A STUDY ON SITE-SPECIFIC STRONG GROUND MOTION FOR SEISMIC RETROFIT DESIGN OF THE HANSHIN EXPRESSWAY LONG-SPAN BRIDGES IN OSAKA BAY AREA

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ABSTRACT

The site-specific strong ground motion in Osaka Bay Area is studied in order to estimate the seismic load for the seismic retrofit of the Hanshin Expressway long-span bridges. We consider the crustal earthquake and the plate boundary earthquake as the maximum credible earthquake deterministically. The empirical Green's function method and the stochastic semi-empirical Green's function method are used to predict the site-specific ground motion. The study shows that there are some differences in the acceleration response spectra between the predicted strong ground motion and the standard ground motion in the Japanese specifications for highway bridges.

1. INTRODUCTION

Many bridges suffered heavy damage from the Hyogoken-nanbu earthquake that struck the Kobe city in Japan on Jan. 17, 1995. The seismic retrofit program for the existing bridges made a full-fledged start slightly behind the restoration of the damaged structures in the wake of the disaster in Hanshin Expressway Public Corporation. Until today, we have already strengthened most of the middle- or small-scale brides seismically. But the long-span bridges, mainly located in Bay Route of the Hanshin Expressway network, have not retrofitted yet due to the financial problems.

Although most of the highway bridges are retrofitted seismically according to the standard seismic loads in the current Japanese specifications for highway bridges [JRA(2002)], it is desirable in view of earthquake engineering that the input ground motion for the seismic design of a structure is estimated in consideration of source, path and local site effects, shown in Figure 1. In this paper, the site specific strong ground motion for seismic retrofit design of the Hanshin Expressway long-span bridges are estimated and compared with the Japanese specifications for highway bridges in terms of the acceleration response spectra.

2. THE LONG-SPAN BRIDGES IN HANSHIN EXPRESSWAY NETWORK

The 18 sites of the Hanshin Expressway long-span bridges, mainly located along the coastline of Osaka Bay, are the objective sites to predict the strong ground motion. Table 1 is the list of the 18 long-span bridges, indicating regions, bridge names, bridge types, abbreviations of each bridge and longer natural periods between the longitudinal and transverse direction. The locations of the 18 bridges are shown in Figure 2.

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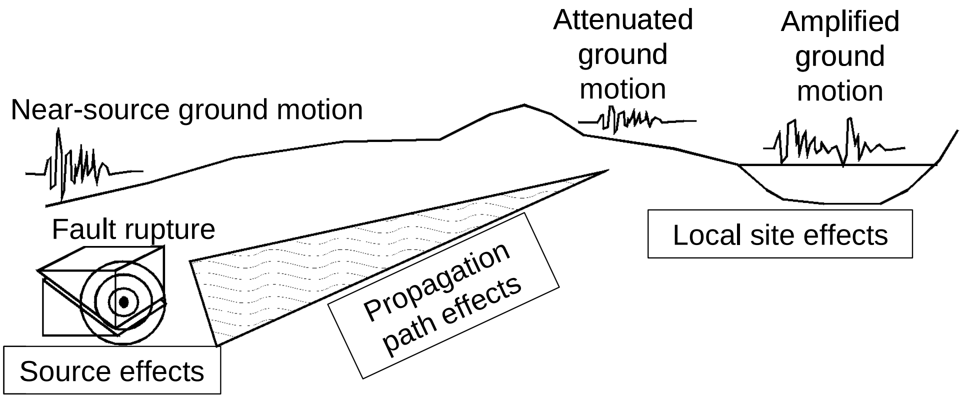


Figure 1 Schematic diagram of source, path and local site effects

Table 1 List of the 18 Hanshin Expressway long-span bridges

Region	Bridge	Type	Abbrev.	Period (s)
Kobe	Rokko Island	Lohse arch	rar	2.5
	Higashikobe	Cable stayed	hkb	4.9
	Shinashiyagawa	Girder	sas	2.5
	Nishinomiyako	Nielsen arch	nmk	2.0
North Osaka	Amagasakiko	Girder	amk	1.8
	Nakajimagawa	Nielsen arch	njk	1.2
	Kanzakigawa	Nielsen arch	kzk	1.2
	Shorenji	Girder	srj	1.8
Central Osaka	Umemachi	V-shape rigid frame	uto	1.6
	Tempozan	Cable stayed	tbz	3.8
	Minato	Gerber truss	mnt	4.6
	Nankosuiro	Lohse arch	msr	1.4
South Osaka	Hirabayashi	Girder	hrb	2.6
	Yamatogawa1	Cable stayed	ymt	3.1
	Yamatogawa2	PC Box Girder	yms	2.5
	Shinhamadera	Nielsen arch	sht	1.9
Far South Osaka	Harukigawa	Girder	hkk	2.5
	Kisiwada	Nielsen arch	kwt	2.9

