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EVALUATION OF EARTHQUAKE MOTION FOR NUCLEAR POWER PLANT ON QUATERNARY DEPOSIT

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ABSTRACT

The purpose of this papers is to describe the evaluation of the earthquake motion on the Quaternary deposits. In order to investigate seismic safety of the structure to be constructed on the Quaternary deposits which are softer comparing to bedrock, it has become necessary to confirm properties of the earthquake motion propagating in the Quaternary deposits. Earthquake motion records of vertical array observation including the Quaternary deposits have been collected to estimate the response spectrum on the Quaternary desposits. The response spectrum on the Quaternary desposits was obtained from regression analyses of response spectra concerning the magnitude and the hypocentral distance. The calculated response spectrum on the Quaternary desposits has a similar tendency to the current standard response spectrum defined on the outcropping bedrock for the rock siting in the short period domain. However, in the long period domain, the value of the velocity component of the tentative response spectrum is larger than that of standard response spectrum due to the amplification of the Quaternary deposits. Authors are going to further collect earthquake motion records to contribute on the evaluation of the earthquake motions for siting nuclear power plants on the Quaternary deposits.

KEYWORDS

Quaternary Deposits, Nuclear Power Plants, Vertical Array Observation, Design Basis Earthquake, Regression Analyses, Standard Response Spectrum, Tentative Response Spectrum

INTRODUCTION

In Europe and America,nuclear power plants have been built on the Quaternary Deposits in many cases, while, in Japan, they have been reguired to be built on bedrocks because of the high safety reliability for the frequent intensive earthquakes. Because of the limited bedrock sites,however,it is now considered to be necessary to establish new siting technologies on the Quaternary deposits to cope with the siting problems in a long term. The Nuclear Power Engineering Corporation is investigating the seismic safety of the reactor building and the plant equipments and the foundation soil stability on the Quaternary deposits in cooperation with the academic and the industrial circles at the request of the Ministry of International Trade and Industry of Japan who projects to establish the draft of guidelines on seismic safety design of the nuclear reactor buildings on the Quaternary deposits. The properties of the earthquake motions on the Quaternary deposits are considered quite different form those on bedrocks. In order to evaluate the earthquake motions to be applied to the Quaternary deposits, this papers describes the analytical studies based on the earthquake records obtained in the Quaternary deposits.

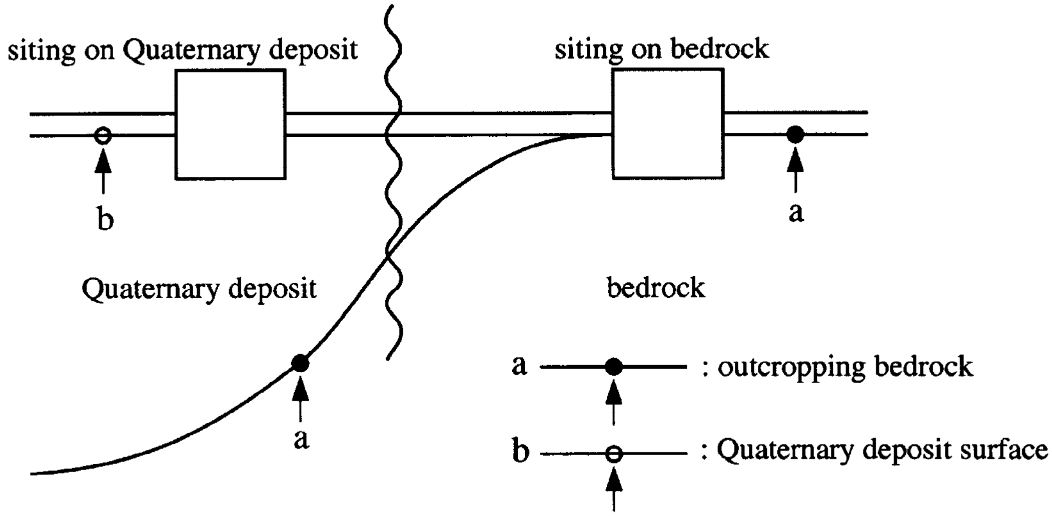

Fig. 1. Evaluation methods for earthquake ground motion

ANALYTICAL METHODS

In case of studying the seismic safety of the buildings on the deposits softer than bedrocks like the Quaternary deposits, it is necessary to consider changing properties of earthquake motions which propagate through the Quaternary deposits as well as the non-linearities to be caused by the increased soil strain during a large earthquake. As shown in Fig. 1,the following two methods can be useful for the evaluation of the earthquake motions to be used for earthquake response analyses.

