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TOPOGRAPHIC SITE RESPONSE AT A QUATERNARY TERRACE IN HACHIOJI, JAPAN, OBSERVED IN STRONG MOTIONS AND MICROTREMORS

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SUMMARY

We investigated a topographic site effect of a Quaternary terrace in Hachioji, Japan, on ground-motion amplification. The terrace discussed herein is about 12-m high consisting of volcanic ash, clay, silt and sand. 7 accelerographs were deployed in the site: 6 on the crest and 1 on the base of the terrace. The maximum PGA and PGV ratios with respect to the base are 3 and 2.7, respectively, demonstrating that the site amplification due to the topographic effect of the terrace is significant. Next we evaluated crest/base spectral ratios in order to investigate the relative site response. It is found that ground motions at frequencies above 5 Hz are amplified and the fundamental frequency of the terrace is about 7 Hz. The crest/base spectral ratios also show that ground motions at frequencies above 10 Hz are affected by directional topography of the terrace and the maximum difference of horizontal ground motions is about 5. Additional microtremor observations and eigenvalue analysis demonstrated that the crest edges tend to oscillate higher in the direction perpendicular to the edges.

INTRODUCTION

Earthquake damage is sometimes worsened due to ground-motion amplification. A topographic effect is one of the main factors of the ground-motion amplification. During the 1994 Northridge earthquake, for instance, high PGA of 1.78 g was observed at a 15-m high and 130-m wide hill at Tarzana (Shakal [1]). The unusual seismic response was probably caused by the resonance of the hill (Spudich [2]). Another example is that according to an observational case study conducted in Yokohama, Japan, a strong-motion station atop 25-m high plateau observed stronger ground motions by a factor of 2 in comparison to an adjacent lowland (base) station (Toshinawa [3]). This was presumably because ground motions were amplified in the plateau that mainly consists of soft volcanic ash flown from Mt. Fuji during the

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Quarternary period. As is evident from these examples, upland sites have possibilities to be amplified during earthquakes. Thus we made an investigation on the topographic effect on ground-motion amplification at a Quaternary terrace in Hachioji, Japan,by using strong-motion observation, microtremor observation and 3-D FEM calculation.

SITE DESCRIPTION

The site considered herein is located about 30 km west of the center of Tokyo (Figure 1). This site is mapped as a part of hills that cover the western part of Kanto area. Figure 2 shows a plan and side views of the terrace. For a land use, an original terrace was artificially cut and filled forming a 12.5-high and southwestern-cornered terrace. On the top of the terrace, low story buildings were built, the locations of which are depicted in the figure. Figure 3 shows soil, SPT N-value and PS profiles at GR1, GR4, and GR3(GR0). GR1 sits on cut ground while GR4 is covered by 4-m artificial fill with shear-wave velocity of 90-200 m/s. The depths to sandy gravel are 8.5-9 m. 7 accelerographs (GR1-GR7) were deployed on the ground surface and one accelerograph (GR0) was installed in the ground beneath GR3 (Kawakami [4]). GR7 was installed on the base of the terrace.

