ESTIMATION OF EARTHQUAKE ENGINEERING BASEMENT AND SEISMIC RESPONSE ON NAGOYA CITY IN THE NOBI PLAIN, JAPAN

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SUMMARY

The Nobi plain, consist of the Nagoya City and surrounding area, has been repeatedly suffered from the destructive earthquakes in the past. So, it is very important to clarify the depth of earthquake engineering basement and the underground structure. Since there are only few data of underground structure in and around this area, the authors have attempted to investigate the ground structure extended to deep layer and seismic response at representative sits in Nagoya City. The depth of earthquake engineering basement was discussed from the comparison of spectral characteristics of earthquake motions with theoretical results based on the structure models. Consequently, it was suggested that the earthquake engineering basement should be settled at deeper depth than that considered up to this time. This may be exist at 400 to 1200m in depth, which corresponds to the upper boundary of the deepest layer with a shear wave velocity of 1300m/s. As for deeper layer than this, it is expected that new information will be obtained from the investigation about hot spring boring which is just now under executing.

INTRODUCTION

Totally about ten million persons live in the Nobi plain, and the Nagoya City, one of the largest city in Japan, of which population is over two million. The Nobi Earthquake (*M8.0*), which was the most destructive earthquake, happened at north direction of the plain in1891, and the Tonankai Earthquake (*M7.9*) in 1944 and the Mikawa Earthquake (*M6.8*) in 1945 were occurred at south direction of the plain. In addition, the plain is surrounded by many active faults such as the Yoro, the Sanageyama and the Ise-wan faults, etc.

After the 1995 Hyogoken-Nanbu Earthquake, it has been clarified that the deep ground structure strongly affected to the amplification characteristics of seismic wave. To estimate properly the damages due to earthquake, it is necessary to know detailed information regarding to deep structure of ground. Many studies have been conducted at each major urban area, however, a study of deep structure in the Nobi plain is a few in comparison with those in the other places such as the Kanto and the Osaka plains. Therefore, the structural models of this area have not been established up to this time.

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EARTHQUAKE OBSERVATION

Observation sites and instruments

As shown in Figure 1, earthquake observation has been carried out at three sites, Higashiyama campus of Nagoya University (HYM), Tsurumai campus (TRM) and Kinjo wharf (KNJ). Among them, the seismographs are settled on ground surface (-1m) and in bore hole (-29m) for HYM, -1m and -82.4m for KNJ, though only at surface (-1m) of TRM. HYM and TRM are the observational sites of Nagoya University and KNJ belongs to Port and Harbor Research Institute, Ministry of Transport.
The seismograph is strong seismometer of acceleration type. SMAC-MD2 (AKASHI Co., Ltd.) is set at HYM and TRM, and ERS-G [Port and Harbor Research Institute, 1998] is installed at KNJ. Those seismographs have nearly same frequency characteristics in the range from 0.1 to 10Hz.

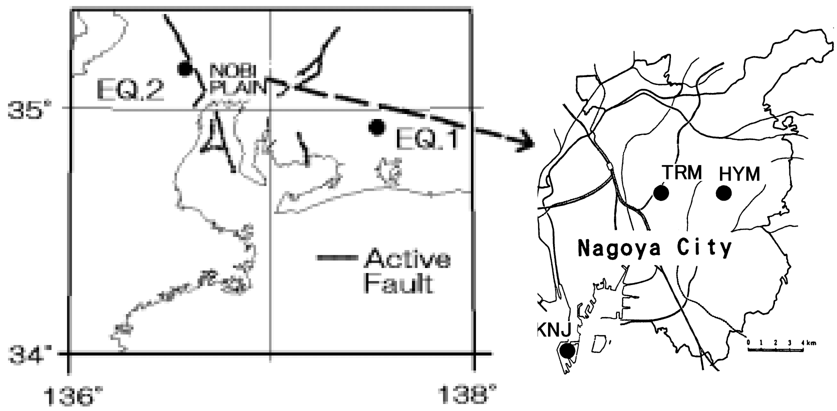

Figure 1: Location of Nobi plain, epicenters of two earthquakes, active faults and observation sites in Nagoya city

