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Ground motion study by fault model for tall building design

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ABSTRACT:This paper presents an evaluation methodology of strong ground motion based on a earthquake fault model for seismic design of high-rise buildings on soft alluvial soil. Two kinds of analytical methods are applied to three of past or hypothetic earthquakes. One is a semi-empirical method using ground motion records of small earthquakes. The other is a superposition method of normal modes in multilayered elastic media, using earthquake fault parameters. The proposed method is rational from the viewpoint of taking into account the local site conditions regarding seismology and geology, and is more advanced in comparison with the conventional method used in Japan. The evaluated strong ground motions were applied as an input ground motion for the seismic design of a 33-story reinforced concrete building which is to be constructed in the Tokyo Bay area.

1. INTRODUCTION

Recent development of the water front in the big cities in Japan demands the land use of coastal area as the construction site for various buildings. Soil surface of almost all of these coastal area is soft alluvial layers with thickness of 30 meters or more. Consequently , more accumulated considerations into geology in the entire design procedure, especially for high-rise building, is necessary than before. This is because the effect of surface geology governs the dynamic behavior of the building structure as well as the ground motion itself.

The guideline by the High-rise Building Appraisal Committee established in The Building Center of Japan (BCJ) specifically recommends several earthquake records as design ground motions adaptable to high-rise buildings, although requesting to consider the most destructive ground motion of the past empirical earthquake and/or the future theoretical ones. Recommended records include El Centro, Taft and Hachinohe among others. These were obtained during the 1940 Imperial Valley, the 1952 kern county and the 1968 Tokachi-Oki earthquakes respectively. It is also recommended, after defining that the ground motion is located on the ground surface, to adjust the maximum velocity to 40 to 50 cm/s irrespective of the site's geological conditions. This is attributed to the Japanese general consensus in the past that the high-rise building should be constructed on consolidated and firm ground with rigid foundation. However, seismological conditions are not reflected too much.

Under the aforementioned circumstances, therefore, it became an urgent matter to establish a rational method to evaluate and decide the design ground motions for a high-rise building in the light of geological and seismological knowledge of the construction site. This paper describes the whole procedure to evaluate the design ground motion for a 33-story building constructed in the Tokyo Bay area of which surface ground is deep alluvial soil. The methodology developed and used in this paper is applicable to seismic design in general.

2. EVALUATION METHOD

At the present, a great amount of seismological and geological information, such as the focal source mechanism of destructive earthquakes, strong-motion observation records and geological survey results, have been accumulated regarding the Tokyo Bay area. Various analytical tools using computers are also available. With consideration to such research background, the strong ground motion evaluation based on a fault model should be more applicable for practical use than BCJ recommendations.

From this viewpoint, an evaluation methodology of strong ground motions for seismic design of high-rise building on soft alluvial soil is proposed as shown in Figure 1. These strong motions are first evaluated as an incident wave on the surface of consolidated and stiff diluvial deposits beneath the alluvial deposits spreading under the Tokyo Bay area.

The methodology has several advantages for the design of buildings by;

1) specifying the subject earthquakes taking into account of seismological information,

2) using an earthquake fault model,

3) evaluating the ground motions on the surface of a bearing stratum such as the stiff diluvial deposits,

