International Technical Meeting
on "Seismic Safety of NPPs"

Tivoli (Roma) - Italy March 25-26, 2010

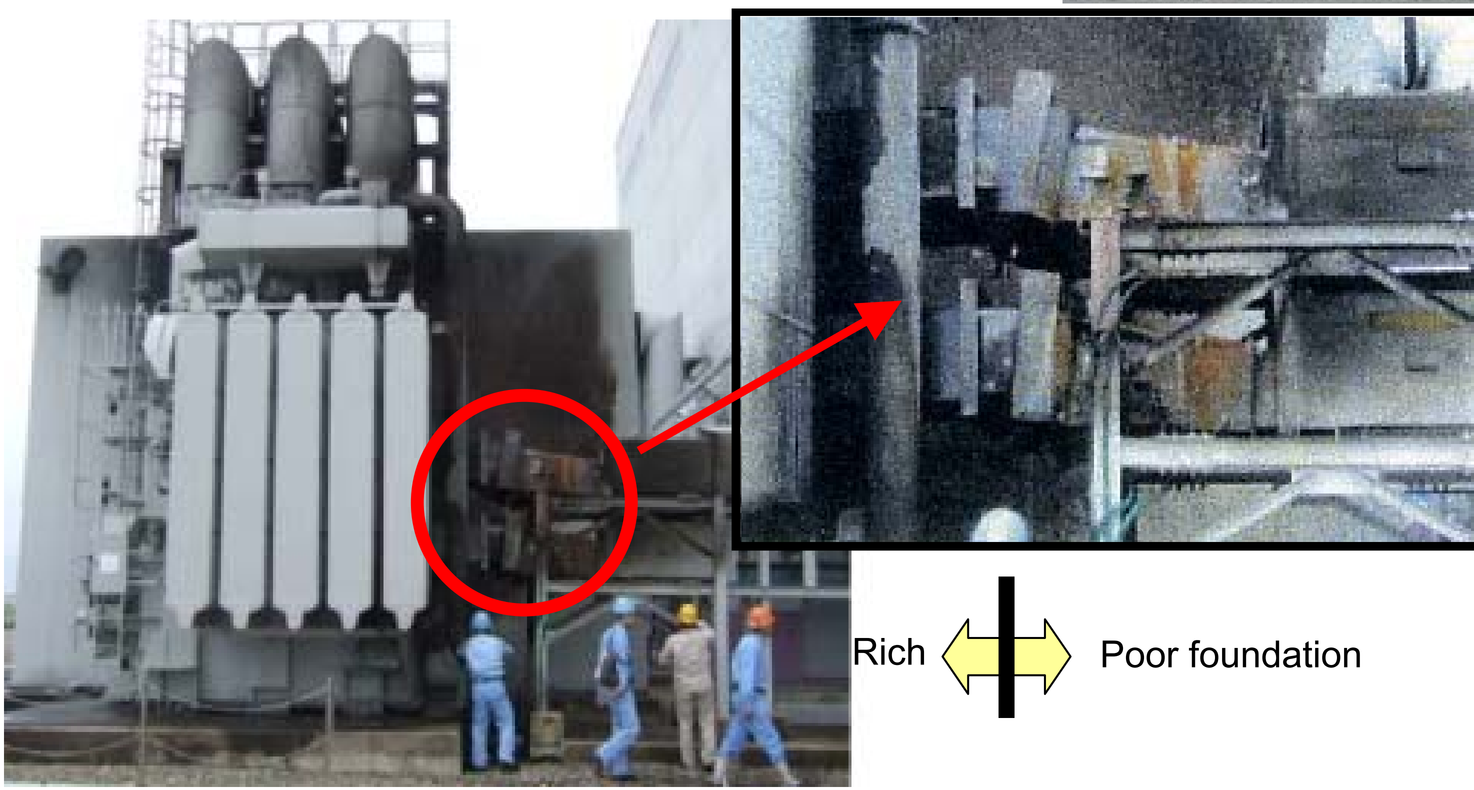
Seismic safety requirements for NPP and experience feedback in Japan

Yoshi. FUKUSHIMA

Japan Nuclear Energy Safety Organization (JNES)
Seismic Safety Division

Fire of transformer at unit 3

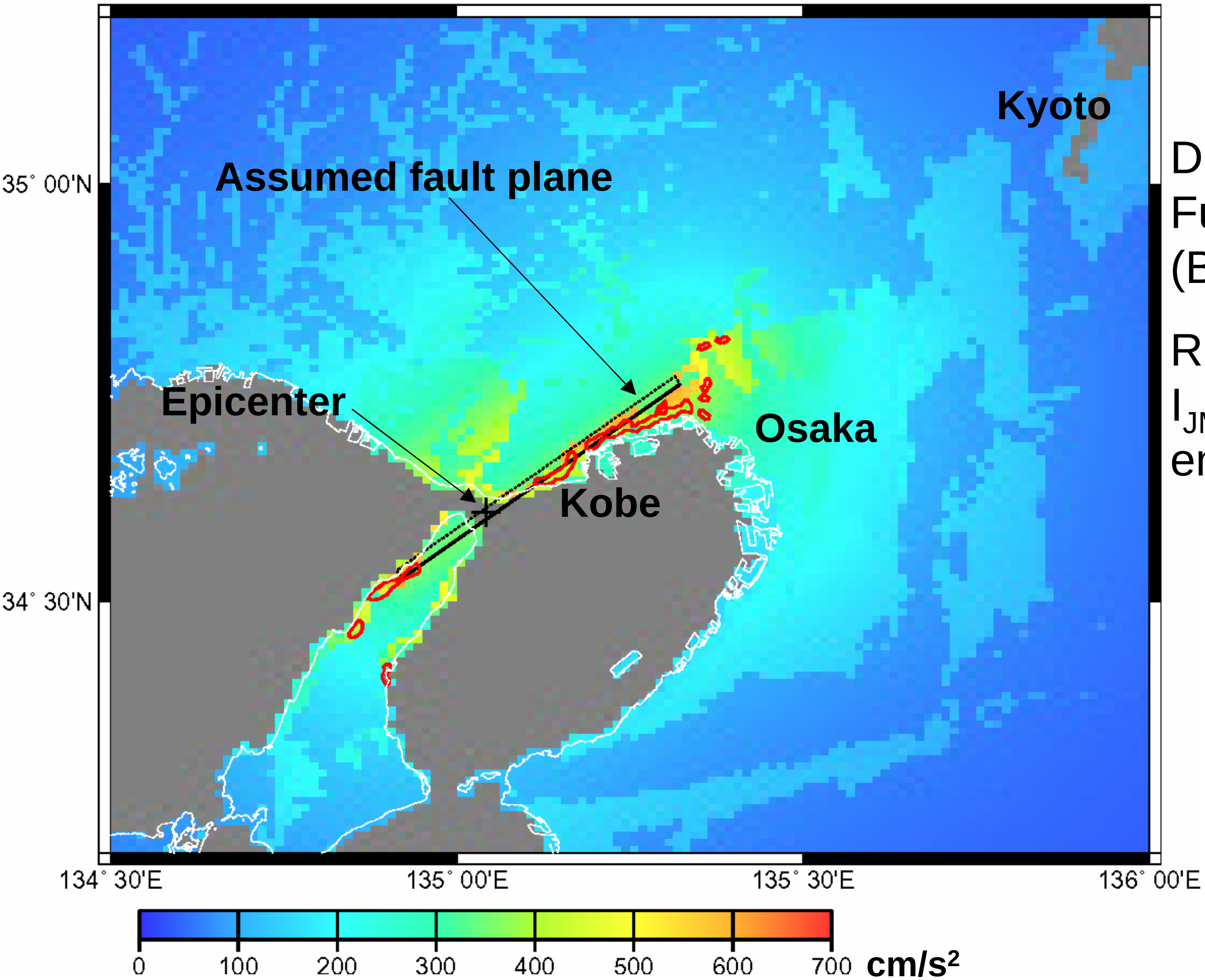
- **Part : joint part**
- **Failure mode : bending by soil behavior**



□ **Hyogo-Ken Nambu Earthquake** (1995.1)

Triggered revision of safety Guide

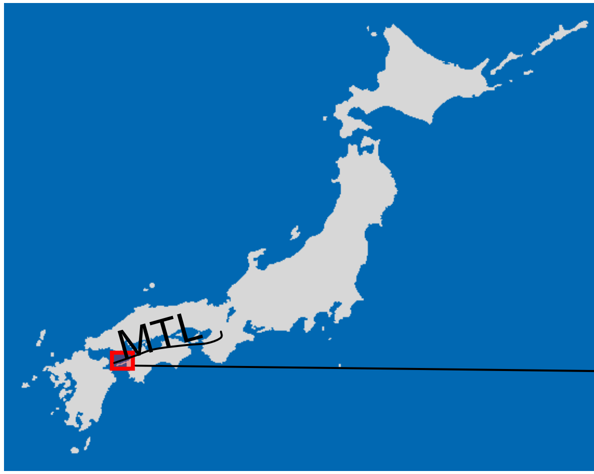
Point source (Ohsaki Spectrum) ➔ **Active fault**

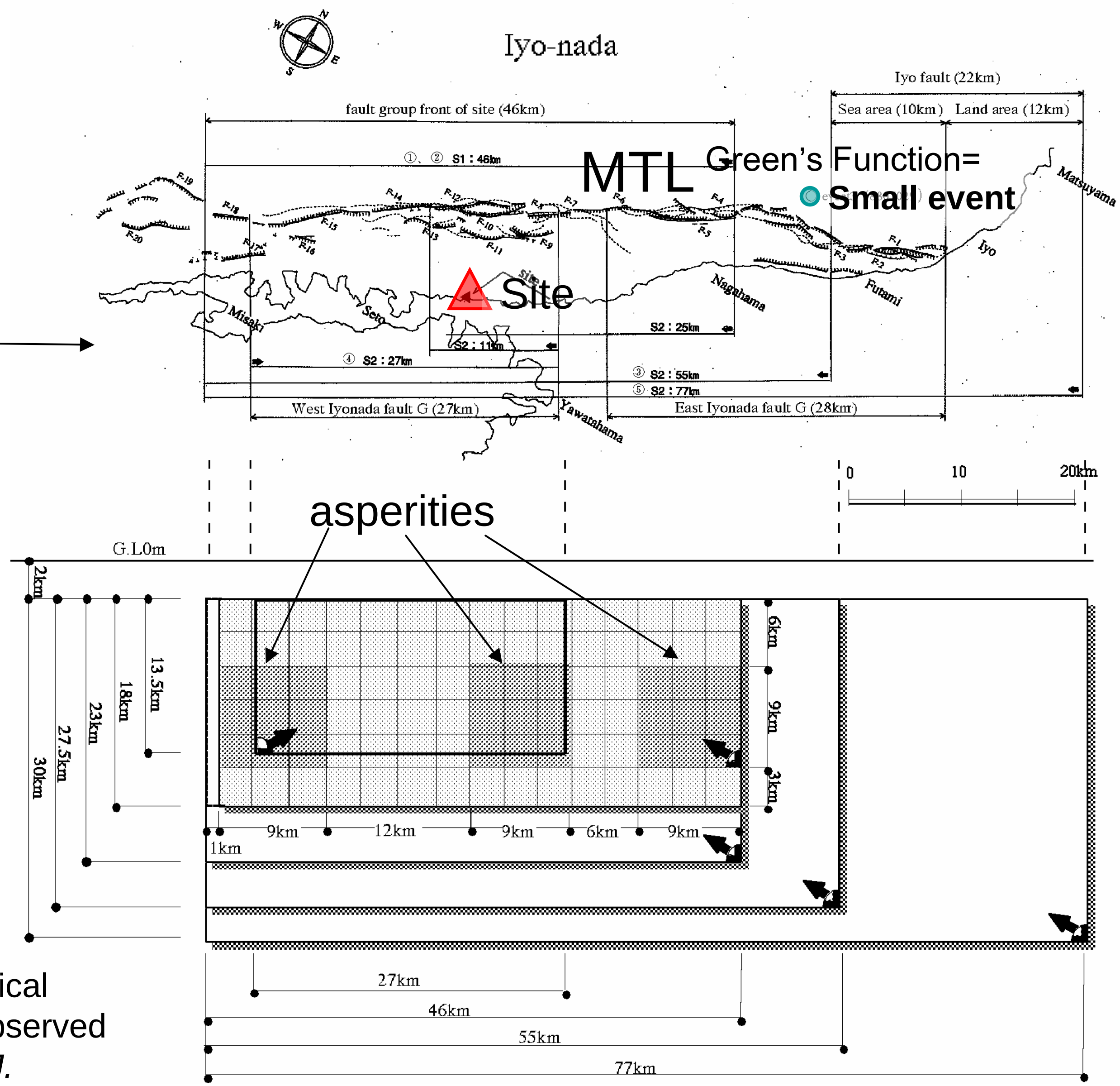


Distribution of predicted PGA by Fukushima's attenuation relation (BSSA, 1990)

Red lines indicate area of I_{JMA}=VII, site condition is empirically corrected.

High PGA area was elongate and well agree with high intensity area.





Example of characteristic source modeling

Fukushima et al. (2001). Semi-empirical estimation of ground motion using observed records at a site in Shikoku, Japan, *J. Seismology*, 5, pp.63-72.

Modeling and simulation

- Dynamic
- Kinematics
- Hybrid
- Semi-empirical Green's function

Acquisition of accurate parameters is required.

Stress
3-D geology
etc.

Confirmation of derived result

Physical knowledge

Empirical

Attenuation equation

Reflecting characteristics of observed strong motion

Large amount of data exists already.
(NIED etc.)

