	Motor operated gate valves	β	
20-inch	Motor operated butterfly valves	α	



Motor operated globe valves



Motor operated gate valves

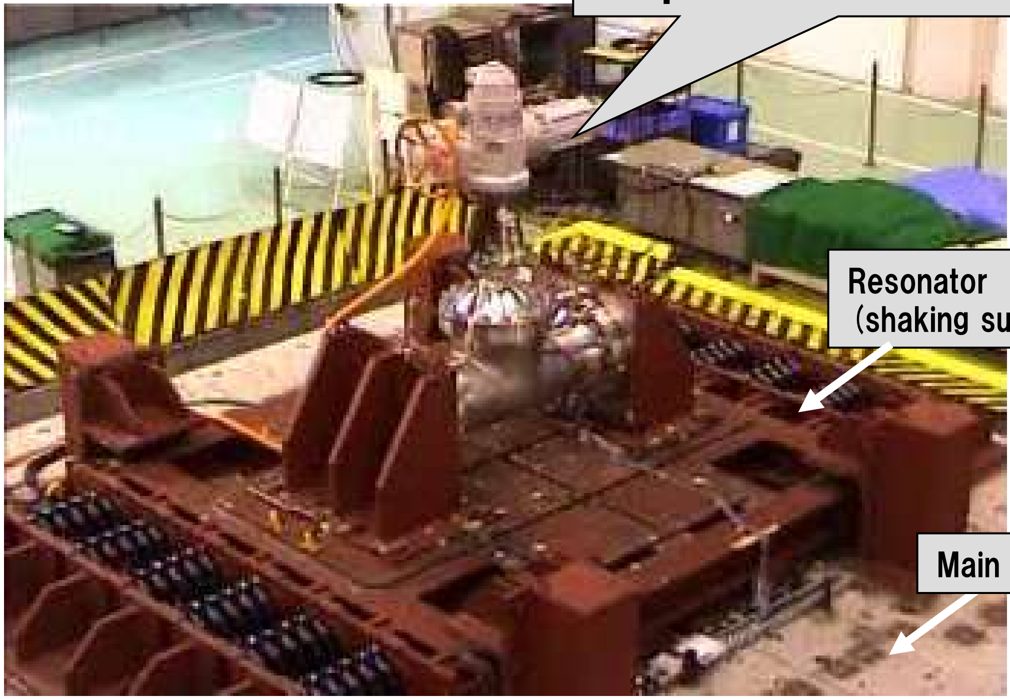


Motor operated butterfly valves

Test conditions (Horizontal and vertical shaking)

Test valve	Shaking method	Installation conditions	Shaking input waves	Target acceleration
2-inch Motor operated globe valves	Electromagnetic vibration exciter	Erection state with shaking by each direction in all three directions	Sine wave (15 to 20 Hz)	$9\times9.8 m/S^2$
3-inch Motor operated gate valves	Electromagnetic vibration exciter	Erection state with shaking by each direction in all three directions	Sine wave (15 to 20 Hz)	$9\times9.8 m/S^2$
16-inch Motor operated gate valves	Shaking table with resonator	Shaking in all three directions with installation direction changed	Sine wave (10 Hz)	$10\times9.8 m/S^2$
20-inch Motor operated butterfly valves	Shaking table with resonator	Shaking in all three directions with installation direction changed	Sine wave (10 Hz)	$10\times9.8 m/S^2$

Test scene



Motor operated gate valve test video

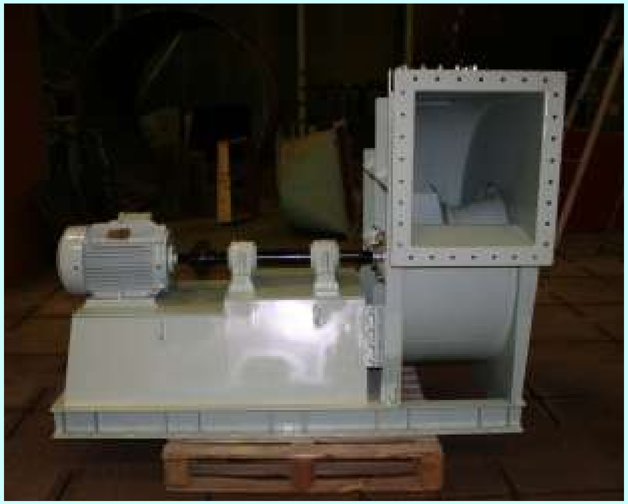
16-inch motor operated gate valve test model