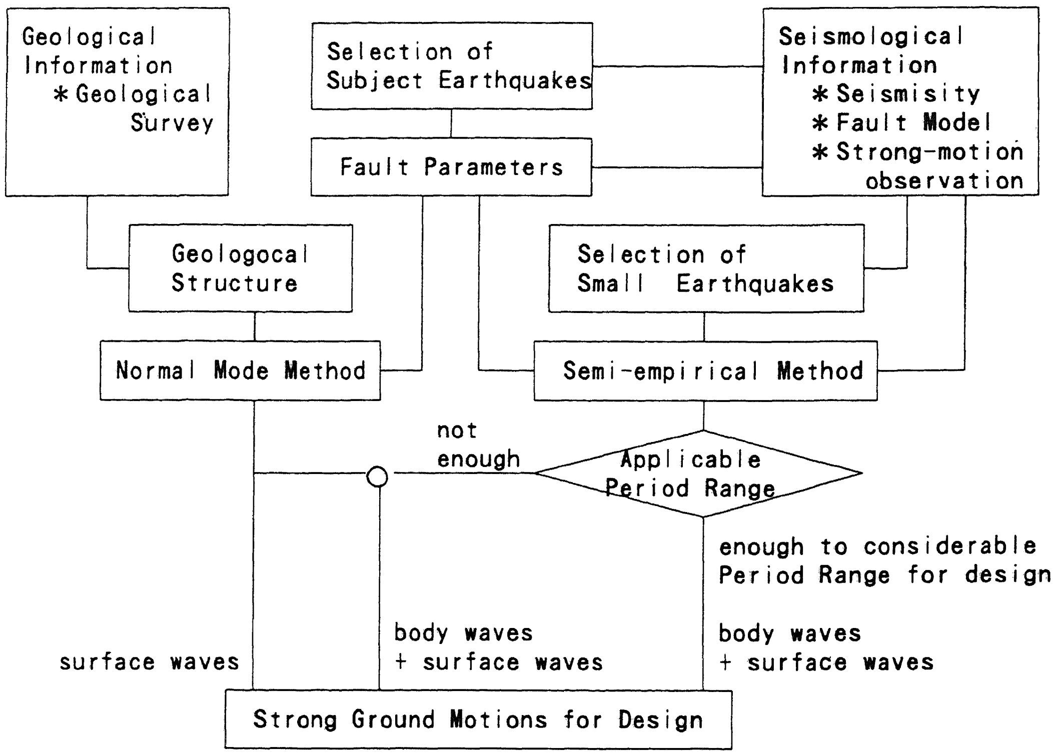


Figure 1. Flow chart of evaluation methodology of strong ground motions for seismic design of highrise buildings

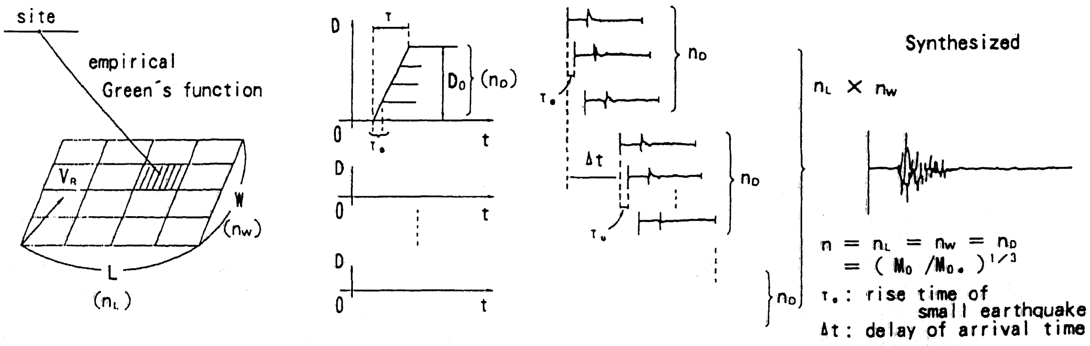


Figure 2. Schematic procedure of semi-empirical method

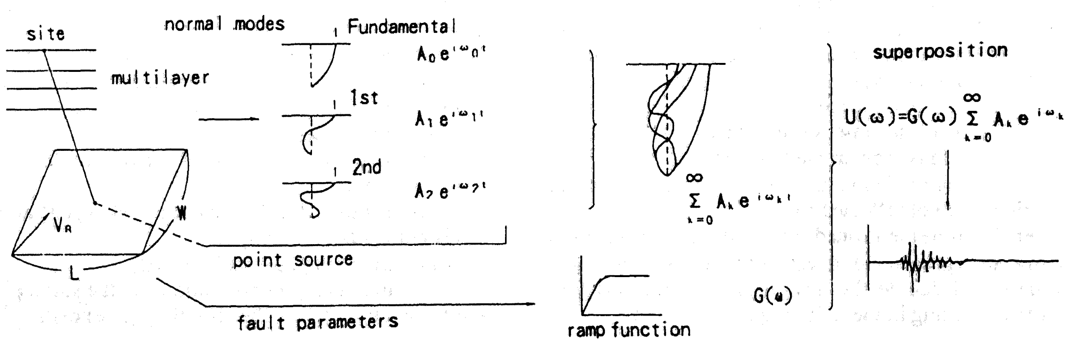


Figure 3. Schematic procedure of normal mode method

4) making easy to take into account the non-linear behavior of soil and soil-foundation-building interaction system for dynamic analyses, and, consequently,

5) making possible to take into account of local site conditions on seismology and geology.