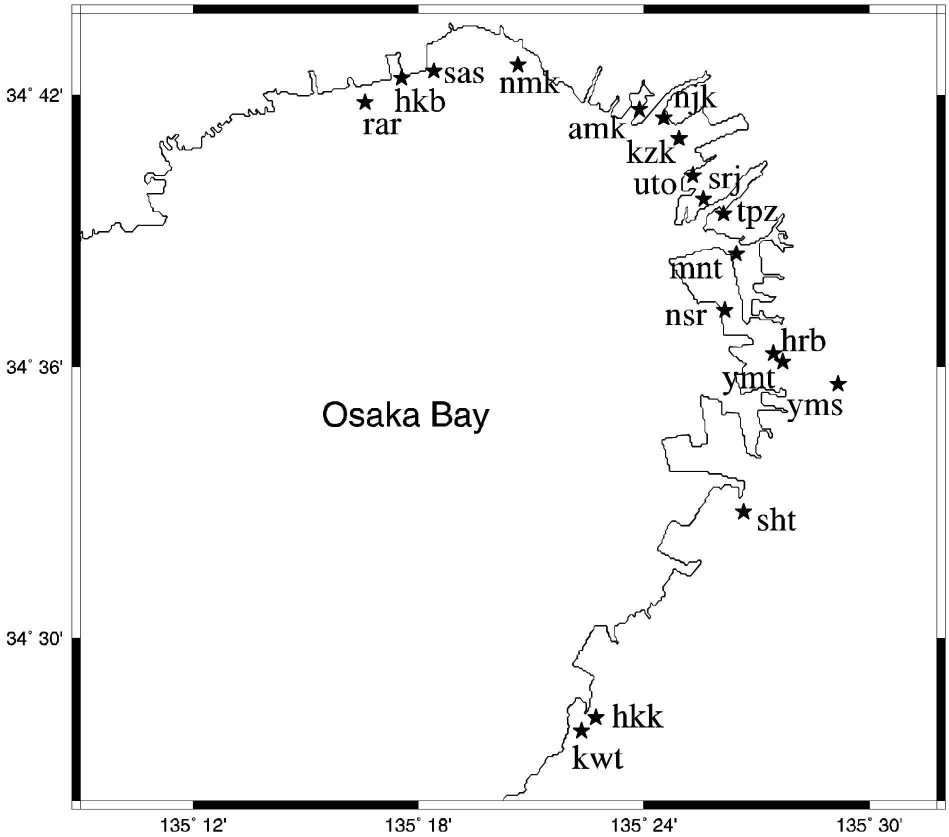


Figure 2 Locations of the 18 Hanshin Expressway long-span bridges

3. ACTIVE FAULTS IN OSAKA BAY AREA AND PLATE BOUNDARY FAULTS

There are 6 active faults recognized in Osaka Bay area, shown in Figure 3. As Rokko-Awaji faults triggered the 1995 Hogoken-nanbu earthquake only 8 years ago, they are neglected in this study. Out of the other 5 faults, Uemachi faults and Osaka Bay faults are selected on the basis of the peak ground acceleration (PGA) attenuation study.

In addition to the active faults in Osaka Bay Area, we consider the plate boundary faults located off the southwestern coast of Japan Islands. We adopt the fault model studied by the central government to predict the strong ground motion of the plate boundary earthquake. The fault model is shown in Figure 4.