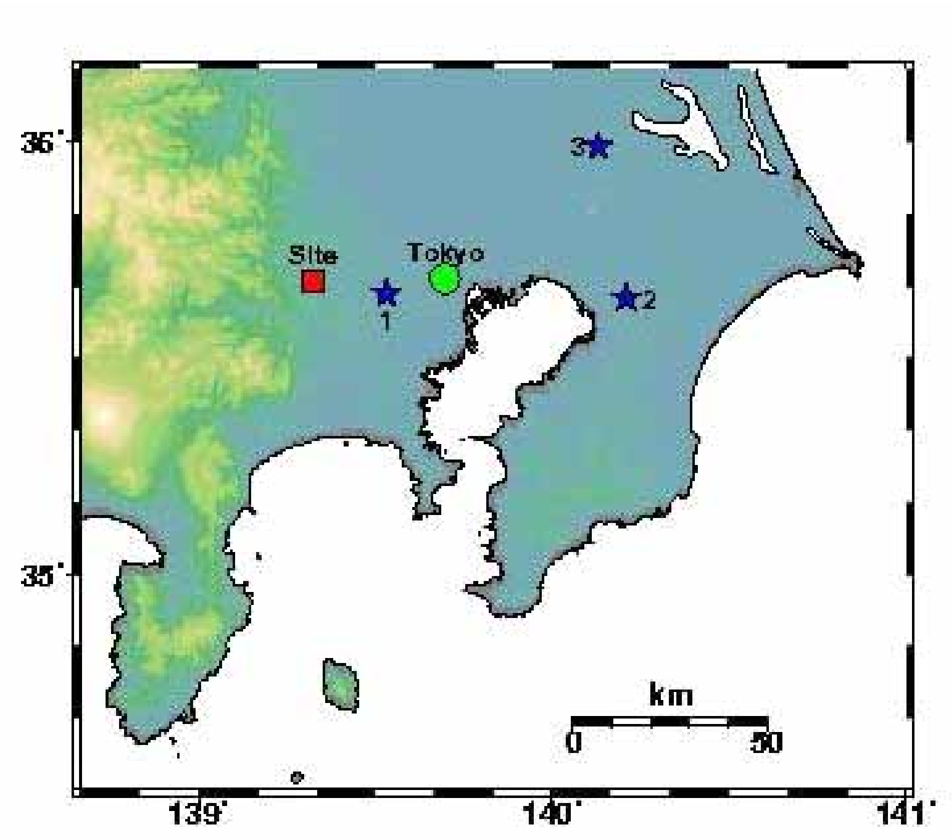

Figure 1. Location of the site and epicenters of the events used.

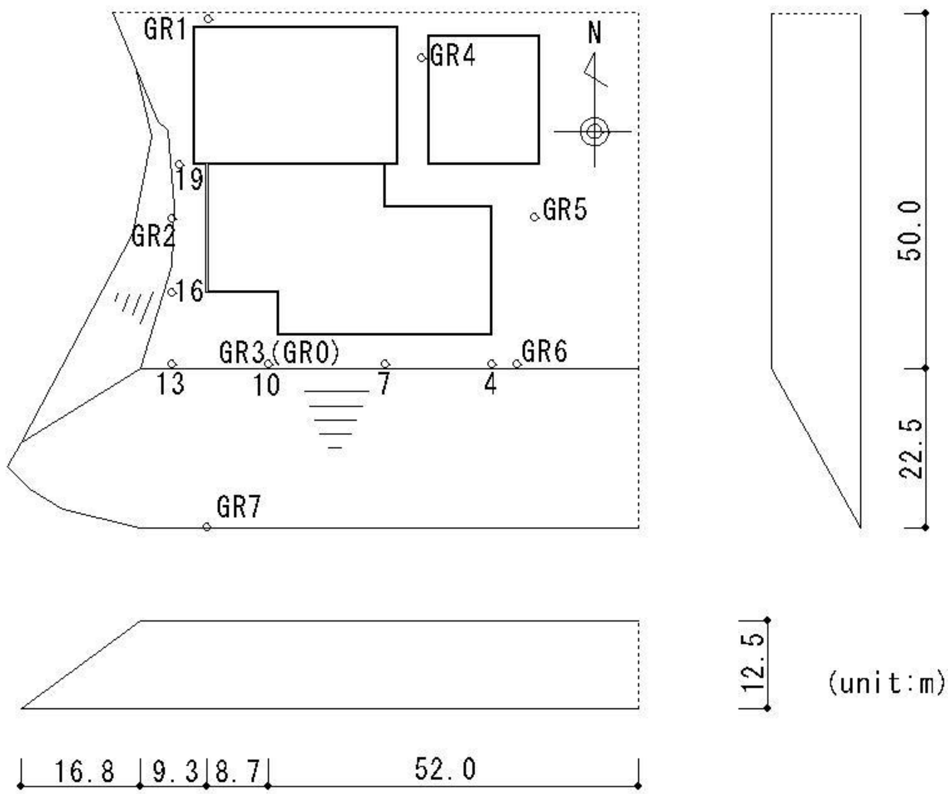

Figure 2. Plan and side views of the terrace with instrument layouts.

