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Earthquake Ground Motion observed during NCO EQ and New Standard Seismic Ground Motion Ss for Kashiwazaki-Kariwa Nuclear Power Plant

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TEPCO

TOKYO ELECTRIC POWER COMPANY

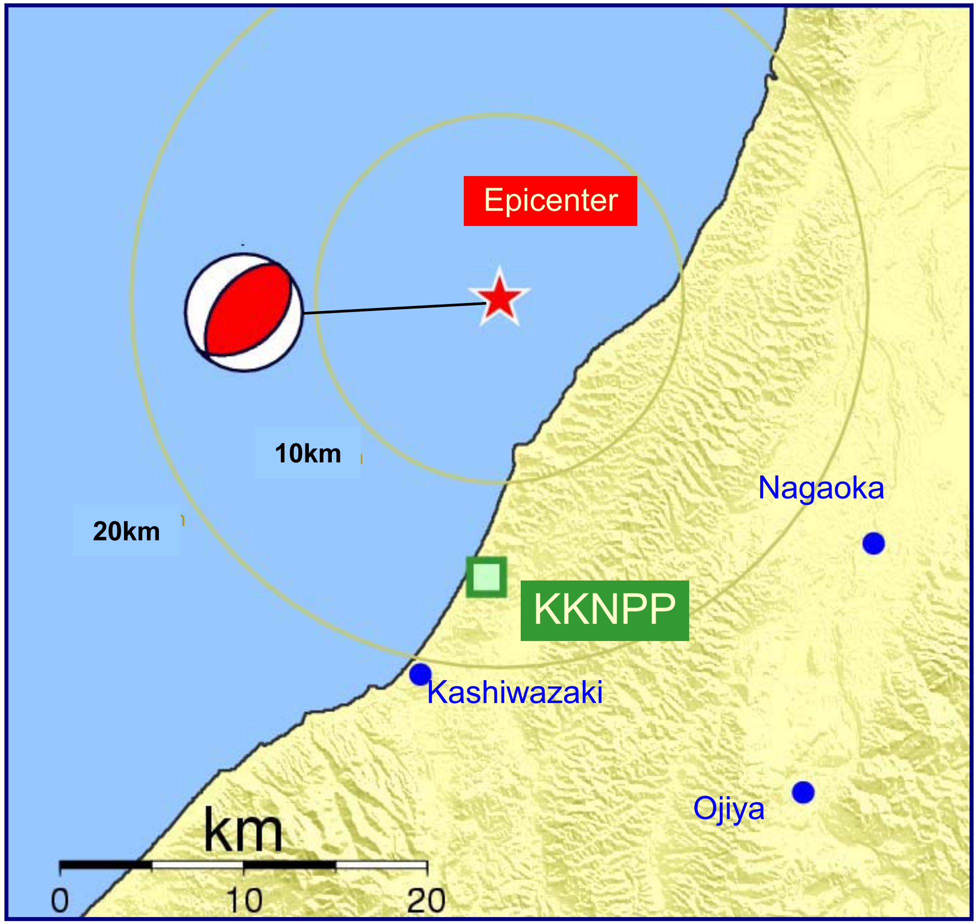
Contents

1.Outline of the Niigataken Chuetsu-Oki EQ

Outline of the Niigataken Chuetsu-Oki EQ

2007 Niigataken Chuetsu-Oki Earthquake

- ✓ Date & Time of the quake: July 16, 2007 10:13 AM
- ✓ Magnitude (determined by JMA): 6.8



Overview of seismic observation points at the KKNPP site

Reactor buildings

On the foundation basemat and mezzanine floor

Turbine Buildings

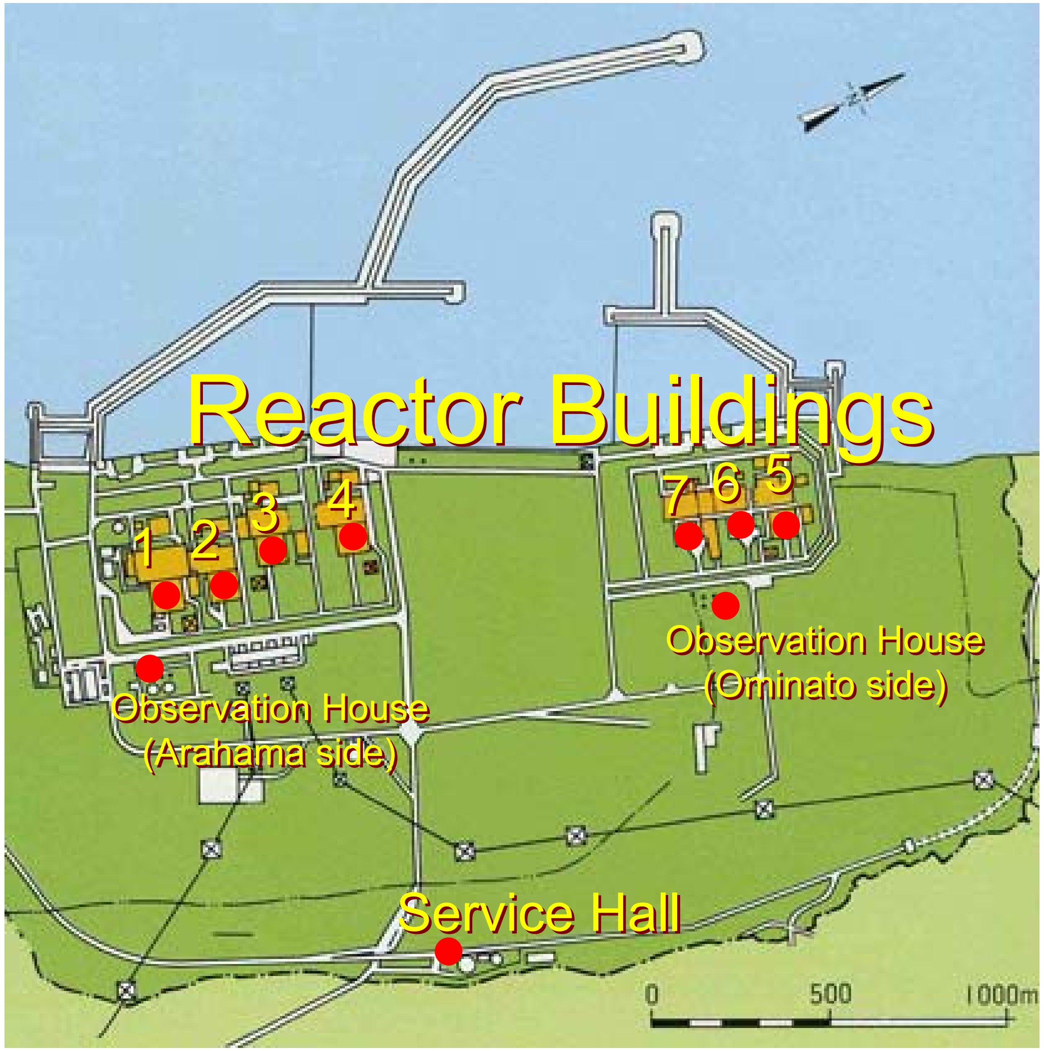
On the foundation basemat and mezzanine floor

Observation house

Near Unit 1 and Unit 5

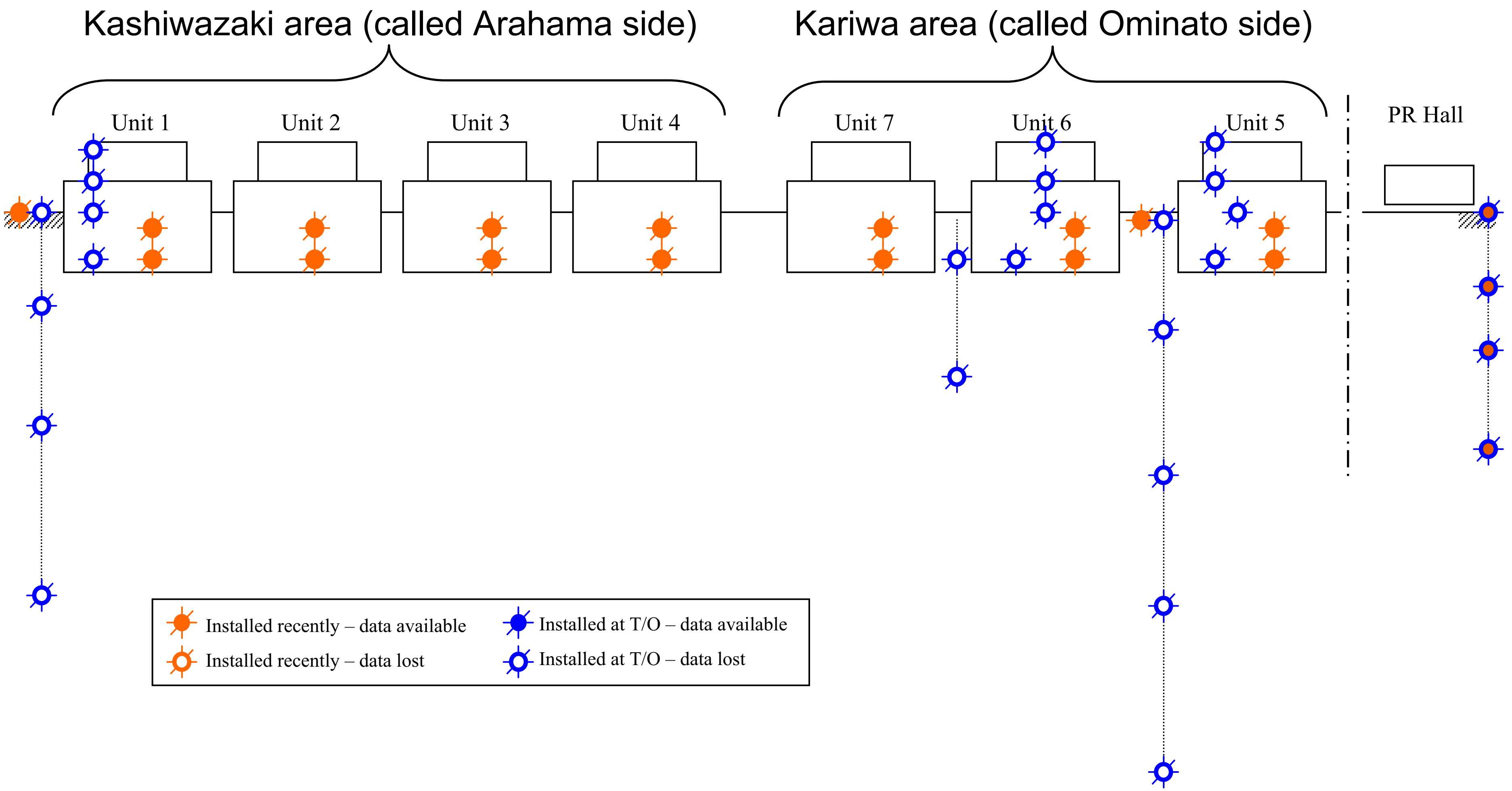
Service Hall

Borehole array (4 depths in total)

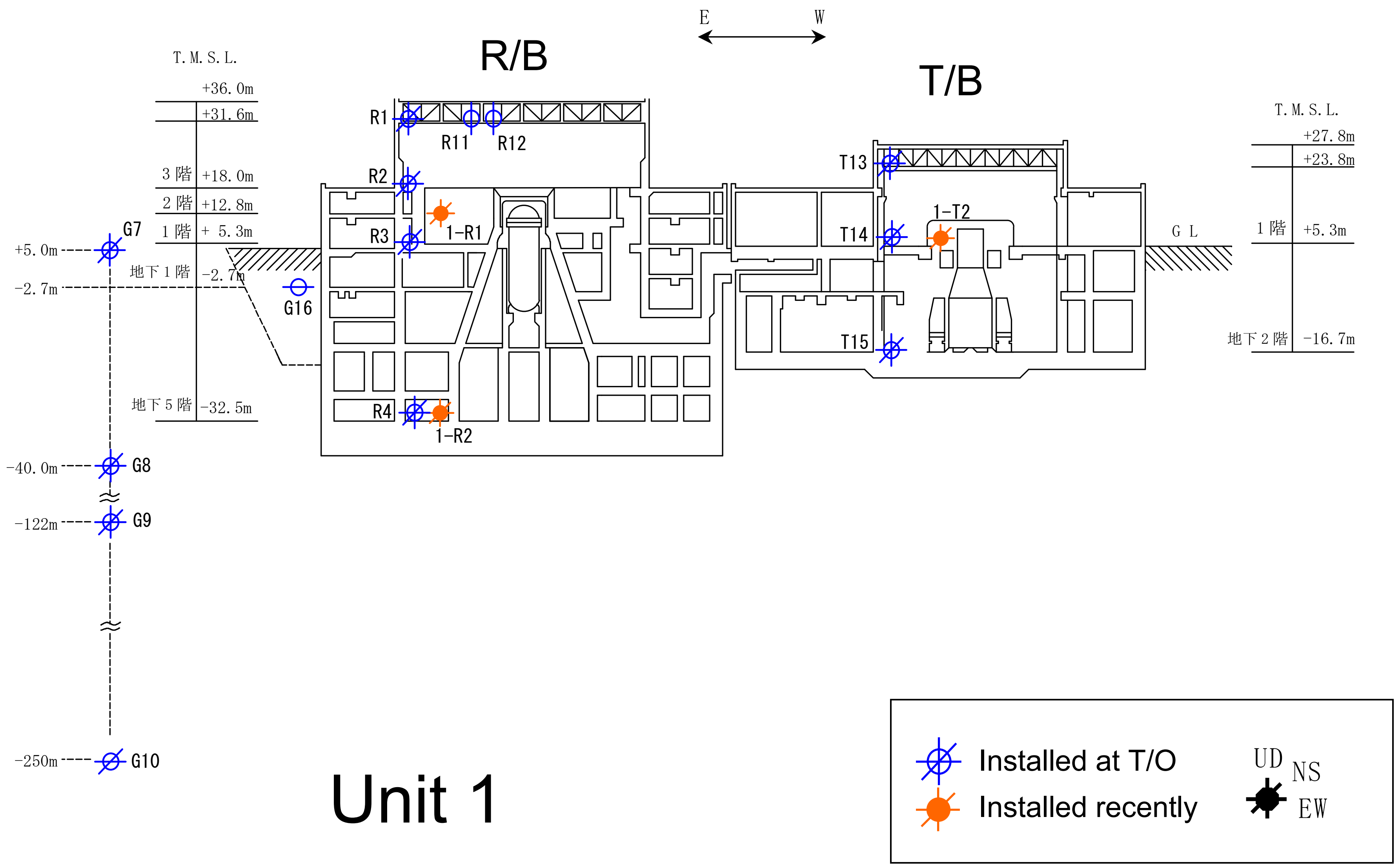


Observation points in KKNPP site

Observation Points



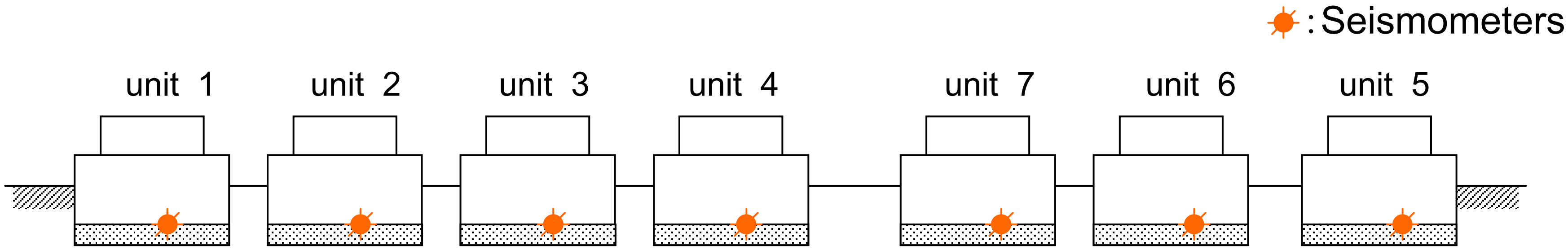
Layout of Seismometers (cross-section)



Overview of the event (1)

(Comparison of the PGA values observed on the foundation of the reactor buildings)

Maximum accelerations showed difference between Units 1 – 4 and Units 5 – 7

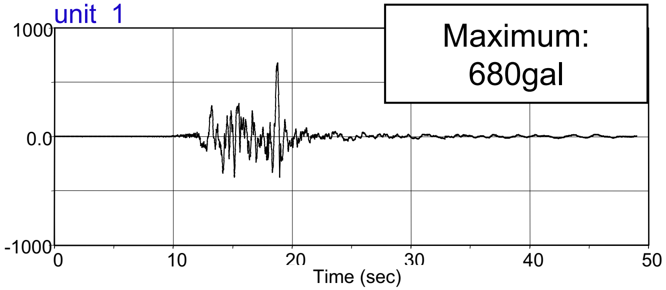


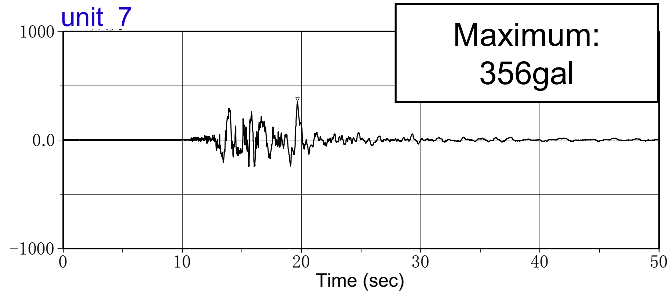
Observed Peak Ground Acceleration (Unit : Gal)

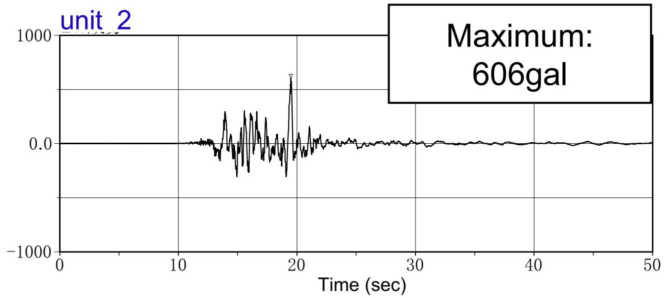
Observed value		NS	EW	UD
# 1	Basemat (B5F)	311	680	408
# 2	Basemat (B5F)	304	606	282
# 3	Basemat (B5F)	308	384	311
# 4	Basemat (B5F)	310	492	337
# 5	Basemat (B4F)	277	442	205
# 6	Basemat (B3F)	271	322	488
# 7	Basemat (B3F)	267	356	355

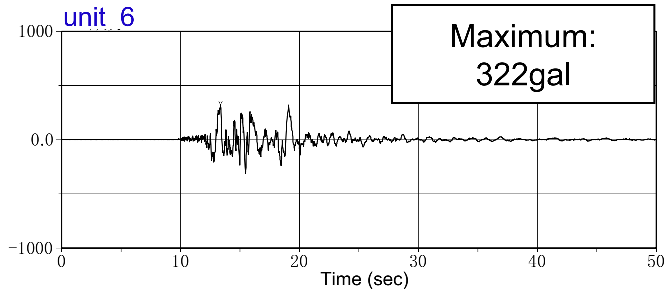
- **All units registered larger acceleration in the EW direction than in the NS direction.**
- **Units 1 – 4 registered larger acceleration in the EW direction compared to Units 5 – 7.**

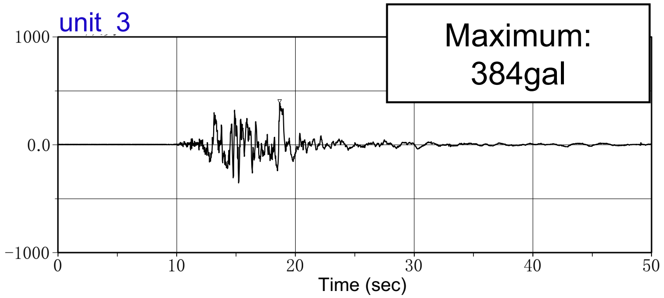
Overview of the event (2)
(Comparison of the ground motions between each units)