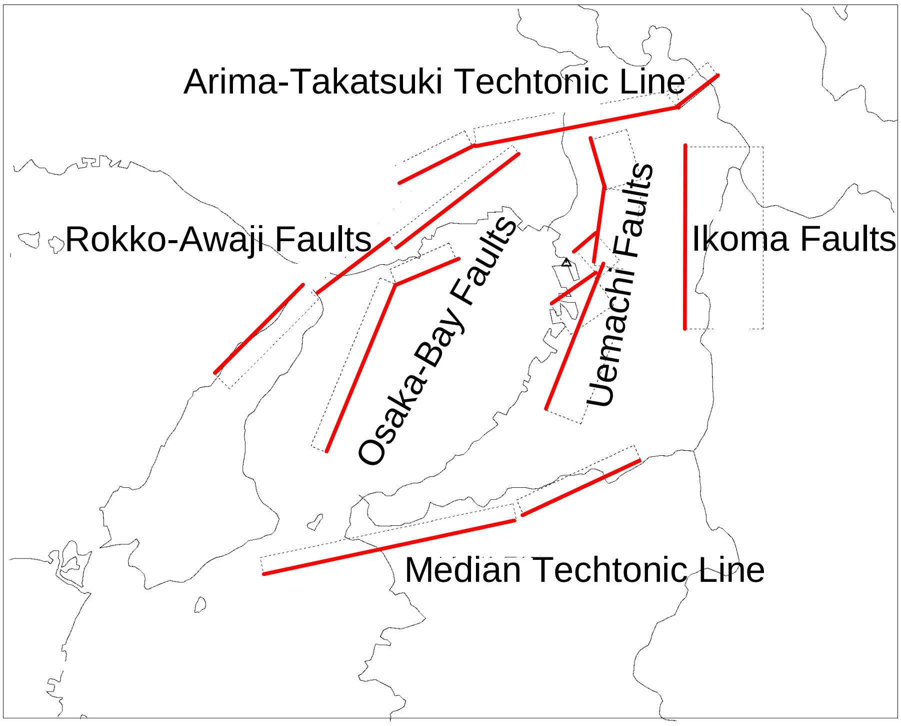


Figure 3 Active faults recognized in Osaka Bay Area

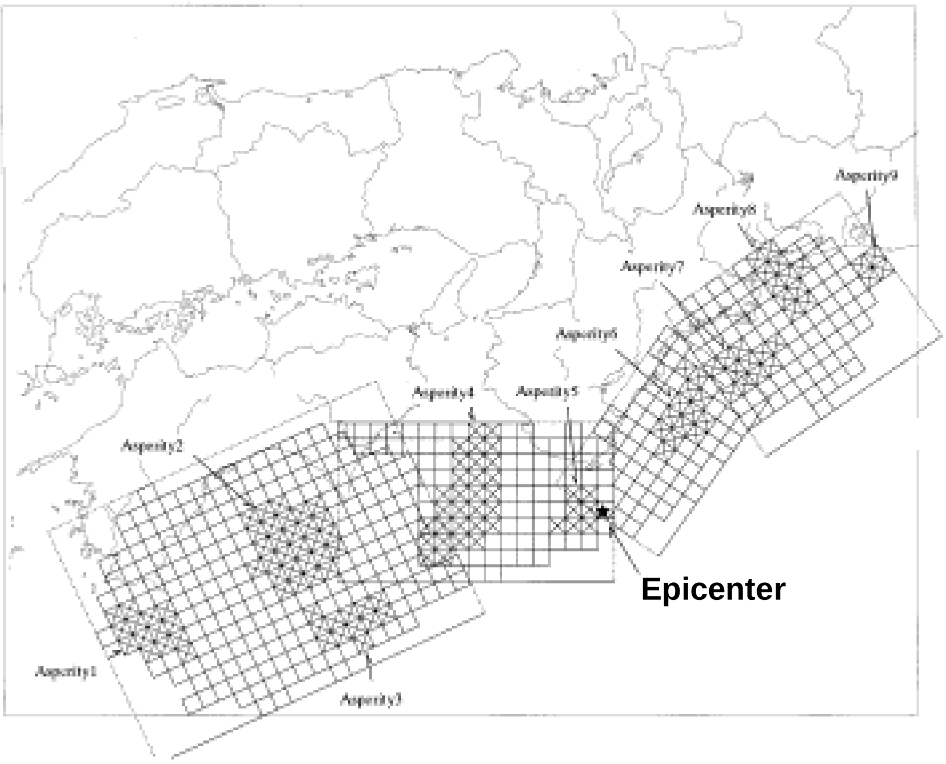


Figure 4 Fault model of the plate boundary earthquake

4. SYNTHESIS PROCEDURE OF STRONG GROUND MOTIONS

The strong ground motions are estimated for the crustal earthquake and the plate boundary earthquake respectively. We suppose that the active faults should cause the crustal earthquake and that the plate boundary faults should bring about the earthquake due to the continental plate movement. Two methods are used for simulating strong ground motion at a specific site resulted from a large earthquake. One is the empirical Green's function method [Irikura(1986)] and the other is the stochastic semi-empirical Green's function method [Boore(1983), Kamae and Irikura(1992)].

The empirical Green's function method is one of the most effective techniques for predicting strong ground motion for the purpose of seismic design of a structure. This method synthesizes ground motion at a site from observed records as empirical Green's function. A large earthquake is constructed by a superposition of many small earthquakes based on the regional scaling relation of source parameters. Figure 5 shows the schematic source model for synthesis. Since the method considers propagation path effects, local site effects, rupture propagation effects on the fault plane and geometrical relation effects between source and site, it is very powerful for predicting the strong ground motion by a future large earthquake. But appropriate records in the objective site are not always available as the empirical Green's function.

The stochastic semi-empirical Green's function method is a revised simulation method when no suitable observation data are available as empirical Green's function. This method uses the stochastically simulated small-event motion based on seismological spectral model as semi-empirical Green's function, instead of the actual observed records.

Since appropriate observation records don't exist as empirical Green's functions for the crustal earthquakes generated by Uemachi faults and Osaka Bay faults, we use the stochastic semi-empirical Green's function method to predict the ground motion of the crustal earthquake. On the other hand, we obtained suitable records in the objective region for the plate boundary earthquake. We use the empirical Green's function method to predict the ground motion of the plate boundary earthquake.

For the crustal earthquake, we consider 3-D topography of deep geologic structure in Osaka Bay Area and calculate the ground motion by the 3-D elastic finite-difference model [Graves(1996), Pitarka(1999)]. Figure 6 shows the 3-D topography of deep geologic structure in Osaka Bay Area. We simulate the ground motion of the crustal earthquake in use of the hybrid method. That is to combine the short period range (0.1-2.0sec.) by the stochastic semi-empirical Green's function method and the long period range (1.0-10.0sec.) by the 3-D elastic finite-difference model. This hybrid method takes the advantages of the two methods.

The prediction procedure in this study is shown in Figure 7.