Table 1: Parameters of observed earthquake

Earthquake	Origin time	Hypocenter		Depth(km)	Epicentral distance(km)			M
		lat.	long.		HYM	TRM	KNJ	
EQ1	1997/3/16 14:51	34.9N	137.5E	39	56.1	59.4	61.2	5.8
EQ2	1998/4/22 20:32	35.2N	136.6E	10	33.6	30.0	28.2	5.4

Observed earthquakes

In this study, two earthquake data were used as shown in Table 1. The epicenters of these earthquakes are illustrated in Figure 1. EQ.1, the magnitude of M5.8, occurred at near Toyohashi City apart about 60km east south-east from observation sites and EQ.2 happened just below the center of Yoro fault located at about 30km west from observation sites. So, travelling waves due to two earthquakes roughly reach at observation sites from opposite directions. Figure 2 shows radial components of accelerograms by two earthquakes at each observation site. Comparing the EQ.1 with EQ.2, the amplitude of EQ.1 is always larger than that of EQ.2 at each point, which seems to be the reason that earthquake magnitude of EQ.1 is large, while the hypocentral distances of EQ.1 are also long. Among the observation sites, the amplitudes of KNJ are larger than that of HYM and TRM, which seems to be due to the difference in the thickness of sedimentary layer.

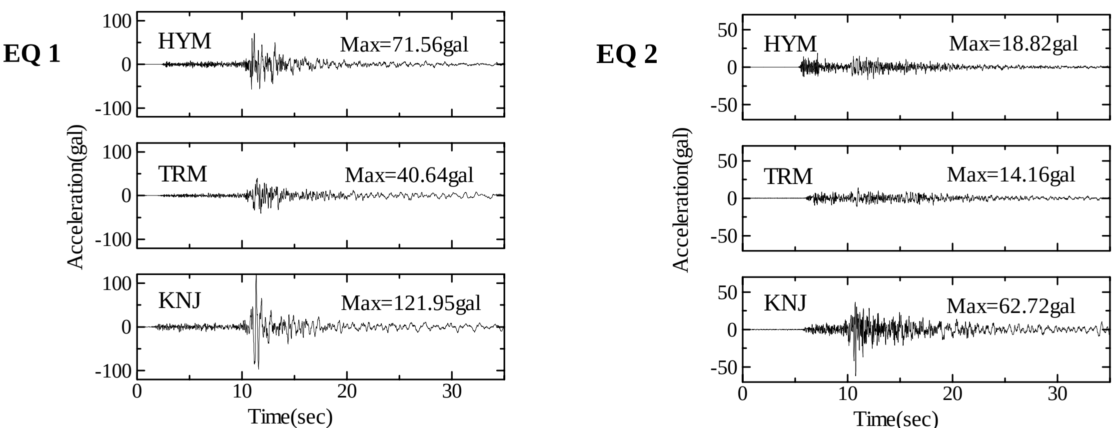

Figure 2: Accelerograms on ground surface recorded at observation sites during EQ1 and EQ2 (radial component)

Fourier's spectra of 20s intervals from S wave arrival are shown in Figure 3. It can be seen that small peaks marked by ▼ exist in low frequency range for HYM and TRM, though there is no peak for KNJ. As for KNJ, the more thick sediment is expected from past studies.