A semi-empirical method (Takemura & Ikeura, 1988) is applied in order to evaluate the strong ground motions during large earthquake, using the records of small earthquakes as an empirical Green's functions from the fault to a site. The schematic procedure of this method is expressed in Figure 2. The synthesis of the strong ground motion is produced by considering stochastic irregularity of the fault plane. An applicable period range of the synthesized motion is restricted by that of the ground motion records of the small earthquakes, and ground motion records include long period component errors caused by the degree of signal/noise ratio. For this reason, another method to evaluate the long period characteristics of the strong ground motion is introduced for comparison. The method is, as shown in the schematic procedure in Figure 3, the superposition of normal mode solutions in multilayered elastic media, taking into account the earthquake fault parameters.

As this method is based on a far-field approximation solution for a point source, it is important to adequately evaluate the analytical conditions with regard to the element size on the fault plane (Nozawa et al. 1990) as well as the contributory minimum distance from the fault to the site .

3. SUBJECT EARTHQUAKES

Three subject earthquakes are selected as being the guideline in which the most destructive strong ground motion in the past and future against a site should be considered. Figure 4 shows locations of the fault models, together with the location of the applicable site and the small earthquakes which are described later.

The earthquake A is the 1885 Ansei-edo Earthquake and is recognized one of the most destructive historical earthquakes that occurred just under the Tokyo Bay area. The epicenter is estimated by Usami(1976), and the fault parameters are proposed by Kawasaki(1987).

The earthquake B is the 1923 Kanto Earthquake and is recognized the most destructive earthquake occurred in the subduction zone around the Tokyo Bay area. Though several kinds of fault parameters of this earthquake are estimated geodetically and seismologically, the fault parameters seismologically estimated by Kanamori(1974) are applied to this study.

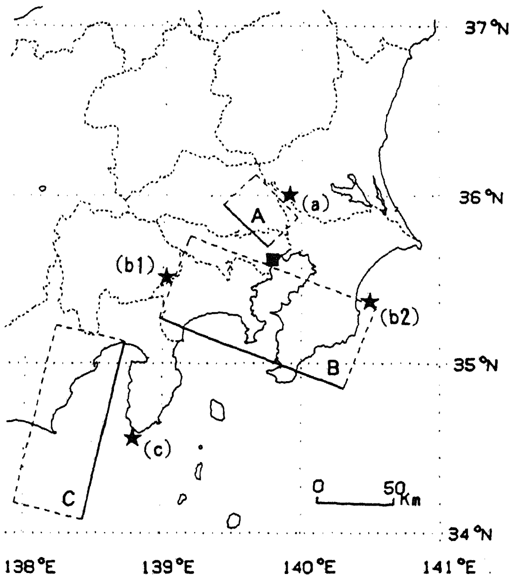


Figure 4. Location of subject earthquake faults and epicenters of small earthquakes. [Note : □; subject earthquake, ■ ; site, ★ ; small earthquake]

Table 1. Fault parameters of the subject earthquakes

earthquake	magnitude (M_{JMA})	length (km)	width (km)	dip (°)	rise time (sec)	rupture velocity (km/s)	seismic moment (dyne · cm)
A:1855 Ansei-edo	6.9	40	30	20	2.5	2.3	0.4×10^{27}
B:1923 Kanto	7.9	130	70	34	5.0	3.0	7.6×10^{27}
C:hypothetic Tokai	8.0	120	50	20	8.6	2.7	9.0×10^{27}

Table 2. Fault parameters of small earthquakes

earthquake	magnitude (M_{JMA})	depth (km)	seismic moment (dyne · cm)
(a) :1974 Southwest of Ibaraki	5.8	50	7.94×10^{24}
(b1) :1983 Kanagawa-Yamanashi border	6.0	22	3.71×10^{24}
(b2) :1987 East off Chiba	6.7	58	9×10^{25}
(c) :1974 Off Izu peninsula	6.9	10	5.9×10^{25}

The earthquake C is the hypothetic Tokai Earthquake and is recognized among the seismologists as the most affective earthquake having the long period components despite of the long distance from the site. As long period ground motions are important for the 33-story building, this earthquake is also selected. The fault parameters are proposed by Ishibashi(1981).

The fault parameters of these earthquakes are listed in Table 1.

4. RESULTS

4. 1 *Semi-empirical method*

As this method uses the records of ground motions of small earthquakes as the empirical Green's function from the fault of an earthquake to a site, the small earthquakes are required to satisfy the following conditions:

1) similarity of source mechanism
2) similarity of seismic wave propagation path from a source to a site

Four small earthquakes were selected among the data base of the ground motion records. The locations of epicenter of small earthquakes (a), (b1), (b2) and (c) are shown in Figure 4 and these fault parameters are listed in Table 2.