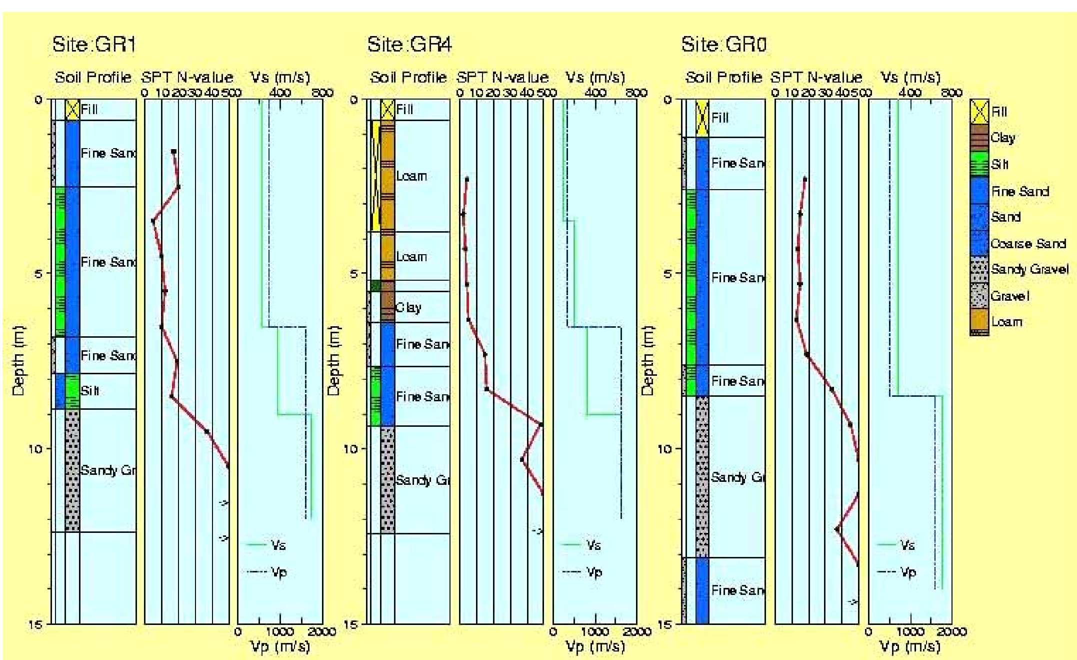

Figure 3. Soil, SPT N-value and PS profiles at GR1, GR4 and GR0.

STRONG MOTIONS

Strong-motion records

Table 1 shows listing of earthquakes observed by the strong-motion system. JMA (Japanese Meteorological Agency) magnitude (M_J) ranges from 3.5 to 5.8 and focal depth ranges from 20 to 80km. Peak ground accelerations (PGA) and peak ground velocities (PGV) at GR7 are 1.6-3.1 cm/s^2 and 0.06-0.20 cm/s, respectively. Epicenters except for the event 4 are plotted with solid stars in Figure1. Figure 4 shows ground accelerations recorded during the #2 event (2002/5/19). It can be seen that even in such a small area ground motions are significantly different suggesting that site response effect should not be negligible in this site. From the records, 10.24-sec shear-wave parts are Fourier transformed and smoothed with a 1.0-Hz Parzen window (Figure 5) In comparison to GR0 and GR7, ground acceleration on the top of the terrace are highly amplified. Figures 6, 7, 8 show amplification factors of PGA and PGV, and difference in instrumental seismic-intensity with respect to GR7. Except for the event 4, PGA and PGV are highly amplified with the highest factors of 3 and 2.7, respectively. The instrumental seismic-intensity difference ranges from 0 to 1.1, which is significant variation in ground-motion intensity observed within small area.

Table 1. Listing of the parameters the events used.

#	Origin Time (local)	M_J	D	Δ	Azimuth	PGA at GR7	PGV at GR7
1	2002/4/30 21:42	3.5	30 km	20km	100°	2.9cm/s^2	0.06cm/s
2	2002/5/19 5:00	4.7	80 km	80km	93°	2.4cm/s^2	0.11cm/s
3	2002/7/13 21:45	4.8	70 km	80km	65°	3.1cm/s^2	0.14cm/s
4	2002/7/24 5:05	5.8	20 km	320km	58°	1.6cm/s^2	0.20cm/s