a) to utilize the standard earthquake motions defined on the outcropping bedrock
b) to set up the response spectrum on the Quaternary desposits based on the observed earthquake records in the Quaternary deposits

The former method is the one ordinarily utilized in Japan where bedrock siting is mandatory and can be positioned as an extended idea of it. In case of bedrock siting, it will be easily possible to input the earthquake motions from the outcrop even if the outcrop is deeper than the building foundation level. In case of the Quaternary deposit siting, however, the rock stratum which are considered to the outcrop in bedrock siting, will presumably be too deep to input the earthquake motions. In that case, considerably difficult problems have to be resolved, like evaluating the amplification properties in the thick deposit layer or considering the effect of inclination of bedrocks.

The latter method, therefore, was studied for this project, where the earthquake motions of the Quaternary deposits on which reactor buildings are to be built, were set based on the observed records on the same deposits; and the following items were surveyed and discussed.

1) collection of the earthquake records observed in the Quaternary deposits
2) elimination of the influence of the surface layers above the diluvial observatories by multi-reflection
3) calculation of the response spectrum on the surface of the Quaternary deposits
4) calculation of the artificial earthquake motion

RESULTS

Collection of the earthquake records observed in the Quaternary deposits

Soil condition. As earthquake observation records to identify amplification and response spectrum properties in the Quaternary deposits, acceleration records were collected at the several observatories in Japan. The soil condition to be collected the earthquake records were the diluvial sandy gravel layer with Vs=300-450m/s on

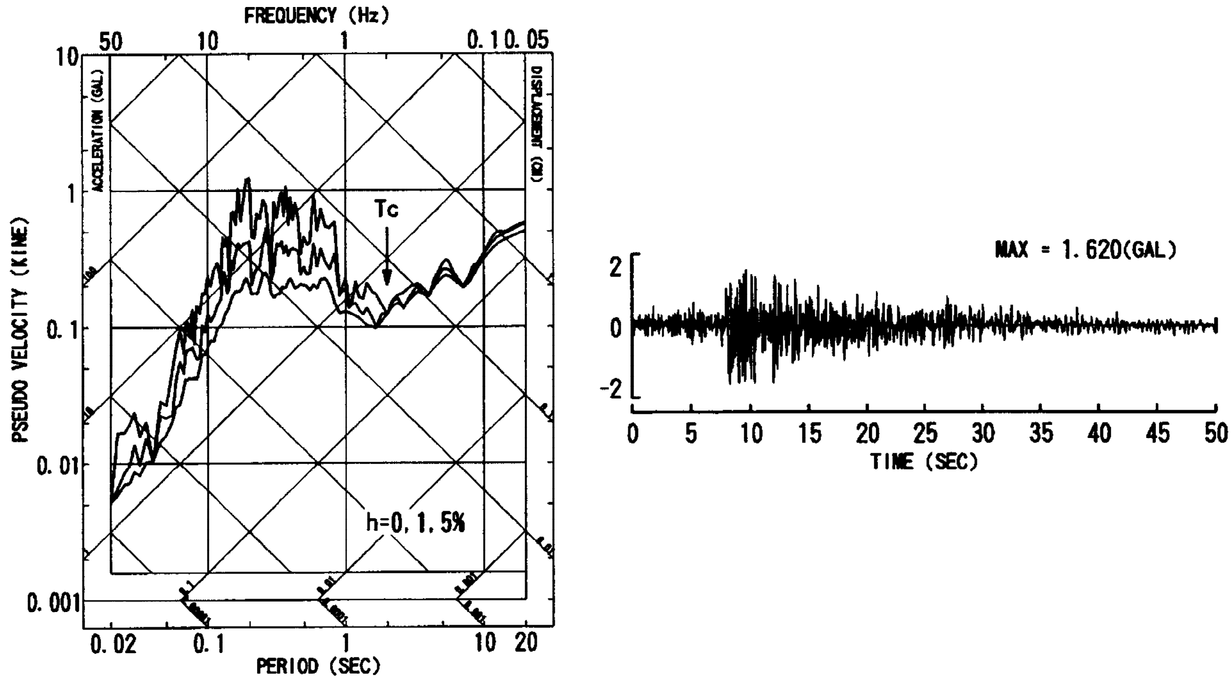

Fig. 2. Response spectra of acceleration record in tripartite showing long period noise

