Earthquake Motion Prediction Focusing on Long Period-spectral Characteristics due to the Deep Ground Structure of Local Region

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SUMMARY:
We developed of the strong motion prediction technique that the long period-spectral characteristics is paid due consideration to local region characteristic. The proposed technique was applied for the Noubi Plain of the Tokai district. For simulation of earthquake motion of the ocean trench earthquake in the Nankai Trough region, the long period-spectral characteristics in this area was estimated. Using the estimated spectral characteristics, the earthquake motion due to the period characteristics of several seconds was able to simulate.

Keywords: Prediction of Ground Motion, Long Period-Spectral Characteristics, Characteristics of Local Region

1. INTRODUCTION

In recent years, the high risk of occurring of the ocean trench earthquake along the Nankai Trough region has been pointed out. Since the ground motion from huge earthquakes include relatively long period motions, the earthquake resistant examination is specially important for large-scale structures. The long period earthquake motion, which is defined as several seconds, is generated specially in case of huge earthquakes. Additionally, the long period earthquake motion is affected by the deep ground structure at the local region. Therefore, in case earthquake motion prediction for huge earthquakes, it is important to incorporate the effect of deep ground structure in local region into the prediction. The analytical estimate of the long period characteristics is difficult, but, it can be estimated from the analysis of discriminative amplification characteristic in the observed strong motion record.

In this study, we developed of the strong motion prediction technique that the long period-spectral characteristics is paid due consideration to local region characteristic. This developed technique improved on the strong motion prediction model, EMPR (Earthquake Motion Prediction model on Rock surface) (Sugito et al., 2000). In the following chapter, the outline of EMPR, and, the technique of estimate for long period-spectral characteristics are presented.

2. OUTLINE OF EARTHQUAKE MOTION PREDICTION MODEL ON ROCK SURFACE (EMPR)

Nonstationary strong motion prediction model, EMPR, was developed of Sugito et al.(2000). EMPR was developed on the basis of rock surface strong motion dataset. The strong motion dataset consists of 118 components of major Japanese accelerograms including the records from the 1995 Hyogoken-nanbu Earthquake.

Earthquake acceleration with nonstationary frequency content can be represented by Eqn. 2.1.

$$x(t)=\sum_{k=1}^{m}\sqrt{4\pi\cdot G_x(t,2\pi f_k)\cdot\Delta f}\cdot\cos(2\pi f_k+\phi_k) \tag{2.1}$$

in which $\sqrt{G_x(t,2\pi f_k)}$ is evolutionary power spectrum (Kameda, 1975) for time t and frequency f_k, ϕ_k is independent random phase angles distributed over $0\sim 2\pi$, and m is the number of superposed harmonic components.

The upper and lower boundary frequencies, f_u, f_l, are fixed as f_u =10.03(Hz), and also m and Δf are fixed as m=166 and Δf =0.06(Hz). The following time-varying function is adopted for the model of $\sqrt{G_x(t,2\pi f_k)}$.

$$\sqrt{G_x(t,2\pi f)}=\alpha_m(f)\frac{t-t_s(f)}{t_p(f)}\exp\left\{1-\frac{t-t_s(f)}{t_p(f)}\right\} \tag{2.2}$$

in which $t_s(f)$, $t_p(f)$ are starting time and duration parameter, respectively, and α_m is intensity parameter which represents the peak value of $\sqrt{G_x(t,2\pi f_k)}$. These parameters have been determined relative to recorded acceleration time histories. Figure 2.1 shows example of recorded and modeled evolutionary spectra. In addition, as shown Figure 2.2, the evolutionary spectra for great earthquake is incorporated the effect of fault size, successive fault rupture, and rupture direction, on characteristics of ground motion.

The superposed evolutionary spectra for great earthquake is given by Eqn. 2.3.

$$\sqrt{G_x(t,2\pi f_k)}=\frac{\beta(f,M_0)\cdot N_G(M_0)}{N_x\cdot N_y}\sum_{i=1}^{N_x}\sum_{j=1}^{N_y}\sqrt{G_{ij}(t,2\pi f_k)} \tag{2.3}$$