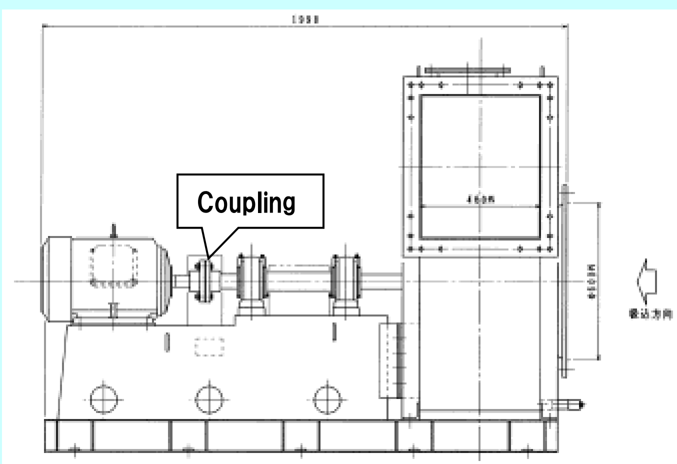
(Scale: 1/1, shaking table fitted with a resonator, Target acceleration: 10 x 9.8m/s^2, sine wave horizontal shaking)

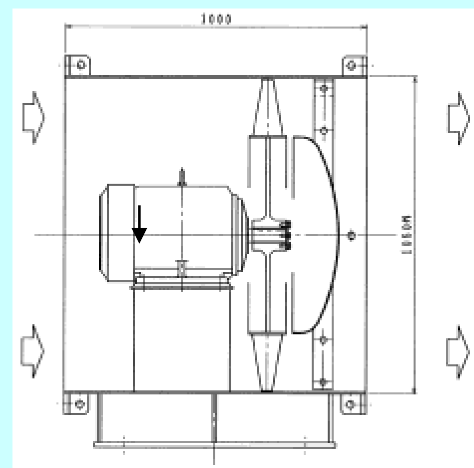
Evaluation of test results (Horizontal and vertical shaking)

Gauge	Valve type	Function* maintaining acceleration (at motor drive section) *operability to open and close	Seat leakage preservation	Pressure boundary integrity	Previous research data on verified function maintaining acceleration
2-inch	Motor operated globe valves	$12.3 \times 9.8 m/s^2$	Validated	Validated	6×9.8 m/s^2
3-inch	Motor operated gate valves	$9.5 \times 9.8 m/s^2$	Validated	Validated	
16-inch	Motor operated gate valves	$10.2 \times 9.8 m/s^2$	Validated	Validated	
20-inch	Motor operated butterfly valves	$12.2 \times 9.8 m/s^2$	Validated	Validated	

3.3 Ventilation fan test







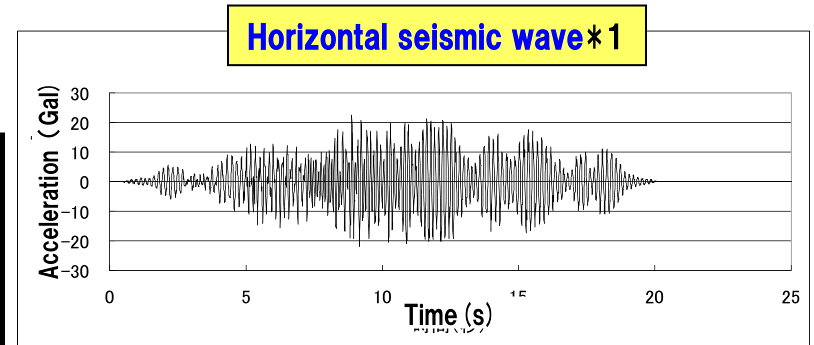
Centrifugal fan with /without labyrinth seals