the Quaternary deposits. As generally observed earthquake records of the Quaternary deposits were mostly those observed in the diluvial layer, except for the records observed on the surface of the diluvial layer or near its surface, the collection includes only the records obtained by vertical array observation including the observatories in diluvial layer deep in the earth. In order to study the amplification properties of the diluvial layer, detailed seismic surveys were conducted on the observation site to confirm their soil profile like the secondary wave velocity Vs and density ρ of soil.

Discussion on long period noise. The Quaternary deposits own a longer dominant period compared to bedrocks. It is necessary to discuss on the long period in the range of several seconds and to eliminate earthquake motions with long period noise from the collected records. Describing the response spectrum of the acceleration record in tripartite, the reliable period Tc is confirmed, where the response spectrum comes right side up at around the long period area as shown in Fig. 2. In most cases,these are the long period noise influenced by the acceleration sensitivity of the recorder or microtremor, and the noise levels will vary depending on the observatories or measuring conditions. Namely, Tc expresses the limit of reliability for long period of the recorded earthquakes. Here selected are the records with the reliability of more than Tc=5sec.

Earthquake observation records selected for analyses. The earthquake observation records for analyses were selected from the collected records in the light of the following conditions:

a) The records shall be obtained from the observatories with a soil profile confirmed.
b) The records shall own the reliability of more than 5 sec. from the results of studying on long period noise of response spectrum.
c) The records shall be of the magnitude M(in JMA scale) more than 5.5 and of the hypocentral distance X within 200km.

The Table 1. shows the selected 78 records obtained at seven different observatories. The Fig. 3. shows the distribution of the magnitudes and hypocentral distances.

Elimination of the influence of the surface layer above the diluvial observatories by multi-reflection

It is desirable to obtain the records on the Quaternary deposits to set the design earthquake motions for the

Table 1. Observatory and number of earthquake records

	OBSERVATORY	DEPTH	Vs (Diluvium)	NUMBERS OF RECORDS
A	OHJI	GL-30m	360m/s	24
B	SHIINAMACHI	GL-27m	430m/s	32
C	SHIBAURA	GL-20m	380m/s	4
D	MINAMISUNA	GL-44m	355m/s	2
E	TADOTSU	GL-20m	330m/s	4
F	FUKUSHIMA	GL-4m	330m/s	8
G	KIYOSE	GL-7m	370m/s	4

