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Modeling of the subsurface structure from the seismic bedrock to the ground surface for a broadband strong motion evaluation

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I THE OUTLINE OF THE STRUCTURE MODEL TO BUILD

In order to perform earthquake ground motion prediction for a broadband, it is important to get to know the foundation structure model from the seismic bedrock to the ground surface. However, in the previous research, the structure model aiming at earthquake motion prediction of the broadband in a wide area is not created.
In this study, we are modeling of the subsurface structure from the seismic bedrock to the ground surface for a broadband strong motion evaluation with about 250m intervals(the 7.5-arc-second JGEM).

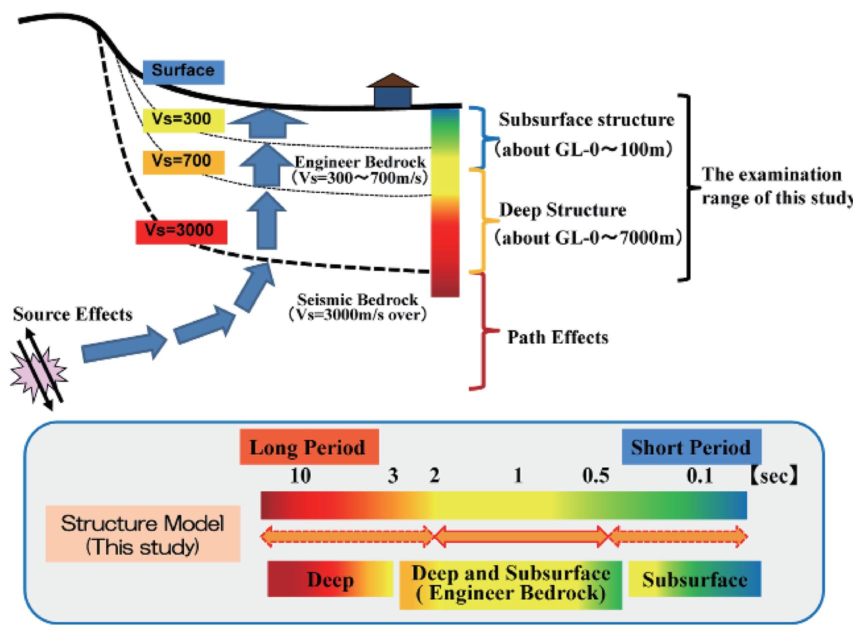


Fig. 1 The relational figure of the S wave of velocity structure, and the periodic characteristic in the kanto plain in Japan.

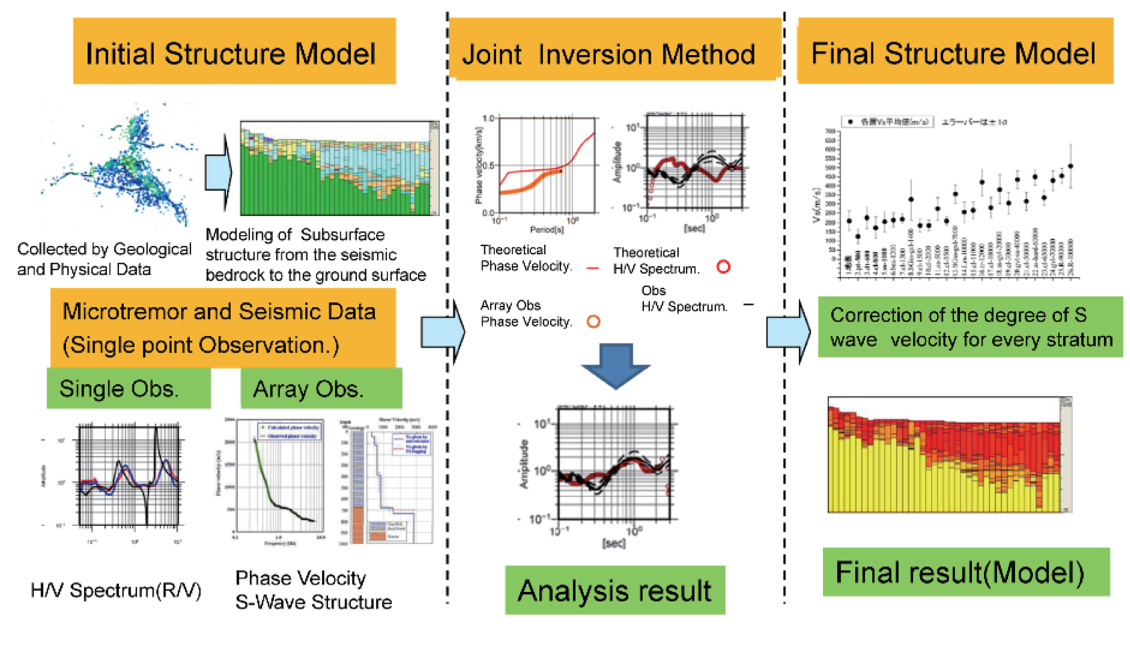


Fig.2 The key map of the subsurface structure from the seismic bedrock to the ground surface creation