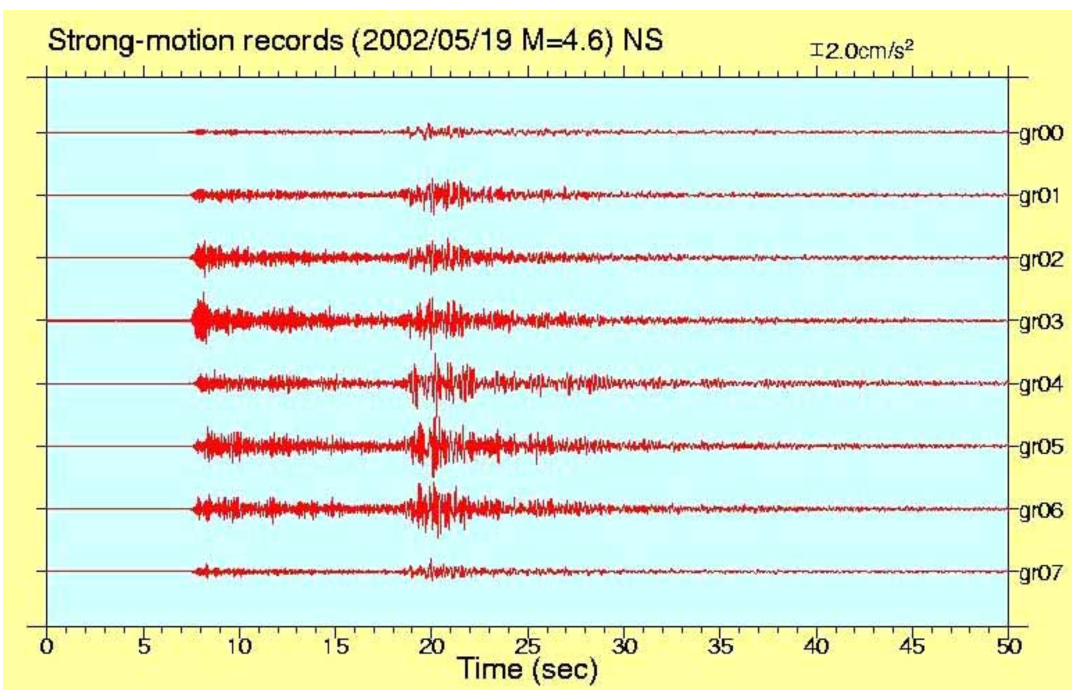

Figure 4. Horizontal ground accelerations recorded during the #2 event (2002/5/19).

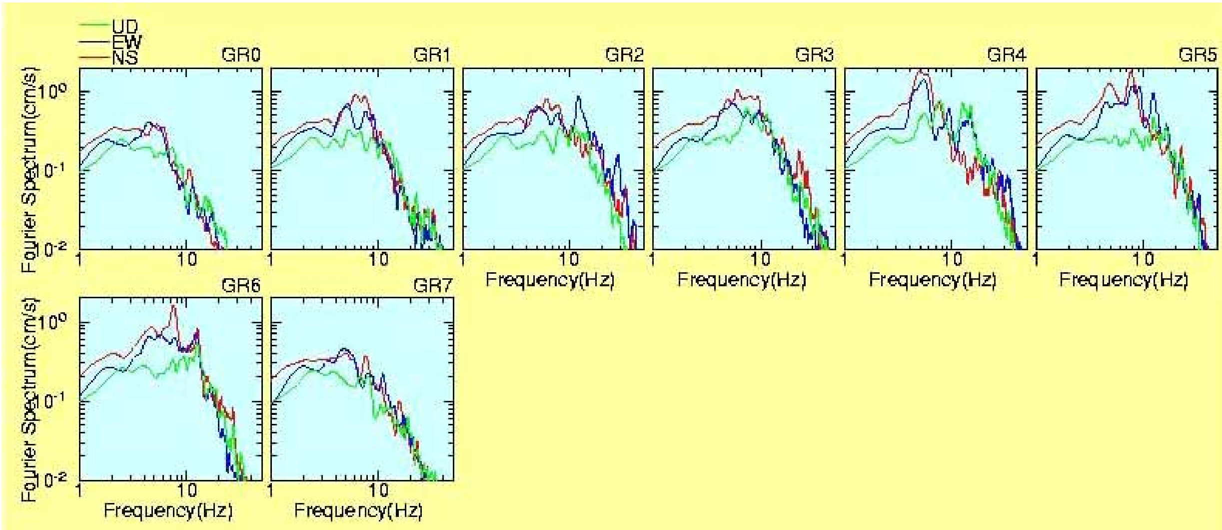

Figure 5. Fourier amplitude-spectra of the accelerations for the #2 event (2002/5/19).

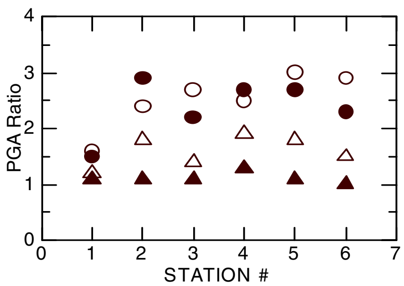

Figure 6. PGA ratios with respect to GR7.

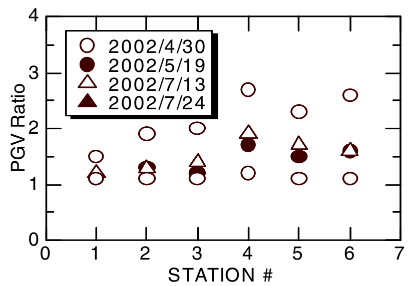

Figure 7. PGV ratios with respect to GR7.

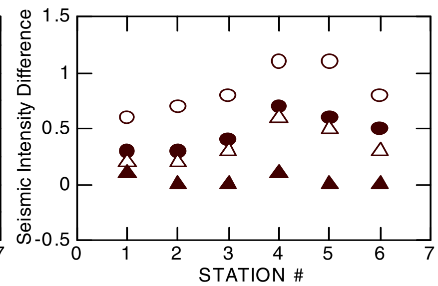

Figure 8. Instrumental seismic intensity difference to GR7.

