14th U.S.-Japan Workshop on the Improvement of Building Structural Design and Construction Practices

“Simulated Earthquake Ground Motion for Structural Design"

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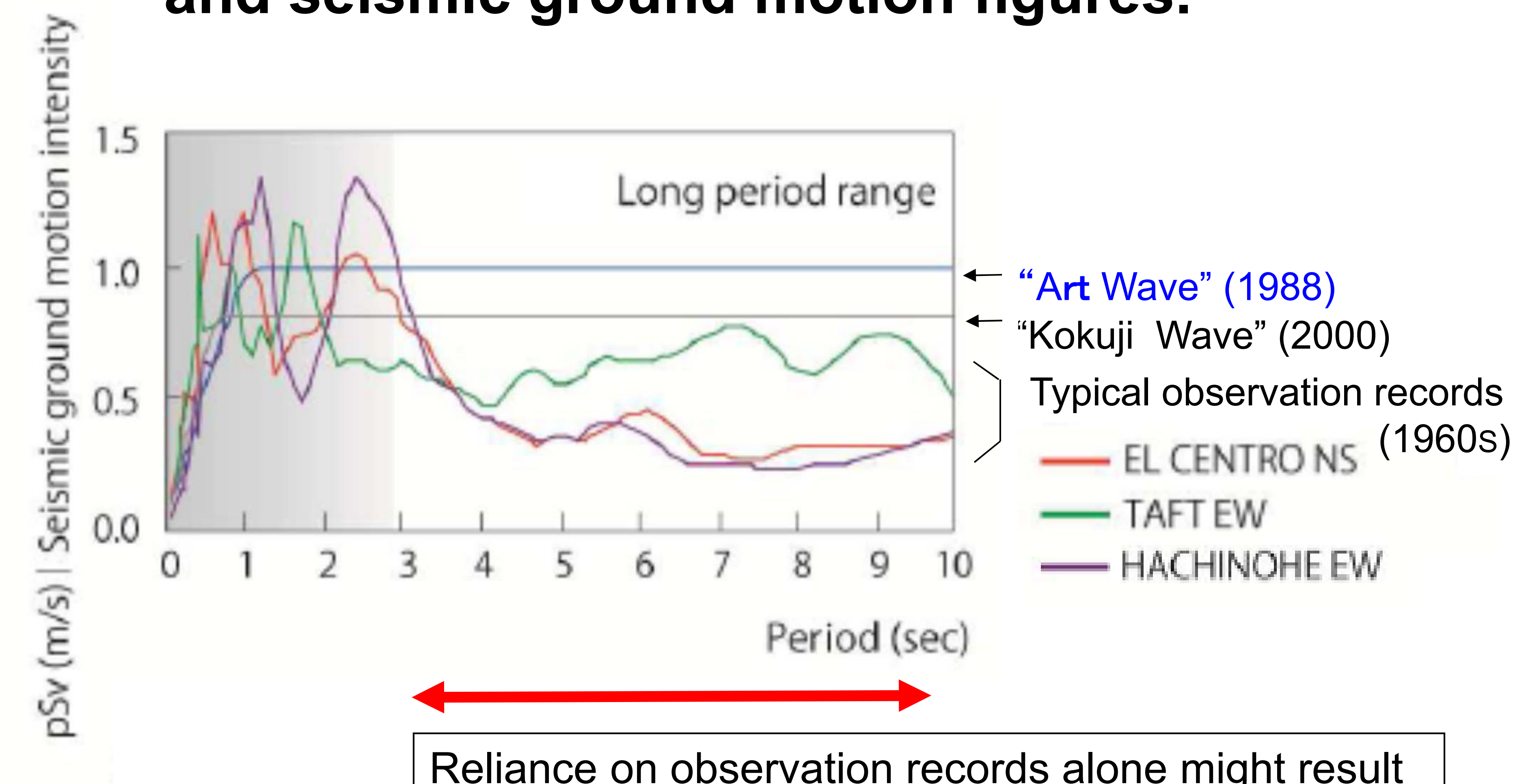
   For performance-based design・・・

1. Introduction

Background and development about simulated earthquake ground motion.

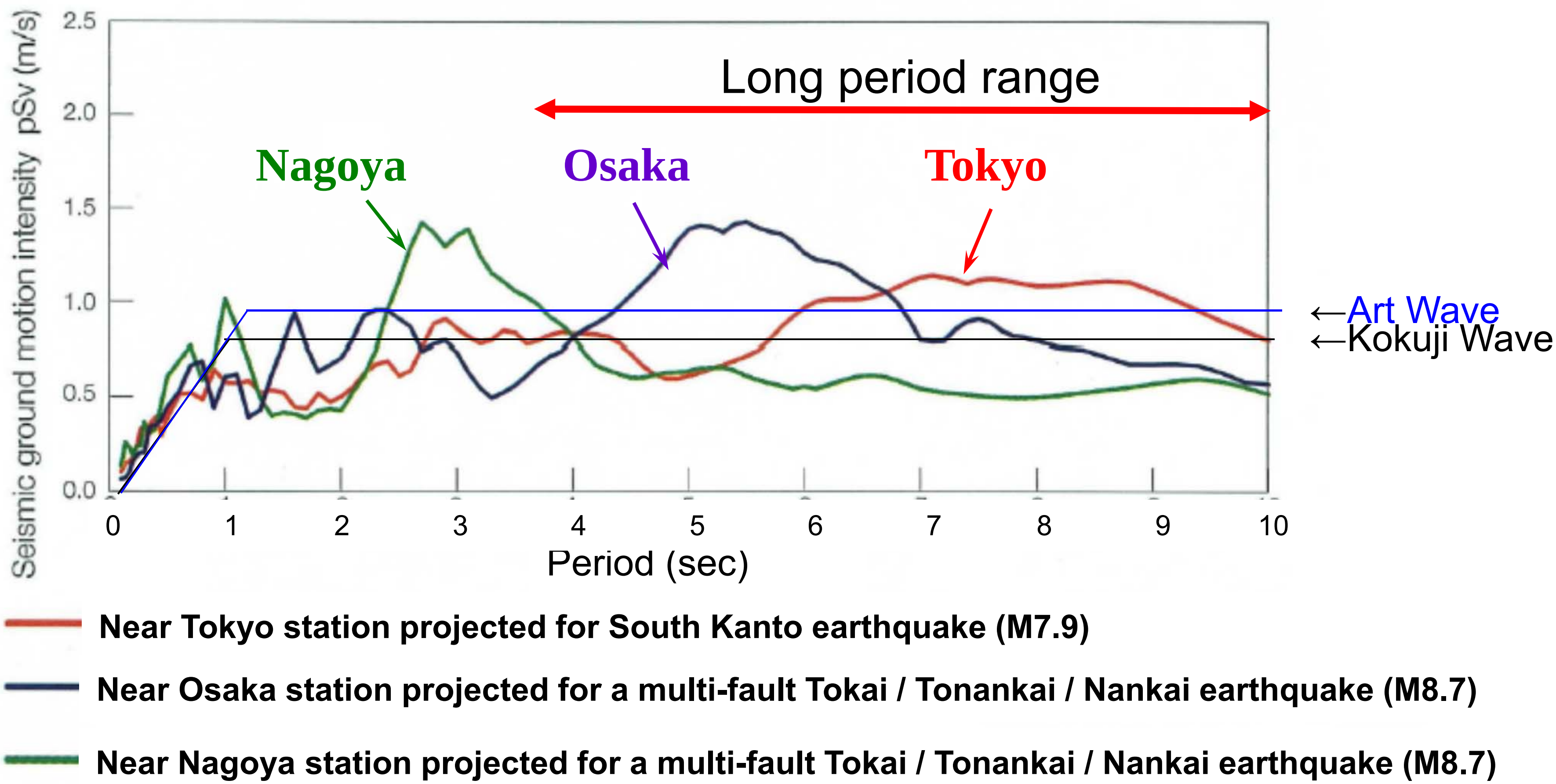
Comparison of observation records and seismic ground motion figures.