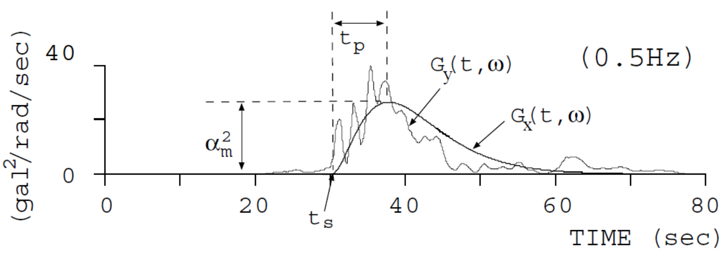


Figure 2.1. Recorded and simulated evolutionary power spectra

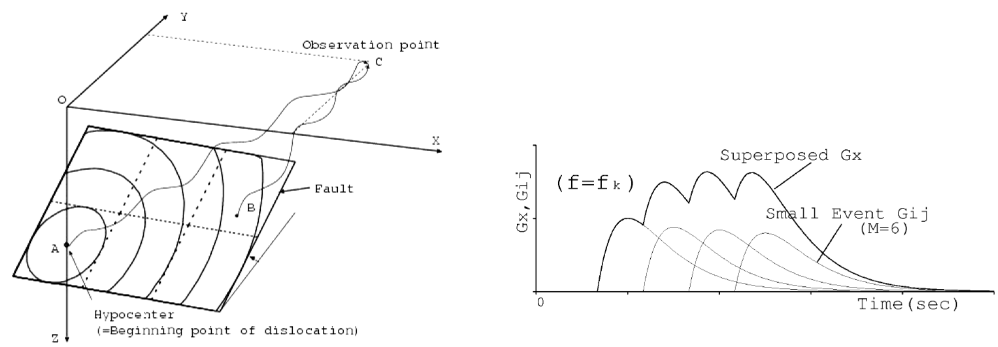


Figure 2.2. Fault modeling with multiple fault rupture and superposed evolutionary power spectra

where G_{ij} is evolutionary spectrum for each unit event corresponding to the earthquake magnitude M=6.0 and hypo-central distance R_{ij}, and the suffix, i and j, represent the position of each event on the fault. N_x and N_y represent the number of unit event in the direction of fault width and length. The number of superposition, $N_G(M_0)$ is the average of the magnification factor that is calculated the range from 0.13(Hz) to 10.03(Hz). $\beta(f, M_0)$ is the correction factor.

The correction factor $\beta(f, M_0) \cdot N_G(M_0)$ is defined of the number of superposition of evolutionary spectrum corresponding to the earthquake of M=6.0 by the EMPR. In addition, there is the relationship of $N_G(M_0)$ and M_0.

$$\log N_G(M_0) = -13.02 + 0.4088 \log M_0 \tag{2.4}$$

3. LONG PERIOD-SPECTRAL CHARACTERISTICS IN LOFAL REGION AND COLLECTION FACTOR *R*(*F*) FOR EARTHQUAKE MOTION PREDICTION

The long period-spectral characteristics at the local region can estimate from the described previously technique. The number of superposition of evolutionary spectrum $n_g(f_k)$ that is calculated from observation record, is get from Eqn. 3.1.

$$n_g(f_k) = \frac{\int_0^T \sqrt{G_{obs}(t, 2\pi f_k)}\, df_k}{\int_0^T \sqrt{G_{x,M=6}(t, 2\pi f_k)}\, df_k} \tag{3.1}$$

where $G_{x,M=6}(t, 2\pi f_k)$ is evolutionary spectrum for EMPR that is calculated from the case of M=6, and $G_{obs}(t, 2\pi f_k)$ is evolutionary spectrum from observation record.

The scale factor $r_0(f_k)$ from one observed record is get from following equation.

$$r_0(f_k) = \frac{n_g(f_k)}{\beta(f_k, M_0) \cdot N_G(M_0)} \tag{3.2}$$

The long period-spectral characteristics of the local region can estimate using to the scale factors that the ratio for the evolutionary power spectra is calculated from the target area. Specifically, the correction factor of the target area, $r(f_k)$, is the average from the strong motion records that is observed from several earthquakes.

$$r(f_k) = \bar{r}_0(f_k)^{a(f_k)} \tag{3.3}$$

where $\bar{r}_0(f_k)$ is average of the scale factor $r_0(f_k)$, $a(f_k)$ is the weight coefficient. The average of scale factor $\bar{r}_0(f_k)$ is included of the amplification characteristic of subsurface ground. Therefore, the correction factor $r(f_k)$ that is excluded of high frequency domain is used of the strong motion prediction.