Small earthquake of (a) is used for evaluation of the earthquake A, and small earthquakes of (b1) and (b2) are for the earthquake B, and small earthquake of (c) is for the earthquake C respectively. As for the earthquake B, since the site is located over the fault plane and the wave propagation paths differ between the west side and the east side of the fault plane, two small earthquakes of (b1) and (b2) are necessarily selected as the Green's functions from the west and the east.

The ground motion records used are applicable to the period range of less than about five seconds for small earthquakes (a), (b1) and (b2), and less than ten seconds for small earthquake (c) respectively, depending on the signal/noise ratio of long period component.

Since the records of small earthquakes were obtained on the soft deposits, it is necessary to correct the response characteristics of the upper soft deposits on the stiff deposits for the ground motion records of small earthquakes The inverse response analysis based on one dimensional wave propagation theory is applied in order to evaluate the strong motion on the surface of the stiff deposits.

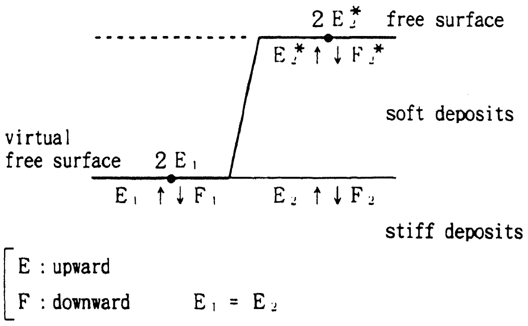


Figure 5. Schematic expression of inverse response analysis on the records of small earthquake

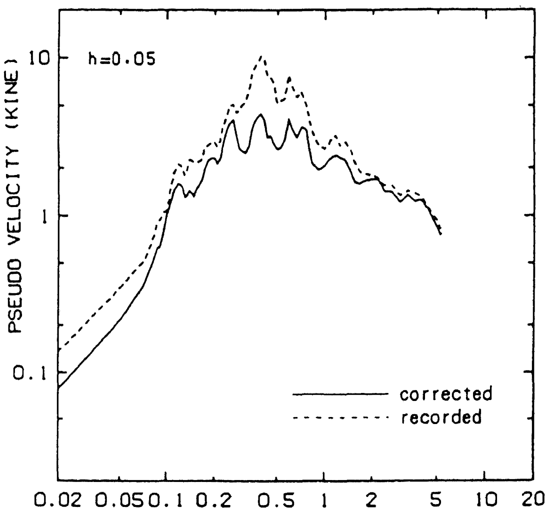


Figure 6. Comparison of response spectra between ground motion ($2E_2^*$)record on the surface of the site and incident ground motion ($2E_1$) on the stiff deposits estimated by inverse response analysis in the case of the small earthquake (a). Longitudinal axis is pseudo velocity amplitude of 5% damping.

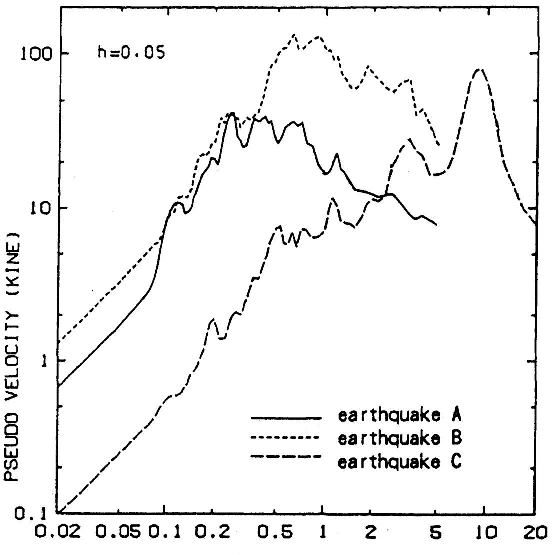


Figure 7. Pseudo velocity response spectra of 5% damping of the evaluated strong ground motions on stiff deposits at the site by the semi-empirical method.

The schematic expression of this procedure is shown in Figure 5 and the result of the small earthquake (a) is shown in Figure 6 as an example.

Synthesis of strong-motions is produced in conformity with the scaling law of fault parameters. Probabilistic parameter S_D which shows the degree of heterogeneity of displacement on the fault plane is selected to be 1. 0 which is led by the simulation analyses of eight large earthquakes(Takemura & Ikeura, 1988).

The response spectra of the evaluated strong ground motions are shown in Figure 7.