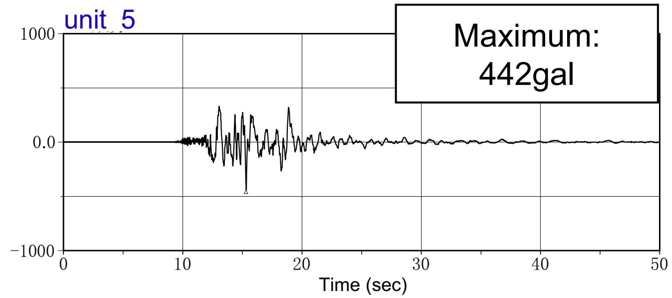


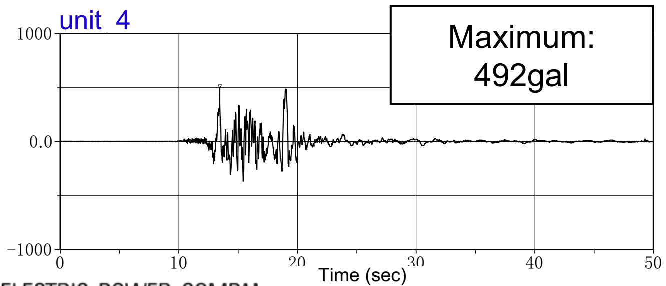








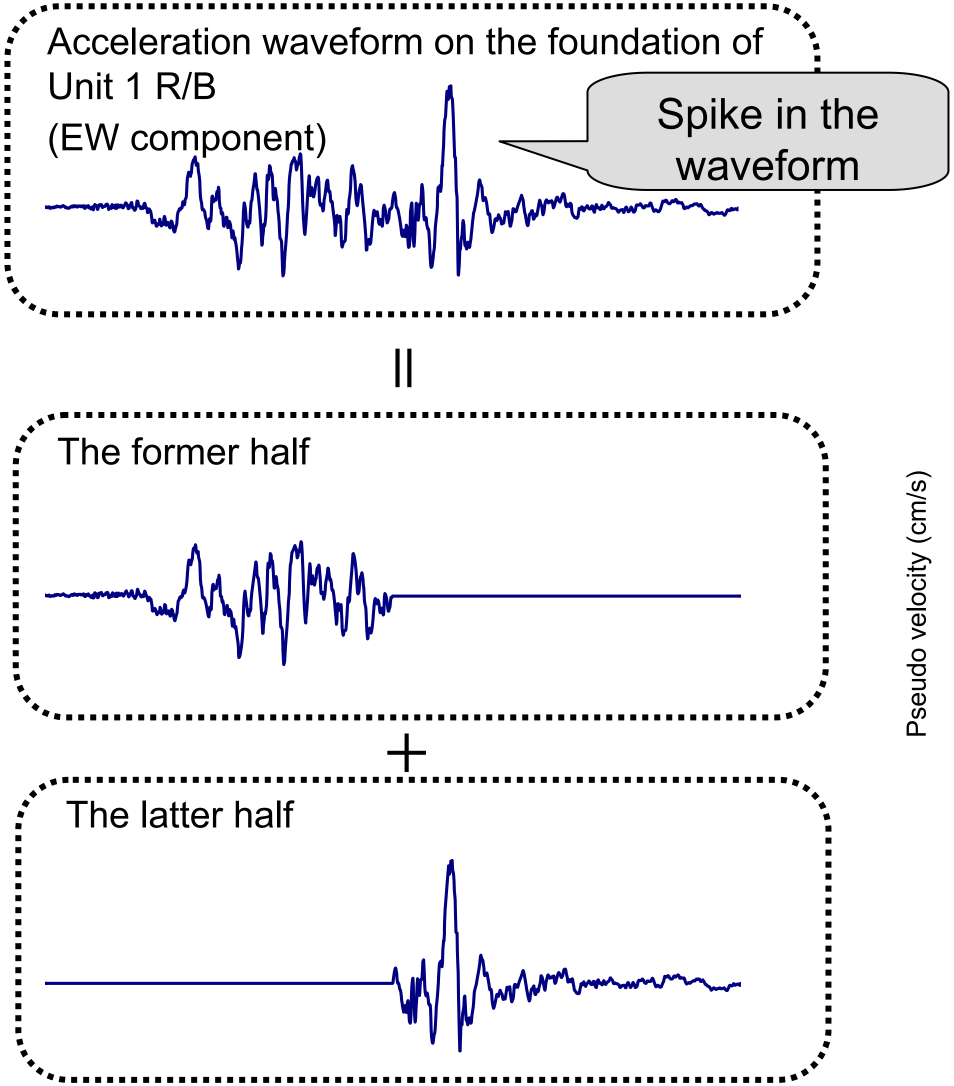


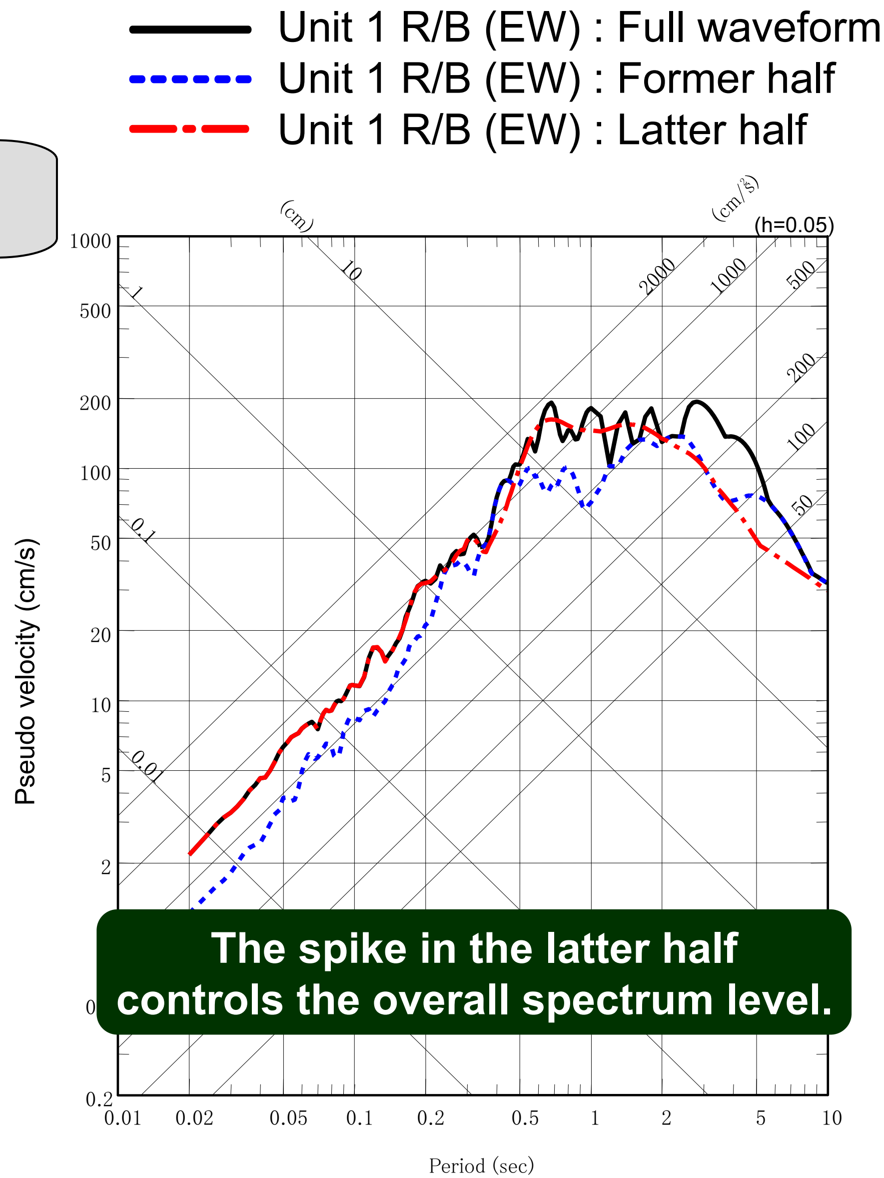


Time history waveform of acceleration observed on the foundation of the R/Bs (EW direction)

The difference in maximum acceleration between Units 1 – 4 and Units 5 – 7 is determined by the amplitude of a spike in the latter part of the event.

Overview of the event (3)
(Characteristics of the spike in the waveform)





The spike in the latter half controls the overall spectrum level.

Overview of the event

Summary

- Observed ground motion at KKNPP site was larger than that observed in the surrounding area
- The EW component of the ground motions at the R/Bs of Units 1 - 4 were significantly larger than those of Units 5 - 7.

  -> There are variations in the response within the same compound.
- The response spectrum for the latter half corresponds well to the spectrum of the entire waveform.

  -> The large variation in the PGA values of Units 1 - 4 compared to those of Units 5 - 7, are attributed to the spike in the latter half.

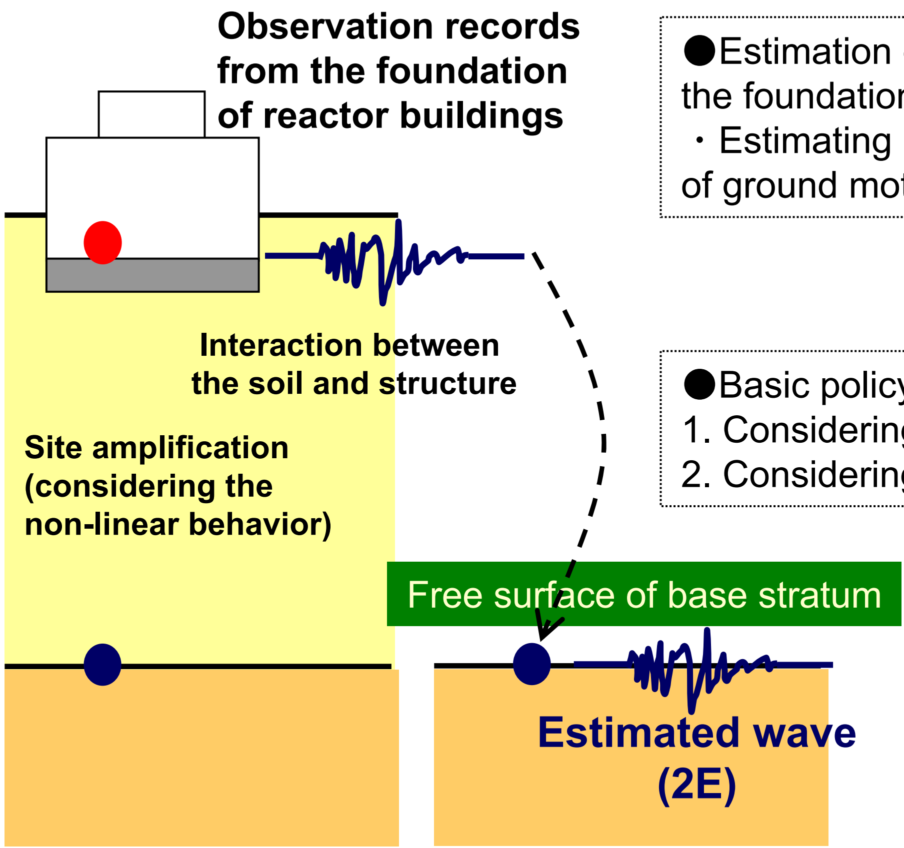
These respects are taken into account in order to analyze the factors that magnified the ground motion at the KKNPP site.

2.Analysis on the observed ground motions at the KKNPP site

1) Examination based on the observation records

1. Examining observation records at KKNPP site

Estimating ground motions based on data from the foundation of reactor buildings



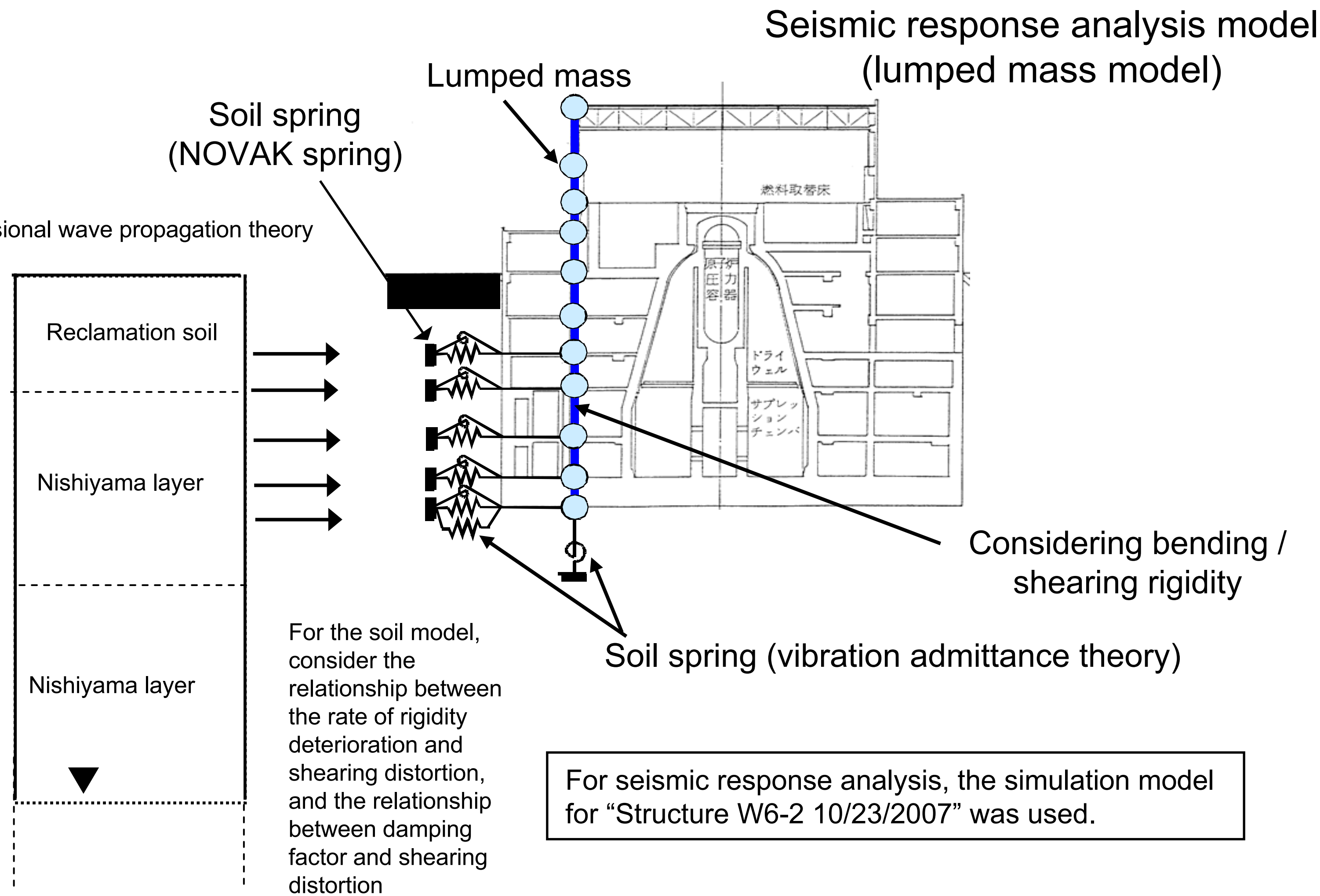
●Estimation of bedrock waves based on the seismic data from the foundation of reactor buildings
・Estimating bedrock waves at Units 1 - 7 to analyze difference of ground motions at these sites

●Basic policy in estimating bedrock waves
1. Considering the interaction between the buildings and strata
2. Considering the non-linear nature of bedrock (equivalent linear)

Concept of bedrock wave estimation based on seismic data on the basemat of reactor buildings

1. Examining observation records at KKNPP site

Seismic response analysis model for estimating bedrock waves



For seismic response analysis, the simulation model for “Structure W6-2 10/23/2007” was used.

1. Examining observation records at KKNPP site

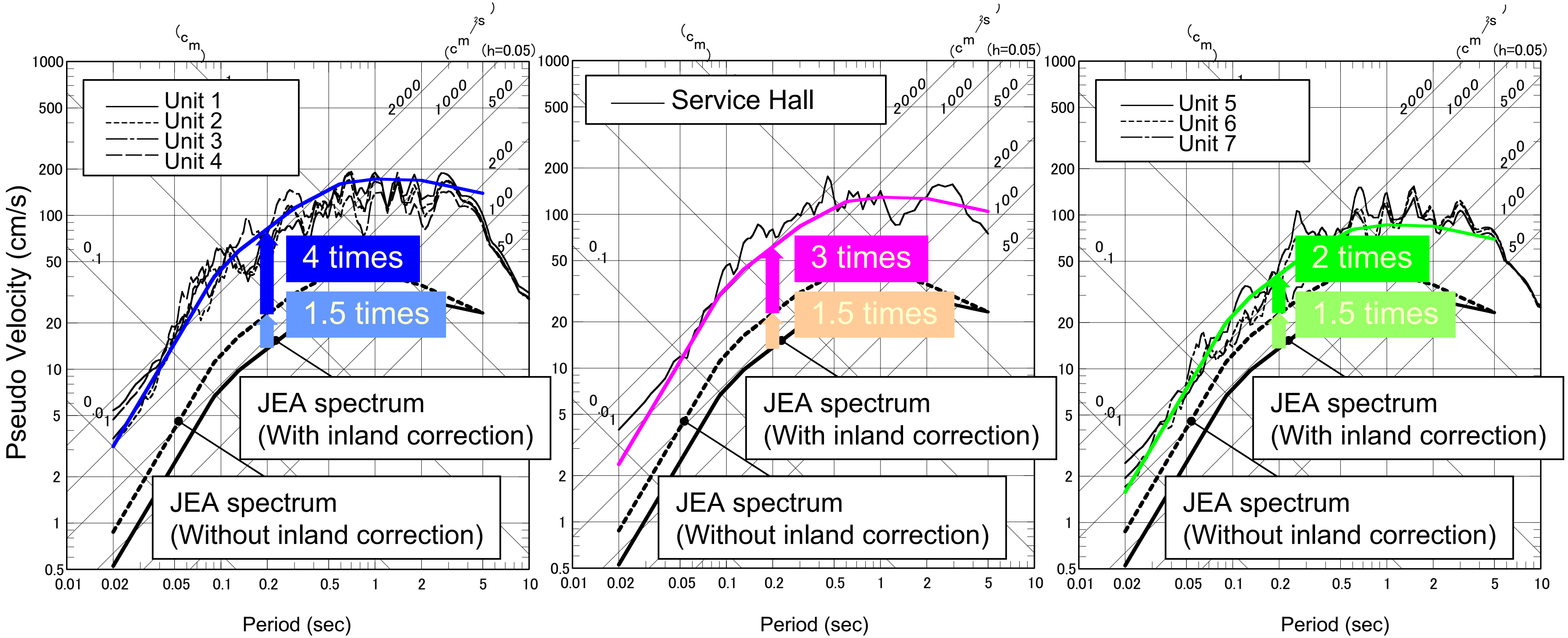
Comparing the observation data from the foundation of reactor buildings against the estimated acceleration on the free surface of base stratum

<EW direction>

	unit 1	unit 2	unit 3	unit 4	unit 5	unit 6	unit 7
Observed data from the foundation of reactor buildings (Gal)	680	606	384	492	442	322	356
Estimated acceleration on the free surface of base stratum (Gal)	1699	1011	1113	1478	766	539	613

1. Examining observation records at KKNPP site

Response spectrum of the estimated wave (EW component)



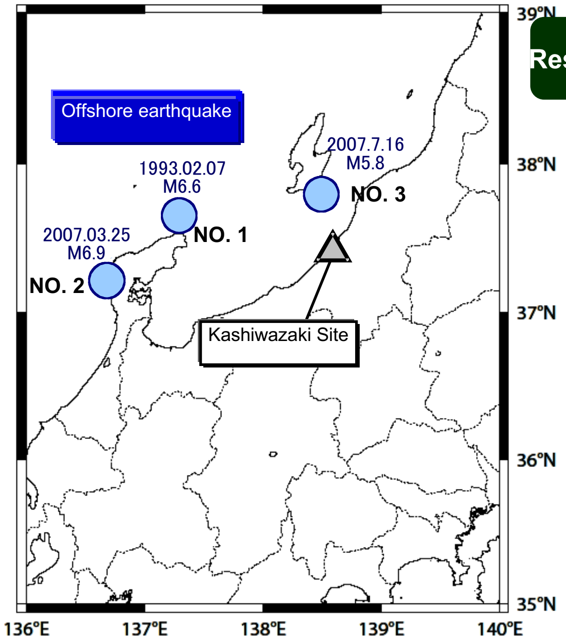
Unit 1 side
(Arahama side)

Service Hall

Unit 5 side
(Ominato side)