□ **Hyogo-Ken Nambu Earthquake** (1995.1):

↓

Nuclear Safety Commission revised

“ Reviewing Guide for Seismic Design of NPP “ (2006.9)

- Require remained risk assessment due to exceedance of expected earthquake
- Adopt “Fault Source Model prediction”

□ **Miyagi-Oki Earthquake** (Onagawa NPP Shut Down, 2005.8)**,**

Noto-Hanto-Oki Earthquake (Shika NPP Shut Down State ,2007.3) and

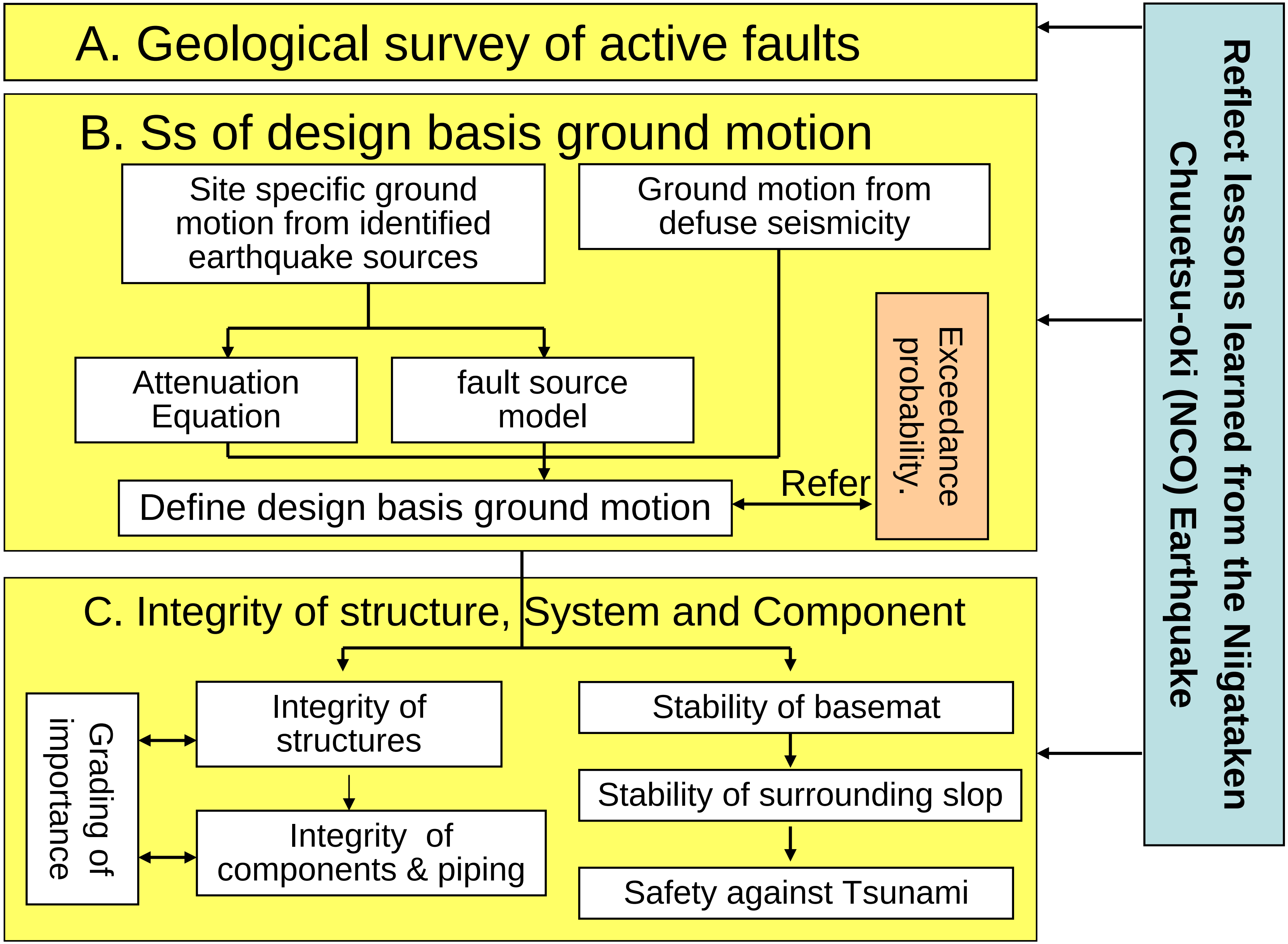
Suruga Bay Earthquake (Hamaoka NPP Shut Down State ,2009.8):

Slightly over design level and no Influence on standards

□ **Niigata-Ken Chuets-Oki Earthquake** (2007.7)

Kashiwazaki-Kariwa NPPs were safely shut down, but lower seismic grade facilities were damaged by the extreme ground motion.

Flow of Seismic Reevaluation According to New Seismic Regulatory Guide

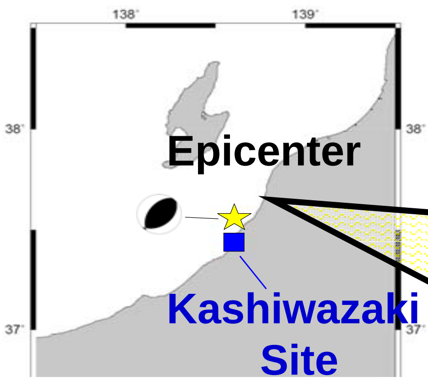


New Design Basis Ground Motions

Plant sites	Contributing earthquakes	**New DBGM Ss** *	Old DBGM S2
Tomari	Defuse seismicity	**550 Gal**	370 Gal
Onagawa	Soutei Miyagiken-oki (M8.2)	**580**	375
Higashidoori	Defuse seismicity	**450**	375
Fukushima	Earthquake near the site (M7.1)	**600**	370
Tokai	Defuse seismicity	**600**	380
Hamaoka	Assumed Tokai (M8.0), etc.	**800**	600
Shika	Sasanami-oki Fault (M7.6)	**600**	490
Tsuruga	Urazoko-Uchiikemi Fault (M6.9), etc. →Mera-Kareizaki-Kaburagi F.(M7.8)	**650→800****	532
Mihama	C, Fo-A Fault (M6.9)→B-Fault(M7.7)	**600→750****	405
Ooi	C, Fo-A Fault (M6.9)→Fo-A+Fo-B（M7.4)	**600→700****	405
Takahama	Fo-A Fault (M6.9)	**550**	370
Shimane	Shinji Fault (M7.1)	**600**	456
Ikata	Median Tectonic Line (M7.6)	**570**	473
Genkai	Defuse seismicity	**500**	370
Sendai	Defuse seismicity	**540**	372
Kashiwazaki-Kariwa	F-B Fault (M7.0), expanded NCO Nagaoka-plain-west Fault (M8.1)	**2300 (#1 side) 1209 (#5 side)**	450

Note: * Black : Ss by interim report (March 2008).
** **Red** : **still under examination** (29 June 2009)

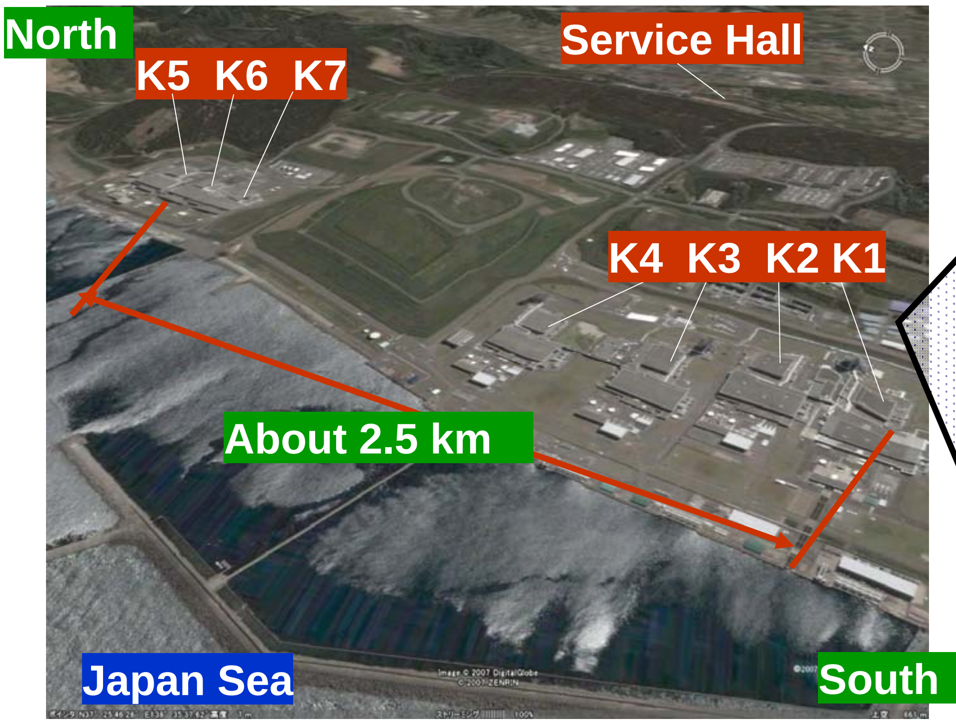
■ Infomation of Earthquake



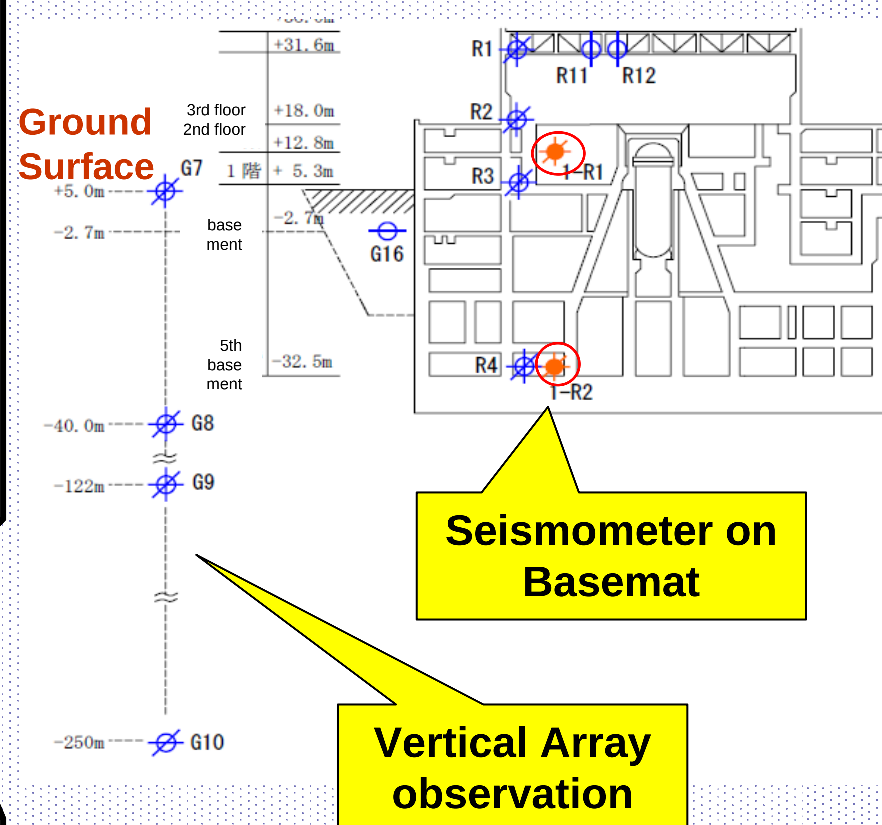
Main shock:

- July 16, 2007
- Mjma : 6.8
- Focal Depth : 10 km
- Epicentral Distance :14 km

■ Location of Units K1-7

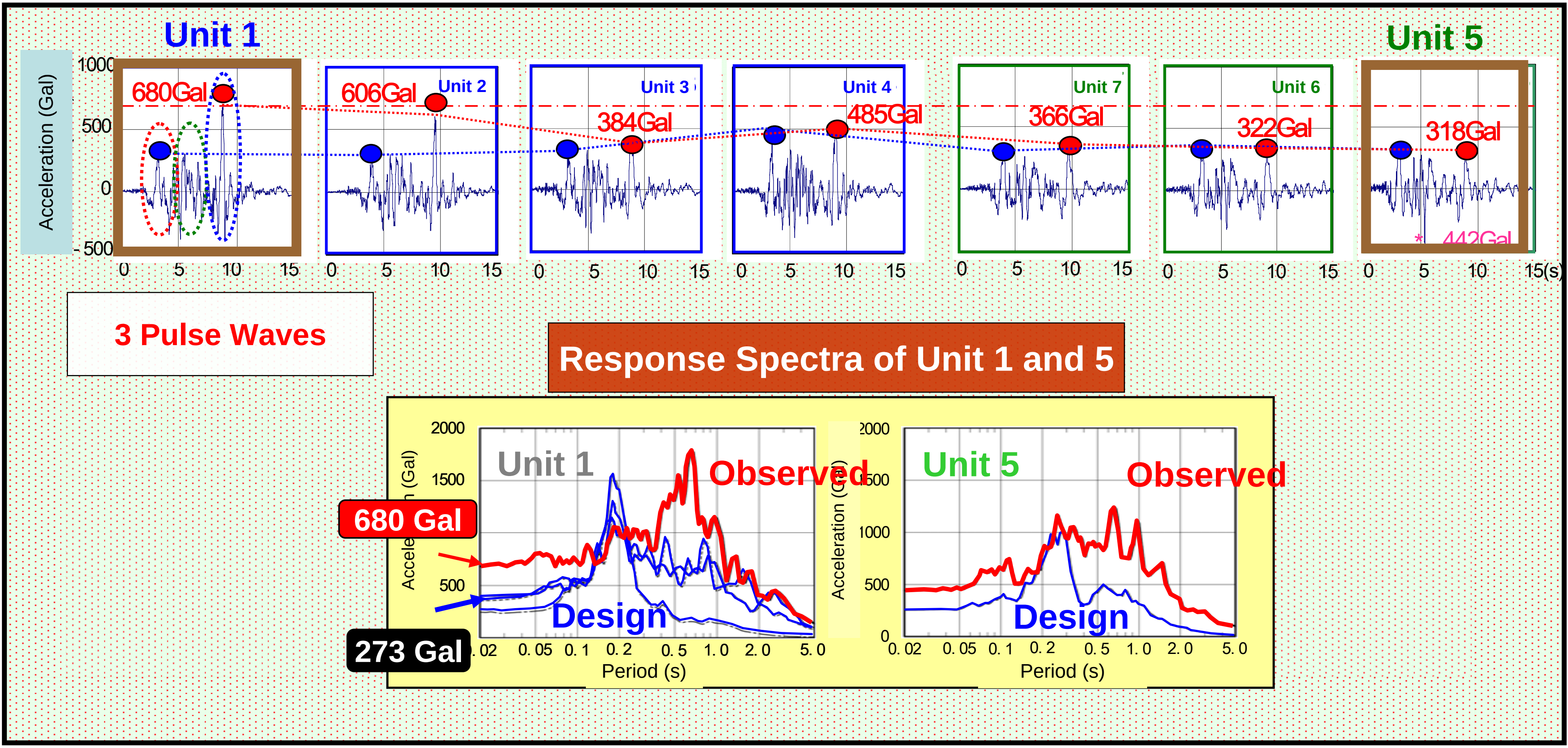


■ Earthquake Motion observation at Reactor Building of Unit 1



Most of records were disappeared due to over flow with many aftershocks

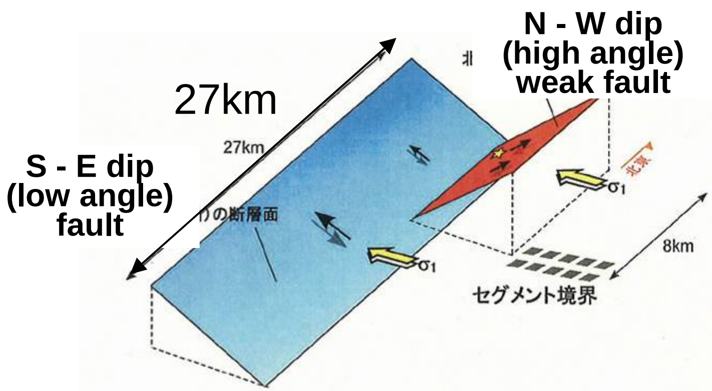
Amplification of Earthquake Ground Motion

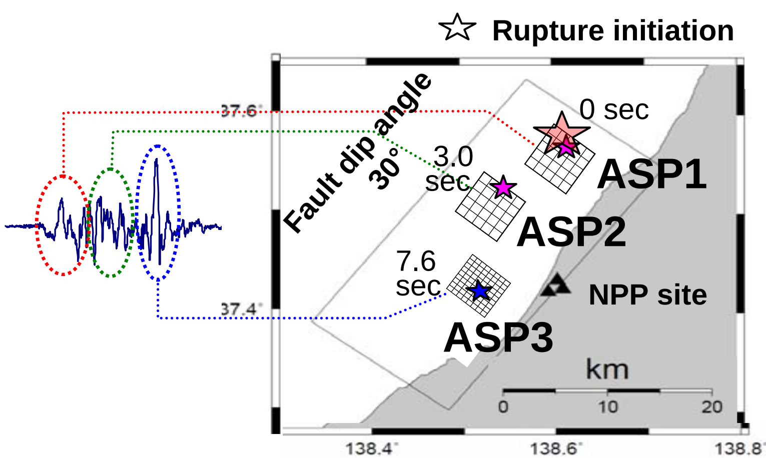


(1) Why did 3 pulses happen ?
(2) Why did the observed seismic motions exceed design level ?
(3) Why PGA at Unit 1 was the largest as more than double of the design level, although it was located most far from the epicenter ?

Modeling of Source Fault and Sediments

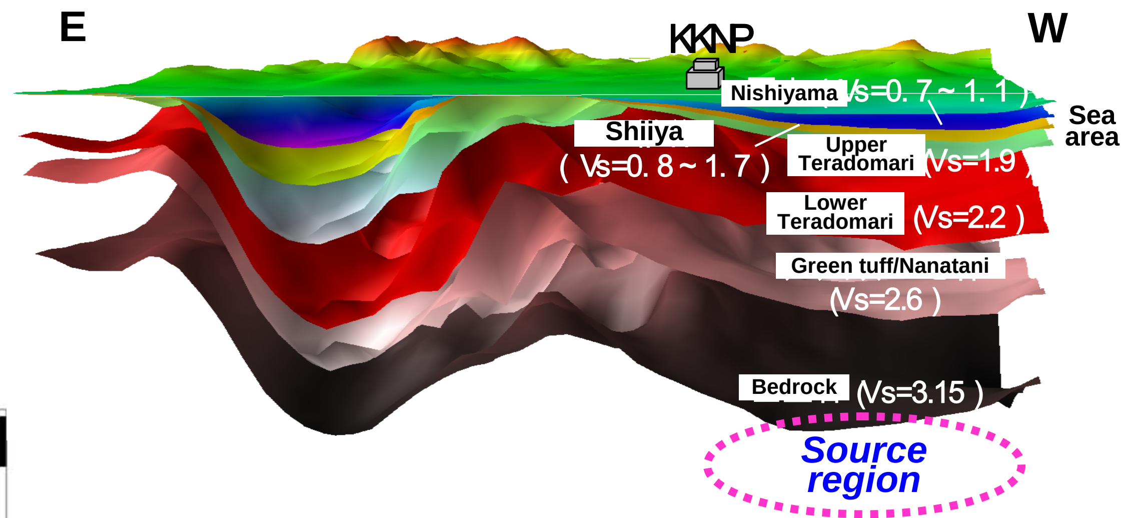
Source fault model



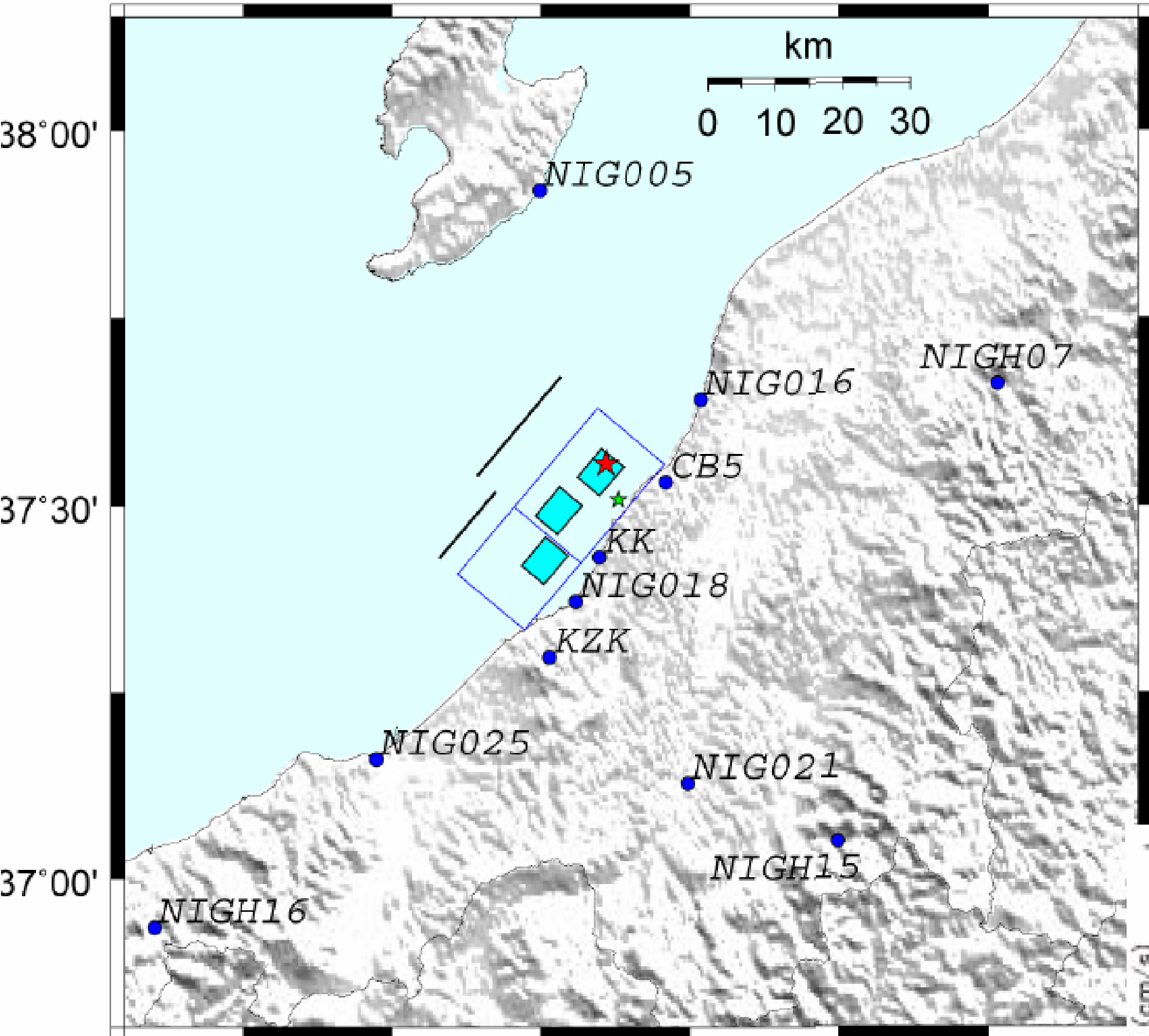


Strong pulses came from 3 asperities.

Cross section of geological layers



- 3D irregularity of sediment
- Deep seismic bedrock about 5~8 km



Epicenter   Observation Sta.

Aftershock used as a Green's function

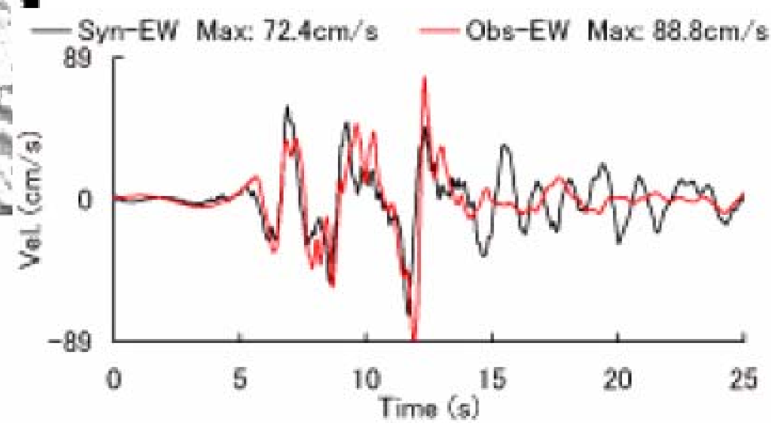
High stress drop about x1.5 times

Micro parameters

	Strike (°)	Dip (°)	Rake (°)	S (km^2)	Mo (Nm)	Δσ (MPa)
Asp 1	40	40	90	5.6×5.6	1.33×10^{18}	18.4
Asp 2	40	40	90	5.6×5.6	2.00×10^{18}	27.6
Asp 3	40	40	90	5.6×5.6	2.00×10^{18}	27.6

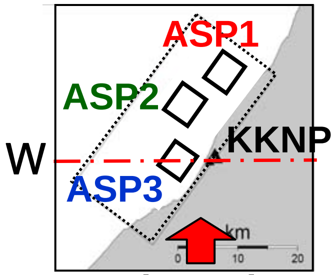
Rupture velocity :2.7km/s

Comparison between synthesized and observed time history at KK1 base

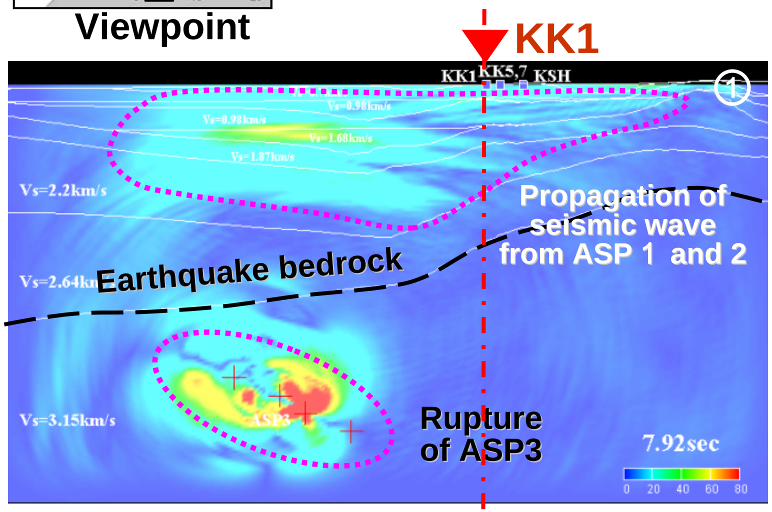


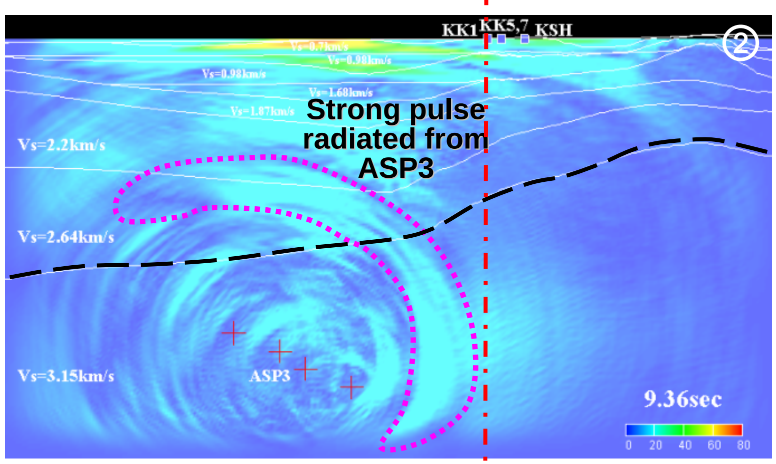
http://www.rri.kyoto-u.ac.jp/jishin/eq/niigata_chuetsuoki_5/chuuetsuoki_20080307.pdf