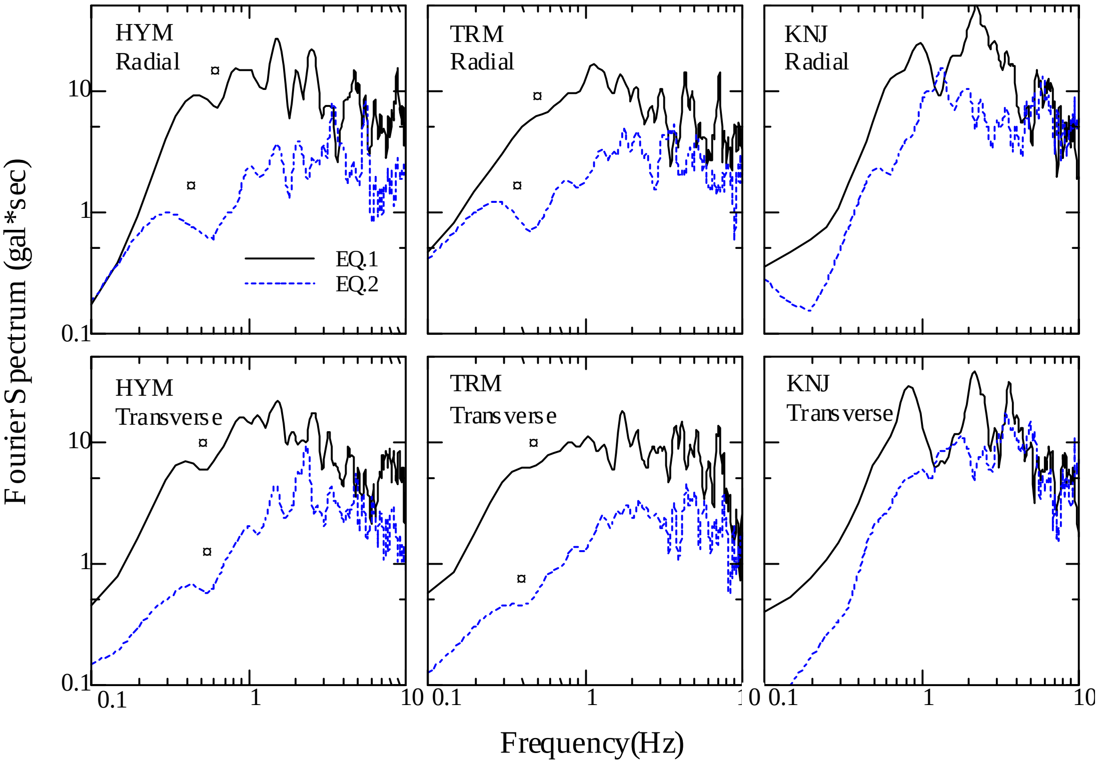

Figure 3: Fourie's spectra of observed waves due to EQ1 and EQ2

GROUND STRUCTURE MODEL

Estimation of sallow ground structure model

As for HYM and KNJ, the shallow ground structure models were estimated through the identification method, based on multiple reflection theory, applied to transfer functions between surface and underground. The authors obtained the observed transfer functions as a result of spectral ratio of surface with respect to underground data, and estimated the optimum structural model so that the sum of residual square between theoretical and observe transfer functions became minimum.

Table 2: Identified shallow ground structure model (KNJ)

EL	H	Vs	ƒ Ï	h
0.0				
-4.5	4.5	118	1.7	0.017
-10.4	5.9	151	1.7	0.020
-13.1	2.7	134	1.7	0.033
-16.6	3.5	144	1.8	0.033
-26.6	10.0	284	1.8	0.020
-34.5	7.9	252	1.8	0.025
-39.4	4.9	235	1.9	0.033
-44.5	5.1	312	1.9	0.033
-48.4	3.9	265	1.9	0.033
-66.4	18.0	298	2.0	0.025
-70.3	3.9	450	2.0	0.033
-76.4	6.1	315	2.0	0.033
-82.9	6.5	473	2.1	0.025

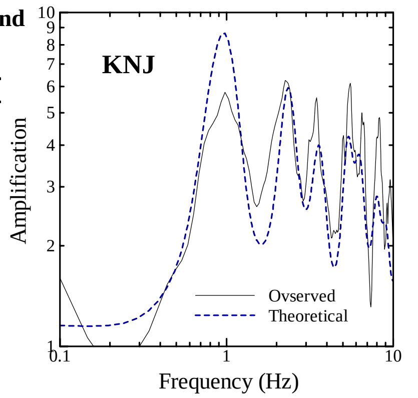

Figure 4: Comparison of theoretical transfer function with observed spectral ratio (KNJ)

A comparison of observed transfer function with theoretical one is drawn in Figure 4 at KNJ and the final structural parameters is shown in Table 2, as an example. There is good coincidence between both transfer functions, indicating the propriety of estimated structure model. Since there was no underground record at TRM, PS logging data up to 36m in depth were directly used to shallow structural model.