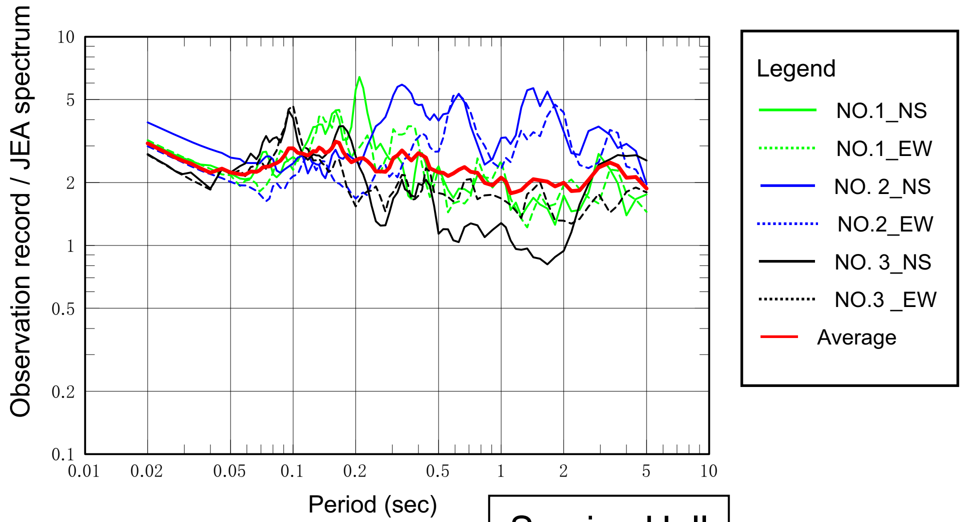
1. Examining observation records at KKNPP site

Examination of the offshore earthquakes

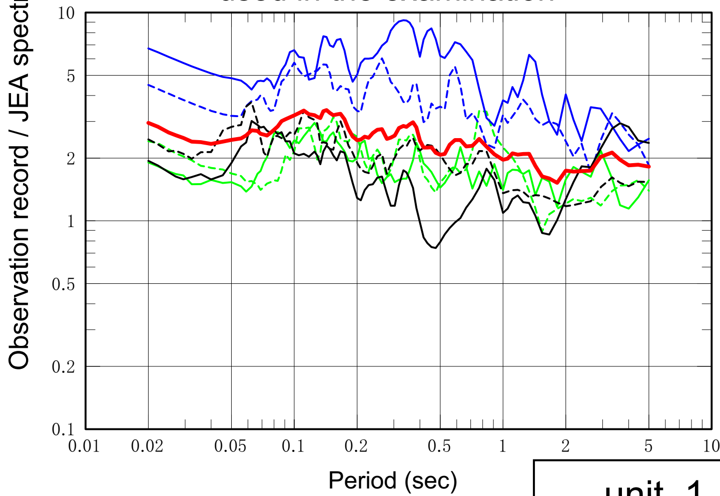


Epicenter distribution of earthquakes used in the examination

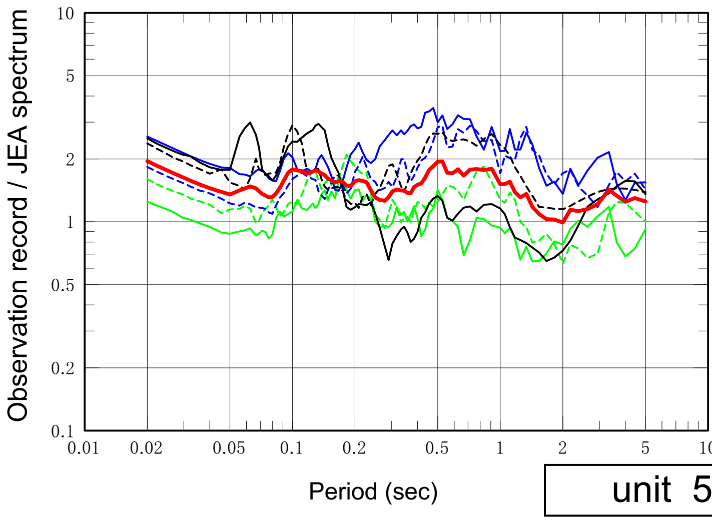
Residual error (observation record [estimated wave] / JEA spectrum <no inland correction>)



Service Hall



unit 1

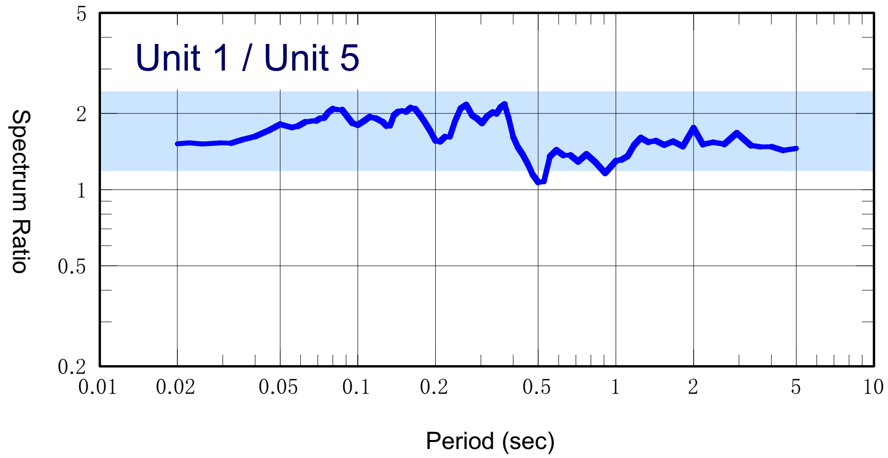


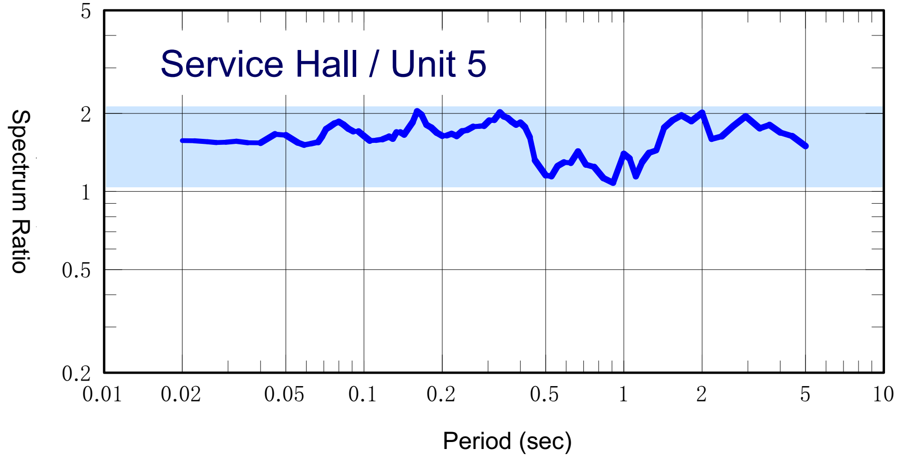
unit 5

1. Examining observation records at KKNPP site

Comparison in offshore earthquakes

Comparing Unit 1 avg. / Unit 5 avg. & Service Hall avg. / Unit 5 avg.



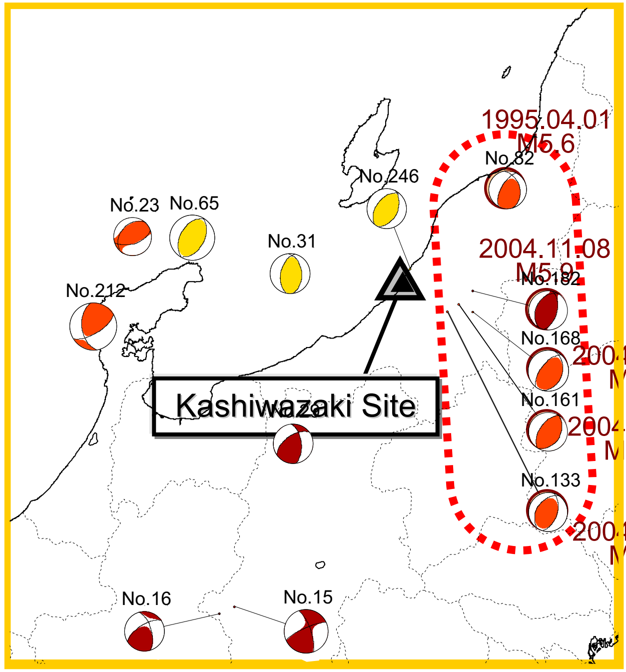


Unit 1 avg. / Unit 5 avg. = approx. 2

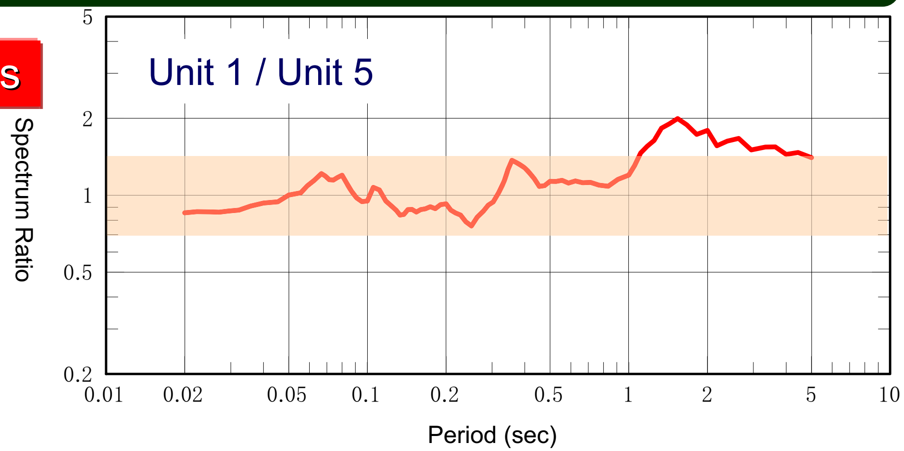
Service Hall avg. / Unit 5 avg. = approx. 1.5 to 2

Comparing Unit 1 avg. / Unit 5 avg. & Service Hall avg. / Unit 5 avg.

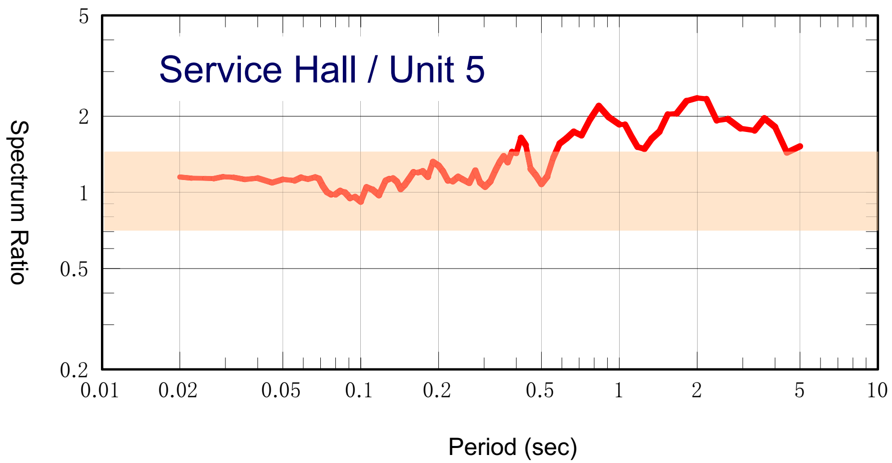
Inland earthquakes



Epicenter distribution of earthquakes used in the examination



Unit 1 ≒ Unit 5



(Reference) Service Hall ≒ Unit 5

2) Examination based on the analytical approach

1. Examination based on seismic source inversion method

Conditions of seismic source inversion

●Analysis method

Seismic source inversion
using the Empirical Green's function method

●Empirical Green's function

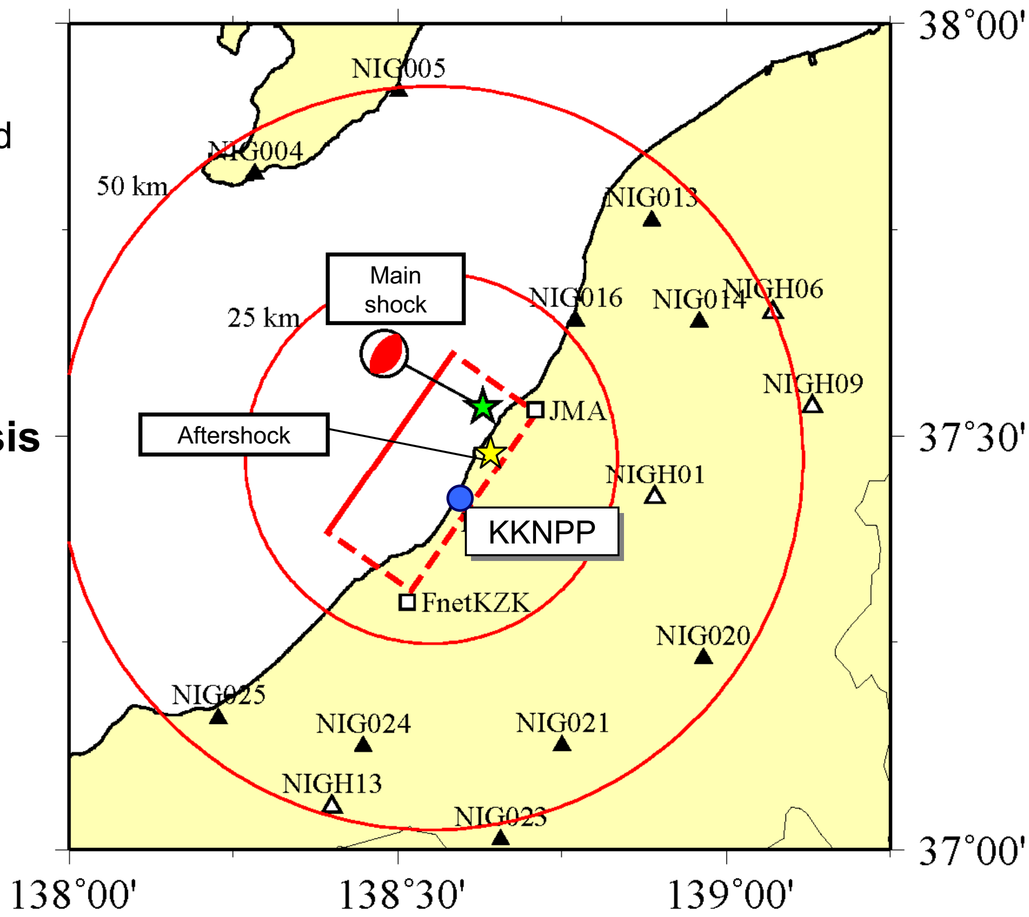
Aftershock measuring M_{JMA} 4.4,
recorded at 21:08 on July 17, 2007

●Observation stations used in the analysis

•Kashiwazaki Site: 2 points
(on the foundation of the R/Bs of Unit 1 and 5)
•K-NET：10 sites、KiK-net：4 sites
•JMA、F-net：1 site each

●Objective function

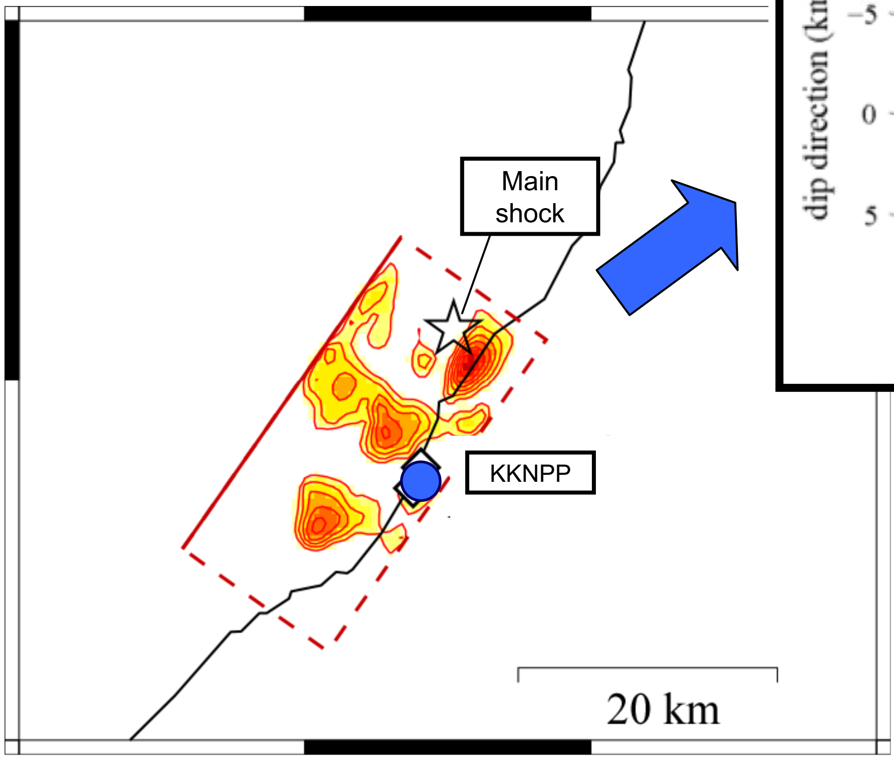
•Analysis frequency range: 0.1～2Hz
•Displacement waveform

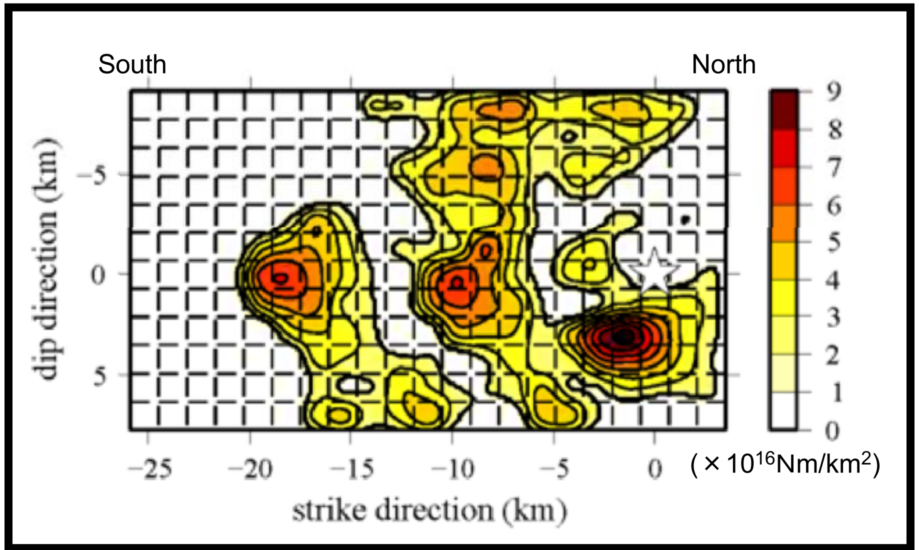


Distribution of observation stations used for the analysis

1. Examination based on seismic source inversion method

Estimated seismic moment distribution

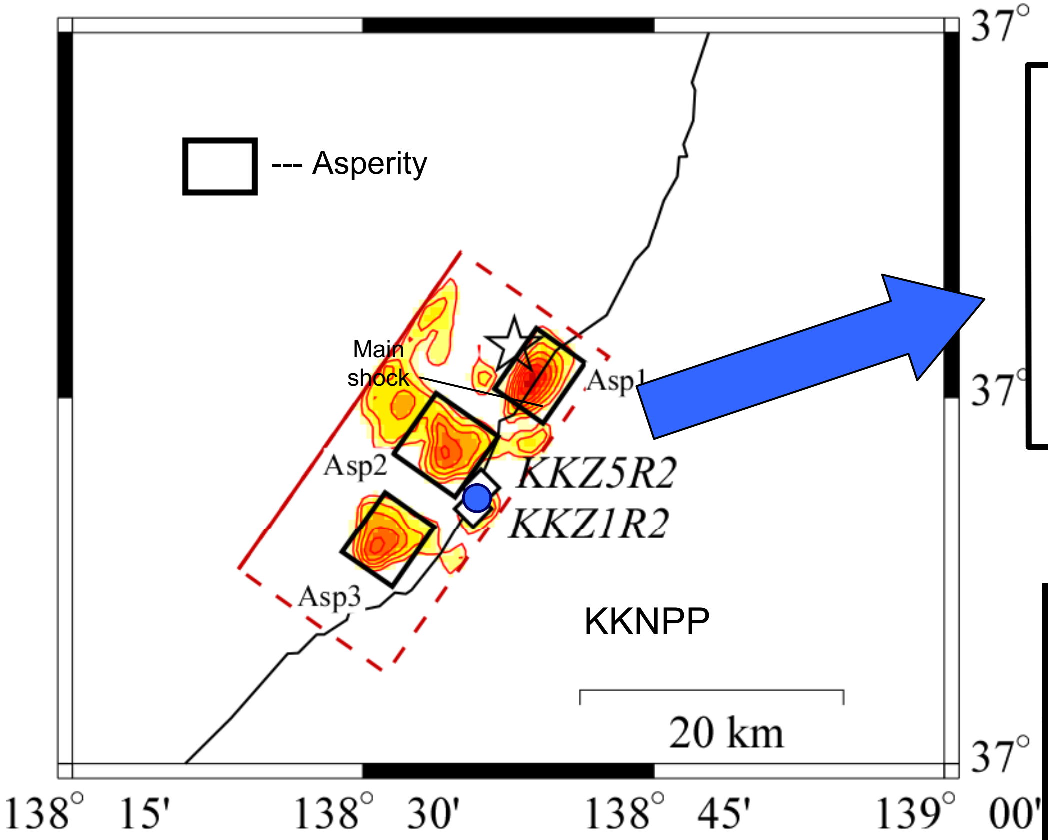




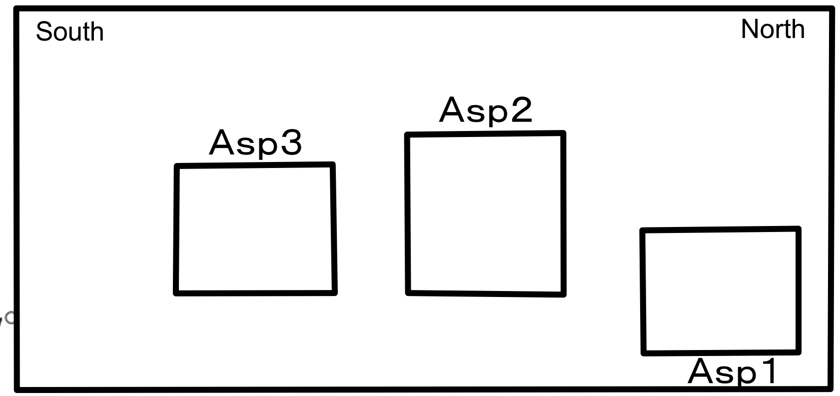
Mapping of seismic moment distribution

1. Examination based on seismic source inversion method

Characterizing the seismic source model based on the results of seismic source inversion