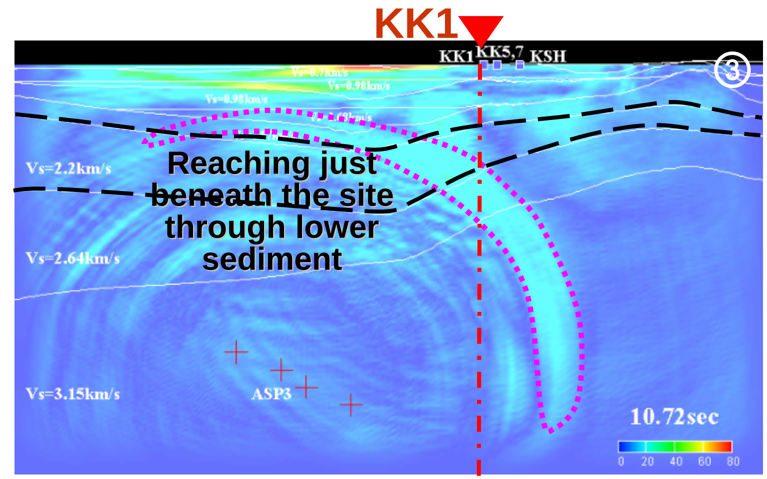
3D Propagation Behavior

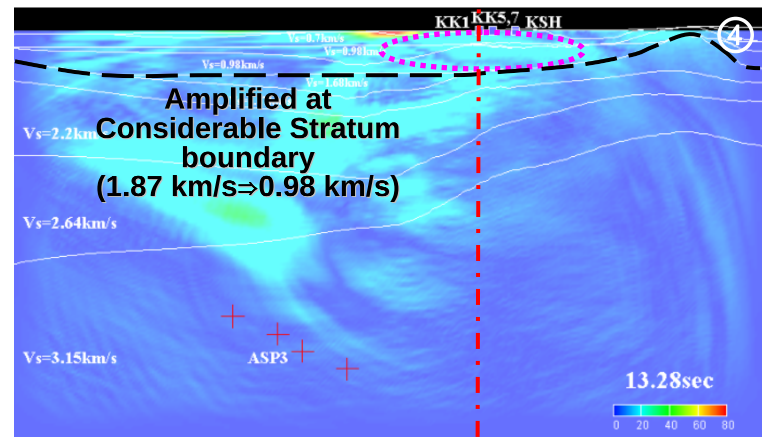


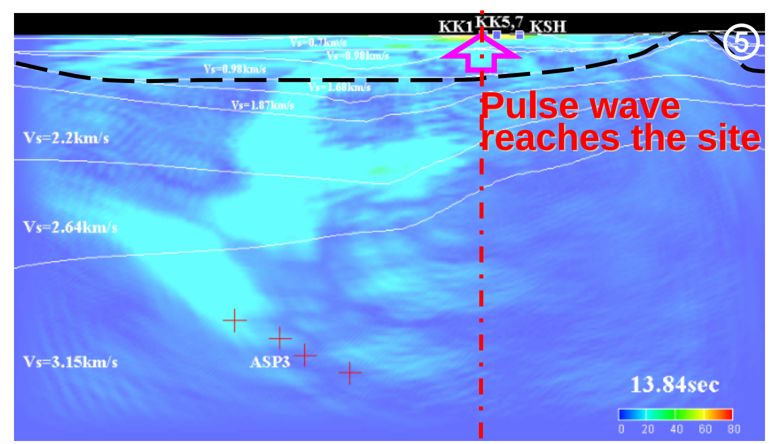
Wave propagation in ASP3~KK1 section



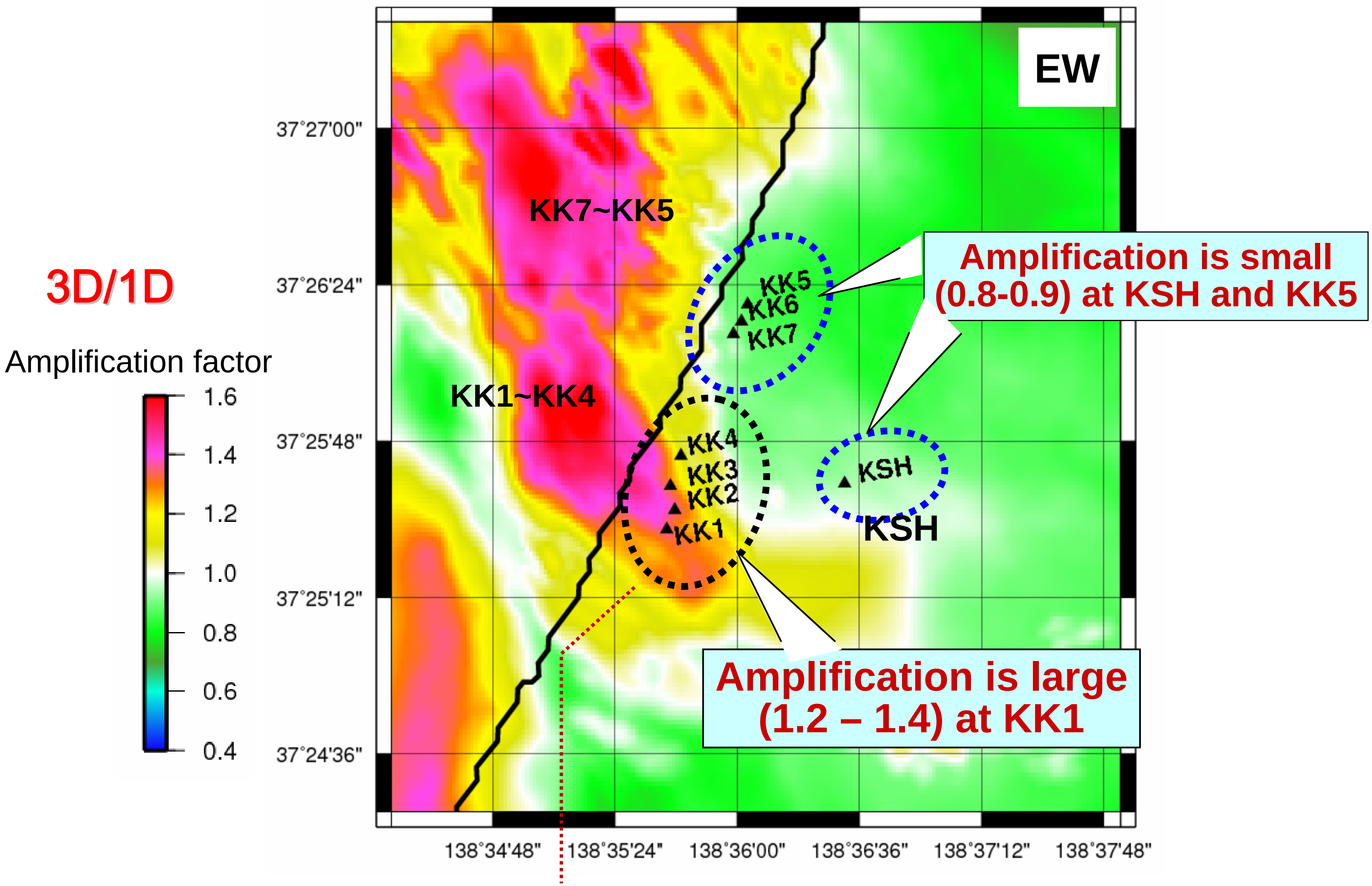






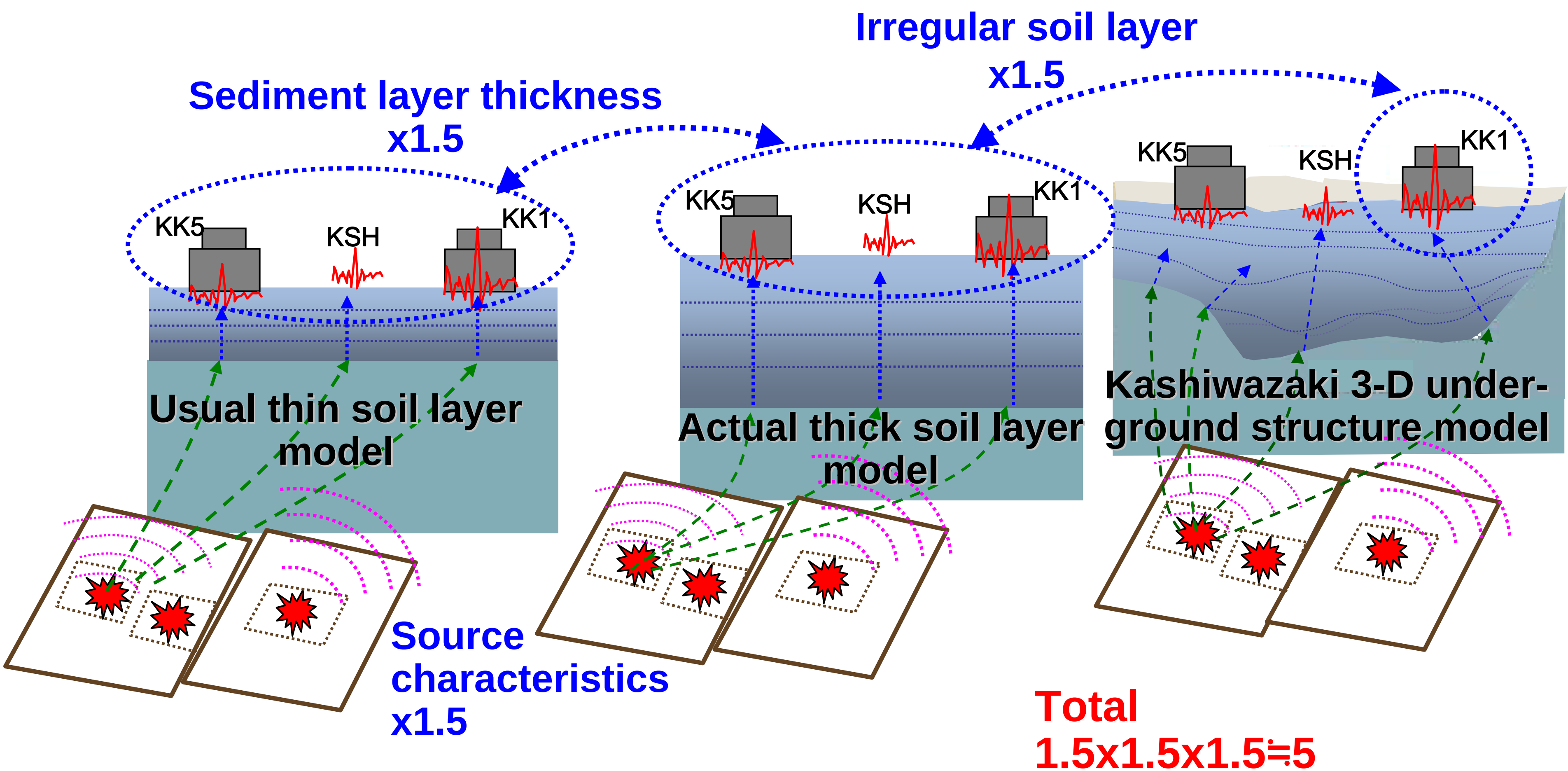


Amplification of PGV between 3D and 1D



Amplification of seismic wave from seismic bedrock to free base stratum at Unit 1 side is estimated 1.5 times as large as at Unit 5 side.