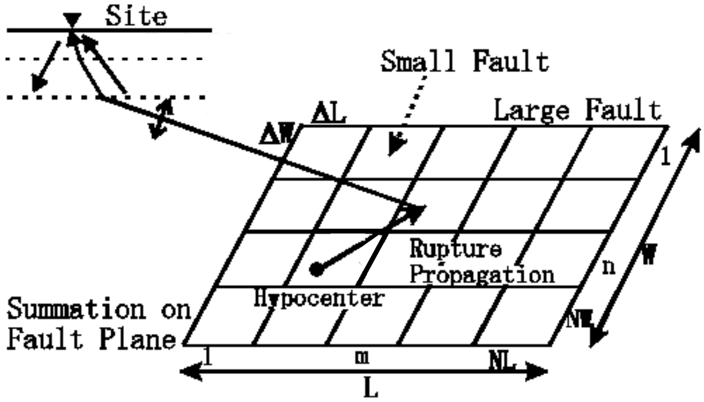


Figure 5 Schematic source model for synthesis

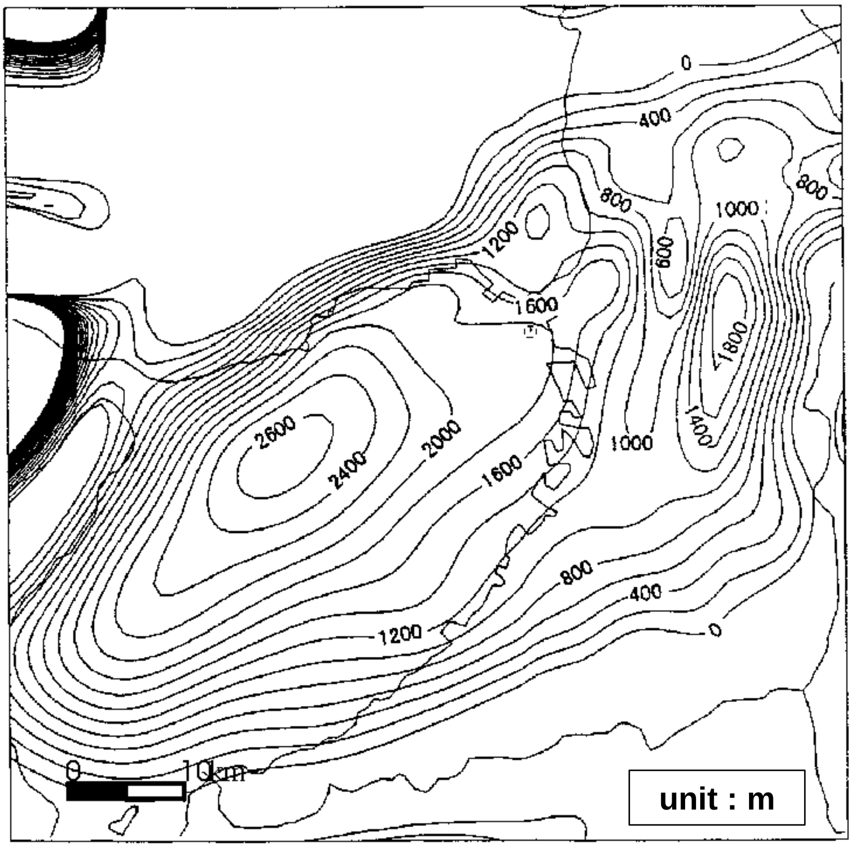


Figure 6 3-D topography of deep geologic structure in Osaka Bay Area

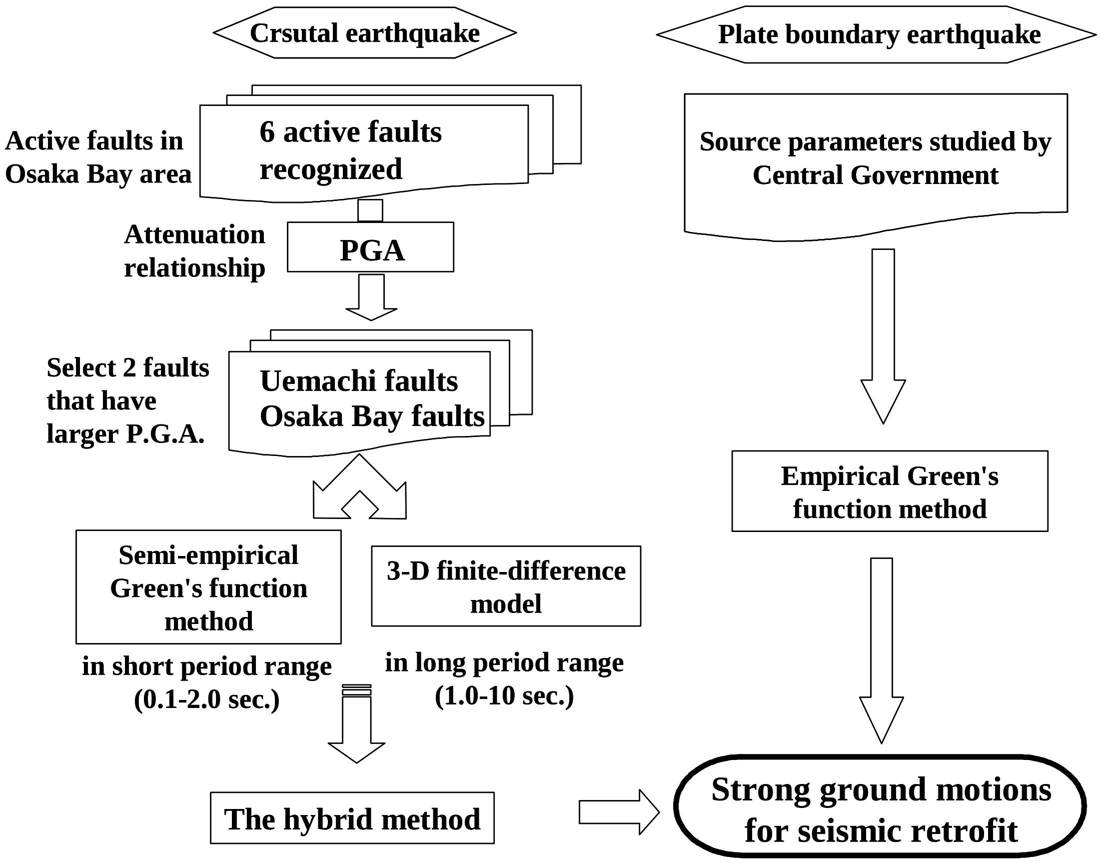


Figure 7 Prediction procedure

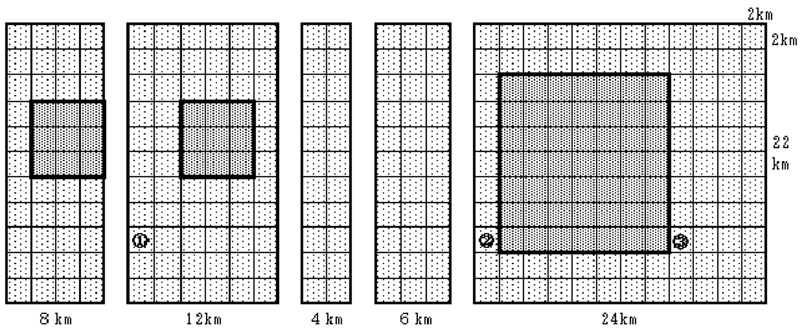
5. STRONG GROUND MOTIONS OF THE CRUSTAL EARTHQUAKE

The source parameters of Uemachi faults and Osaka Bay faults are shown in Table 2. Uemachi faults consist of 5 segments. The moment magnitude of the maximum credible earthquake (MCE) by Uemachi faults is assumed to be M_w=6.9. Osaka Bay faults are made up of 2 segments and the moment magnitude of MCE is M_w=6.7. For synthesizing the strong ground motion, we assume 5 fault rupture scenarios to Uemachi faults and Osaka Bay faults. The 5 types of the asperities are shown in Figure 8. These assumptions are based on Irikura(2002)'s research.

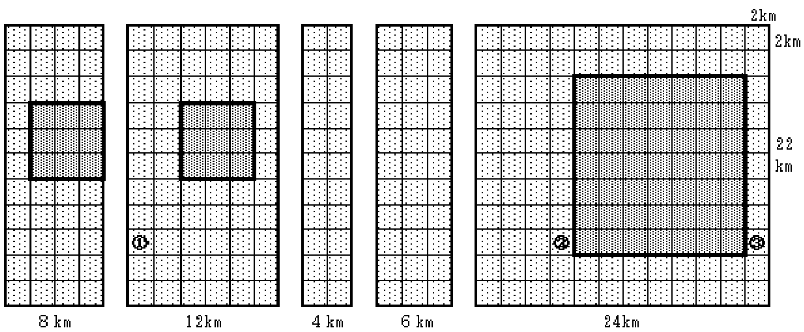
The acceleration response spectra S_A of the synthesized ground motion are calculated in the 5 regions (Kobe, North Osaka, Central Osaka, South Osaka and Far south Osaka). The non-linearity of the seismic response of the surface ground is taken into account by the SHAKE program. Figures 9-13 are the S_A of the simulated ground motion. The spectrum of the Japanese specifications for highway bridges, drawn with broken line in Figures 9-13, is the one of the strong ground motion of the maximum credible crustal earthquake in the soil classification 3 [JRA(2002)]. The comparison shows that most of the S_A of the site-specific ground motion in the short period range are smaller than those of the specification. However, in some longer periods, the S_A of the site-specific ground motion go beyond those of the specification. Since the long-span bridges have long natural periods, we should pay much attention to the S_A of the site-specific ground motion in the long period range when we conduct the seismic retrofit design of those structures.

Table 2 Source parameters of Uemachi faults and Osaka Bay faults

	Uemachi faults					Osaka Bay faults	
	Part A	Part B	Part C	Part D	Part E	Part A	Part B
Length (km)	8	12	4	6	24	26	10
Width (km)	22					16	
Strike (deg.)	-16.2	7.4	48.4	55.8	21.4	-158	-114
Dip (deg.)	60					80	
Moment magnitude M_w	6.9					6.7	
Seismic moment (10^{19} N・m)	0.38	0.58	1.29	0.32	0.19	1.03	0.39