Mapping of the characterized seismic source model

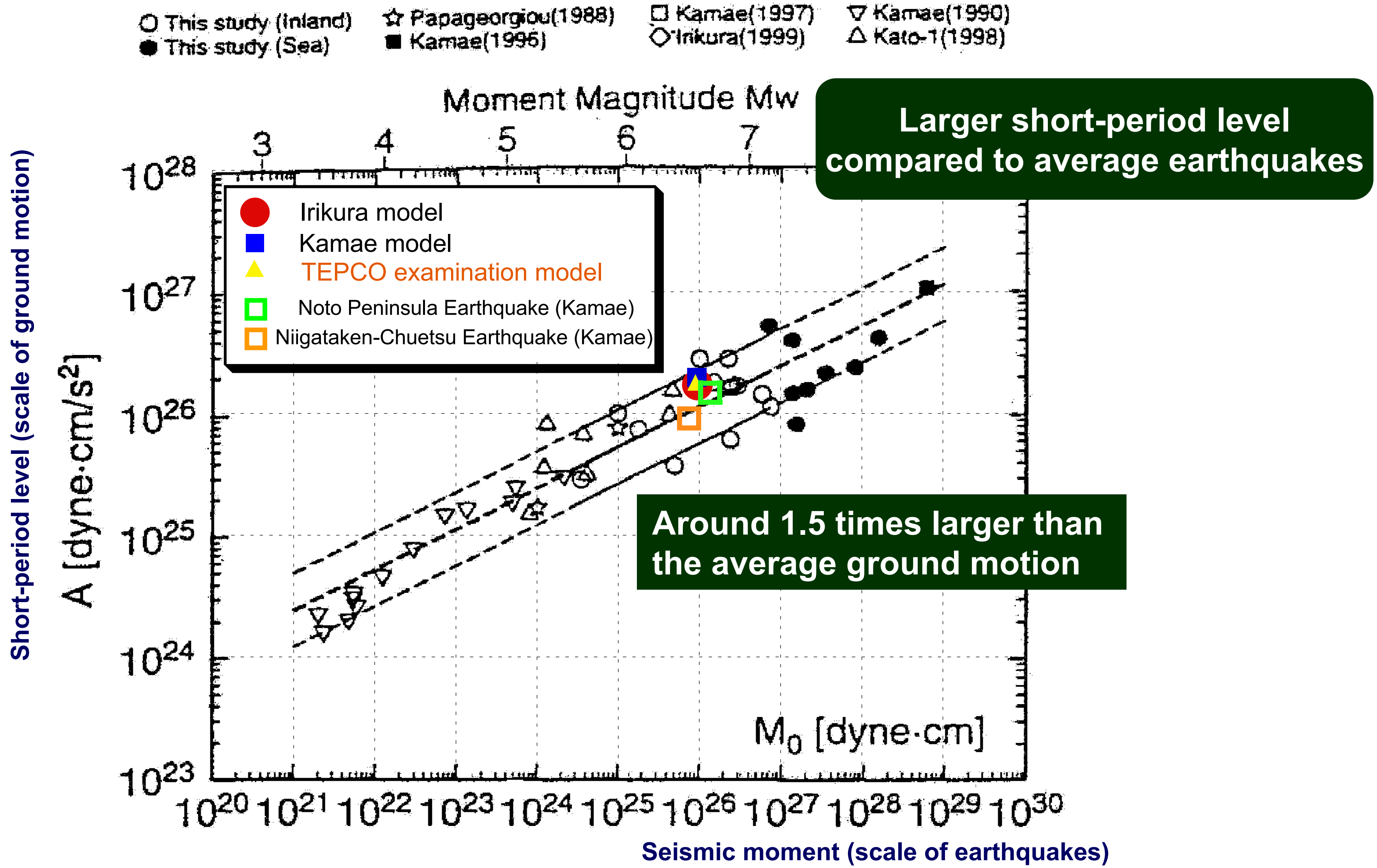


Parameters of the characterized seismic source model

	Length (Km)	Width (Km)	Stress drop (MPa)
Total	29.4	16.8	—
Asp1	5.6	5.6	25.47
Asp2	5.6	7.0	20.84
Asp3	5.6	5.6	19.91

1. Examination based on seismic source inversion method

Short-period level of the Niigataken-Chuetsu-Oki Earthquake



*Information added to the chart by Dan et al (2001)

2. Analysis of a 2-D irregular soil model considering the folding structure

Developing a 2-D FEM ground model in cross-sections orthogonal to the Madonosaka syncline

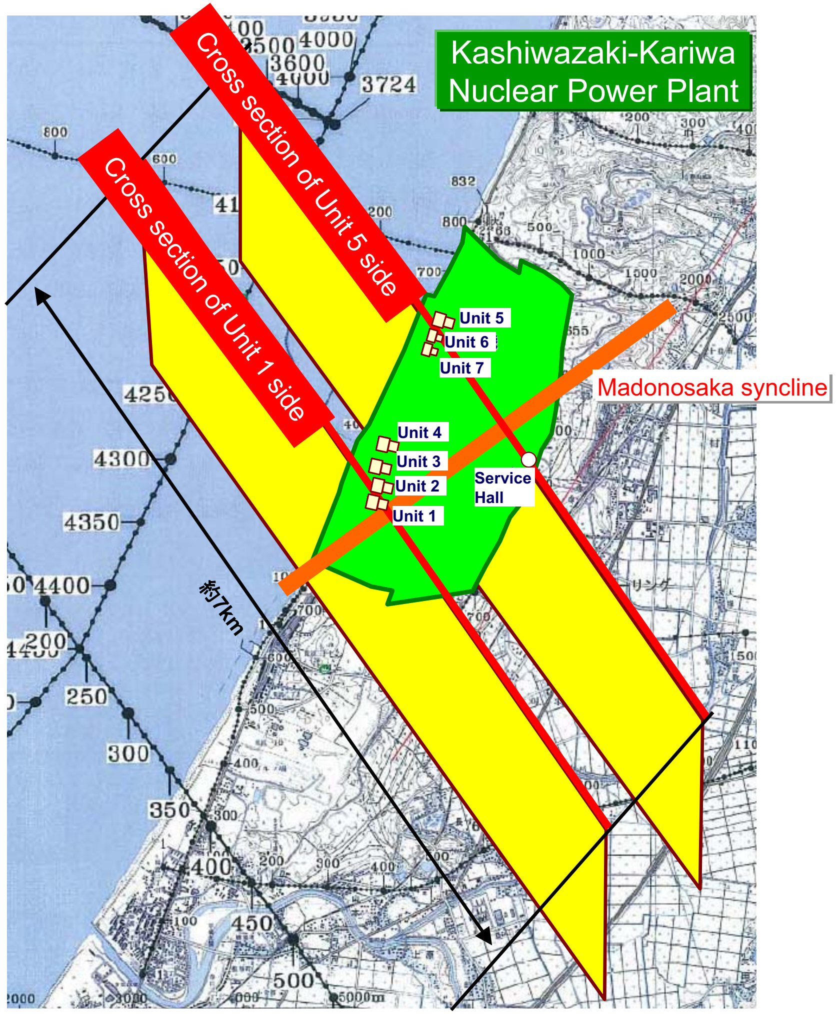
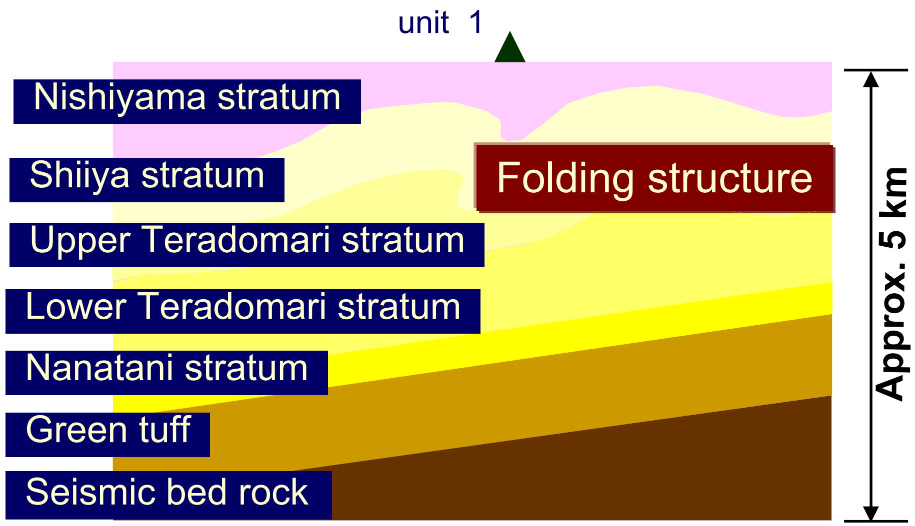
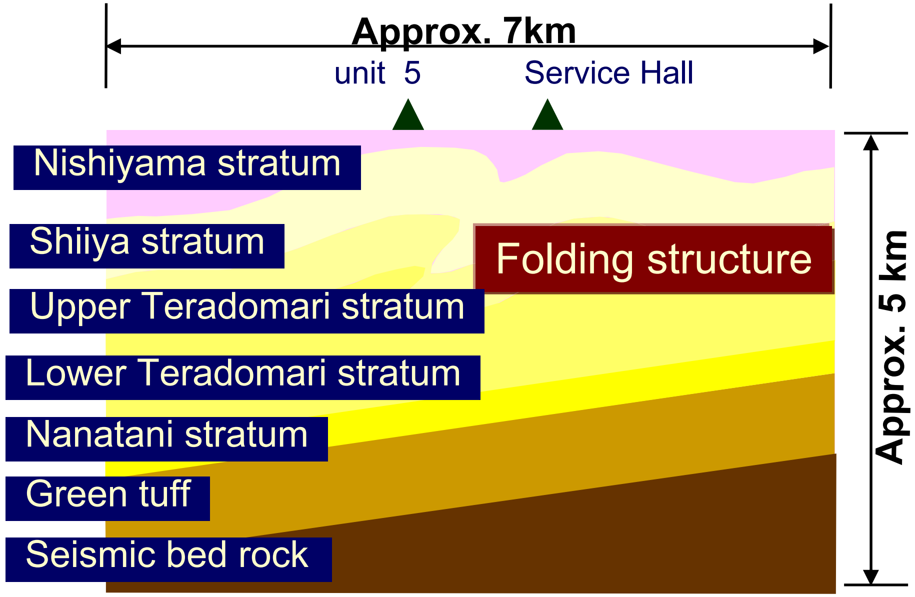


Image of the ground model



Cross-section at Unit 1

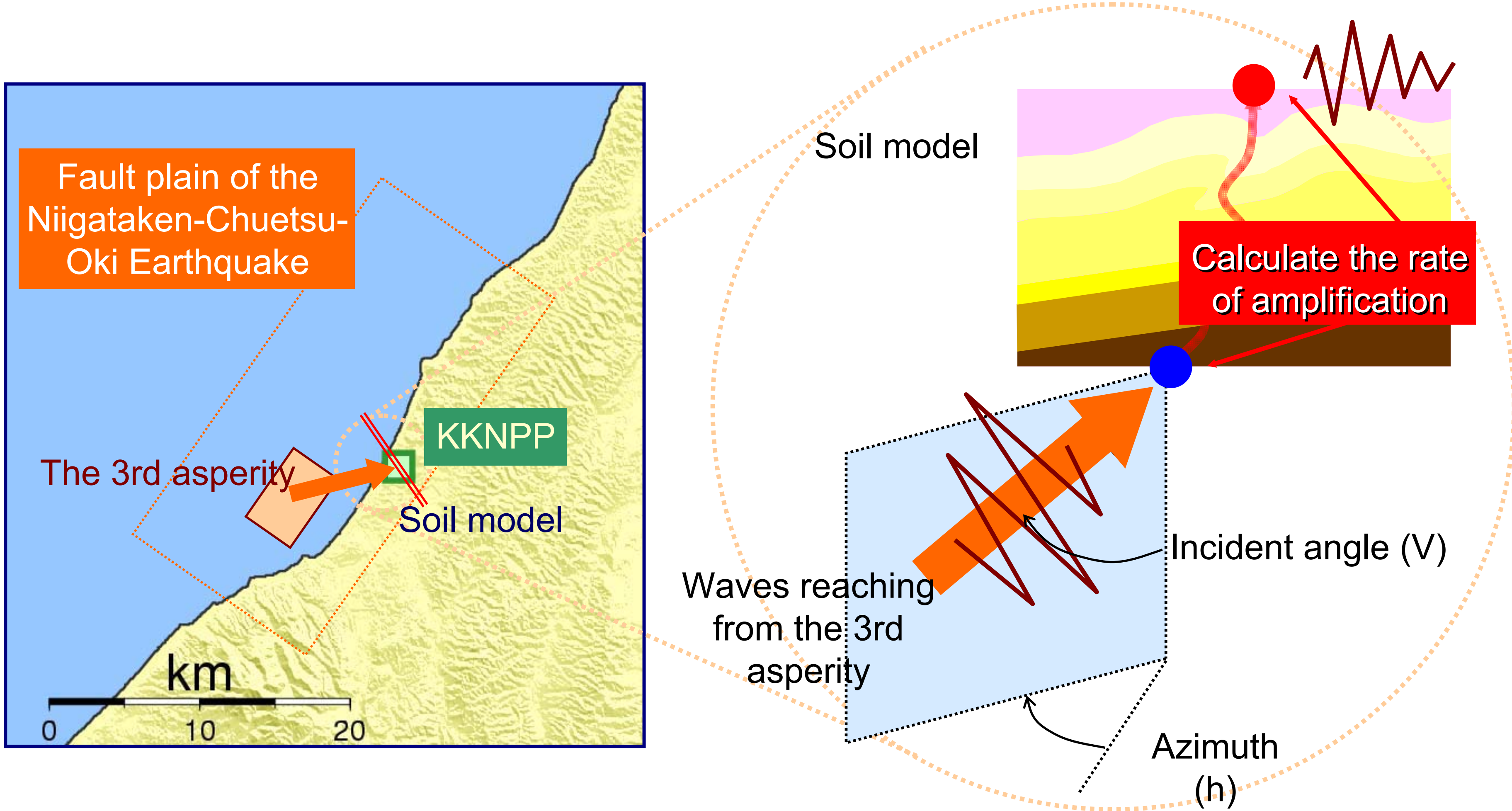


Cross-section at Unit 5

2. Analysis of a 2-D irregular soil model considering the folding structure

The incident angle and radiant angle of the input ground motion

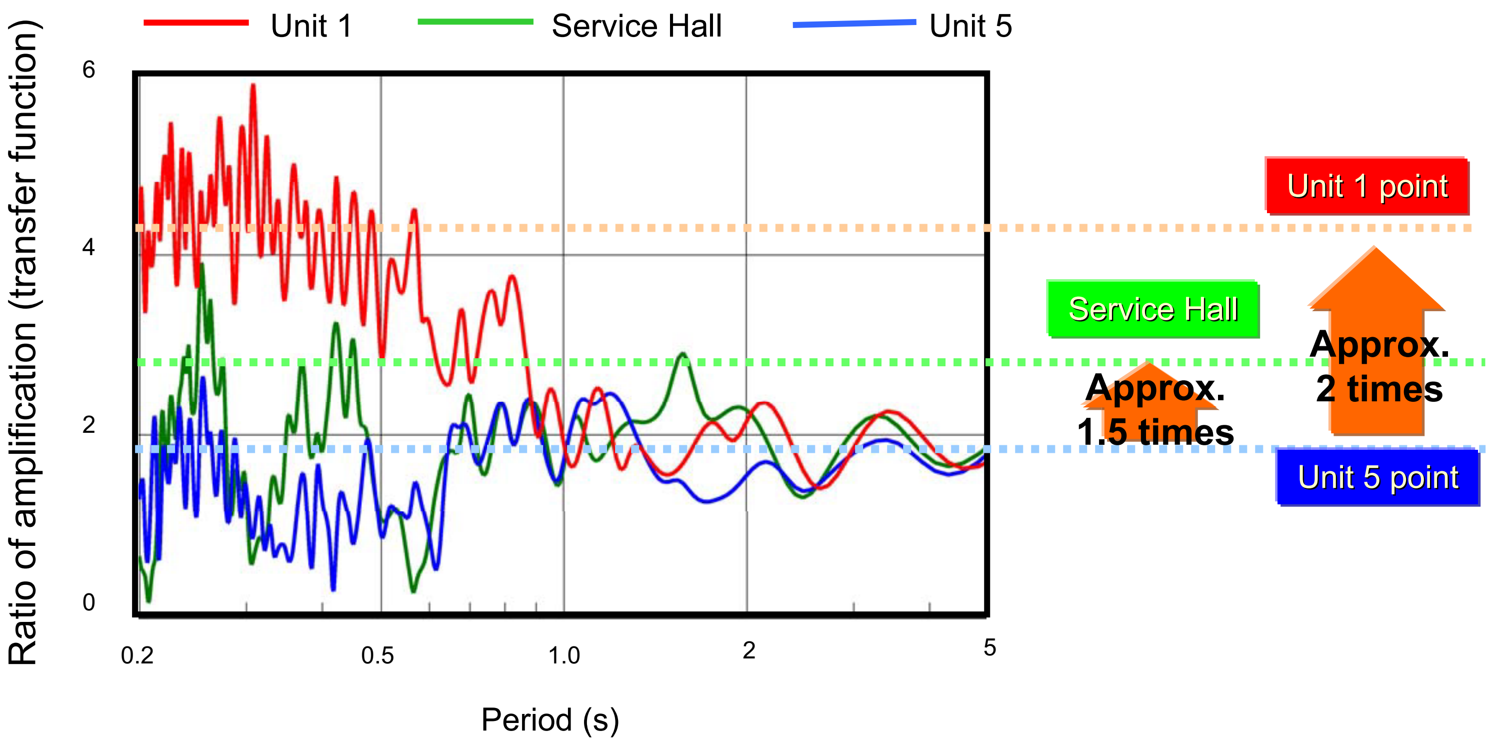
Assume the Niigataken-Chuetsu-Oki Earthquake's seismic waves reaching from the position of the third asperity, and define the angles of diagonal incidence and directional incidence.