4. 2 *Normal modes superposition method*

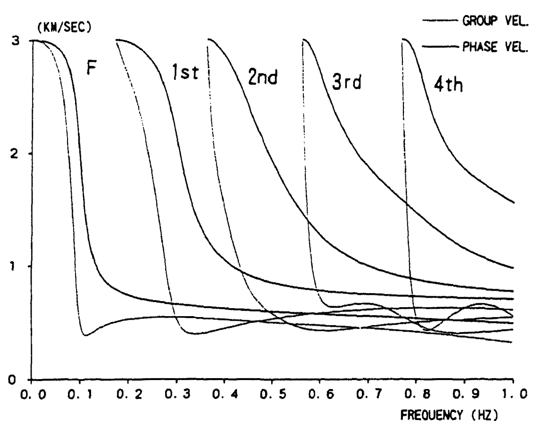
This method is applied in case of surface waves in long period components where the applicable period range is approximately from 1 to around 20 seconds. Table 3 shows the geological structure model around the Tokyo Bay area. The geology of the site is modeled from the soft surface deposits. The top 20 meters of the model is simplified into one layer and the bottom layer lower than 2. 3km in depth is assumed as half space. Figure 8 shows dispersion curves of Love wave and Rayleigh wave. Fundamental to fourth mode solutions by dispersion analyses are taken into account to evaluate the ground motions.

The contributory minimum distance from the fault plane to the site is regarded as one wave-length or absolutely 10 km, since this method is based on the far-field approximation solution. Consequently, the subject earthquake A should not be evaluated because of being out side of applicability.

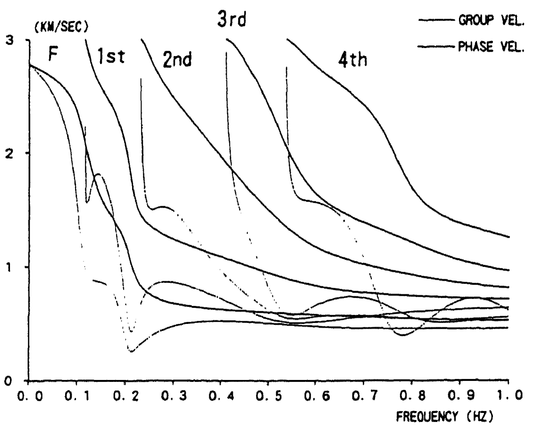
The evaluated ground motions depend on the size of the element on the fault plane. If the size is too large, the ground motions will contain unexpected effects of inhomogenous of faulting(Nozawa et al. 1990). In order to decide the size of the element, a convergence procedure is employed in this study. As the result, the faults of earthquakes B and C are divided in 52 × 32 and 48 × 24 taking into account the applicable period range longer than about one second. Figure 9 shows response spectra of ground motions at the site by the normal modes superposition.

Table 3. Analytical model of geological structure around the Tokyo bay area

depth (km)	geology	P-wave Velocity (km/s)	S-wave Velocity (km/s)	density (g/cm^3)
0.02	Alluvial	1.5	0.14	1.64
0.035	Diluvial	1.6	0.30	1.86
0.07	Diluvial	1.7	0.43	2.0
0.4	Pliocene	1.8	0.58	2.0
1.5	Pliocene	1.8	0.7	2.0
2.3	Miocene	2.8	1.5	2.2
	Oligocene	5.6	3.0	2.5



LOVE WAVE DISPERSION CURVE



RAYLEIGH WAVE DISPERSION CURVE

Figure 8. The results of dispersion analysis of Love wave and Rayleigh wave.

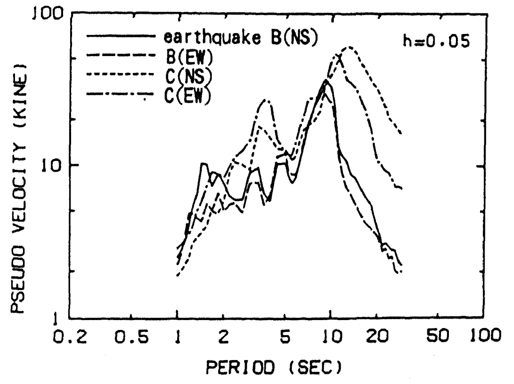


Figure 9. Pseudo velocity response spectra of 5% damping of the evaluated strong ground motions at the site by the normal modes superposition.