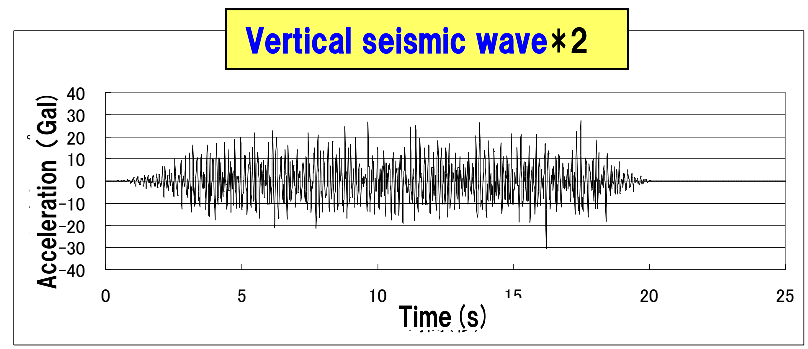
Axial fan without labyrinth seals

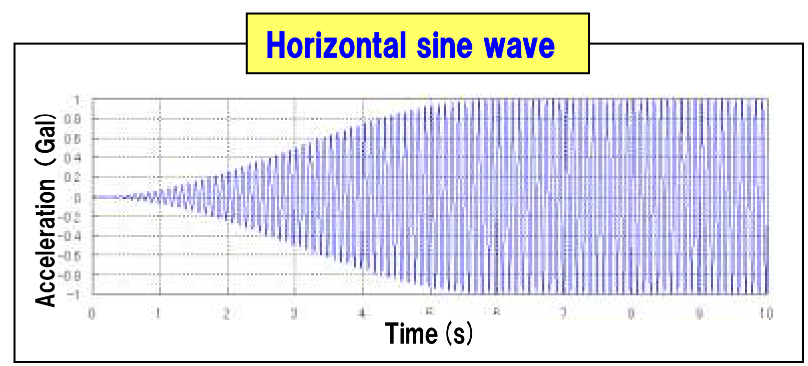
Test conditions (Horizontal and vertical shaking)

Test fan	Shaking method	Shaking direction	Input wave	Target acceleration
Centrifugal fan / Axial fan	Shaking table with resonator	Horizontal (along the shaft)	Sine wave (11Hz)	$7.5\times9.8m/s^2$
			Seismic wave	$2.3\times9.8m/s^2$
		Horizontal (perpendi-cular to the shaft)	Sine wave (11Hz)	$7.5\times9.8m/s^2$
			Seismic wave	$2.3\times9.8m/s^2$
		Vertical	Seismic wave	$3\times9.8m/s^2$

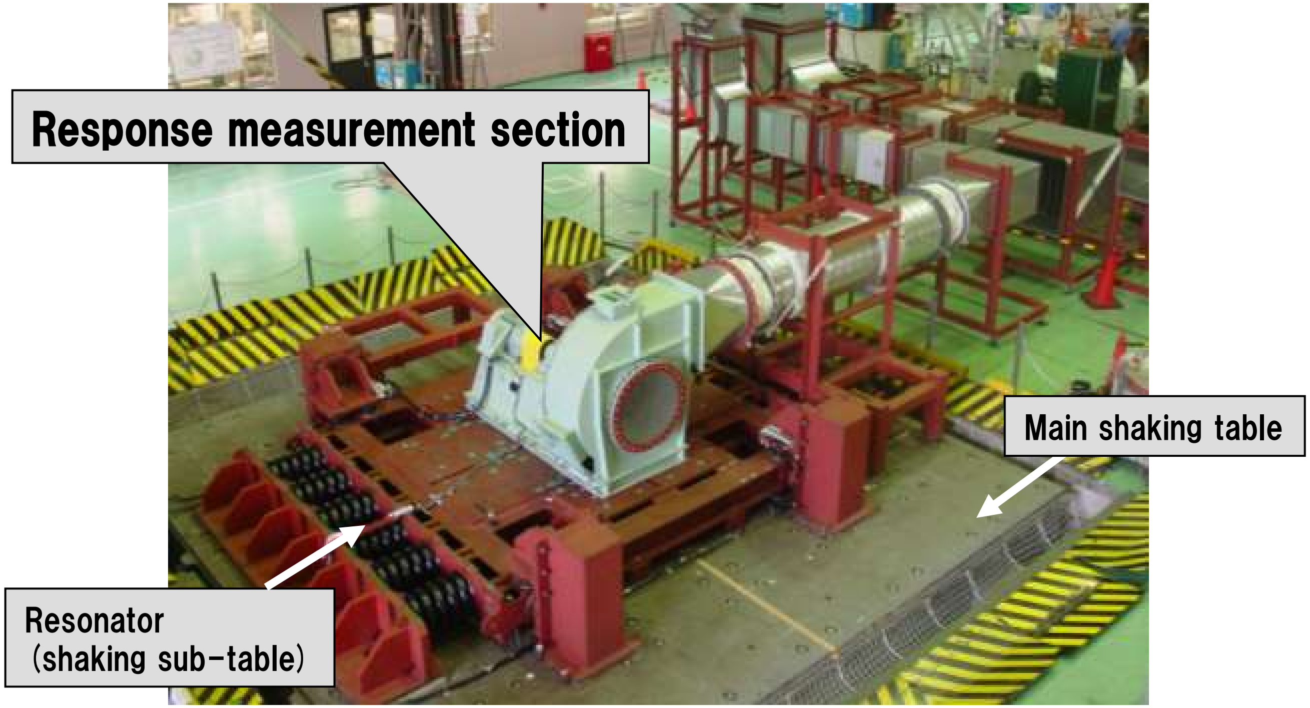
*1: The same as the seismic wave used in the horizontal shaft pump test.
*2: The same as the seismic wave used in the vertical shaft pump test.