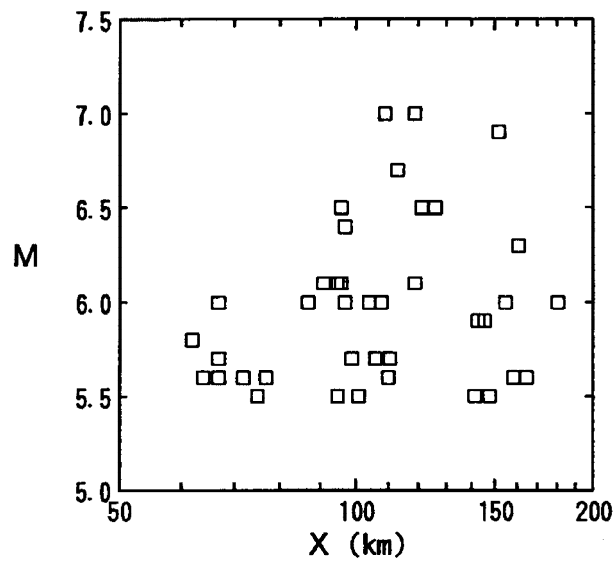

Fig. 3. Relation between magnitudes M and hypocentral distances X

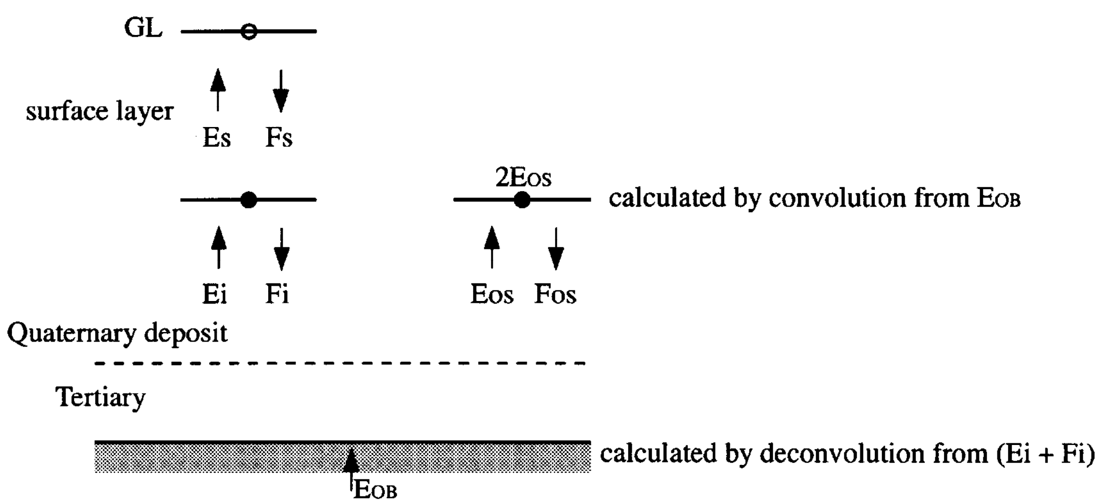

Fig. 4. Method for elimination of surface layer effects

siting on the Quaternary deposits. However, the records obtained are mostly from within the diluvial layer in the earth as shown in Table 1. It, therefore, is necessary to analytically remove the influence of multi-reflection in the surface layer above the diluvial observatories and to convert the observed records to assumed earthquake motions on the surface of diluvial layer. The method to eliminate the influence of the surface layer is shown in Fig.4. Assuming that the observed records can be explained by multi-reflection theory of SH wave, incident motion E_{OB} on the base rock were tried to be induced by means of deconvolution from the records of diluvial layer. Then, this incident motion was set into the soil model without surface layer to obtain responses on the assumed the Quaternary deposits' surface and as a result, the earthquake motion 2Eos was obtained on the surface of the diluvial layer.

Examples without the influence of surface layer are shown in Fig. 5. The figure also shows the comparison of the observed earthquakes in the deep of the Quaternary deposits and the analytically obtained earthquake motions on the assumed the Quaternary desposits' surface together with the respective response spectra. The analytically obtained response spectrum's amplitudes eliminating the influence of surface layer are two times larger comparing to the records of the Quaternary deposits in the side of shorter period than the fundamental of surface layer.