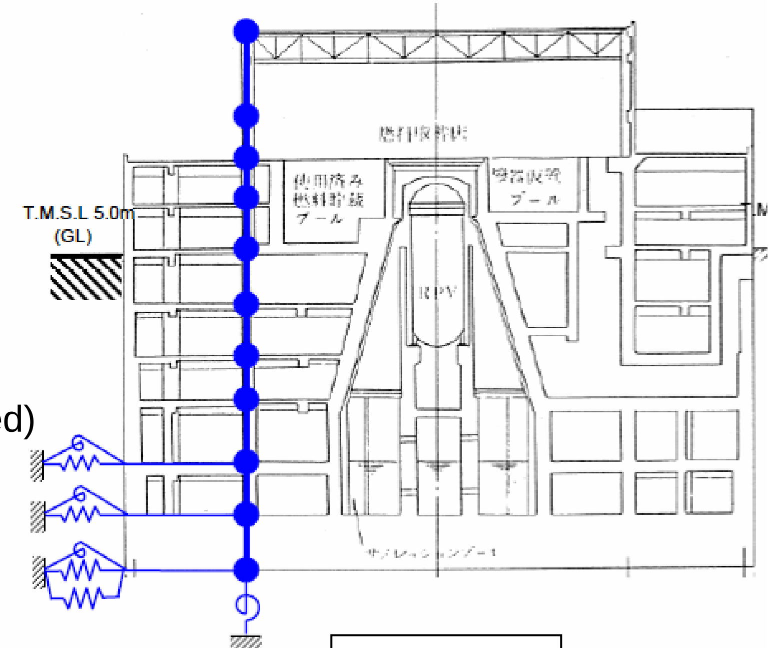
Summary of Factor Analysis



Inconsistency between Analyzed and Observed Responses

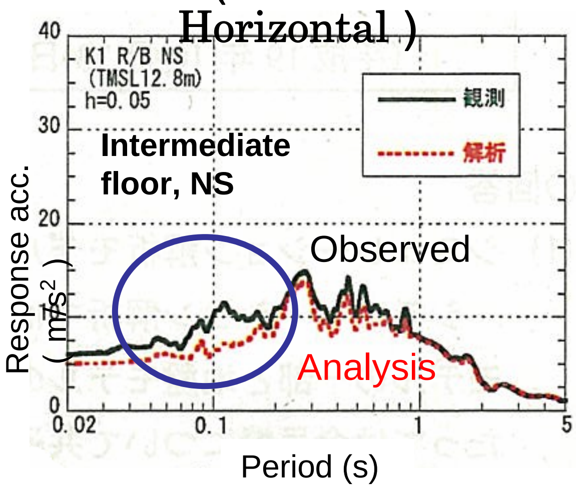
Lumped mass model

(TEPCO, 2007.Oct.25, partially retouched)



Point 1

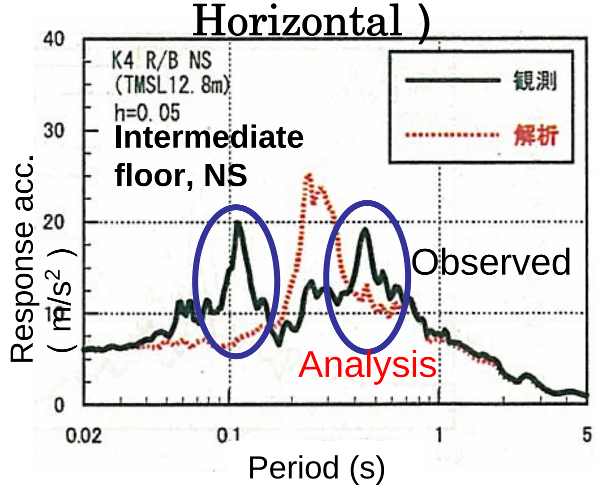
(Unit 1 : Horizontal)



Observed > Analyzed at around 0.1 ~ 0.3 s

Point 2

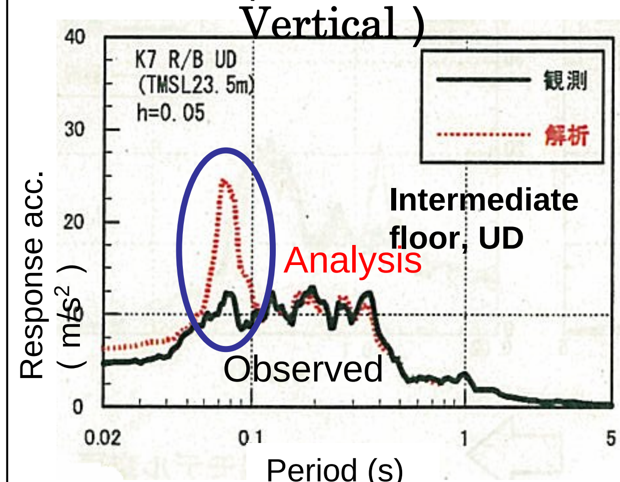
(Unit 4 : Horizontal)



Observed : 2 peaks
Analysis : 1 peak at 0.3 s

Point 3

(Unit 7 : Vertical)

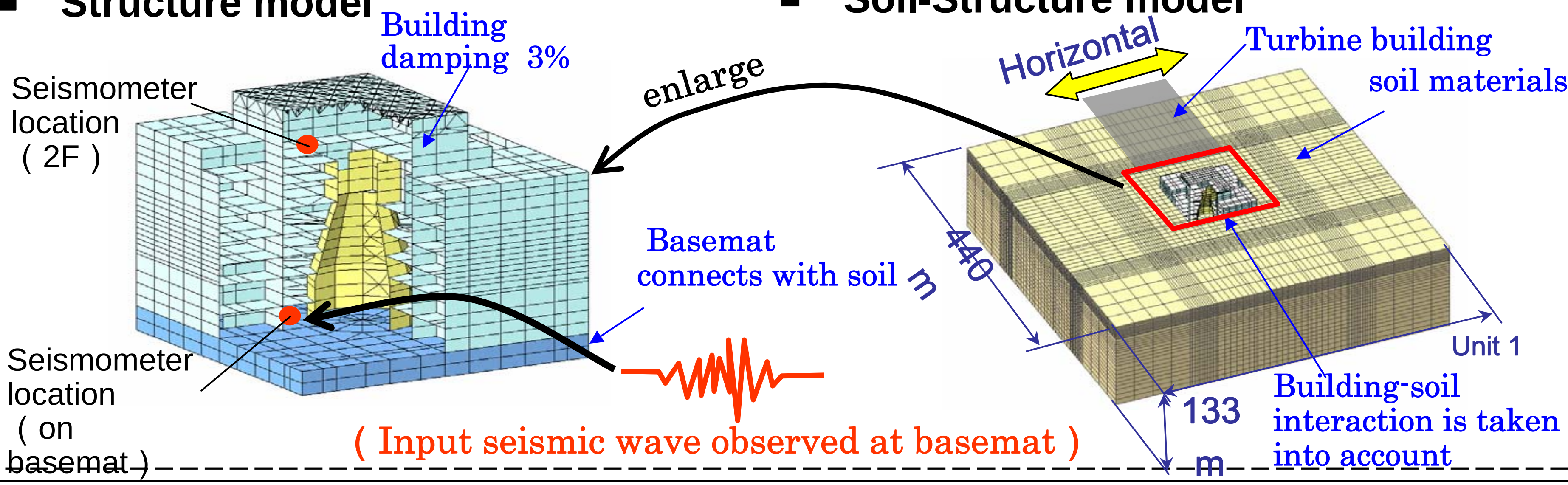


Observed < Analysis at around 0.09 s

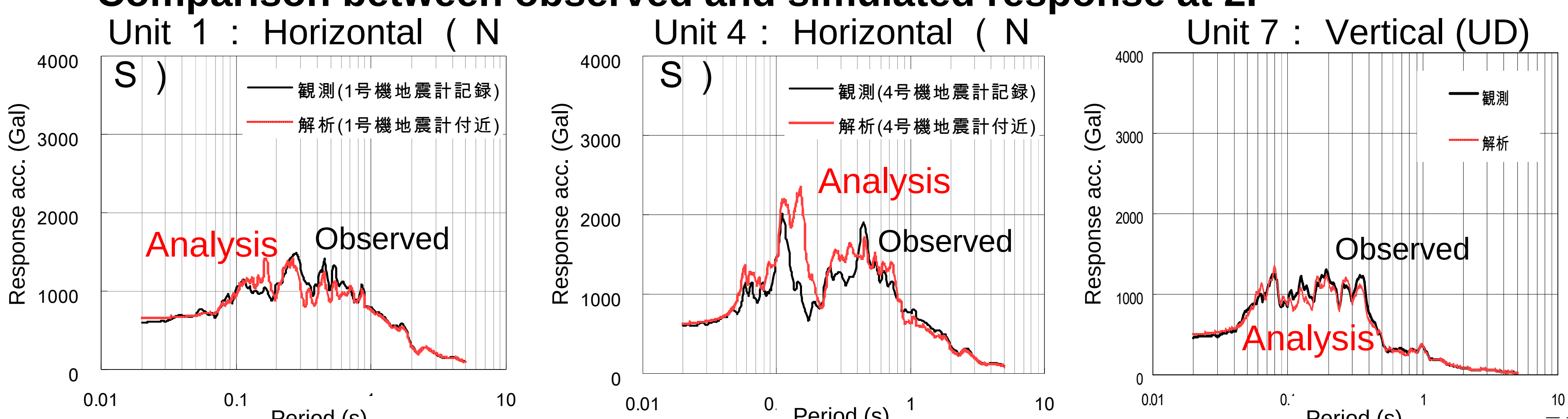
(TEPCO, 2007.12.25) (partially retouched)

3-D FEM model, considering (1) flexure of floor and basemat, (2) interaction between soil&building, and (3) constraint turbine building.

■ **Structure model** ■ **Soil-Structure model**

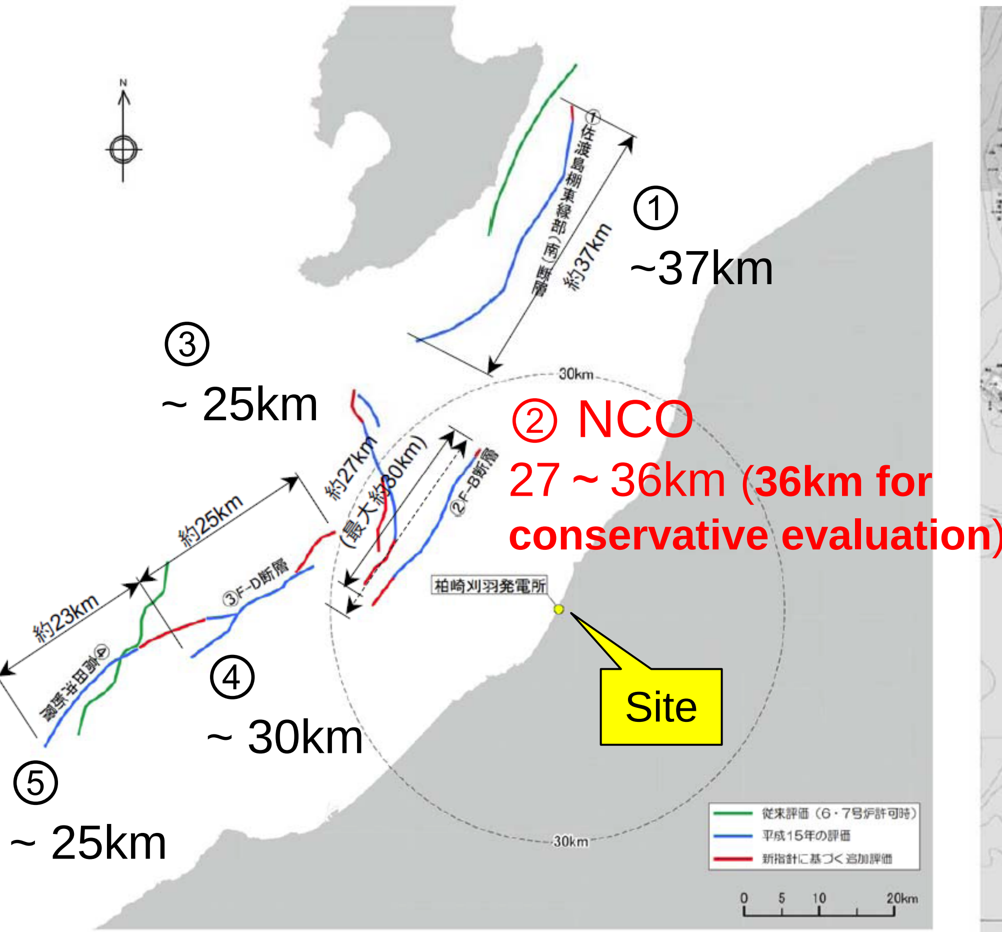


■ Comparison between observed and simulated response at 2F

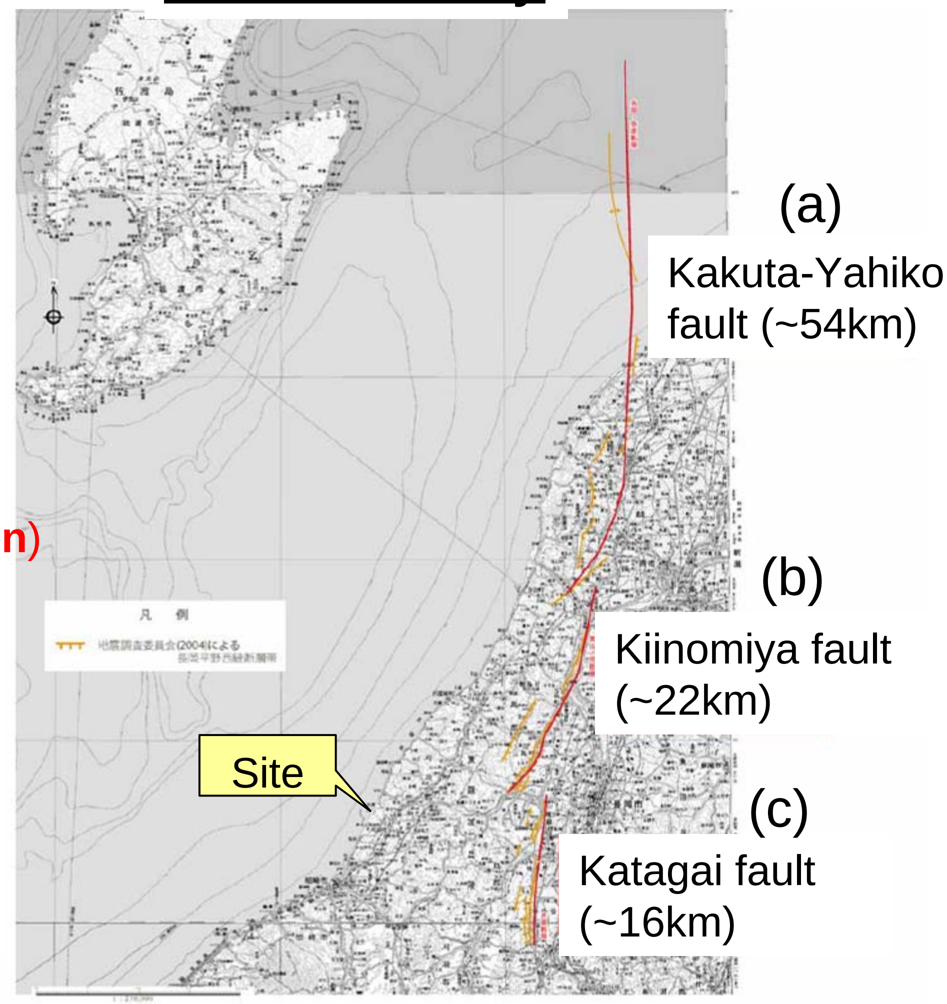


Reevaluation of seismic safety at KK (called back check)