Terrace/Base spectral ratio

Fundamental resonance

Figure 9 shows spectral ratios of accelerograms on the terrace obtained for all the events with respect to GR7. Consistent trend can be found at each station suggesting that the amplification was caused due to each site-amplification effect. Figure 10 shows the arithmetic meanings the spectra obtained for the north-south (NS) and the east-west (EW) directions. It is clear from these figures that the ground-motion amplification occurs at frequencies above 5 Hz and each station has fundamental peaks at 6-8Hz. The spectral amplitudes at the fundamental peaks are 3 to 5 and no significant difference in direction is found. Therefore, the 6-8 Hz site response can be regarded as the overall resonant oscillation of the terrace. Assuming the averaged thickness to the sand stones and fundamental frequency to be 9 m and 7 Hz, respectively, an averaged shear-wave velocity of the terrace can be estimated to be 250 m/s by the quarter wavelength law. The estimate is consistent with the P-S profiles shown in Figure 3.

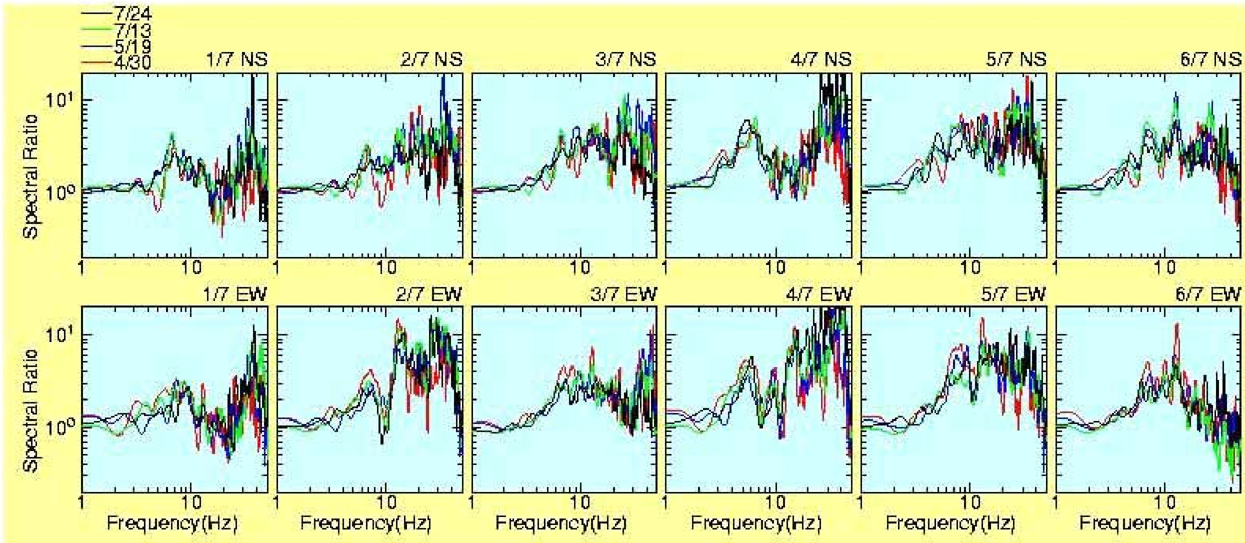

Figure 9. Spectral ratios of strong motions with respect to GR7.

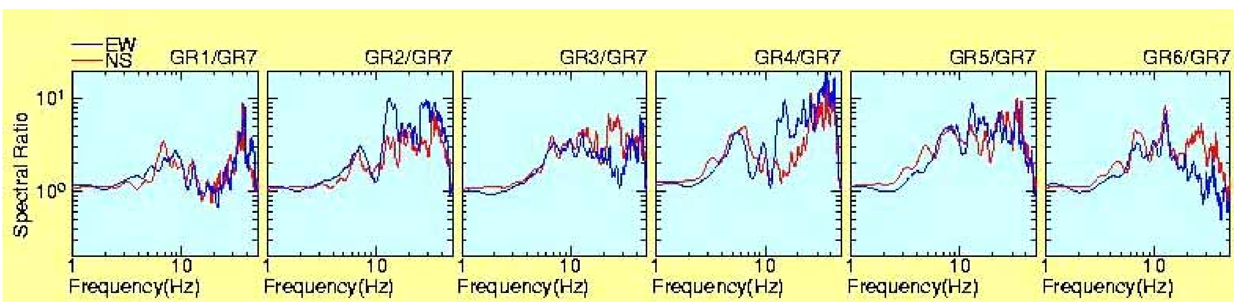

Figure 10. Averaged spectral ratios of strong motions with respect to GR7.