5. DISCUSSIONS

As to the results of the semi-empirical method in Figure 7, the characteristics of three strong ground motions on the surface of stiff deposits indicate their individual features, namely, shorter period components are predominant and maximum acceleration is high in the earthquake A, maximum velocity as well as maximum acceleration are high in the earthquake B, and longer period components are predominant in the earthquake C.

The results of the semi-empirical method for the earthquake C correspond to those of the normal mode method in the period range less than about 10 seconds where both methods are applicable. These results suggest that the ground motion during the earthquake C are mainly composed of surface waves at the site. For the earthquake B, the results of the normal mode method indicate that the ground motions of surface waves are predominant in a period range from 7 to 12 seconds where the semi-empirical method is out side of applicability.

The specific ground motions recommended by the committee are defined on the ground surface at the site. Consequently the results of the normal mode method can compare with the specific ground motions. On the other hand, the results of the semi-empirical method are necessary to transfer to the surface of the site by seismic response analysis of the surface deposits taking into account the non-linearity of soil. Figure 10 shows the results of seismic response of the surface deposits at the site for the earthquake B and the results of the normal mode method for the earthquakes B and C, together with the specific ground motions. The special features of the earthquakes B and C cannot be expressed by the specific ground motions which have been used conventionally in Japan.

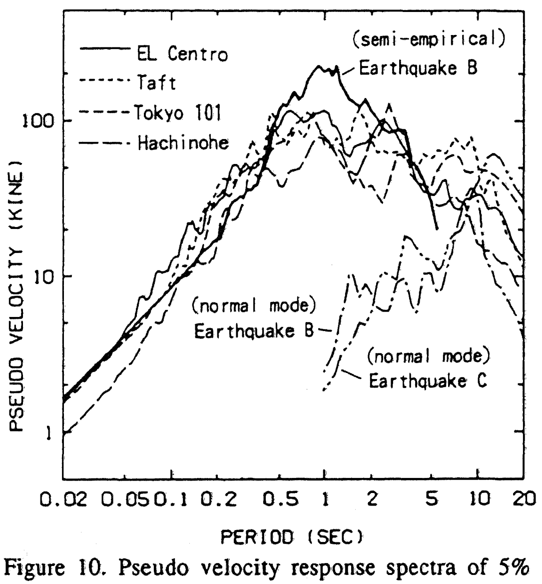


Figure 10. Pseudo velocity response spectra of 5% damping of the specific strong ground motions recommended by the committee in The Building Center of Japan .Maximum velocity of each strong ground motion is adjusted to 50 cm/s.

Since the first natural period of the 33-story building is about two seconds in elastic analysis, the evaluated strong ground motion of the earthquake B, which is the 1923 Kanto Earthquake, is employed as the input ground motion for the seismic design. It is the most destructive against a building in considerable period range even if the elasto-plastic condition of the subject building is taken into account.

6. CONCLUSIONS

It is important to take into account the local site conditions in evaluation of the strong ground motion for the seismic design of a high-rise building on soft ground. The proposed methodology is more advanced in comparison with the guideline recommended by the High-rise Building Structure Appraisal Committee established in The Building Center of Japan from the viewpoint of seismic disaster prevention of the coastal region. In order to evaluate the strong ground motion in other areas where sufficient seismological and geological information are not available, the earthquake observation and the geological survey in broader and denser scale are awaited.

REFERENCES

Ishibashi,K.1981. Specification of a soon-to-occur seismic faulting in the Tokai district, central Japan, based upon seismotectonics:Maurice Ewing Ser. Vol.4, Am. Geophys. Union:297-332

Kanamori,H.1974. Long-period ground motion in the epicentral area of major earthquakes : Techtono-physics Vol.21 :341-356

Kawasaki, I., K.Matsuda. 1987. Study on seismic activity and prediction in and around Kanto plain: Special report on natural disaster science sponsored by Ministry of Education, Japan, No.A-61-2:156-170 (in Japanese)

Nozawa,T., A.Fukuoka, F.Sasaki & K.Kudo. 1990. Evaluation of longer period seismic motion than 2.0 sec based on the normal mode superposition Part 1. The effect of the moment release at each element : Summaries of technical papers of annual meeting Architectural Inst. of Japan 1990 : 265-266

Takemura,M., T.Ikeura. 1988. A semi-empirical method using a hybrid of stochastic and deterministic fault models ; Simulation of strong ground motions during large earthquake, Journal of Physics of the Earth Vol. 36 : 89-106

Usami,T.1976. Investigation of the Edo Earthquake of November, 11, 1855 by newly collected old documents: Bull. Earthq. Res. Inst. Vol. 51:209-230