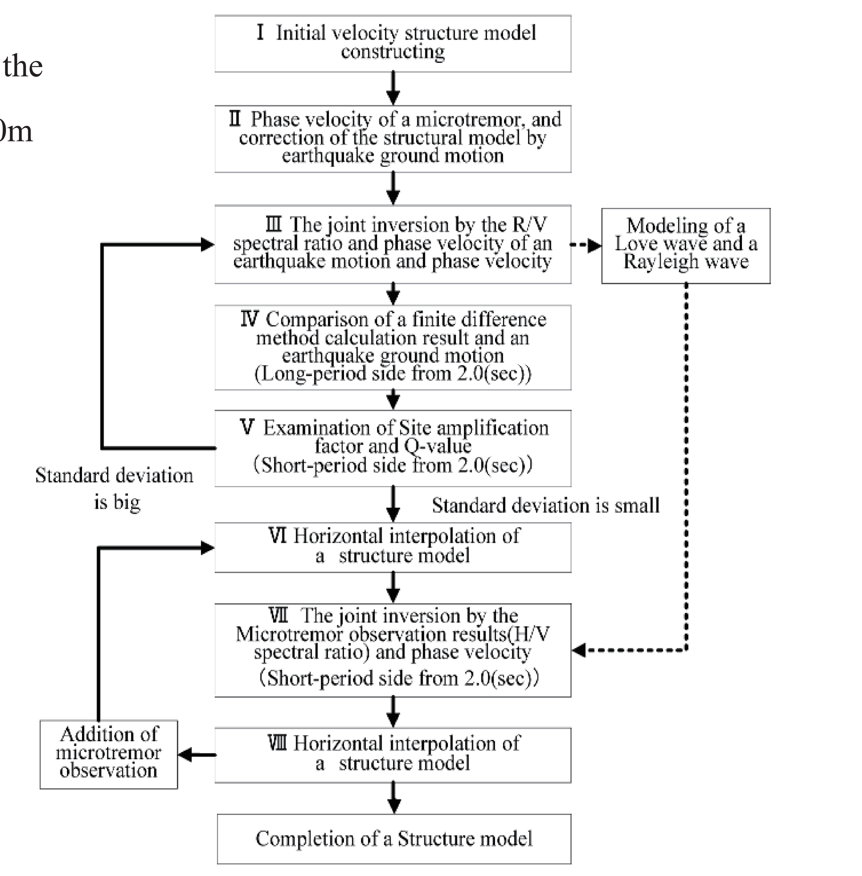


Fig. 3 The flow of formation of a structure model construction

II COLLECTION OF DATA FOR STRUCTURE MODEL

We carried out microtremor observation of the single point (H/V) at intervals of about 2 km. On the other hand, we carried out microtremor array observation at intervals of about 5 to 10km. Microtremor observation points are always seismic observation point or school. We used an integrated microtremor observation unit (JU-215, Hakusan Corp.), equipped with two horizontal elements, one vertical element, and a data-logger (LS-7000XT).

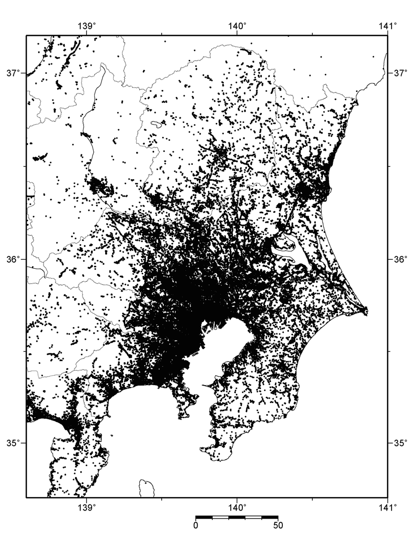


Fig. 4 Collected borehole data in the Kanto district (Data of about 100,000 points or more)

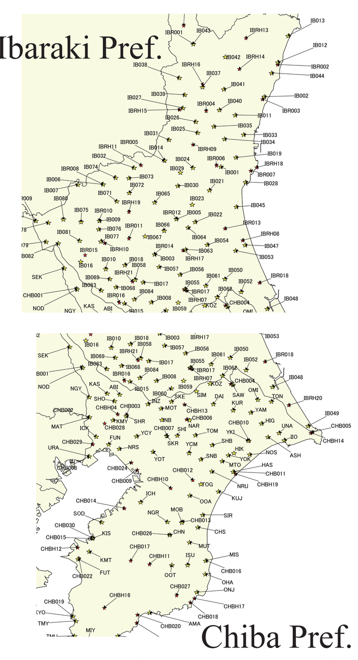


Fig. 5 The seismograph station which collected the data of Chiba and Ibaraki Prefecture