Estimation of deep structure model

On the time of this examination, there has been no information about S wave velocity of deep ground in and around Nagoya City, therefore, the authors introduced the survey of deep ground structure by using the array observation of microtremor. The SPAC Method (Spatial Auto-Correlation Method) [Okada et al., 1997] was applied to the analysis of microtremor data. Three circular arrays were formed with radius of about 250m, 125m and 62.5m and totally 10 velocity type seismographs, extended those natural period to 5 seconds by condenser [Moriya et al., 1998] were set on the top of inscribed rectangular triangle of each circle. The observation interval was 45 minutes in each array. The phase velocities depending on frequencies were obtained from extracting the most suitable Bessel function by using the least square method in order to agree with the space auto-correlation coefficients with respect to distances. The estimation of phase velocity was carried out in the frequency range of 0.5 – 3.7 Hz.

Considering the phase velocities obtained above as those of the fundamental mode of Rayleigh wave, the underground structure was examined by using the inversion method. Figure 5 indicates the comparisons of phase velocities due to microtremor observation with theoretical dispersion curves of optimized models and S wave velocity along the depth at each site. Accordingly, the deepest layer with S wave velocity of about 1300m/s commonly appears at a depth of 435m for HYM campus, 675m for TRM and about 1200m for KNJ. These results namely agree with the geological stratigraphy at Nobi plain, in which the accumulated layer covered the base rock becomes thick from east to west [Chubu Branch of the Japanese Society of Soil Mechanics and Foundation Engineering, 1988]. However, the S wave velocity of deepest layer deduced in this survey is not so high, corresponding to that of soft rock. The hard rock layer of large velocity such as 3000m/s was not detected. It is considered that the luck in power of microtremor at long period range is cause of that result.