2. Analysis of a 2-D irregular soil model considering the folding structure

Characteristics of the soil amplification from seismic bed rock (1)

Ground amplification characteristics of ground motions coming from the 3rd asperity

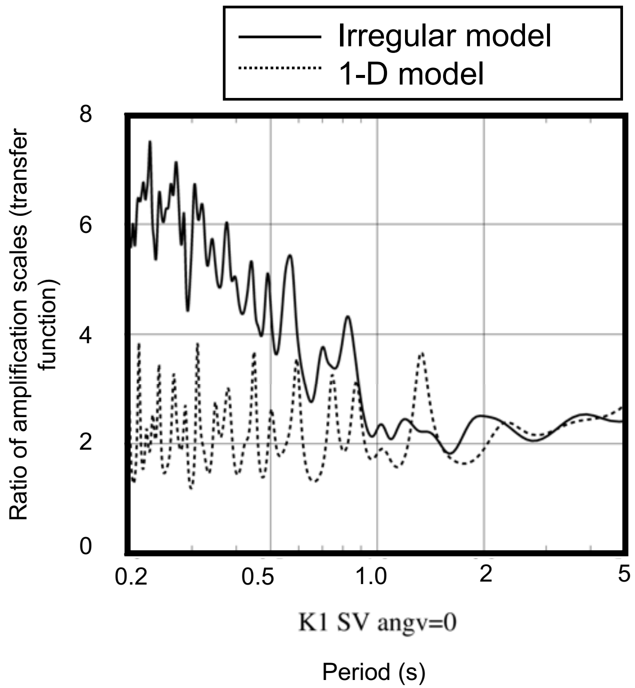


(Incident angle: 45 deg, azimuth: 15 deg)

Rate of amplification when the seismic waves entered from the bottom of the soil model and reached the surface of the model

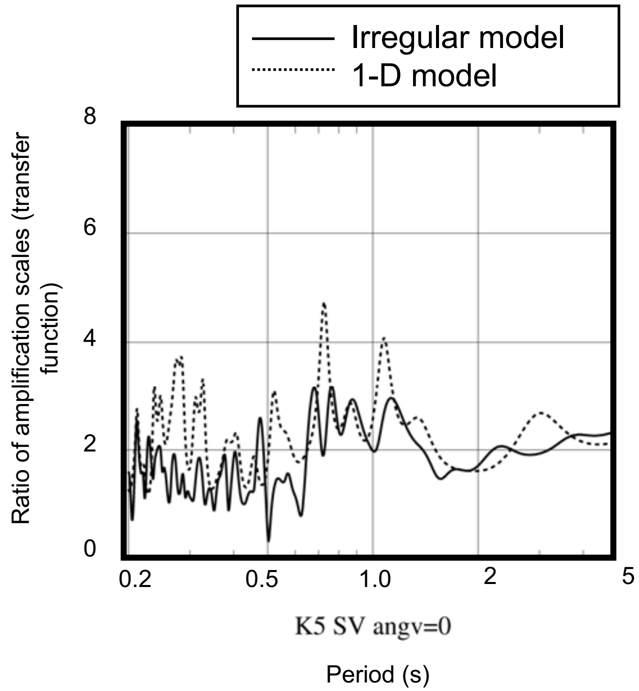
2. Analysis of a 2-D irregular soil model considering the folding structure

Characteristics of the soil amplification from seismic bed rock (2)



1-D soil model < Irregular soil model

Unit 1



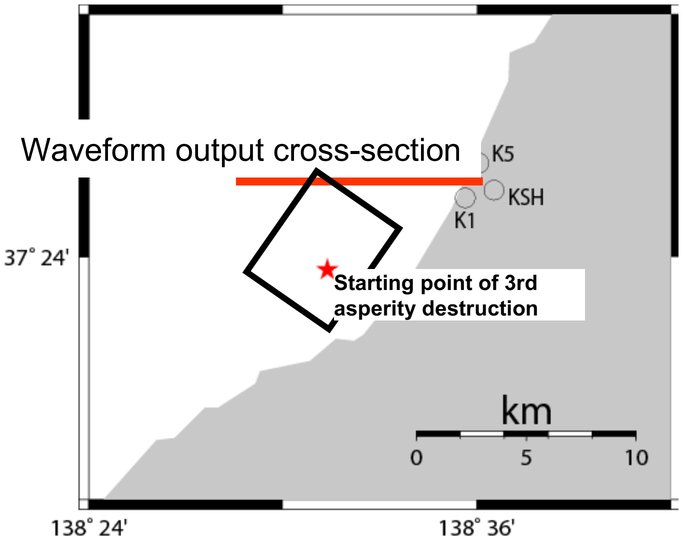
1-D soil model ≈ Irregular soil model

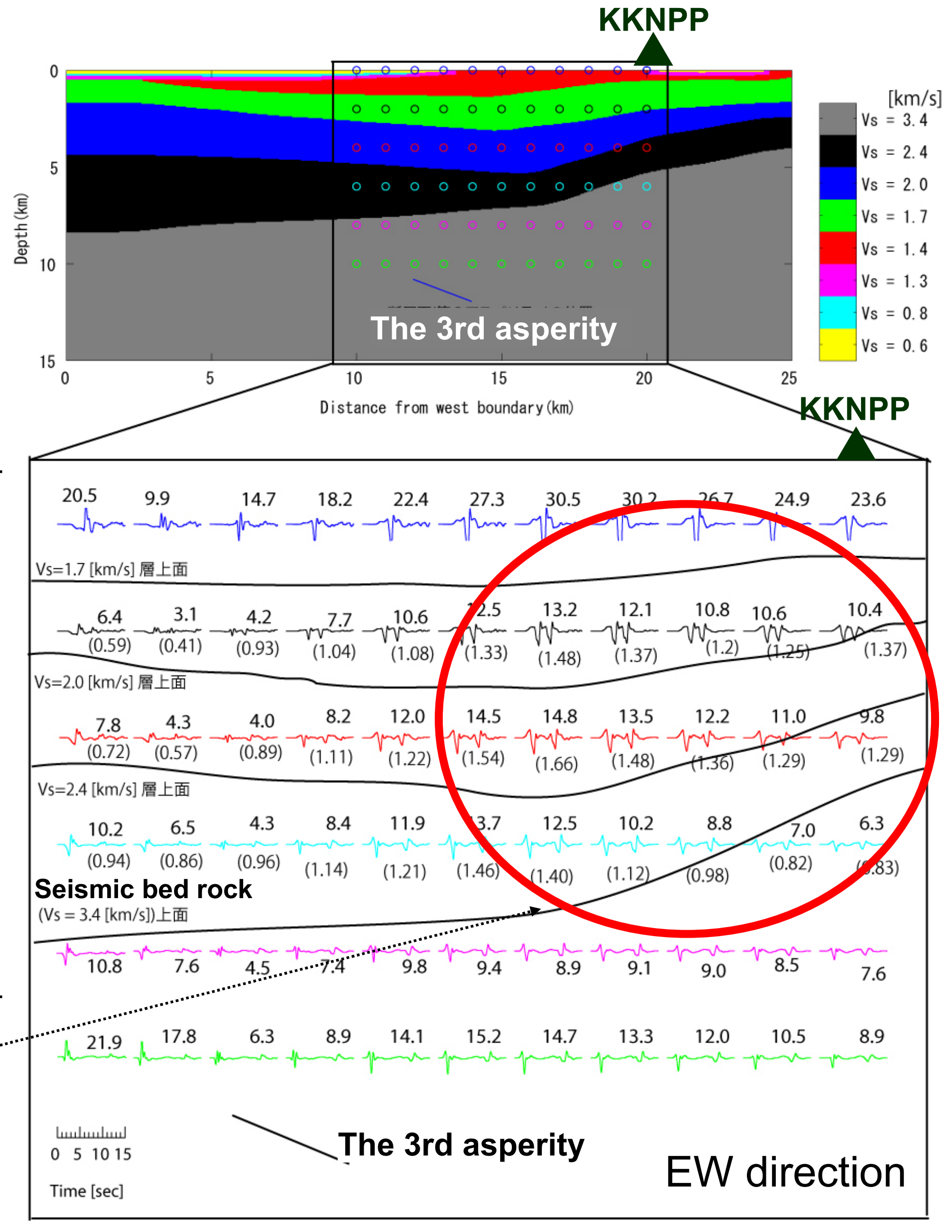
Unit 5

The irregularity of the ground has a greater impact on the Unit 1.

3. Examining the effect of the irregularity of deep soil structure on ground motions

Analysis result



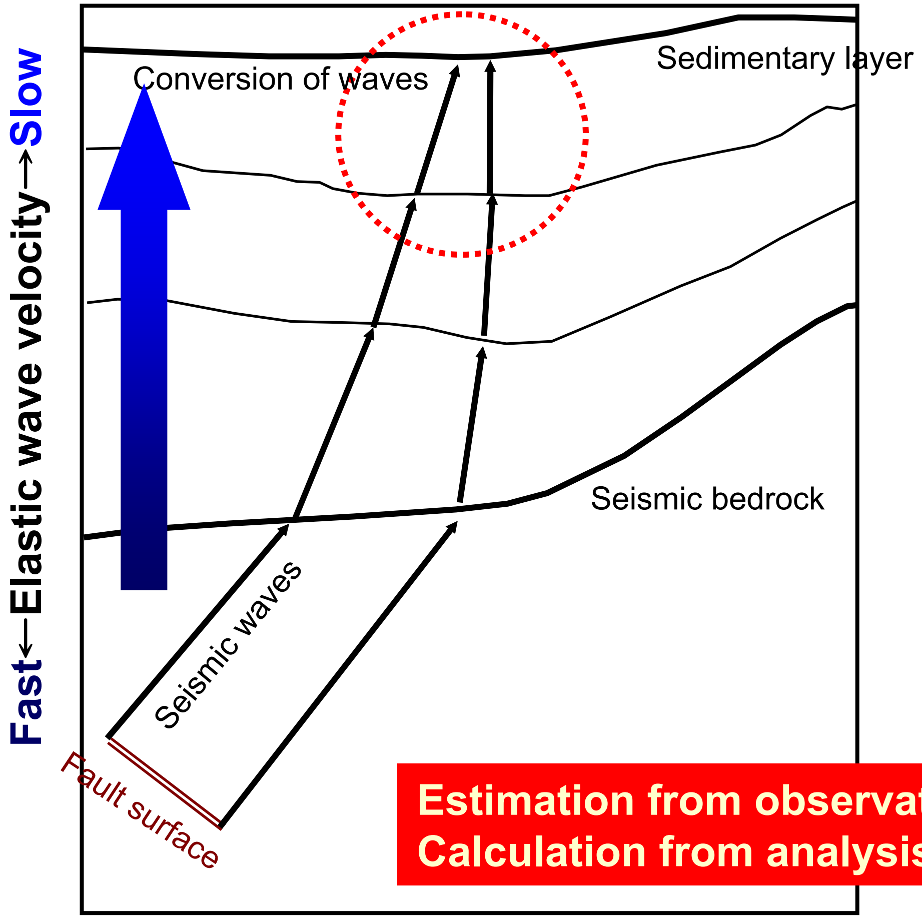


The top figures indicate the maximum value of velocity waveforms.
The figures in brackets indicate the ratio against the maximum velocity waveforms (shown in pink) at the seismic bedrock.

● Ground motion from the 3rd asperity has shown the large amplification.

Interpretation of amplification caused by deep ground irregularity

The irregularity of deep underground structure causes focusing of the waves.



Estimation from observation: Approx. 2 times
Calculation from analysis: Approx. 1.5 times

Conceptual diagram

3) Estimated factors of the large ground motion at the site

Estimation of factors (Summary)

the Niigataken-Chuetsu-Oki Earthquake

Observation records at the site was larger than JEA spectrum (without inland correction) that corresponds to the magnitude of the Niigataken-Chuetsu-Oki Earthquake.

(Estimation) Units 1 - 4: Approx. 4 times, Units 5 - 7: Approx. 2 times

Estimation of factors

I. The ground motions, estimated from the magnitude of the earthquake, are greater than the average of past earthquakes.

Source factor	- approx. 1.5 times

II. The complexity of the deep underground structure amplified ground motions (focusing, etc.).

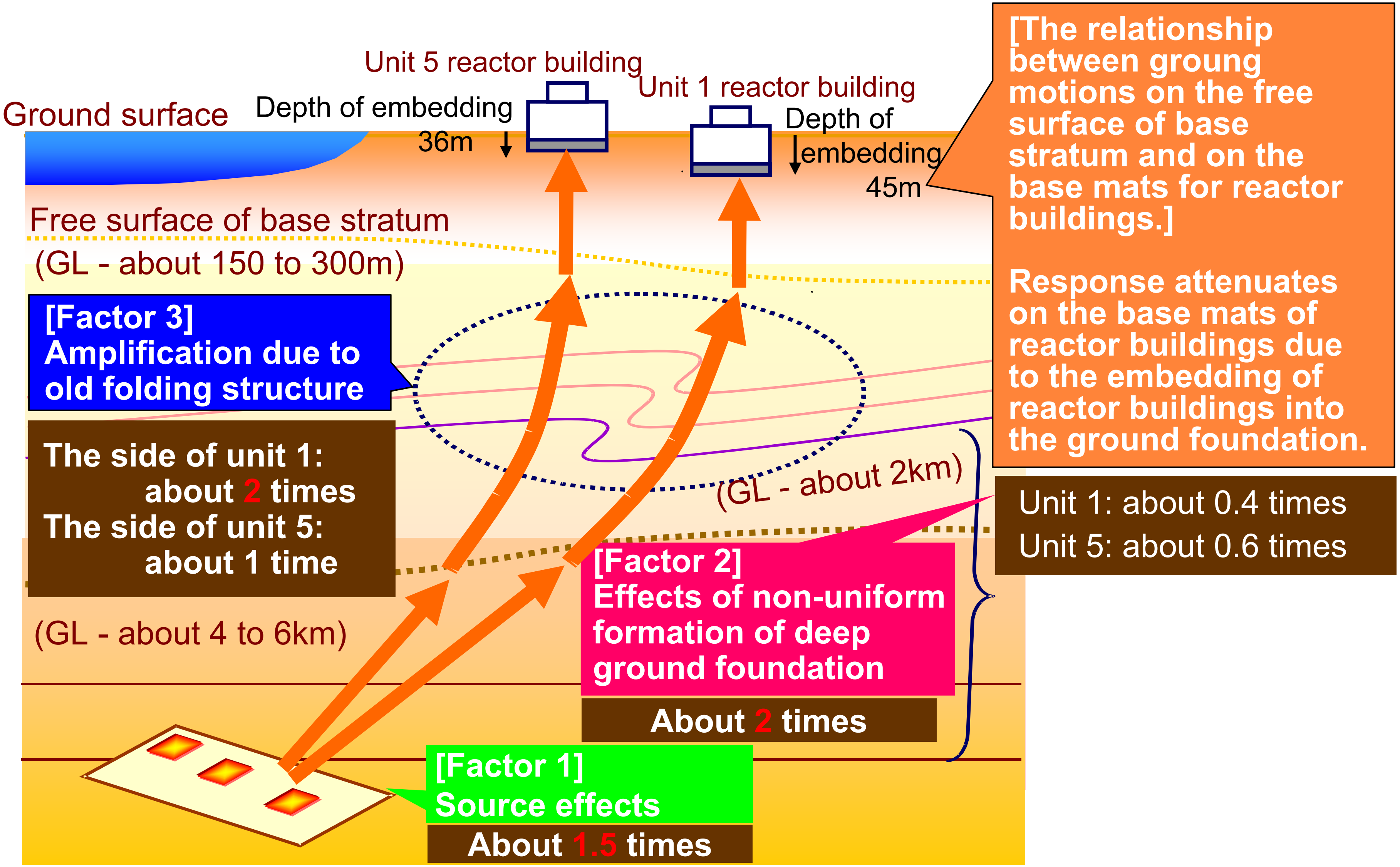
Deep ground factor	- approx. 2 times

III. The folding structure underneath the site deflected and converged seismic waves, amplifying ground motions at Units 1 - 4, which stand just above the anticline.

Subsurface folding structure factor	•Units 1 - 4: Approx. 2 times •Units 5 - 7: Approx. 1 time

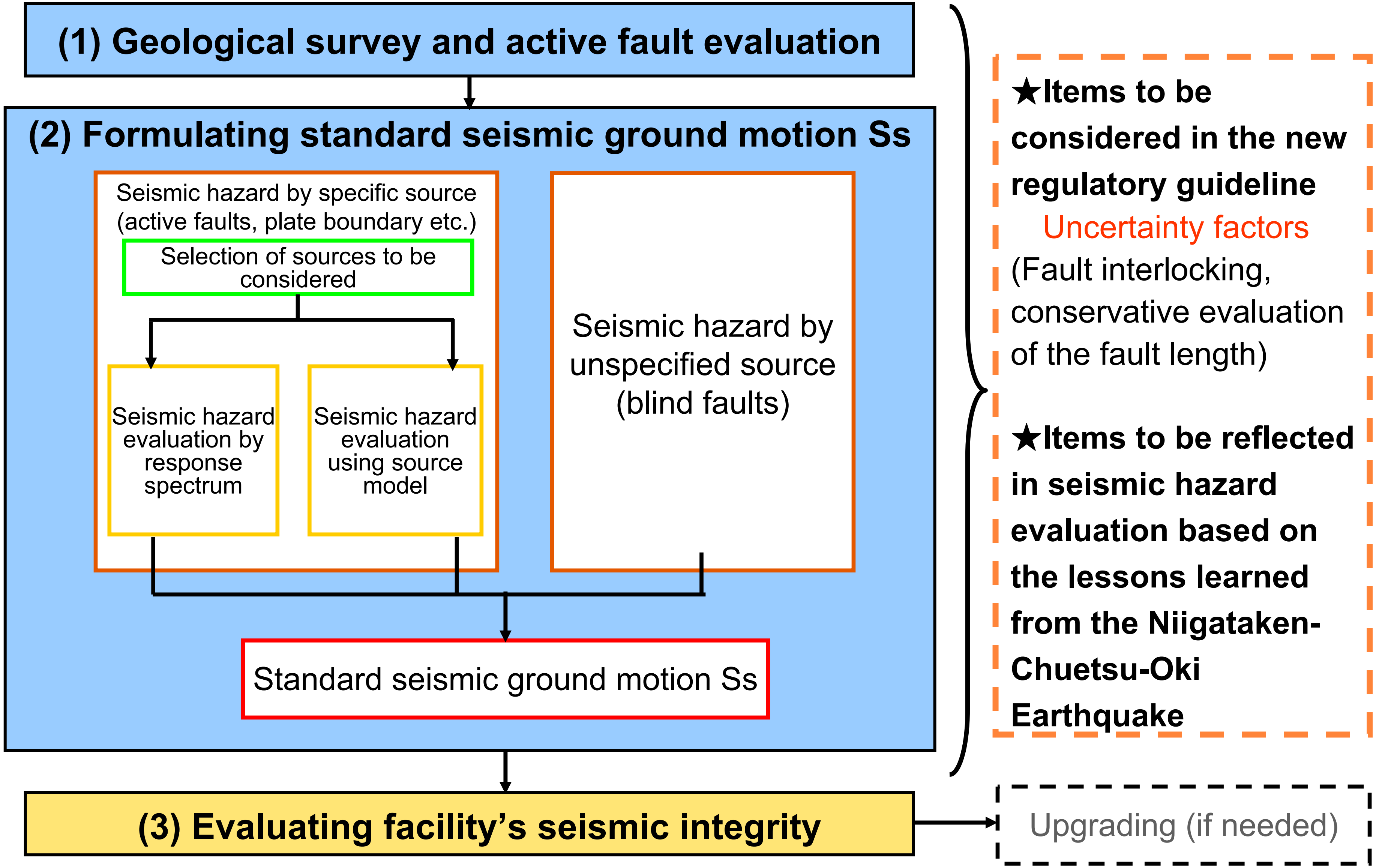
2.3 Reevaluation of Seismic Safety of KK NPS

- Analysis of Amplification of Ground Motions by Underground Structure



3.Formulation of New Standard Seismic Ground Motion Ss based on the lessons learned from the NCO earthquake

1. Policy on formulating Ss



2. Items to be reflected based on the lessons learned from the NCO EQ

Items to be reflected

(1) Results of the geological survey

- The active faults to be considered are selected based on the survey result.

(2) Difference of ground motions in offshore earthquakes between the Arahama side (Units 1-4) and the Ominato side (Units 5-7)

- Separate standard seismic ground motions are defined for the Arahama side and Ominato side for earthquakes caused by offshore faults.

(3) Influence of source characteristics

- Inland correction is not applied in the response spectrum method based on Noda et al(2002).
- The short-period level is increased by 1.5 times in the source fault model.