Test scene



Ventilation fan test video

Centrifugal fan

(Scale: 1/1, shaking table fitted with a resonator, Target acceleration: 3 x 9.8m/s^2, seismic wave vertical shaking)

Evaluation of test results (Horizontal and vertical shaking)

Test fan		Shaking direction (under operating condition)	Acceleration at bearing bracket: Functional failure (*)	Acceleration at bearing bracket: Function maintaining	Previous research data on verified function maintaining acceleration
Centrifugal fan	With labyrinth seals	Horizontal (along the shaft)		$7.9 \times 9.8 m/s^2$	$2.3 \times 9.8 m/s^2$
		Horizontal (perpendicular to the shaft)	$5.0 \times 9.8 m/s^2$		
		Vertical		$4.2 \times 9.8 m/s^2$	$1.0 \times 9.8 m/s^2$
	Without labyrinth seals	Horizontal (along the shaft)		$7.9 \times 9.8 m/s^2$	$2.3 \times 9.8 m/s^2$
		Horizontal (perpendicular to the shaft)		$8.0 \times 9.8 m/s^2$	
		Vertical		$4.2 \times 9.8 m/s^2$	$1.0 \times 9.8 m/s^2$
Axial fan	Without labyrinth seals	Horizontal (along the shaft)		$7.8 \times 9.8 m/s^2$	$2.4 \times 9.8 m/s^2$
		Horizontal (perpendicular to the shaft)		$8.1 \times 9.8 m/s^2$	
		Vertical		$4.8 \times 9.8 m/s^2$	$1.0 \times 9.8 m/s^2$

*Functional failure: air leakage from the sealing section

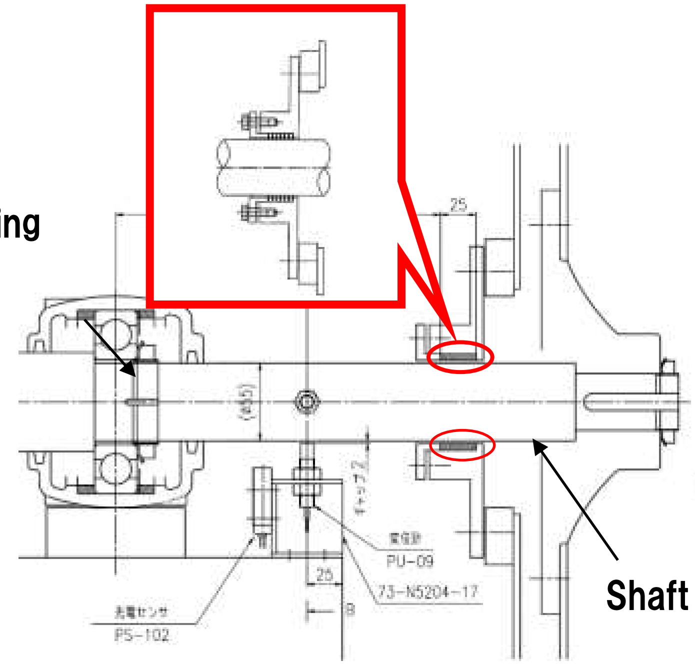
Evaluation of test results (Failure mechanism)

■ **Functional failure** occurred during shaking at 5G in the horizontal direction perpendicular to the driving shaft.

