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Kashiwazaki-Kariwa Nuclear Power Station's Case of Evaluation on Plant Integrity and Seismic Reinforcement

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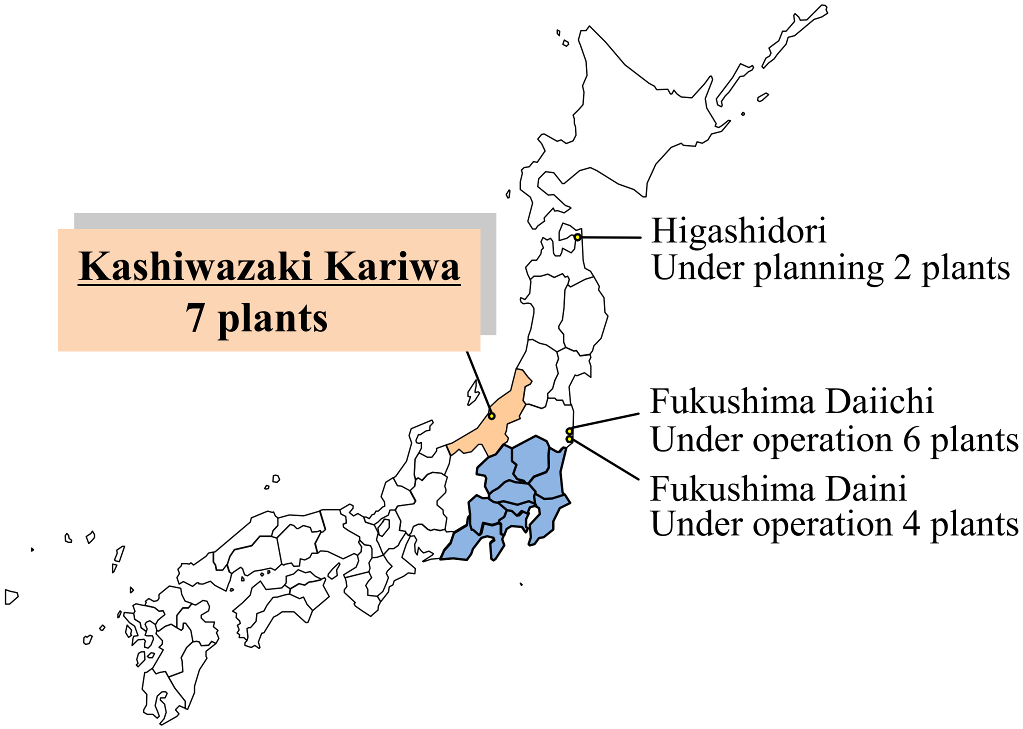
Takashi Yamamiya

Contents

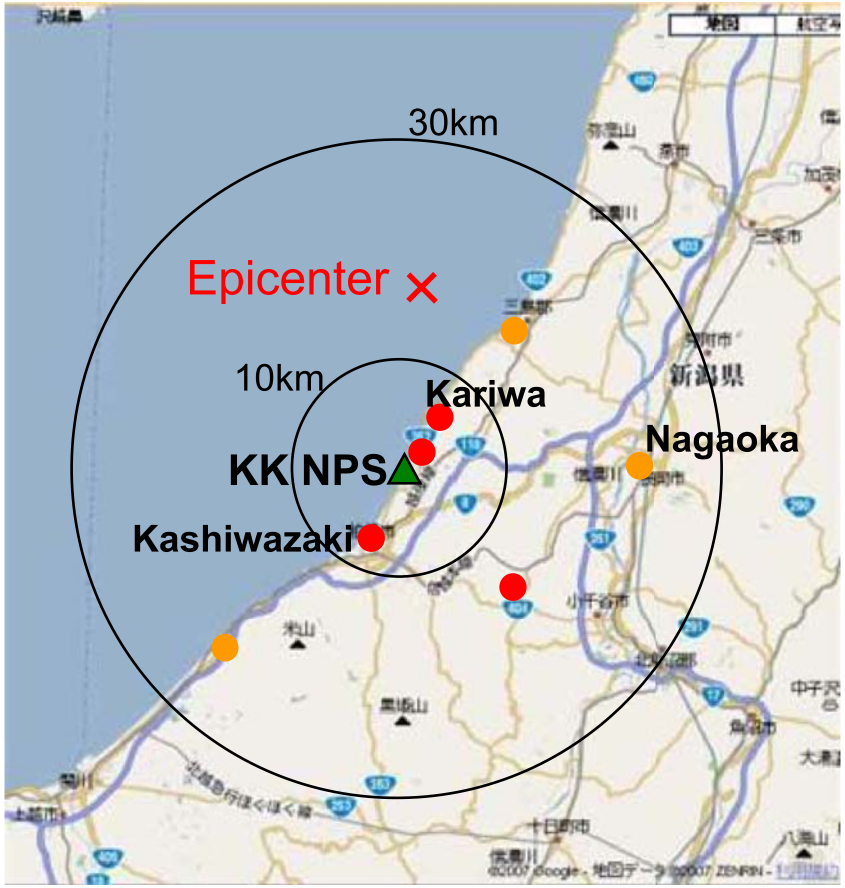
1. Outline of the Kashiwazaki Kariwa NPS

- The world's largest nuclear power station with capacity of 8,212 MWe
- 5 units of Boiling Water Reactors (BWR with 1100 MWe-units 1 to 5) and 2 units of Advanced BWRs (ABWR with 1356 MWe-units 6 and 7)
- Located in Kashiwazaki City and Kariwa Village



2. Outline of NCO Earthquake

- Niigataken Chuetsu-Oki Earthquake (kashiwazaki-kariwa 2007)
  - Data and Time of the quake : July 16, 2007 10:13 AM
  - Magnitude on the Richter scale: 6.8



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Observed Acceleration at R/B Base Mat

Unit:gal (cm/s^2), Design value in ( )

Unit	Horizontal-NS	Horizontal-EW	Vertical
1	311(274)	680(273)	408(235)
2	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	271(263)	322(263)	488(235)
7	267(263)	356(263)	355(235)

- ✓ Unit1, 5, 6 : stopped
- ✓ Unit2, 3, 4, 7 : automatically shutdown

3.1 Method of Evaluation on Plant Integrity

■Method of Evaluation on Plant Integrity

3.1.1 Immediate Walk Down Inspection

↓

3.1.2 Component Level Evaluation

↓

3.1.3 System Level Evaluation

↓

3.1.4 Plant Level Evaluation

3.1.1 Immediate Work Down Inspection

■Outline of Immediate Walk Down Inspection

●By operators

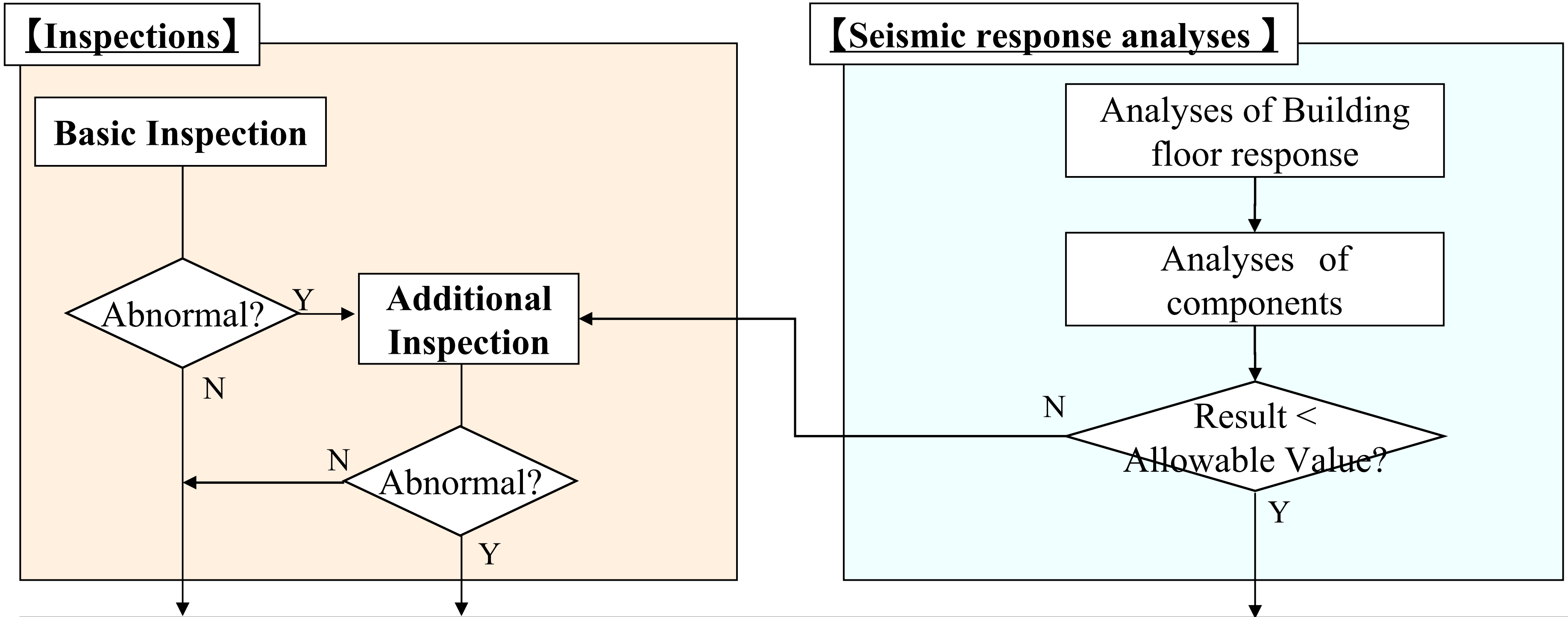
- ✓Performed soon after the earthquake
- ✓Overall condition of the NPS were grasped

●By engineers

- ✓Performed after completion of walk Down inspection by operators
- ✓Focusing likely parts to be damaged and damage modes
- ✓It took about 1 month to complete the inspection.

3.1.2 Component Level Evaluations

Outline of Component Level Evaluations



Comprehensive Evaluation		
Inspection / Analysis	**Abnormality not found**	**Abnormality found**
Less than Allowable Value	Judged as sound	Restoration (Repair /Replace)
More than Allowable Value	Further Analyses and/or Inspections	

3.1.2 Component Level Evaluations

■ Method of Inspections

◆Categorization of components

- ➢dynamic equipment ⇒vertical pump, etc.
- ➢static equipment ⇒piping, etc.
- ➢supporting structures ⇒base, etc.