Reliance on observation records alone might result underestimation for period of 3 or more seconds.

⇒ "Art Wave" ,"Kokuji Wave" and "**NS Wave**"

Examples of ground motions produced by "NS Wave"



Considering earthquake source and transmission characteristics as well as local ground characteristics,

⇒ Expected to produce strong shaking at construction sites

2. Method of Simulating Earthquake Ground Motions

Basic concepts

Basic concepts of performance-based design

(i) examine the performance of each building.

(ii) clearly explain the results to the public.

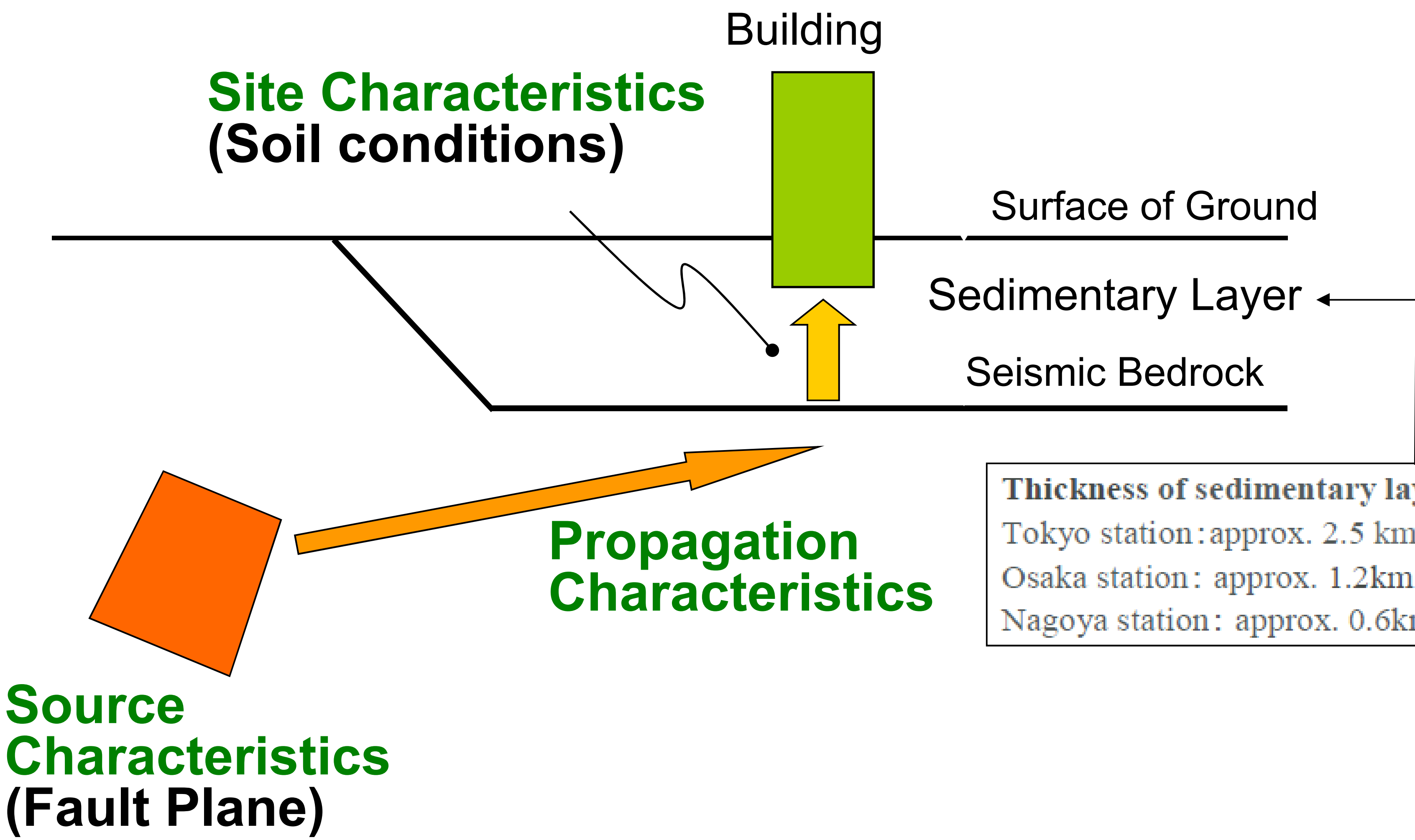
⇩

Time histories of the acceleration of seismic waves, which reflect the earthquake environment, soil conditions at the construction site, etc.

⇩

Practical method of simulating earthquake ground motions that can be easily applied to a variety of projects.

Propagation of Seismic Waves



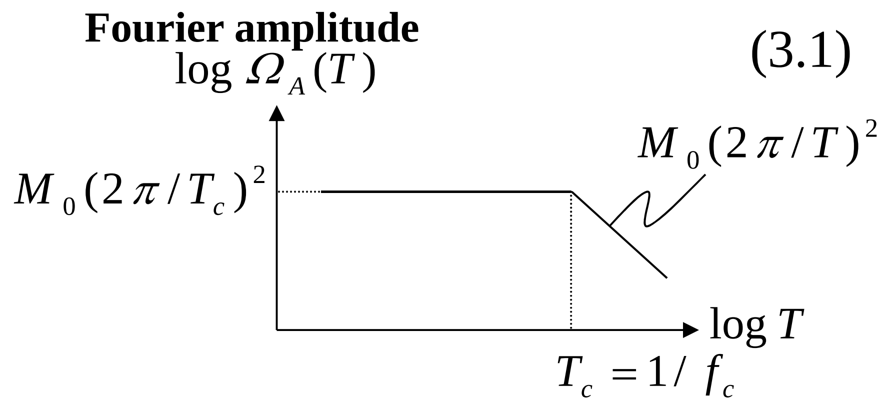
Thickness of sedimentary layer
Tokyo station：approx. 2.5 km
Osaka station： approx. 1.2km
Nagoya station： approx. 0.6km

Framework of the Proposed Method

	Fourier Amplitude	Fourier Phase
Source Characteristics	ω^2 Model	
Propagation Characteristics	Geometrical Damping	Quantitative Evaluation
Site Characteristics	Multiple Reflection Theory	

Fourier Amplitude

◇**Source Characteristics**: ω^2 **M**odel



(3.1)

◇**Propagation Characteristics** :Geometrical Damping

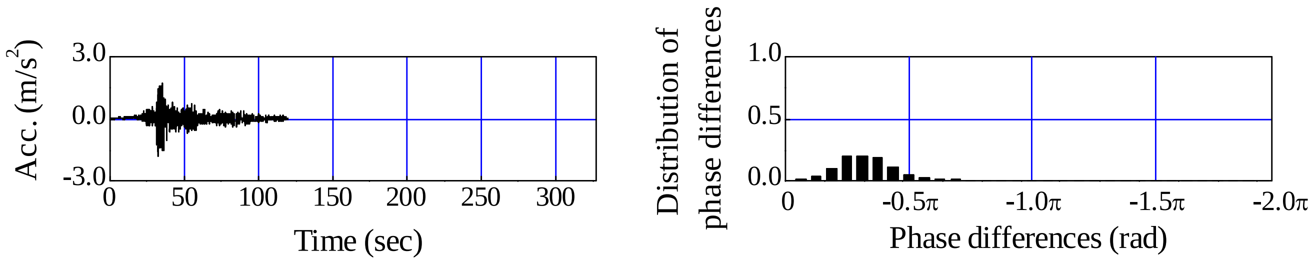
$$\left|\ddot{U}(r_0, T)\right| \propto \frac{1}{r_0} \Omega_A(T) \qquad (3.2)$$