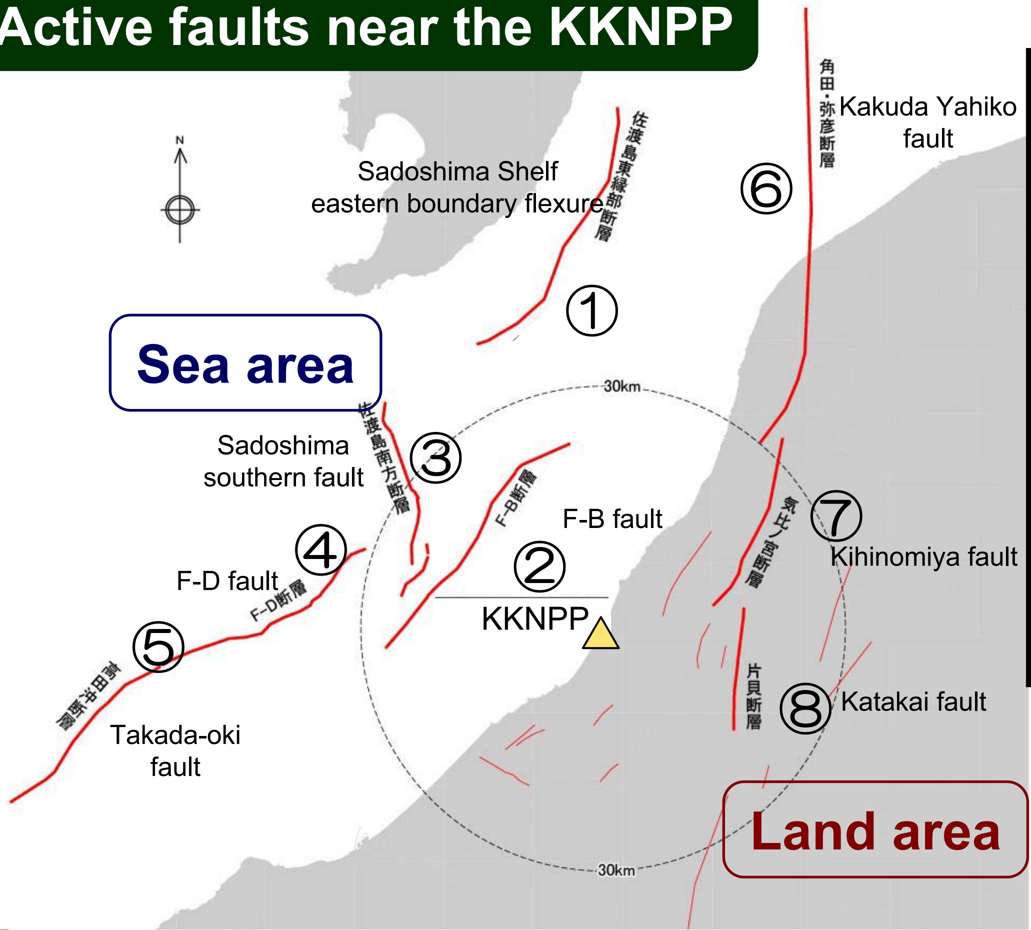
(4) Influence of propagation characteristics from the source to the site

- Separate site correction coefficients are selected for offshore and inland earthquakes in the response spectrum method based on Noda et al(2002).
- Appropriate element events are selected when using the Empirical Green's Function method.

3. Selection of active faults to be considered

- Compare active faults by the response spectrum method based on Noda et al. (2002), and identify those that to have a major impact on the KKNPP site.

Active faults near the KKNPP



Major active faults

	Fault name	Fault length
Sea area	(1) Sadoshima Shelf eastern boundary flexure	Approx. 37km
	(2) F-B fault	Approx. 36km*
	(3) Sadoshima Southern fault	Approx. 29km
	(4) F-D fault	Approx. 30km
	(5) Takada-oki fault	Approx. 25km
Land area	(6) Kakuda Yahiko fault	Approx. 54km
	(7) Kihinomiya fault	Approx. 22km
	(8) Katakai fault	Approx. 16km

*This fault is 27km long according to the TEPCO survey, and is assessed to have the length of 36km for the purpose of safety evaluation.

4. Selection of the earthquakes for examination

Selection of the active faults to be considered

↓

Grouping into offshore / inland faults

The ground motion characteristics at the NPP site is affected by the epicentral location (offshore / inland) .

↓

Comparison by the response spectrum method based on Noda et al.(2002)

A site correction coefficient is not considered, as the objective is to compare the level of the impact on the KKNPP site.

↓

Selection of earthquakes for examination

Active faults that have the largest impact on the site are selected as sources for examination earthquakes .

↓

ground motion evaluation

5. Evaluation of seismic hazard by the earthquake for examination

Earthquakes for examination

Offshore active fault

- Earthquake caused by F-B fault

Inland active fault

- Earthquake caused by Katakai fault
  (Nagaoka plain western boundary fault zone)

Ground motion evaluation

- Ground motion evaluation by response spectrum

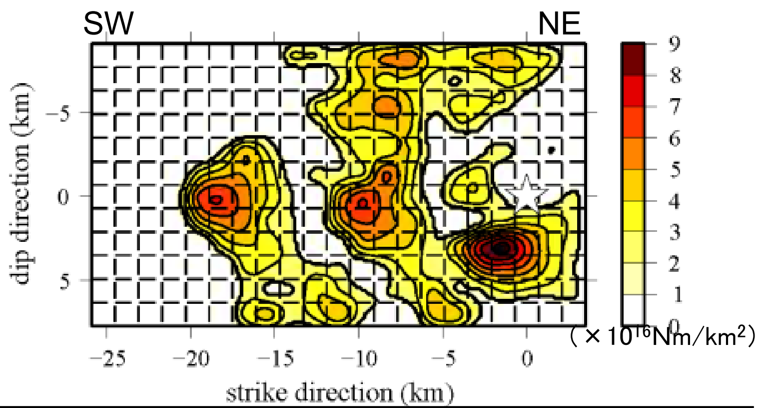
  Use separate correction coefficients for offshore and inland earthquakes in the response spectrum method based on Noda et al(2002).

- Ground motion evaluation by fault model

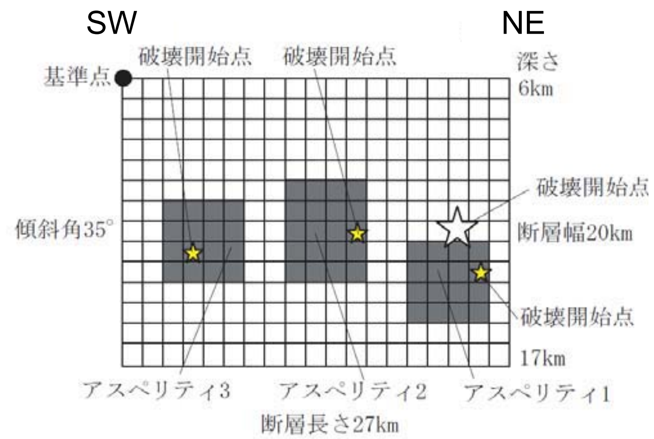
  Use minor earthquakes that have occurred in the assumed source area, to conduct evaluation in the Empirical Green's Function method, which can reflect wave propagation characteristics etc…

5-1. F-B fault (Formulating source model)

1. Asperity model was formulated based on the recipe for strong motion prediction by Headquarters for Earthquake Research Promotion (2008) (Fault length: 27km x width: 20km)

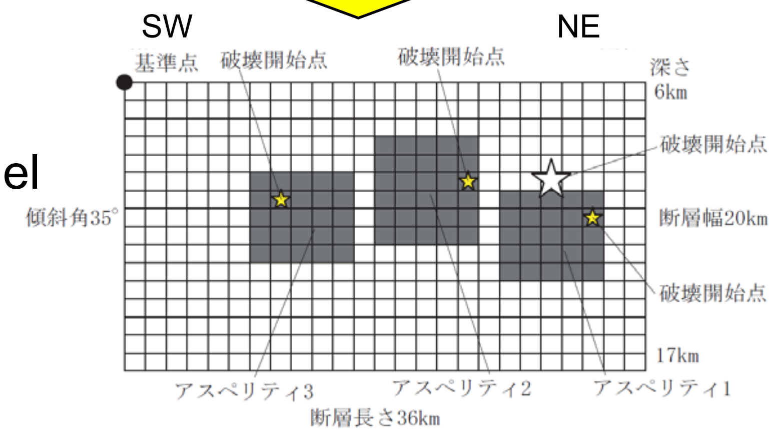


Seismic inversion of NCO EQ (M6.8)



1. Asperity model for NCO EQ (M6.8)

2. Source fault model was formulated by extending fault length of the asperity model formulated at 1., into 36km (M7.0) which is based on the geological survey result

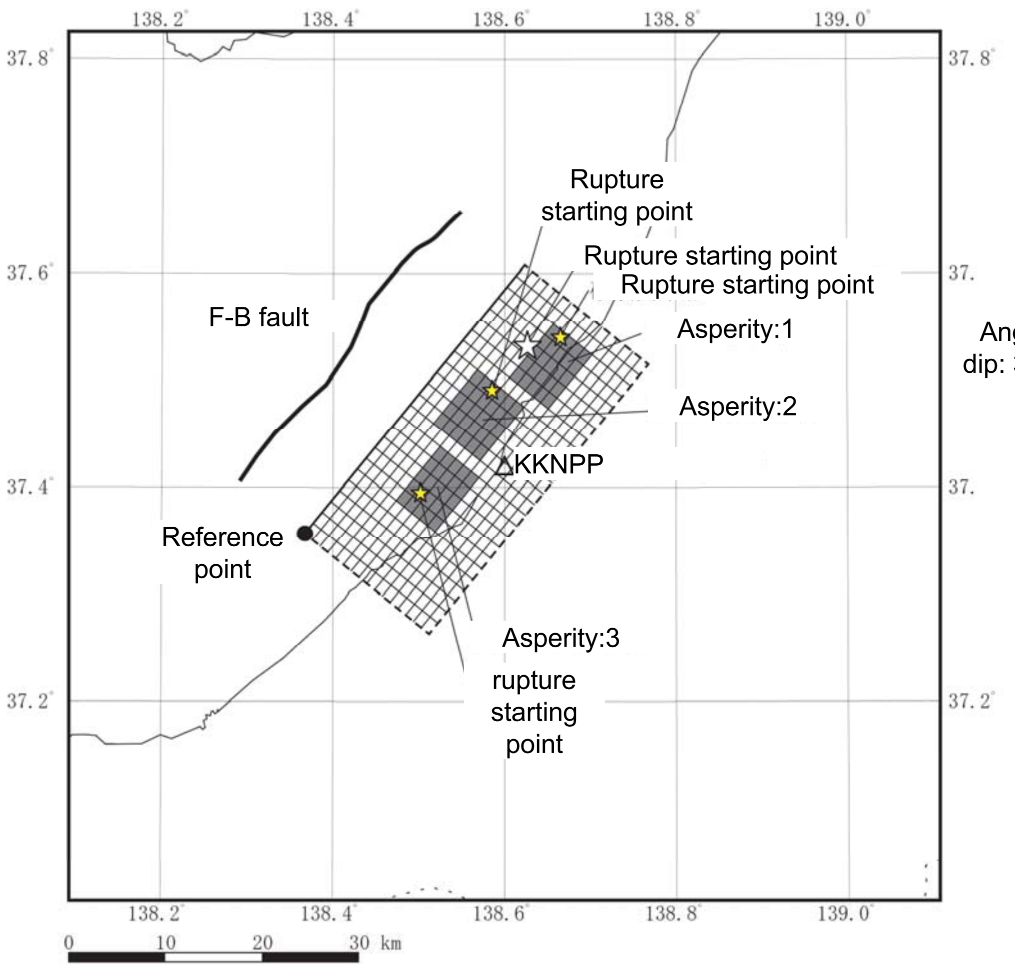


2. Source fault model of F-B fault (M7.0)

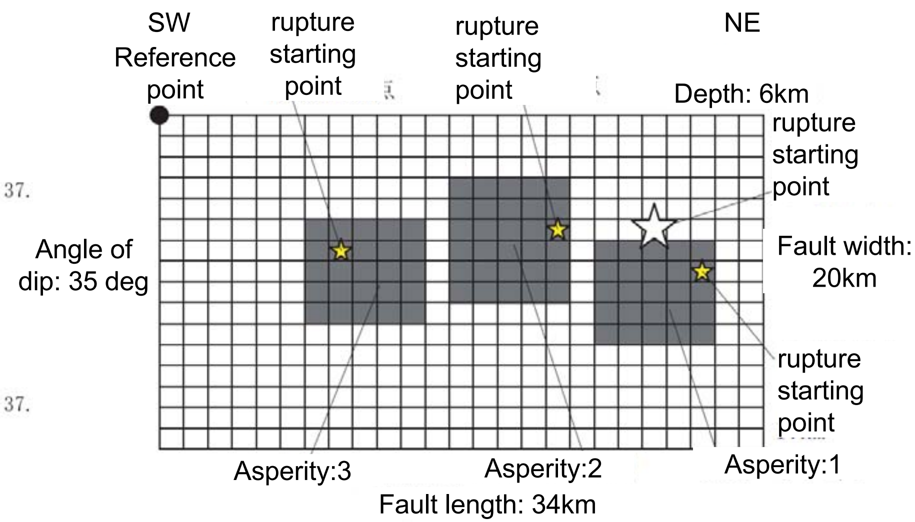
5-1. F-B fault (Formulating source model)

Source fault model (fault length: 36km)

Plan



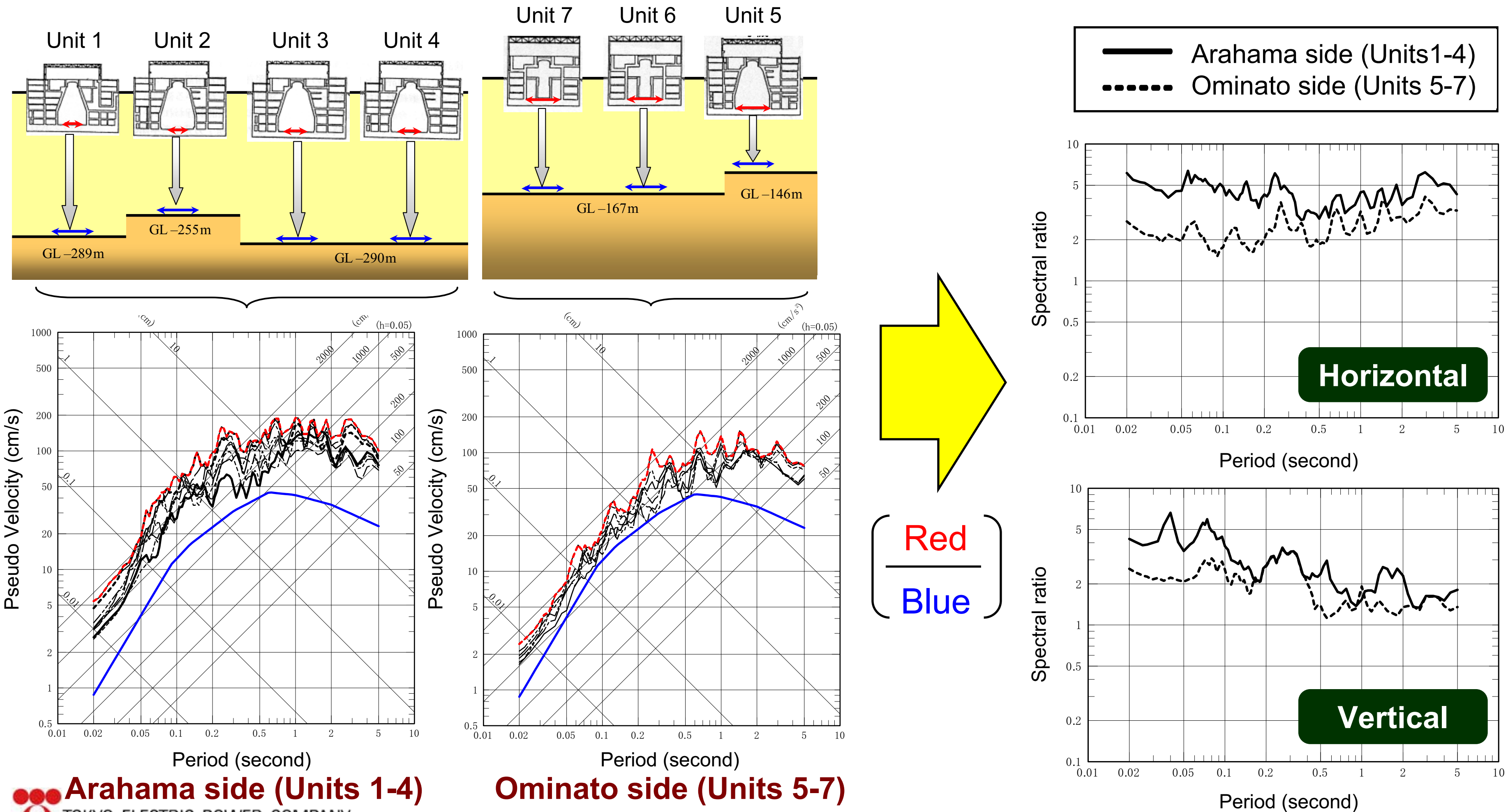
Cross section diagram



(Main specification)
Fault length: 36km
Fault width: 20km
Angle of dip: 35 deg
(east dipping)
Number of asperity: 3

5-1. F-B fault (Site correction used with response spectrum method)

- **Evaluation method:** Noda et al. (2002)
- **Site correction:**
  defined so as to envelop the ratio of estimated response spectrum at the free surface of base stratum, to the spectrum calculated by Noda et al. (2002)



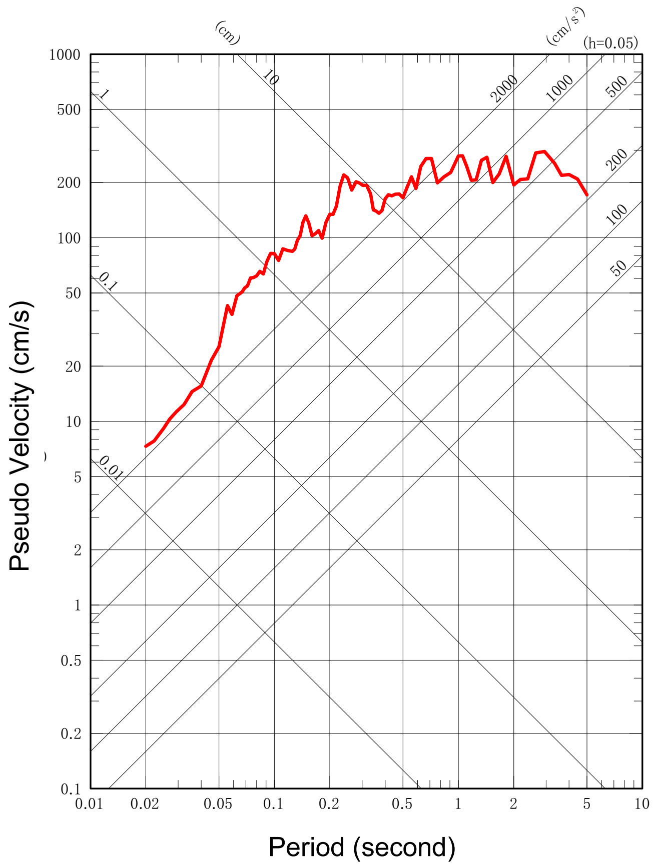
Arahama side (Units 1-4)

Ominato side (Units 5-7)

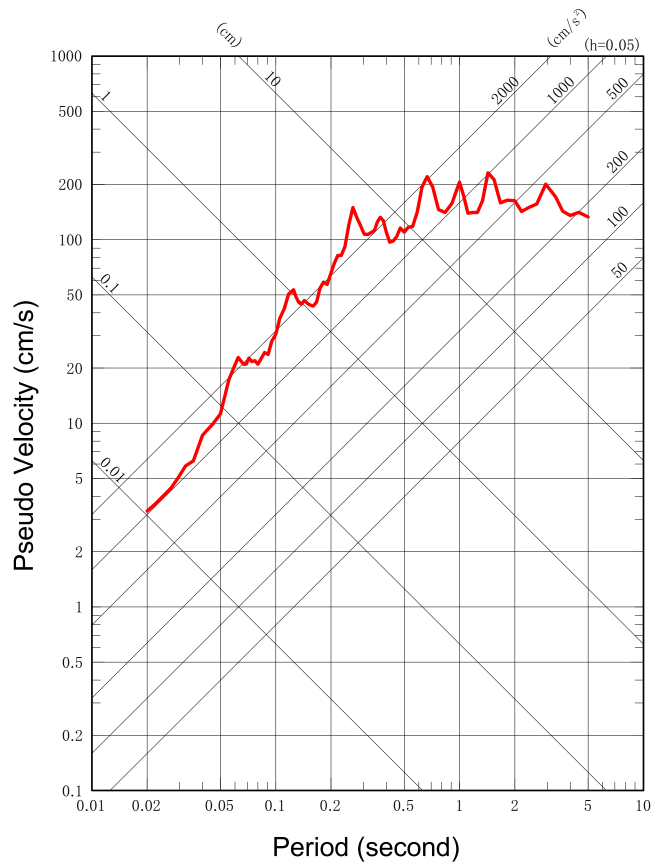
5-1. F-B fault (Ground motion evaluation by response spectrum method)