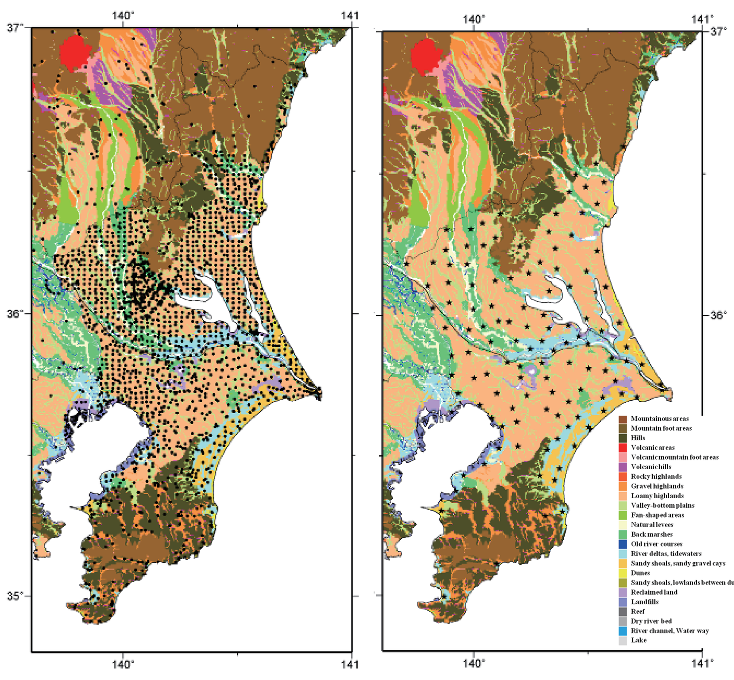


Fig.6 Microtrmor observational data of Chiba and Ibaraki Prefecture(left: single observation points, right: array observation points)

III INITIAL VELOCITY STRUCTURE MODEL CONSTRUCTING

In the initial stage, we combined the two ground structure models (Shallow-structure and Deep-structure) to form the seismic bedrock to the ground surface. To use the initial velocity structure model as the basis for analysis, we adopted the existing deep structure model (J-SHIS model) deeper than engineering bedrock, and created a shallow structure model from the geologic columns provided by the Chiba and Ibaraki prefectures or ourselves.
The creation method of a shallow structure model and an initial model(deep structure and shallow structure combine model) are shown.

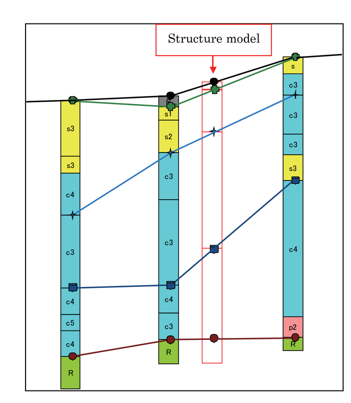


Fig.7 The key map of the modeling method by space interpolation of the analyzed structure models

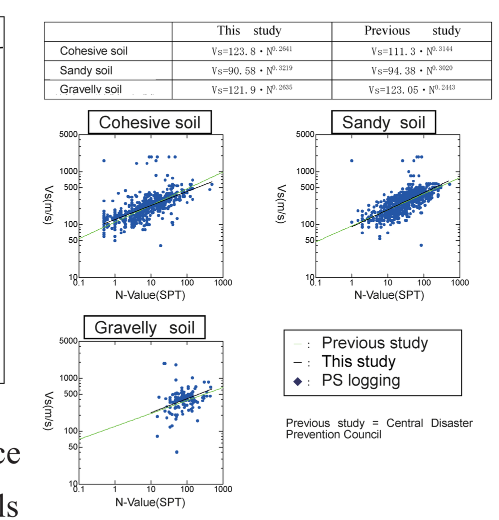


Fig.8 Calculation of initial S wave velocity (Vs(m/s))