↓

◆List up parts that is susceptible to earthquake, and develop effective inspection methods for all the parts

↓

◆Basic inspection (example; visual inspection, operating, inspection)

Normalcy → Results

Abnormality ↓

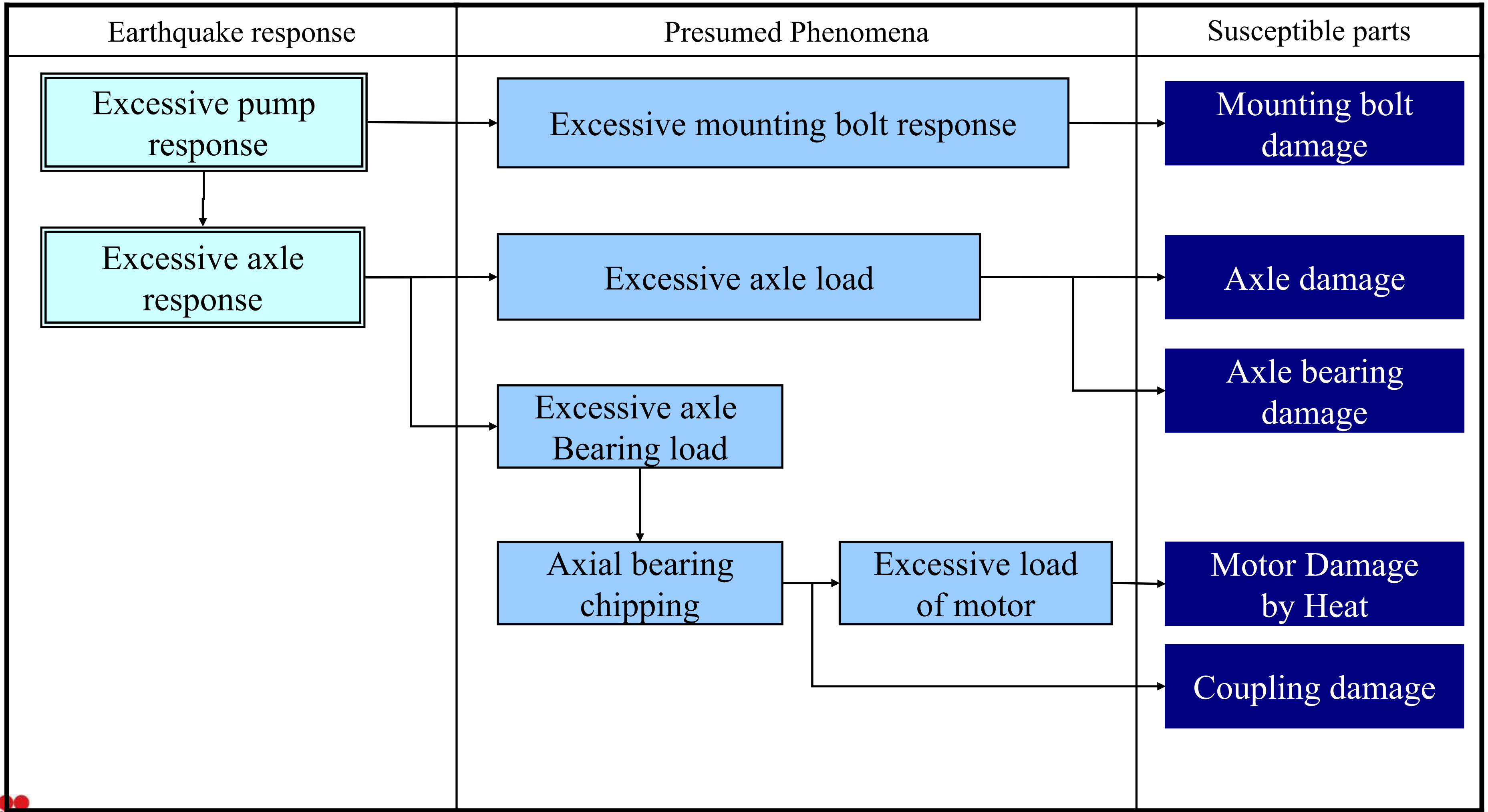
◆Additional inspection (example; nondestructive inspection)

↓

◆Results

3.1.2 Component Level Evaluations

● Flow of Determining Earthquake Susceptible Parts (Vertical pump as an example)



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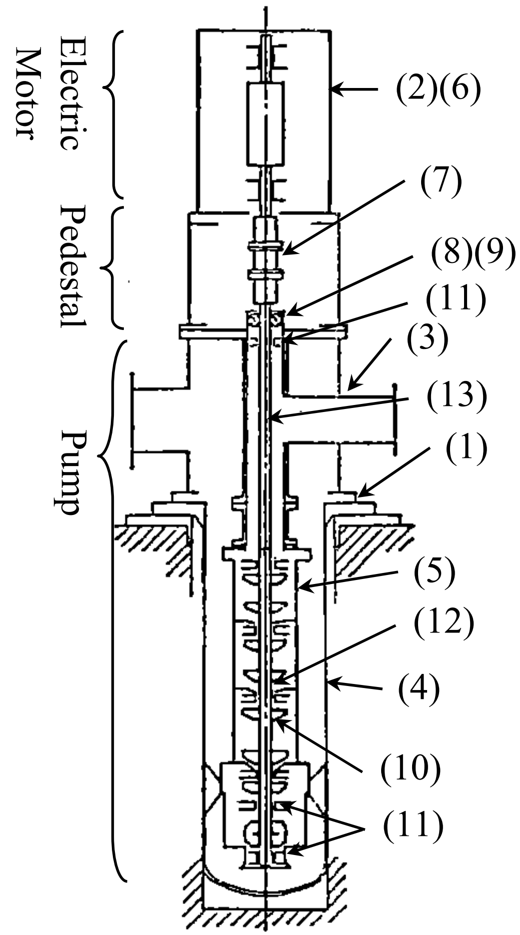
3.1.2 Component Level Evaluations

Effective Inspection Methods (Vertical Pump)

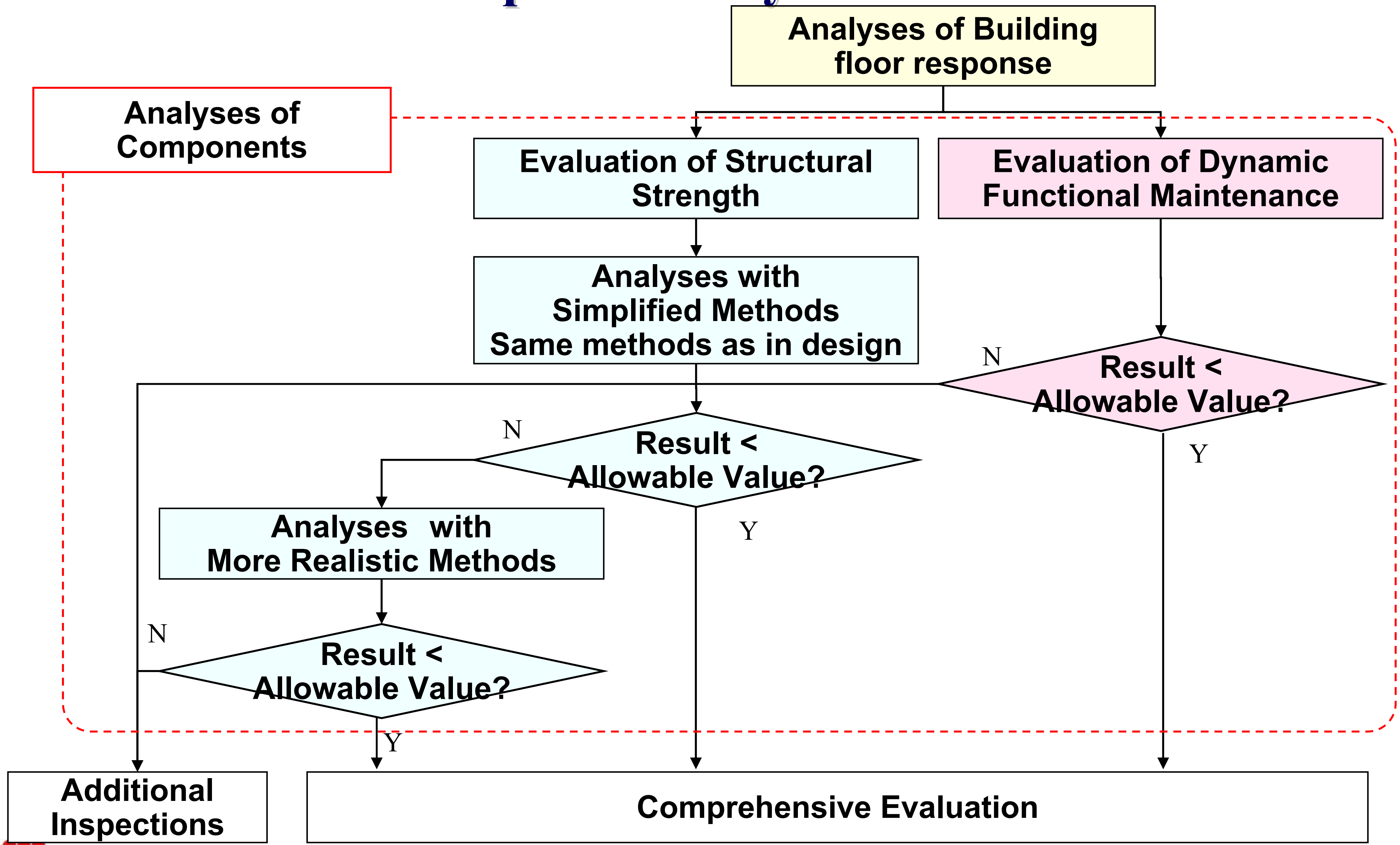
Expected damage of Earthquake susceptible parts	Basic Inspection		Additional Inspection
	Visual Inspection	operation Inspection	Disassembling Inspection
(1) Mounting bolt damage	○	○	
(2) Drive function loss		○	
(3) Discharge casing damage		△	○
(4) Barrel damage		△	○
(5) Column damage		○	
(6) Electric motor burn		○	
(7) Coupling damage	○	○	○
(8) Mechanical seal leak		○	
(9) Mechanical seal damage		○	○
(10)Impeller damage		△	○
(11)Axle bearing damage		○	○
(12)Liner ring chipping		○	○
(13)Axle damage		○	○
(14)Coolant water pipe damage	○	○	
(15)Mechanical seal heat exchanger damage	○	○	