$$a(f_k) = \begin{cases} 1.0 & (f_k \le 0.5\text{Hz}) \\ 1.33 - 0.67 f_k & (0.5\text{Hz} < f_k \le 2.0\text{Hz}) \\ 0.0 & (f_k > 2.0\text{Hz}) \end{cases} \tag{3.4}$$

From the above-mentioned correction factor r (f_k), the strong motion prediction based on the long period-spectral characteristics of the local region can calculate using Eqn. 2.1, and Eqn. 3.5.

$$\sqrt{G_x(t, 2\pi f_k)} = \frac{r(f_k) \cdot \beta(f_k, M_0) \cdot N_G(M_0)}{N_x \cdot N_y} \sum_{i=1}^{N_x} \sum_{j=1}^{N_y} \sqrt{G_{ij}(t, 2\pi f_k)} \tag{3.5}$$

4. APPLICATION TO THE NOUBI PLAIN OF THE TOKAI DISTRICT

4.1. Correction Factor *r*(*f*) in Noubi Plain

The proposed technique is applied for the Noubi Plain of the Tokai district in Japan. Figure 4.1 shows the physiographic division around the Noubi Plain (green and light blue area), and, the observation stations. The Noubi Plain is become deposited of the river deposit, and, this area has the deep subsurface ground structure.

Table 3.1 shows the list of earthquakes in this study. The red earthquakes as shown Table 4.1, are relatively large earthquakes as described below in Figure 4.3. As shown this table, the 18 earthquakes are used. As one example, Figure 4.2 shows the comparison with the scale factor $r_0(f_k)$ and magnitude. As shown this figure, the characteristics of the low frequency level with the large scale earthquakes are relatively large than the small scale earthquakes. Because the trend that the low frequency level are stood out, is shown the large scale earthquakes, it's thought of as the source property and the characteristics around local region. Based on the above-mentioned consideration, the estimation of the long period-spectral characteristics is used to the strong motion records observed by the large scale earthquakes.

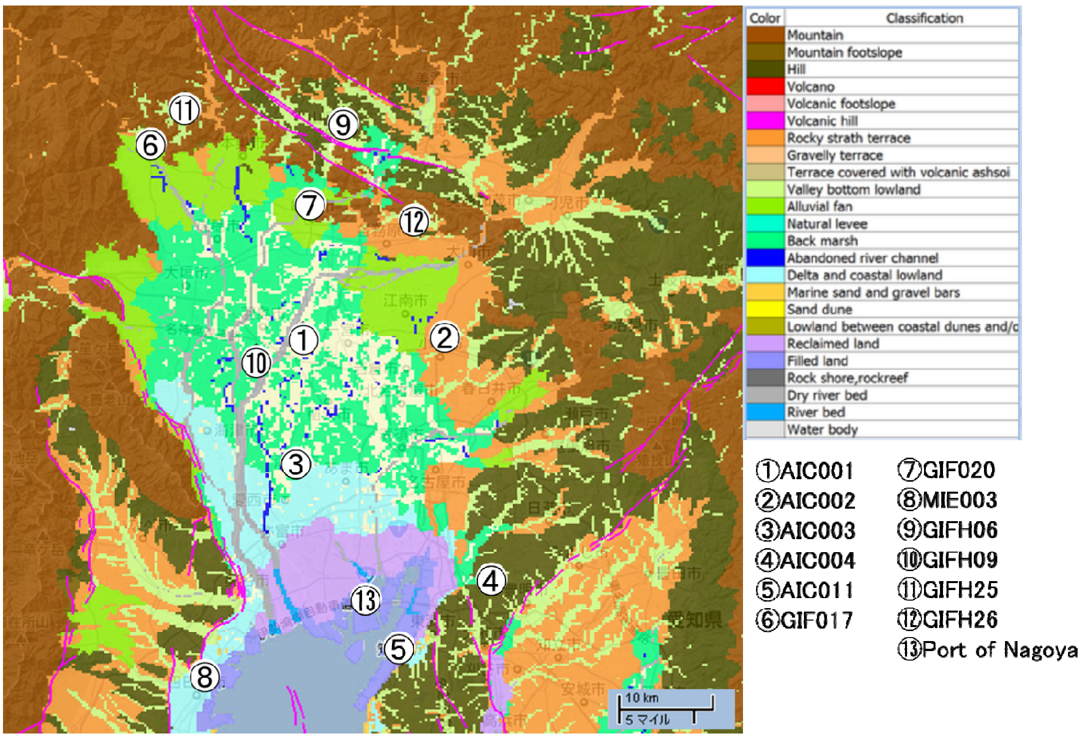


Figure 4.1. Physiographic division around the Noubi Plain and observation stations (touch up the map(J-SHIS 2012))