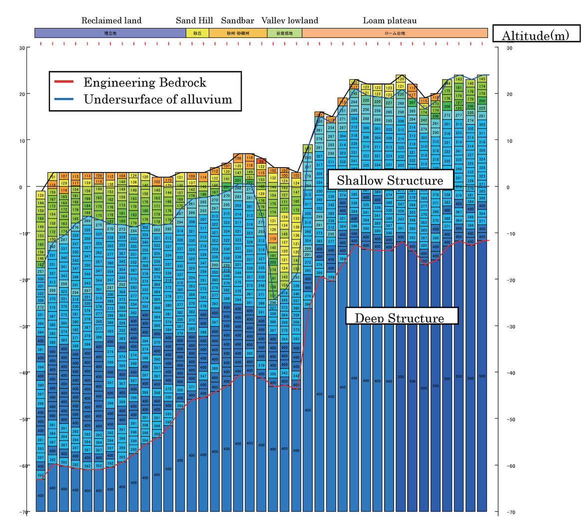


Fig.9 The built initial structure model

IV CORRECTION ANALYSIS OF A STRUCTURE MODEL

First, the depth of seismic bedrock was adjusted with the R/V spectrum of seismic observation record. Next, the reverse-analysis by the H/V spectral ratio and the phase velocity was applied on the initial model.
In order to create a final velocity structure model, we were reverse-analyzed by the phase velocity created by the above-mentioned velocity structure model, and microtremor observation (H/V spectral ratio) result.
Reverse analysis is conducted in two steps. The last structure model averaged the S wave velocity of the same geological formation model, and was created.