Hypocentral distance

◇**Site Characteristics**: Multiple Reflection Theory

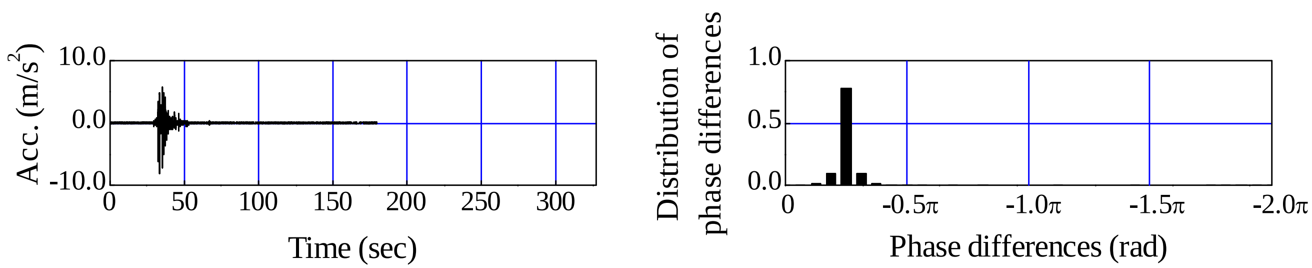
(Ex. SHAKE by U. C. Berkeley)

Quantitative Evaluation of the Fourier Phase
By Standard Deviation of the Phase Differences σ/π



$$\sigma / \pi = 0.18$$

(a) EW component accelerogram and distribution of the phase differences recorded at Hachinohe Harbour during the 1968 Tokachi-oki Earthquake



$$\sigma / \pi = 0.05$$

(b) NS component accelerogram and distribution of the phase differences recorded at JMA Kobe during the 1995 South Hyogo Prefecture Earthquake

Figure 2.1 Examples of accelerograms and distributions of the phase differences

Relational Expression of σ/π against the Hypocentral Distance for Crustal Earthquake

$$\sigma / \pi = 0.06 + 0.0003 r_0 \quad (2.3)$$

r_0 : hypocentral distance (km)

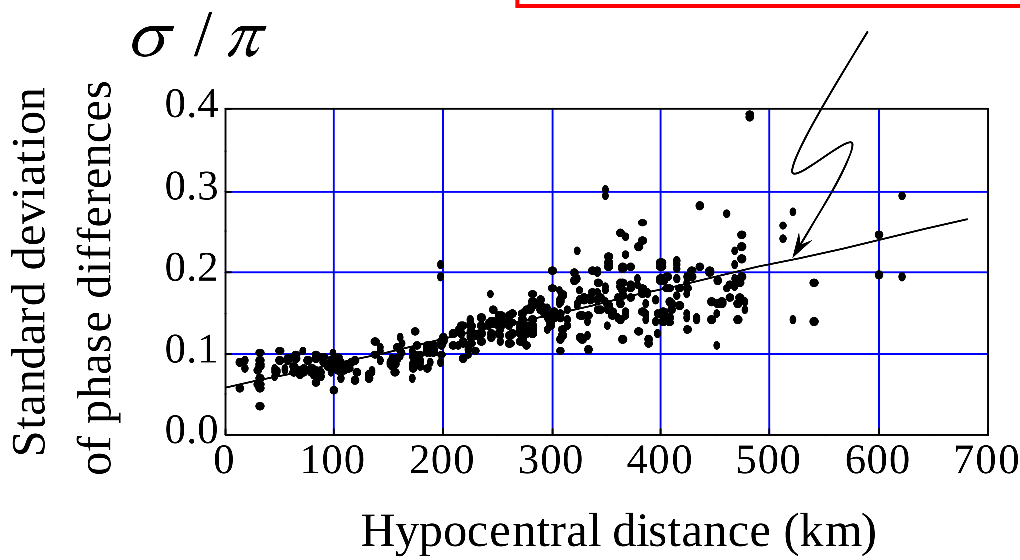
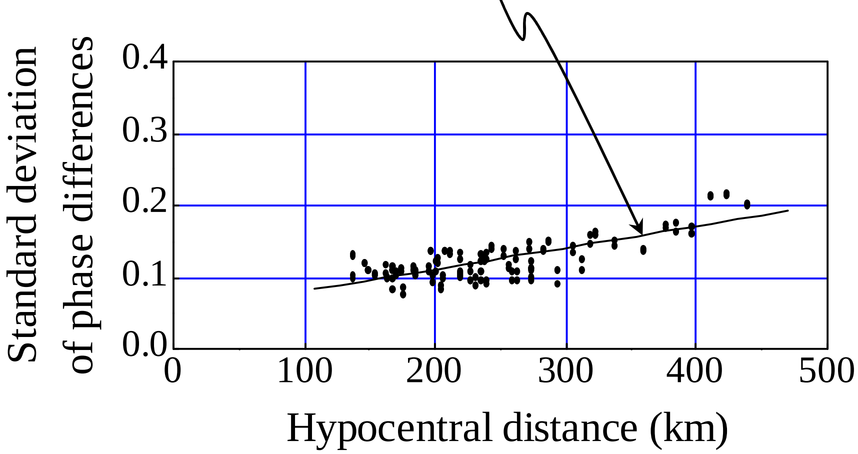


Figure 2.2 Standard deviation of the phase differences against the hypocentral distance for the records at the KiK-net observation sites with respect to the 2000 Western Tottori Prefecture Earthquake

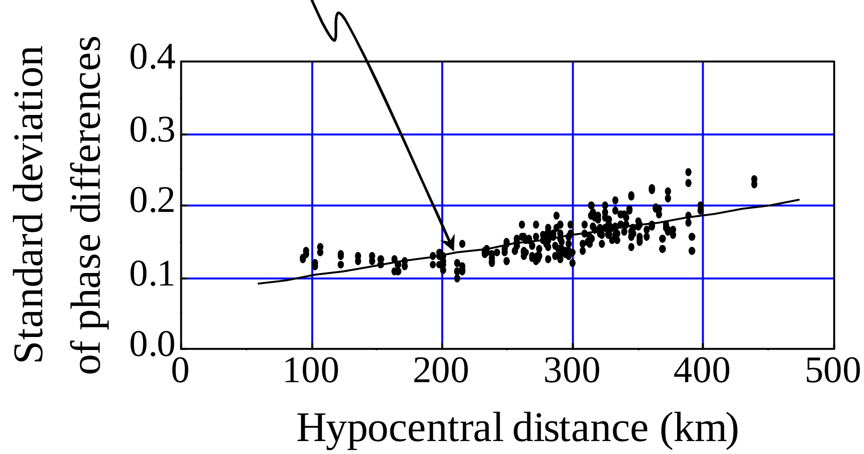
Relational Expression of σ/π against the Hypocentral Distance for Inter-plate Earthquake

$$\sigma/\pi = 0.05 + 0.0003r_0 \quad (2.4)$$



(b) Plots of σ/π of the NS and EW components in eastern Hokkaido (In the direction of rupture propagation)

$$\sigma/\pi = 0.08 + 0.0003r_0 \quad (2.5)$$



(c) Plots of σ/π of the NS and EW components in western Hokkaido (In the orthogonal direction of rupture propagation)

