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OBSERVATORY SHED EFFECT ON STRONG MOTION RECORDS IDENTIFIED BY MICRO-TREMOR MEASUREMENT

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SUMMARY

For the 2000 Tottori-ken-seibu earthquake (Mj7.3), horizontal strong motion more than 900gal was recorded at the KiK-net Hino station. Several studies have been carried out to obtain reasonable bedrock motion with horizontally layered models, simulating transfer functions of the station floor to GL-100m by the genetic algorithm. We have done micro-tremor observation at and around the station to find significant soil-structure interaction effects around 8Hz for weak motion at the station floor. Then, a soil coupled structure model for the station at a small strain level is constructed to simulate transfer functions of the station floor to the free surface consulting our dispersion curves. Finally, we evaluate horizontal motion at the ground surface during main shock by eliminating the interaction effects with equivalent linear soil properties, observing that the interaction effects were not significant for strong motion during main shock because of large damping due to soil hysteresis.

INTRODUCTION

For the 2000 Tottori-ken-seibu earthquake (Mj7.3), horizontal strong motion more than 900gal was recorded at the KiK-net Hino station. Several studies, e.g. Nagano [1], Higashi [2], and etc., tried to obtain reasonable bedrock motion with horizontally layered models for aftershocks, as well as for the main shock, simulating vertical array transfer functions of the station floor to GL-100m by the genetic algorithm; however, none of them seemed successful to simulate the transfer function from 5 Hz to 10 Hz.

Speculating that the recorded acceleration could be different from the free-surface motion because of soil-structure interaction of a station shed, we carried out simultaneous observations of micro-tremor at the station terrace and nearby ground surface. We found that the motion at the terrace was amplified around 8 Hz to the ground surface for micro-tremor and weak motion of a small earthquake due to the soil-structure interaction (Hibino [3]). These soil-coupled dynamic characteristics were later identified by free vibration excited by hammering at the shed (Yoshimura [4]). We also carried out micro-tremor array observations for Rayleigh wave dispersion curves and found that shear wave velocity just beneath the ground surface must be less than those of PS logging data (Maeda [5]), which is in accordance with aforementioned studies of the vertical array transfer function simulation.

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In this paper, we will simulate the transfer functions of the station terrace to the nearby ground surface by modeling the station as a rigid structure supported by horizontally layered soil. Then, we compute the horizontal motion at the free surface by eliminating the interaction effects from the record at the station floor during the main shock with equivalent linear soil properties, observing that the interaction effects were not significant for strong motion during main shock because of large damping due to soil hysteresis.

VERTICAL ARRAY TRANSFER FUNCTIONS

KiK-net HINO station

KiK-net HINO station (NIED [6]) is located at the lakeside in the mountainous area of the western Japan. The station shed is one-story reinforced concrete building of 3.15m high and 2.2m by 3.2m in plan, we designate horizontal axis of X (N53E) parallel to the longer wall and Y (N37W) parallel to the shorter wall as shown in Fig. 1. The station has two sets of seismographs on the floor and at GL-100m, both of which measure NS, EW, and UD components. Surface geology shows that the station sits on deposit next to rock boundary, and PS logging data reveals stiff soil profile down to GL-100m, with Vs=210m/sec for a top layer of 11 m thick classified as gravel underlain by granite as shown in Fig. 2.