Table 4.1. List of earthquakes for in this study

No.	Date and Time of Occurrence yyyy/mm/dd hh:mm	Epicenter		Depth (km)	Magnitude	Seismic Moment (N･m)	Epicentral Area
		Latitude (degree)	Longitude (degree)				
1	1999/02/01 04:47	34.9463	136.8180	15.76	3.1	3.55E+13	ISE BAY REGION
2	1999/03/16 16:43	35.2773	135.9312	11.64	5.2	5.01E+16	NW SHIGA PREF
3	1999/08/21 05:33	34.0308	135.4705	65.83	5.6	3.60E+17	CENTRAL WAKAYAMA PREF
4	1999/10/26 08:26	34.9387	136.7753	16.54	3.1	3.55E+13	ISE BAY REGION
5	1999/11/07 03:34	36.0593	135.7942	15.04	5.0	2.51E+16	NW OFF KINKI DISTRICT
6	1999/11/29 21:34	35.1130	137.0265	44.92	4.8	1.26E+16	CENTRAL AICHI PREF
7	2001/02/23 07:23	34.7933	137.5488	32.34	5.0	2.51E+16	HAMANAKO LAKE REGION
8	2001/09/27 18:14	34.8677	137.1255	15.82	4.3	2.24E+15	MIKAWA BAY REGION
9	2003/07/09 02:14	34.9103	136.8462	17.47	4.1	1.12E+15	ISE BAY REGION
10	2003/11/05 08:05	35.0080	136.8610	12.92	3.0	2.51E+13	CENTRAL AICHI PREF
11	2004/01/06 14:50	34.2157	136.7143	37.46	5.4	8.31E+16	SE OFF KII PENINSULA
12	2004/04/01 07:59	34.9123	136.8072	11.85	3.8	3.98E+14	ISE BAY REGION
13	2004/09/05 19:07	33.0332	136.7977	37.58	7.1	9.80E+18	SE OFF KII PENINSULA
14	2004/09/05 23:57	33.1375	137.1413	43.54	7.4	2.11E+20	SE OFF KII PENINSULA
15	2004/10/05 08:33	35.9333	136.3782	12.38	4.8	1.26E+16	CENTRAL FUKUI PREF
16	2005/12/24 11:01	35.2307	136.8402	42.96	4.8	1.26E+16	CENTRAL AICHI PREF
17	2007/03/25 09:41	37.2207	136.6860	10.70	6.9	1.13E+19	OFF NOTO PENINSULA
18	2007/04/15 12:19	34.7912	136.4077	15.97	5.4	1.00E+17	NORTHERN MIE PREF

Figure 4.3 shows the scale factor $r_0(f_k)$ of three large scale earthquakes. The red lines and the blue lines are observation stations that are into the Noubi Plain. The grey lines are observation stations that are into the Noubi Plain shown the Figure 3.1, but, there are boundary division of the Noubi Plain and hilly district. Therefore, these stations have different propensity to the long period-spectral characteristics relative to the Noubi Plain that is shown the red lines and blue lines stations. In addition, because, the red and blue lines are shown the share a common habit, the dominant frequency shown red and blue lines are thought of as the characteristics of the Noubi Plain.

Figure 4.4 shows the average of scale factor $r_0\,(f_k)$ and the correction factor $r(f_k)$. The correction factor $r(f_k)$ is calculated by the strong motion records that were observed by the off the Kii Peninsula earthquake (as shown Figure 3.3 (a)) and the off the Tokaido eartuquake (as shown Figure 4.3 (b)). As shown this figure, the Noubi Plain has the dominant frequency that the frequency bands are 0.2Hz to 0.4Hz.