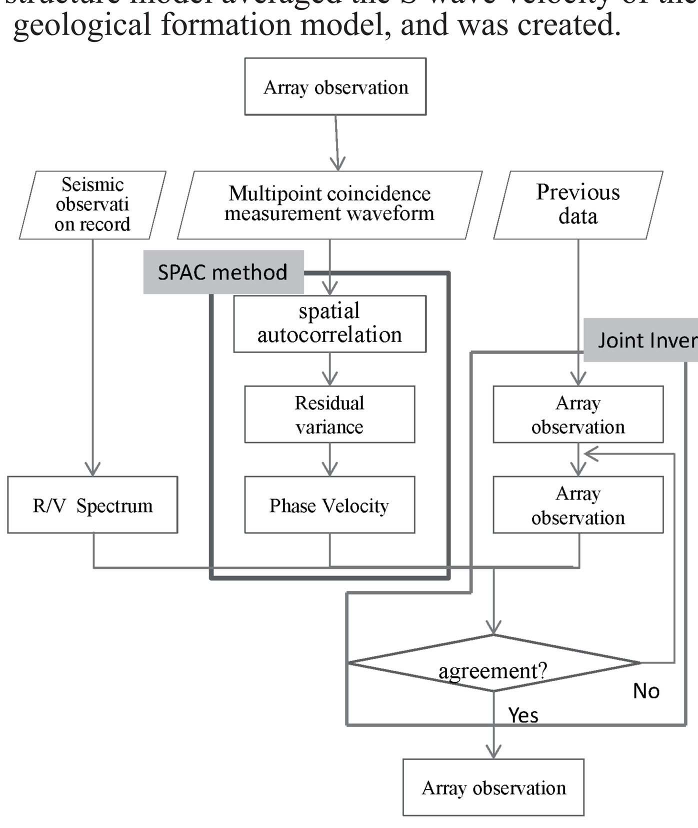


Fig.10 The flow of reverse analysis

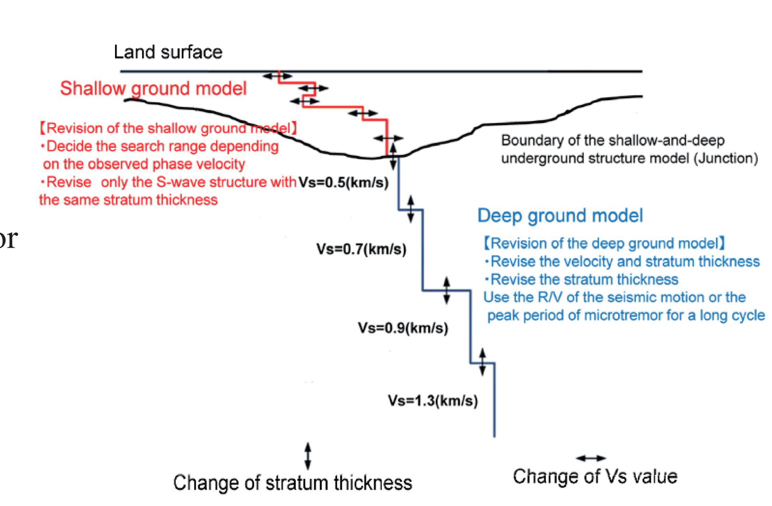


Fig.11 The layer structure revision method in a joint inversion

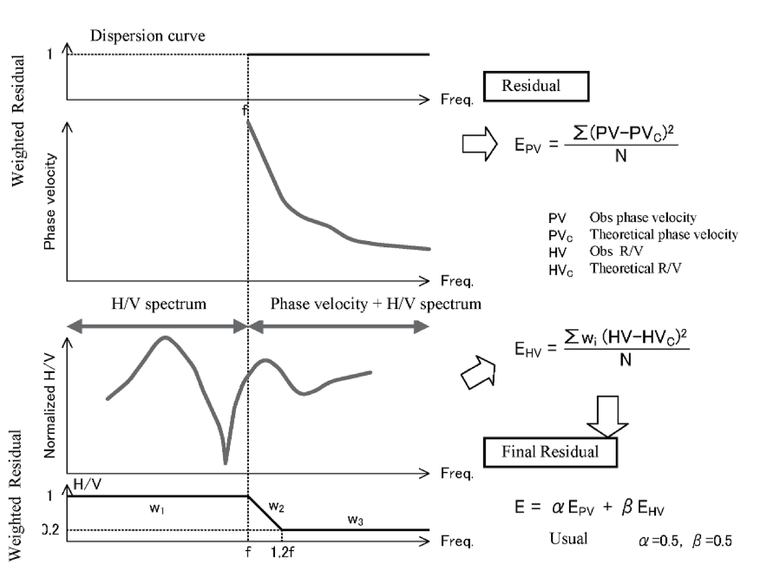


Fig.12 The key map of the modeling method by space interpolation of the analyzed structure models

R/V(Seismic Obs) + Phase velocity(microtrmor array) Joint Inversion

$$E_{PV} = \left(1/N^{PV}\right)\sum_{j=1}^{N^{PV}}\left[w(f_j)\left(C^O(f_j)-C^C(f_j)\right)/C^O(f_j)\right]^2 \quad (1)$$

$$w(f_j) = 1.0(f_j > 1.0Hz)$$
$$w(f_i) = f_i * 0.5 + 0.5(f_i \le 1.0Hz) \quad (2)$$

$$E_{RV} = \left(1/N^{RV}\right)\sum_{j=1}^{N^{RV}}\left[\left(\frac{RV^O(f_j)}{RV^O_{\max}} - \frac{RV^C(f_j)}{RV^C_{\max}}\right)\right]^2 \quad (3)$$

$$E = 0.5E_{PV} + 0.5E_{RV} \quad (4)$$

E : Residual
PV : Phase Velocity RV : R/V spectrum
Npv : the number of data of phase velocity.
Co(fj) is the observation phase velocity.
Cc(fj)is theoretical phase velocity.
W (f) is a weight function.

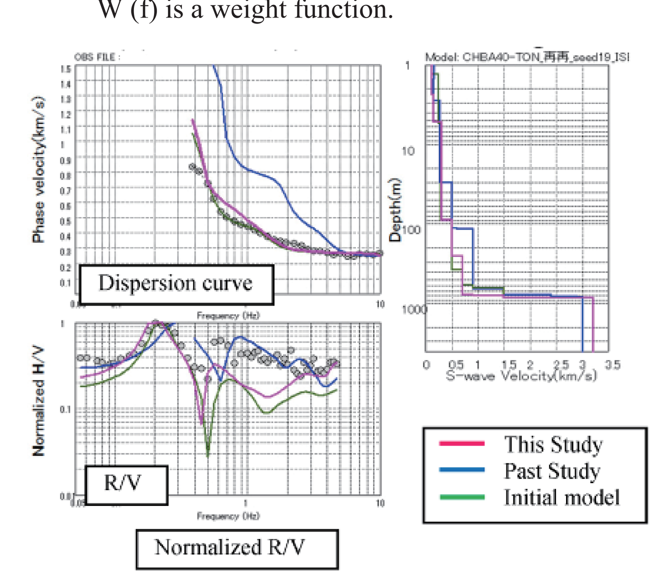


Fig.13 Joint inversion result

H/V(Microtremor Obs) + Theoretical phase velocity (Initial model) Joint Inversion

$$F = \frac{w_R}{I_R}\sum_{i=1}^{I_R}\left(\frac{c^R_{mi}-c^R_{Si}}{c^R_{mi}}\right)^2 + \frac{w_{HV}}{I_{HV}}\sum_{i=1}^{I_{HV}}\left(\frac{(H/V)_{mi}-(H/V)_{Si}}{(H/V)_{mi}}\right)^2 \quad (5)$$

(f < 0.5Hz)

C_R : Rayleigh wave theoretical phase velocity of structure model
H/V : H/V spectrum ratio (Rayleigh/Love ratio = 0.72 : 4th mode composition).
I_R and I_{HV} : data number.
Subscript m and S : observed and theoretical value.
W : weight function(W_R=1.0 and W_{HV}=1.0)