○ confirmable directly
△ confirmable indirectly

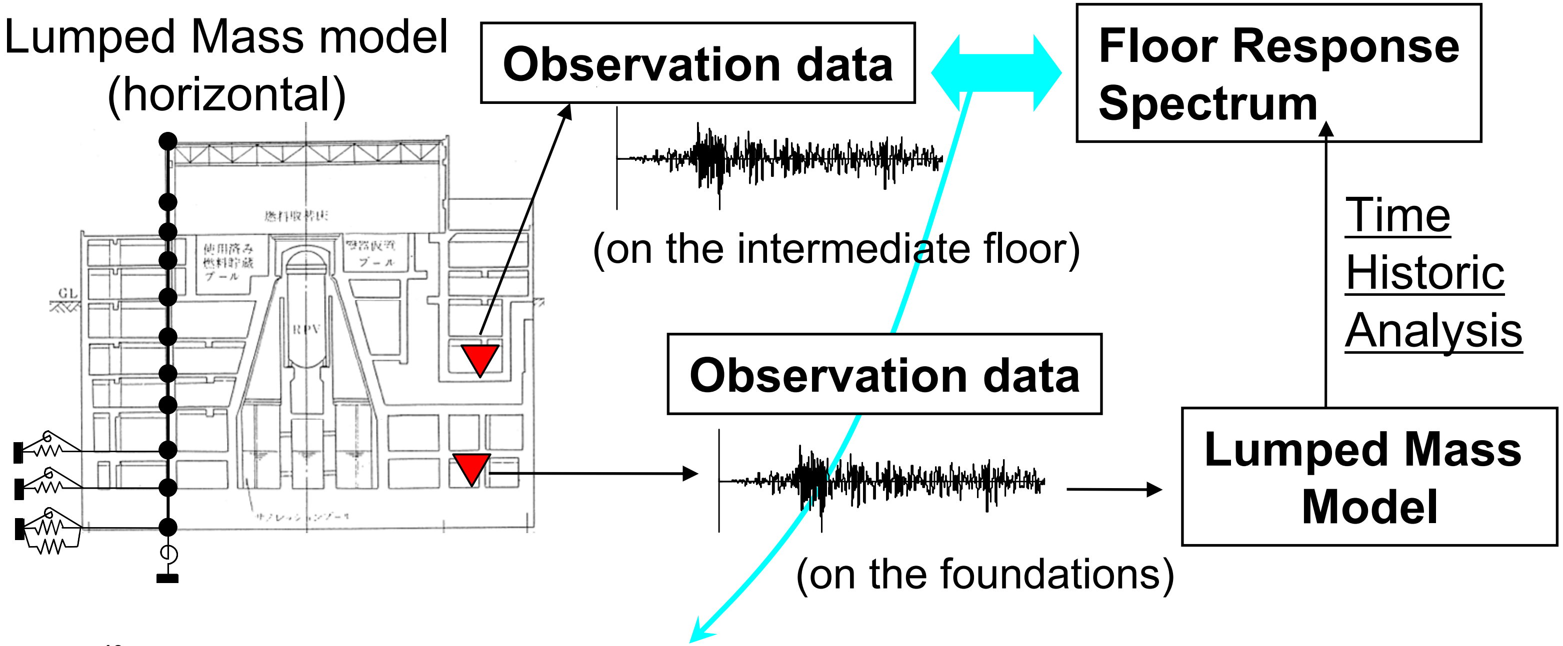
3.1.2 Component Level Evaluations

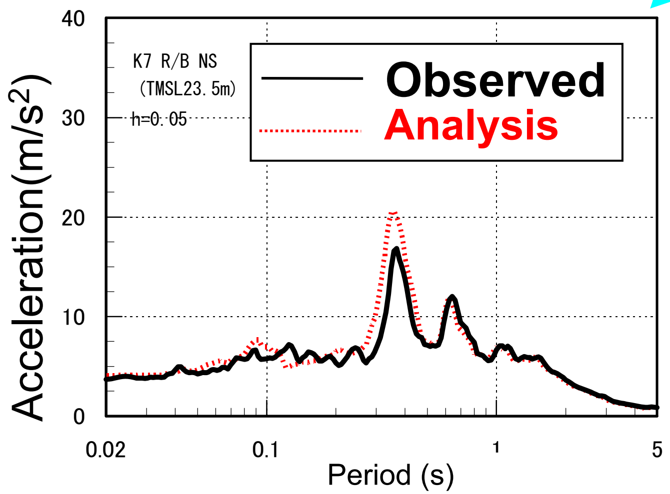
■ Flow of Seismic response Analyses



3.1.2 Component Level Evaluations

■ Analyses of Building floor Response





The results showed a good agreement

The simulation model was validated

3.1.2 Component Level Evaluations

■Evaluation of Structural Strength

Evaluation of structural strength was calculated by tiered approach following methods, and compared with the criteria IIIAs.

- **Simplified method**

  : By using ratio of calculated floor response to design value

- **The same method as in design**

  : Response analysis using floor responses

  ↓ Result > Allowable Value

- **More Realistic method**

  : Evaluation method is modified within codes and standards.
  (FEM, time historical analysis, modified damping factor, etc.)

IIIAs is the allowable condition that limits seismic responses almost completely within elastic area.

3.1.2 Component Level Evaluations

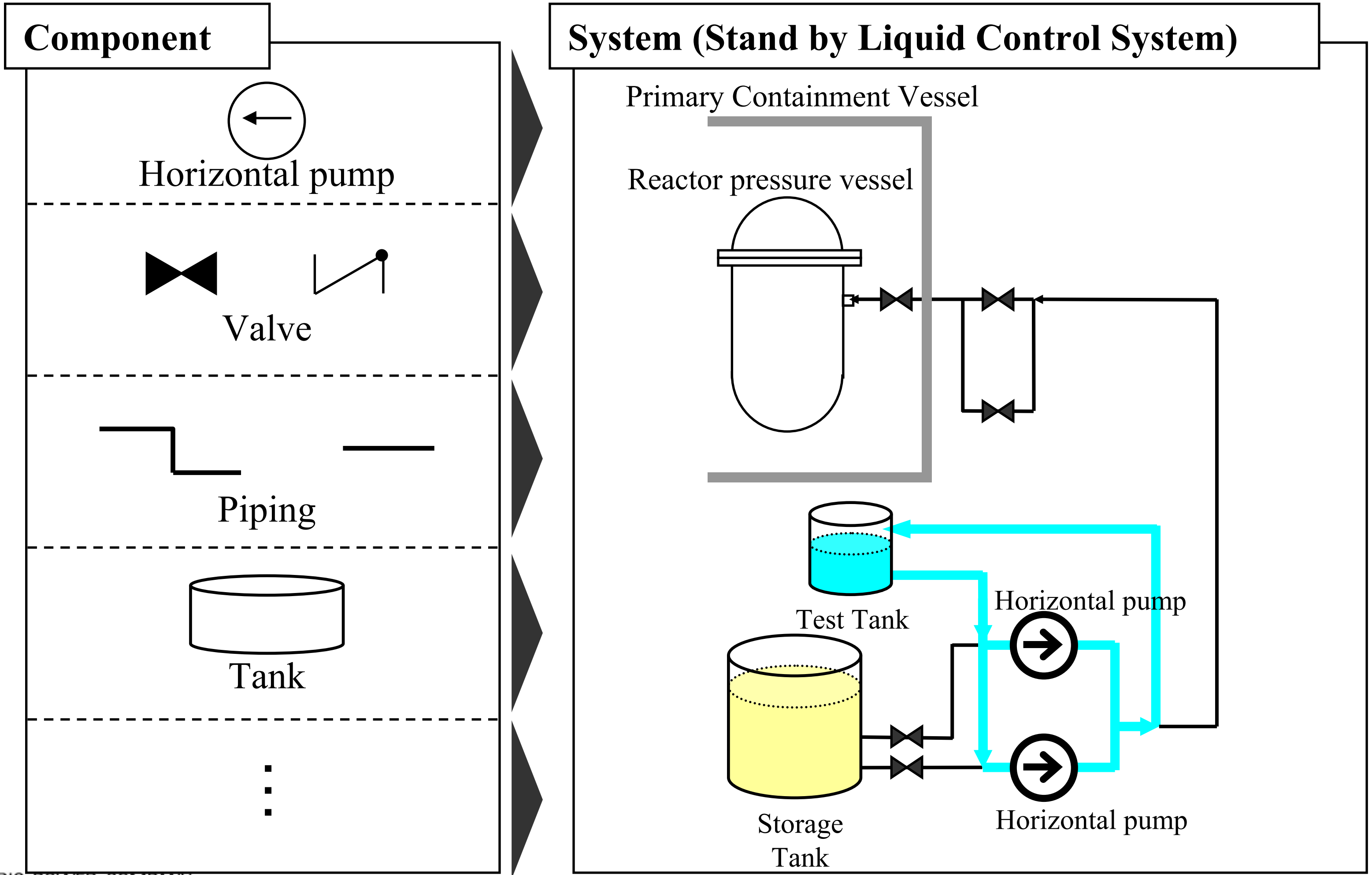
■Evaluation of Dynamic Functional Maintenance

- ✓Performed for dynamic components whose dynamic functions are required at the time of an earthquake.
- ✓Evaluated by comparing calculated seismic accelerations with functionally confirmed accelerations.

3.1.3 System Level Evaluation

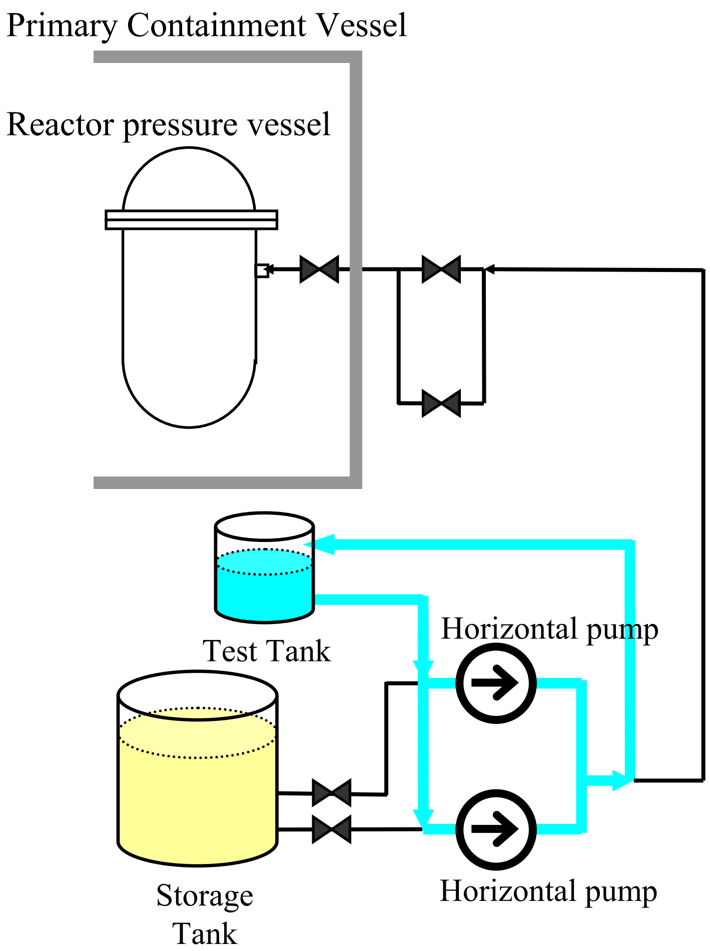
■ Outline of system level evaluation

- The soundness of the systems were confirmed by **system function test**.



3.1.3 System Level Evaluation

■ System function test (Stand by Liquid Control System as an example)



● Function of Stand by Liquid Control System

If Control rod wouldn't be insert by any possibility, the nuclear power reactor would be stopped in safety by injection of boric-acid solution that function same Control rod.

● Method of Function test

Function of the system was assessed by confirming following points.

- Pump running performance
  - ✓Discharge Pressure
  - ✓Vibration
  - ✓Abnormal noise
  - ✓Abnormal odor
- Valve opening motion
- Mass of boric-acid in Storage Tank

3.1.4 Plant Level Evaluation

■Outline of Plant Level Evaluation

- **Inspections on component level after the plant start-up**
- **System function test after the plant start-up**

⇒ The soundness of all components and systems are confirmed by performing these inspections and system function tests included in those previously.

- **Comprehensive evaluation for Plant Operating condition**

Plant parameters related operation such as following were measured.

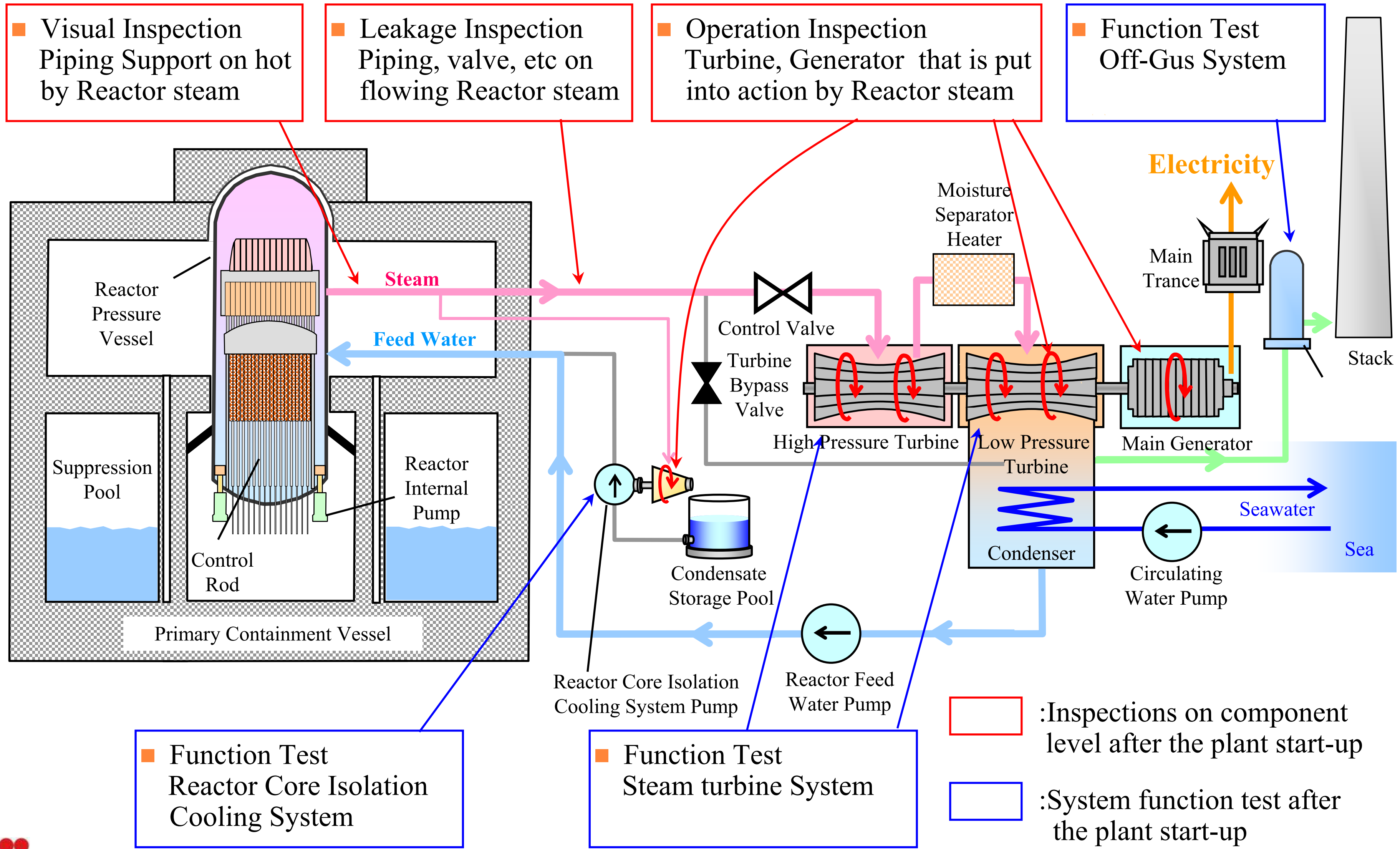
✓Reactor Pressure
✓Reactor Water Level
✓Main Steam Pressure
✓Generator Electric Power etc.