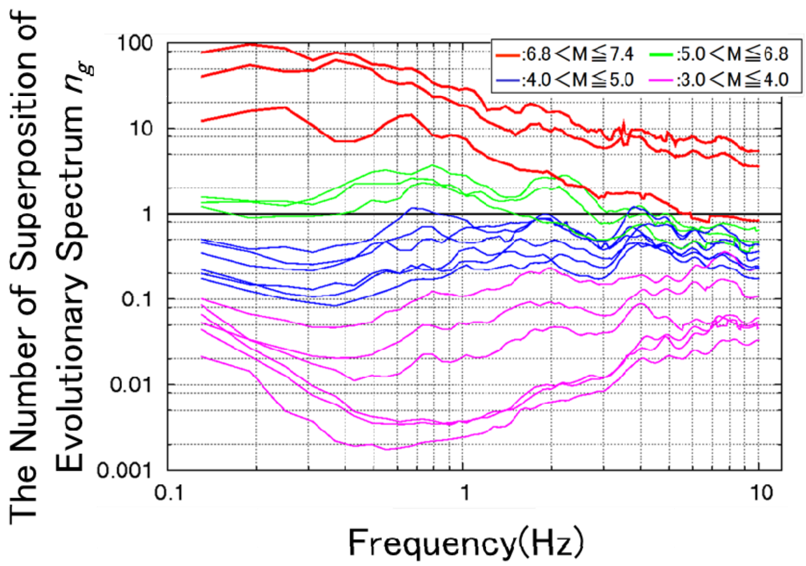
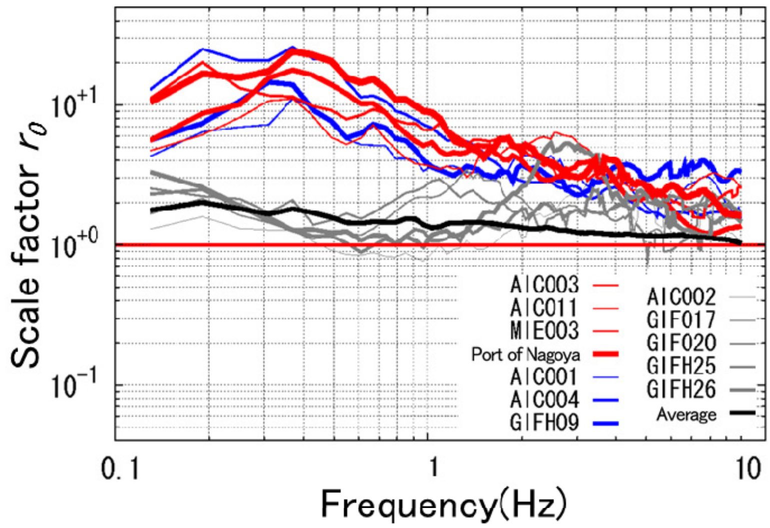
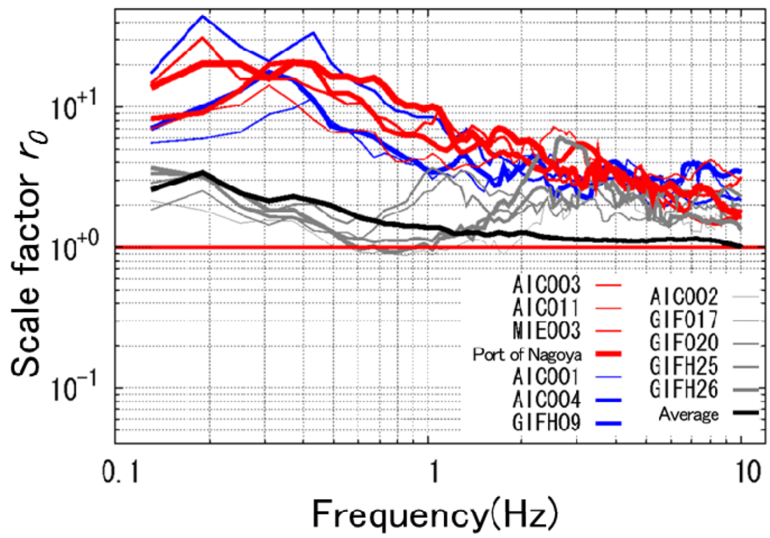