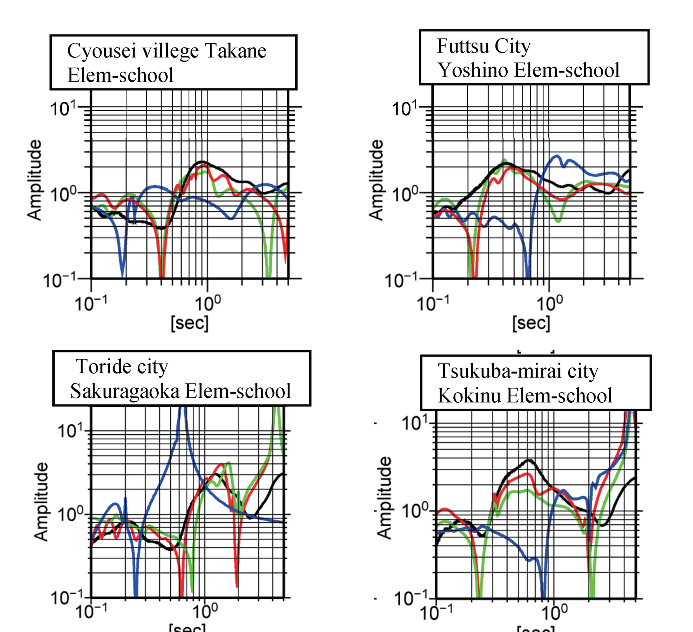


Fig.14 Joint inversion result by H/V spectrum and phase velocity.(Brackline:microtremor(H/V),Blueline:Past Study,Greenline:Initial model,Redline:This study)

V THE CREATED STRUCTURE MODEL (LAST RESULT)

In addition, the spectral amplification rate obtained from our model is consistent with that of earthquake ground motion recorded by strong ground motion observation point. As a result, the velocity structure model which can mainly explain the excellence period of the range for 2.0 to 0.5 second was able to be created.In response to this result, modeling from the seismic bedrock for earthquake motion prediction to the ground is due to be performed in a wide area from now on.

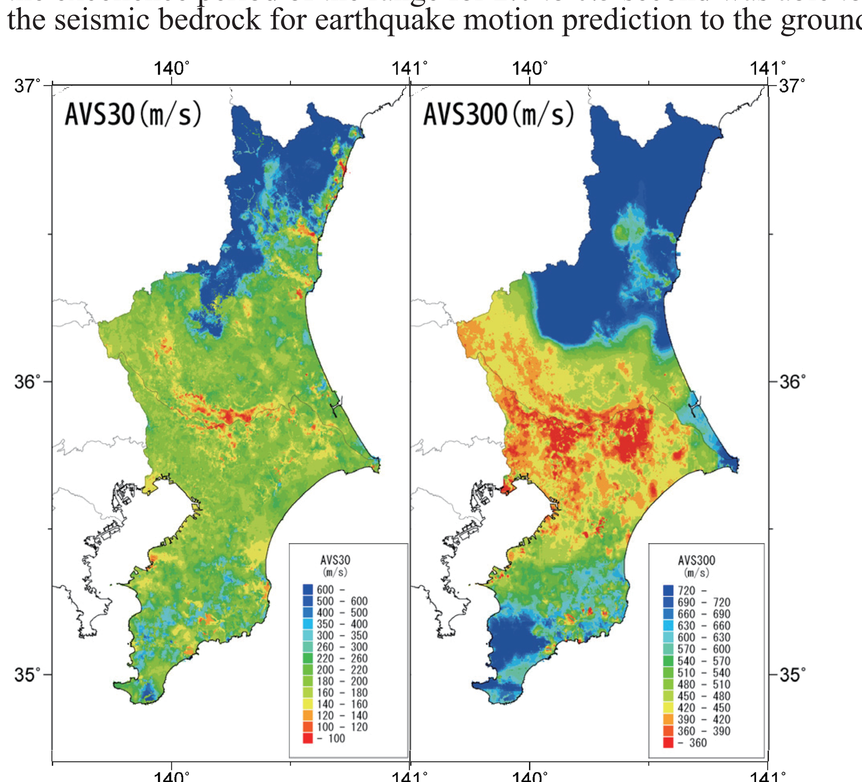


Fig.15 Vs30 map and Vs300map from the 7.5-arc-second JGEM (about 250m mesh) in Ibaraki and Chiba Pref.