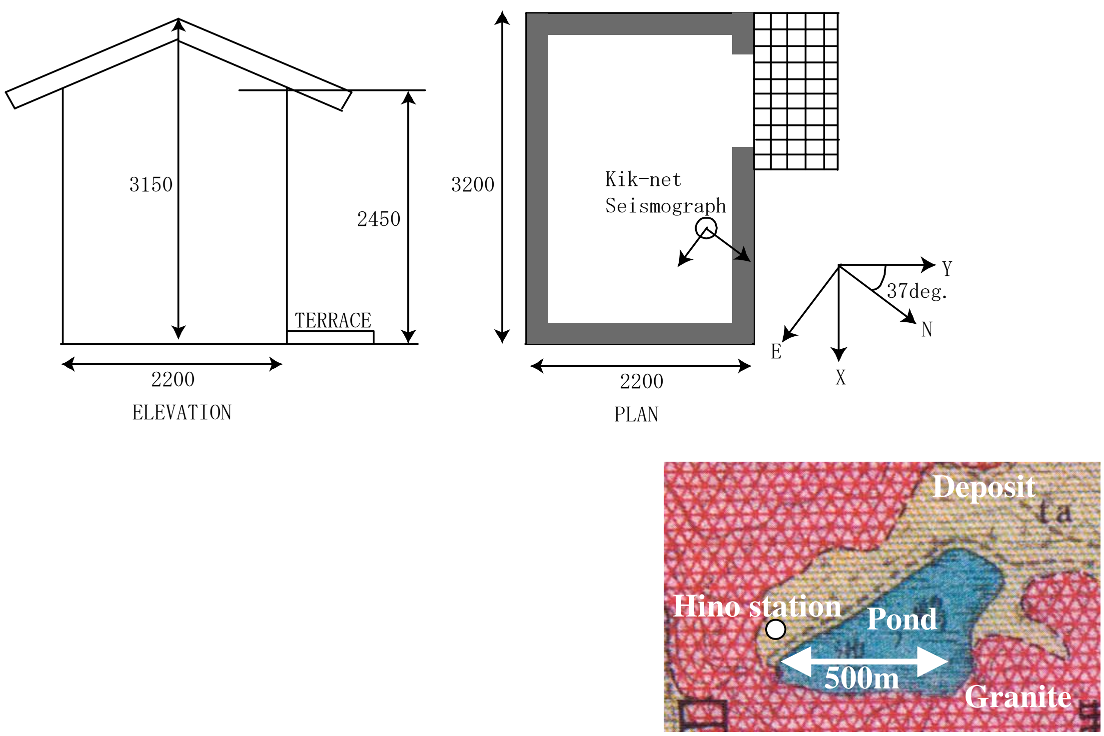


Fig. 1 KiK-net Hino station

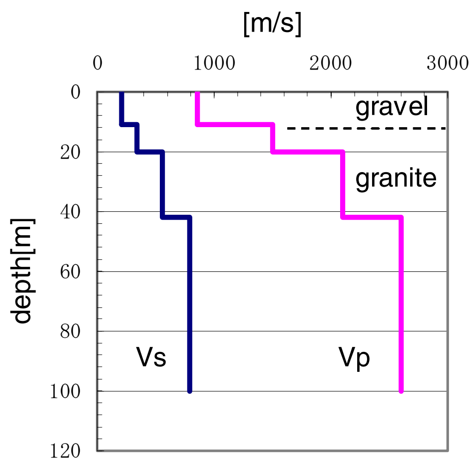


Fig. 2 PS logging data at KiK-net Hino station

Transfer functions

Nagano [1] tried to evaluate bedrock motion with one-dimensional equivalent linear soil models, which were constructed by simulating vertical array transfer function for a main shock and aftershocks with GA, the genetic algorithm. The Vs structure of Nagano's model for aftershocks, shown in Fig. 3, scarcely altered Vs of PS logging, exhibiting lower 1^{st} frequency and larger amplitude around 6Hz compared to the averaged transfer function as shown in Fig. 4, where averaged transfer function for four aftershocks used in Nagano [1] is shown. He attributed the lower evaluated 1^{st} frequency to one-dimensional modeling for the complex geology. Higashi [2] also constructed one-dimensional model with GA incorporating with reflection survey data to put bedrock at GL-84m of about three times of Vs as PS logging data as shown in Fig. 3; damping factor was not explicitly shown in their paper. The 1^{st} frequency for aftershocks was simulated well by Vs structure of Higashi [2] with damping factor of Nagano [1] assigned; however, the second frequency was higher and amplitude around 6Hz were underestimated.

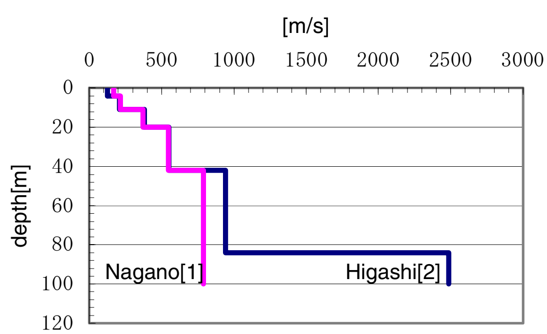


Fig. 3 Shear wave velocity structure of models proposed by Nagano [1] and Higashi [2]