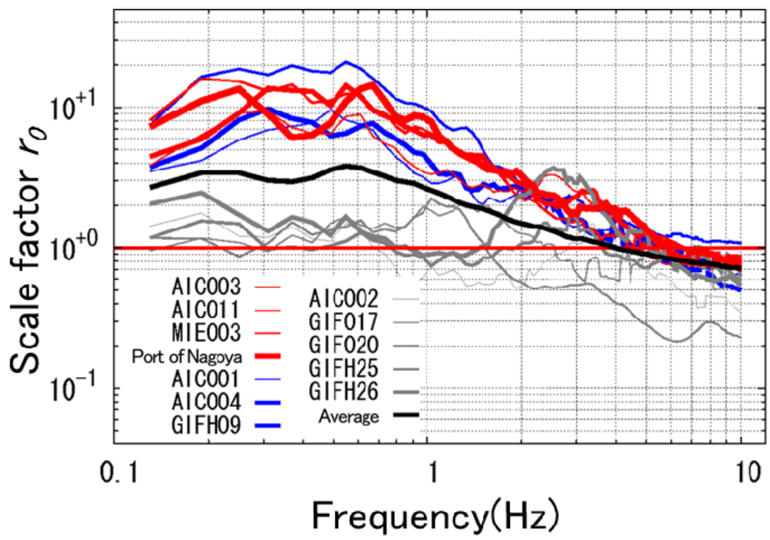
Figure 4.2. Comparison with the scale factor $r_0(f_k)$ at the Port of Nagoya



(a) 2004/09/05 19:07, M7.1 (The off the Kii Peninsula Earthquake)



(b) 2004/09/05 23:57, M7.1 (The off the Tokaido eartuquake)



(c) 2007/03/25 09:41, M6.9 (The Noto Hanto Earthquake in 2007)

Figure 4.3. Comparison with the scale factor $r_0(f_k)$ at the Port of Nagoya

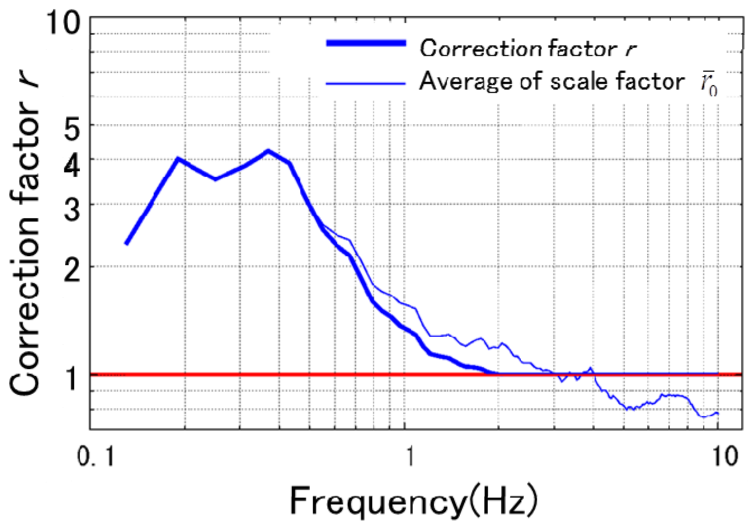


Figure 4.4. Estimated correction factor r (f_k) at the Noubi Plain.

4.2. Simulation of Strong Motion

The long period-spectral characteristic due to the deep ground structure at the Noubi Plain was estimated in the preceding section. To use the correction factor, the earthquake motion that assumed of Tokai and Tounannkai coupled earthquake is simulated. Figure 4.5 shows the location of the Port of Nagoya, and the fault model of Tokai and Tounankai coupled earthquake. Figure 4.5 shows the comparison of acceleration time histories and fourier spectrum at the Port of Nagoya. For comparison, the fourier spectrum that was observed at the Port of Nagoya from the Tokaido earthquake, is shown Figure 4.6. As shown Figure 4.5, the simulated fourier spectrum based on estimated the correction factor is improved.

5. CONCLUSIONS

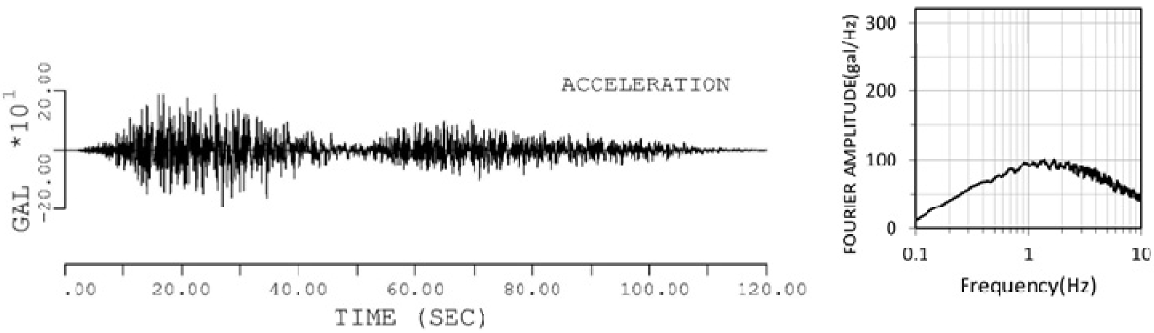
In this study, the strong motion prediction technique that the long period-spectral characteristics was presented. The major results derived here may be summarized as follows.

