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A SIMPLE CONVERSION FACTOR OF SEISMIC INTENSITIES FROM ENGINEERING-ROCK SURFACE TO SOIL SURFACE

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SUMMARY

A simple method is developed for conversion between soil surface and rock surface earthquake motion including nonlinear amplification effect of soil layers overlying bedrocks. The rock-surface motions are generated for several combinations of magnitudes and distances and seismic response analysis are derived for typical ground models at local sites, focusing on the nonlinear amplification characteristics of soil layers. Based on these simulated rock-surface earthquake motions and corresponding soil-surface motions, conversion factors are proposed for peak acceleration, peak velocity, JMA seismic intensity and acceleration response spectra.

INTRODUCTION

Since earthquake ground motion is usually affected strongly by nonlinear behavior of soils at local site, empirical estimation models for earthquake ground motion have been developed on engineering-rock surface rather than on soil surface. In the case that the distribution of the ground motion intensity is required at many sites within a wide area, however, the detailed site conditions for all the area and a lot of numerical calculations are necessary to obtain the corresponding soil-surface motion from rock-surface motion. For this reason, it is useful to develop a simple method to convert the ground motion from rock-surface layer to soil surface, taking into consideration the nonlinear amplification effect of soil layers [1].

In this paper, conversion factors are proposed for peak acceleration, peak velocity, JMA (Japan Meteorological Agency) seismic intensity and acceleration response spectra, based on simulated rock-surface earthquake motions and corresponding soil-surface motions. Since most of recorded data from vertical arrayed observation systems were those for relatively weak earthquakes, the earthquake-motion databases were developed based on the simulated earthquake motions. The rock-surface motions are generated for several combinations of magnitudes and distances by using Earthquake Motion Prediction model on Rock surface (EMPR-I) [2]. The multi-reflection theory with the frequency-dependent equivalent linearized technique (FDEL) [3] is used on the seismic response analysis, focusing on the nonlinear amplification characteristics of soil layers. The conversion factors are modeled as the functions

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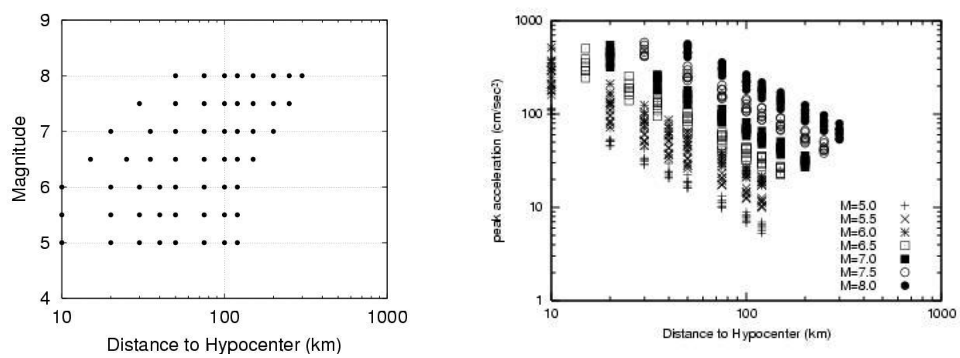
of not only the soil parameters, which represent the softness and the depth of ground layers, but also intensity of earthquake motion on the rock surface.

SIMULATED EARTHQUAKE MOTION BOTH FOR ENGINEERING-ROCK SURFACE AND SOIL SURFACE

Generation of Rock Surface Motions for Various Combinations of Magnitude and Focal Distance

After 1995 Hyogoken-Nambu Earthquake, the vertical array observation systems for earthquake ground motion on soil surface and bedrock have been completes vigorously in Japan. However, the data obtained from these systems are not enough to characterize the amplification of the ground motions including nonlinear behavior of soil at local site. Herein, the simulated motion both for rock surface and soil surface have been used for the development of conversion technique. The simulated rock surface motions have been generated for various combinations of magnitude and distance using the EMPR-I model that predicts the non-stationary earthquake motion [2]. Figure 1 shows the distributions of magnitude and distance used for simulation of rock surface motion. Generated earthquake motions total 392 samples that consist of 56 combinations and 7 different random phase angles for each.



(a) Combination of Magnitude and Distance (b) Distribution of peak Acceleration on Rock Surface

Figure 1:Distribution of Simulated Earthquake on Rock Surface

Simulation of Soil Surface Motions from Generated Rock Surface Motions and Ground Model

The typical 42 soil profiles in Japan have been selected from those of borehole logging data obtained in urban area and the strong motion observation stations where the soil profile data to the bedrock are available [4-8]. They are listed in Appendix Table. The corresponding soil surface motions on these sites for each input rock surface motion as mentioned before have been calculated by using FDEL, frequency-dependent equivalent linearized technique [3].

Incorporating the technique of FDEL, the equivalent strain, which controls equivalent shear modulus and damping factor, is given in proportional to the spectral amplitude of shear strain in frequency domain, since the strong spectral characteristic of shear strain amplitude are included in the seismic ground response. The frequency-dependent equivalent strain $\gamma_f(\omega)$ is defined in the following equation.

$$\gamma_f(\omega) = C \cdot \gamma_{\max} \cdot \frac{F_\gamma(\omega)}{F_{\gamma_{\max}}} \tag{1}$$

Where C is constant, γ_{max} is maximum shear strain, $F_\gamma(\omega)$ is Fourier spectrum of shear strain, and $F_{\gamma\max}$ represents the maximum of $F_\gamma(\omega)$.

Simple Soil Parameters *Sn* and *dp*

For the use of the simple technique to estimate a distribution of ground motion intensity, simple soil parameters, which are easily obtained at specific sites, were proposed by Sugito et al [1]. Although they are simple in their definition, the soil parameter *Sn*, softness index of ground, generally includes relatively higher frequency characteristic and *dp* does relatively lower frequency characteristic of those over bedrock in terms of seismic response analysis.

The soil parameter *Sn* is given by the weighted integration of the blow-count profile obtained from the standard penetration test, as follows.

$$S_n = 0.264\int_0^{ds} \exp\{-0.04N(x)\}\exp\{-0.14x\}dx - 0.885 \tag{2}$$

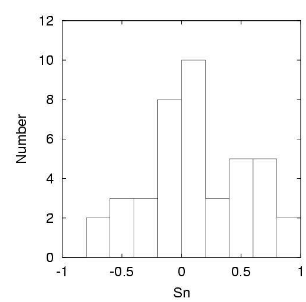
Where N(x) is blow-count at depth x meters and *ds* is depth of the blow-count profile. The parameter *Sn* represents the effect of the softness of surface layers within 15-20 meters. The parameter *dp* gives the depth to the bedrock where the shear velocity is approximately 400-600 m/sec.