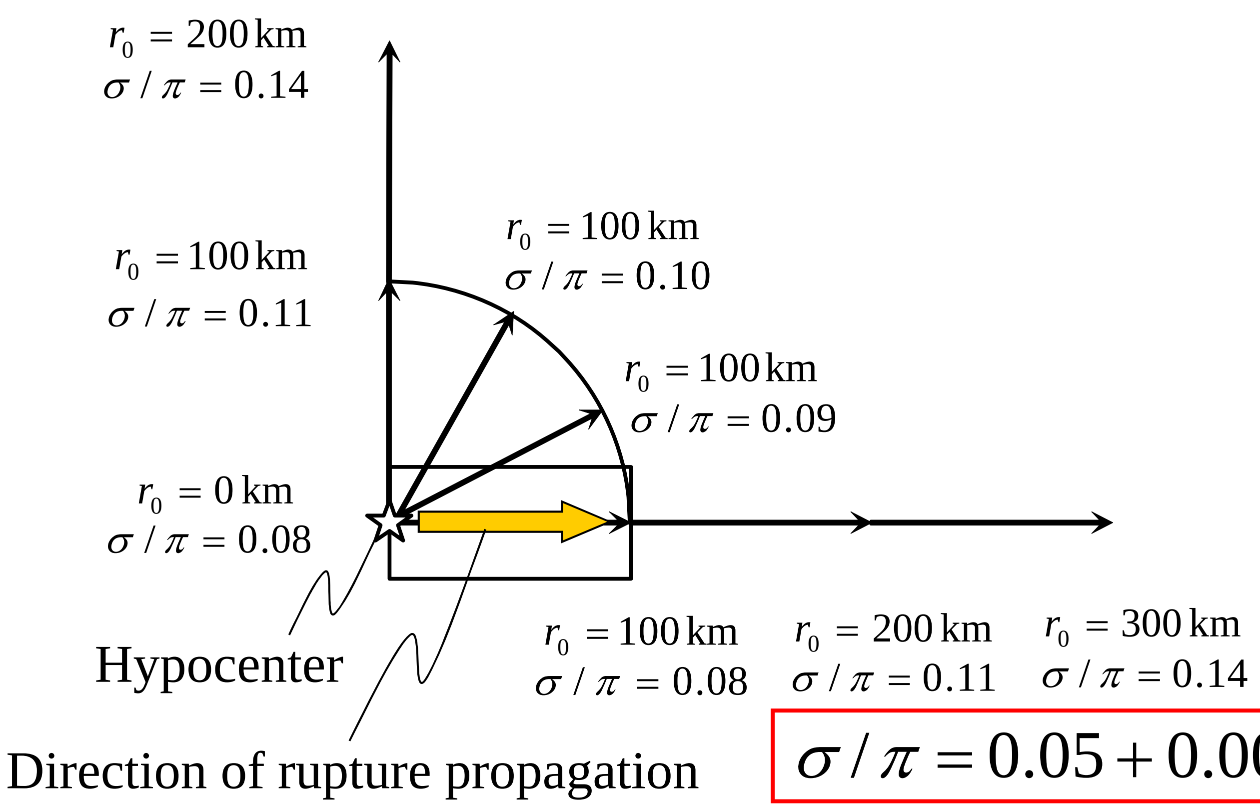
Figure 2.3 Standard deviation of the phase differences at the K-NET observation sites in Hokkaido with respect to the 2003 Tokachi-oki Earthquake

Criteria For Selecting Fourier Phase

Inter-plate Earthquake

Fault length = 100 km

$$\sigma/\pi = 0.08 + 0.0003 r_0 \quad (2.5)$$



$$\sigma/\pi = 0.05 + 0.0003 r_0 \quad (2.4)$$

Figure 3.1 Standard deviation of the phase differences at the observation sites

Flow Chart of the Proposed Method

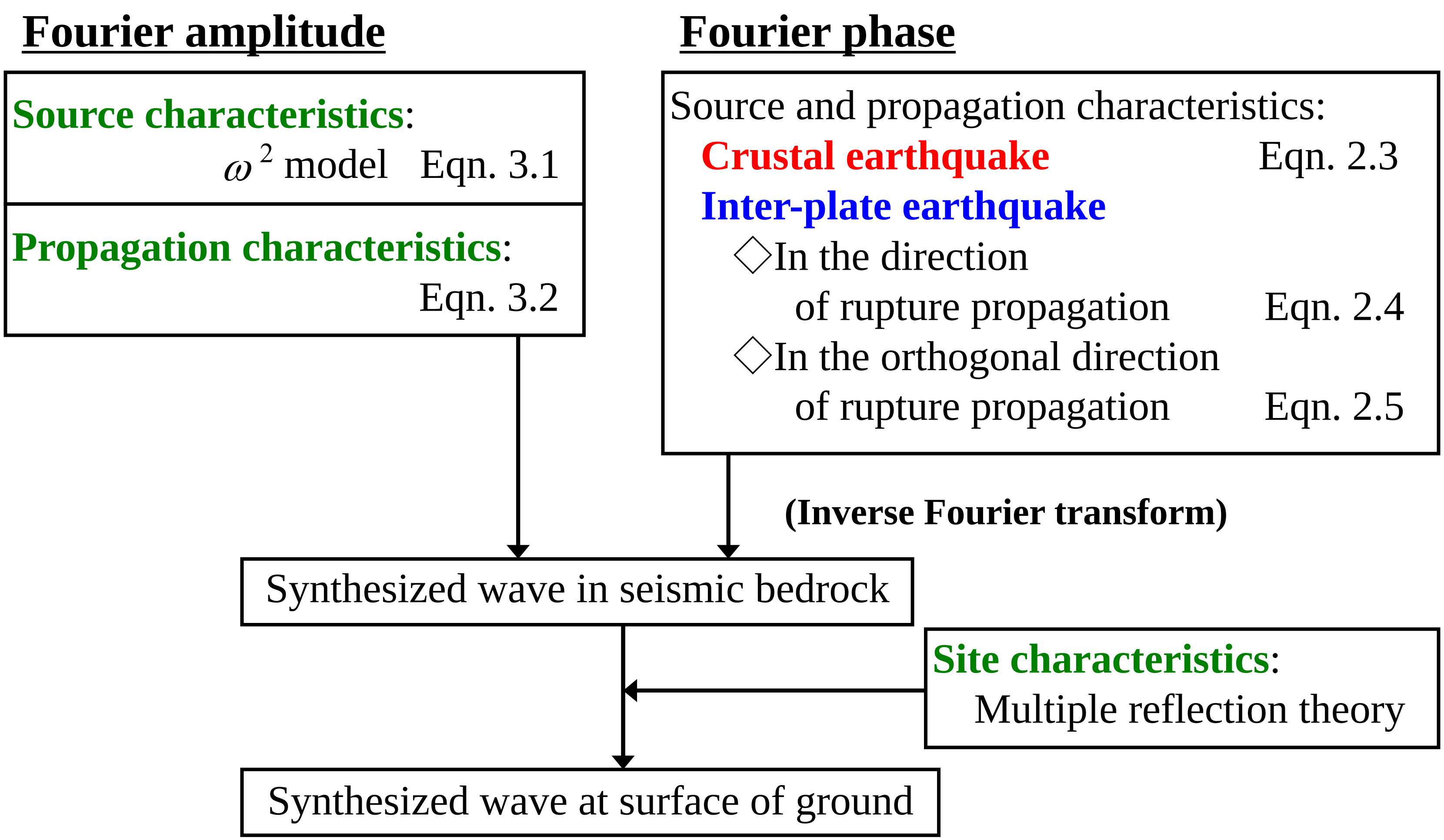
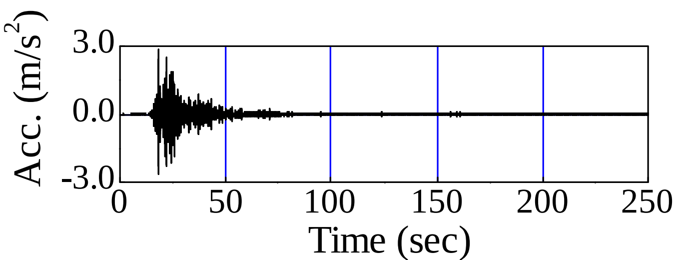


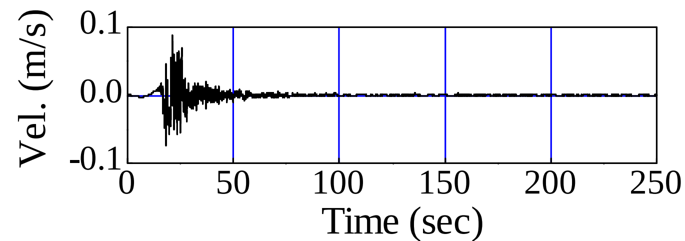
Figure 3.3 Flow chart of the proposed method