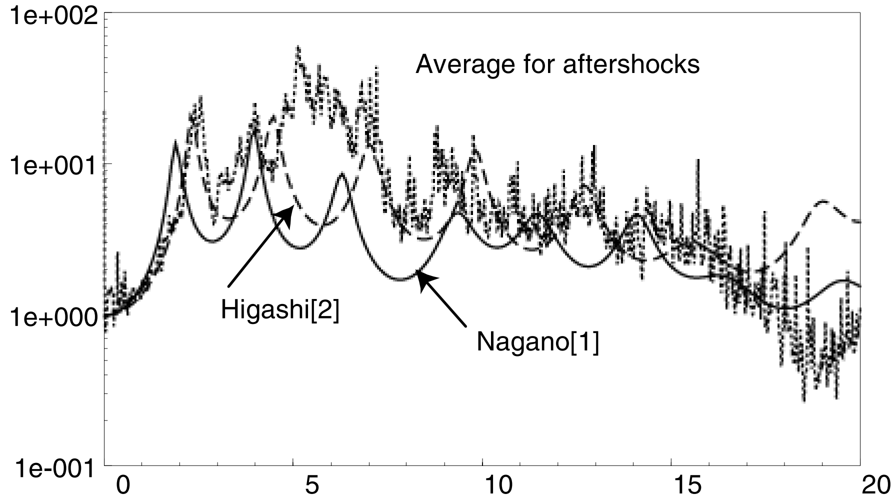


Fig. 4 Vertical array transfer functions of Vs structures proposed by Nagano [1] and Higashi [2]

MICRO TREMOR OBSERVATION AND SIMULATION

Array observation

We carried out micro-tremor array observation near the station for dispersion curves of Rayleigh wave phase velocities. Three circular arrays with different radii of 3m, 10m, and 20m constitute four three-component seismographs, one at the center and other three at the circumference as shown in Fig.5. Those seismographs are over-damped velocity meter with sensitivity of 1V/gal, sampling period of 0.005 sec., and low-pass filtered at 50 Hz. We have applied the SPAC method (Aki [7]) on vertical components to obtain dispersion curves shown in Fig. 6.

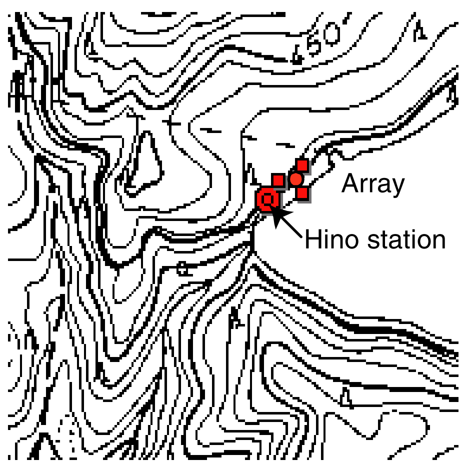


Fig. 5 Array configurations (r=20m)

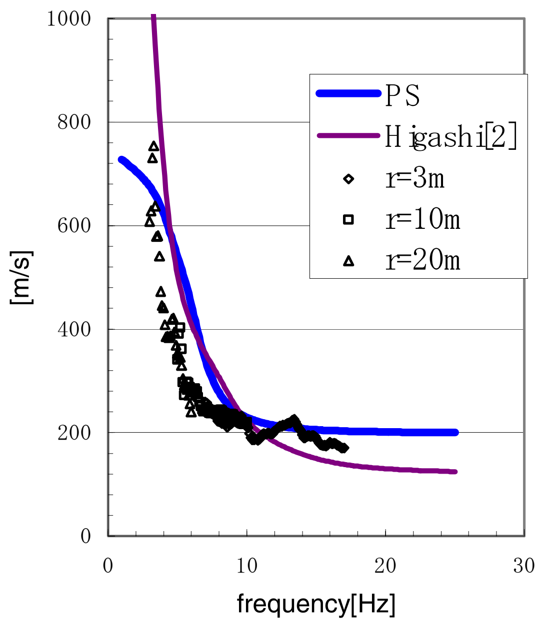
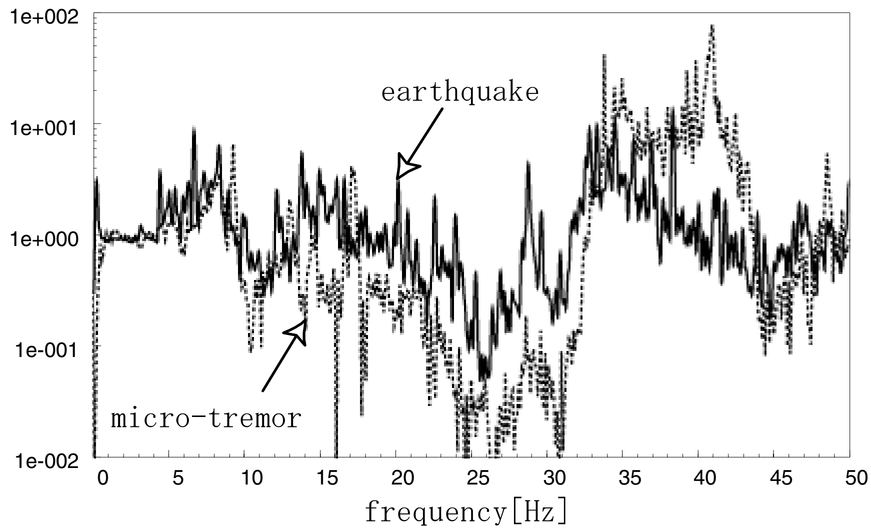