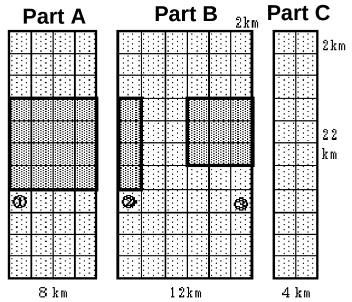


(a) Uemachi faults, Type 1

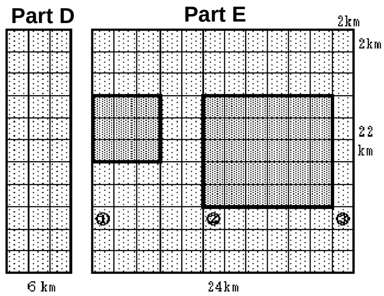


(b) Uemachi faults, Type2

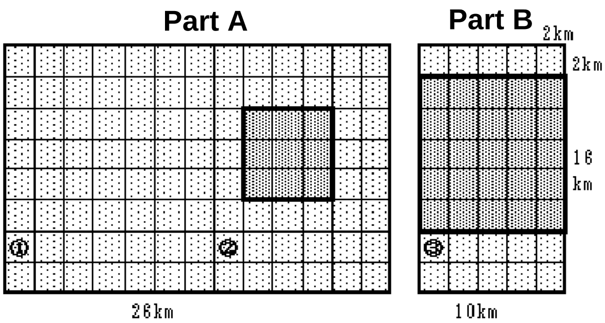
Figure 8 Assumed asperities in Uemachi faults and Osaka Bay faults