Verification of the Proposed Method

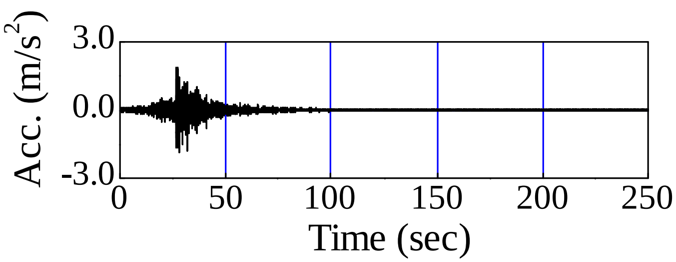
Crustal earthquake（σ/π=0.07）



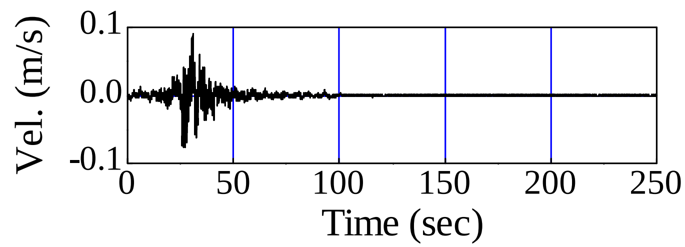
(a) Acceleration of observed wave



(c) Velocity of observed wave



(b) Acceleration of synthesized wave

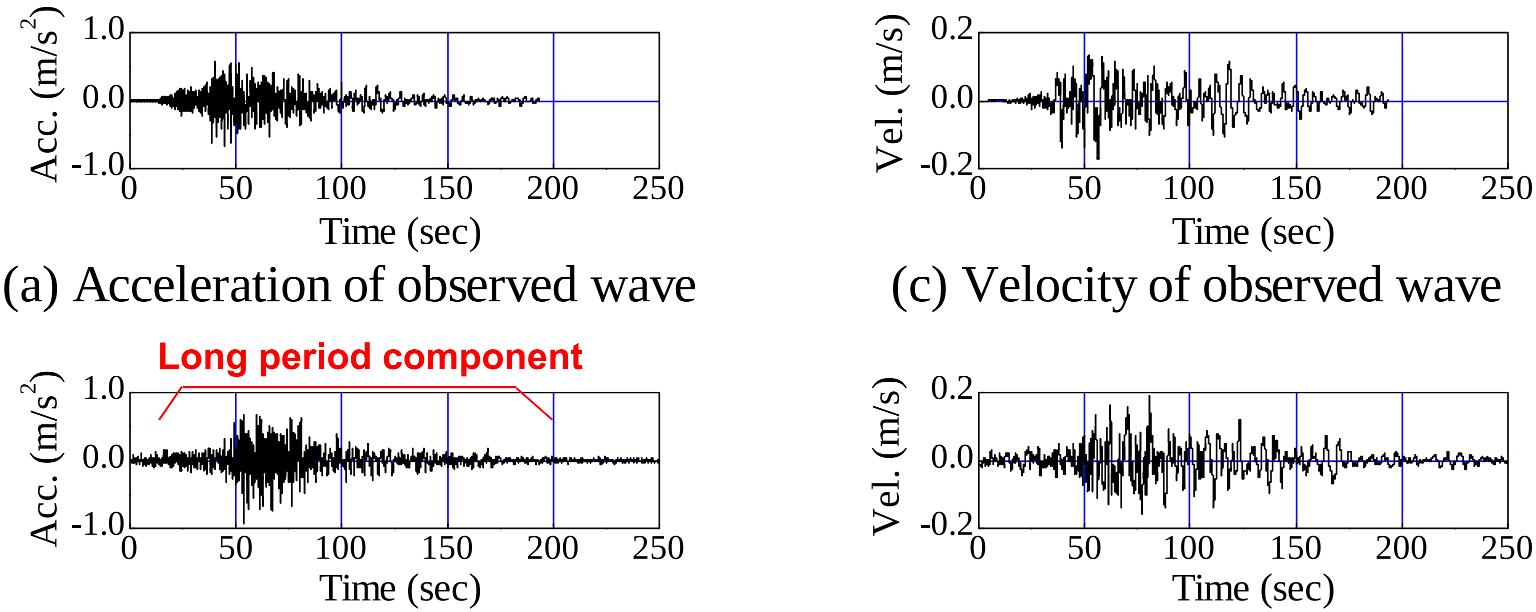


(d) Velocity of synthesized wave

Figure 4.1 Comparison between observed waves (EW component) recorded at Yubara, Okayama, and synthesized waves with respect to the 2000 Western Tottori Prefecture Earthquake

Verification of the Proposed Method

Inter-plate earthquake (σ/π=0.17)



(a) Acceleration of observed wave

(c) Velocity of observed wave

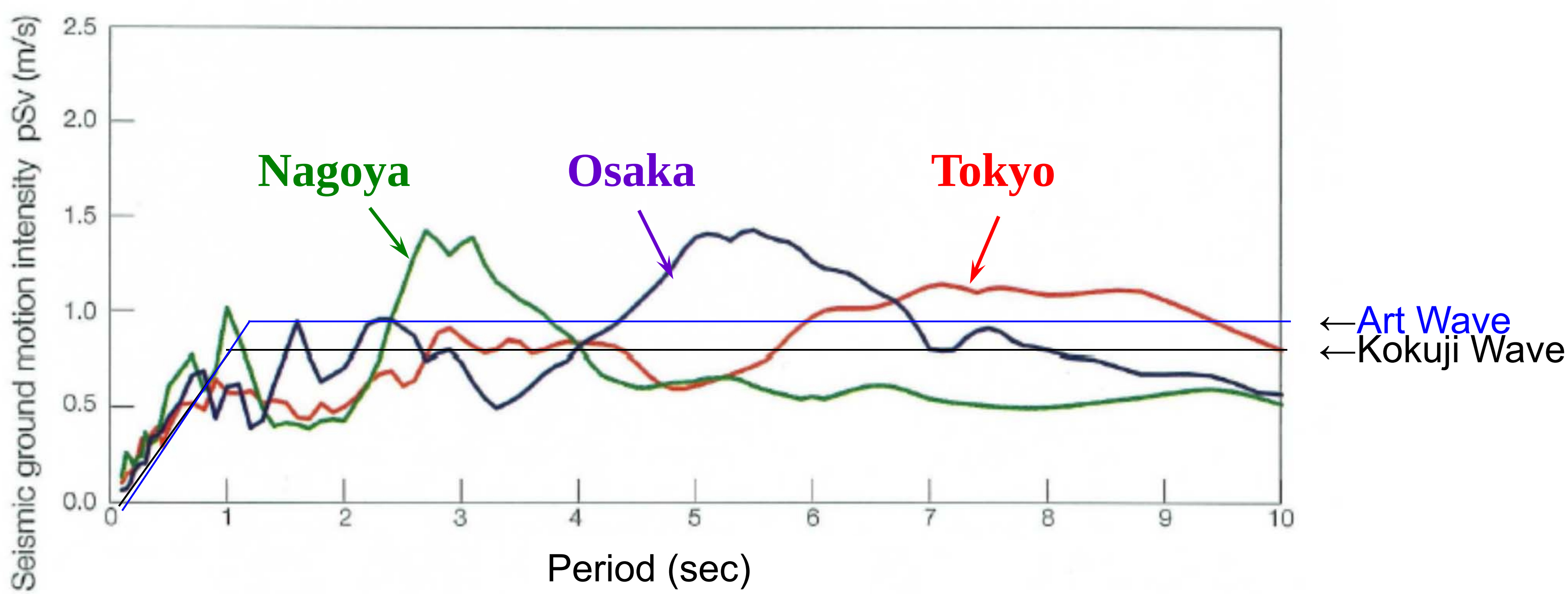
(b) Acceleration of synthesized wave

(d) Velocity of synthesized wave

Figure 4.2 Comparison between observed waves (NS component) recorded at Sapporo, Hokkaido, and synthesized waves with respect to the 2003 Tokachi-oki Earthquake