} The number of these parameters are about 800.

⇒ We confirm effects of the plant overall by the earthquake, and rate that we can operate the plant continuously.

3.1.4 Plant Level Evaluation

Examples of Plant Level Evaluation



3.2 Results of Evaluation on Plant Integrity

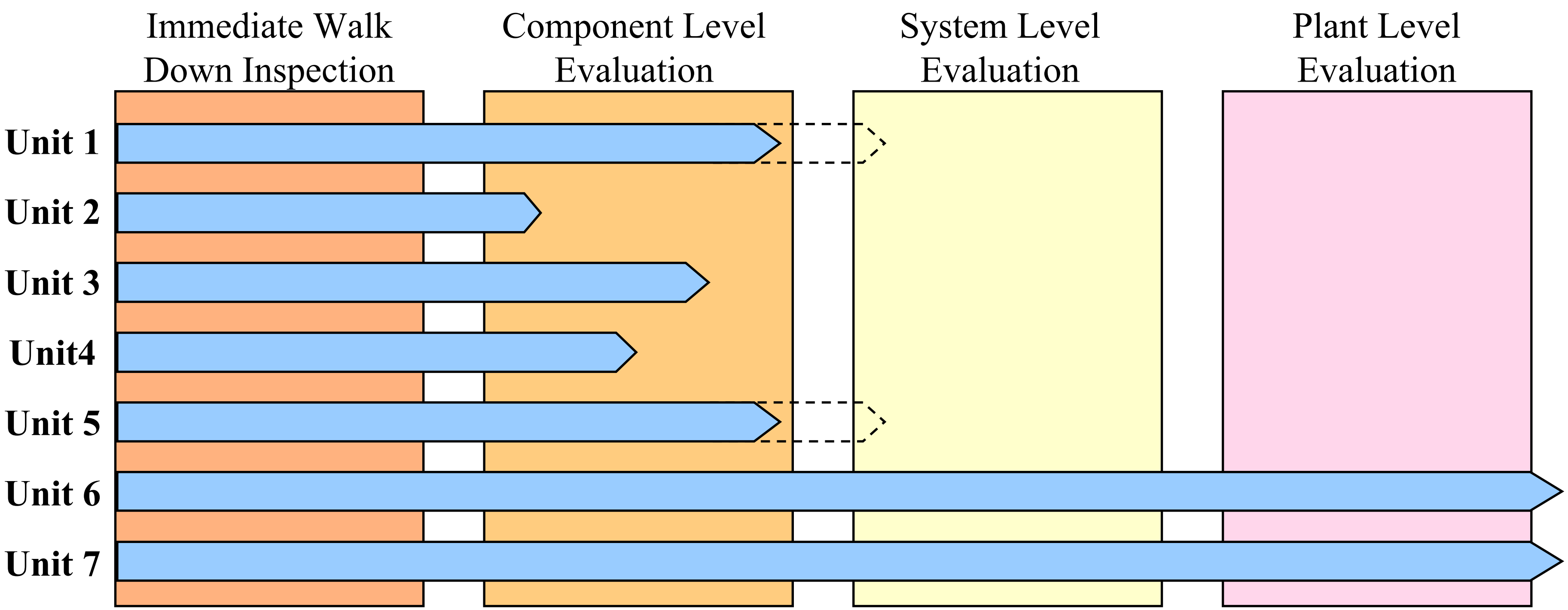
- 3.2.1 Immediate Walk Down Inspection
- 3.2.2 Component level evaluation
- 3.2.3 System level evaluation
- 3.2.4 Plant level evaluation

→ Exemplify Unit 7

- 3.2.5 Main damage in Unit1 to 6

3.2 Results of Evaluation on Plant Integrity

■ Current Status



3.2.1 Immediate Work Down Inspection

Results of Immediate Walk Down in Unit7

Seismic Safety Class		Examples of Equipment	Damage
Safety Related	As	• Reactor pressure vessel • Primary containment vessel • Control rods	*None*
	A	• ECCS • Reactor building	*None*
Non Safety Related	B	• Turbine facilities • Radioactive waste processing system	*Minor* (Overhead crane cable trolley etc.)
	C	• Main generators • Transformers • House steam boilers	*Minor* (House transformer etc.)

3.2.2 Component Level Evaluations

■ Results of Inspection in Unit 7

- The number of Components Conducted Inspection: 1,360

Components without abnormalities	1,289
Components with abnormalities	71
✓Due to Non- NCO earthquake (aged deteriorations, etc.)	42
✓Due to NCO earthquake	29

Minor damages such as turbine blade wearing marks not to decrease safety of NPS

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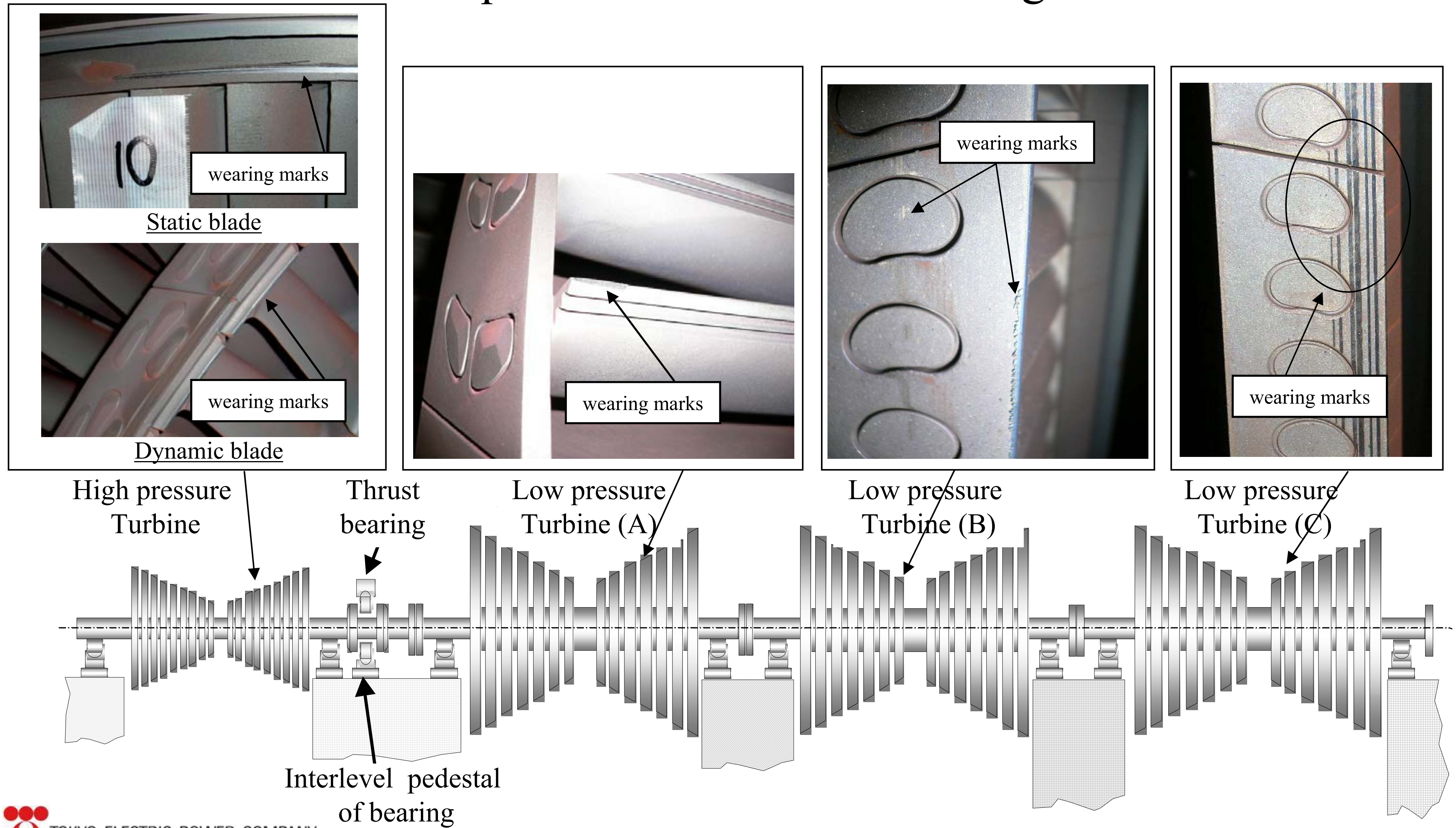
3.2.2 Component Level Evaluations

■ Examples of abnormalities

- Due to NCO earthquake： turbine blade wearing marks



3.2.2 Component Level Evaluations

■ Results of Seismic Response Analyses of Components in Unit 7

● Structural Strength

Function	Subject	Classification	Calculated Value (MPa)	Criteria (MPa)
Core Cooling	Main Steam Piping	Stress	136	281
	RHR Piping	Stress	239	274
	RHR Pump (Foundation Bolt)	Stress	5	350
Containment	Reactor Pressure Vessel (Foundation Bolt)	Stress	115	499
	Core Support Structure (Shroud Support Leg)	Stress	32	243
	Primary Containment Vessel	Stress	27	264

● Dynamic Functionality

Function	Subject	Classification	Calculated Value	Criteria
Reactivity Control	Control Rod Insertion	Displacement	7.1 (mm)	40.0 (mm)
Core Cooling	RHR Pump	Acceleration	0.37 G (H) 0.37 G (V)	10.0 G (H) 1.0 G (V)