Table 1 shows soil parameters, *Sn* and *dp* and Figure 2 shows the distribution of these parameters that are calculated from the 42 ground models for the analysis listed in Appendix Table. The neighborhood of *Sn*=0 that becomes the median of the softness index of ground has the mean of the data in the Figure 2(a), and the deviation of the samples is relatively small. On the other hand, a lot of samples are gathered within the depth of 20 meters in terms of the parameter, *dp* (Figure 2b).

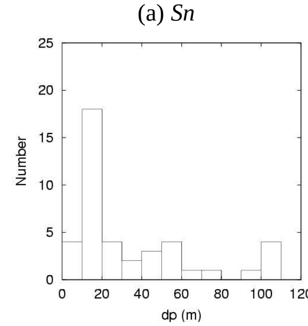
Table 1: Soil Parameters *Sn* and *dp* for model sites (42 sites)

Site	*Sn*	*dp* (m)	Origin	Site	*Sn*	*dp*(m)	Origin
Yono	0.801	41.0	E	Gamagori	0.099	19.0	C
Shinagawa-S	0.726	28.9	A	Yamashita-6-S	0.085	20.2	A
Ecchujima	0.699	100.0	E	Miyazaki-M	0.044	15.9	A
Akune	0.603	17.8	C	Tokachi-M	0.016	16.2	A
Aoyama	0.569	21.5	E	Muroran-S	0.011	14.5	A
Itajima Bridgr	0.511	16.5	B	Ohita-S	-0.007	12.5	A
Shimotsuruma	0.459	100.0	E	Toyohashi	-0.014	13.4	C
Yamashita-hen-S	0.418	35.0	A	Nagoya	-0.023	16.4	C
Chita	0.347	15.2	C	Kushiro-ji-S	-0.034	52.0	A
Kobe B20	0.342	42.1	D	Yokogawa	-0.047	12.0	C
Sakude	0.322	11.0	C	Hachinohe-S	-0.048	75.0	A
Kobe B48	0.269	23.8	D	Kobe B27	-0.056	56.5	D
Kobe B06	0.260	46.1	D	Kobe B22	-0.113	13.5	D
Soken	0.252	97.0	E	Miyako-S	-0.129	11.6	A
Kobe B23	0.230	40.2	D	Kobe B26	-0.159	16.6	D
Hososhima-S	0.171	51.0	A	Onahama-ji-S	-0.221	8.3	A
Takasago	0.168	100.0	E	Tsuwano	-0.296	9.8	C
Kainanko	0.150	66.5	E	Izumi	-0.418	6.4	C
Samukawa	0.128	100.0	E	Nagashino	-0.430	12.0	C
Toyota	0.121	16.6	C	Fujioka	-0.456	4.4	C
Kobe B04	0.109	32.5	D	Miyanojo	-0.653	10.8	C

A: PHRI[4], B: PWRI[5],
C: K-net[6],
D: KOBE JIBANKUN[7],
E: Others [8]



(a) *Sn*



(b) *dp*

Figure 2: Distribution of soil parameters *Sn* and *dp*

MODELING OF CONVERSION FACTOR FOR PEAK GROUND MOTION

Based on the simulated ground motions both on rock surface and soil surface, the conversion factors, β, for peak ground motion such as peak acceleration, peak velocity and effective acceleration, have been characterized as a function of the two soil parameters, *Sn* and *dp*. Let *Ys* and *Yr* represent the peak ground motion on soil surface and that on rock surface, respectively. These ground motion intensities are related by the conversion factor, β, as follows [1].

$$Y_s = \beta \cdot Y_r \tag{3}$$

The ground motion intensity, *Yr*, on rock surface level is indispensable for the definition of β so that the nonlinear soil amplification effect, which strongly depend on the intensity of input motion, can be incorporated.

The conversion factor for peak ground motion has been obtained in the following procedure.

1. The amplification ratio between soil-surface and rock-surface peak ground motion have been obtained for the modeling of the conversion factor. Figure 3 shows the typical examples for the amplification ratio of the peak acceleration. The axis of the ordinate represents the amplification factor between soil-surface and rock-surface motion, β*(=Ys/Yr)*, and the abscissa represents the peak ground motion on rock surface, *Yr*. These simulation data were plotted for 42 sites listed in Appendix Table.
2. Using the least square method, the relation between β and peak motion on rock surface have been obtained for the each site by using the formula shown in Table 2.
3. By using the multiple regression analysis, the regression coefficients have been obtained in terms of the soil parameters *Sn* and *dp*. The results are also shown in Table 2.

The formulation of β*ae*, the conversion factor of effective acceleration *Ae*, is also listed in Table 2. *Ae*, one of the ground intensity, is associated with JMA seismic intensity, *I*, by following equation.

$$I = 2\log A_e + K \tag{4}$$

Where K is constant. Then the conversion factor, β*ae*, between the effective acceleration on soil surface, *Is*, and the effective acceleration on rock surface, *Ir*, is given by the following equation.

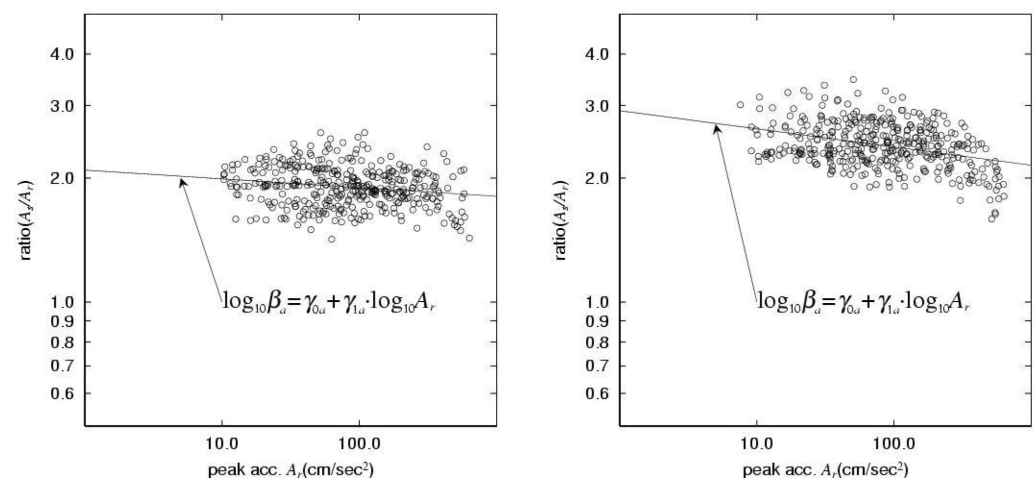
$$I_s = I_r + 2\log \beta_{ae} \tag{5}$$

Figure 4 gives the variation of the conversion factor for three combinations *Sn* and *dp*. As shown in the figure, firstly the amplification ratio between soil surface and rock surface becomes small depending on input motion intensity, secondary the amplification ratio of softer ground (*Sn*=0.6) is larger than that of harder ground (*Sn*=-0.2) in both case of peak acceleration (Figure 4a) and peak velocity (Figure 4b). Considering the effect of nonlinear amplification surface layers, the results developed herein generally coincide with the actual phenomena.