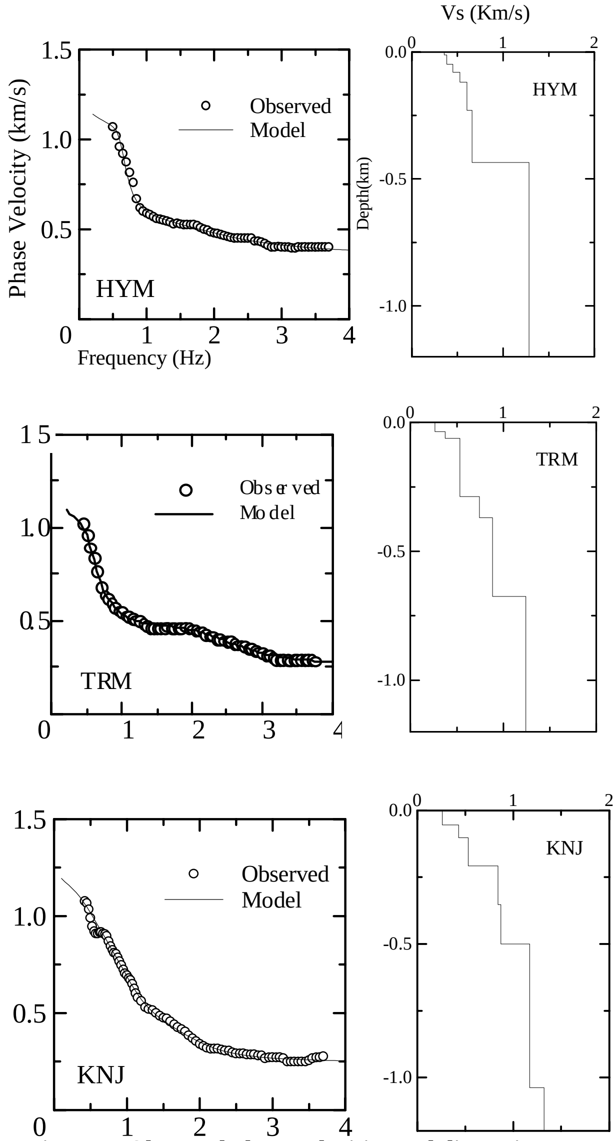

Figure 5: Observed phase velocities and dispersion curves due to models (left side), and Vs of models (right side).

Anyway, the authors have created the whole structure model at each site by combining above shallow and deep structure models. However there is a difference of about 10% in the velocity at the depth jointed the shallow model and deep model, the whole models were connected as it is. The depth of each model is GL.–435m for HYM, GL.-675m for TRM and GL.-1038m for KNJ.

ENGINEERING BASEMENT AND DISCUSSION

Suppose A(ω) as transfer function between base rock and surface, F(ω) as Fourie's spectrum of earthquake motion at site and R as hypocenteral distance, the next relation between two observation sites, i and j, will come into existence, if it is consider that the input wave's spectrum at the base rock is roughly equal in both sites because of large hypocentral distance as compared with the distance among the sites and a little difference in direction angle from the sites to epicenters.

$$\frac{F_i(\omega)}{F_j(\omega)} \cong f_{ij} \frac{A_i(\omega)}{A_j(\omega)} \qquad (4.1)$$

Where, $f_{ij} = R_i / R_j$

The authors obtained the observed spectral ratios at TRM and KNJ normalized by the spectra at HYM, and then, calculated the theoretical transfer function' ratios at each sites as well as spectral ratio. The comparison of observed results with theoretical those are shown in Figure 6.

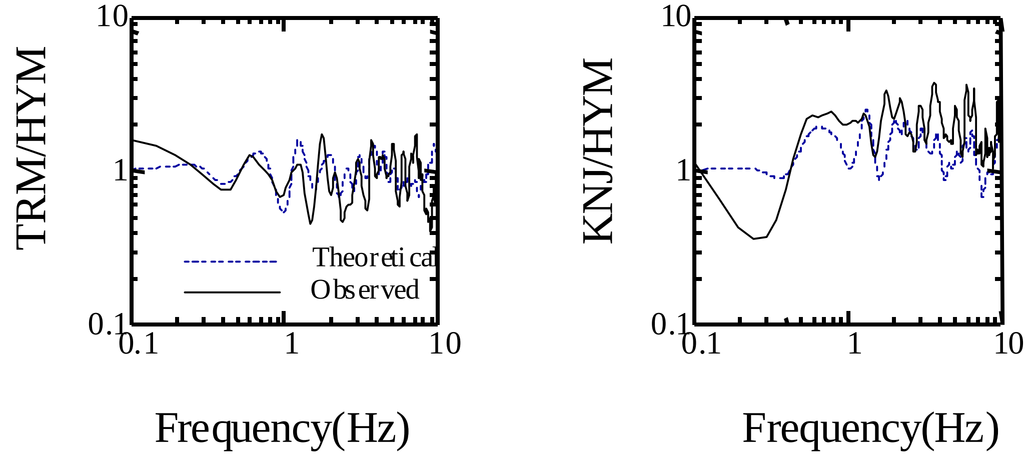

Figure 6: Comparison of observed spectral ratio with theoretical one normalized by HYM

The observed and theoretical results of TRM/HYM are generally yielding good correspondence, which indicates an adequacy of estimated structure model. On the other hand, KNJ/HYM reveals that the observed spectral ratio is roughly consistent to theoretical one in the high frequency range more than 0.4 Hz, even though the amplitude of theoretical spectral ratio is entirely lower than observation result. However, on the lower frequency range less than 0.4 Hz, a discrepancy is fairly recognized in both spectral ratios. Theoretical curve has a little peak at around 0.2 Hz. On the contrary, observed spectral ratio has a dominant trough at frequency of 0.25-0.3 Hz. Any peak doesn't exist in long period range of spectra at KNJ, as shown in Figure 2, therefore, it is consider that the spectrum characteristics of KNJ becomes a reason of above discrepancy.