3.2.3 System Level Evaluation

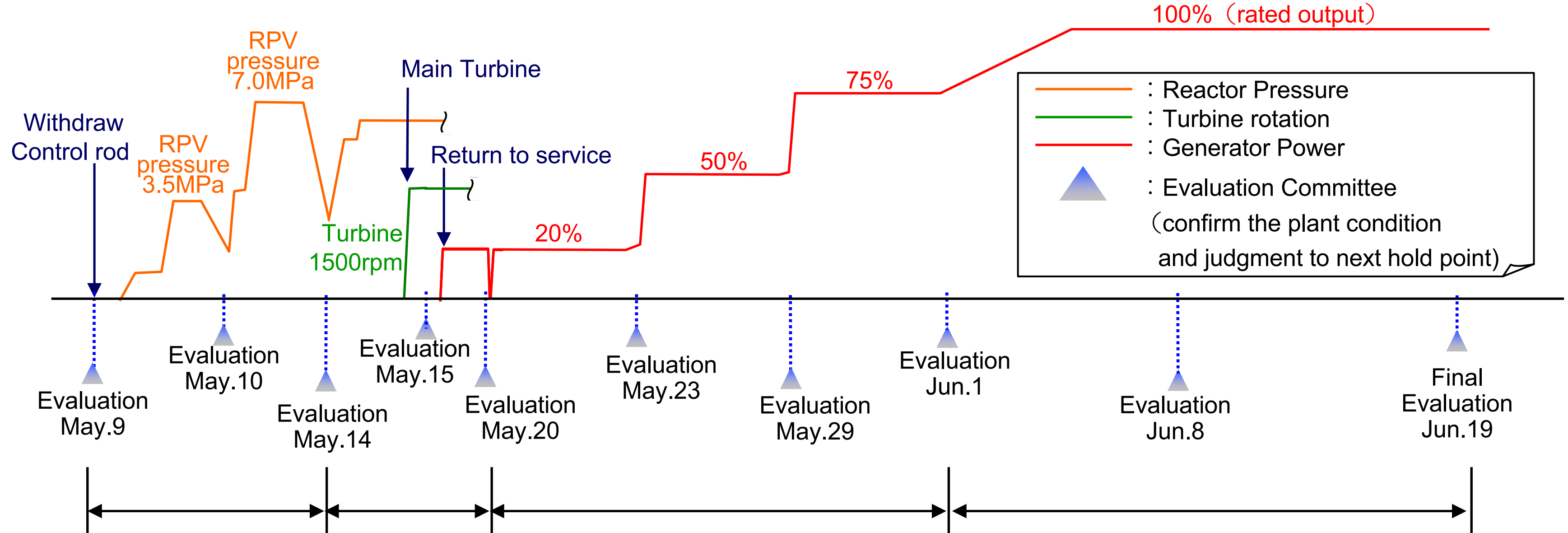
Results of System level evaluation in Unit 7

- The number of System function test : 23
- In all test, confirmed the system fulfill a function
- Abnormality by earth-quake was not founded in all test.

Case of System Function test (Reactor Feed Water System)

3.2.4 Plant Level Evaluation

■Plant start-up progress in Unit 7



■ Visual Inspection
Piping Support on hot by Reactor steam

■ Leakage Inspection
Piping, valve, etc on flowing Reactor steam

■ Operation Inspection
Turbine, Generator that is put into action by Reactor steam

■ System Function Test
Steam turbine System

■ Visual Inspection
Piping Support on hot by Reactor steam

■ Leakage Inspection
Piping, valve, etc on flowing Reactor steam

■ System Function Test
- Reactor Core Isolation Cooling System
- Off-Gus system
- Steam turbine system

3.2.4 Plant Level Evaluation

Results of Plant Level Evaluation

- Results of Inspections on component level after the plant start-up
  - Number of Components Conducted Inspections: 106

Components without abnormalities	104
Components with abnormalities	2
✓Due to Non-NCO earthquake	2
✓Due to NCO earthquake	0

Minor abnormality such as maladjustment of valve limit switch not to decrease safety of NPS

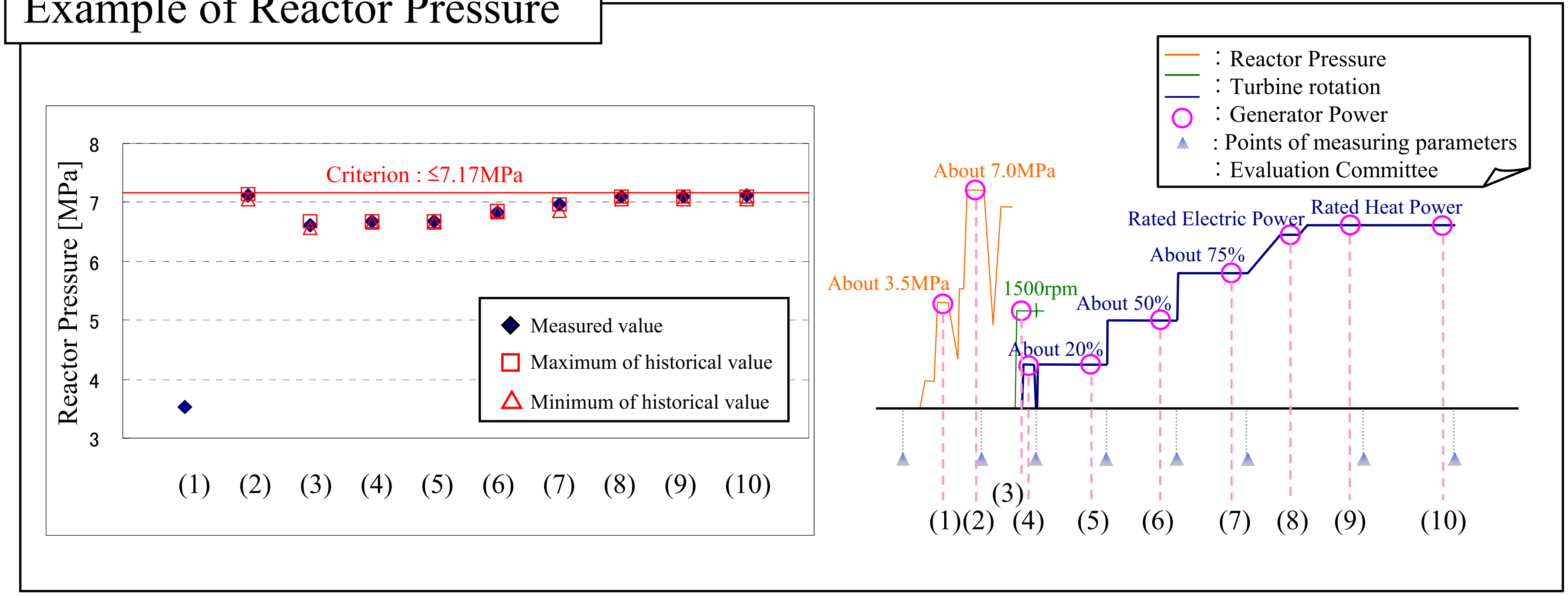
- Results of System function test after the plant start-up
  - The number of System function test : 4
  - In all test, confirmed that the system fulfill a function
  - Abnormality by earth-quake was not founded in all test

3.2.4 Plant Level Evaluation

■Results of Plant Level Evaluation

- Results of Comprehensive evaluation for Plant Operating condition
  - None of parameter affected adversely by the earthquake have been found.

Example of Reactor Pressure



3.2.5 Main damage in Unit1 to 6

Damage Situation to the NCO Earthquake

Damage by High Acceleration

e.q. Service Water Tank
- ✓ Side Wall Buckling
- ✓ Damage of Anchorage Bolts

Damage by Subsidence and Displacement

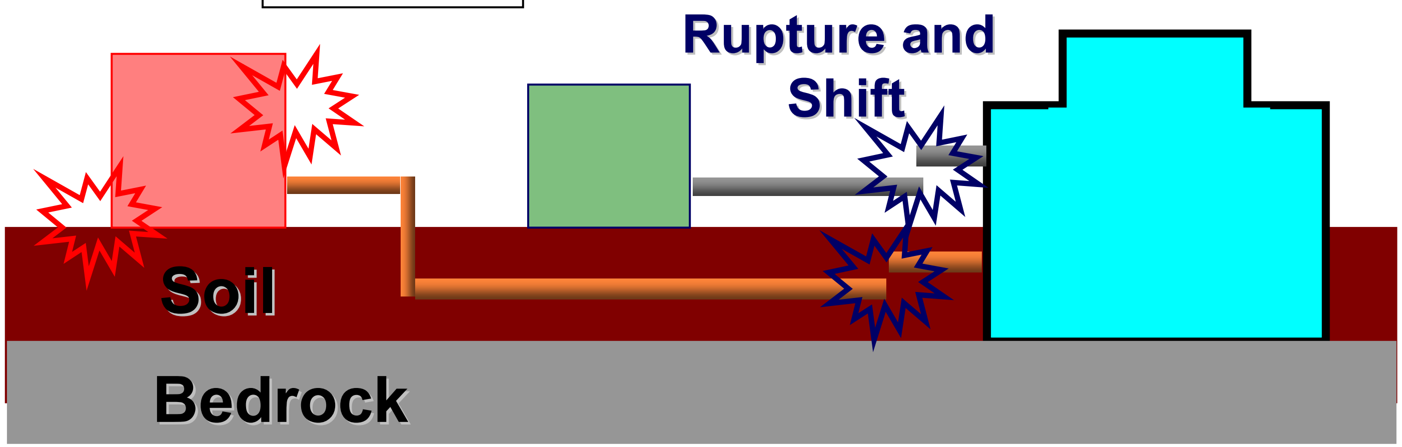
e.q. Transformer
- ✓ Connecting Bus Bar Shift