Horizontal

Noda et al. (2002)



Arahama side (Units 1-4)



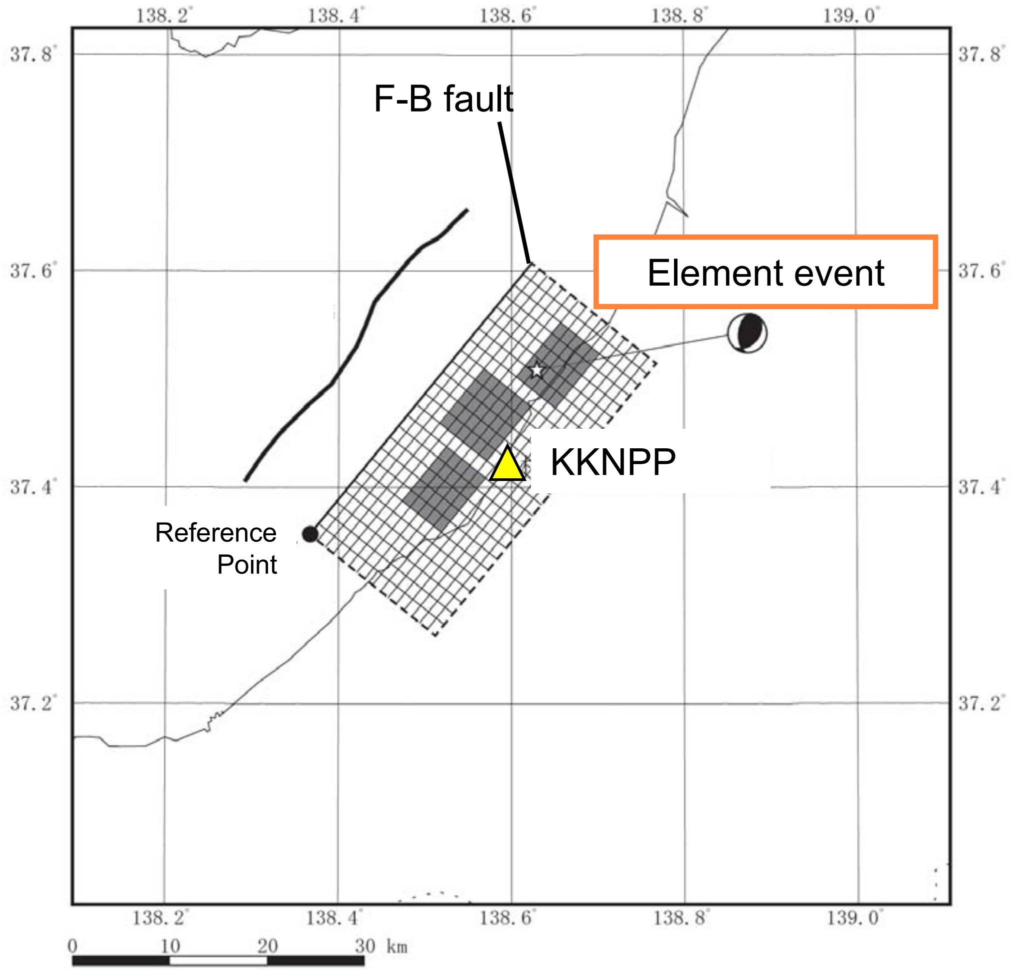
Ominato side (Units 5-7)

5-1. F-B fault (Specification of the element event for the EGF)

- An aftershock of the NCO EQ was selected to be used as an element event for the empirical Green's function (EGF)
  [element event] 2007/7/16, 21:08(M4.4)

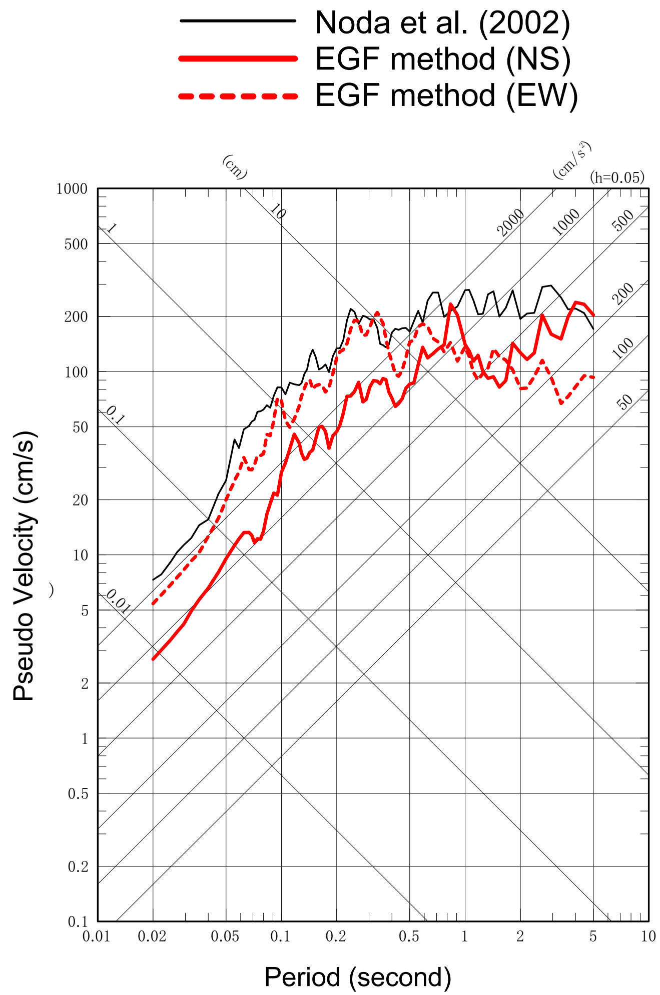
Source parameters

Date & Time		2007.7.16,21:08
M_{JMA}		4.4
Location	Longitude (deg)	37.509
	Latitude (deg)	138.630
	Depth (km)	13.6
	Strike (deg)	187;39
	Dip (deg)	54;41
	Rake (deg)	70;115
Seismic moment	(Nm)	5.21×10^{16}
Critical freq.	(Hz)	1.65
Fault length	(km)	1.40
Fault width	(km)	1.40
Avg. slip	(cm)	8.0
Effective stress	(MPa)	4.6
Rigidity	(N/m^2)	3.31×10^{10}
S-wave velocity	(km/s)	3.5
Unit weight	(g/cm^3)	2.7

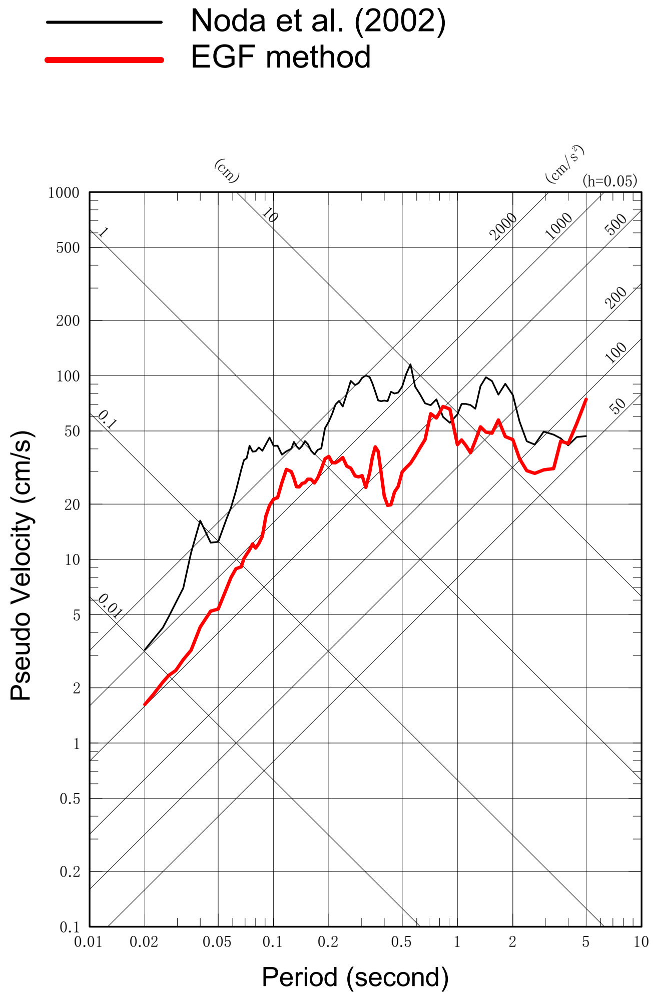


5-1. F-B fault (Ground motion evaluation by source fault model method)

Arahama side (Units 1-4)



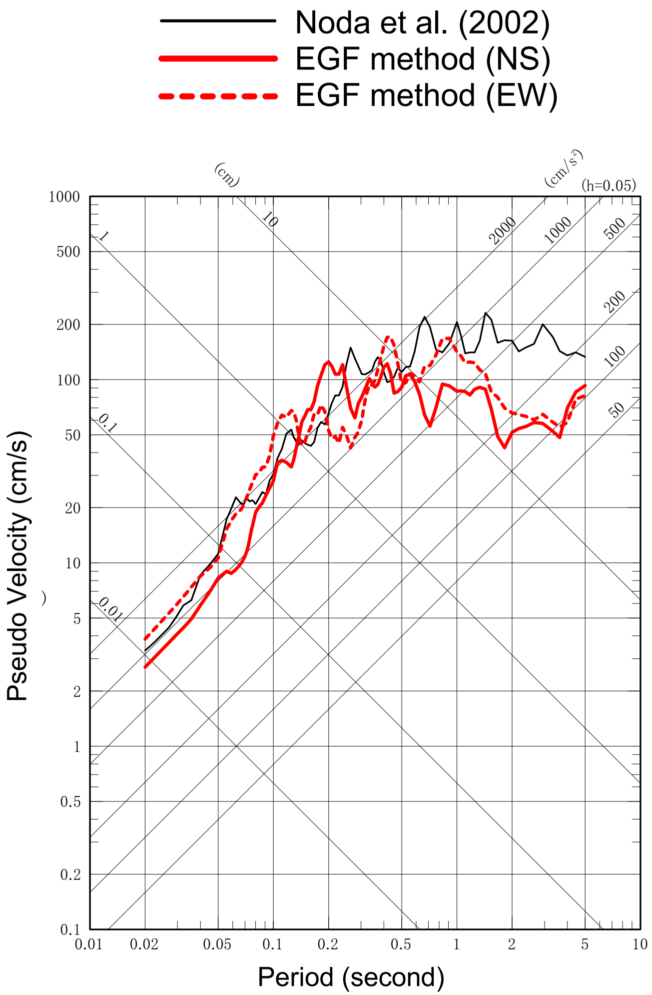
Horizontal



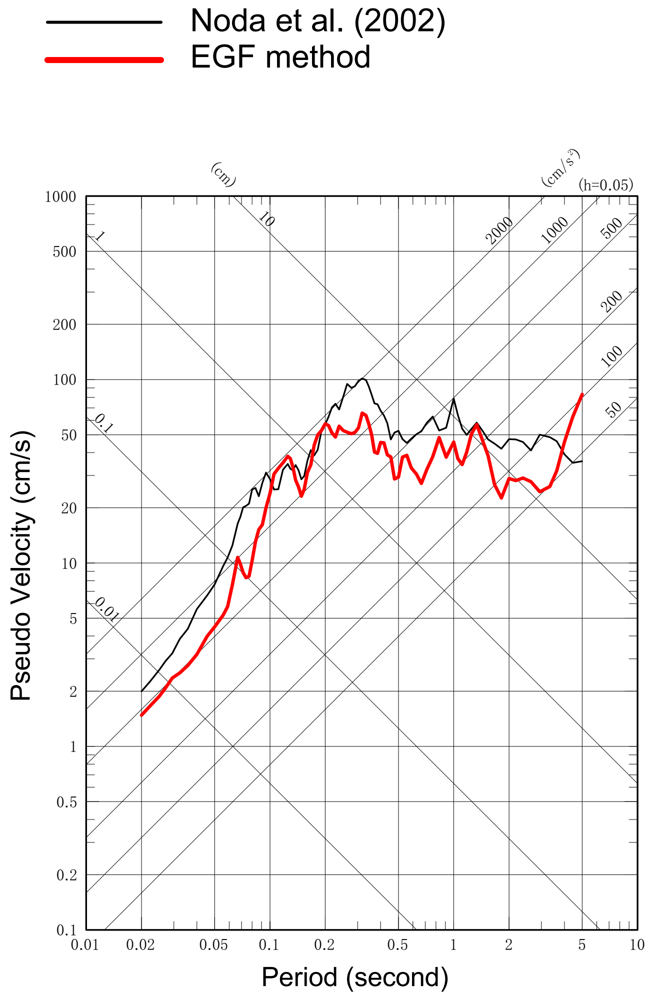
Vertical

5-1. F-B fault (Ground motion evaluation by source fault model method)

Ominato side (Units 5-7)



Horizontal

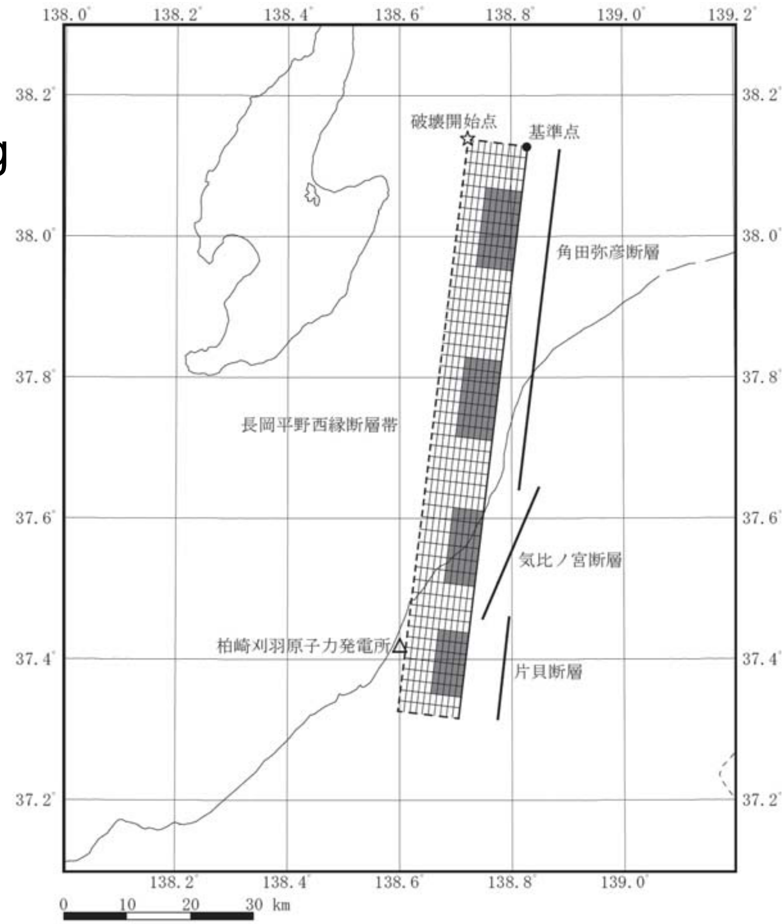


Vertical

5-2. Katakai fault (Standard source model and consideration of uncertainties)

Parameters to be considered with uncertainty

- **Fault length**
  Activity of Katakai fault is standard case, and consider fault interlocking with its surrounding faults (Kihinomiya fault, Kakuda-Yahiko fault)
- **Fault dipping angle**
  50 deg. Is the standard case according to the evaluation of HERP, and 35 deg. is also taken into account as an uncertainty.
- **The number & location of asperity**
  Upper-center position of the fault plain is the standard case, and lower-center is also considered.
- **The amount of stress drop & avg. slip**
  1.5 times larger than recipe is considered.



- **Rupture starting point**
  Place which rupture proceed toward the site is the standard case, and boundary of asperity is also considered as an uncertainty

6. Outline of the standard seismic ground motion Ss

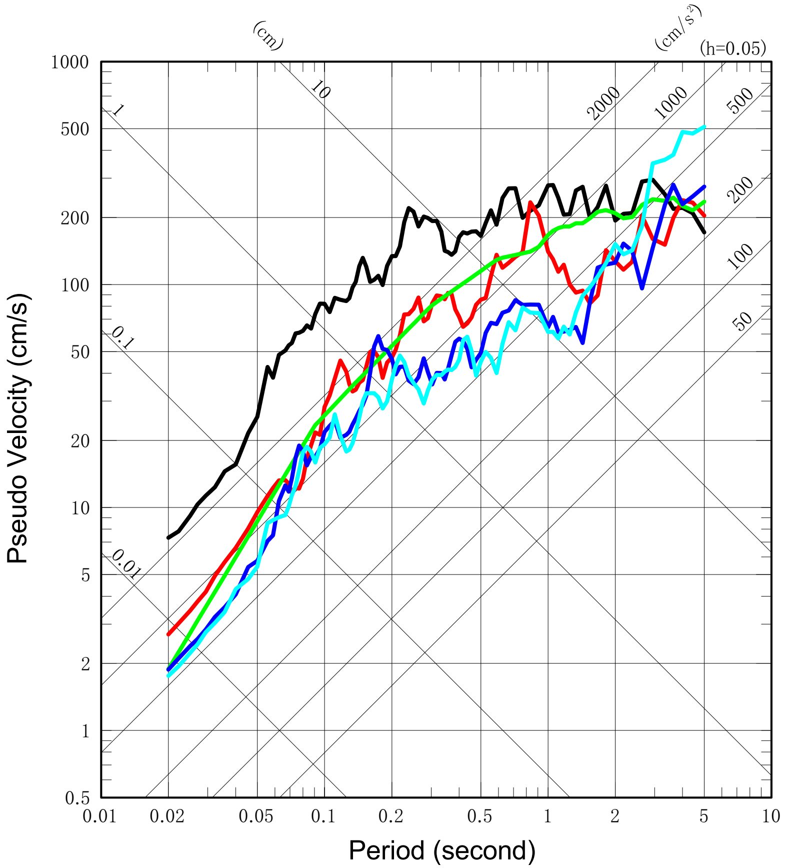
■Each result of the ground motion evaluation on the earthquake for examination is defined as standard seismic ground motion Ss.