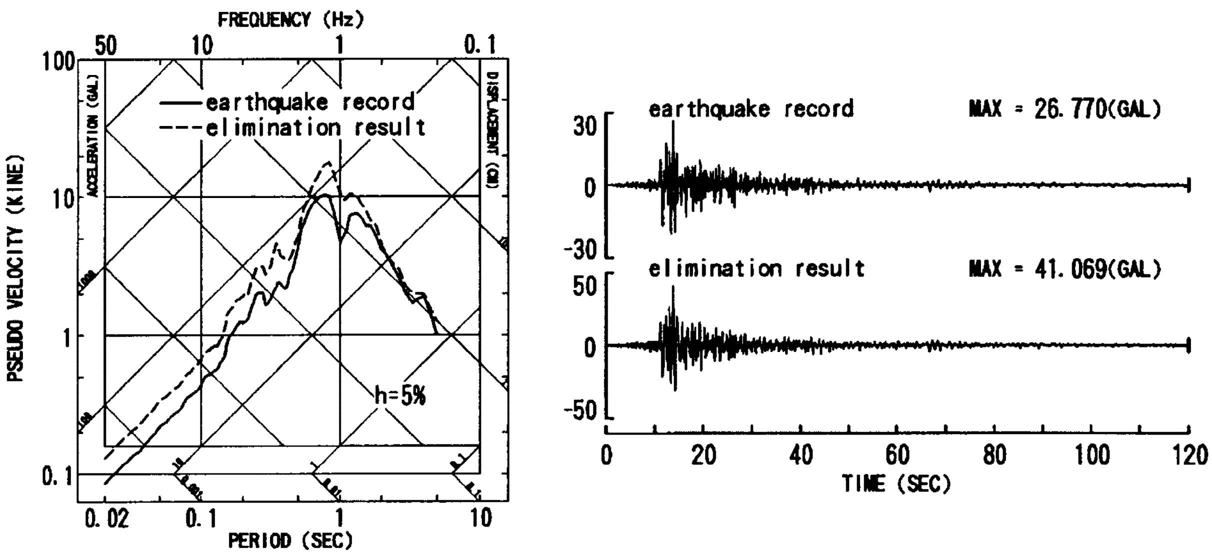

Fig. 5. Comparison between earthquake record and the elimination result of the surface layer influence

Calculation of the response spectrum on the surface of the Quaternary deposits

Regression analyses were conducted for calculation of response spectrum from the collected 78 earthquake motions obtained at the seven observatories. The following equation was used for the regression analyses.

$$\log S(T)=a(T)M-[b(T)Xeq+\log Xeq]+ci(T) \quad (1)$$

where, a(T), b(T) and ci(T) are the regression coefficients achieved by the regression analyses; a(T)is the coefficient of the magnitude M representing the scale of the earthquake; b(T), the coefficient of the equivalent hypocentral distance Xeq and the both coefficients are in common for all the observatories; ci(T), the coefficient representing the soil amplification from the base rock at each observation site and has to be achieved for each different observatory. The equivalent hypocentral distance Xeq which is considered to be applied to the near field of the earthquake focus, can be achieved from the following equation:

$$Xeq = \frac{R}{\sqrt{\ln\left[1+(R/Xc)^2\right]}} \quad (2)$$

$$R=10^{0.5M-2.28} \quad (3)$$

where, R represents the radius of the fault plane being assumed as a circle. The Xc represents the distance from the center of the fault to the observatory. Many of the observed records used for this analysis are of rather small earthquakes and of rather long distance earthquakes, the area of the fault plane could be disregarded compared with the Xc and could be assumed that the hypocentral distance X would be almost the same as Xc. The equivalent hypocentral distance Xeq derived from the equation (2) becomes larger compared to the Xc as the fault plane becomes larger.As the result, the equation (1) can represent the earthquake motion which hit ceiling at around the near field as a phenomenon.

Fig. 6. shows the regression coefficients derived from the regression analyses. The broken-line in Fig. 7. represents the first tentative response spectrum on the Quaternary desposits from the averaged response spectra at the seven observatories obtained by substituting those regression coefficients to the equation (1) assuming M=8.0 and X=50km. The first tentative response spectrum are those from the regression analyses in 1992 using 78 earthquake motions of the seven different observatories. Thenafter, in order to improve the reliability of the regression analyses, more data have been collected to be increased to 124 earthquake motions from 14 different observatories for analyses. The second tentative response spectrum in solid line are from 1994 analysis conducted