Fig. 6 Dispersion curves

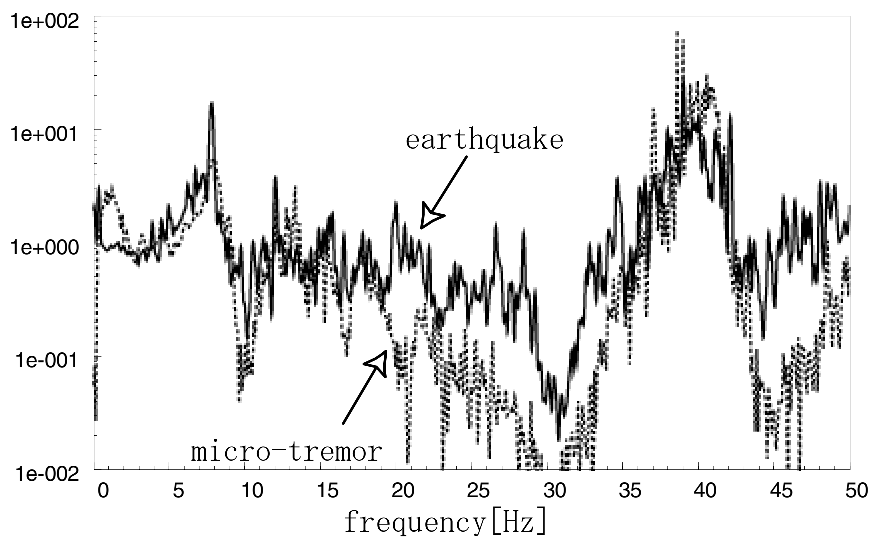
Those dispersion curves are compared for Rayleigh wave fundamental mode computed by the generalized transfer and reflection matrix method proposed by Luco [8]. Fig.6 shows that the top layer should have smaller Vs than PS logging data of 210m/s.

Simultaneous observation at the station terrace and the ground

We speculated a possibility that acceleration records obtained on the floor were affected by dynamic soil structure interaction, and we simultaneously measured micro-tremor at the station terrace and the ground surface at several meters from the station. Transfer functions of the floor to the ground surface are evaluated for X- and Y-components shown in Fig. 7. X-component parallel to the longer wall shows a peak of 9Hz and Y-component to the shorter wall 8Hz. Since Y-component of the transfer function to the ground surface looks simpler and vertical component also shows a peak at 8Hz, we simulate Y-component of the weak motion.



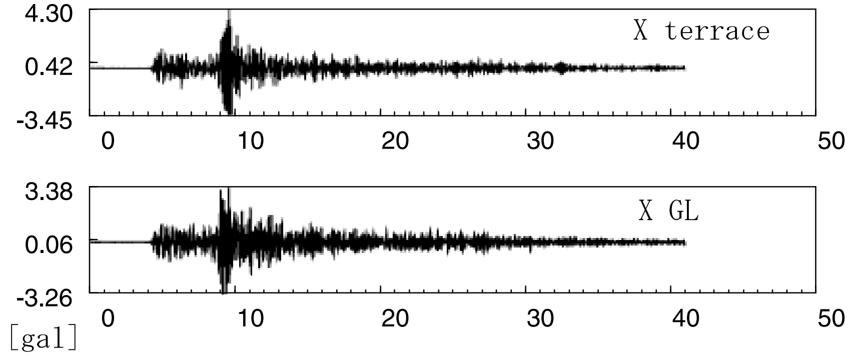
(a) X-component parallel to the longer wall



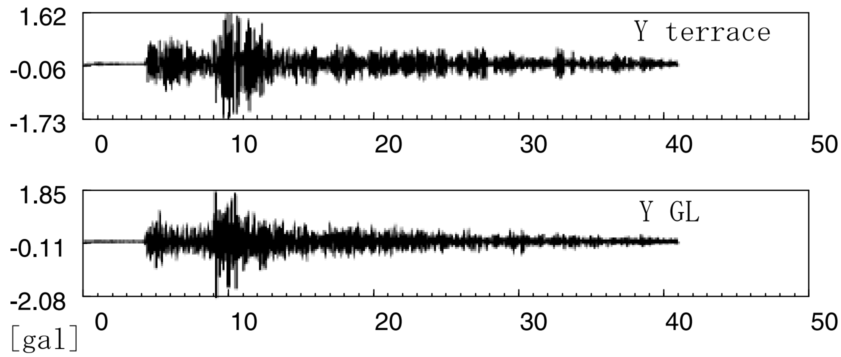
(b) Y-component parallel to the shorter wall

Fig. 7 Transfer functions of station terrace to the ground surface

Ground motion for a small earthquake of M3.9 in this region was obtained during micro tremor measurement. Acceleration waveform low-pass filtered at 20Hz is shown in Fig.8. Comparison of major part of the acceleration shows remarkable predominance of 8Hz to 9 Hz at the terrace as shown in Fig. 9, and transfer functions have similar properties observed for micro tremor as shown in Fig.7. Thus, transfer functions of the station terrace to the ground surface for micro tremor can be used to study soil-structure interaction under weak motion during earthquakes.