Resonance in higher mode

Spectral amplitudes at frequencies above 10Hz are quite different from station to station:

GR1: Peaks at 36 Hz in the NS and EW directions. No significant difference in direction.

GR2: Peaks at 13 Hz and 29 Hz in the EW direction.

GR3: Peak at 22Hz in the NS direction.

GR4: Peak at 15Hz in the EW direction. High spectral amplitude at frequencies above 20Hz.

GR5: Peaks at 13Hz and 33 Hz. No significant difference in direction.

GR6: Peaks at 13Hz in the NS and EW directions and at 27Hz in the NS direction.

Because marked differences in direction are found at some stations, NS/EW spectral ratios are obtained (Figure 11). From Figure 11, it is found that GR3 and GR6 tend to have higher NS amplitudes while GR2 and GR4 to have higher EW amplitudes. The difference is as large as 5 at some frequencies.

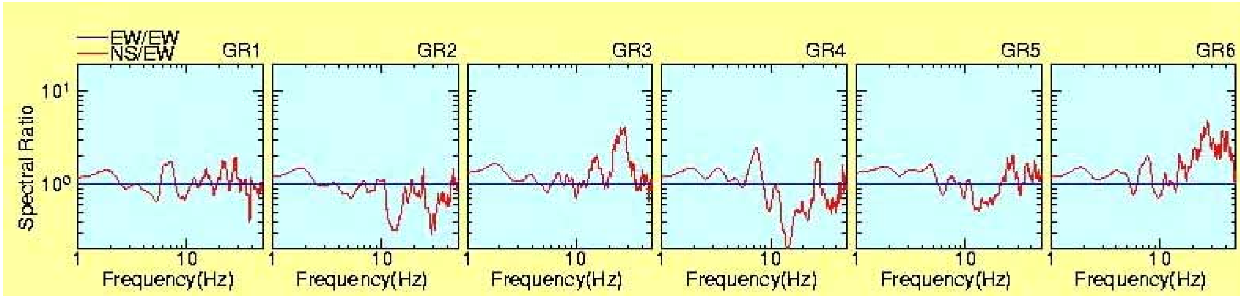

Figure 11. Spectral ratios of NS strong motions with respect to EW motions.

MICROTREMORS

Observation at strong-motion points

At the strong-motion stations, microtremor measurements were carried out. The recording system consists of servo-type velocity sensors with a 16-bit analog-to-digital converter and a note-book computer. At each station, the NS and EW components of microtremors in velocity were recorded with a sampling rate of 100 Hz and a recording length of 180 sec. At each station, three sets of 10.24-sec-long samples from the 180-sec recordings were selected. Fourier spectra of the samples were calculated and then smoothed with a 1.0-Hz Parzen window. NS to EW spectral ratios were obtained after which the spectra were averaged. Figure 12 shows the averaged NS/EW spectra at each station. From Figure 12, it is found that GR3 and GR6 tend to have higher NS amplitudes while GR2 and GR4 to have higher EW amplitudes. The results are quite similar to those of Figure 11.

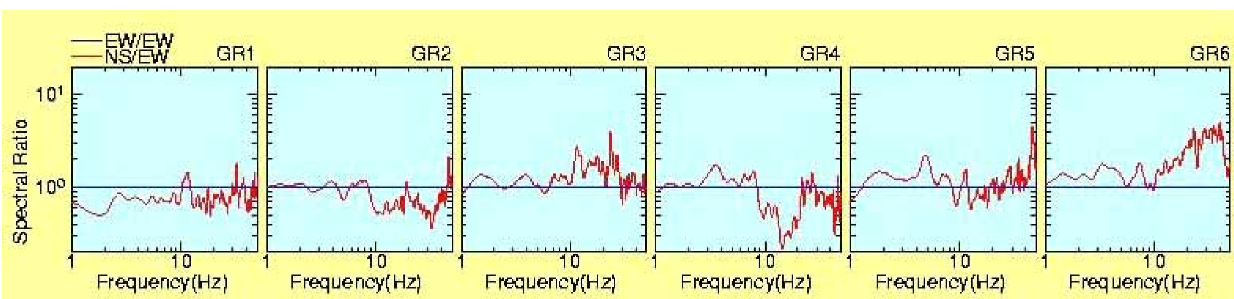

Figure 12. NS/EW spectral ratios of microtremors at strong-motion stations.