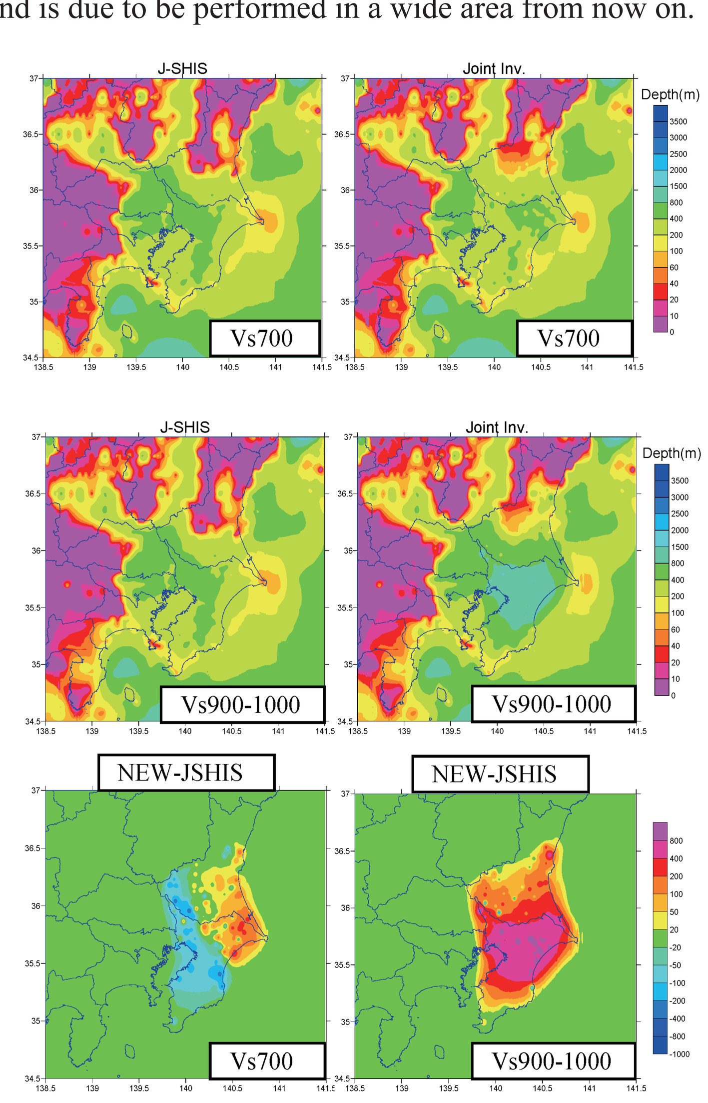


Fig.16 Upper surface depth of the deep structure model created by this study and previous study (J-SHIS) (Upper : Vs700(m/s), Middle : Vs900-1000(m/s), Lower : difference of two models).

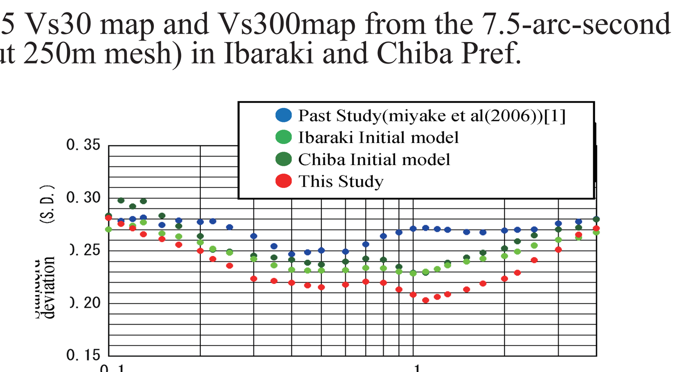
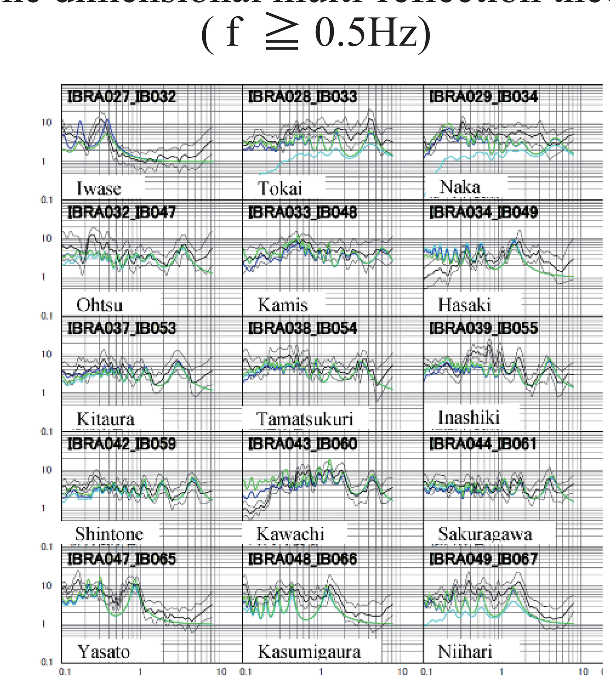


Fig.17 Joint inversion result by H/V spectrum and phase velocity (Blueline:Past Study,Greenline:Initial model,Redline:This study) (Standard deviation by structure models to the microtremor observations shown in Fig.14)

VI VERIFICATION OF THE CREATED STRUCTURE MODEL (REFERENCE INFORMATION)

About the structure model which we created by this study, after dividing the short period and the long period, accuracy was verified.The site amplification factor of the observation point by conducting spectrum conversion analysis of earthquake ground motion was calculated.