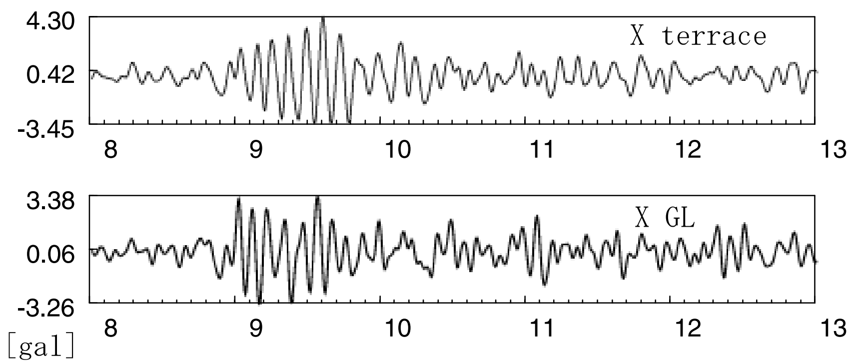


(a) X-component parallel to the longer wall

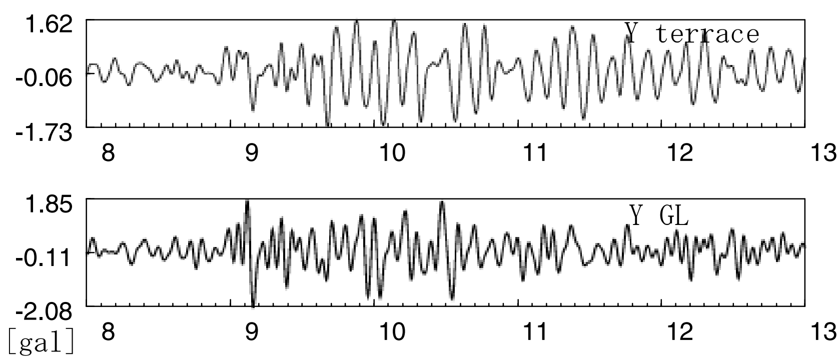


(b) Y-component parallel to the shorter wall

Fig. 8 Weak motion of small earthquake observed during micro-tremor measurement



(a) X-component parallel to the longer wall



(b) Y-component parallel to the shorter wall

Fig. 9 Major part of weak motion of small earthquake

The station is made of reinforced concrete, yet detailed specifications are not known. We assume density of 2.4t/m^3, projected roof thickness 0.3m for horizontal area, wall thickness of 0.2m, and foundation thickness of 0.5m, 0.7m, and 1.0m. The superstructure is modeled by two lumped mass of 7.6t at GL+2.8m and 11.0t, 14.4t, and 19.5t at GL-0m. Soil is modeled by axisymmetric FEM valid up to 20 Hz with an energy transmitting boundary at the circumference and viscous boundary at the bottom, as shown in Fig. 10. Since the top layer of the soil should have less shear wave velocity than that of PS logging data, 210m/s, we consult the shear wave velocity structure proposed by Higashi [2] for soil-structure interaction simulation, of which the top layer has Vs of 127m/s as shown in Table 1, where Vs_initial and h_initial are used.