e.q. Fire Protection Piping
- ✓ Rupture

Class C

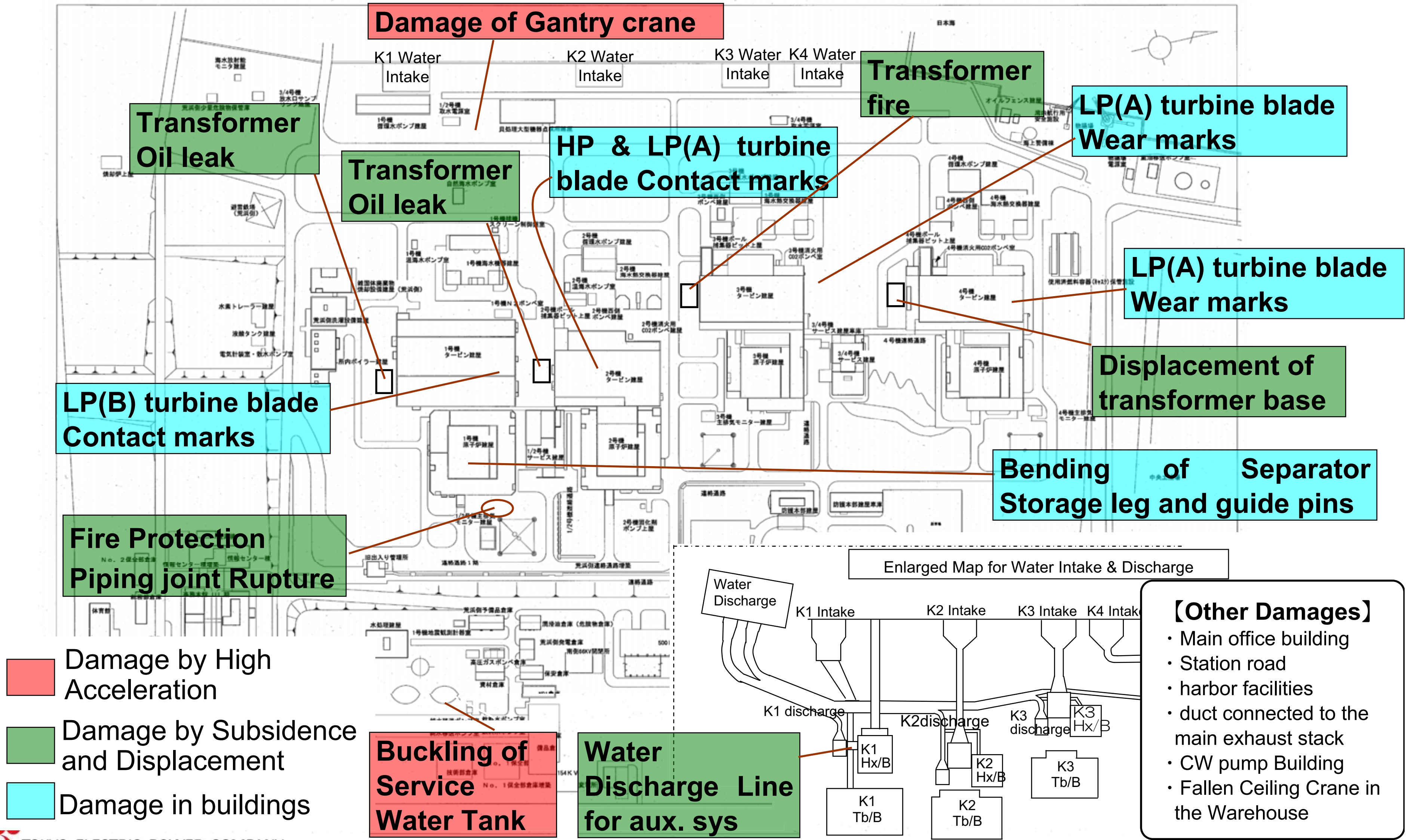
No or Minor Damage in the Building

Class As,A,B



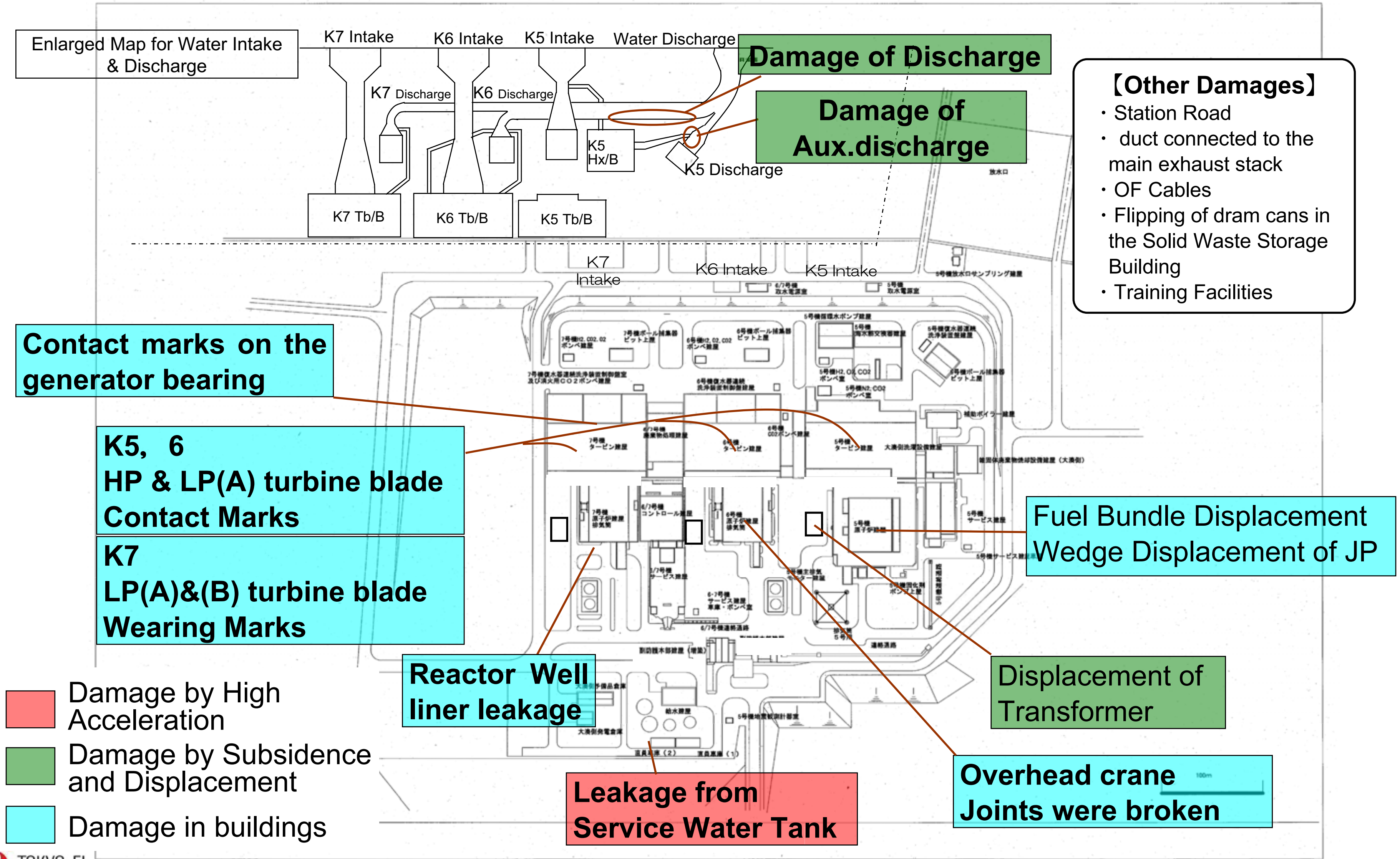
3.2.5 Main damage in Unit1 to 6

■ Damage Situation to the NCO Earthquake (Overview:#1-4)



3.2.5 Main damage in Unit1 to 6

■ Damage Situation to the NCO Earthquake (Overview:#5-7)



【Other Damages】
- Station Road
- duct connected to the main exhaust stack
- OF Cables
- Flipping of dram cans in the Solid Waste Storage Building
- Training Facilities

3.2.5 Main damage in Unit1 to 6

Example of Damage by Subsidence and Displacement

- **Fire Protection Piping joint Rupture**

Coupling joint

Coupling joint

Threaded joint

3.2.5 Main damage in Unit1 to 6

Example of Damage by Subsidence and Displacement

■ Fire Protection Piping joint Rupture

- **Restoration state**

FP piping trench

Placing FP piping aboveground

3.2.5 Main damage in Unit1 to 6

Example of Damage by Subsidence and Displacement

- **Fire Protection Piping joint Rupture**

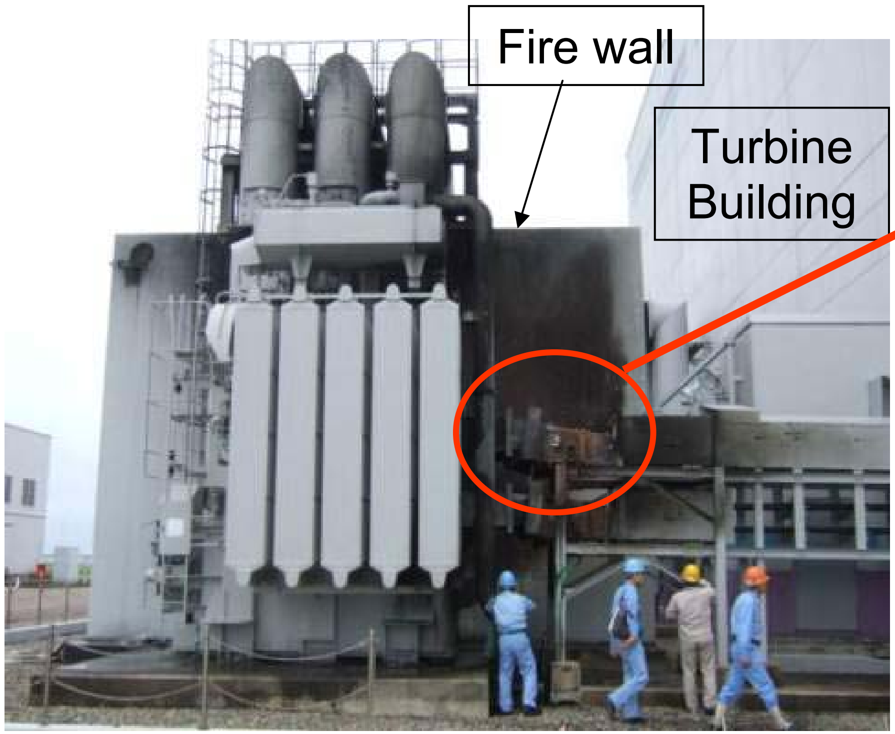
A fire of house transformer

Burned house transformer

3.2.5 Main damage in Unit1 to 6

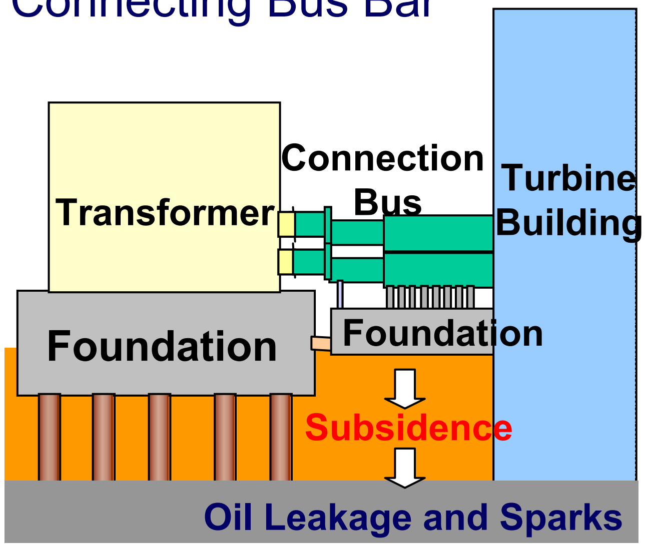
Example of Damage by Subsidence and Displacement

■Transformer Damages



Fire of House Transformer of unit 3

Connecting Bus Bar

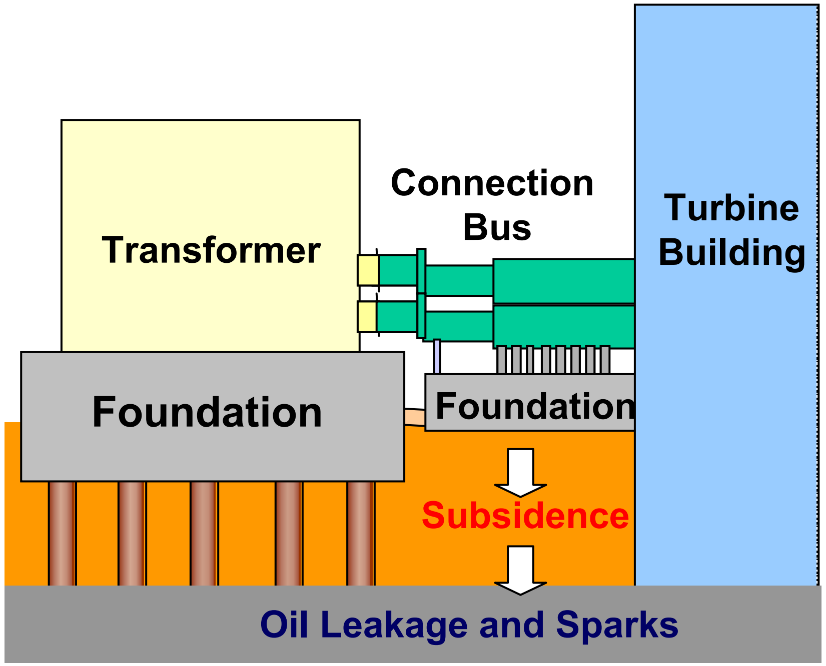


3.2.5 Main damage in Unit1 to 6

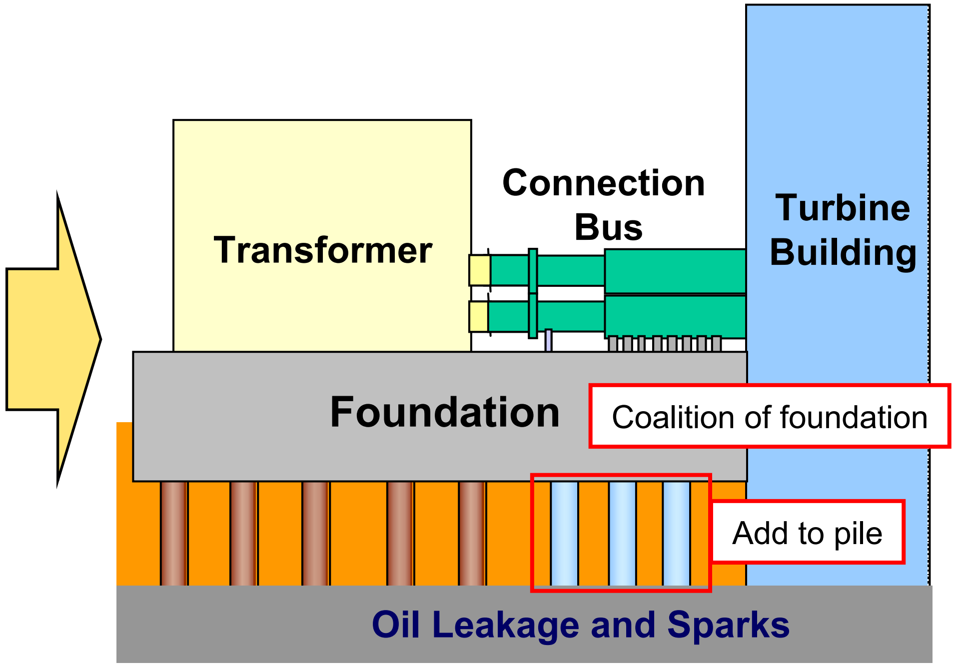
Example of Damage by Subsidence and Displacement