Off-shore



Inland survey

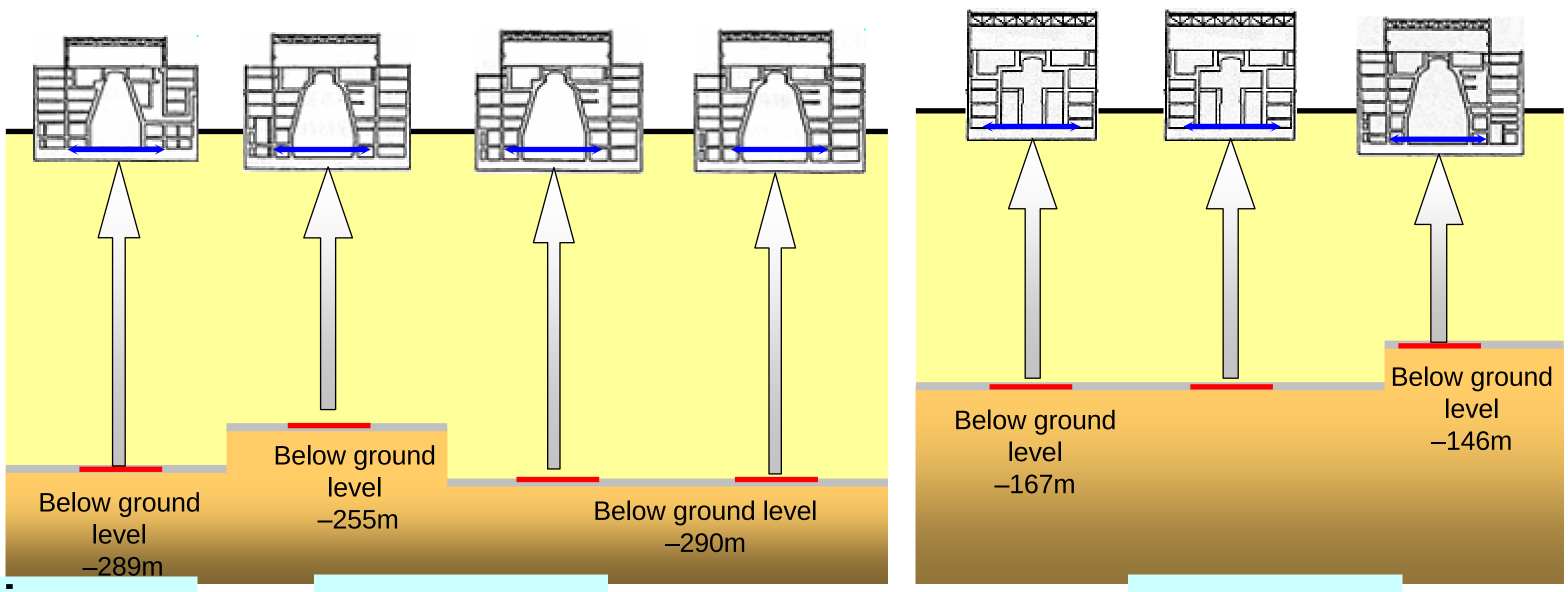


At establishment permission, fault ② was estimated to be 7~8km (M<6.5) and non active fault.

At Reactor building bedrock	Unit 1	Unit 2	Unit 3	Unit 4	Unit 7	Unit 6	Unit 5
Chuetsu-oki Earthquake (observed)	680	606	384	492	356	322	442
New design basis seismic motion Ss	829	739	663	699	642	656	543
Old DBSM: S2	**273**	**167**	**193**	**194**	**263**	**263**	**254**

At basemat

Outcrop of base stratum

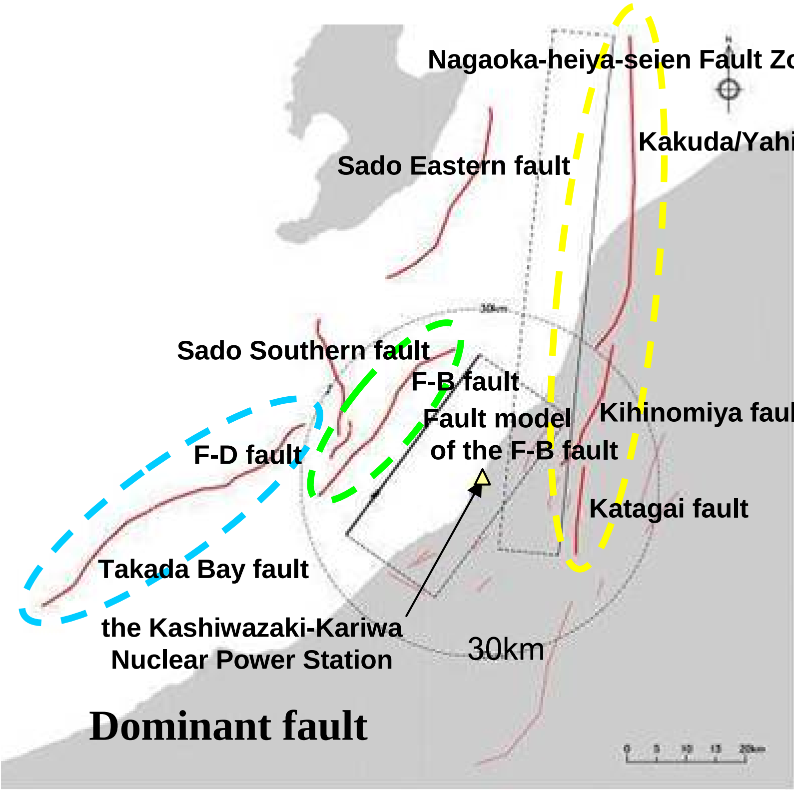


	Units 1–4	Units 5–7
Design-basis seismic motion Ss (Old DBSM:S2)	2,280 (**450**)	1,156 (**450**)

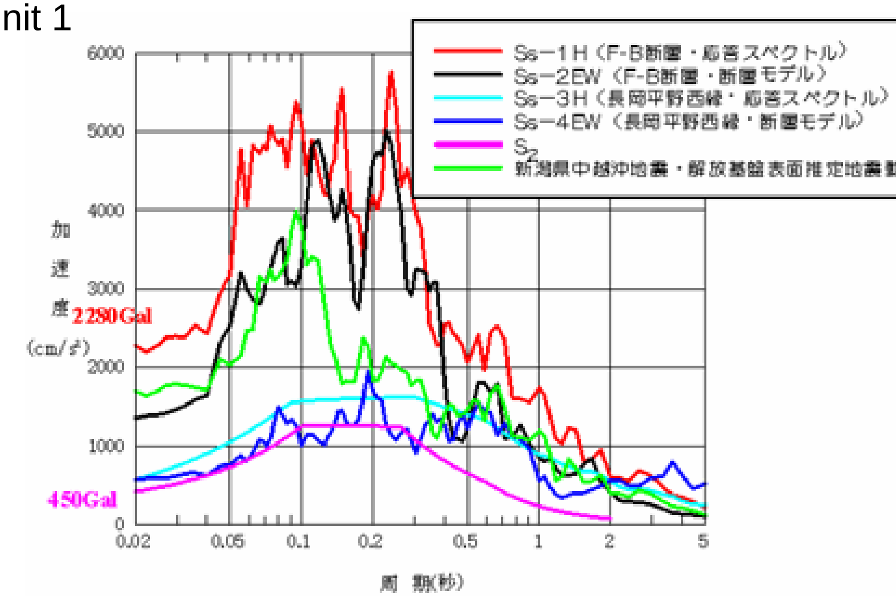
Static force of 3 times of conventional building is preserved for reactor building.

Quoted from Tepco HP

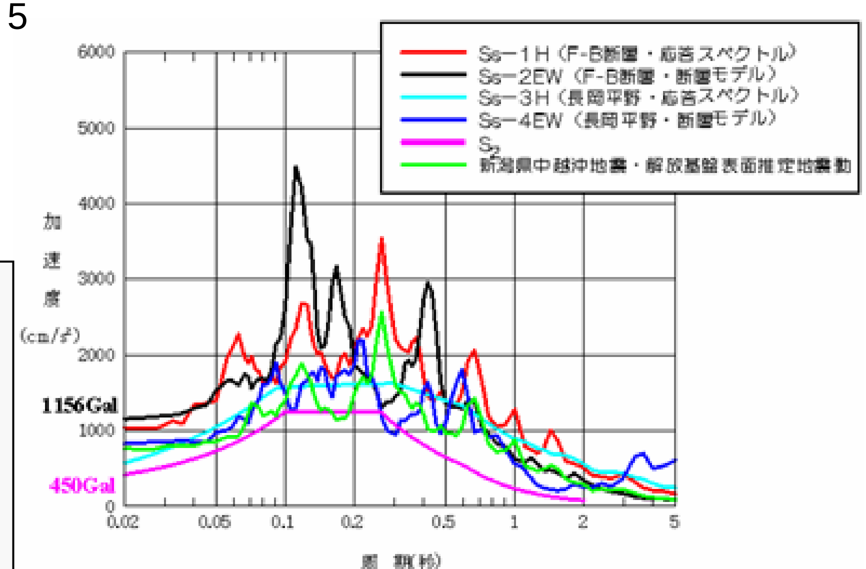
Response Spectra of Design-basis Seismic Motion （Outcrop of base stratum ）



（a）Unit 1



（b）Unit 5



– Ss-1H (F-B fault, Attenuation Equation)
– Ss-2EW (F-B fault, Simulated with characteristic source model)
– Ss-3H (Nagaoka heiya seien Fault Zone, attenuation Equation)
– Ss-4EW (Nagaoka heiya seien Fault Zone, simulated)
– S2 (Ex-design)
– Estimated motion on outcrop of base stratum from NCO Earthq.

Quoted from TEPCO HP

Part of Logic Tree

Basic path

Specified Seismic Source

Active Fault

Inland Area

Nagaoka-heiya-seien Fault Zone

Coupling Scenario	Seismic source location	Magnitude: M_J Length: L(km)	Dip (°)	Asperity location	Average activity interval	Last active period (Earthquake occurrence model)
Kakuda-Yahiko	TEPCO fault model	M 7.7 (L=54km)	West 50 West 35	Top Middle Bottom	8600 years 1300 years	Unknown (Poisson)
Kehinomiya	TEPCO fault model	M 7.1 (L=22km)	West 50 West 35	Top Middle Bottom	1200 years 3700 years	808 years ago (BPT) 404 years ago (BPT)
Katagai	TEPCO fault model	M 6.8 (L=16km)	West 50 West 35	Top Middle Bottom	1100 years	Unknown (Poisson)
Kakuda-Yahiko + Kehinomiya	TEPCO fault model	M 8.0 (L=76km)	West 50 West 35	Top Middle Bottom	1200 years 3700 years 8600 years	808 years ago (BPT) 404 years ago (BPT) Unknown (Poisson)
Kehinomiya + Katagai	TEPCO fault model	M 7.4 (L=36km)	West 50 West 35	Top Middle Bottom	1200 years 3700 years	808 years ago (BPT) 404 years ago (BPT)
Nagaoka-heiya-seien	TEPCO fault model	M 8.1 (L=91km)	West 50 West 35	Top Middle Bottom	1200 years 3700 years 8600 years	808 years ago (BPT) 404 years ago (BPT) Unknown (Poisson)