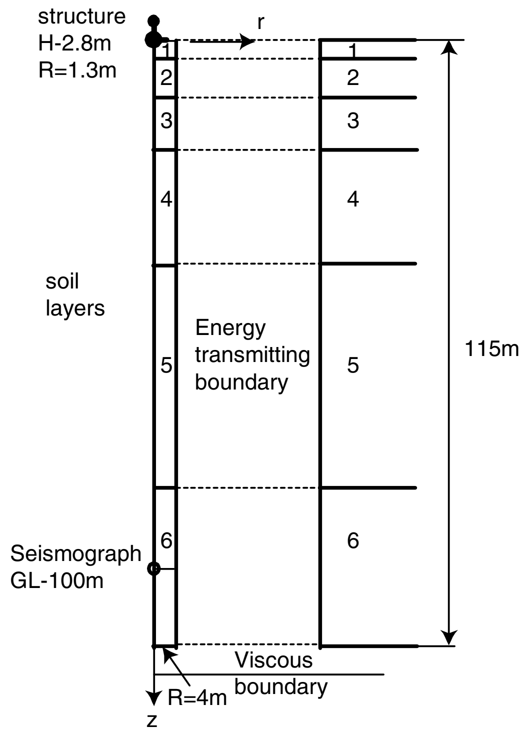


Fig. 10 Axisymmetric FE model for simulation

Table 1 Soil model for soil-structure interaction

No.	Depth [m]	Thickness [m]	ρ [t/m^3]	ν	Vs_initial [m/s]	h_initial	Vs_eq [m/s]	h_eq
1	4	4	1.7	0.4	127	0.01	64	0.20
2	11	7	1.7	0.4	211	0.01	105	0.21
3	21	10	1.9	0.4	382	0.01	266	0.15
4	43	22	1.9	0.4	551	0.01	418	0.12
5	85	42	2.2	0.4	943	0.01	822	0.07
6	115	30	2.2	0.4	2487	0.01	2466	0.02

Fig. 11 compares amplitudes of the transfer functions evaluated by micro-tremor and computed by FEM with different foundation thicknesses. With Vs structure proposed by Higashi [2], Y-component of the transfer function of the terrace to the ground surface is simulated well by the structure model with foundation of 0.7m thick, exhibiting a peak at 8Hz with amplification of around 2 and a trough at 9.5Hz with de-amplification of around 1/5. Although the structure model is roughly assumed and we do not adhere to the foundation thickness of 0.7 m, we will use this in the following for a case study.

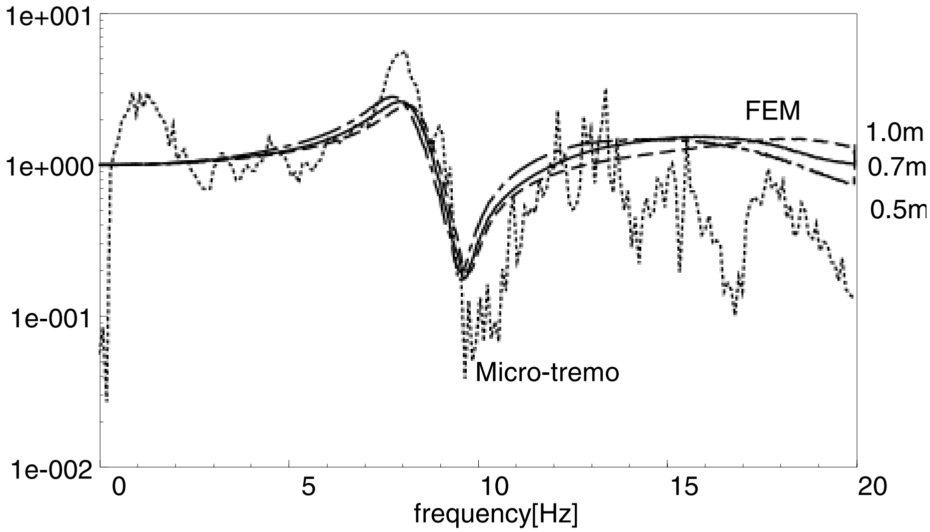


Fig. 11 Comparison of transfer functions of the floor to the ground surface for weak motion

GROUND MOTION EVALUATED FROM THE RECORDS

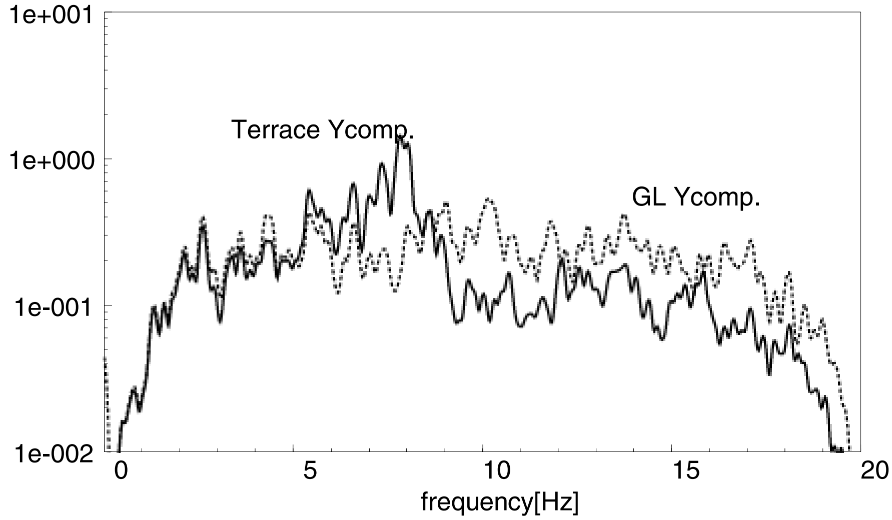
Weak motion of a small earthquake

We evaluate the ground motion from the records at the terrace and compare that with the records at the ground surface for weak motion of a small earthquake. Fourier amplitudes smoothed by the Parzen window of 0.2Hz are compared in Fig. 12, which shows that dominated components around 8Hz at the terrace is removed, but higher frequency components are not recovered to the observed level. In Fig. 13, acceleration wave forms shows less dominated components of 8Hz as compared with Fig. 9.