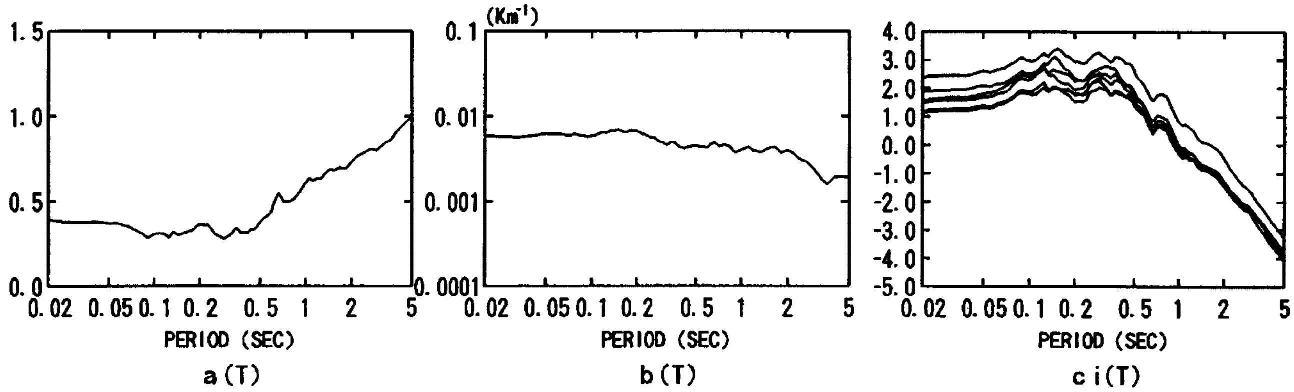

Fig. 6. Regression coefficients a(T), b(T) and ci(T)

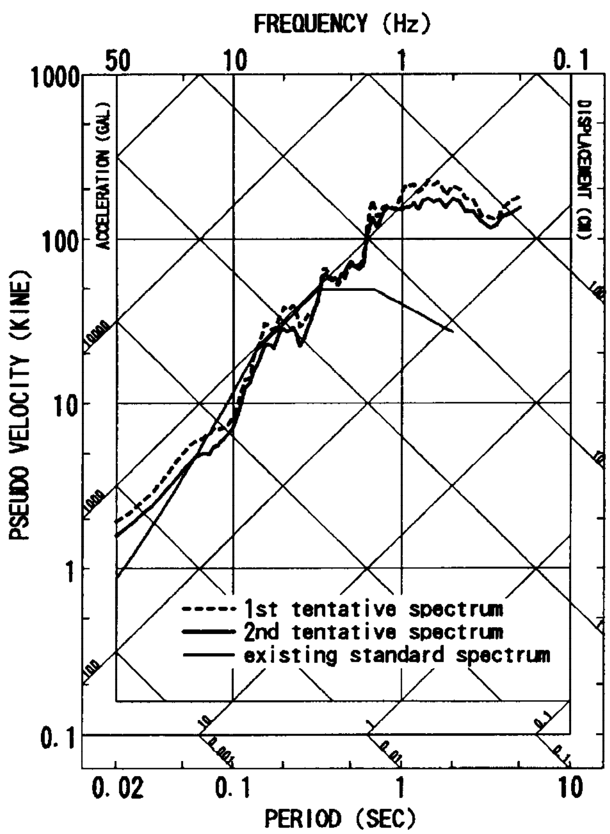

Fig. 7. Tentative response spectra on the Quaternary deposits (h=5%)
M=8.0, X=50km(Xeq=60.9km)