Figure 5 shows the examples of the modeled conversion factors and simulated data for two typical sites. The values given by conversion factor are consistent with the peak ground motion obtained by simulated surface motions. It can be observed that the modeled conversion factor represents the nonlinear amplification characteristic of surface layers clearly even the conversion factor is estimated from the two simple soil parameters such as *Sn* and *dp*.

Table 2: Conversion Factor for Peak Ground Motion

Peak Ground Motion in considering and Difinition of Conversion Factor	Formulation of Conversion Factor	Regression Coefficient
peak acceleration $A_s = \beta_a \cdot A_r$	$\beta_a = 10^{\gamma_{0a}} \cdot A_r^{\gamma_{1a}}$; $\gamma_1 \leq 0$ $\beta_a = 10^{\gamma_{0a}}$; $\gamma_1 \succ 0$	$\gamma_{0a} = 0.342 + 0.186 \cdot S_n - 0.115 \cdot \log_{10} d_p$ $\gamma_{1a} = -0.040 - 0.033 \cdot S_n + 0.024 \cdot \log_{10} d_p$
peak velocity $V_s = \beta_v \cdot V_r$	$\beta_v = 10^{\gamma_{0v}} \cdot V_r^{\gamma_{1v}}$; $\gamma_1 \leq 0$ $\beta v = 10^{\gamma_{0v}}$; $\gamma_1 \succ 0$	$\gamma_{0v} = 0.092 + 0.194 \cdot S_n - 0.025 \cdot \log_{10} d_p$ $\gamma_{1v} = -0.040 - 0.033 \cdot S_n + 0.024 \cdot \log_{10} d_p$
effective acceleration $A_{es} = \beta_{ae} \cdot A_{er}$	$\beta_{ae} = 10^{\gamma_{0ae}} \cdot A_{er}^{\gamma_{1ae}}$; $\gamma_1 \leq 0$ $\beta_{ae} = 10^{\gamma_{0ae}}$; $\gamma_1 \succ 0$	$\gamma_{0ae} = 0.205 + 0.247 \cdot S_n - 0.022 \cdot \log_{10} d_p$ $\gamma_{1ae} = -0.049 - 0.046 \cdot S_n + 0.030 \cdot \log_{10} d_p$



(a) Miyazaki-M Site (Sn=0.044,dp=15.9m) (b) Shinagawa-S Site (Sn=0.726,dp=28.9m)

Figure 3: Relation between Amplification Ratio As/Ar and Corresponding Peak Acceleration on Rock Surface

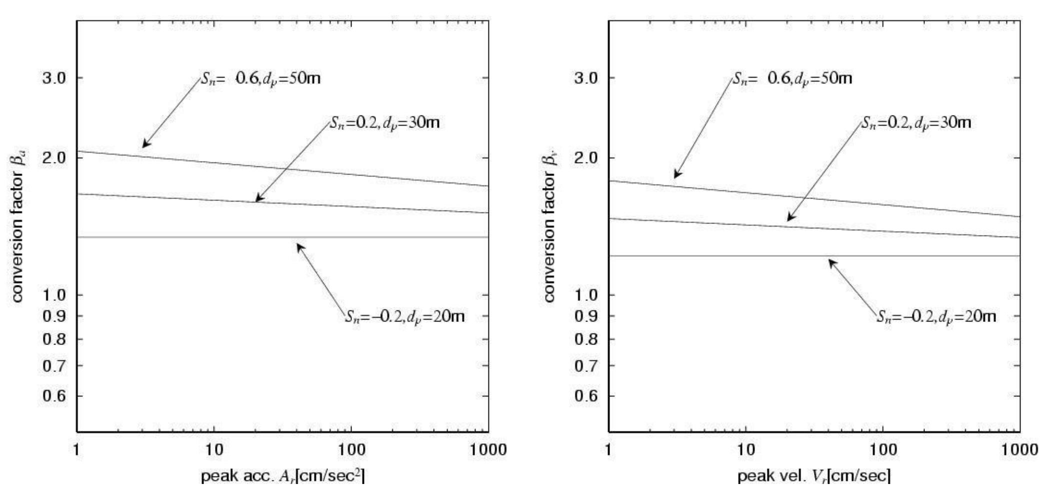
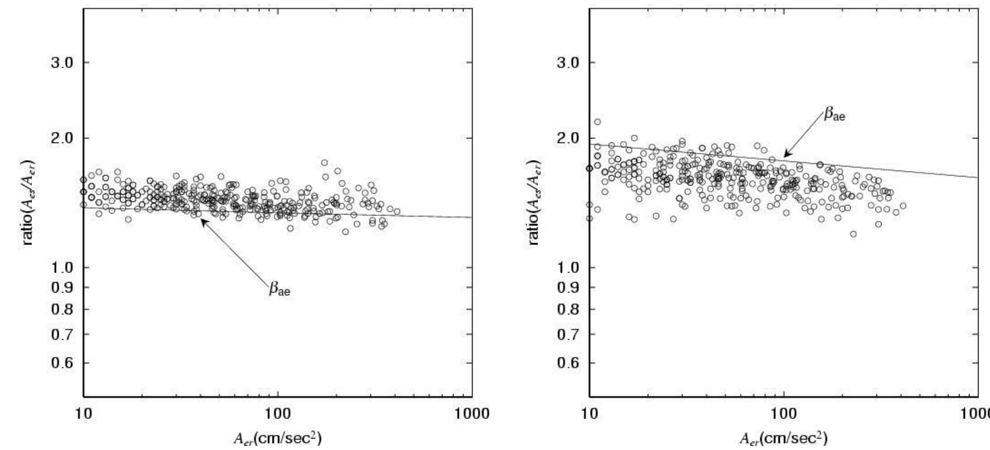
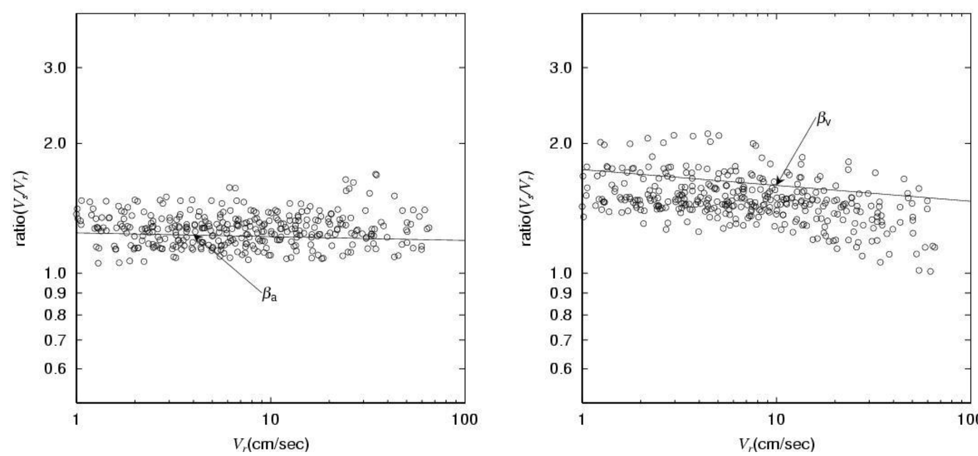