■ Transformer Damages

●Restoration state



Damage situation



Restoration state

3.2.5 Main damage in Unit1 to 6

Example of Damage by High Acceleration

Anchor Bolts and Brackets were damaged

3.2.5 Main damage in Unit1 to 6

Example of Damage by High Acceleration

■Service Water Tanks Damages

Damage of Anchor
Bolts and Brackets

Leakage from the Tank

3.2.5 Main damage in Unit1 to 6

Example of Damage by High Acceleration

■Service Water Tanks Damages

●Restoration state

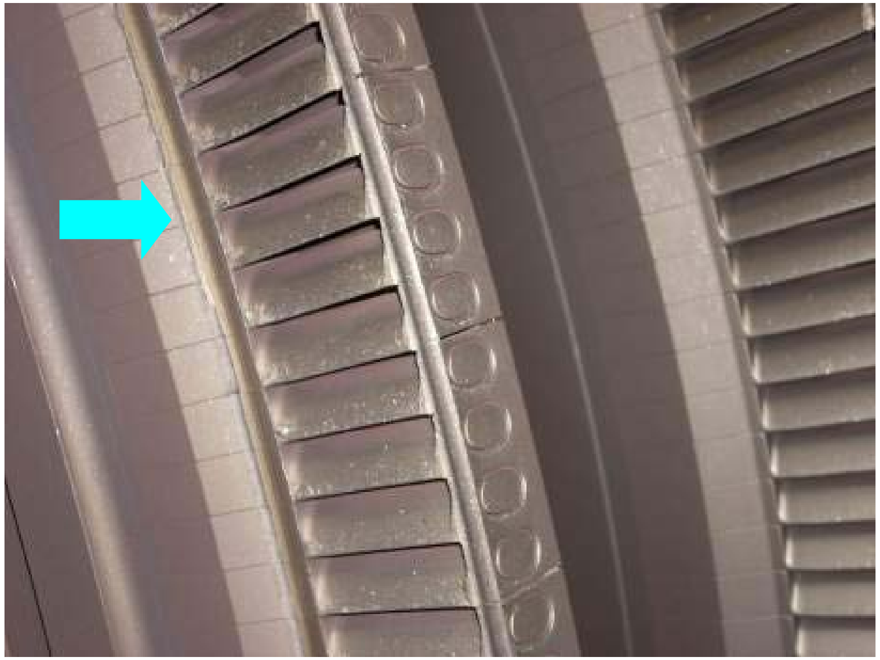
Damage situation

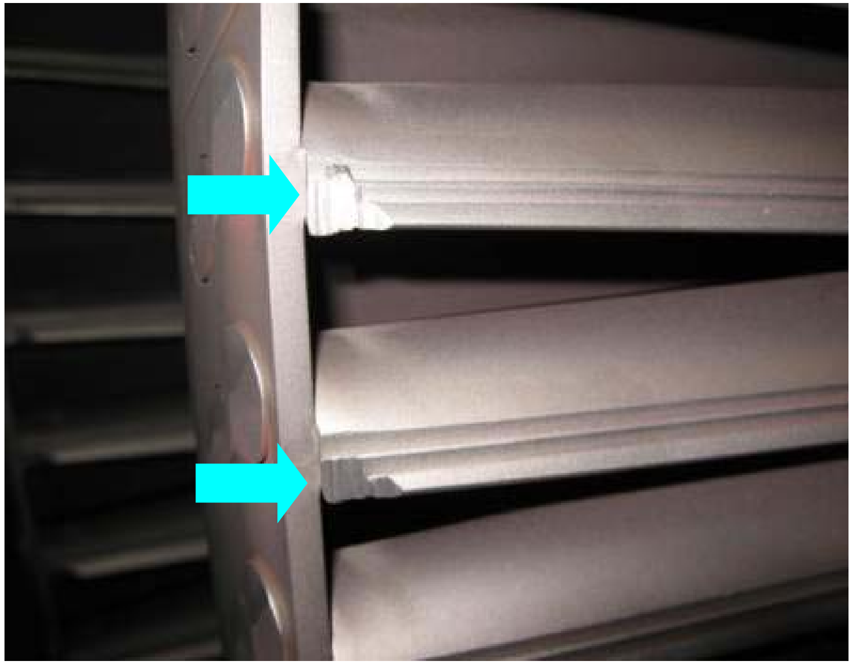
Restoration state

3.2.5 Main damage in Unit1 to 6

Example of No or Minor Damage in the Building

■Minor Damage in Non-Safety Related Facilities





Turbine Blade Wear Marks of KK-3/4 LP(A)

3.2.5 Main damage in Unit1 to 6

Example of No or Minor Damage in the Building

- **No Damage in Safety Related Facilities**

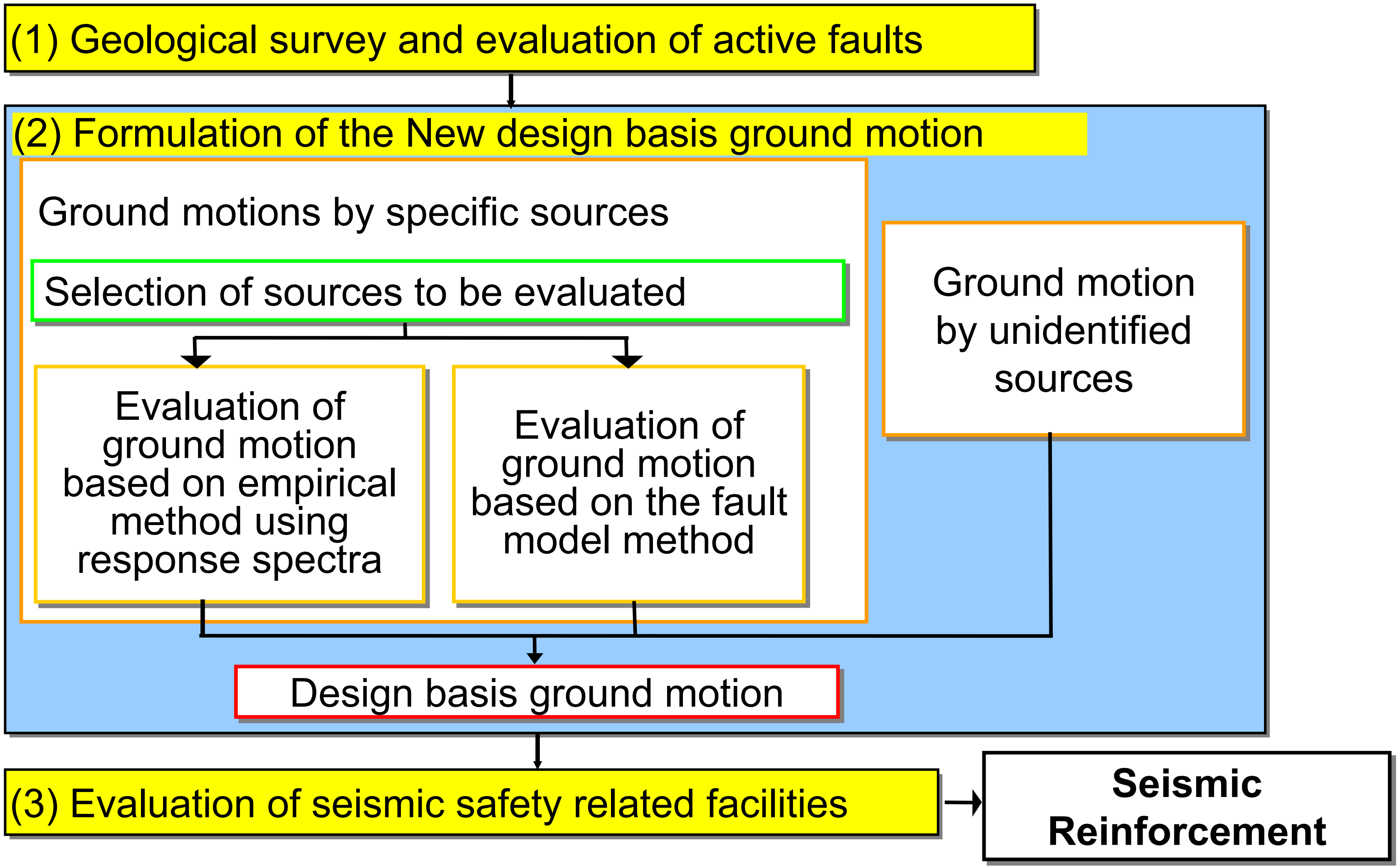
Diesel Generator

Primary Loop Recirculation Pump

4.1 Re-evaluation of Seismic Safety

Re-definition of New Design Basis Ground Motion

✓Flow for Defining Design Basis Ground Motion



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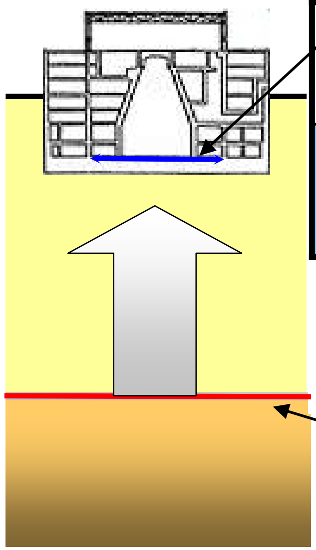
4.1 Re-evaluation of Seismic Safety

Response acceleration of the Design Basis Ground Motion



Unit: Gal

On the basemat of reactor building	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
NCO Earthquake (observed values)	680	606	384	492	442	322	356
Ss Response acceleration	845	809	761	704	606	724	738

Unit: Gal

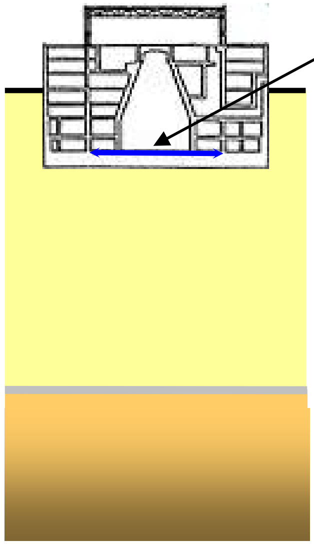
On the free surface of base stratum	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
The peak value of the design basis ground motion S_2	450						
The peak value of the design basis ground motion Ss	2,300				1,209		

The value represents the larger value among horizontal ones (south-north and east-west). (Unit: Gal)

4.1 Re-evaluation of Seismic Safety

Upgrading to Improve Seismic Safety

Earthquake motion for upgrading to improve seismic safety of all units is configured at 1,000 gals.