3. Dynamic Behavior of High-rise Buildings

Examples of “NS Wave” figures



Near Tokyo station projected for South Kanto earthquake (M7.9)

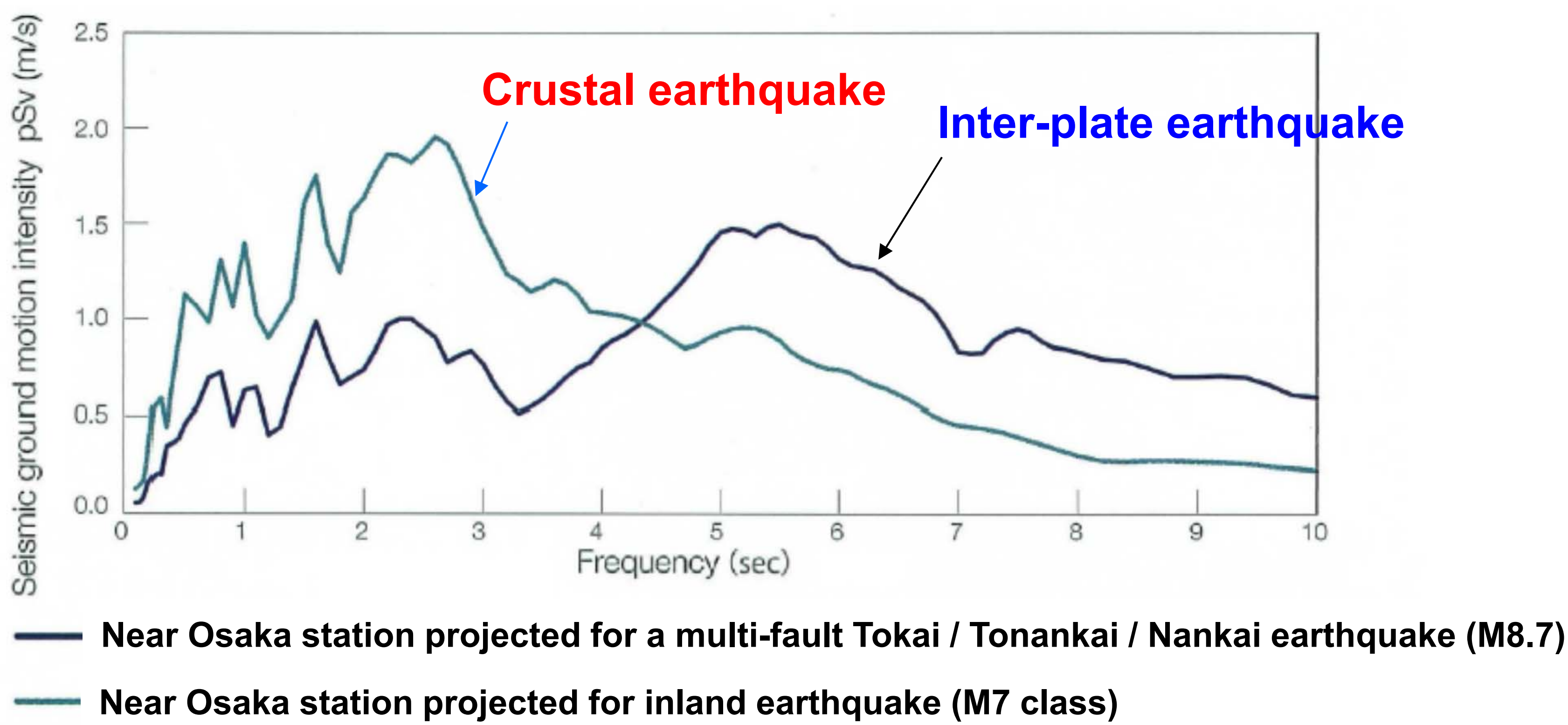
Near Osaka station projected for a multi-fault Tokai / Tonankai / Nankai earthquake (M8.7)

Near Nagoya station projected for a multi-fault Tokai / Tonankai / Nankai earthquake (M8.7)

Expected to produce strong shaking

at construction sites

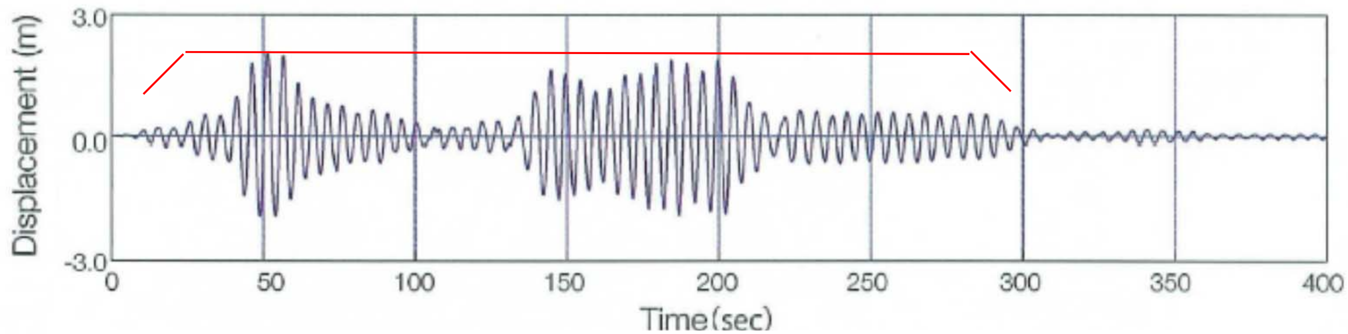
Differences in seismic intensity near plate boundaries inland



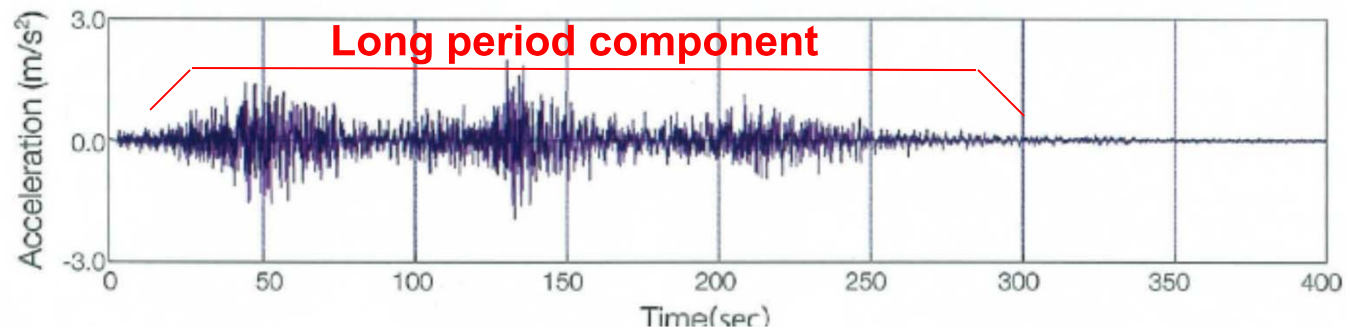
The strength of an earthquake can differ depending on the earthquake type, even at the same site.