One dimensional multi-reflection theory (f ≧ 0.5Hz)

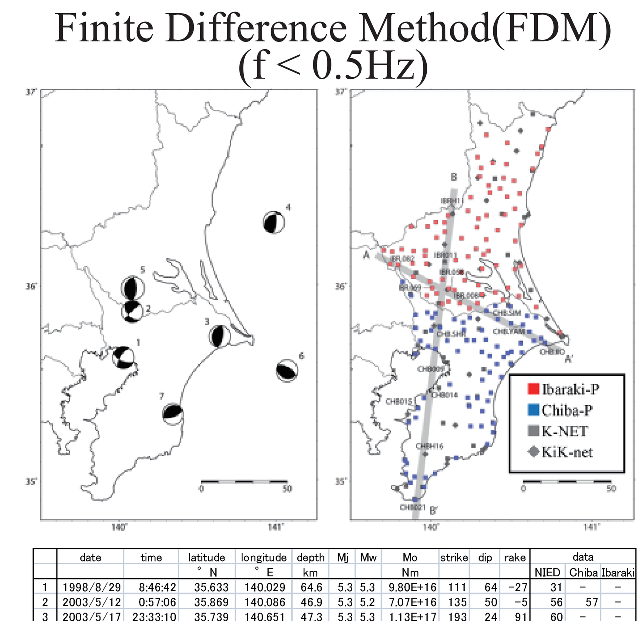


$$Q(f) = \frac{Vs}{a}\cdot f^b (f < f_c) \qquad Q(f) = \frac{Vs}{a}\cdot f_c^b (f \ge f_c)$$

(b = 0.44, a = searches for 0.1 to 100)

Fig.18 Identification analysis result of Q-value, black: observation amplifying characteristic (spectrum inversion result), light blue: result of AVS100, blue: average value (a=10.6), green: identification analysis result (15 Results of Ibaraki Prefecture)

Finite Difference Method(FDM) (f < 0.5Hz)



	date	time	latitude	longitude	depth	Mj	Mw	Mo	strike	dip	rake	data		
			° N	° E	km			Nm				NIED	Chiba	Ibaraki
1	1998/8/29	8:46:42	35.633	140.029	64.6	5.3	5.3	9.80E+16	111	64	-27	31	-	-
2	2003/5/12	0:57:06	35.869	140.086	46.9	5.3	5.2	7.07E+16	135	50	-5	56	57	-
3	2003/5/17	23:33:10	35.739	140.651	47.3	5.3	5.3	1.13E+17	193	24	91	60	-	-
4	2004/3/11	11:34:57	36.322	141.008	47.5	5.3	5.3	1.04E+17	5	72	66	50	22	30
5	2004/10/6	23:40:40	35.989	140.090	66.0	5.7	5.7	4.52E+17	360	64	83	65	59	63
6	2005/5/19	10:14:26	35.559	141.082	33.4	5.4	5.3	1.21E+17	301	61	99	52	34	8
7	2007/8/18	16:55:08	35.342	140.345	20.2	5.2	5.1	5.72E+16	236	20	76	57	-	17

Fig.19 The earthquake (left figure) used for calculation of a finite difference method, and the observation point which performed waveform calculation (right figure)

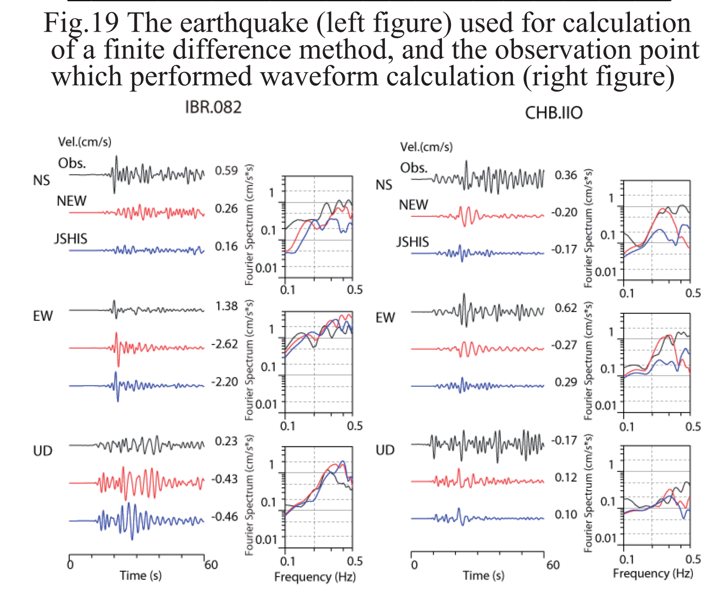


Fig. The velocity waveform in two points of course-of-traverse A-A' of the Fig16(left figure), and comparison of the Fourier spectrum. Observation record (black line: Obs) . The analysis result (red line: NEW) using the foundation model of this research. The result (blue line: J-SHIS) of having used the J-SHIS model.