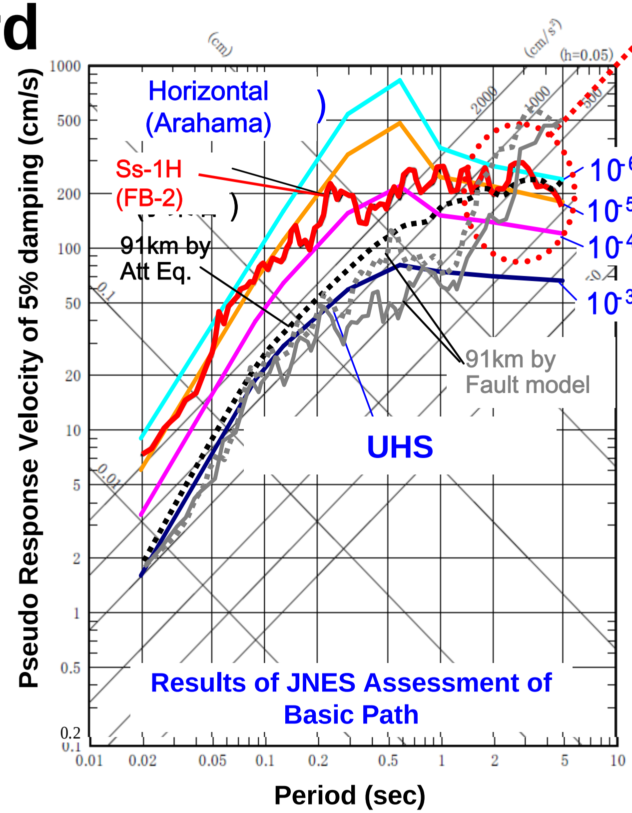
START

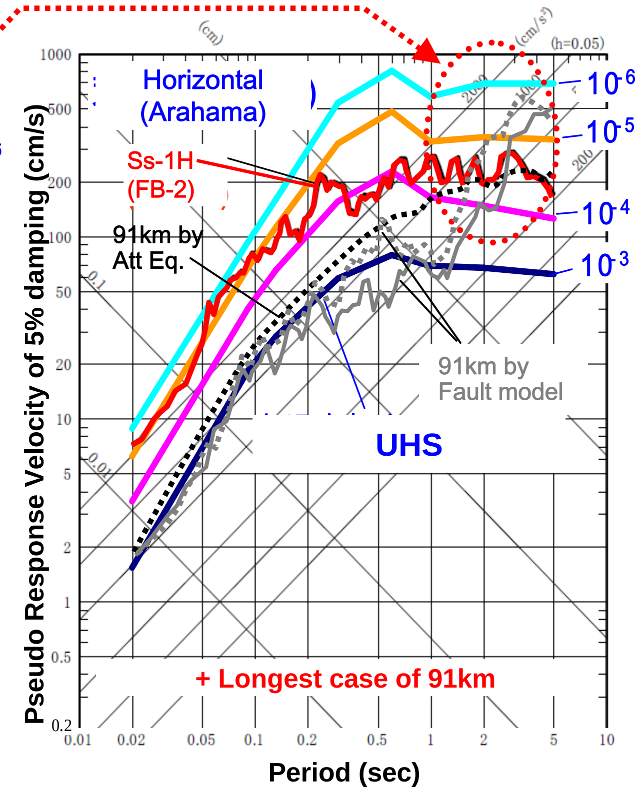
A

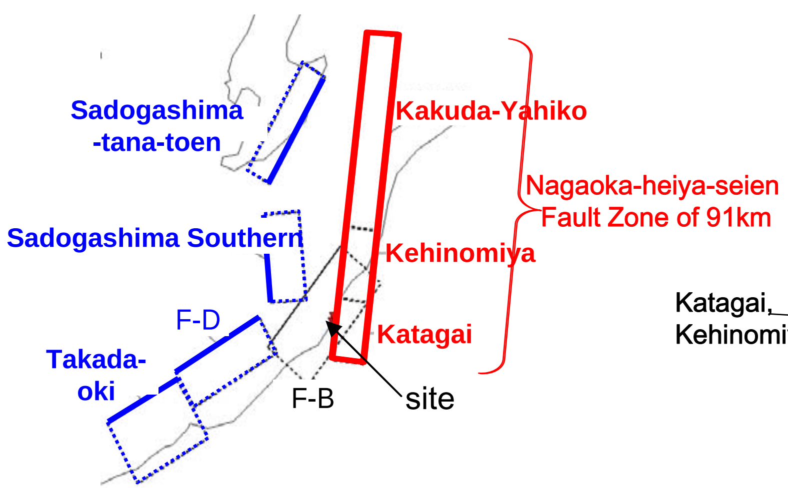
Most conservative case

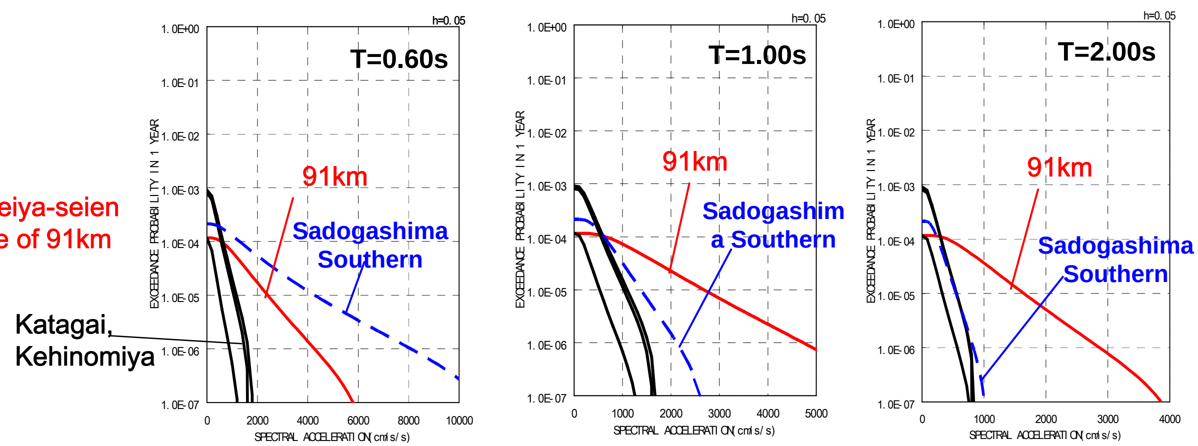
Refer Unified Hazard Spectrum

Influence of the longest case is considerable in longer predominant period range than 2.0 second from 10^{-5}.







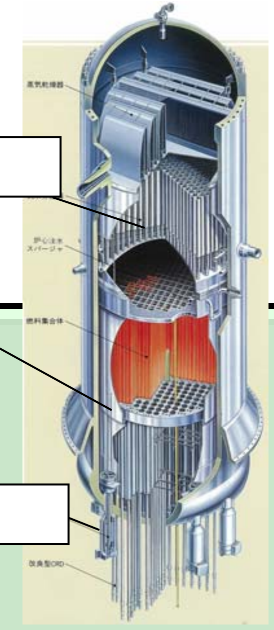


Integrity of equipment and piping

■ Selected important Equipments and pipes

(As，A-Class in design criteria)

- **Equipment （77equipment、99parts）**
  - reactor pressure vessel, reactor containment vessel
  - core internals (shroud、standpipe、internal pump e
  - pump、heat exchanger、tank
  - refueling machine、reactor building crane
  - other equipment
- **Pipe （13system）**
  - main steam system, residual heat removal system etc



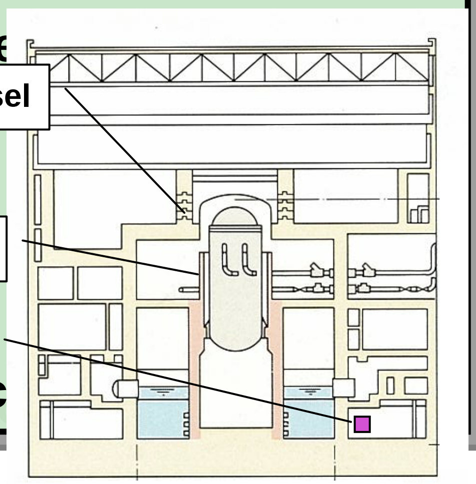
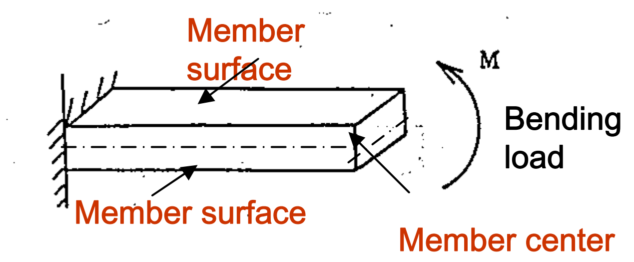


Figure was excerpted from the pamphlet of Toshiba Corporation and made.

Example ofEvaluation standards for equipment integrity

- Moment at final allowable stage IIIAS (JEAG4601 of an Japanese guide) is 1.5 times of the yielding in some case.
- The yield stress (Sy) in this condition was adopted as a criteria of selecting target equipments for additional inspection.



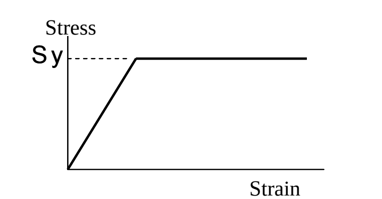
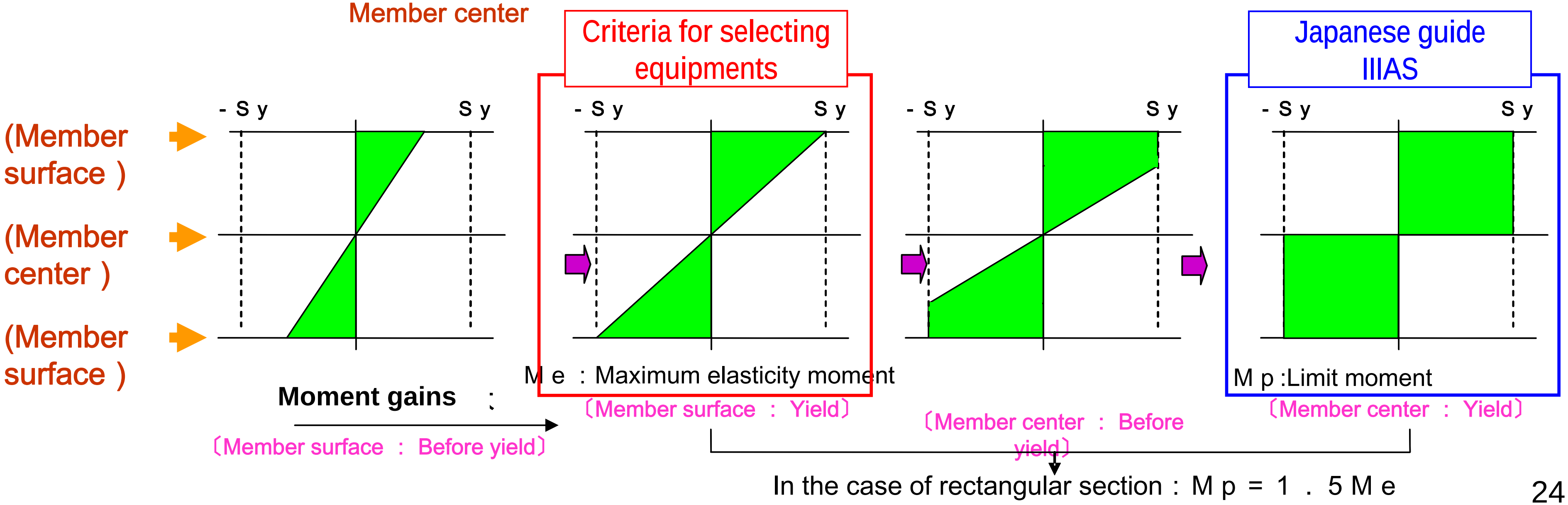
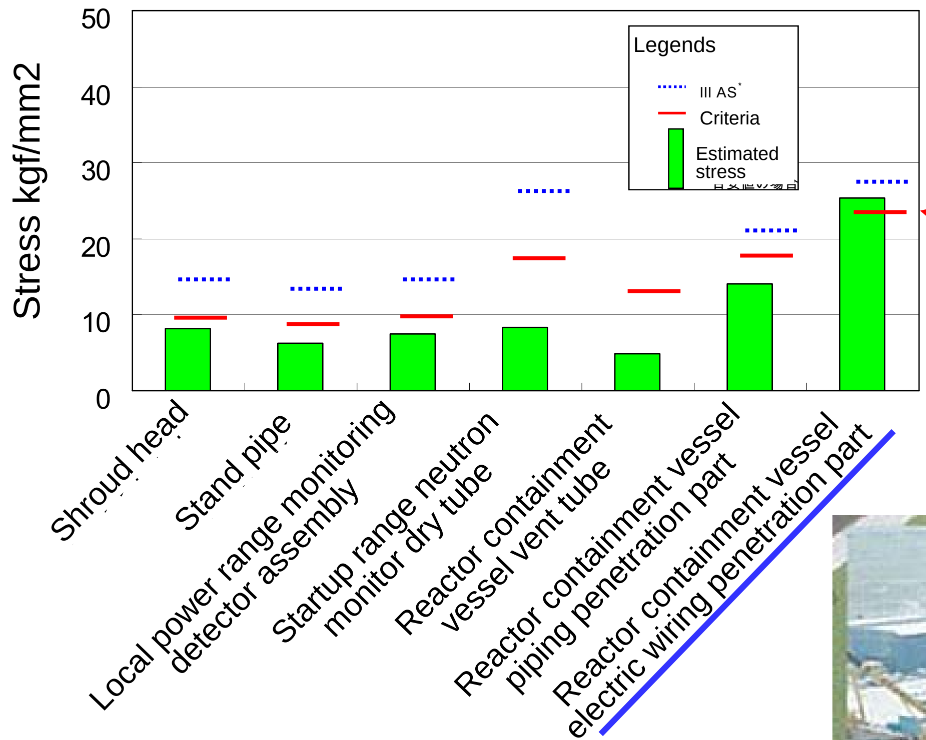


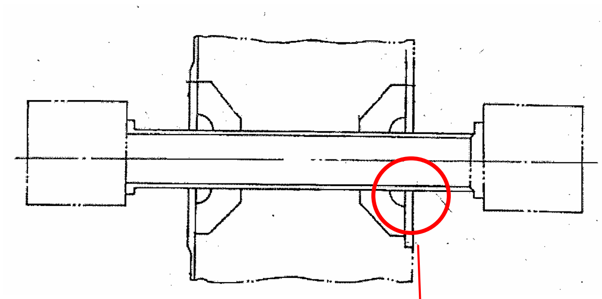
Diagram of stress - strain (conceptual)