Complementary observation

The similarity between NS/EW spectral ratios of strong motions and microtremors enables us to investigate vibration characteristics of the terrace by making use of microtremors. Thus complementary microtremor observations were carried out along the edge of the terrace, the layout of the sensors are depicted in Figure 2. NS/EW spectral ratios were obtained in the same manner as the previous calculation. Figure 13 shows the results, and from this figure it is found that points 04, 07 and 10 (the southern edge) tend to have higher NS amplitudes while points 13, 16 and 19 (the western edge) to have higher EW amplitudes.

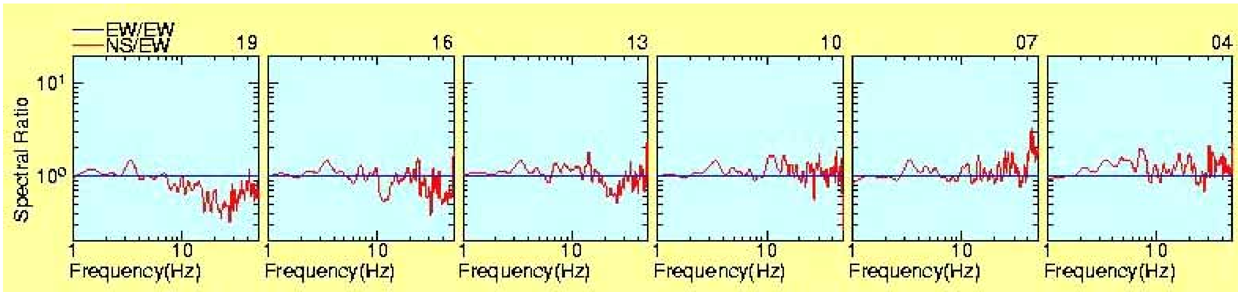

Figure 13. NS/EW spectral ratios of microtremors along the crest edges.

EIGENVALUE ANALYSIS

The strong-motion observation demonstrated that site amplification occurred atop the terrace at frequencies above 5 Hz. Besides, with additional observations of microtremors, directional topographic response were observed. In order to investigate the directional characteristics of dynamic behavior of the terrace, an eigenvalue analysis using a 3-D finite element method is conducted. Figure 14 shows the analytical model. The model is 50-m long, 40-m wide and 9-m high. The finite element modeling was made by dividing E-, N- and U- lengths by 25, 20 and 5, respectively. The material properties of the model are tabulated in Table 2. Northern, eastern and bottom nodes are fixed. From this model, eigenvalues and eigenvectors are calculated. Figure 15 shows eigenvalues and eigenvectors for the 1st to 5th modes. The first- and second- mode frequencies are relatively close, and the two modes can be assumed as a pair of the fundamental oscillations of the terrace. The mode shapes show that:

Modes 1 & 2: Large deformation in the E-W and N-S directions, respectively.

Mode 3: Large deformation in the N-S direction along the southern edge.

Mode 4: Large deformations in the E-W and N-S direction along the western and southern edges.

Mode 5: Large deformations in the E-W and N-S direction along the western and southern edges.

From the eigenvalue analysis it is clearly found that the western and southern edges are highly deformed in the direction perpendicular to the axis of each edge. The analytical results are consistent with the results of the strong-motion and microtremor observations.

Table 2 Material properties of the analytical model.

mass density	S-wave velocity	Poisson's ratio
1.5 t/m^3	250m/s	0.3

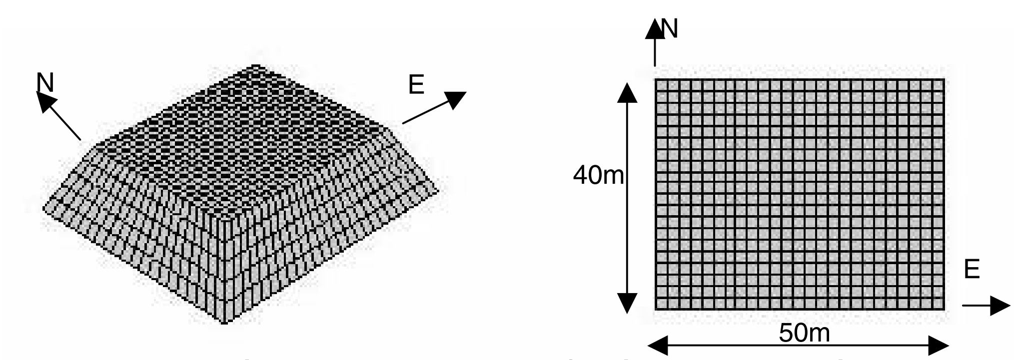

Figure 14. 3-D FEM model for eigenvalue analysis.