Unit: Gal

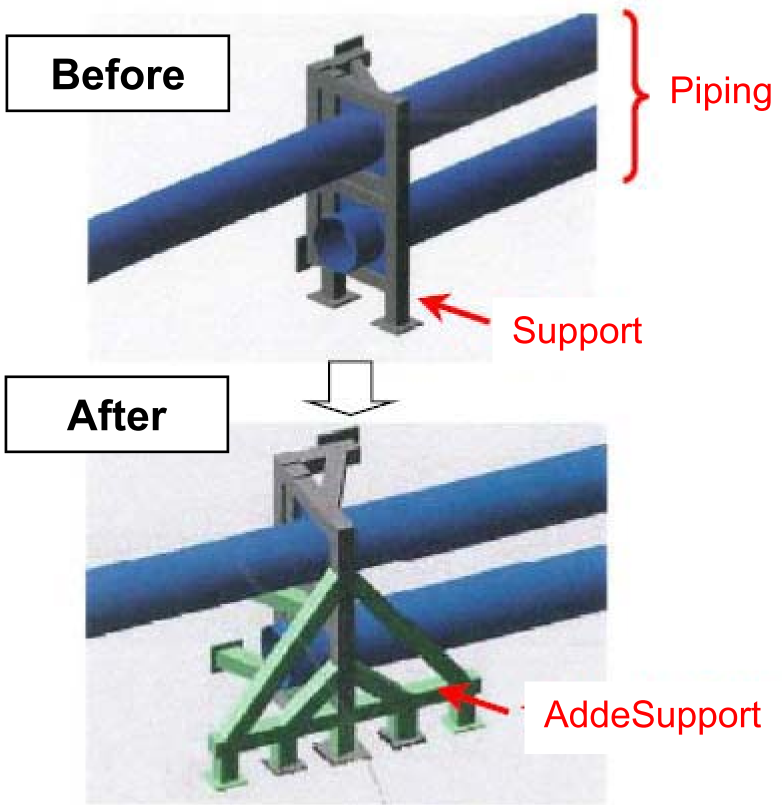
On the basemat of reactor building	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Chuetsu-oki Earthquake (observed values)	680	606	384	492	442	322	356
Response to the design basis ground motion Ss	845	809	761	704	606	724	738
Ground motion for upgrading to improve seismic safety	**1,000**						

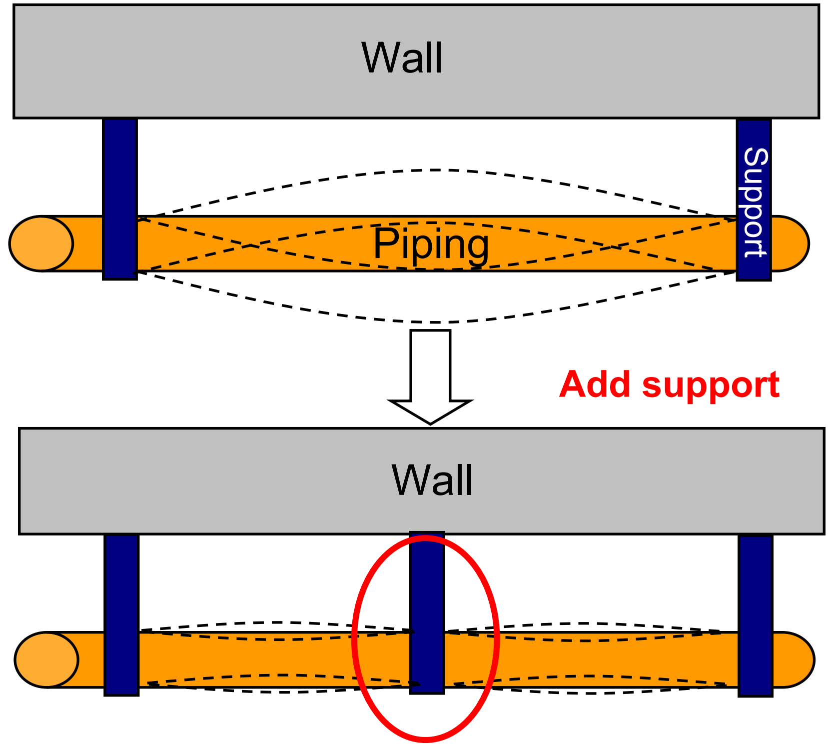
4.2 Example of Reinforcement Works

- **Reinforcement works for the following Structure and Components have been being performed.**
  - Support structures of piping
  - Exhaust stack
  - Roof truss of Reactor Building
  - Fuel handling machine
  - Reactor Building overhead crane

4.2 Example of Reinforcement Work

■Support structure of piping

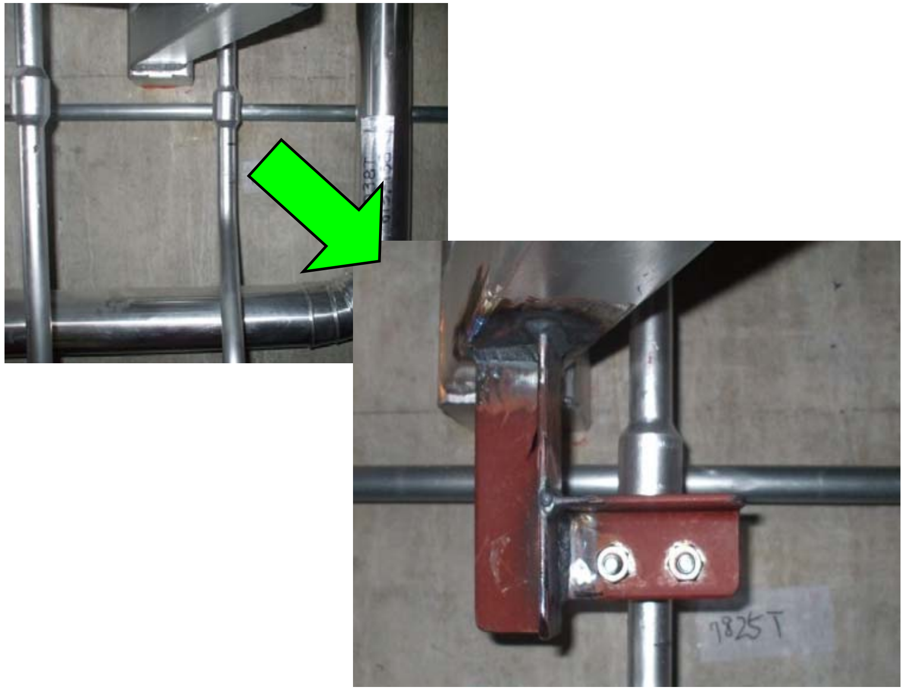




Adding support structures contributes to a decrease in shaking of piping.

4.2 Example of Reinforcement Work

■Support structure of piping



Add support structures to reduce piping vibration

Add support structures to increase support rigidity

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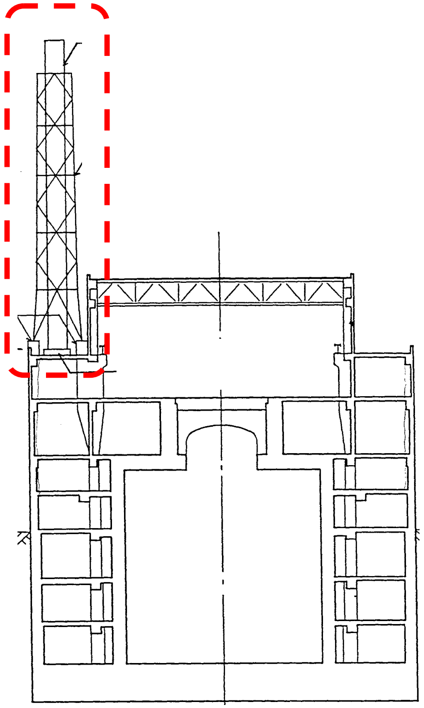
4.2 Example of Reinforcement Work

■Exhaust stack

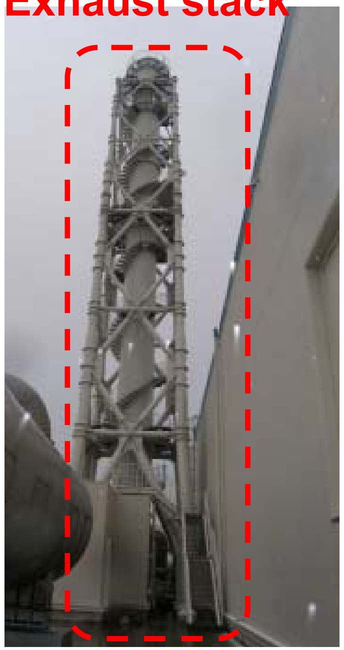
Installation of vibration control device

Exhaust stack

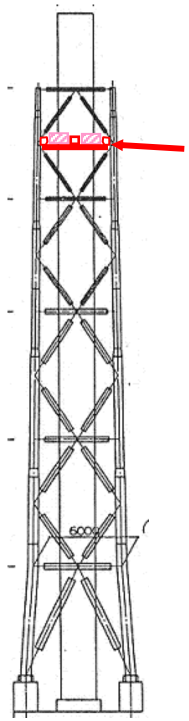


Section view of reactor building Unit 6 &7

Exhaust stack



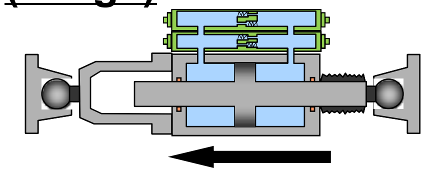
Exhaust stack



Installation of vibration control device

Example of upgrading exhaust stack

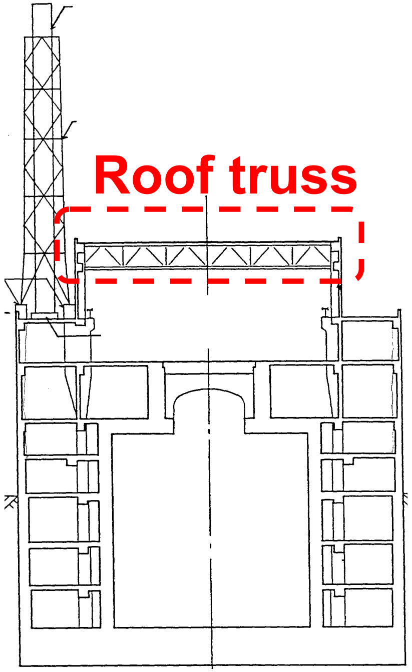
Vibration control device (image)



Absorption of vibration energy by fluid resistance of oil

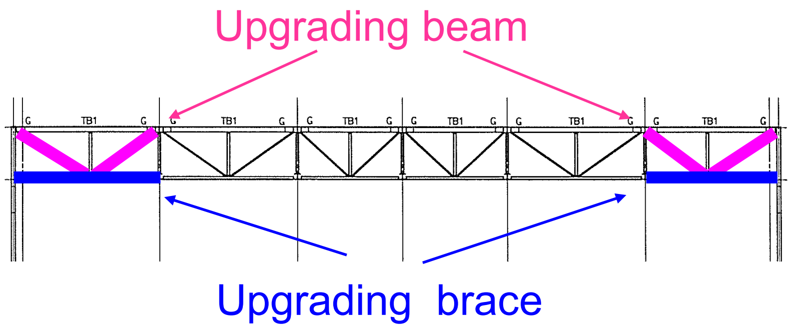
4.2 Example of Reinforcement Work

■Roof truss of R/B



Section view of reactor building Unit 6 &7

Reactor building roof truss



Example of upgrading Reactor building roof truss

5. Conclusion

Evaluation on Plant Integrity

- As a results up to now of Component Level Evaluation,
  - ✓ No damage to safety rerated facilities has been found.
  - ✓ All results of Seismic response analysis obtained meet evaluation criteria.
- As a results up to now of System and Plant Level Evaluation,
  - ✓ There was not abnormal occurrences from earth-quake.
  - ✓ The system and whole plant fulfilled a function.

Seismic Reinforcement

- A safety-related Structure and Components have been reinforcing for being performance under the Ground motion for upgrading to improve seismic safety.

Thank you for your attention.