1) The technique developed the long period-spectral characteristics due to the deep ground structure of local region. This technique improved on the strong motion prediction mode, EMPR (Sugito et al., 2000).

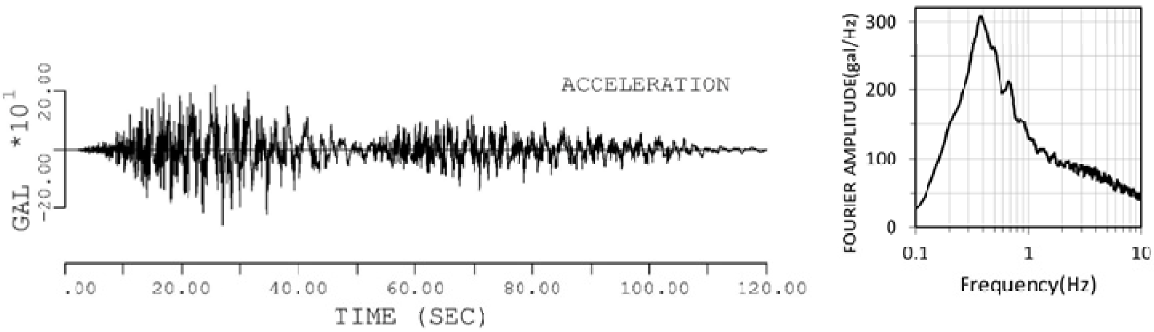
2) In the presumption of the long period-spectral characteristics, the scale factor based on EMPR, is use. The correction factor $r(f_k)$ is calculated by the evolutionary power spectra from the observed strong motion record, and EMPR which corresponds to the M=6.0.

3) The proposed technique was applied for the Noubi Plain of the Tokai district. For simulation of earthquake motion of the ocean trench earthquake in the Nankai Trough region, the long period-spectral characteristics in this area was estimated. As the result, the Noubi Plain has the dominant frequency that the frequency bands are 0.2Hz to 0.4Hz.

4) Using the estimated spectral characteristics that the correction factor $r(f_k)$ was estimated from strong motion records, the earthquake motion due to the period characteristics of several seconds was able to simulate.



(a) Simulated by EMPR



(b) Simulated by EMPR (using the estimated spectral characteristics at the Noubi Plain)

Figure 4.5. Comparison of acceleration time histories and fourier spectrum at the Port of Nagoya

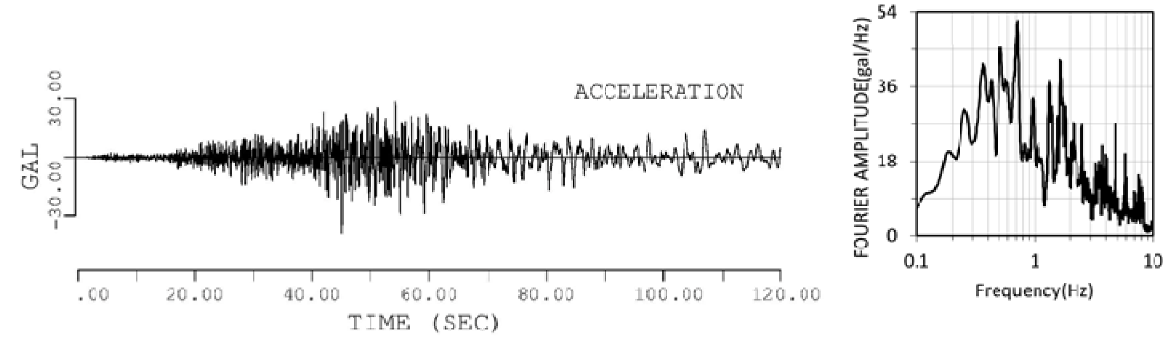


Figure 4.6. Recorded fourier spectrum at the Port of Nagoya (The off the Tokaido eartuquake, EW)

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