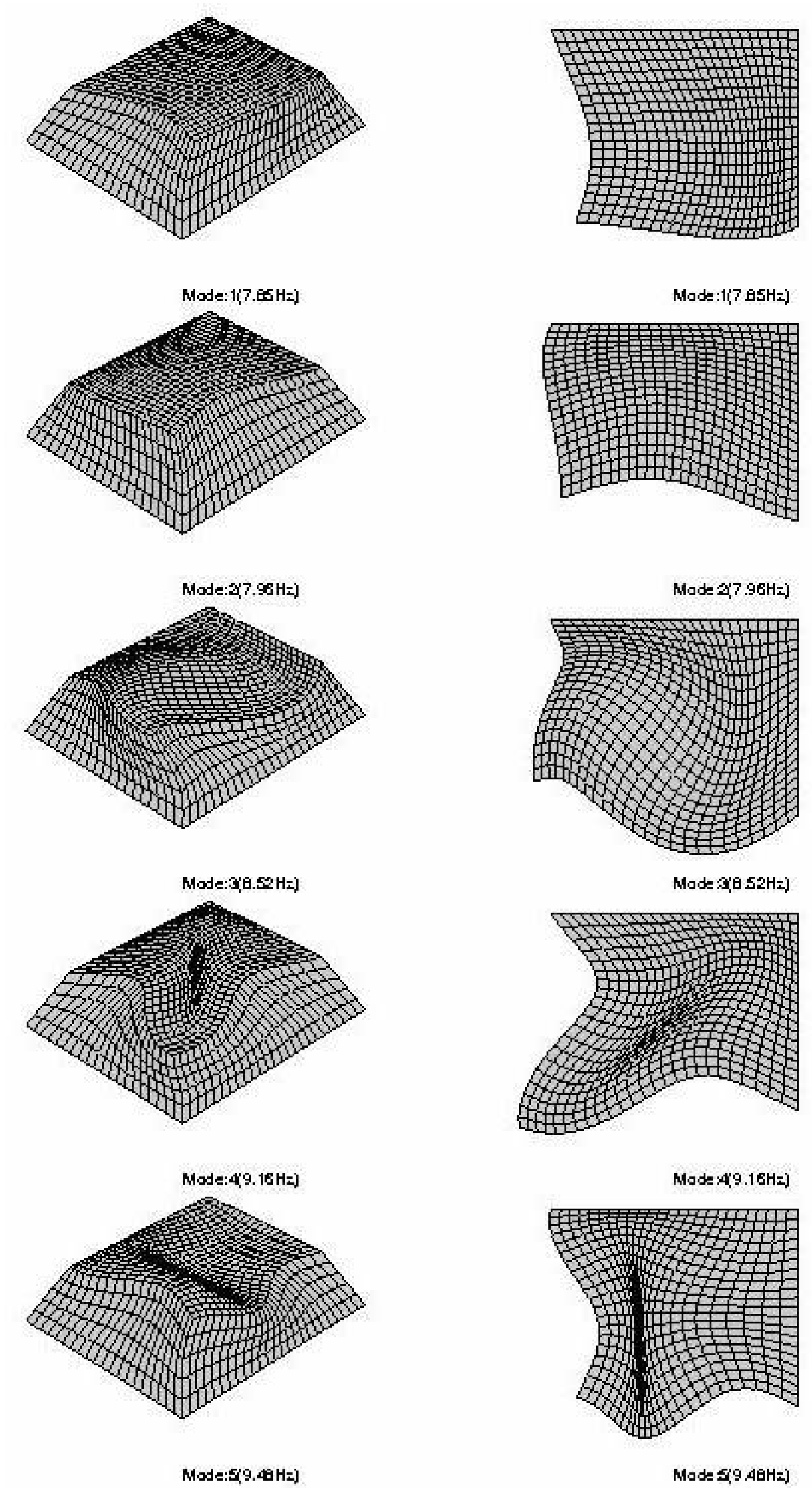

Figure 15. Eigenvalues and eigenvectors for the 1st to 5th modes.

CONCLUSIONS

In this study we investigated a topographic site response of a Quaternary terrace on ground-motion amplification by using strong-motion observation, microtremor observation and eigenvalue analysis. From these investigations, the following findings are obtained:

1. Due to the topographic site effect of the terrace, ground motions are amplified with the highest factors of 3 (PGA) and 2.7 (PGV), respectively, with respect to the base of the terrace.
2. The site amplification occurs at frequencies above 5 Hz and the fundamental resonance oscillation of the terrace is about 7 Hz .
3. At frequencies above 10 Hz, some points show directional amplification with the highest difference of about 5. The highly-amplified directions at the terrace edges are perpendicular to the terrace edges.

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