Figure 4: Values of Conversion Factors for Typical Combinations of Soil Parameters



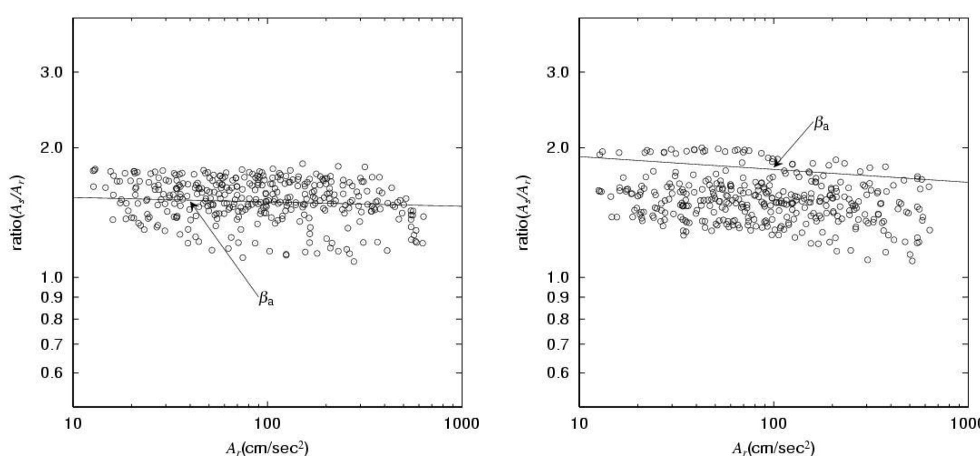
MIYAKO Site (*Sn*=0.129, *dp*=11.6m) AKUNE site (*Sn*=0.603,*dp*=11.8m)

(a) Peak Acceleration



MIYAKO Site (*Sn*=0.129, *dp*=11.6m) AKUNE site (*Sn*=0.603,*dp*=11.8m)

(b) Peak Velocity



MIYAKO Site (*Sn*=0.129, *dp*=11.6m) AKUNE site (*Sn*=0.603,*dp*=11.8m)

(c) Effective Acceleration

Figure 5: Relation between Amplification Ratio and Corresponding Peak Values on Rock Surface with Values of Conversion Factors

CONVERSION FACTOR FOR ACCELERATION RESPONSE SPECTRUM

The conversion factor for response spectra is obtained in the procedure, which is nearly the same as that in the peak ground motion. Herein the conversion factor for acceleration response spectra is defined based on the simulated motion developed in preceding section. The conversion factor βs proposed here relates both the response spectra on rock surface and soil surface in the following formula [1].

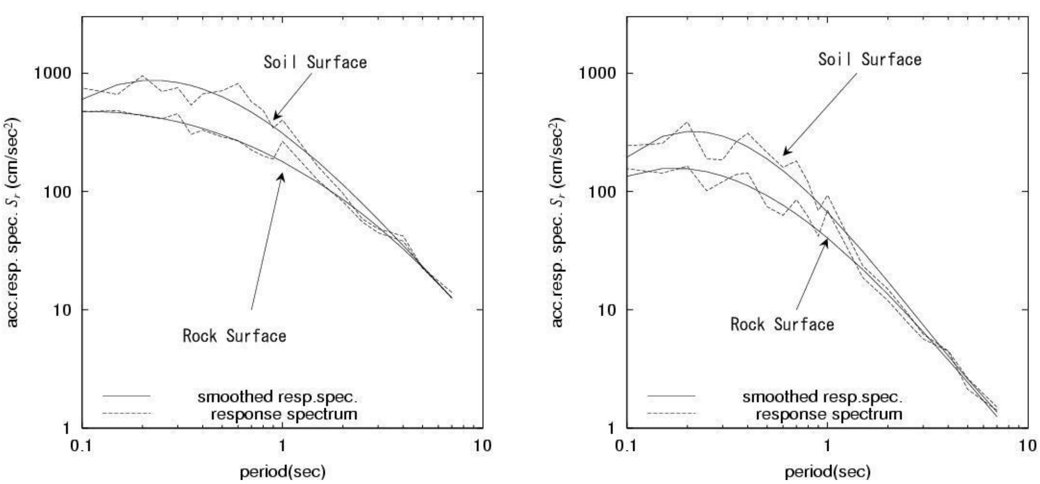
$$S_s(T) = \beta_s(T) \cdot S_r(T) \tag{6}$$

Where *Sr(T), Ss(T)* are acceleration response spectrum for rock surface and soil surface, respectively, and $\beta s(T)$ is conversion factor for a period *T*.

Figure 6 shows the examples of the acceleration response spectra for Itajima-bridge site with the corresponding response spectra on rock surface with damping factor h=0.05. These kinds of figures have been obtained for 42 sites for 20 periods that are distributed in the period ranges between 0.1 to 7.0 second. The solid lines in Figure 6 represent the smoothed response spectra as the function of log *T* with the order of three by using the least square method. Herein the ratios of the smoothed response spectra are used. Table 3 and 4 gives the summary of the estimation formulas for the conversion factor βs. Figure 7 shows the coefficients appear in Table 4.

The reason to deal with the smoothed response spectra is as follows [1]. In the original response-spectra, the frequency-characteristics of the ground are usually remarkable. For the estimation of these frequency-dependent characteristic, the transfer function of the ground, calculated form the detailed information for a specific site, is indispensable. However, the objectives of the analysis here is to propose the simple conversion factor of response spectra that are obtained from the simple soil parameters. For this purpose, it is considered better to deal with the smoothed values to grasp the general inclination of the response spectra.

Figure 8 shows the examples for the comparison between the conversion factor βs and simulation data. The abscissa represents the values of the acceleration response spectra on rock surface and the ordinate represents the amplification coefficients obtained from the simulated ground motion. The solid lines represent the modeled conversion factor βs given by Table 3 and 4.