Air leakage from the sealing section (where labyrinth seals were excessively worn due to rubbing with the rotating shaft)

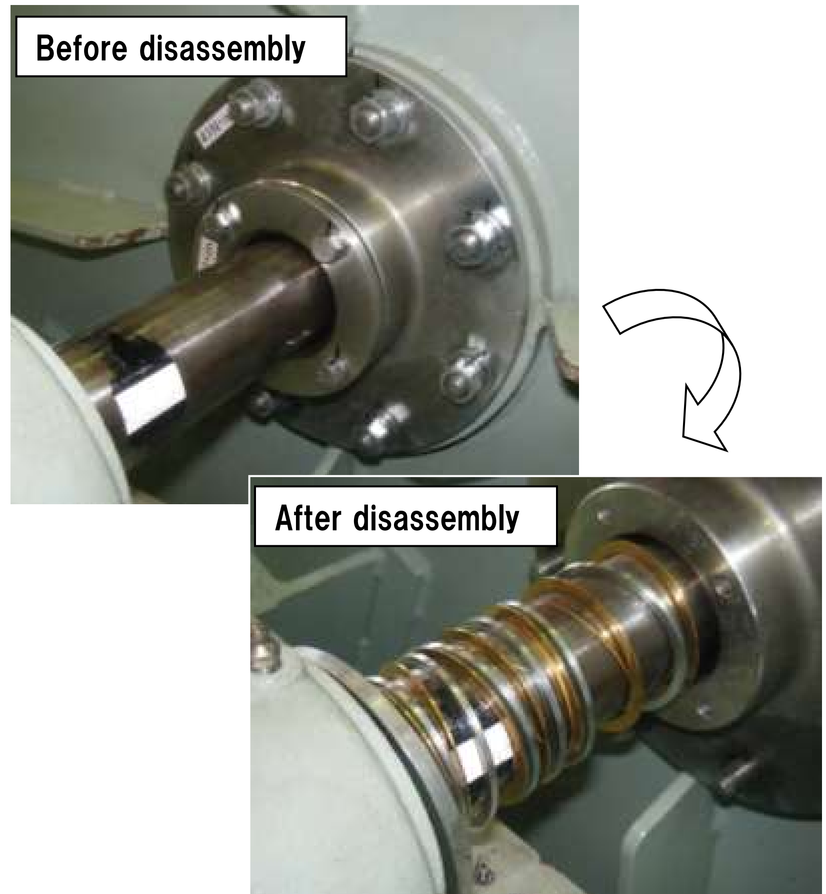
Labyrinth sealing section

Bearing

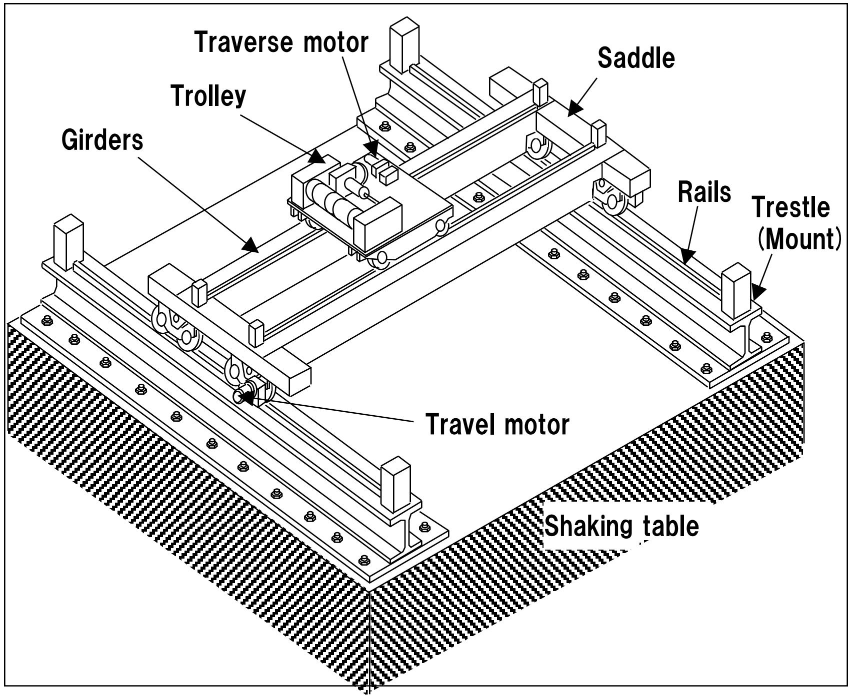


Shaft

Centrifugal fan



3.4 Overhead crane test



Overhead crane model (Scale: 1/2.5)