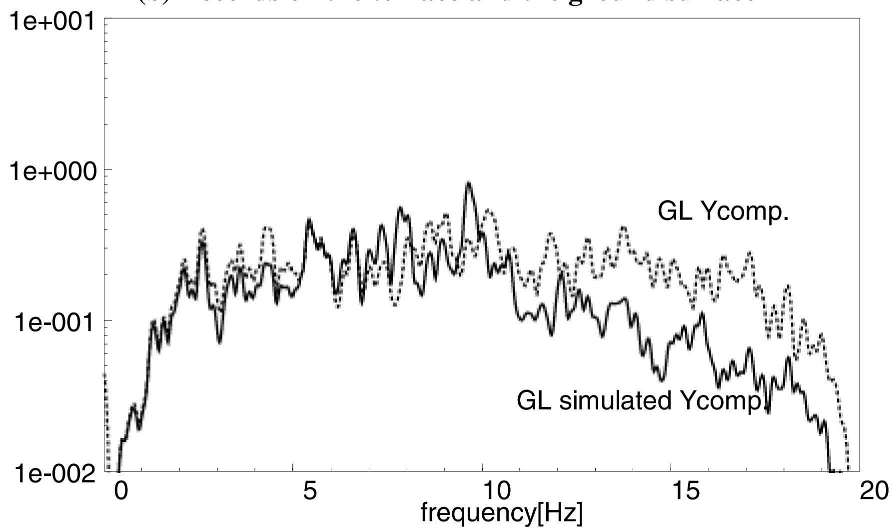
Strong motion during the main shock

We evaluate Vs and damping factors in equivalent linear analysis by specifying acceleration records at GL-100m of the model shown in Table 1. G-γ and h-γ curves shown in Fig. 14, which were proposed for sand in Japanese national codes for buildings, are used for layers other than bedrock. Since maximum shear strain is large for equivalent linear analysis, we take average of converged Vs and damping factors in each layer to evaluate layer property shown in Table 1 as Vs_eq and h_eq. With these soil parameters, transfer function of the floor to the ground surface during the main shock is evaluated by axisymmetric FEM up to 20Hz.

The evaluated transfer function exhibits a wide and smooth peak around 3Hz with amplitude a little larger than unity as shown in Fig. 15. The acceleration record obtained at the floor is divided by this transfer function to give acceleration time history shown in Fig.16 via inverse FFT. Comparison of the computed motion at the ground surface and the records on the floor low-pass filtered at 20 Hz shows little difference due to soil-structure interaction. This insignificant effect is attributed to large damping factor around 0.2 evaluated by equivalent linear analysis. Vibration caused by inertial soil-structure interaction should be died out quickly by large hysteretic energy loss in the soil.

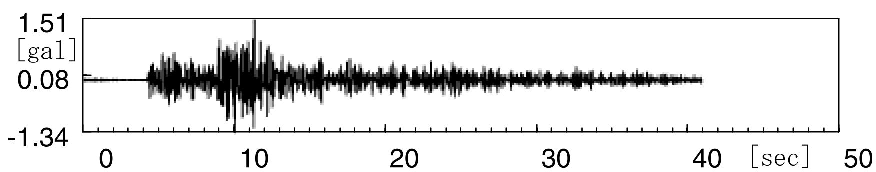


(b) Records on the terrace and the ground surface

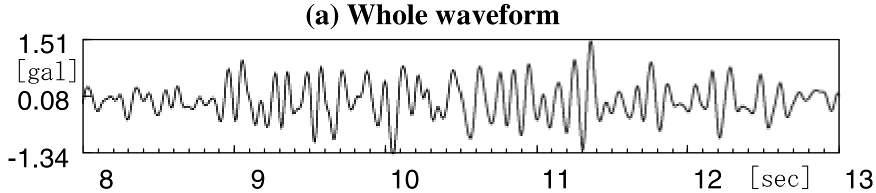


(b) Record and simulation on the ground surface

Fig. 12 Fourier amplitudes of weak motion of a small earthquake (Y-component)



(a) Whole waveform



(b) Major part of waveform

Fig. 13 Simulated acceleration of weak motion at the ground surface (Y-component)