Standard seismic ground motion	Examination earthquakes	ground motion evaluation method
Ss－1	Earthquake caused by F-B fault (M7.0)	JEA spectrum [Noda et al.(2002)]
Ss－2		Fault model [Empirical Green's Function method]
Ss－3	Earthquake caused by the Nagaoka plain western boundary fault zone (M8.1)	JEA spectrum [x1.5 stress drop + 50deg. dipping] [avg. stress drop + 35deg. dipping]
Ss－4		Fault model [x1.5 stress drop + 50deg. dipping]
Ss－5		Fault model [avg. stress drop + 35deg. dipping]

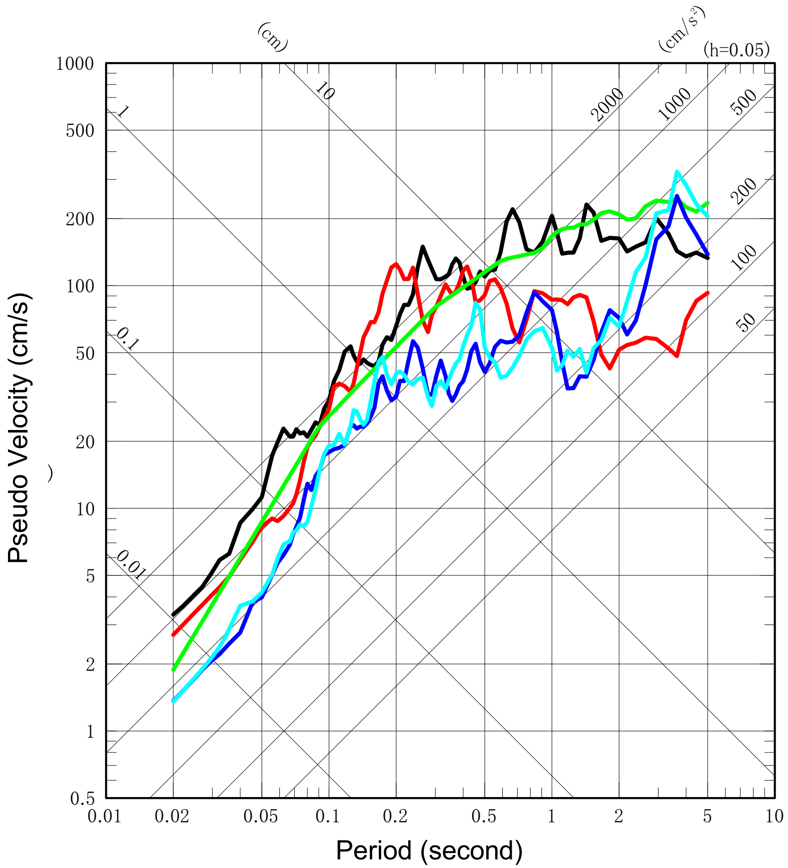
6. Outline of the Ss (pseudo velocity response spectra)

NS

Standard seismic ground motion Ss-1H
Standard seismic ground motion Ss-2NS
Standard seismic ground motion Ss-3H
Standard seismic ground motion Ss-4NS
Standard seismic ground motion Ss-5NS



Arahama side (Units 1-4)

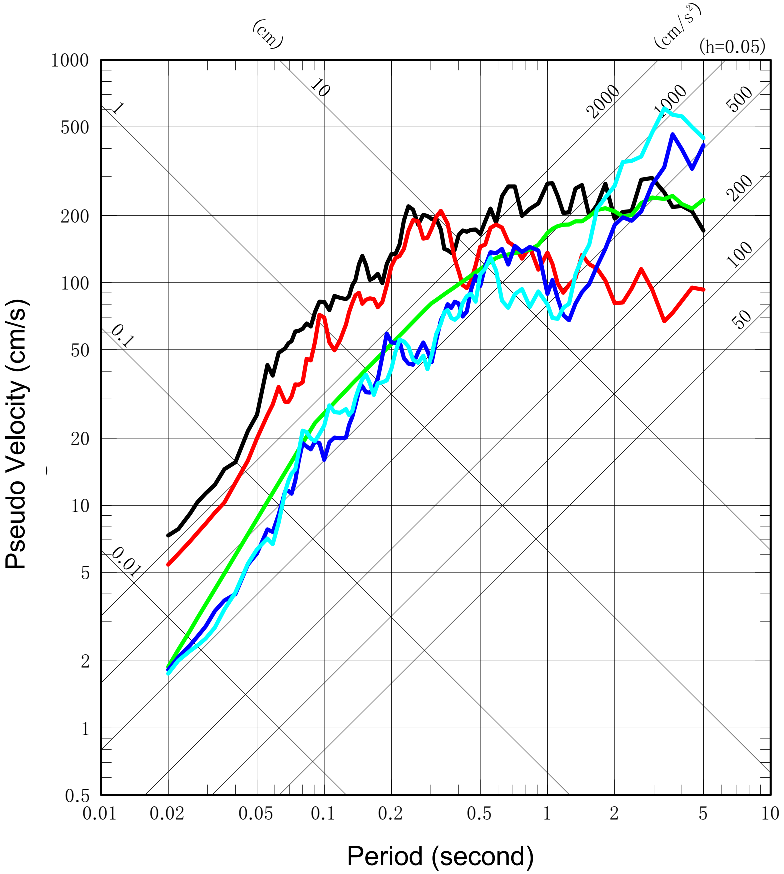


Ominato side (Units 5-7)

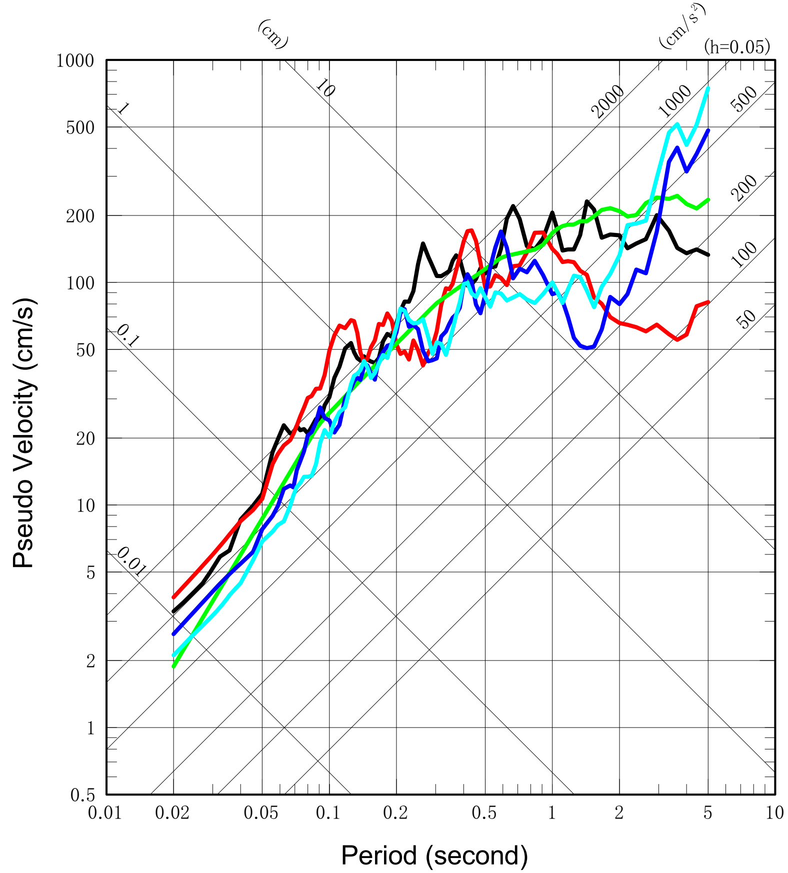
6. Outline of the Ss (pseudo velocity response spectra)

EW

- Standard seismic ground motion Ss-1H
- Standard seismic ground motion Ss-2EW
- Standard seismic ground motion Ss-3H
- Standard seismic ground motion Ss-4EW
- Standard seismic ground motion Ss-5EW



Arahama side (Units 1-4)

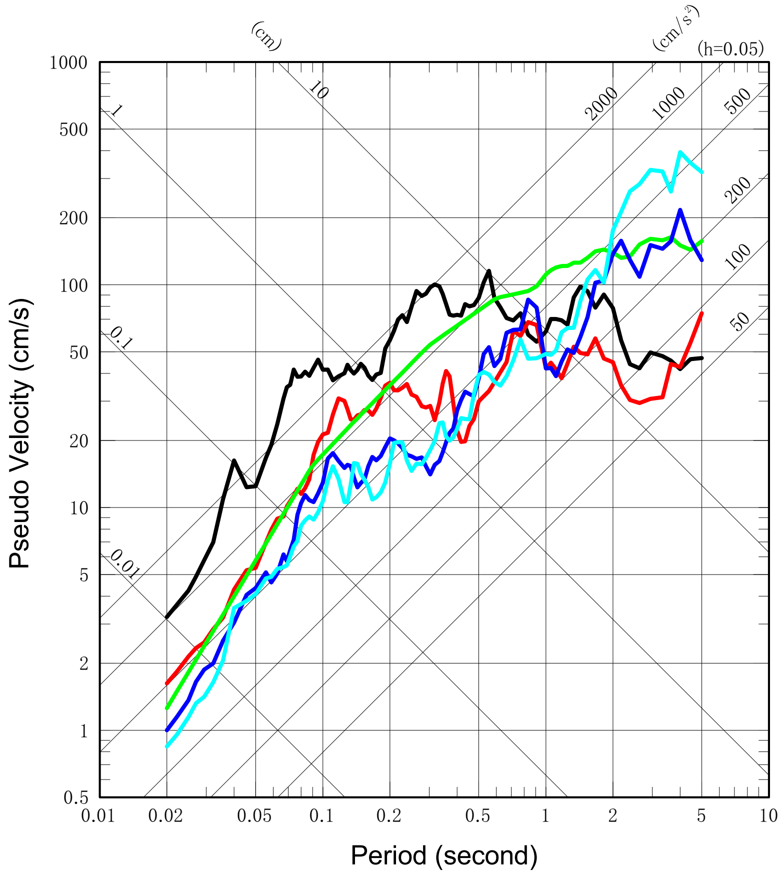


Ominato side (Units 5-7)

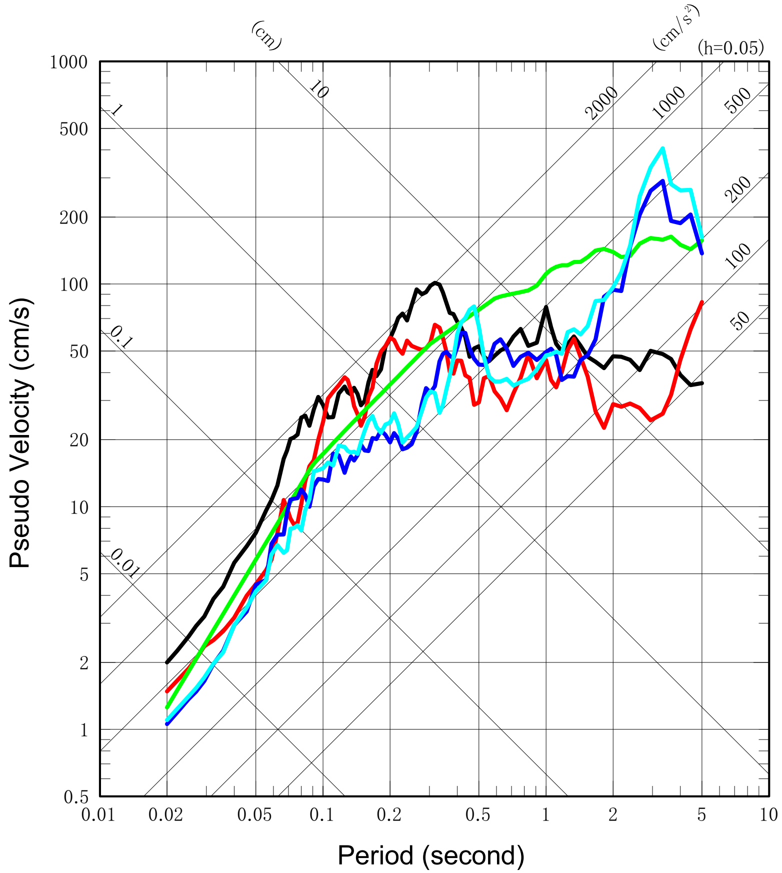
6. Outline of the Ss (pseudo velocity response spectra)

UD

- Standard seismic ground motion Ss-1V
- Standard seismic ground motion Ss-2UD
- Standard seismic ground motion Ss-3V
- Standard seismic ground motion Ss-4UD
- Standard seismic ground motion Ss-5UD



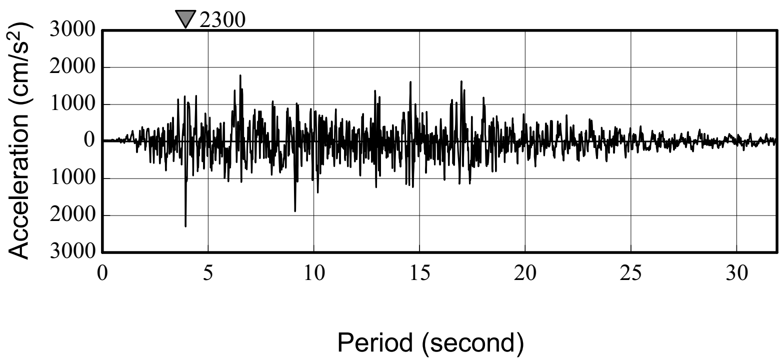
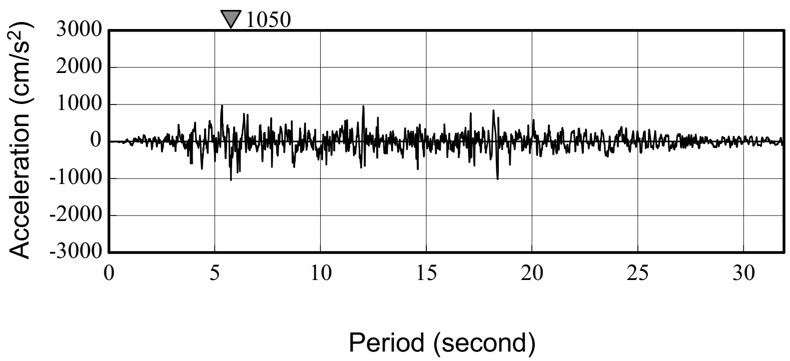
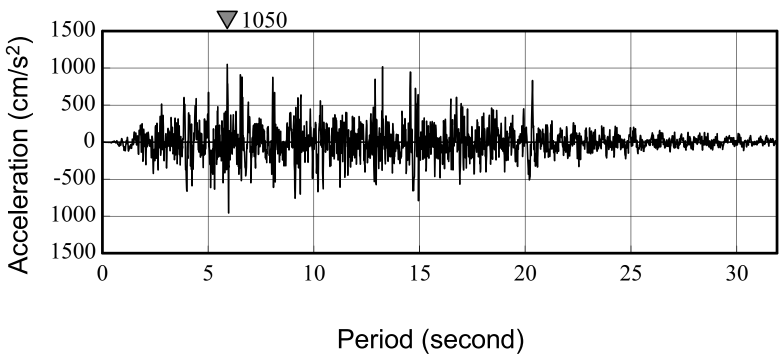
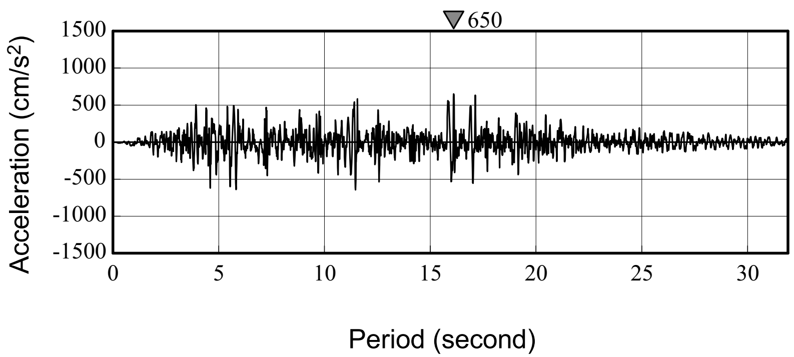
Arahama side (Units 1-4)



Ominato side (Units 5-7)

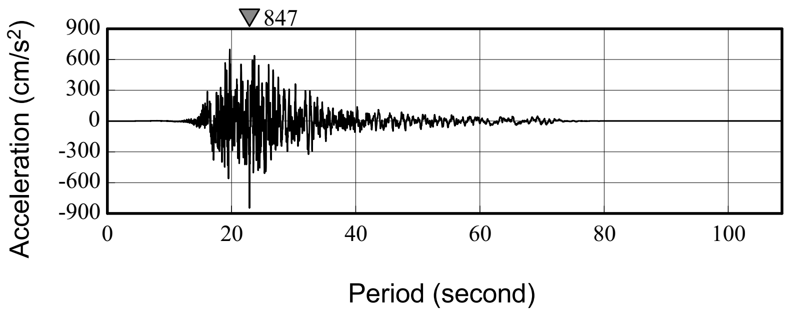
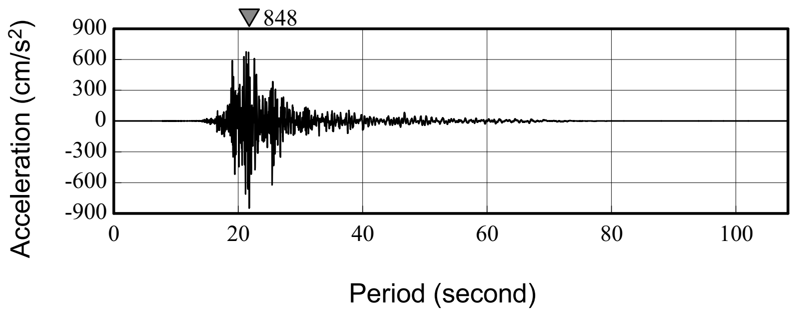
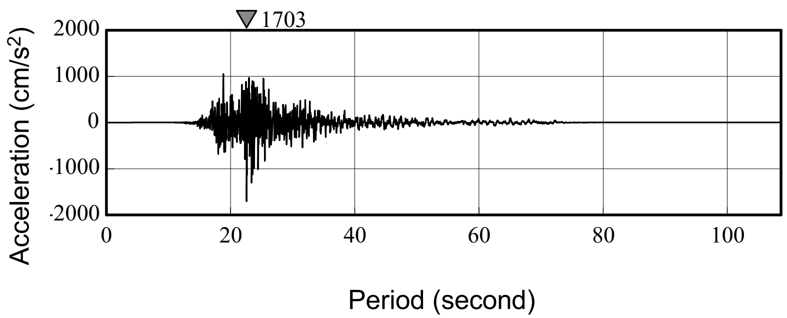
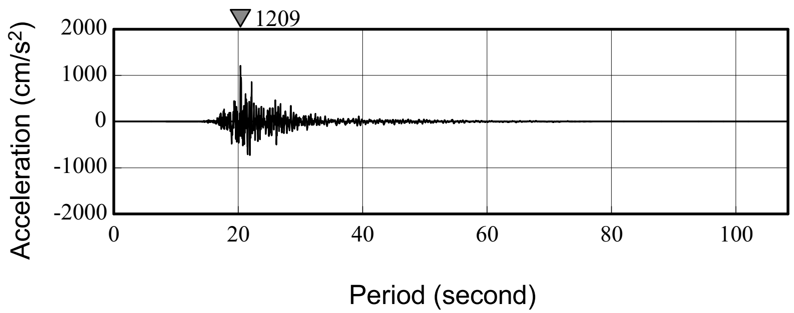
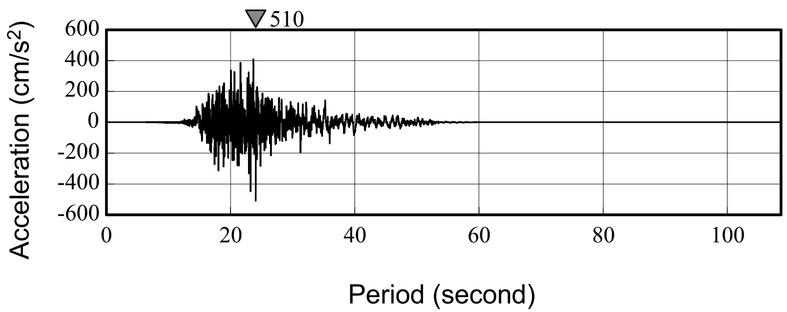
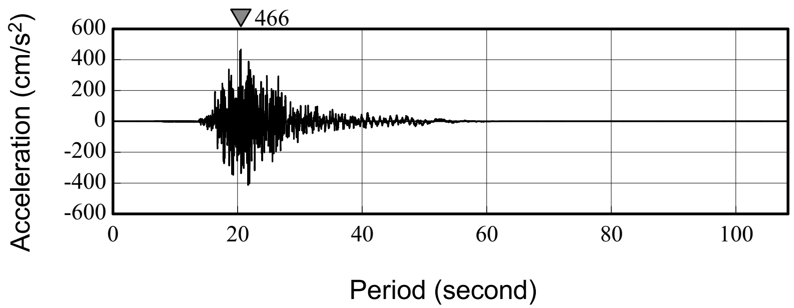
6. Outline of the Ss (Acceleration time history)

Acceleration time history of Ss-1

	Arahama side (Units 1-4)	Ominato side (Units 5-7)
Horizontal		
Vertical		

6. Outline of the Ss (Acceleration time history)

Acceleration time history of Ss-2

	Arahama side (Units 1-4)	Ominato side (Units 5-7)
NS		
EW		
UD		

6. Outline of the Ss (Maximum peak acceleration value)

(Unit: Gal)

Standard seismic ground motion	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Ss－1 (F-B fault / JEA spectrum)	Horizontal: 2300 Vertical: 1050				Horizontal: 1050 Vertical: 650		
Ss－2 (F-B fault / Empirical Green's function)	NS: 847 EW: 1703 UD: 510				Ns: 848 EW: 1209 UD: 466		
Ss－3 (Nagaoka plain western boundary fault zone / JEA spectrum)	Horizontal: 600 Vertical: 400						
Ss－4 (Nagaoka plain western boundary fault zone / Empirical Green's function)	NS：589 EW ：574 UD：314				NS：428 EW：826 UD：332		
Ss－5 (Nagaoka plain western boundary fault zone / Empirical Green's function)	NS：553 EW ：554 UD：266				NS：426 EW：664 UD：346		

Thank you for your attention.