(a) Itajima Bridge Site (M=6.0,R=50km) (b) Itajima Bridge Site (M=8.0,R=150km)

Figure 6: Example for Acceleration Response Spectra and Their Smoothed Curves

Table 3: Formulas for Estimation of Conversion Factor

Conversion factor for Acceleration Response Spectra with damping factor h = 0.05	$S_s(T) = \beta_s(T) \cdot S_r(T)$
Formulation of Conversion Factor	$\beta_s(T) = 10^{\gamma_{0s}} \cdot S_r^{\gamma_{1s}}$; $\gamma_1 \leq 0$ $\beta_s(T) = 10^{\gamma_{0s}}$; $\gamma_1 \succ 0$
Regression Coefficient	$\gamma_{0s} = \gamma_{00}(T) + \gamma_{01}(T) \cdot S_n + \gamma_{02}(T) \cdot \log_{10} d_p$ $\gamma_{1s} = \gamma_{10}(T) + \gamma_{11}(T) \cdot S_n + \gamma_{12}(T) \cdot \log_{10} d_p$

Table 4: Values of Coefficients Appear in Table 3

T (sec)	γ_{00}	γ_{01}	γ_{02}	γ_{10}	γ_{11}	γ_{12}
7.000	0.000	0.000	0.000	0.000	0.000	0.000
5.000	-0.023	0.021	0.032	0.000	0.000	0.000
4.000	-0.050	0.025	0.048	0.000	0.000	0.000
3.000	-0.070	0.041	0.068	0.000	0.000	0.000
2.500	-0.079	0.055	0.080	0.000	0.000	0.000
2.000	-0.083	0.073	0.092	0.000	0.000	0.000
1.500	-0.077	0.101	0.103	0.000	0.000	0.000
1.000	-0.049	0.140	0.108	0.004	-0.003	-0.003
0.900	-0.038	0.150	0.107	0.004	-0.003	-0.004
0.800	-0.024	0.161	0.104	0.005	-0.004	-0.004
0.700	-0.004	0.174	0.099	0.005	-0.005	-0.004
0.600	0.024	0.191	0.087	0.003	-0.008	-0.003
0.500	0.064	0.216	0.069	-0.001	-0.016	-0.001
0.400	0.122	0.248	0.039	-0.007	-0.027	0.002
0.350	0.160	0.265	0.016	-0.011	-0.033	0.004
0.300	0.208	0.279	-0.013	-0.017	-0.040	0.008
0.250	0.266	0.285	-0.051	-0.024	-0.045	0.011
0.200	0.338	0.276	-0.104	-0.032	-0.049	0.016
0.150	0.437	0.229	-0.184	-0.043	-0.045	0.023
0.100	0.588	0.056	-0.303	-0.064	-0.009	0.027

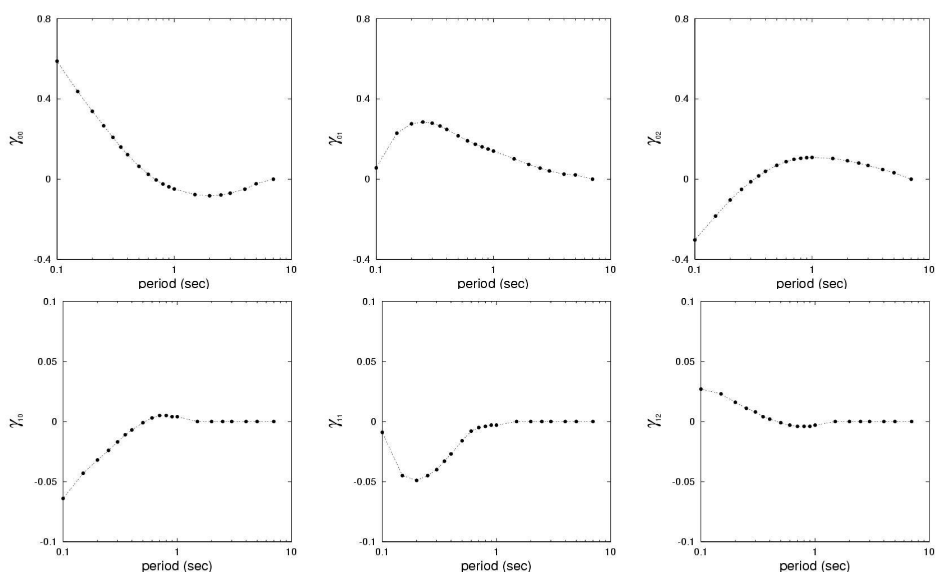
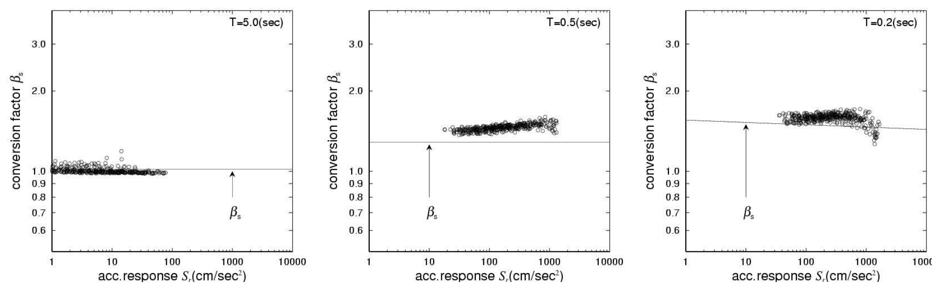


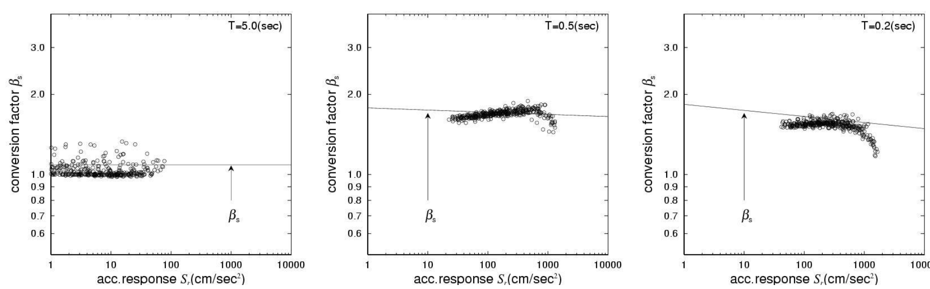
Figure 7: Values of Coefficients Appear in Table 4

Figure 8(a) is the example for relatively hard ground (Miyako-S Site, *Sn*=-0.129, *dp*=11.6m), and Figure 8(b) for very soft ground (Kobe B20, *Sn*=0.342, *dp*=42.1m). It can be observed that the conversion factor β described by solid lines coincide with the simulation data and represent the nonlinear amplification characteristic of soil fairly well.

Figure 9 shows the comparison of response spectra between *S* , represented by solid line, for rock surface motion, *Ss*, represented by circles, for soil surface motion given by conversion factor and for *Ss*, represented by the other solid line, the simulated soil surface motion, respectively. It is observed that the estimated value *Ss* by use of βs represent fairly well general characteristic of response spectra for simulated soil surface motion.