(c) Uemachi faults, Type 3

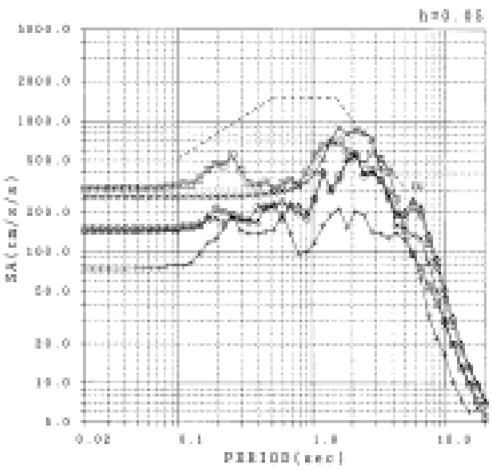


(d) Uemachi faults, Type 4

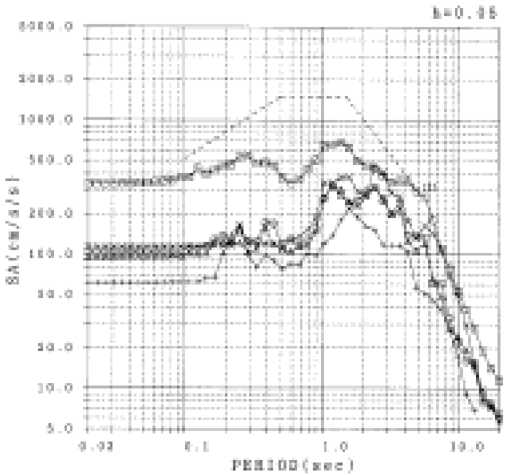


(e) Osaka Bay faults, Type5

Figure 8 Assumed asperities in Uemachi faults and Osaka Bay faults

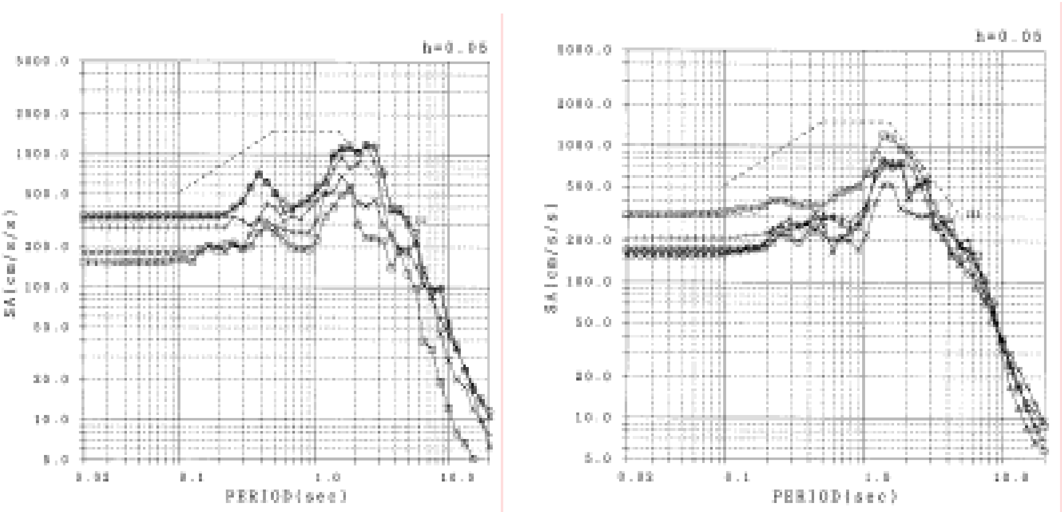


(a) EW component



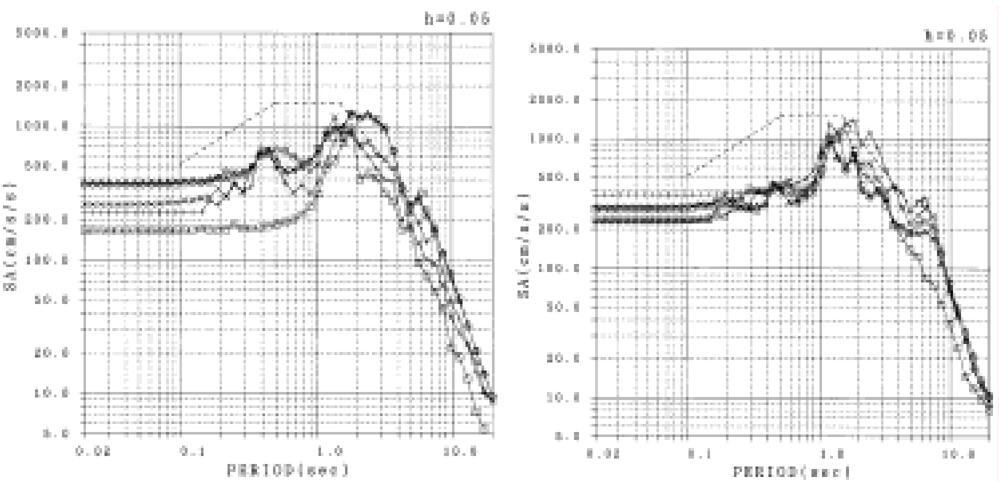
(b) NS component

Figure 9 Acceleration response spectra S_A of the ground motion in Kobe Region



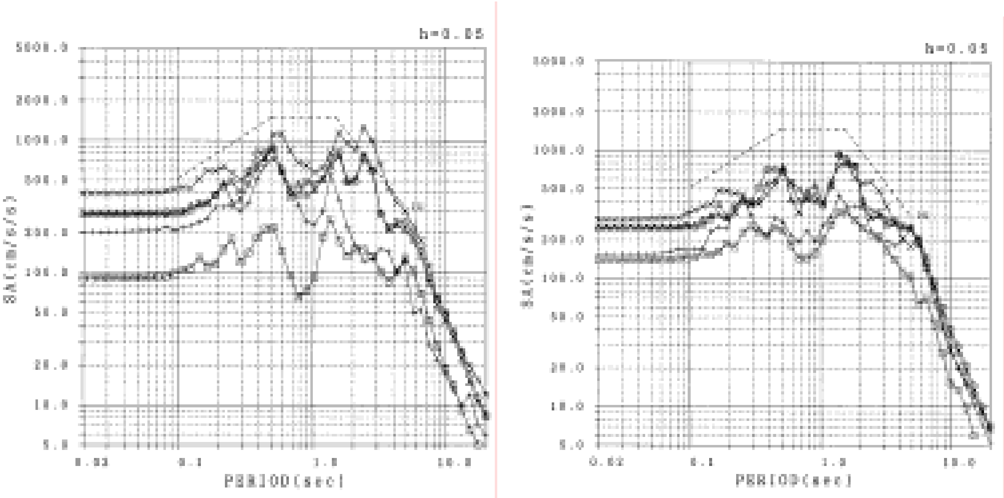
(a) EW component (b) NS component

Figure 10 Acceleration response spectra S_A of the ground motion in North Osaka Region



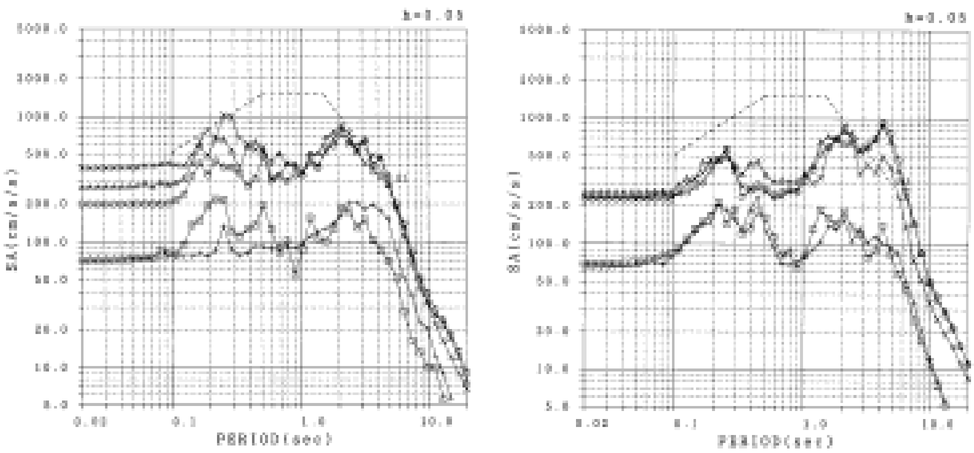
(a) EW component (b) NS component

Figure 11 Acceleration response spectra S_A of the ground motion in Central Osaka Region



(a) EW component (b) NS component

Figure 12 Acceleration response spectra S_A of the ground motion in South Osaka Region



(a) EW component (b) NS component

Figure 13 Acceleration response spectra S_A of the ground motion in Far South Osaka Region

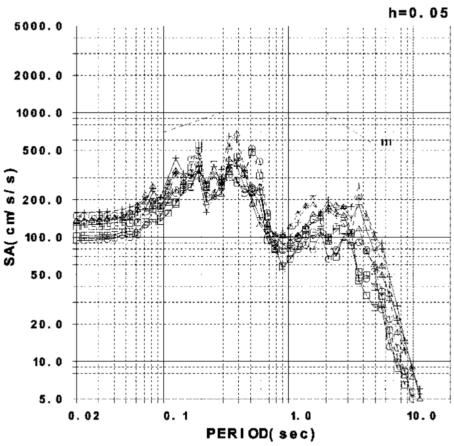
6. STRONG GROUND MOTIONS OF THE PLATE BOUNDARY EARTHQUAKE

The source parameters of the plate boundary faults are shown in Table 3. The fault model, shown in Figure 4, is based on the study of the central government. There are Nankai faults and East Nankai faults off the southwestern coast of Japan Islands. The moment magnitude of MCE is assumed to be M_w=8.6 when Nankai faults and East Nankai faults are ruptured at the same time.