How buildings sway? **Inter-plate earthquake**

200m model building (natural period 5 seconds)



Displacement at top of 200m building model

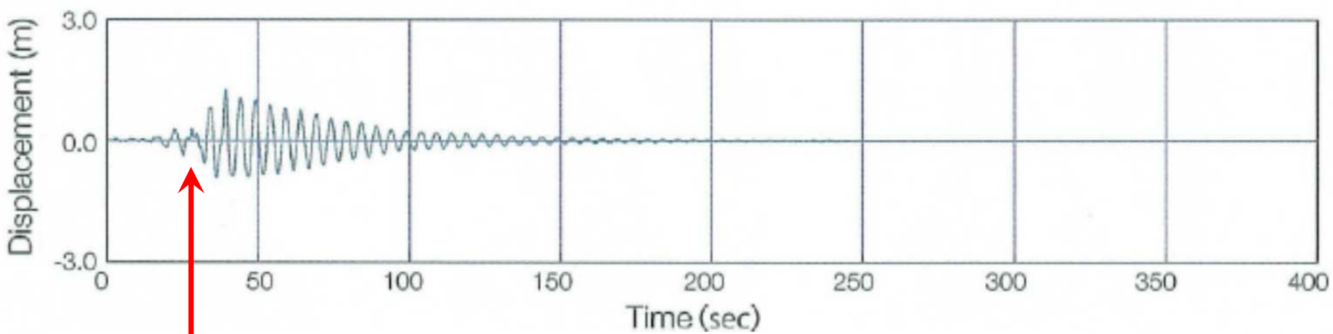


Ground motion

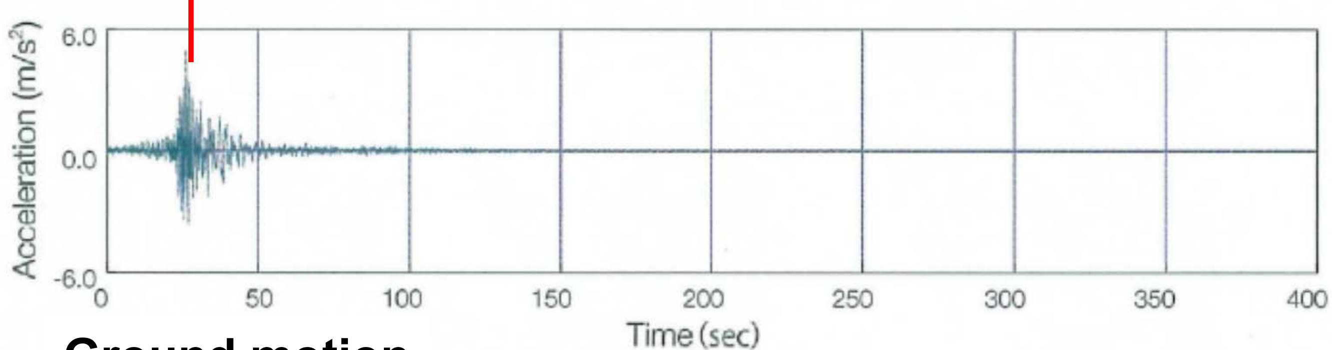
Inter-plate earthquake : near Osaka Station projected for a multi-fault Tokai / Tonankai / Nankai earthquakes

How buildings sway? **Crustal earthquake**

200m model building (natural period 5 seconds)



Displacement at top of 200m building model



Ground motion

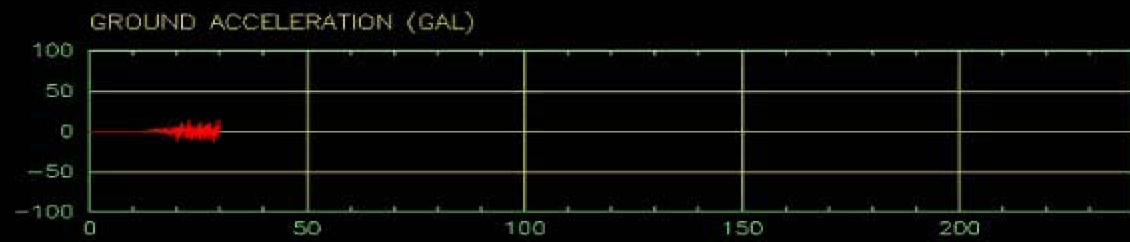
Crustal earthquake : Osaka Station projected for shallow inland earthquake (magnitude 7)

ー Movie ー

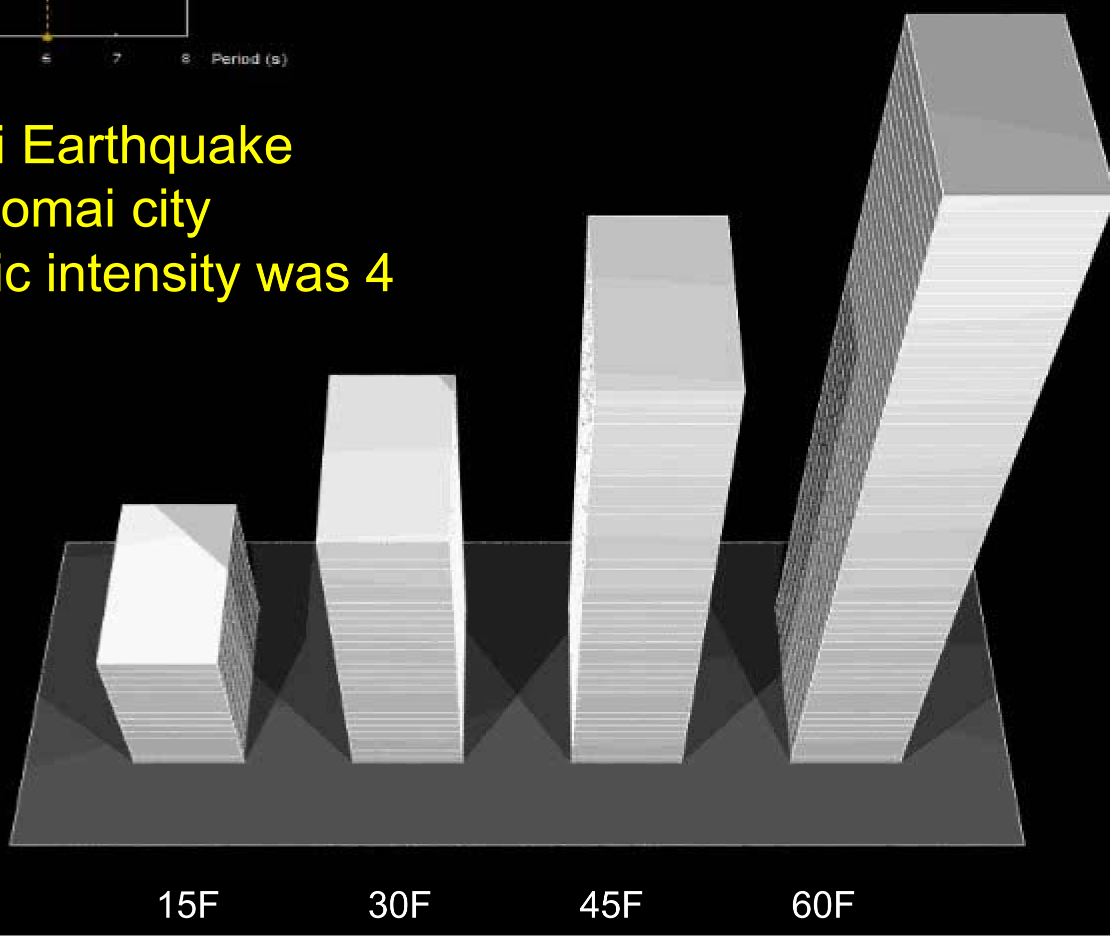
How differences in ground motion characteristics affect the swaying of the building？