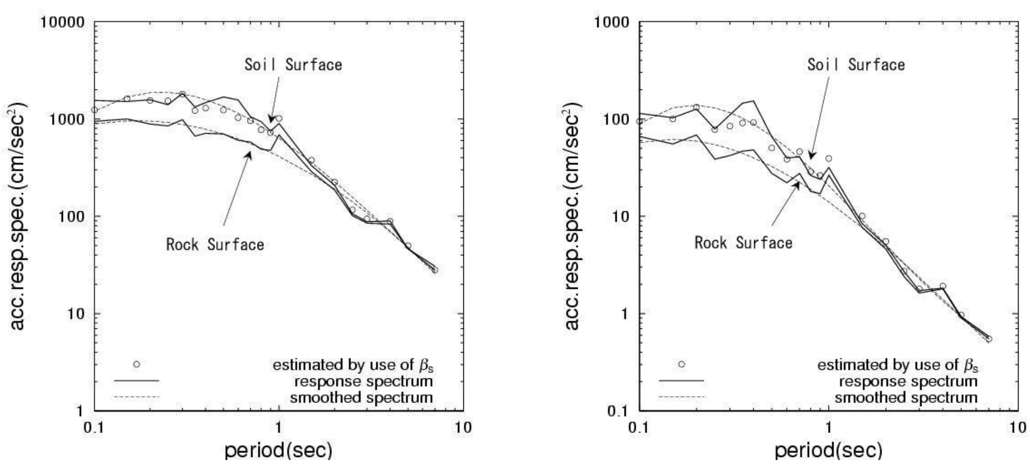


(a) Miyako-S (*Sn*=-0.120,*dp*=11.6m)



(b) Kobe B20 (*Sn*=0.342,*dp*=42.1m)

Figure 8: Relation between Amplification and Acceleration Response Spectrum on Rock Surface



(a) Aoyama Site (M=6.0, R=50km) (b) Aoyama Site (M=8.0, R=150km)

Figure 8: Comparison of Response Spectra for Rock Surface and soil Surface Motion with Estimated Values by Use of Conversion Factors

CONCLUSIONS

A simple conversion factor between earthquake ground motion on soil surface and engineering-rock surface has been developed. The major results derived here may be summarized as follows.

The dataset of the simulated ground motion on rock surface for several combinations of magnitude and distance have been generated by using the non-stationary ground motion prediction model (EMPR-I).

The typical 42 soil profiles in Japan have been selected from those of borehole logging data obtained in urban area and the strong motion observation stations where the soil profile data to the bedrock are available. The corresponding soil-surface motions of these model sites have been calculated based on the multi-reflection theory with the frequency-dependent equi-linearized technique (FDEL).

Based on this simulated ground motion dataset, the conversion factor for peak acceleration, peak velocity and JMA seismic intensity has been developed focusing on the nonlinear amplification characteristic of surface layers over bedrock. These conversion factors are defined by the simple soil parameters *Sn* and *dp* that are generally available at a specific construction sites, and the peak earthquake motion on rock surface. The peak ground motions on soil surface are simply converted from those on rock surface.

The technique has been applied for acceleration response spectra. In the development of the conversion factor for these spectrum intensities, the significant characteristic of the nonlinear amplification effect of surface layers has been derived.

To verify the validity of the conversion factor proposed in this paper by actual data, several sets of ground motion data recorded both on soil surface and bedrock for several type of sites are indispensable. Since the multi-observation system for ground motion have been completed by many research grounds and the simultaneous records both on soil surface and bedrock or rock surface have been accumulated gradually, the verification and the further development of the conversion technique will be possible.

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Appendix Table: Soil Profiles for 42 sites (1/4)

(1)YONO

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
4.5	1.5	115.0	clay	3.0
2.5	1.8	270.0	clay	5.0
1.5	1.8	270.0	sand	35.0
3.0	1.8	270.0	clay	10.0
8.5	1.8	270.0	sand	20.0
3.0	1.9	410.0	sand	50.0
7.0	1.8	260.0	clay	8.0
9.0	1.8	200.0	clay	6.0
2.0	1.8	270.0	clay	10.0
base	2.0	520.0	gravel	50.0

(2)SHINAGAWA-S

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
5.9	1.4	101.8	silt	0.3
5.4	1.5	132.2	clay	1.9
3.4	1.8	189.5	sand	10.0
1.8	1.5	215.2	clay	10.3
6.0	1.9	317.4	gravel	50.0
4.8	1.8	278.1	sand	50.0
1.7	1.9	330.9	gravel	50.0
base	2.2	600.0	rock	50.0

(3)ECCHUJIMA

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
10.5	1.7	110.0	silt	5.0
5.5	1.6	130.0	clay	1.0
9.5	1.7	130.0	silt	1.0
11.5	1.7	230.0	silt	10.0
16.0	2.0	440.0	gravel	50.0
16.5	1.9	440.0	sand	50.0
5.5	1.9	300.0	sand	50.0
7.5	1.9	460.0	sand	50.0
17.5	1.9	460.0	rock	50.0
base	1.9	460.0	rock	50.0

(4)AKUNE

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.6	1.5	120.0	clay	0.5
2.2	1.6	120.0	clay	5.0
2.3	1.6	250.0	sand	7.5
2.7	1.6	250.0	sand	7.0
8.0	1.7	140.0	clay	4.5
base	2.0	380.0	gravel	24.0

(5)AOYAMA

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
3.0	1.3	130.0	clay	3.0
3.5	1.3	130.0	clay	5.0
4.5	1.4	140.0	clay	2.0
8.5	1.9	230.0	sand	15.0
2.0	2.1	270.0	gravel	50.0
base	2.0	480.0	sand	50.0

(6)ITAJIMA BRIDGE

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
3.0	1.5	107.0	clay	3.0
1.0	1.5	107.0	sand	3.0
4.0	1.7	125.0	sand	5.0
5.0	1.8	145.0	silt	10.0
3.5	1.8	125.0	clay	7.0
base	2.2	480.0	rock	50.0

(7)SHIMOTSURUMA

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-Count
9.0	1.3	190.0	clay	5.0
6.0	1.6	270.0	clay	10.0
19.0	2.1	640.0	gravel	50.0
5.0	1.7	350.0	silt	25.0
4.5	1.7	350.0	sand	40.0
4.5	1.7	260.0	clay	30.0
5.0	1.7	260.0	silt	20.0
33.0	2.0	650.0	rock	50.0
14.0	2.1	520.0	rock	50.0
base	2.1	520.0	rock	50.0

(8)YAMASHITA-HEN-S

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-Count
3.4	1.8	145.9	sand	11.0
5.9	1.4	135.0	silt	3.5
2.6	1.8	174.8	sand	4.0
6.9	1.8	202.1	sand	19.5
2.2	1.9	306.4	gravel	34.5
14.1	1.4	360.3	silt	27.3
base	2.2	600.0	rock	50.0