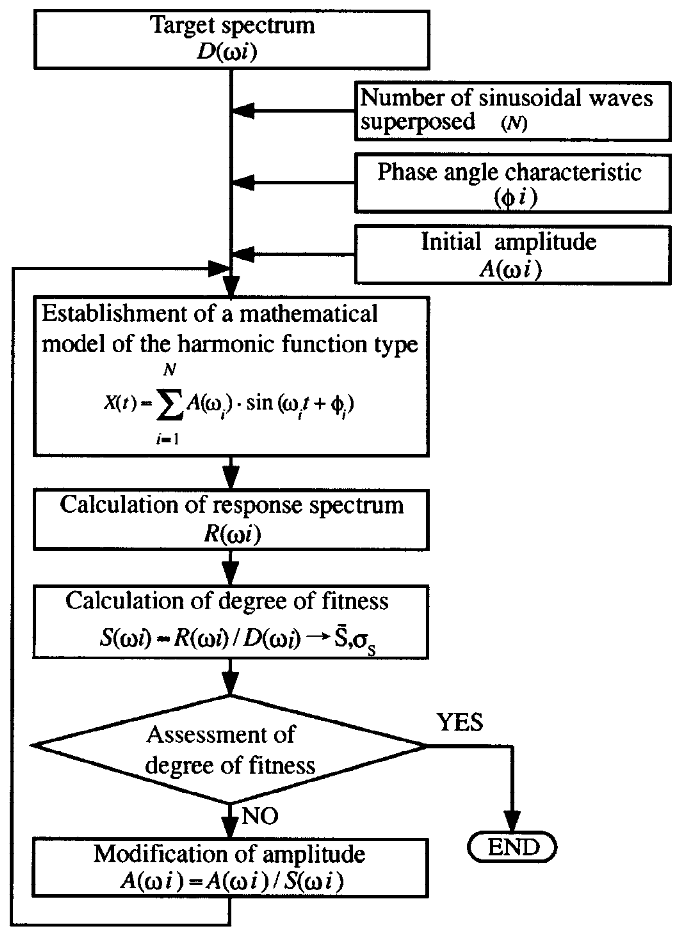

Fig. 8. Flow chart for generation of artificial waves

after the aforementioned discussions. The second tentative response spectrum are becoming rather smaller throughout the effective zones comparing to the first tentative response spectrum, showing milder curves. The figure also shows the current standard response spectra set on the bedrocks. The limit of long period reliability of the standard response spectra is regarded as within 2 seconds, however, the spectra for the Quaternary deposits are evaluated for up to 5 seconds as mentioned before. The standard response spectrum in the short period range of 0.3 seconds or less, shows a tendency of being equivalent or larger than those of the Quaternary deposits, however, in the range of long period, the response spectrum on the Quaternary desposits is evaluated considerably larger.

Calculation of the artificial earthquake motion

The artificial earthquake motion was calculated by means of spectrum fitting to the second tentative response spectrum as the target spectrum. The assumed earthquake is of M=8.0 and X=50km, and the calculation followed the flow in Fig. 8. Because the phase properties for calculation of the artificial earthquake motion are theoretically unresolved in many ways, the phase properties of the observed earthquake motion were applied as they were. Although it is ideal that the observed earthquake applied owns the similar condition to the assumed earthquake, it is very difficult to obtain such records. The Hachinohe records(X= 235km) with rather outstanding long period was selected from among those obtained at Tokachioki Earthquake(M=7.9, 1968.5.16) of which M value is closer to the assumed earthquake. The Fig. 9. shows the target spectrum of the second tentative response spectrum and response spectrum of the Hachinohe record in comparison together with the time history of the Hachinohe earthquake motion. Calculated earthquake motion was set on the Quaternary deposits' surface in accordance with the flow given in the Fig. 8. The Fig. 10. shows the response spectrum of the artificial earthquake motion together with the target spectrum. It is confirmed that the artificial earthquake motion fits well to that of the target spectrum. The Fig.11 gives the time history of acceleration motion derived by fitting.

CONCLUSIONS

The following conclusions were obtained from the analytical studies made by use of the earthquake records observed in the Quaternary deposits with the purpose of evaluating the applicable in-put earthquake motion to the nuclear power plant buildings on the Quaternary deposits.

1) The 124 earthquake records from 14 different observatories that are moderately distributed within the range