Differences of the swaying

Inter-plate earthquake

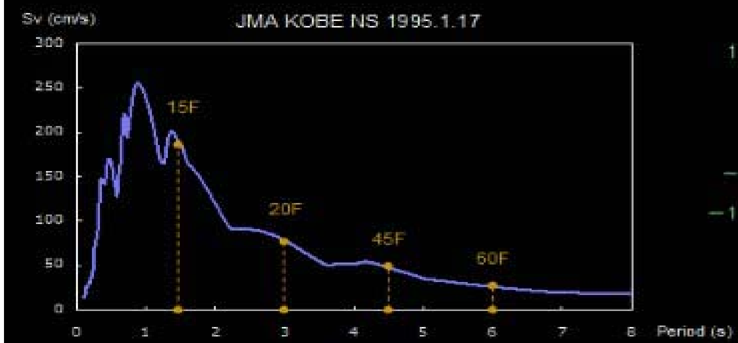


♯2003 Tokachi-oki Earthquake
in Tomakomai city
♯Japanese seismic intensity was 4

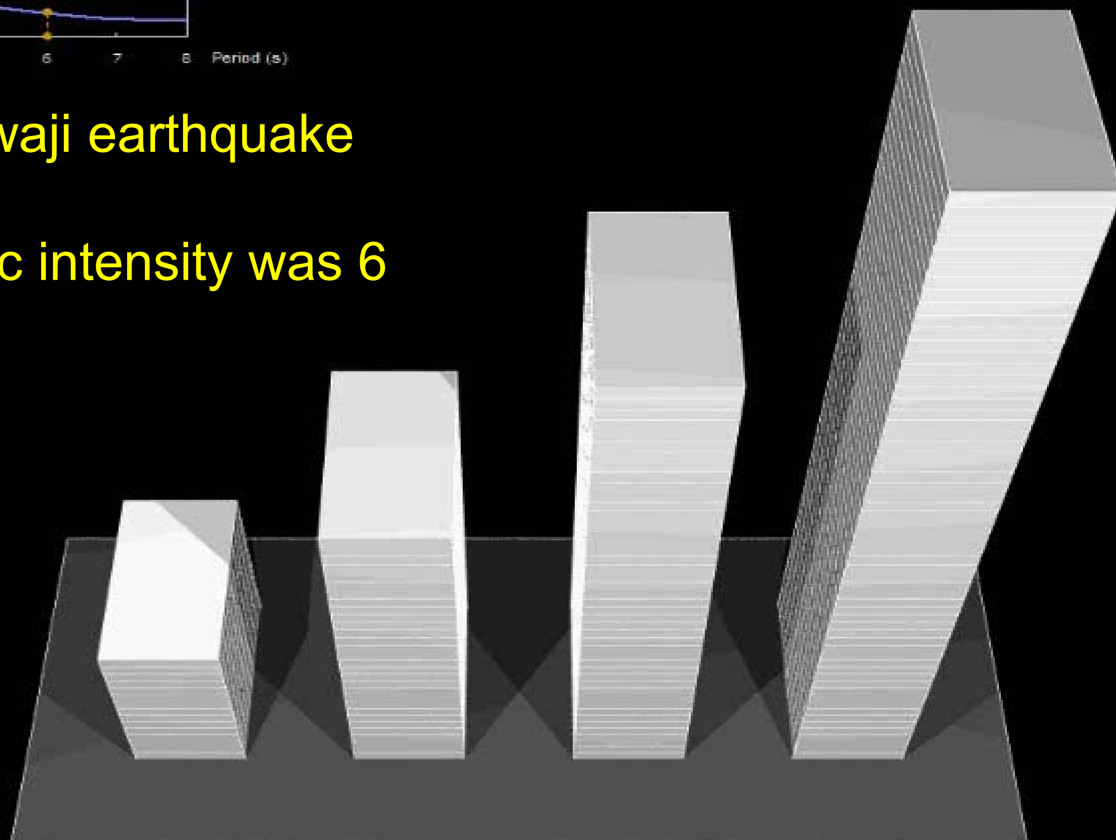


Differences of the swaying

Crustal earthquake

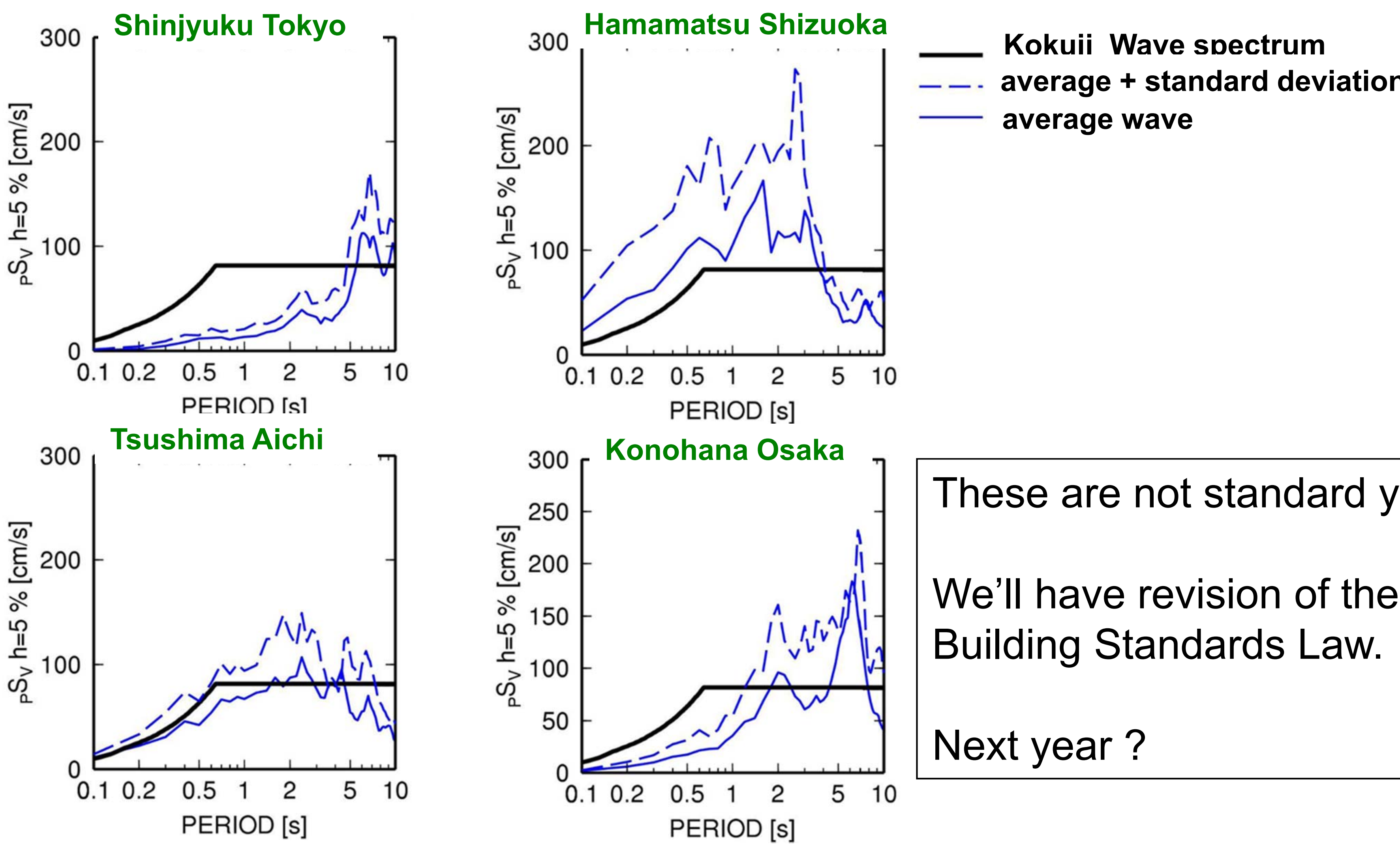


- ♯1995 Hanshin-Awaji earthquake in Kobe city
- ♯Japanese seismic intensity was 6



15F 30F 45F 60F

Tentative spectra for long period ground motion, announced by government 2012



These are not standard yet.

We'll have revision of the Building Standards Law.

Next year ?

4. Conclusions

Conclusion

1. A method of simulating earthquake ground motions based on a quantitative evaluation of the Fourier phase has been introduced.

   Examples of the synthesized waves for inter-plate and crustal earthquakes have shown.

2. The dynamic behavior of high-rise buildings differs widely depending on the property of earthquake ground motions.

3. In performance-based design, it is important to consider the frequency characteristics of seismic waves.

And Finally･･･ points of seismic design and suggestions

1. Appropriate choice of seismic safety measures according to required performance and each form of buildings.

2. Adequate damping performance with the well- balanced Installment of devices in a building in addition to the structural strength of buildings.

3. Earthquake resistance of finishing materials and building equipments, not only of structural frame, in terms of “operational” or “fully operational” use of buildings.

4. Correct evaluation of seismic performance for existing skyscrapers.

Thank you

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