(9)CHITA

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-Count
1.3	1.8	140.0	silt	8.0
5.7	1.8	140.0	sand	5.0
0.9	1.8	140.0	sand	7.0
1.3	1.8	155.0	gravel	15.0
4.7	1.8	170.0	silt	10.0
1.4	1.8	170.0	sand	50.0
base	1.9	450.0	rock	50.0

(10)KOBE B20

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
11.1	1.8	150.0	sand	9.5
5.1	1.8	230.0	sand	13.4
6.3	2.0	360.0	sand	18.6
3.5	2.0	270.0	sand	19.9
4.2	1.7	270.0	clay	11.0
7.3	2.0	380.0	sand	24.0
4.6	2.0	310.0	sand	31.0
base	2.0	430.0	sand	50.0

Appendix Table: Soil Profiles for 42 sites (2/4)

(11) SAKUDE

Thick-Ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
3.0	1.8	140.0	clay	5.7
0.6	1.9	140.0	gravel	4.0
7.5	1.8	140.0	sand	6.1
base	1.9	200.0	sand	12.9

(12)KOBE B48

Thick-Ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
4.4	1.8	130.0	sand	4.3
6.8	1.8	170.0	sand	15.8
3.1	1.8	230.0	sand	31.6
2.4	2.0	230.0	gravel	32.5
2.8	2.0	320.0	gravel	41.0
4.4	1.8	270.0	clay	21.3
base	2.0	490.0	gravel	50.0

(13)KOBE B06

Thick-Ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
4.4	1.7	100.0	clay	4.0
11.1	1.8	190.0	sand	22.6
4.5	1.9	270.0	gravel	30.1
9.3	2.0	270.0	gravel	17.7
16.9	2.0	330.0	sand	21.0
base	2.0	400.0	gravel	50.0

(14)SHOKEN

Thick-Ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.0	1.4	98.0	clay	12.0
1.0	1.4	117.0	silt	5.0
4.0	1.7	117.0	gravel	13.0
1.0	1.7	149.0	sand	7.0
3.0	1.6	149.0	silt	4.0
6.0	2.0	342.0	gravel	35.0
1.0	2.0	222.0	clay	7.0
2.0	2.0	154.0	sand	15.0
10.0	2.0	400.0	clay	27.5
3.0	2.0	375.0	gravel	50.0
6.0	1.7	375.0	clay	10.0
3.0	1.7	231.0	clay	12.0
3.0	2.0	286.0	gravel	50.0
7.0	2.0	255.0	sand	50.0
2.0	2.0	222.0	sand	50.0
4.0	2.0	177.0	clay	25.0
2.0	2.0	222.0	clay	33.0
7.0	2.0	389.0	clay	48.0
7.0	2.0	333.0	clay	32.0
20.0	2.0	303.0	clay	30.0
1.0	2.0	455.0	clay	50.0
2.0	2.0	455.0	clay	50.0
base	2.0	455.0	clay	50.0

(15)KOBE B23

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.0	1.8	80.0	sand	4.0
3.0	1.7	110.0	silt	5.3
10.0	1.8	250.0	sand	22.7
5.2	2.0	440.0	gravel	50.0
3.5	2.0	380.0	sand	31.1
8.1	2.0	460.0	gravel	40.0
8.4	2.0	330.0	sand	27.8
base	2.0	410.0	sand	50.0

(16)HOSOSHIMA-S

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
12.0	1.5	200.4	clay	15.7
7.5	1.4	174.4	silt	6.0
3.1	1.8	241.4	sand	27.5
5.4	1.5	243.4	clay	10.5
4.3	1.5	359.8	clay	26.0
5.7	1.5	348.8	clay	22.0
10.0	1.5	291.4	clay	10.0
3.0	1.5	566.9	clay	48.0
base	2.2	600.0	rock	50.0

(17)TAKASAGO

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
3.4	1.7	140.0	gravel	15.0
3.8	1.7	130.0	silt	10.0
6.3	1.6	200.0	clay	8.0
5.6	1.9	310.0	gravel	50.0
6.0	1.9	400.0	gravel	50.0
5.1	1.8	330.0	gravel	50.0
3.0	1.7	230.0	clay	15.0
4.0	1.7	320.0	clay	15.0
6.7	1.9	560.0	gravel	50.0
4.8	1.8	250.0	sand	30.0
11.8	1.9	405.0	gravel	50.0
13.2	1.9	650.0	sand	50.0
9.8	1.9	500.0	gravel	50.0
16.7	1.8	460.0	clay	35.0
base	1.8	460.0	clay	35.0

(18)KAINANKO

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
1.8	1.6	238.0	sand	25.0
2.0	1.6	100.0	silt	3.0
13.2	1.7	179.0	sand	18.0
6.5	1.6	220.0	silt	5.0
3.7	1.7	270.0	sand	50.0
2.8	1.7	188.0	sand	30.0
7.1	1.6	216.0	clay	10.0
2.6	1.7	206.0	sand	30.0
7.2	1.7	315.0	sand	25.0
6.5	1.6	263.0	silt	30.0
2.4	1.8	370.0	gravel	45.0
5.2	1.7	274.0	silt	15.0
5.5	1.8	325.0	sand	50.0
base	1.8	700.0	gravel	50.0

Appendix Table: Soil Profiles for 42 sites (3/4)

(19)SAMUKAWA

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
5.0	1.6	110.0	silt	4.0
4.5	2.0	300.0	gravel	35.0
8.0	1.9	300.0	sand	50.0
3.5	1.8	300.0	sand	50.0
7.0	1.8	230.0	silt	15.0
3.0	1.8	230.0	silt	50.0
6.0	1.9	370.0	sand	50.0
6.0	1.7	320.0	clay	20.0
12.0	1.7	400.0	clay	30.0
7.0	2.4	850.0	gravel	50.0
20.0	1.9	450.0	silt	50.0
6.0	2.4	870.0	gravel	50.0
12.0	1.9	500.0	sand	50.0
base	1.9	500.0	sand	50.0

(20)TOYOTA

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
1.5	1.8	160.0	clay	2.0
2.4	1.7	160.0	silt	7.0
9.0	2.0	290.0	sand	22.9
3.7	2.2	430.0	gravel	41.3
base	2.0	290.0	sand	23.8

(21)KOBE B04

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.5	1.8	230.0	gravel	17.0
2.0	1.8	220.0	gravel	17.0
3.0	1.8	130.0	sand	15.0
4.1	1.8	240.0	gravel	14.0
3.9	1.7	240.0	silt	13.8
8.4	1.7	240.0	clay	12.7
8.6	2.0	320.0	sand	30.0
base	2.0	430.0	sand	50.0