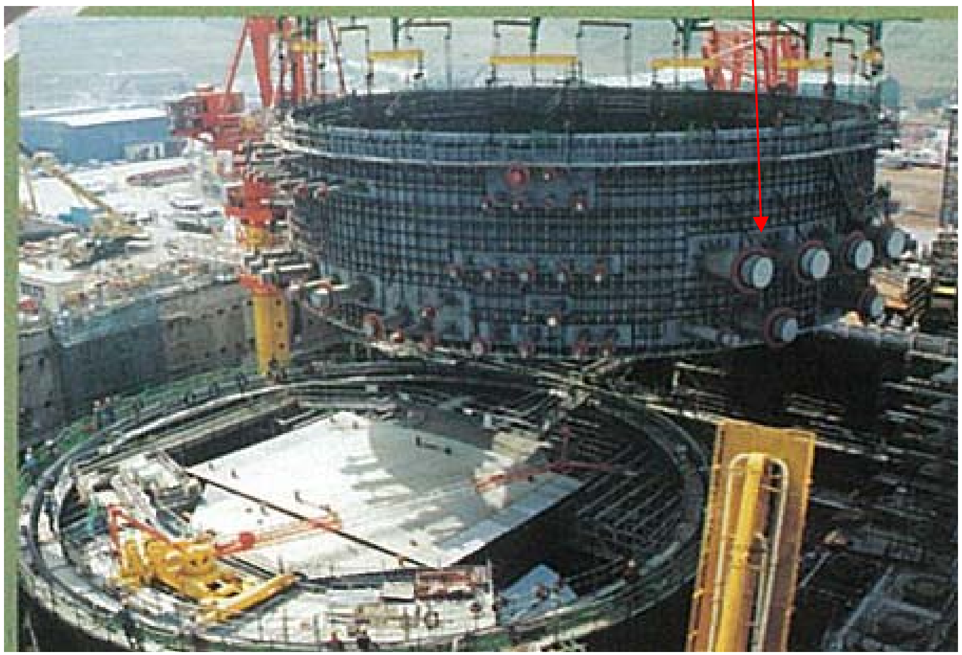


An example: reactor containment vessel-related equipment



Adopted criteria





Evaluation point in reactor containment vessel electric wire tube penetration part

Ground Deformation (TEPCO, December 25, 2007)

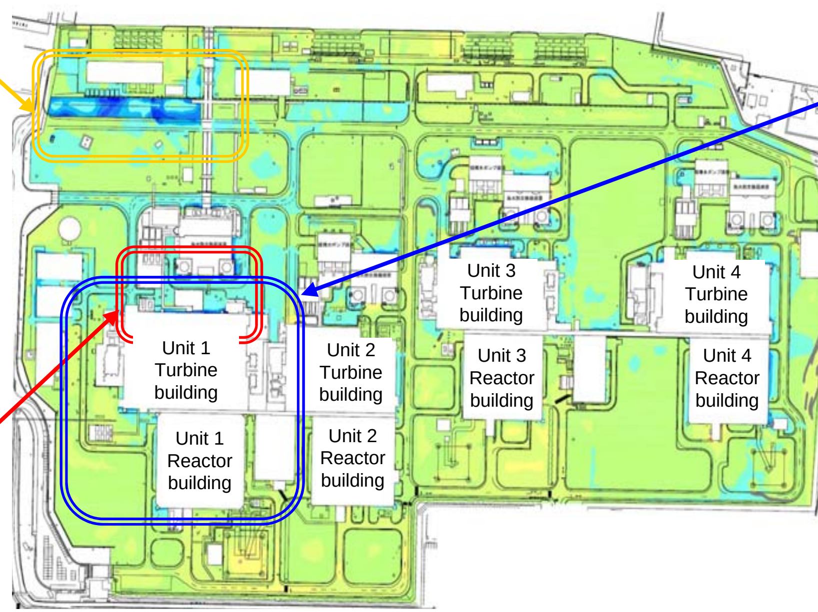
Ground subsidence distribution

(2) Large subsidence at sea side (high underground water level)

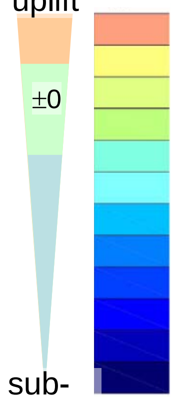
(3) Large subsidence where re-filled soil is thick

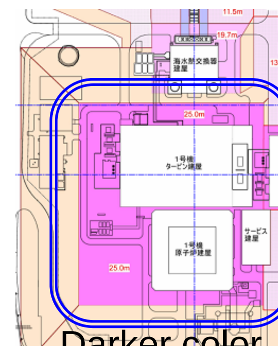
(1) Large subsidence adjacent to buildings (low underground water level)

Sea side



Unit 1~Unit 4





Darker color indicates thicker reclaimed soil.

gradient changes of buildings

TEPCO, February 15, 2008)

Unit	Building description	Max gradient change from **(2)** to **(1)**
		Gradient
Unit 1	Reactor building	ca.1/25,000
	Turbine building	ca.1/53,000
Unit 2	Reactor building	ca.1/14,000
	Turbine building	ca.1/10.000
Unit 3	Reactor building	ca.1/16,000
	Turbine building	ca.1/14,000
Unit 4	Reactor building	ca.1/22,000
	Turbine building	ca.1/6,700
Unit 5	Reactor building	ca.1/10,000
	Turbine building	ca.1/7,800
Unit 6	Reactor building	ca.1/5,500
	Turbine building	ca.1/15,000
	Control building	**ca.1/4,200**
	Waste disposal building	ca.1/9,000
Unit 7	Reactor building	ca.1/5,000
	Turbine building	ca.1/10,00

Measurement		
(1)	After earthquake	2008 February
(2)	Before earthquake	2006 May

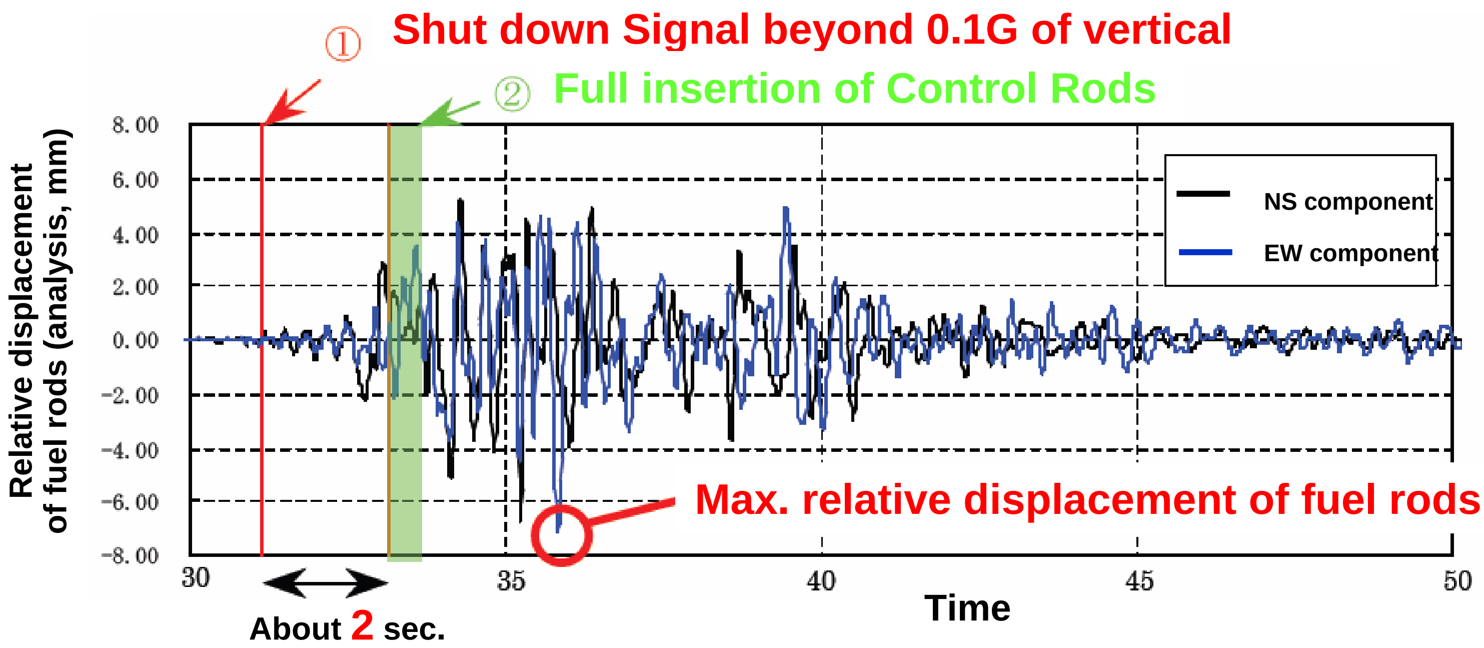
Gradient of the building can be judged sufficiently low compared with the subsidence limit level based on “Recommendation for the Design of Building Foundations” revised in 2001 (Architectural Institute of Japan).

(TEPCO, March 27, 2008)

Change in loads of equipment anchor etc. was evaluated to be about 0.1% and negligibly small. For control rod insertion performance, relative displacement between control rod and fuel assemblies is less than 0.1mm (design limit: 40mm).

Automatic shut down system is adopted in NPPs in Japan.

Working Group on the Operational Management and Evaluation of the Facilities Integrity



Insertion time evaluation of control rods for K-7

External power supply was continued from out of grid in the region, therefore emergency diesel generators did not start-up at the NCO earthquake,

Seismic Safety Regulation System in Japan

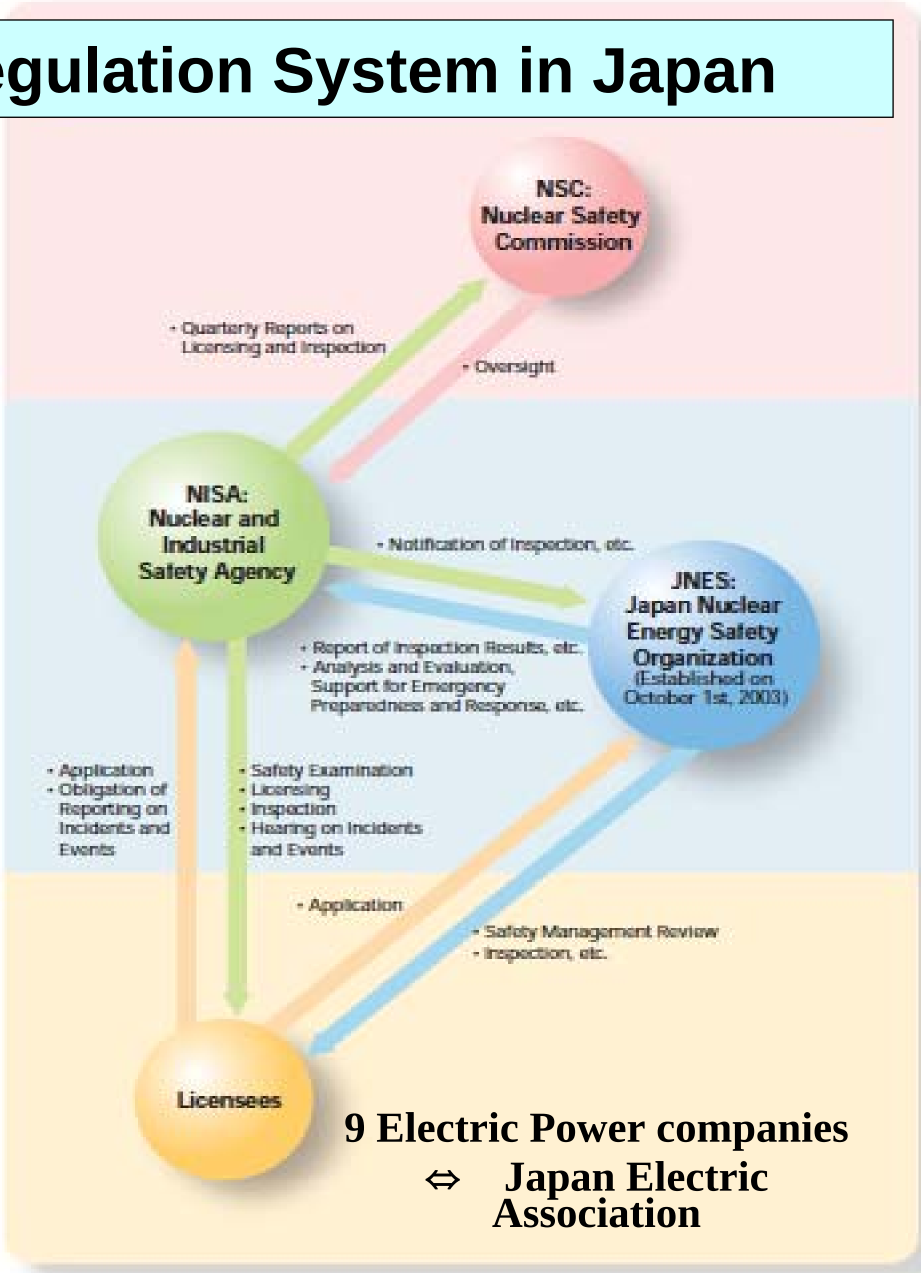
IAEA (ISSC)

Following

Reviewing

Lesson learned

Joint closely!



Site investigation

Follow up

Further Collaboration By EBP

Recommendation

We came over heavy difficulties from NCO earthquake. Technically and scientifically, we learned many things. But the most important lesson learned is valuable collaboration with IAEA. Public respected high level authority in such emergency situation beyond national authorities. They desired whatever nuclear safety even inconvenience without NPPs. Actions of IAEA relieved this contradiction. We shall contribute to IAEA by providing our experiences and resources. It will enhance the IAEA SS practically. On the contrary, it will return to MS as great benefits. Your contribution to ISSC is really encouraged by the lesson learned in KK.

Grazie molto!

Fine