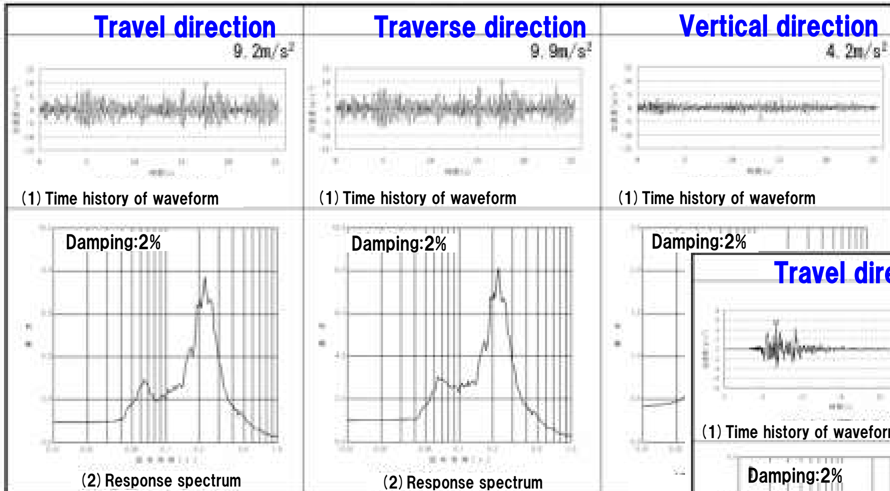
(Girder length: approx. 18m, Trolley height: approx 4m)

During the NCO earthquake , an overhead crane driving shaft coupling was damaged in the reactor building at No. 6 Unit of Kashiwazaki-Kariwa Nuclear Power Plant.

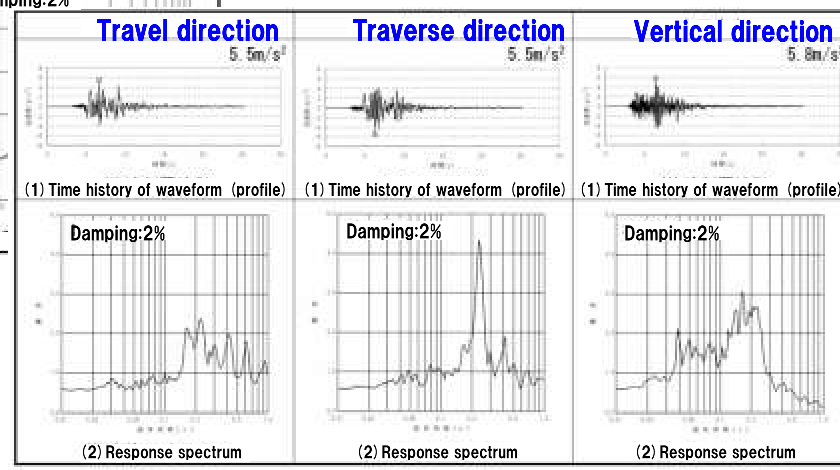
(September 25, 2008, the 14th operation management/equipment soundness evaluation WG, equipment soundness evaluation SWG, Source: Tokyo Electric Power Company Report)

Test conditions (Horizontal and vertical shaking)

Input wave 1: (Simulated S2 wave)



Input wave 2: (Niigata-ken Chuetsu-oki Earthquake observed wave)



- Input wave 1 shaking was implemented with acceleration **increased by 1.5 times in the horizontal direction and by 5.1 times in the vertical direction** taking maximum capability of the shaking table into account, .
- Input wave 2 shaking was implemented with acceleration **increased by 1.5 times both in the horizontal and vertical direction**.