(22)GAMAGOHRI

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.3	1.8	180.0	clay	9.0
0.7	1.8	400.0	gravel	50.0
2.0	1.9	400.0	clay	28.0
3.8	1.9	260.0	clay	9.5
1.9	1.8	260.0	sand	9.5
2.2	2.0	260.0	sand	10.0
1.5	2.0	260.0	clay	22.0
2.9	2.0	450.0	sand	16.7
1.9	2.0	450.0	gravel	30.5
base	2.1	450.0	sand	50.0

(23)YAMASHITA-6-S

Thick-Ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
5.5	1.8	142.6	sand	8.0
1.0	1.9	290.3	gravel	35.0
1.4	1.8	168.3	sand	8.0
1.0	1.9	293.3	gravel	35.0
6.8	1.4	415.8	silt	38.0
3.2	1.9	316.4	gravel	50.0
1.4	1.4	439.1	silt	38.0
base	2.2	600.0	rock	50.0

(24)MIYAZAKI-M

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
4.2	1.8	156.4	sand	13.0
0.4	1.4	149.0	silt	5.0
7.5	1.8	189.3	sand	20.3
3.8	1.8	200.6	sand	10.3
base	2.2	600.0	rock	50.0

(25)TOKACHI-M

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.0	1.5	125.8	clay	4.0
4.2	1.8	152.7	sand	10.0
10.0	1.9	304.6	gravel	50.0
base	2.2	600.0	rock	50.0

(26)MURORAN-S

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
3.0	1.8	135.9	sand	2.0
2.4	1.8	182.2	sand	33.0
1.6	1.9	280.9	gravel	24.5
2.0	1.5	235.3	clay	17.5
5.5	1.9	303.6	gravel	45.0
base	2.2	600.0	rock	50.0

(27)OHITA-S

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
4.9	1.8	149.5	sand	5.5
1.1	1.8	181.9	sand	24.0
6.5	1.9	307.2	gravel	48.7
base	2.2	600.0	rock	50.0

(28)TOYOHASHI

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
0.9	1.8	270.0	clay	10.0
0.8	2.0	270.0	clay	15.0
5.0	2.1	270.0	gravel	17.0
1.1	2.1	270.0	clay	3.0
1.2	1.8	270.0	silt	6.0
2.5	2.0	270.0	sand	26.0
2.1	2.1	400.0	gravel	38.5
base	1.9	400.0	sand	40.6

(29)NAGOYA

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
1.0	1.8	240.0	clay	6.0
2.3	1.9	240.0	silt	12.0
6.7	1.8	240.0	sand	23.0
2.6	1.9	310.0	silt	19.3
1.0	2.0	310.0	gravel	35.0
2.9	1.9	310.0	silt	35.0
base	1.9	310.0	sand	42.0

Appendix Table: Soil Profiles for 42 sites (4/4)

(30)KUSHIRO-JI-S

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
9.5	1.7	169.4	sand	15.2
3.5	2.1	233.7	sand	50.0
1.0	2.0	300.3	gravel	35.0
4.5	2.1	253.5	sand	50.0
4.5	1.9	261.6	sand	41.2
2.0	1.9	214.1	silt	7.5
12.0	1.8	293.8	sand	33.7
3.0	1.7	244.0	silt	7.0
4.0	1.7	333.3	sand	30.0
2.0	1.7	301.8	silt	12.5
6.0	2.0	366.9	sand	35.3
base	1.7	600.0	sand	50.0

(31)YOKOGAWA

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
1.3	1.5	150.0	sand	10.0
3.4	1.5	150.0	sand	2.6
0.9	1.7	310.0	gravel	63.6
6.4	1.6	310.0	gravel	55.8
base	1.7	420.0	gravel	50.0

(32)HACHINOHE-S

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.0	1.8	100.0	sand	8.0
2.0	1.8	160.0	sand	18.5
5.0	1.9	200.0	gravel	18.0
21.0	1.7	275.0	sand	50.0
30.0	1.7	320.0	sand	50.0
15.0	1.8	340.0	sand	50.0
base	1.9	379.0	gravel	50.0

(33)KOBE B27

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
3.0	1.8	100.0	gravel	29.0
10.0	1.9	210.0	gravel	20.1
7.0	1.7	170.0	clay	5.4
4.2	1.7	300.0	silt	12.7
0.8	1.8	300.0	clay	16.0
11.0	2.0	330.0	gravel	25.0
4.0	2.0	420.0	sand	38.0
6.0	1.7	260.0	clay	15.8
7.0	2.0	360.0	gravel	39.0
3.5	2.0	380.0	sand	50.0
base	2.0	430.0	gravel	50.0

(34)KOBE B22

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.8	1.8	250.0	sand	19.0
3.4	1.8	220.0	sand	13.4
7.3	1.8	290.0	sand	23.4
base	2.0	470.0	sand	50.0

(35)MIYAKO-S

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.2	1.8	164.0	sand	5.0
7.6	1.9	308.0	gravel	30.0
1.9	1.5	164.0	clay	12.0
base	2.2	600.0	rock	50.0

(36)KOBE B26

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
7.8	1.9	150.0	gravel	18.6
3.2	1.8	160.0	sand	23.3
2.8	2.0	420.0	gravel	50.0
2.8	2.0	370.0	sand	38.0
base	2.0	420.0	sand	50.0

(37)ONAHAMA-JI-S

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
0.8	1.8	162.0	sand	4.0
3.2	1.8	162.0	sand	15.0
1.9	1.8	250.0	sand	38.0
0.9	1.8	448.0	sand	35.0
1.6	1.9	448.0	gravel	16.0
base	2.2	784.0	rock	50.0

(38)TSUWANO

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.0	1.5	160.0	clay	8.3
1.0	1.3	160.0	silt	7.4
5.8	1.8	320.0	gravel	50.0
1.0	1.6	320.0	clay	34.0
base	1.8	320.0	gravel	50.0

(39)IZUMI

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
1.0	1.5	230.0	clay	5.0
0.5	1.5	230.0	clay	8.0
4.5	1.8	356.0	gravel	37.0
0.4	1.9	440.0	sand	42.0
base	2.2	500.0	rock	50.0

(40)NAGASHINO

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
1.7	1.9	470.0	sand	15.0
10.3	2.1	470.0	gravel	40.0
base	2.1	670.0	gravel	50.0

(41)FUJIOKA

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
1.0	1.8	130.0	clay	11.0
1.0	1.8	130.0	clay	11.0
1.2	1.9	370.0	sand	25.0
1.2	2.1	370.0	gravel	41.0
base	2.2	370.0	sand	50.0

(42)MIYANOJO

Thick-ness(m)	Density (gf/cm3)	Vs (m/s)	Soil class	Blow-count
2.0	1.6	180.0	sand	43.0
8.2	1.8	300.0	sand	50.0
0.6	1.8	430.0	sand	31.0
base	2.0	430.0	rock	50.0