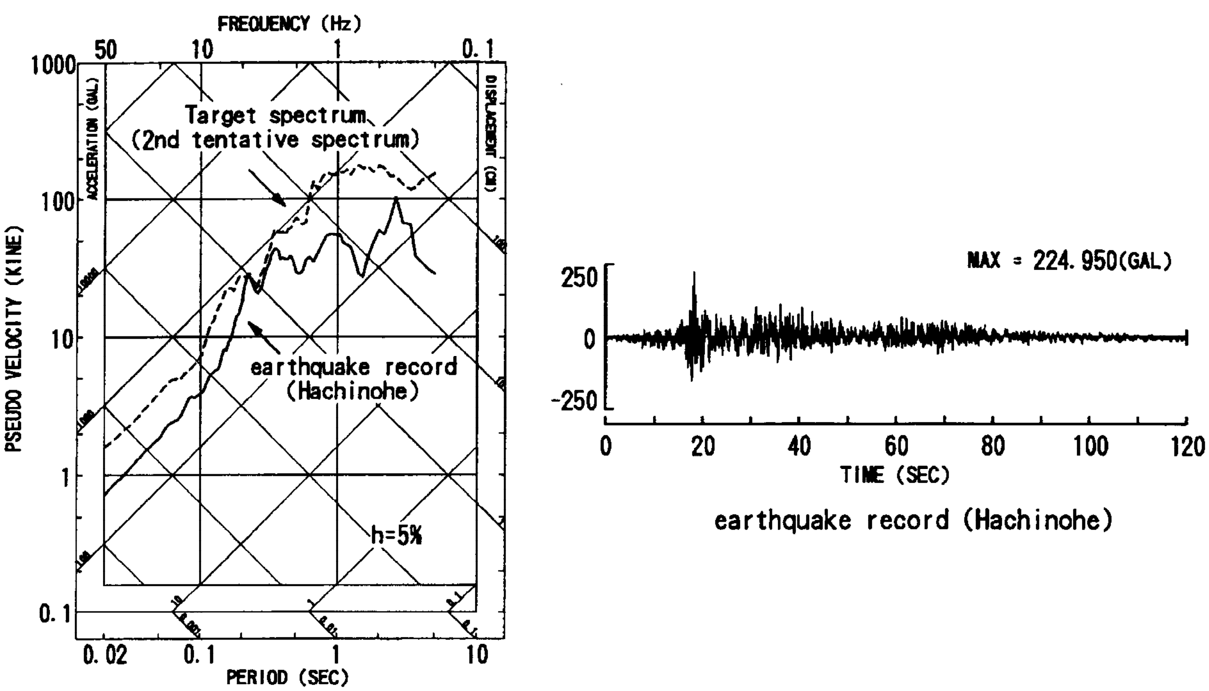

Fig. 9. Observed earthquake record for phase properties

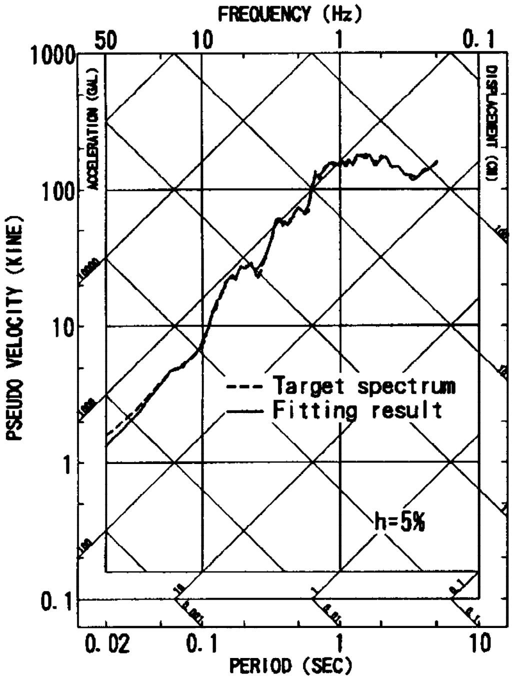

Fig. 10. Target spectrum and fitting result

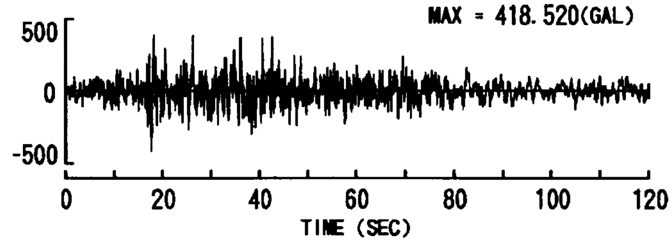

Fig. 11. Time history of an artificial earthquake acceleration motion fitting to the target spectrum

of magnitude M of 5.5 - 7.0 and the hypocentral distance X of 50 - 200km were selected from the collected records in various points of view like the soil condition of the observatory and long period noise discussion.

2) Tentative response spectrum of the Quaternary deposits' surface were obtained for the reference design of a nuclear power plant on the Quaternary deposits by assuming M=8.0 and X=50km in the regression formula applicable to the near field area of the hypocenter and by eliminating the influence of the surface layer from the observed point of diluvial layer deep in the earth.

3) In comparison with the tentative response spectrum set on the Quaternary deposits and the current standard response spectrum set on bedrocks, it was found that in the range of short period, both spectra correspond well, however, in the range of long period, tentative response spectrum gains substantially larger value being influenced by the amplification of the diluvial layer in the Quaternary deposits.

More earthquake records are going to be collected to contribute to develop the siting technologies of the nuclear power plants on the Quaternary deposits.

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