Figure 7 indicates the equivalent depth line of base rock estimated by using the results of gravity survey in the past [Chubu Branch of the Japanese Society of Soil Mechanics and Foundation Engineering, 1988], and location of observation sites are also plotted in this figure. From the result of gravity survey, the depth of base rock beneath HYM and TRM was estimated to be 250-300m and 450-500m, respectively, which is 150-200m shallow as compared with the results of this study. As for KNJ, while there is also considerable difference in both results, it is necessary to conduct further detailed investigation in order to make clear the depth of base rock.

Recently, several hot spring borings have been excavated in and around Nagoya City. The authors are now investigating about one of them which locates at the center of city as shown by a symbol•(SNO) in Figure 7. According to boring cores, it was confirmed that the hard granite layer exist about 700m below. Figure 8 shows the preliminary result of S wave logging survey. S wave velocity reaches to about 3km/s in hard granite layer.

Consequently, it is suggested that the structure models proposed in this study should be improved, considering higher velocity layer such as granite.

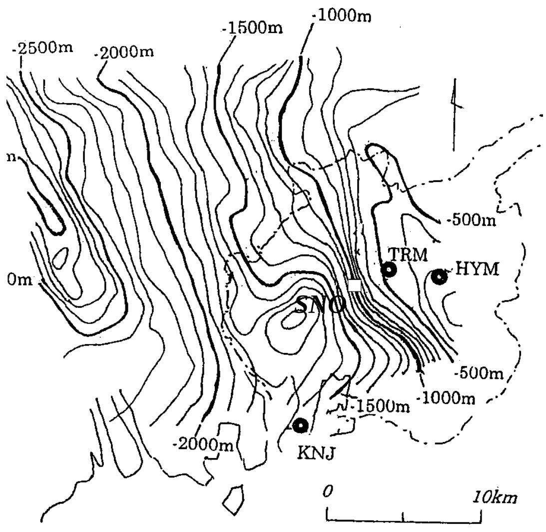

Figure 7: Equivalent depth line of base rock estimated by gravity survey data and each observation site

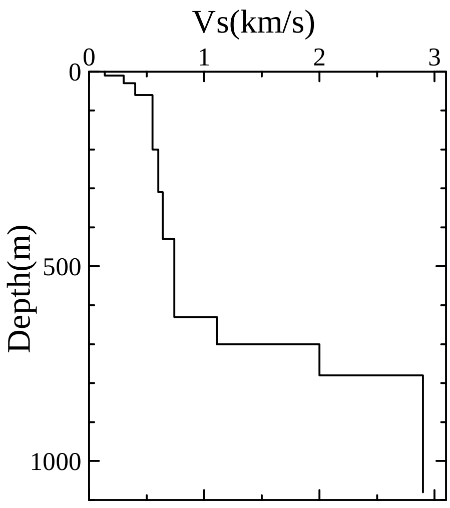

Figure 8: S wave velocity distribution at SNO

CONCLUSION

The examination results regarding to earthquake engineering basement and earthquake response of sediment layer in Nagoya City are summarized as follows.
(1) The depth of basement with S wave velocity of 1300m is estimated to be 430m for HYM and 670m for TRM.
(2) The depth of basement beneath both sites is 150-200m deeper than those estimated from gravity survey.
(3) As for KNJ, there is possibility that deep structure is complicated and it is necessary to conduct further investigation and analysis.
(4) The further investigation about distribution of hard rock such as granite should be carried out in order to evaluate properly the earthquake hazard in the Nobi plain.

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