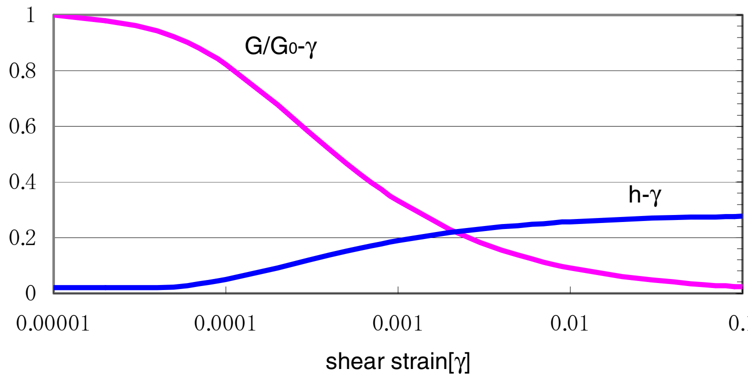


Fig. 14 G/G_0-γ and h-γ curves for equivalent linear model

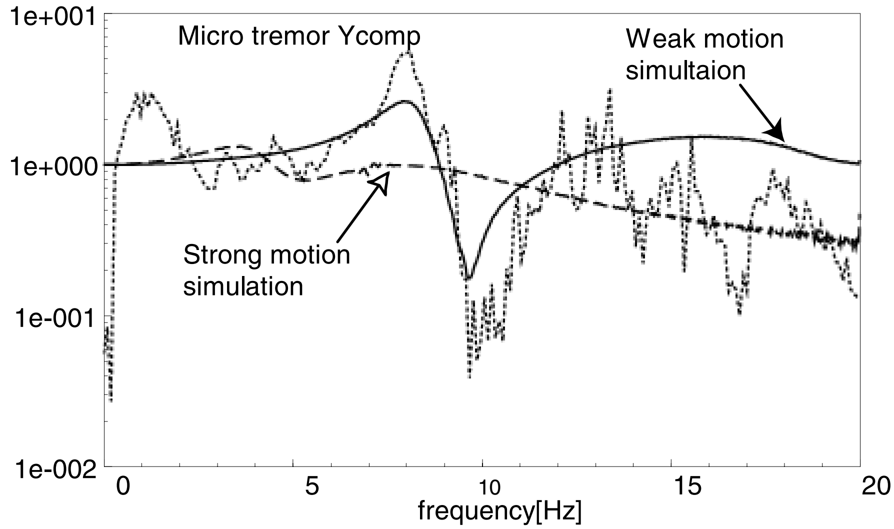
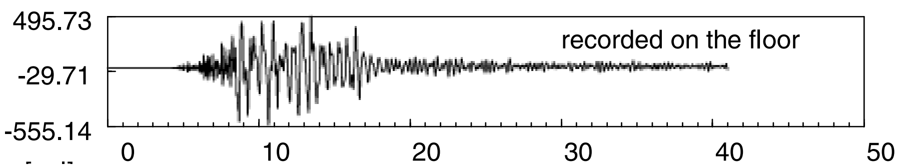
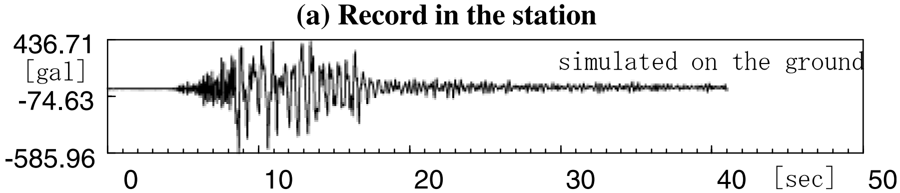


Fig. 15 Comparison of transfer functions to the ground surface for the main shock



(a) Record in the station



(b) Simulation on the ground surface

Fig. 16 Strong motion records and evaluated ground motion during the main shock

CONCLUSIONS

Micro-tremor measurement was carried out to find soil-structure interaction effects on the record of KiK-net Hino station during the 2000 Tottori-ken-seibu earthquake. Simultaneous observation at the station terrace and nearby ground surface shows significant amplification at the terrace around 8Hz revealing the interaction effects for micro-tremor and weak motion of a small earthquake. We have simulated transfer function of the terrace to the ground surface by axisymmetric FEM with a rigid structure model supported by horizontally layered soil model to show a good agreement consulting soil parameters proposed for vertical array simulation. Then we have evaluated acceleration waveform of the main shock on the ground surface from the record obtained inside the station by adapting equivalent linear soil parameters to the FE model to depict that soil-structure interaction effects on the record of the main shock was insignificant due to large damping representing large plastic deformation.

We wish to express our gratitude to National Research Institute for Earth Science and Disaster Prevention for allowing us to use KiK-net data.

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