Test scene

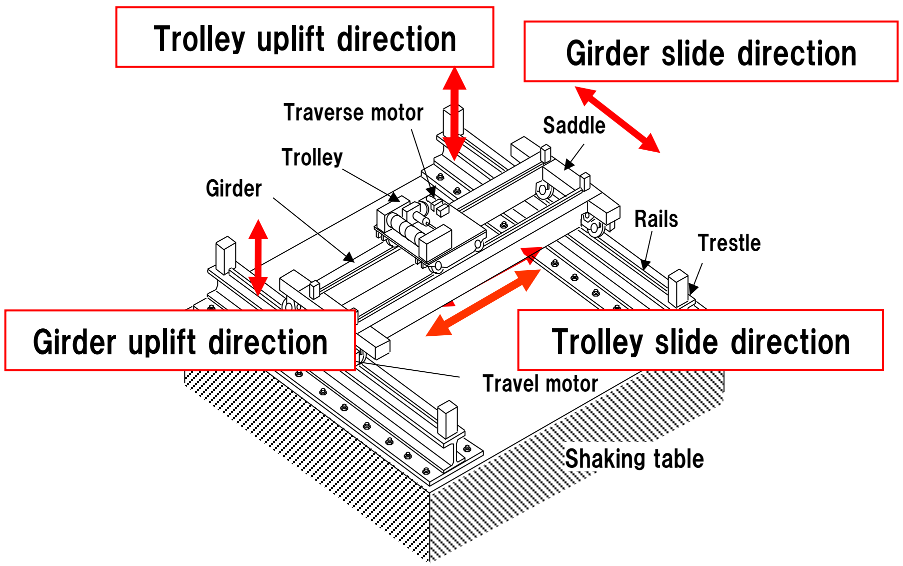
Trolley wheels

Girder wheels

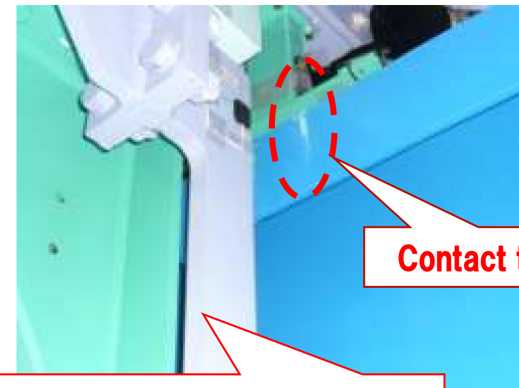
Overhead crane test video (wheel section)

Overhead crane test video (overview): Seismic wave 1 shaking test

Evaluation of test results (Horizontal and vertical shaking)



Post-test examination results
(traces of the contact of trolley derailing prevention lugs)



Input conditions \ Maximum response	Slide amount (cm)		Uplift amount (cm)	
	Trolley	Girder	Trolley	Girder
Input wave 1 Horizontal: Approx. 1.4G, vertical: Approx. 2.7G	97	13	16	6
Input wave 2 Horizontal & vertical: Approx. 0.9G	17	33	6	2.5

■ Even if input acceleration in the vertical direction is less than 1G, if the response exceeds 1G, the wheels lift off the rails.

■ Even if the trolley and girder wheel uplift off the rails is large, **the derailing prevention lugs work effectively and prevent derailing**.

4. Summary (Seismic capacity test results)

Components and equipment	Shaking direction	Main points in seismic capacity test results
Large vertical shaft pump	Horizontal	Structural failure (material yielding) acceleration was12G (at motor crown), 31G (at pump barrel bottom) ,including a high frequency ingredient caused by the collision between the pump barrel and its support).
	Vertical	Function maintaining acceleration was 2.4G (at motor crown), 1.6G (at pump column head).
Motor operated valve	Horizontal	Function maintaining acceleration was between 9G and 12G (at motor drive section).
	Vertical	
Ventilation fan	Horizontal	With labyrinth sealing : Functional failure (leakage) acceleration was 5G (at bearing bracket). Without labyrinth sealing: Function maintaining acceleration was 7.8G (at bearing bracket).
	Vertical	With/without labyrinth sealing: Function maintaining acceleration was 4G (at bearing bracket).
Overhead crane	Horizontal and Vertical	Function maintaining (fall prevention) uplift amount was 6cm (at girder), 16cm (at trolley).

4. Summary（Application of test results）

International contribution through the case-by-case basis offering of data and information

Assessment of residual risk

Assessment of seismic margin

Interaction with seismic hazard evaluation

Indicating parameter of seismic input?

Seismic source information（Seismic wave feature）?

The failure mechanism and damage indicating parameter?

The ultimate capacity on functional failure and structural failure?

The effect on seismic response and damage due to different input waves?

The design functions under horizontal excitation up to 6G（10G）, and under vertical excitation over 1G?