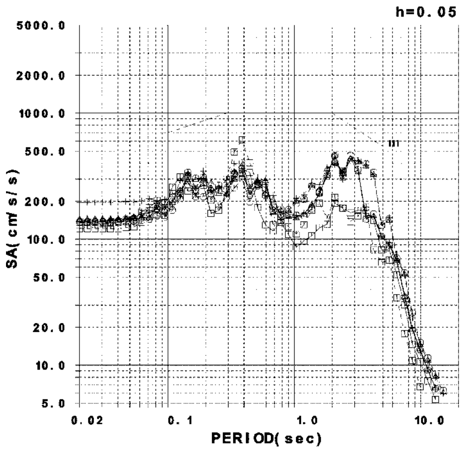
The S_A of the synthesized ground motion in the 5 regions are shown in Figure 14. The broken line is the S_A of the Japanese specifications for highway bridges with the maximum credible plate boundary earthquake in the soil classification 3 [JRA(2002)]. The S_A of the site-specific ground motion are found to be below the S_A of the specifications in most period range.

Table 3 Source parameters of the plate boundary faults

	Nankai faults		East Nankai faults	
	Part A (West)	Part B (East)	Part A (West)	Part B (East)
Length (km)	220	170	120	130
Width (km)	160	100	80	110
Strike (deg.)	245	270	215	235
Dip (deg.)	7	14	14	10
Moment magnitude M_w	8.6			
Seismic moment (10^{22} N･m)	1.08			

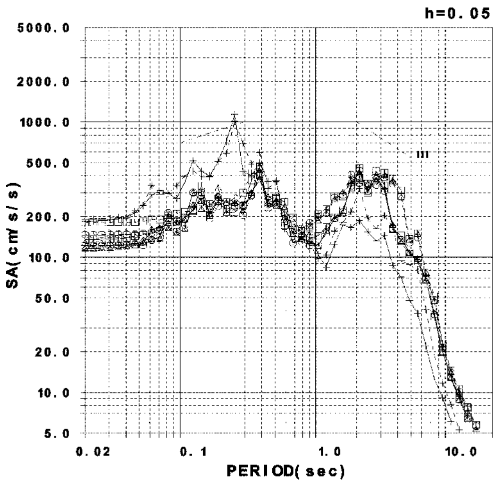


(a) Kobe Region

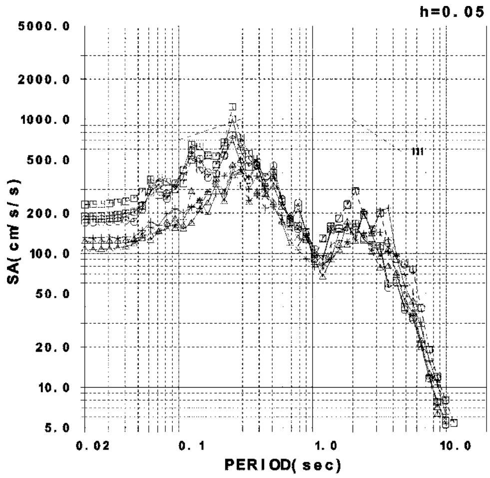


(b) North Osaka Region

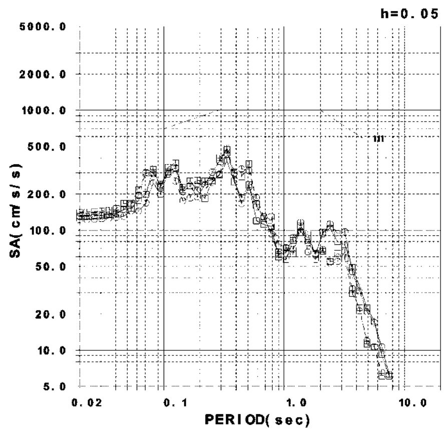
Figure 14 Acceleration response spectra S_A of the ground motion of the plate boundary faults



(c) Central Osaka Region



(d) South Osaka Region



(e) Far South Osaka Region

Figure 14 Acceleration response spectra S_A of the ground motion of the plate boundary faults

7. CONCLUSION

The site-specific strong ground motion in Osaka Bay Area is studied in order to estimate the seismic load for the seismic retrofit of the Hanshin Expressway long-span bridges. The study shows that there are some differences in the acceleration response spectra between the predicted strong ground motion and the standard ground motion in the Japanese specifications for highway bridges. Since it is desirable to consider source, path and local site effects for the seismic design of a structure, the site-specific ground motion should be taken into consideration, especially for the important structures such as the long-span bridges.

ACKNOWLEDGEMENT

We have precious advice from Prof. Tadanobu Sato and Prof. Sumio Sawada, Kyoto University in this study. We would like to express our appreciation to them.

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